Central and Eastern United States Seismic Source Characterization for Nuclear Facilities

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ABSTRACT

This report describes a new seismic source characterization (SSC) model for the Central and Eastern United States (CEUS). It will replace the *Seismic Hazard Methodology for the Central and Eastern United States*, EPRI Report NP-4726 (July 1986) and the *Seismic Hazard Characterization of 69 Nuclear Plant Sites East of the Rocky Mountains,* Lawrence Livermore National Laboratory Model, (Bernreuter et al., 1989). The objective of the CEUS SSC Project is to develop a new seismic source model for the CEUS using a Senior Seismic Hazard Analysis Committee (SSHAC) Level 3 assessment process. The goal of the SSHAC process is to represent the center, body, and range of technically defensible interpretations of the available data, models, and methods. Input to a probabilistic seismic hazard analysis (PSHA) consists of both seismic source characterization and ground motion characterization. These two components are used to calculate probabilistic hazard results (or seismic hazard curves) at a particular site. This report provides a new seismic source model.

Results and Findings

The product of this report is a regional CEUS SSC model. This model includes consideration of an updated database, full assessment and incorporation of uncertainties, and the range of diverse technical interpretations from the larger technical community. The SSC model will be widely applicable to the entire CEUS, so this project uses a ground motion model that includes generic variations to allow for a range of representative site conditions (deep soil, shallow soil, hard rock). Hazard and sensitivity calculations were conducted at seven test sites representative of different CEUS hazard environments.

Challenges and Objectives

The regional CEUS SSC model will be of value to readers who are involved in PSHA work, and who wish to use an updated SSC model. This model is based on a comprehensive and traceable process, in accordance with SSHAC guidelines in NUREG/CR-6372, *Recommendations for Probabilistic Seismic Hazard Analysis: Guidance on Uncertainty and Use of Experts*. The model will be used to assess the present-day composite distribution for seismic sources along with their characterization in the CEUS and uncertainty. In addition, this model is in a form suitable for use in PSHA evaluations for regulatory activities, such as Early Site Permit (ESPs) and Combined Operating License Applications (COLAs).

Applications, Values, and Use

Development of a regional CEUS seismic source model will provide value to those who (1) have submitted an ESP or COLA for Nuclear Regulatory Commission (NRC) review before 2011; (2) will submit an ESP or COLA for NRC review after 2011; (3) must respond to safety issues resulting from NRC Generic Issue 199 (GI-199) for existing plants and (4) will prepare PSHAs to meet design and periodic review requirements for current and future nuclear facilities. This work replaces a previous study performed approximately 25 years ago. Since that study was

completed, substantial work has been done to improve the understanding of seismic sources and their characterization in the CEUS. Thus, a new regional SSC model provides a consistent, stable basis for computing PSHA for a future time span. Use of a new SSC model reduces the risk of delays in new plant licensing due to more conservative interpretations in the existing and future literature.

Perspective

The purpose of this study, jointly sponsored by EPRI, the U.S. Department of Energy (DOE), and the NRC was to develop a new CEUS SSC model. The team assembled to accomplish this purpose was composed of distinguished subject matter experts from industry, government, and academia. The resulting model is unique, and because this project has solicited input from the present-day larger technical community, it is not likely that there will be a need for significant revision for a number of years. See also Sponsors' Perspective for more details.

Approach

The goal of this project was to implement the CEUS SSC work plan for developing a regional CEUS SSC model. The work plan, formulated by the project manager and a technical integration team, consists of a series of tasks designed to meet the project objectives. This report was reviewed by a participatory peer review panel (PPRP), sponsor reviewers, the NRC, the U.S. Geological Survey, and other stakeholders. Comments from the PPRP and other reviewers were considered when preparing the report. The SSC model was completed at the end of 2011.

Keywords

Probabilistic seismic hazard analysis (PSHA)
Seismic source characterization (SSC)
Seismic source characterization model
Central and Eastern United States (CEUS)

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EXECUTIVE SUMMARY

The Central and Eastern United States Seismic Source Characterization for Nuclear Facilities (CEUS SSC) Project was conducted over the period from April 2008 to December 2011 to provide a regional seismic source model for use in probabilistic seismic hazard analyses (PSHAs) for nuclear facilities. The study replaces previous regional seismic source models conducted for this purpose, including the Electric Power Research Institute–Seismicity Owners Group (EPRI-SOG) model (EPRI, 1988, 1989) and the Lawrence Livermore National Laboratory model (Bernreuter et al., 1989). Unlike the previous studies, the CEUS SSC Project was sponsored by multiple stakeholders—namely, the EPRI Advanced Nuclear Technology Program, the Office of Nuclear Energy and the Office of the Chief of Nuclear Safety of the U.S. Department of Energy (DOE), and the Office of Nuclear Regulatory Research of the Nuclear Regulatory Commission (NRC). The study was conducted using Senior Seismic Hazard Analysis Committee (SSHAC) Study Level 3 methodology to provide high levels of confidence that the data, models, and methods of the larger technical community have been considered and the center, body, and range of technically defensible interpretations have been included.

The regional seismic source characterization (SSC) model defined by this study can be used for site-specific PSHAs, provided that appropriate site-specific assessments are conducted as required by current regulations and regulatory guidance for the nuclear facility of interest. This model has been designed to be compatible with current and anticipated ground-motion characterization (GMC) models. The current recommended ground-motion models for use at nuclear facilities are those developed by EPRI (2004, 2006a, 2006b). The ongoing Next Generation Attenuation–East (NGA-East) project being supported by the NRC, DOE, and EPRI will provide ground-motion models that are appropriate for use with the CEUS SSC model. The methodology for a SSHAC Level 3 project as applied to the CEUS SSC Project is explained in the SSHAC report (Budnitz et al., 1997), which was written to discuss the evolution of expert assessment methodologies conducted during the previous three decades for purposes of probabilistic risk analyses. The methodological guidance provided in the SSHAC report was intended to build on the lessons learned from those previous studies and, specifically, to arrive at processes that would make it possible to avoid the issues encountered by the previous studies (NRC, 2011).

The SSHAC assessment process, which differs only slightly for Level 3 and 4 studies, is a technical process accepted in the NRC's seismic regulatory guidance (Regulatory Guide 1.208) for ensuring that uncertainties in data and scientific knowledge have been properly represented in seismic design ground motions consistent with the requirements of the seismic regulation 10 CFR Part 100.23 ("Geologic and Seismic Siting Criteria"). Therefore, the goal of the SSHAC assessment process is the proper and complete representation of knowledge and uncertainties in the SSC and GMC inputs to the PSHA (or similar hazard analysis). As discussed extensively in the SSHAC report (Budnitz et al., 1997) and affirmed in NRC (2011), a SSHAC assessment process consists of two important sequential activities, *evaluation* and *integration.* For a Level 3 assessment, these activities are conducted by the Technical Integration (TI) Team under the leadership of the TI Lead. As described in NRC (2011),

> The fundamental goal of a SSHAC process is to carry out properly and document completely the activities of evaluation and integration, defined as:
>
> > *Evaluation:* The consideration of the complete set of data, models, and methods proposed by the larger technical community that are relevant to the hazard analysis.
> >
> > *Integration:* Representing the center, body, and range of technically defensible interpretations in light of the evaluation process (i.e., informed by the assessment of existing data, models, and methods).

Each of the assessment and model-building activities of the CEUS SSC Project is associated with the evaluation and integration steps in a SSHAC Level 3 process. Consistent with the requirements of a SSHAC process, the specific roles and responsibilities of all project participants were defined in the Project Plan, and adherence to those roles was the responsibility of the TI Lead and the Project Manager. The technical assessments are made by the TI Team, who carry the principal responsibility of evaluation and integration, under the technical leadership of the TI Lead. The Database Manager and other technical support individuals assist in the development of work products. Resource and proponent experts participate by presenting their data, models, and interpretations at workshops and through technical interchange with the TI Team throughout the project. The Participatory Peer Review Panel (PPRP) is responsible for a continuous review of both the SSHAC process being followed and the technical assessments being made. The project management structure is headed by the Project Manager, who serves as the liason with the sponsors and the PPRP and manages the activities of all participants. The SSHAC Level 3 assessment process and implementation is discussed in depth in Chapter 2 of this report.

Each of the methodology steps in the SSHAC guidelines (Budnitz, 1997) was addressed adequately during the CEUS SSC Project. Furthermore, the project developed a number of enhancements to the process steps for conducting a SSHAC Study Level 3 project. For example, the SSHAC guidelines call for process steps that include developing a preliminary assessment model, calculating hazard using that model in order to identify the key issues, and finalizing the model in light of the feedback provided from the hazard calculations and sensitivity analyses. Because of the regional nature of the project and the multitude of assessments required, four rounds of model-building and three rounds of feedback were conducted. These activities ensured that all significant issues and uncertainties were identified and that the appropriate effort was devoted to the issues of most significance to the hazard results. A comparison of the activities conducted during the CEUS SSC Project with those recommended in the SSHAC guidelines themselves (Section 2.6) led to the conclusion that the current standards of practice have been met for a SSHAC Study Level 3 process—both those that are documented in the SSHAC report and those that resulted from precedents set by projects conducted since the SSHAC report was issued.

The catalog of past earthquakes that have occurred in a region is an important source of information for the quantification of future seismic hazards. This is particularly true in stable continental regions (SCRs) such as the CEUS where the causative mechanisms and structures for the occurrence of damaging earthquakes are generally poorly understood, and the rates of crustal deformation are low such that surface and near-surface indications of stresses in the crust and the buildup and release of crustal strains are difficult to quantify. Because the earthquake catalog is used in the characterization of the occurrence of future earthquakes in the CEUS, developing an updated earthquake catalog for the study region was an important focus of the CEUS SSC Project. The specific goals for earthquake catalog development and methods used to attain those goals are given in Chapter 3.

The earthquake catalog development consists of four main steps: catalog compilation, assessment of a uniform size measure to apply to each earthquake, identification of dependent earthquakes (catalog declustering), and assessment of the completeness of the catalog as a function of location, time, and earthquake size. An important part of the catalog development process was review by seismologists with extensive knowledge and experience in catalog compilation. The result is an earthquake catalog covering the entire study region for the period from 1568 through the end of 2008. Earthquake size is defined in terms of the moment magnitude scale (Hanks and Kanamori, 1979), consistent with the magnitude scale used in modern ground-motion prediction equations (GMPEs) for CEUS earthquakes. A significant contribution of the CEUS SSC Project is the work conducted to develop an updated and consistent set of conversion relationships between various earthquake size measures (instrumental magnitudes and intensity) and moment magnitude.

The conceptual SSC framework described in Chapter 4 was developed early in the CEUS SSC Project in order to provide a consistent approach and philosophy to SSC by the TI Team. This framework provides the basic underpinnings of the SSC model developed for the project, and it led to the basic structure and elements of the master logic tree developed for the SSC model. In considering the purpose of the CEUS SSC Project, the TI Team identified three attributes that are needed for a conceptual SSC framework:

1. A systematic, documented approach to treating alternatives using logic trees, including alternative conceptual models for future spatial distributions of seismicity (e.g., stationarity); alternative methods for expressing the future temporal distribution of seismicity (e.g., renewal models, Poisson models); and alternative data sets for characterizing seismic sources (e.g., paleoseismic data, historical seismicity data).
2. A systematic approach to identifying applicable data for the source characterization, evaluating the usefulness of the data, and documenting the consideration given to the data by the TI Team.
3. A methodology for identifying seismic sources based on defensible criteria for defining a seismic source, incorporating the lessons learned in SSC over the past two decades, and identifying the range of approaches and models that can be shown to be significant to hazard.

Each of these needs was addressed by the methodology used in the project. For example, the need for a systematic approach to identifying and evaluating the data and information that underlie the source characterization assessments was met by the development of Data Summary and Data Evaluation tables. These tables were developed for each seismic source to document the information available at the time of the CEUS SSC assessments (the Data Summary tables) and the way those data were used in the characterization process (the Data Evaluation tables). Given the evolution of approaches to identifying seismic sources, it is appropriate to provide a set of criteria and the logic for their application in the CEUS SSC Project. In the project, unique seismic sources are defined to account for distinct differences in the following criteria:

- Earthquake recurrence rate
- Maximum earthquake magnitude (Mmax)
- Expected future earthquake characteristics (e.g., style of faulting, rupture orientation, depth distribution)
- Probability of activity of tectonic feature(s)

Rather than treat these criteria as operating simultaneously or without priority, the CEUS SSC methodology works through them sequentially. Further, because each criterion adds complexity to the seismic source model, it is applied only if its application would lead to hazard-significant changes in the model. In this way, the model becomes only as complex as required by the available data and information.

The CEUS SSC master logic tree is tied to the conceptual SSC framework that establishes the context for the entire seismic source model. The master logic tree depicts the alternative interpretations and conceptual models that represent the range of defensible interpretations, and the relative weights assessed for the alternatives. By laying out the alternatives initially, the subsequent detailed source evaluations were conducted within a framework that ensures consistency across the sources. Important elements of the master logic tree are as follows:

- Representation of the sources defined based on paleoseismic evidence for the occurrence of repeated large-magnitude earthquakes (RLMEs, defined as two or more earthquakes with $\mathbf{M} \geq 6.5$).
- Alternatives to the spatial distribution of earthquakes based on differences in maximum magnitudes (Mmax zones approach).
- Representation of uncertainty in spatial stationarity of observed seismicity based on smoothing of recurrence parameters.
- Representation of possible differences in future earthquake characteristics (e.g., style, seismogenic thickness, and orientation of ruptures), which lead to definition of seismotectonic zones in the logic tree (seismotectonic zones approach).

The methodologies used by the project to make the SSC assessments are discussed in Chapter 5. The heart of any SSC model for PSHA is a description of the future spatial and temporal distribution of earthquakes. Continued analysis of the historical seismicity record and network monitoring by regional and local seismic networks has led to acceptance within the community that the general spatial patterns of observed small- to moderate-magnitude earthquakes provide predictive information about the spatial distribution of future large-magnitude earthquakes. The analyses leading to this conclusion have focused on whether the observed patterns of earthquakes have varied through time; therefore, in effect, this is an assessment of uncertainty in whether small- to moderate-magnitude earthquakes have been relatively stationary through time. However, the available data on larger-magnitude earthquakes and their relationship to the spatial distribution of smaller earthquakes based on the observed record are quite limited. These data are not sufficient to allow confidence in the predictions generated by empirical spatial models. For this reason, geologic and geophysical data are needed to specify the locations of future earthquakes in addition to the observed patterns of seismicity.

Detailed studies in the vicinity of large historical and instrumental earthquakes, and liquefaction phenomena associated with them, coupled with field and laboratory studies of geotechnical properties, are leading to a stronger technical basis for (1) placing limits on the locations of paleoearthquakes interpreted by the distribution of liquefaction phenomena and (2) defining their magnitudes. In some cases, the paleoseismic evidence for RLMEs is compelling, and the TI Team has included the RLME source in the SSC model. The locations of RLME sources notwithstanding, the spatial distribution of distributed seismicity sources has advanced in PSHA largely because of the assumption of spatial stationarity, and the SSC and hazard community uses approaches to “smooth” observed seismicity to provide a map that expresses the future spatial pattern of recurrence rates. The CEUS SSC model is based largely on the assumption, typical in PSHA studies, that spatial stationarity of seismicity is expected to persist for a period of approximately 50 years.

Estimating Mmax in SCRs such as the CEUS is highly uncertain despite considerable interest and effort by the scientific community over the past few decades. Mmax is defined as the upper truncation point of the earthquake recurrence curve for individual seismic sources, and the typically broad distribution of Mmax for any given source reflects considerable epistemic uncertainty. Because the maximum magnitude for any given seismic source in the CEUS occurs rarely relative to the period of observation, the use of the historical seismicity record provides important but limited constraints on the magnitude of the maximum event. Because of the independent constraints on earthquake size, those limited constraints are used to estimate the magnitudes of RLME. For distributed seismicity source zones, two approaches are used to assess Mmax: the Bayesian approach and the Kijko approach. In the Bayesian procedure (Johnston et al., 1994), the prior distribution is based on the magnitudes of earthquakes that occurred worldwide within tectonically analogous regions. As part of the CEUS SSC Project, the TI Team pursued the refinement and application of the Bayesian Mmax approach becauses it provides a quantitative and repeatable process for assessing Mmax.

The TI Team also explored alternative approaches for the assessment of Mmax that provide quantitative and repeatable results, and the team identified the approach developed by Kijko (2004) as a viable alternative. While the Kijko approach requires fewer assumptions than the Bayesian approach in that it uses only the observed earthquake statistics for the source, this is offset by the need for a relatively larger data sample in order to get meaningful results. Both approaches have the positive attribute that they are repeatable given the same data and they can be readily updated given new information. The relative weighting of the two approaches for inclusion in the logic tree is source-specific, a function of the numbers of earthquakes that are present within the source upon which to base the Mmax assessment: sources with fewer earthquakes are assessed to have little or no weight for the Kijko approach, while those with larger numbers of events are assessed higher weight for the Kijko approach. In all cases, because of the stability of the Bayesian approach and the preference for "analogue" approaches within the larger technical community, the Bayesian approach is assessed higher weight than the Kijko approach for all sources.

A major effort was devoted to updating the global set of SCR earthquakes and to assessing statistically significant attributes of those earthquakes following the approach given in Johnston et al. (1994). In doing so, it was found that the only significant attribute defining the prior distribution is the presence or absence of Mesozoic-or-younger extension. The uncertainty in this assessment is reflected in the use of two alternative priors: one that takes into account the presence or absence of crustal domains having this attribute, and another that combines the entire CEUS region as a single SCR crustal domain with a single prior distribution. The use of the Bayesian—and Kijko—approach requires a definition of the largest observed magnitude within each source, and this assessment, along with the associated uncertainty, was incorporated into the Mmax distributions for each seismic source. Consideration of global analogues led to the assessment of an upper truncation to all Mmax distributions at 8¼ and a lower truncation at 5½. The broad distributions of Mmax for the various seismic source zones reflect the current epistemic uncertainty in the largest earthquake magnitude within each seismic source.

The CEUS SSC model is based to a large extent on an assessment that spatial stationarity of seismicity will persist for time periods of interest for PSHA (approximately the next 50 years). Stationarity in this sense does not mean that future locations and magnitudes of earthquakes will occur exactly where they have occurred in the historical and instrumental record. Rather, the degree of spatial stationarity varies as a function of the type of data available to define the seismic source. RLME sources are based largely on paleoseismic evidence for repeated large-magnitude ($M \geq 6.5$) earthquakes that occur in approximately the same location over periods of a few thousand years. On the other hand, patterns of seismicity away from the RLME sources within the Mmax and seismotectonic zones are defined from generally small- to moderate-magnitude earthquakes that have occurred during a relatively short (i.e., relative to the repeat times of large events) historical and instrumental record. Thus, the locations of future events are not as tightly constrained by the locations of past events as for RLME sources. The spatial smoothing operation is based on calculations of earthquake recurrence within one-quarter-degree or half-degree cells, with allowance for "communication" between the cells. Both *a*- and *b*-values are allowed to vary, but the degree of variation has been optimized such that *b*-values vary little across the study region.

The approach used to smooth recurrence parameters is a refinement of the penalized-likelihood approach used in EPRI-SOG (EPRI, 1988), but it is designed to include a number of elements that make the formulation more robust, realistic, and flexible. These elements include the reformulation in terms of magnitude bins, the introduction of magnitude-dependent weights, catalog incompleteness, the effect of Mmax, spatial variation of parameters within the source zone, and the prior distributions of *b*. A key assessment made by the TI Team was the weight assigned to various magnitude bins in the assessment of smoothing parameters (Cases A, B, and E). This assessment represents the uncertainty in the interpretation that smaller magnitudes define the future locations and variation in recurrence parameters. Appropriately, the penalized-likelihood approach results in higher spatial variation (less smoothing) when the low-magnitude bins are included with high weight, and much less variation (higher smoothing) in the case where the lower-magnitude bins are given low or zero weight. The variation resulting from the final set of weights reflects the TI Team's assessment of the epistemic uncertainty in the spatial variation of recurrence parameters throughout the SSC model.

The earthquake recurrence models for the RLME sources are somewhat simpler than those for distributed seismicity sources because the magnitude range for individual RLMEs is relatively narrow and their spatial distribution is limited geographically such that spatial variability is not a concern. This limits the problem to one of estimating the occurrence rate in time of a point process. The data that are used to assess the occurrence rates are derived primarily from paleoseismic studies and consist of two types: data that provide estimated ages of the paleoearthquakes such that the times between earthquakes can be estimated, and data that provide an estimate of the number of earthquakes that have occurred after the age of a particular stratigraphic horizon. These data are used to derive estimates of the RLME occurrence rates and their uncertainty.

The estimation of the RLME occurrence rates is dependent on the probability model assumed for the temporal occurrence of these earthquakes. The standard model applied for most RLME sources in this study is the Poisson model, in which the probability of occurrence of an RLME in a specified time period is completely characterized by a single parameter, λ, the rate of RLME occurrence. The Poisson process is "memoryless"—that is, the probability of occurrence in the next time interval is independent of when the most recent earthquake occurred, and the time between earthquakes is exponentially distributed with a standard deviation equal to the mean time between earthquakes. For two RLME sources (Reelfoot Rift–New Madrid fault system and the Charleston source), the data are sufficient to suggest that the occurrence of RLMEs is more periodic in nature (the standard deviation is less than the mean time between earthquakes). For these RLME sources a simple renewal model can also be used to assess the probability of earthquake occurrence. In making an estimate of the probability of occurrence in the future, this model takes into account the time that has elapsed since the most recent RLME occurrence.

The CEUS SSC model has been developed for use in future PSHAs. To make this future use possible, the SSC model must be combined with a GMC model. At present, the GMPEs in use for SCRs such as the CEUS include limited information regarding the characteristics of future earthquakes. In anticipation of the possible future development of GMPEs for the CEUS that will make it possible to incorporate similar types of information, a number of characteristics of future earthquakes in the CEUS are assessed. In addition to characteristics that might be important for ground motion assessments, there are also assessed characteristics that are potentially important to the modeling conducted for hazard analysis. Future earthquake characteristics assessed include the tectonic stress regime, sense of slip/style of faulting, strike and dip of ruptures, seismogenic crustal thickness, fault rupture area versus magnitude relationship, rupture length-to-width aspect ratio, and relationship of ruptures to source boundaries.

Chapters 6 and 7 include discussions of the seismic sources that are defined by the Mmax zones and the seismotectonic zones branches of the master logic tree. Because of convincing evidence for their existence, both approaches include RLME sources. The rarity of repeated earthquakes relative to the period of historical observation means that evidence for repeated events comes largely from the paleoseismic record. By identifying the RLMEs and including them in the SSC model, there is no implication that the set of RLMEs included is in fact the total set of RLMEs that might exist throughout the study region. This is because the presently available studies that locate and characterize the RLMEs have been concentrated in certain locations and are not systematic across the entire study region. Therefore, the evidence for the existence of the RLMEs is included in the model where it exists, but the remaining parts of the study region are also assessed to have significant earthquake potential, which is evidenced by the inclusion of moderate-to-large magnitudes in the Mmax distributions for every Mmax zone or seismotectonic zone.

In Chapter 6, each RLME source is described in detail by the following factors: (1) evidence for temporal clustering, (2) geometry and style of faulting, (3) RLME magnitude, and (4) RLME recurrence. The descriptions document how the data have been evaluated and assessed to arrive at the various elements of the final SSC model, including all expressions of uncertainty. The Data Summary and Data Evaluation tables (Appendices C and D) complement the discussions in the text, documenting all the data that were considered in the course of data evaluation and integration process for each particular seismic source.

Alternative models for the distributed seismicity zones that serve as background zones to the RLME sources are either Mmax zones or seismotectonic zones. The Mmax zones are described in Chapter 6 and are defined according to constraints on the prior distributions for the Bayesian approach to estimating Mmax. The seismotectonic zones are described in Chapter 7 and are identified based on potential differences in Mmax as well as future earthquake characteristics. Each seismotectonic zone in the CEUS SSC model is described according to the following attributes: (1) background information from various data sets; (2) bases for defining the seismotectonic zone; (3) basis for the source geometry; (4) basis for the zone Mmax (e.g., largest observed earthquake); and (5) future earthquake characteristics. Uncertainties in the seismotectonic zone characteristics are described and are represented in the logic trees developed for each source.

For purposes of demonstrating the CEUS SSC model, seismic hazard calculations were conducted at seven demonstration sites throughout the study region, as described in Chapter 8. The site locations were selected to span a range of seismic source types and levels of seismicity. The results from the seismic hazard calculations are intended for scientific use to demonstrate the model, and they should not be used for engineering design. Mean hazard results are given for a range of spectral frequencies (PGA, 10 Hz, and 1 Hz) and for a range of site conditions. All calculations were made using the EPRI (2004, 2006) ground-motion models such that results could be compared to understand the SSC effects alone. Sensitivity analyses were conducted to provide insight into the dominant seismic sources and the important characteristics of the dominant seismic source at each site. The calculated mean hazard results are compared with the results using the SSC model from the 2008 U.S. Geological Survey national seismic hazard maps and the SSC model from the Combined Operating License applications for new nuclear power reactors. The hazard results using the CEUS SSC model given in Chapter 8 are reasonable and readily understood relative to the results from other studies, and sensitivities of the calculated hazard results can be readily explained by different aspects of the new model. The TI Team concludes that the SSC model provides reasonable and explainable calculated seismic hazard results, and the most important aspects of the SSC model to the calculated hazard (e.g., recurrence rates of RLME sources, recurrence parameters for distributed seismicity sources, Mmax) and their uncertainties have all been appropriately addressed.

Presumably, the GMC model input to the PSHA calculations will be replaced in the future by the results of the ongoing NGA-East project. The calculated hazard at the demonstration sites in Chapter 8 comes from the regional CEUS SSC model and does not include any local refinements that might be necessary to account for local seismic sources. Depending on the regulatory guidance that is applicable for the facility of interest, additional site-specific studies may be required to provide local refinements to the model.

To assist future users of the CEUS SSC model, Chapter 9 presents a discussion on the use of the model for PSHA. The basic elements of the model necessary for hazard calculations are given in the Hazard Input Document (HID). This document provides all necessary parameter values and probability distributions for use in a modern PSHA computer code. The HID does not, however, provide any justification for the values, since that information is given in the text of this report.

Chapter 9 also describes several simplifications to seismic sources that can be made to increase efficiency in seismic hazard calculations. These simplifications are recommended on the basis of sensitivity studies of alternative hazard curves that represent a range of assumptions on a parameter's value. Sensitivities are presented using the test sites in this study. For applications of the seismic sources from this study, similar sensitivity studies should be conducted for the particular site of interest to confirm these results and to identify additional simplifications that might be appropriate. For the seismic sources presented, only those parameters that can be simplified are discussed and presented graphically. The sensitivity studies consisted of determining the sensitivity of hazard to logic tree branches for each node of the logic tree describing that source. The purpose was to determine which nodes of the logic tree could be collapsed to a single branch in order to achieve more efficient hazard calculations without compromising the accuracy of overall hazard results.

Finally, this report provides a discussion of the level of precision that is associated with seismic hazard estimates in the CEUS. This discussion addresses how seismic hazard estimates might change if the analysis were repeated by independent experts having access to the same basic information (geology, tectonics, seismicity, ground-motion equations, site characterization). It also addresses how to determine whether the difference in hazard would be significant if this basic information were to change and that change resulted in a difference in the assessed seismic hazard. This analysis was performed knowing that future data and models will continue to be developed and that a mechanism for evaluating the significance of that information is needed. Based on the precision model evaluated, if an alternative assumption or parameter is used in a seismic hazard study, and it potentially changes the calculated hazard (annual frequency of exceedence) by less than 25 percent for ground motions with hazards in the range 10^{-4} to 10^{-6}, that potential change is within the level of precision at which one can calculate seismic hazard. It should be noted, however, that a certain level of precision does not relieve users from performing site-specific studies to identify potential capable seismic sources within the site region and vicinity as well as to identify newer models and data. Also, this level of precision does not relieve users from fixing any errors that are discovered in the CEUS SSC model as it is implemented for siting critical facilities. In addition, NRC has not defined a set value for requiring or not requiring siting applicants to revise or update PSHAs.

Included in the report are appendices that summarize key data sets and analyses: the earthquake catalog, the Data Summary and Data Evaluation tables, the paleoliquefaction database, the HID, and documentation important to the SSHAC process. These data and analyses will assist future users of the CEUS SSC model in the implementation of the model for purposes of PSHA. The entire report and database will be provided on a website after the Final Project Report is issued.

The TI Team, Project Manager, and Sponsors determined the approach for quality assurance on the CEUS SSC Project in 2008, taking into account the SSHAC assessment process and national standards. The approach was documented in the CEUS SSC Project Plan dated June 2008 and discussed in more detail in the CEUS SSC Report (Appendix L). Beyond the assurance of quality arising from the external scientific review process, it is the collective, informed judgment of the TI Team (via the process of evaluation and integration) and the concurrence of the PPRP (via the participatory peer review process), as well as adherence to the national standard referred to in Appendix L, that ultimately lead to the assurance of quality in the process followed and in the products that resulted from the SSHAC hazard assessment framework.

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Gentlemen:

Reference: *Central and Eastern United States Seismic Source Characterization for Nuclear Facilities Project:* Participatory Peer Review Panel Final Report

Introduction

This letter constitutes the final report of the PPRP[1] ("the Panel") for the *Central and Eastern United States Seismic Source Characterization for Nuclear Facilities Project* (the "CEUS SSC Project" or "the Project"). The eight Panel members (Jon P. Ake, Walter J. Arabasz, William J. Hinze, Annie M. Kammerer, Jeffrey K. Kimball, Donald P. Moore, Mark D. Petersen, J. Carl Stepp) participated in the Project in a manner fully consistent with the SSHAC Guidance.[2] The Panel was actively engaged in all phases and activities of the Project's implementation, including final development of the Project Plan and planning of the evaluation and integration activities, which are the core of the SSHAC assessment process.

[1] Participatory Peer Review Panel

[2] Budnitz, R. J., G. Apostolakis, D. M. Boore, L. S. Cluff, K. L. Coppersmith, C. A. Cornell, and P. A. Morris, 1997. *Recommendations for Probabilistic Seismic Hazard Analysis: Guidance on Uncertainty and the Use of Experts* (known as the "Senior Seismic Hazard Analysis Committee Report," or the "SSHAC Guidance"). NUREG/CR-6372, U. S. Nuclear Regulatory Commission. TIC; 235076. Washington, DC.

The Panel's involvement, described more fully later in this letter, also included review of analyses performed by the Project to support the evaluation and integration processes, review of interim evaluation and integration products, and review of the interim draft project report and the final project report. Additionally, panel members participated in specific analyses as resource experts, and panel members were observers in or participated as resource experts in eight of the eleven Technical Integrator Team (TI Team) working meetings held to implement the integration phase of the assessment process. We want to express our appreciation for the opportunity to participate in the CEUS SSC Project in this way.

In the remainder of this letter we provide our observations and conclusions on key elements of the project implementation process, and we summarize our reviews of the draft and final project reports. As we explain in our comments, assurance that the center, body, and range of the technically-defensible interpretations ("CBR of the TDI")[3] have been properly represented in the CEUS SSC Model fundamentally comes from implementing the structure and rigor of the SSHAC Guidance itself. We are aware that the SSHAC Guidance is accepted by the Nuclear Regulatory Commission and the Department of Energy for developing seismic hazard models that provide reasonable assurance, consistent with the seismic safety decision-making practices of these agencies, of compliance with their seismic safety policies and regulatory requirements. For these reasons, we describe aspects of the SSHAC Guidance to provide context for our observations and conclusions.

Project Plan: Conformity to the SSHAC Assessment Process

The SSHAC Guidance recognizes that observed data, available methods, models, and interpretations all contain uncertainties. These uncertainties lead to alternative scientific analyses and interpretations. In other words, experts in the broad technical community do not hold a single interpretation. Accepting this scientific situation, the SSHAC assessment process is designed to engage the scientific community in an orderly assessment of relevant data, methods, models, and interpretations that constitute current scientific knowledge as the basis for development of a seismic hazard model that represents the CBR of the TDI.

The assessment process is carried out by means of two main activities: *evaluation* and *integration*.[4] In implementation, the evaluation activities are structured to inform the integration activities. The evaluations are carried out by means of workshops in which the TI Team engages proponents of alternative interpretations that represent the range of relevant current community knowledge. Resource experts in the various relevant data sets are also engaged. The workshops have the dual purposes of, first, evaluating the degree to which alternative interpretations are supported by observed data and, second, defining uncertainties in the degree to which the interpretations are defensible, given the observed data. Integration is carried out by individual evaluator experts or evaluator expert teams (Level 4 process) or by a Technical Integrator (TI) Team (Level 3 process) who, informed by the evaluation activities, characterize the range of

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[3] See Section 2.1 in the CEUS SSC Final Report for discussion of concepts relating to the center, body, and range of the "technically-defensible interpretations" vs. the center, body, and range of the "informed technical community."

[4] For an excellent discussion of this two-stage process, see *Practical Implementation Guidelines for SSHAC Level 3 and 4 Hazard Studies*, USNRC NUREG-XXXX, Draft for Review, Office of Nuclear Regulatory Research, May 2011.

defensible alternative interpretations in an integrated hazard model and assess the scientific uncertainty distribution. Based on our review of the Project Plan and our subsequent discussions with the Project Team, we concurred that the Plan conformed with the SSHAC Guidance, incorporating lessons learned from fourteen years experience using the Guidance, and that the planned implementation was structured to properly carry out the SSHAC assessment process for development of the CEUS SSC Model.

SSHAC Level 3 Assessment Process

The SSHAC Guidance describes implementation processes for four levels of assessment depending on the scientific complexity of the assessment and the intended use of the assessed hazard model. For an assessment such as the regional SSC model for the Central and Eastern United States, which will be used at many sites for making safety and licensing decisions for nuclear facilities, the SSHAC Guidance recommends using an assessment Level 3 or Level 4.

There are process differences between a Level 3 and Level 4 implementation, but the objective is the same: to obtain from multiple proponent experts information that supports an informed assessment of the range of existent relevant interpretations and associated uncertainties that together represent current community knowledge and to perform an informed assessment of the CBR of the TDI. We understand that within the SSHAC assessment process "technically defensible" means that observed data are sufficient to support evaluation of the interpretation and the corresponding uncertainty.

In a Level 4 assessment process a TI Team facilitates the assessment, identifying and engaging proponent and resource experts, performing supporting analyses, and conducting knowledge evaluation workshops and assessment integration working meetings. Multiple experts or teams of experts perform as evaluators of the range of existent interpretations and as integrators of the hazard model. The individual evaluator experts or evaluator expert teams take ownership of their individual or team assessments. In a Level 3 assessment all of these activities are consolidated under a single TI Team consisting of a TI Lead, multiple evaluator experts representing the scope of required scientific expertise, and experienced data and hazard analysts.

As we noted earlier in this report, assurance that the CBR of the TDI is properly represented in a hazard model comes from rigorously implementing the SSHAC assessment process itself. We note that an important lesson learned from multiple implementations of the SSHAC Guidance over the past fourteen years is that the Level 3 and Level 4 assessment processes provide comparably high assurance that the relevant scientific knowledge and the community uncertainty distribution are properly assessed and represented in the hazard model. The Level 3 assessment is significantly more integrated and cohesive and is more efficient to implement. These considerations led us to endorse use of the Level 3 assessment for implementation of the CEUS SSC Project in our Workshop No. 1 review letter. During the course of the Project we observed that the higher level of cohesiveness inherent in the Level 3 assessment process leads to significantly improved communication, facilitating the experts' performance of their technical work.

Overall Project Organization

A complex project with multiple sponsors such as the CEUS SSC Project cannot be successful unless it is well organized and energetically managed so that the various participants understand the interconnectedness of their activities and perform their technical work as a cohesive group. In this regard the adopted project management structure allowed the Project Manager to provide integrated overall project leadership, manage the database development activities, and effectively maintain communication with the PPRP and project sponsors while allowing TI Team lead to concentrate on the structural and technical activities of the assessment as the Project unfolded. We conclude that the project organization was effective overall and particularly so with regard to facilitating the TI Team's implementation of the assessment process.

Implementing the SSHAC Level 3 Assessment Process

Irrespective of the level of implementation, evaluation and integration are the main activities of a SSHAC assessment. The evaluation activities aim to identify and evaluate all relevant available data, models, methods, and scientific interpretations as well as uncertainties associated with each of them. The integration activities, informed by the evaluations, aim to represent the CBR of the TDI in a fully integrated SSC model.

Evaluation

Consistent with the SSHAC Guidance the evaluation phase of the CEUS SSC project accomplished a comprehensive evaluation of the data, models, methods, and scientific interpretations existent in the larger technical community that are relevant to the SSC model. In significant part the process was carried out in three structured workshops, each focusing on accomplishing a specific step in the evaluation process.

The first workshop (WS-1) focused on evaluations of relevant geological, geophysical, and seismological datasets (including data quality and uncertainties) and on identification of hazard-significant data and hazard-significant SSC assessment issues. It became clear that a number of issues relating to the earthquake catalog, the paleoliquefaction data set, the potential-field geophysical data, updating procedures for assessing maximum earthquake magnitude, and development of procedures for assessing earthquake recurrence would require focused analyses. These analyses were appropriately carried out within the TI Team working interactively with appropriate resource experts recognized by the larger scientific and technical community.

WS-2 focused on evaluations of the range of alternative scientific interpretations, methods, and models within the larger scientific community and on corresponding uncertainties. WS-3 focused on evaluations of hazard feedback derived at seven representative test locations using a preliminary CEUS SSC model. Specifically, the workshop focused on the identification of the key issues of most significance to completing the SSC model assessment.

Experience has shown that evaluations to gain understanding of the quality of various data sets and uncertainties associated with them are essential for fully informing an SSC assessment. We observed that in WS-1 resource experts for the various data sets did a high-quality job of describing the data sets and giving their perspective about the data quality and associated uncertainties. We conclude that the understanding of data quality and uncertainties gained in WS-1 together with continued interactions between the TI Team and data resource experts significantly informed the TI Team's evaluations. The TI Team's evaluations of the data quality and uncertainties are well documented in the innovative "Data Summary Tables" and "Data Evaluation Tables" included in the Project Report. Importantly, the TI Team continued to effectively engage data resource experts in productive analyses of potential-field geophysical data, the earthquake catalog, development of the paleoearthquake data set (including an integrated assessment of the paleoliquefaction data in order to extend the earthquake catalog), the development of methods for assessing maximum earthquakes, and the development of earthquake recurrence analyses. All of these focused analyses strongly informed the assessment process. Moreover, documentation of the analyses resulted in stand-alone products of the Project that will serve future users of the CEUS SSC Model.

The compilation and evaluation of potentially relevant methods, models, and alternative scientific interpretations representing the community knowledge and corresponding uncertainties must be considered the core process activity of any SSHAC assessment. This step was largely carried out in WS-2. Success in defining the community knowledge depends on fully engaging proponent experts representing the range of methods, models, and interpretations existent at the time. Full engagement means that the proponent experts completely and clearly describe their interpretations and the data that support them and provide their individual evaluations of corresponding uncertainties. We observed that the actions taken by the Project and TI Team to explain the workshop goals and to guide participants toward meeting those goals was very productive. We conclude that the workshop was highly successful in meeting the stated goals and that it fully met the expectation of the SSHAC Guidance with respect to evaluating the range of alternative scientific interpretations. The discussions during the workshop and between the TI Team and Panel following the workshop evolved the "SSC Framework" concept, which provided transparent criteria that framed the TI Team's systematic identification and assessment of seismic sources throughout the CEUS.

Feedback from hazard calculations and sensitivity analyses is an important step in a SSHAC assessment to understand the importance of elements of the model and inform the final assessments. For development of a regional SSC model to be used for site-specific probabilistic seismic hazard analyses (PSHAs) at many geographically distributed sites, feedback based on the preliminary model is particularly important. Following WS-2 a preliminary SSC model termed "the SSC sensitivity model," was developed and used for hazard sensitivity calculations that were evaluated in WS-3. While the SSC sensitivity model was clearly preliminary, the evaluation of sensitivity results that took place in WS-3 provided important feedback for completing analyses and for supporting the TI Team's development of the preliminary CEUS SSC model. The Panel was able to review the preliminary model and provide feedback in a subsequent project briefing meeting on March 24, 2010.

Together the three workshops provided the TI Team interactions with the appropriate range of resource and proponent experts. These experts were carefully identified to present, discuss, and debate the data, models, and methods that together form the basis for assuring that the CBR of the TDI have been properly represented in the hazard model. Experts representing academia, government, and private industry participated. The TI Team also reached out to a wide range of experts as they developed the database and performed the integration activities to develop the SSC model. The Panel participated throughout this process, and is satisfied that the TI Team fully engaged appropriate experts to accomplish the goals of a SSHAC Guidance.

Integration

Consistent with the SSHAC Guidance, integration is the process of assessing the CBR of the TDI and representing the assessment in the SSC model. Informed by the evaluation process, the integration process includes representation of the range of defensible methods, models, and interpretations of the larger technical community together with new models and methods developed by analyses during the evaluation and integration process.

For the CEUS SSC Project, development of the earthquake catalog, methods for assessing and representing maximum earthquake magnitudes, and methods for earthquake recurrence assessment continued during the integration process. The Panel reviewed all the analyses at various stages of development and provided comments and recommendations. The TI Team performed the integration process by means of eleven working meetings. Members of the Panel participated in most of these working meetings as observers or resource experts. The full Panel participated in the discussions during both feedback meetings and provided formal comments and recommendations following the meetings. <u>We observed that the integration process was thorough and that it acceptably complied with the SSHAC Guidance. Based on our participation and observations we conclude that the integrated CEUS SSC Model appropriately represents the center, body, and range of current methods, models and technically defensible interpretations.</u>

PPRP Engagement

Consistent with the SSHAC Guidance, the Panel was fully engaged in peer-review interactions with the TI Team and the Project Manager of the CEUS SSC Project throughout the entire project period—from development of the Project Plan in early to mid 2008 through production of the Final Project Report in mid to late 2011.[5] The Panel provided both written and oral peer-review comments on both technical and process aspects at many stages of the Project's evolution. Key PPRP activities, leading up to this final report, have included:

- Review of the Project Plan.
- Formulation of a PPRP implementation plan, specifically for the CEUS SSC Project, to ensure adherence to the general guidance provided by SSHAC and NUREG-1563 for the scope and goals of a PPRP review.
- Involvement in *each* of the three Project workshops, including advising in the planning stage; participating collectively as a review panel during the workshop (and individually as resource experts when requested by the TI Team), providing timely comments on technical and process issues; and submitting a written report of the Panel's observations and recommendations following each workshop.
- Development and implementation of a process, together with the TI Team, to document the resolution of recommendations made in PPRP formal communications.
- Participation as observers (and occasionally as resource experts when requested by the TI Team) in eight of the TI Team's 11 working meetings.
- Peer-review and written comments, including several informal reports, on the TI Team's intermediate work products, particularly early versions of the CEUS SSC Model.

[5] See CEUS SSC Final Report: Section 2.5, Table 2.2-1, and Appendix I

- Direct interaction with the TI Team and Project Manager in more than 20 teleconferences and four face-to-face briefings—in addition to the three workshops and eight working meetings of the TI Team noted above.
- Extensive, critical peer-review of the Project's 2010 Draft Report and 2011 Final Report.

The Panel, collectively and individually, fully understood the SSHAC Guidance for a structured participatory peer review and the requirements for a Level 3 assessment process; had full and frequent access to information and interacted extensively with the TI Team and Project Manager throughout the entire project; provided peer-review comments at numerous stages; and, as documented within the Final Project Report, was fully engaged to meet its peer-review obligations in an effective way.

Project Report

The SSHAC Guidance makes clear that adequate documentation of process and results is crucial for their understanding and use by others in the technical community, by later analysis teams, and by the project sponsors. The Panel understood what was needed to conform to the SSHAC requirements, and it was committed to ensuring that the documentation of technical details associated with the CEUS SSC Model in the Project Report was clear and complete. The Panel was equally committed to ensuring the transparency of process aspects of the project, both in implementation and in description in the Project Report.

The Panel provided lengthy compilations of review comments (see Appendix I of the Project Report) for both the 2010 Draft Report and the 2011 Final Report. These included hundreds of comments, categorized as general, specific, relating to clarity and completeness, or editorial. The massive amount of detail provided by the TI Team in the Project Report and the intensiveness of the Panel's review comments both reflect great diligence and a mutual understanding by the TI Team and the PPRP of the thoroughness and high quality of documentation expected in the Project Report.

The Project Manager and the TI Lead provided review criteria to the Panel for both the draft and final versions of the Project Report. The criteria for reviewing the Draft Report[6] covered the range of technical and process issues consistent with requirements of the SSHAC Guidance, including draft implementation guidance (see footnote #4). Key criteria, among others, include sufficiency of explanatory detail; adequate consideration of the full range of data, models, and methods—and the views of the larger technical community; adequate justification of the data evaluation process, logic-tree weights, and other technical decisions; proper treatment of uncertainties; and conformance to a SSHAC Level 3 assessment process. To be clear, the PPRP is charged with judging the adequacy of the documented *justification* for the CEUS SSC Model and its associated logic-tree weights. The TI Team "owns" the Model and logic-tree weights.

Criteria for reviewing the Final Report focused on reaching closure to comments made on the Draft Report and ensuring that no substantive issues remained unresolved. To that end, among its many review comments on the Final Report the Panel identified "mandatory" comments, which the TI Team was required to address in the final version of the Project Report.

[6] See PPRP report dated October 4, 2010, in Appendix I of CEUS SSC Final Report

The Panel made thorough, extensive efforts in its documented reviews of the 2010 Draft Report and the 2011 Final Report (as well as in many related interactions with the TI Team) to ensure a high-quality Project Report that fully meets SSHAC requirements for clear, complete, and transparent documentation of all aspects of the CEUS SSC Project. We are pleased to confirm that implementation of the CEUS SSC Project fully conformed with the SSHAC Guidance and that the resulting CEUS SSC Model properly meets the SSHAC goal of representing the center, body, and range of technically-defensible interpretations.

This concludes our PPRP Final Report for the CEUS SSC Project.

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Jeffrey F. Hamel was the EPRI Advanced Nuclear Technology Program Manager. Lawrence A. Salomone of Savannah River Nuclear Solutions, LLC, served as the Project Manager for the study. Kevin J. Coppersmith of Coppersmith Consulting Inc., served as the lead for the TI Team. J. Carl Stepp of Earthquake Hazards Solutions, and Walter J. Arabasz, Research Professor Emeritus of Geology and Geophysics at the University of Utah, served as Co-chairmen for the PPRP. The entire Central and Eastern United States Seismic Source Characterization Project Team and their roles are discussed in Section 2 and are shown on the project oganization chart (Figure 2.3-1) of the report.

The authors of the report wish to acknowledge the contributions of the following people: the resource experts who participated in Workshop 1, the proponent experts who participated in Workshop 2, and the technical experts who provided valuable insights, perspective, and references throughout the study. The names of all these contributors are listed in Table 2.2-2.

In addition, the authors of the report appreciate the support of Geraldine Moore-Butler as administrative assistant and Nancy L. Sutherland as technical editor for the project. This report was assembled at AMEC.

SPONSORS' PERSPECTIVE

This report describes a new seismic source characterization model for the Central and Eastern United States (CEUS) for use in probabilistic seismic hazard analysis (PSHA) for nuclear facilities. PSHA has become a generally accepted procedure for supporting seismic design, seismic safety and decision making for both industry and government. Input to a PSHA consists of seismic source characterization (SSC) and ground motion characterization (GMC); these two components are necessary to calculate probabilistic hazard results (or seismic hazard curves) at a particular geographic location.

The 1986 Electric Power Research Institute and Seismicity Owners Group (EPRI-SOG) study included both an SSC and GMC component. Recent applications for new commercial reactors have followed U.S. Nuclear Regulatory Commission (NRC) regulatory guidance (RG 1.208) by using the EPRI-SOG source model as a starting point and updating it as appropriate on a site-specific basis. This CEUS SSC Project has developed a new SSC model for the CEUS to replace the SSC component of the EPRI-SOG study.

The CEUS SSC Project was conducted using a Senior Seismic Hazard Analysis Committee (SSHAC) Level 3 process, as described in the NRC publication, *Recommendations for Probabilistic Seismic Hazard Analysis: Guidance on Uncertainty and Use of Experts* (NUREG/CR-6372). The goal of the SSHAC process is to represent the center, body, and range of technically defensible interpretations of the available data, models, and methods. The CEUS SSC model is applicable to any site within the CEUS and can be used with the EPRI 2004/2006 GMC model to calculate seismic hazard at any site of interest. Long-term efforts to replace the EPRI 2004/2006 GMC model with the Next Generation Attenuation Relationships for Central and Eastern North America obtained from the NGA-East Project is scheduled for completion in 2014.

The updated CEUS SSC model provides industry and government with the following: a new model for the commercial nuclear industry to perform PSHAs for future reactor license applications; the NRC to support its review of early site permit (ESP) and construction and operating license (COL) applications; and the U.S. Department of Energy (DOE) to support modern PSHAs to meet design and periodic review requirements for its current and future nuclear facilities. Specific benefits of the model are as follows:

- **Consistency:** For many sites, seismic sources at distances up to 300 km (186 mi.) or more significantly contribute to hazard at some spectral frequencies. Consequently, seismic hazard models for many sites have significant geologic overlap. If done separately, there is a likelihood of conflicting assessments for the same regions. A regional source model allows for consistent input into a PSHA. An updated conceptual SSC framework that provides a consistent basis for identifying and characterizing seismic sources in the CEUS has been developed. The NRC will no longer need to review each time each applicant's regional SSC model when the accepted CEUS SSC model is used. This will avoid lengthy review of the regional SSC model in ESP and COL applications for sites within the CEUS that use the accepted regional CEUS SSC model to develop its site-specific SSC model.

- **Stability:** This CEUS SSC model was developed using the accepted state-of-practice SSHAC methodology that involved the following tasks:
    - Development of a comprehensive database and new tools for documenting the data consideration process.
    - Multiple workshops to identify applicable data, debate alternative hypotheses, and discuss feedback.
    - Multiple working meetings by the Technical Integration (TI) Team to develop the SSC model and fully incorporate uncertainties.
    - Technical advancements in a number of areas, such as developing a uniform earthquake catalog, developing an updated approach for assessing maximum magnitude, compiling data evaluation tables, incorporating paleoseismic data, and using spatial smoothing tools.
    - Participatory peer review, including four panel briefings, multiple interactions, and periodic formal feedback.
    - Proper documentation of all process and technical aspects of the project.

  Experience has shown that stability is best achieved through proper and thorough characterization of our knowledge and uncertainties, coupled with the involvement of the technical community, regulators, and oversight groups.

- **Greater Longevity:** An explicit goal of the SSHAC methodology is to represent the center, body, and range of the technically defensible interpretations of the available data, models, and methods. Using the SSHAC process provides reasonable assurance that this goal has been achieved. Representing the center, body, and range of interpretations at the time of the study means that as new information is acquired and various interpretations evolve as a result, the current thinking at any point is more likely to be addressed in the study. As new information becomes available, an existing SSC will require periodic reviews to evaluate the implications of the new findings. The need for updates to a particular study is now better understood as a result of findings of the CEUS SSC Project sensitivity studies to determine the significance of source characteristics.

- **Cost and Schedule Savings:** The CEUS SSC model can be used to perform a PSHA at any geographic location within the CEUS. It is applicable at any point within the CEUS, subject to site-specific refinements required by facility-specific regulations or regulatory guidance. Having stable, consistent input into a regional PSHA will reduce the time and cost required to complete a commercial nuclear site's ESP or COL licensing application, prepare a DOE site's PSHA, and develop design input for new commercial and DOE mission-critical nuclear facilities.

- **Advancement of Science:** The CEUS SSC Project provides new data, models, and methods. This information was shared at three workshops with international observers as a means to provide technology transfer for application in other regions. The CEUS SSC earthquake catalog, which merges and reconciles several catalogs and provides a uniform moment magnitude for all events, and the CEUS SSC paleoliquefaction database provide a new baseline for future research and updates. New approaches used in this project for spatial smoothing of recurrence parameters, assessment of maximum magnitude, and systematical documentation of all data considered and evaluated also benefit future research and PSHA updates.

The sponsors of the CEUS SSC Project are utilities and vendors on the EPRI Advanced Nuclear Technology Action Plan Committee, the DOE Office of Nuclear Energy, the DOE Office of the Chief of Nuclear Safety, and the NRC Office of Nuclear Regulatory Research. Technical experts from the DOE, NRC, U.S. Geological Survey (USGS), and Defense Nuclear Facility Safety Board (DNFSB) participated in the study as part of the TI Team or as members of the Participatory Peer Review Panel (PPRP).

The product of the CEUS SSC Project is a robust peer-reviewed regional CEUS SSC model for use in PSHAs. This model will be applicable to the entire CEUS, providing an important baseline for future research and updates. The CEUS SSC Project demonstrates that a SSHAC Level 3 approach can achieve the goals of considering the knowledge and uncertainties of the larger technical community within a robust and transparent framework. The value of the new CEUS SSC model has been enhanced by the participation of key stakeholders from industry, government, and academia who were part of the CEUS SSC Project Team.

Looking forward, the NRC will publish NUREG-2117 (2012), *Practical Implementation Guidelines for SSHAC Level 3 and 4 Hazard Studies* that provides SSHAC guidance on the need to update a regional model. The guidance covers updating both regional and site-specific assessments. It addresses the "refinement" process of starting with a regional model and refining it for site-specific applications.

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ABBREVIATIONS

AD	anno domini (in the year of the Lord)
AFE	annual frequency of exceedance
AIC	Akaike information criterion
ALM	Alabama-Louisiana-Mississippi (zone of possible paleoseismic features)
AM	Atlantic Margin (seismotectonic zone)
AHEX	Atlantic Highly Extended Crust (seismotectonic zone)
ANSS	U.S. Advanced National Seismic System
ANT	Advanced Nuclear Technology
APC	Action Plan Comittee
BA	Blytheville arch
BC	before Christ
BCFZ	Big Creek fault zone
BFZ	Blytheville fault zone
BL	Bootheel lineament
BMA	Brunswick magnetic anomaly
BP	before present
BPT	Brownian passage time
BTP	Branch Technical Position
CAD	computer-aided design

CBR	center, body, and range
CCFZ	Crittenden County fault zone
CDZ	Commerce deformation zone
CENA	Central and Eastern North America
CERI	Center for Earthquake Research and Information
CEUS	Central and Eastern United States
CFZ	Commerce fault zone
CFR	Code of Federal Regulations
CGL	Commerce geophysical lineament
CGRGC	Cottonwood Grove–Rough Creek graben
CI	confidence interval
CNWRA	Center for Nuclear Waste Regulatory Analysis
COCORP	Consortium for Continental Reflection Profiling
COCRUST	Consortium for Crustal Reconnaissance Using Seismic Techniques
COL	combined construction and operating license
COLA	combined operating license application
COMP	composite prior, composite superdomain
CON	contemporary (with earthquake occurrence)
COV	coefficient of variation
CPT	cone penetration test
CVSZ	Central Virginia seismic zone
D&G	Dewey and Gordon (1984 catalog)
DEM	digital elevation model

DNFSB	Defense Nuclear Facilities Safety Board
DOE	U.S. Department of Energy
DWM	Division of Waste Management
ECC	Extended Continental Crust
ECC-AM	Extended Continental Crust–Atlantic Margin (seismotectonic zone)
ECC-GC	Extended Continental Crust–Gulf Coast (seismotectonic zone)
ECFS	East Coast fault system
ECFS-C	East Coast fault system—central segment
ECFS-N	East Coast fault system—northern segment
ECFS-S	East Coast fault system—southern segment
EC-SFS	East Coast–Stafford fault system
ECMA	East Coast magnetic anomaly
ECRB	East Continent rift basin
ECTM	Eastern Canada Telemetered Network
E[**M**]	expected moment magnitude listed in the CEUS SSC catalog for an earthquake
ENA	eastern North America
EP	Eau Plain shear zone
EPRI	Electric Power Research Institute
EPRI-SOG	Electric Power Research Institute–Seismicity Owners Group
ERM	Eastern rift margin
ERM-N	Eastern rift margin—north
ERM-RP	Eastern rift margin—river (fault) picks
ERM-S	Eastern rift margin—south

ERM-SCC	Eastern rift margin—south/Crittenden County
ERM-SRP	Eastern rift margin—south/river (fault) picks
ERRM	Eastern Reelfoot Rift Margin
ESP	early site permit
ESRI	Environmental Systems Research Institute
ETSZ	Eastern Tennessee seismic zone
EUS	Eastern United States
FAFC	Fluorspar Area fault complex
FGDC	Federal Geographic Data Committee
ft	foot or feet
FTP	file transfer protocol
ft/s	feet per second
ft/yr	feet per year
FWLA	Fugro William Lettis & Associates
FWR	Fort Wayne rift
Ga	billion years ago
GC	Gulf Coast
GCVSZ	Giles County, Virginia, seismic zone
GHEX	Gulf Coast Highly Extended Crust (seismotectonic zone)
GIS	geographic information system
GLTZ	Great Lakes tectonic zone
GMC	ground-motion characterization (model)
GMH	Great Meteor Hotspot (seismotectonic zone)

GMPE	ground-motion prediction equation
GMRS	ground-motion response spectra
GPR	ground-penetrating radar
GPS	global positioning system
GSC	Geological Survey of Canada
Gyr	gigayears (10^9 years)
HF	Humboldt fault
HID	hazard input document
I_0	maximum intensity
IAEA	International Atomic Energy Agency
IBEB	Illinois Basin Extended Basement (seismotectonic zone)
IPEEE	Individual Plant Examination for External Events
IRM	Iapetan rifted margin
ISC	International Seismological Centre
ITC	informed technical community
ka	thousand years ago
K-Ar	potassium-argon
km	kilometer(s)
km^2	square kilometer(s)
km/sec	kilometers per second
K-S	Kijko-Sellevoll
K-S-B	Kijko-Sellevoll-Bayes
kyr	thousand years

LDO	Lamont-Doherty Earth Observatory (catalog)
LHS	Latin hypercube sampling
LLNL	Lawrence Livermore National Laboratory
ln(FA)	logarithm of felt area (with felt area measured in km^2)
LS	least squares
LSA	La Salle anticlinal belt
LWLS	locally weighted least squares
m	meter(s)
M	magnitude
M, M_W	moment magnitudes
Ma	million years ago
MAR	Marianna (RLME source)
m_b	body-wave magnitude (short period)
m_{bLg}	body-wave magnitude determined from higher-mode (L_g) surface waves
M_C	coda magnitude
MCMC	Markov Chain Monte Carlo
M_D	duration magnitude
MESE	Mesozoic and younger extended crust
MESE-N	Mesozoic-and-younger extended crust or Mmax zone that is “narrow”
MESE-W	Mesozoic-and-younger extended crust or Mmax zone that is “wide”
mi.	mile(s)
$mi.^2$	square mile(s)
MIDC	midcontinent

MidC	Midcontinent-Craton (seismotectonic zone)
Mfa	felt-area magnitude
M_L	local magnitude
M_{max}, Mmax	maximum magnitude
MMI	modified Mercalli intensity
mm/yr	millimeters per year
M_N	Nuttli magnitude
M_o	Scalar seismic moment
MRS	Midcontinent rift system
m/s	meters per second
M_S	surface-wave magnitude
MSF	Meeman-Shelby fault
M_w	
Myr	million years
NAD83	North American Datum of 1983
NAP	Northern Appalachian (seismotectonic zone)
Nd	neodymium
NEDB	National Earthquake Database
NEI	Nuclear Energy Institute
NEIC	National Earthquake Information Center
NF	Niagara fault zone
NMESE	Non-Mesozoic and younger extended crust
NMESE-N	Mesozoic-and-younger extended crust or Mmax zone that is “narrow”

NMESE-W	Mesozoic-and-younger extended crust or Mmax zone that is “wide”
NMFS	New Madrid fault system
NMN	New Madrid North fault
NMS	New Madrid South fault
NMSZ	New Madrid seismic zone
NN	New Madrid north (fault segment as designated by Johnston and Schweig, 1996)
NOAA	National Oceanic and Atmospheric Administration
NPP	nuclear power plant(s)
NR	Nemaha Ridge
NRC	U.S. Nuclear Regulatory Commission
NRHF	Nemaha Ridge–Humboldt fault
NSHMP	National Seismic Hazard Mapping Project
NW	New Madrid west (fault segment as designated by Johnston and Schweig, 1996)
OKA	Oklahoma aulacogen (seismotectonic zone)
OKO	Oklahoma Geological Survey Leonard Geophysical Observatory (catalog)
OSL	optically stimulated luminescence
P_a	probability of activity (of being seismogenic)
PEZ	Paleozoic Extended Crust (seismotectonic zone)
PGA	peak ground acceleration
PM	Project Manager
PPRP	Participatory Peer Review Panel
PSHA	probabilistic seismic hazard analysis
PVHA	probabilistic volcanic hazard analysis

RCG	Rough Creek graben
RF	Reelfoot fault
RFT	Reelfoot thrust (fault)
RLME	repeated large-magnitude earthquake (source)
RR	Reelfoot rift zone
RS	Reelfoot South (fault segment)
SA	spectral acceleration
SCL	St. Charles lineament
SCML	south-central magnetic lineament
SCR	stable continental region
SCSN	South Carolina Seismic Network
SEUS	Southeastern United States (catalog)
SEUSSN	Southeastern United States Seismic Network
SGFZ	Ste. Genevieve fault zone
SHmax	maximum horizontal stress, compression, or principal stress
SLR	St. Lawrence rift (seismotectonic zone)
SLTZ	Spirit Lake tectonic zone
SLU	Saint Louis University (catalog)
SNM	Sanford et al. (2002 catalog)
SOG	Seismicity Owners Group
SPT	standard penetration test
SRA	Stover, Reagor, and Algermissen (1984 catalog)
SRTM	Shuttle Radar Topography Mission

SSC	seismic source characterization
SSE	safe shutdown earthquake
SSHAC	Senior Seismic Hazard Analysis Committee
Str&Tur	Street and Turcotte (1977 catalog)
SUSN	Southeastern United States Network
TC	technical community
TFI	technical facilitator/integrator
TI	technical integration
USGS	U.S. Geological Survey
USNSN	U.S. National Seismograph Network
UTC	Coordinated Universal Time
V_P/V_S	ratio of P-wave velocity to S-wave velocity
WES	Weston Observatory (catalog)
WIPP	Waste Isolation Pilot Project
WQSZ	Western Quebec seismic zone
WRFZ	White River fault zone
WUS	Western United States
WVFS	Wabash Valley fault system
WVSZ	Wabash Valley seismic zone
WWSSN	World-Wide Standardized Seismograph Network

APPENDIX G

Biographies of Project Team

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APPENDIX
BIOGRAPHIES OF PROJECT TEAM

Biographies for CEUS SSC Project team members are provided in this appendix. As described in Section 2.3 and shown on Figure 2.3-1, there are several organizational levels of project participants. In this appendix, biographies for the CEUS SSC Project management team are presented first. These are followed by the biographies for individual members of the TI Team, Technical Support, Database Manager, Participatory Peer Review Panel, and Sponsor Reviewers, in alphabetical order for each organizational level.

EPRI MANAGEMENT

Robert P. Kassawara, PhD, is EPRI Senior Project Manager for the Structural Reliability and Integrity group at EPRI. Dr. Kassawara is responsible for the technical, financial, and administrative planning and management of EPRI's research and development for seismic engineering for commercial nuclear power plants. Projects include all aspects of the discipline from seismic hazard to equipment qualification. Before joining EPRI in 1985, he managed the engineering analysis section of the Plant Engineering Division of IMPELL in Melville, New York. In this position, he was responsible for performing structural engineering analyses predominantly for the nuclear power industry. Between 1970 and 1981, he managed and contributed to nuclear power plant design and analysis at Combustion Engineering in Windsor, Connecticut. Dr. Kassawara has a BS in civil engineering from the Polytechnic Institute of Brooklyn (1966), and an MS (1968) and PhD (1970) in civil engineering from the University of Illinois.

Jeffrey F. Hamel is EPRI ANT Program Manager in the ANT program within the nuclear sector at EPRI. His current research activities focus on supporting deployment of advanced nuclear plants in the near term, while promoting areas of research to support long-term nuclear sustainability and growth. Specifically, Mr. Hamel oversees research on near-term deployment of advanced light-water-reactor nuclear plants, development of the Next Generation Nuclear Plant GEN IV technology, and technical and commercial support for an integrated spent-fuel management strategy. Before joining EPRI in 2007, he worked at General Electric as the manager of special projects and was responsible for managing and leading new growth for GE's nuclear business, particularly in pressurized water reactor and spent-fuel services. In addition, while at GE, he supported the commercial development of new nuclear power plant projects both domestically and internationally, including development of key engineering, mechanical and electrical equipment necessary for project execution. Mr. Hamel received a BS in marine transportation from the Massachusetts Maritime Academy in Buzzards Bay, Mass., along with a U.S. Coast Guard Merchant Marine license and U.S. Navy Reserve commission. He received his MBA from Santa Clara University in Santa Clara, California.

PROJECT MANAGER

Lawrence A. Salomone, PE, is the Project Manager for the CEUS SSC Project. He is a registered Professional Engineer with 40 years of experience in the environmental and earth sciences. He is the Site Chief Geotechnical Engineer at the Savannah River Site (SRS) in Aiken, S.C., where he has developed and managed a $100 million geological, seismological, and geotechnical (GSG) characterization program to integrate geotechnical and geo-environmental work for mission-critical nuclear facilities at the SRS. He has directed 35-person and 70-person multidisciplinary groups. As an Associate with Dames and Moore, he directed the licensing, site preparation, and foundation operations for a nuclear power plant. As a research civil engineer for the National Bureau of Standards (now National Institute of Standards and Technology), he performed research to advance geotechnical, earthquake engineering, and energy technology. Mr. Salomone was nominated by the National Capital Section of the American Society of Civil Engineers for the Walter L. Huber Civil Engineering Research Prize for his work in the area of thermal soil mechanics. His work was used to study backfills for the Yucca Mountain high level waste repository, design underground electric transmission lines and develop mesoscale (severe) weather forecasting models. He currently serves as a consultant to the U.S. House of Representatives and the U.S. Senate on national energy policy issues.

Mr. Salomone established the industry-government partnership to develop a new SSC model for the CEUS. He served as the Department of Energy (DOE) representative supporting the NEI/EPRI New Plant Seismic Issue Resolution Program and interacted with the NRC for its update of seismic regulatory guidance. Currently, he is a member of the Seismic Lessons Learned Panel that advises the DOE Nuclear Facility Safety Program, and he is the EPRI representative on the Joint Management Committee for the Next Generation Attenuation–East Project. He participated in the Pacific Engineering Research Center (PEER) workshops for the Next Generation Attenuation–West Project. He has provided support for the DOE Nuclear Power 2010 program and now serves on the New Carolina Nuclear Power Policy Subcommittee. He is the author or co-author of over 40 published papers and many technical reports. Mr. Salomone earned his BCE in civil engineering from Manhattan College in Riverdale, N.Y., and his MS in geotechnical engineering from the University of California, Los Angeles.

TI TEAM

Kevin J. Coppersmith, PhD, of Coppersmith Consulting, Inc., is the Technical Integrator (TI) lead for the CEUS SSC Project. He has more than 30 years of consulting experience, with primary emphasis in probabilistic hazard analyses (seismic, volcanic, and related geohazards) for design and review of critical facilities within regulated environments. He has pioneered approaches to characterizing earth sciences data and their associated uncertainties for probabilistic seismic hazard analyses (PSHAs) for a range of critical facility sites, including nuclear power plant sites, high-level waste repositories, dams, offshore platforms, pipelines, and bridges. Dr. Coppersmith was a member of SSHAC, which provided PSHA methodology guidance to the NRC, DOE, and EPRI. As a co-principal investigator, he recently completed a study for the NRC on reviewing lessons learned from the application of SSHAC Study Level 3 and 4 methodologies over the past 10 years. He is currently working with NRC research staff to develop a nuclear regulatory (NUREG) series document on detailed implementation guidance for SSHAC Level 3 and 4 studies.

Dr. Coppersmith has extensive experience in leading SSHAC Level 3 and 4 studies for nuclear facilities. He served as the SSC technical facilitator/integrator (TFI) for SSHAC Level 4 seismic hazard studies at the Yucca Mountain, Nevada, high-level waste repository, and he was the SSC TFI for the PEGASOS SSHAC Level 4 study for four nuclear power plants in Switzerland. He was also the TFI for the probabilistic volcanic hazard analysis conducted in 1996 for Yucca Mountain, as well as for the update to that study completed in 2008. He is the SSC TI lead for SSHAC Level 3 seismic hazard studies for licensing of a nuclear power plant at Thyspunt, South Africa. He also serves on the peer review panel for BC Hydro’s SSHAC Level 3 seismic hazard analysis for 41 sites in the service area in British Columbia, Canada. Dr. Coppersmith received his BS in geology from Washington & Lee University in 1974 and his PhD from the University of California, Santa Cruz, in 1979.

Chris Fuller, PhD, is a Senior Geologist with Fugro William Lettis & Associates, Inc., specializing in earthquake geology. Dr. Fuller’s work has focused on performing regional and site-specific investigations to assess geologic and seismic hazards for nuclear power plants throughout the United States, and he has utilized SSHAC processes to develop seismic source characterizations for Turkey, the Meers fault, and the Gulf Coastal region. Dr. Fuller earned his BS (2000), MS (2002), and PhD (2006) in geological sciences from the University of Washington.

Laura Glaser is a Project Geologist for AMEC Geomatrix, Inc., with 4 years of experience in regional and site-specific seismic source characterization for PSHAs. Her project work includes SSHAC Level 2 studies for several sites in the CEUS, eastern Canada, and the United Kingdom. Ms. Glaser is a member of the TI staff for the SSHAC Level 3 seismic hazard studies for the licensing of a nuclear power plant at Thuyspunt, South Africa, performing regional source characterization and site-specific field investigations. Prior to this, Ms. Glaser performed geochemical research, including developing the geochronology of alluvial terraces of the Wind River Range from U-series dating of pedogenic carbonate and determining watershed-scale erosion rates from cosmogenic nuclides and soil–mass balance relationships. Ms. Glaser earned a BA in earth and planetary science from the University of California, Berkeley.

Kathryn L. Hanson is a Principal Geologist with AMEC Geomatrix, Inc. She has over 30 years of applied research and consulting experience, conducting and directing investigations to quantitatively assess geologic hazards to critical facilities in the United States and abroad. Her work has involved integrating earth sciences data and the uncertainty in these data into assessments of seismic, volcanic, and related geohazards in a variety of tectonic environments, both onshore and offshore. She has conducted both probabilistic and deterministic geohazard assessments to support successful siting, engineering, and design of nuclear facilities, dams, pipelines, and other critical facilities. Her consulting experience has emphasized regional and site-specific geologic, seismologic, and geophysical studies to identify and evaluate geohazards such as potential earthquake ground motions and surface faulting. Her work incorporates state-of-the-art methods in the use of geologic data to understand fault behavior and characterize seismic sources. Her recent work involves seismic source characterization and surface faulting investigations in support of Early Site Permits (ESPs) and Combined Construction and Operating License (COL) applications for several potential nuclear power plant sites in central and eastern United States. In addition to writing numerous major consulting reports and abstracts summarizing technical studies, Ms. Hanson was the senior author for NRC NUREG/CR 5503 and has published over 20 papers in peer-reviewed journals and proceedings volumes. She has a BS in geology from Iowa State University and an MS from the University of Oregon.

Ross Hartleb, PhD, is a Senior Geologist with Fugro William Lettis & Associates, Inc., specializing in earthquake geology. He has conducted paleoseismologic studies and post-earthquake surveys in California and Turkey. He has experience performing regional and site investigations to assess geologic and seismic hazards for nuclear power plants throughout the CEUS and has utilized SSHAC processes to develop seismic source characterizations for the Charleston, South Carolina, and northern Caribbean regions. For the CEUS SSC Project, Dr. Hartleb served as a member of the TI team and participated in the development of a paleoliquefaction database and a report on uncertainties related to the collection and interpretation of paleoliquefaction data. Dr. Hartleb earned his BA in geology from Amherst College (1992), his MS in earth science from the University of California, Santa Barbara (1998), and his PhD in earth sciences from the University of Southern California (2006.)

William R. Lettis, PhD, is President of Fugro William Lettis & Associates, Inc. (FWLA). He has over 30 years experience performing regional and site investigations to assess geologic and seismic hazards for large engineered facilities including bridges, dams, nuclear and fossil fuel plants, pipelines, and liquid natural gas terminals. With over 100 publications, he is a recognized authority on the assessment of seismic hazards, both in the United States and throughout the world. As peer reviewer, Dr. Lettis was chosen to observe the SSHAC Level 3 assessment of potential seismic sources and attenuation models for potential nuclear power plant sites in the United Arab Emirates. He provided recommendations to ensure that the results from the SSHAC meeting formed a solid basis for developing the ground motion response spectra and would be acceptable during regulatory review of the construction license application. He is also the TI for a Level 3 SSHAC assessment of seismic sources for the BC Hydro project and directed the development of the tectonic framework. FWLA has completed studies for 18 of the current COL applications in the United States, and Dr. Lettis was in the lead position of oversight, providing direction and input for the seismic source applications, on all of these projects. Dr. Lettis earned his BS in geology from Humboldt State University (1977) and his MS (1979) and PhD (1982) in geology from the University of California, Berkeley.

Scott Lindvall is a Senior Principal Geologist with Fugro William Lettis & Associates, Inc., specializing in earthquake hazards and paleoseismology. He has been active in paleoseismic research to quantify the past behavior and timing of past earthquakes on active faults and has also performed detailed mapping of surface ruptures as part of several post-earthquake investigations in southern California and abroad. He has directed the geologic and seismic evaluations for multiple ESP and COL applications for new nuclear power plants in the CEUS. These studies have focused on geologic and seismic source characterizations, implementation of the SSHAC process, independent technical review, and support for the NRC licensing process. For the CEUS SSC Project, Mr. Lindvall served as a member of the TI team to develop the seismic source model and participated in the development of a paleoliquefaction database and accompanying report. Mr. Lindvall earned his BS in geology from Stanford University (1984) and his MS in geological sciences from San Diego State University (1988).

Stephen (Steve) McDuffie, PhD, has served as a Seismic Engineer for the Chief of Nuclear Safety (CNS) at DOE since September 2008. In this position he helps the CNS and the Under Secretary for Energy fulfill their Central Technical Authority responsibilities by overseeing seismic hazard characterization and design activities at DOE facilities. Previously, Dr. McDuffie worked for DOE's Richland Operations Office as a facility representative at the Hanford Site for 10 years. In that position he served as a representative of DOE management, overseeing contractor cleanup activities in the field, with a focus on nuclear safety, worker safety, and environmental protection. Before coming to DOE, Dr. McDuffie worked for nearly 6 years for the NRC in Rockville, Maryland. During this time, he held several positions, including serving as a geologist reviewing volcanic hazards, seismic hazards, and groundwater flow at the proposed high-level nuclear waste repository at Yucca Mountain. He also managed NRC licensing casework for, and performed inspections of, fabricators and users of spent nuclear fuel and other radioactive material packagings. Dr. McDuffie earned a BA in geology from Whitman College (1987), an MA (1990) and PhD (1992) in earth and planetary sciences from Johns Hopkins University. He also received an MBA (2002) from Washington State University.

Robin K. McGuire, PhD, is the founder of Risk Engineering, Inc., of Boulder, Colorado, and is currently Vice President of Fugro William Lettis & Associates, Inc. For 30 years he has consulted in seismic hazard analysis, earthquake engineering, and the application of probabilistic methods to engineering problems. He has conducted seismic hazard analyses at sites of major engineering facilities at over 100 locations within the United States and at over 30 locations in foreign countries, in a range of technical environments. In addition, he has developed earthquake hazard software that is used around the world in engineering, insurance, risk management, government, and research for seismic hazard estimation. Dr. McGuire is the author of over 100 papers and articles on these topics that have been published in technical journals or as technical reports, as well as *Seismic Hazard and Risk Analysis*, a monograph published by the Earthquake Engineering Research Institute (EERI) in 2004. He is a past president of the Seismological Society of America (SSA) and has served on the Board of Directors of both SSA and EERI. Dr. McGuire was elected to the National Academy of Engineering in 2007. He holds degrees in structural engineering from MIT (SB and PhD) and the University of California, Berkeley (MS).

Gerry L. Stirewalt, PhD, PG, is a Senior Geologist with the NRC Office of New Reactors, Division of Site and Environmental Reviews, Geoscience and Geotechnical Engineering Branch 2. He is a registered Professional Geologist and certified Engineering Geologist with extensive practical knowledge of the standard practices required for characterization of site-specific, area, and regional geology, geomorphology, hydrology, paleoseismicity, seismicity, and seismotectonic settings at nuclear power plant sites, including site-specific geophysical and geotechnical in situ and laboratory testing procedures. Dr. Stirewalt has extensive experience in applying this knowledge under regulatory standards and guidelines for surface and subsurface geologic, hydrologic, paleoseismic, seismic, geophysical, and geotechnical field investigations and geologic hazards analysis at nuclear power plant sites. He also has considerable experience with review of applicant Safety Analysis Reports and preparation of NRC Safety Evaluation Reports for nuclear power plants; 3-D geospatial modeling of high-level radioactive waste (HLW) and non-HLW sites for the NRC; technical, regulatory, and programmatic review of DOE plans and technical reports for the civilian HLW management program; and geologic, hydrologic, and geophysical site characterization and public outreach activities for the DOE civilian HLW management program. Dr. Stirewalt earned a BA in geology and mathematics from Catawba College, North Carolina (1964), a PhD in structural geology from the University of North Carolina (1970), and did postdoctoral study in structural geology at Lamont-Doherty Geological Observatory (1969–1971), and the University of British Columbia (1971–1973).

Gabriel R. Toro, PhD, Senior Principal Engineer with Fugro William Lettis & Associates, Inc., has more than 30 years of experience in PSHA for critical facilities and other applications of probabilistic and statistical methods to the engineering analysis of natural hazards. His project experience includes a number of significant studies that have advanced the state of practice in PSHA. In the EPRI-SOG study, Dr. Toro designed and developed the software for the PSHA calculations and was a key member of the group selecting the ground motion models. As a member of the SSHAC staff, he was a major contributor to the chapter on ground motions, as well as contributing to the chapter on source characterization and to four appendices. He also directed and coordinated the PSHA calculations for the Yucca Mountain and PEGASOS Level 4 PSHA studies. Dr. Toro has made significant contributions to multiple areas of PSHA, including the development of ground motion models for regions with limited data such as the CEUS, the treatment of uncertainty in PSHA inputs, models for temporal clustering in the New Madrid region, and the probabilistic modeling of soil profiles for use in site-response calculations. He has also served as reviewer for PSHA and risk studies in Asia, Africa, and the Americas. Awards he has received include the Fulbright Travel Grant, the OMAE Award from ASME, and the

EERI Outstanding Paper Award. Dr. Toro has a civil engineer’s degree from the National University of Colombia, and a Master’s and PhD in civil engineering from M.I.T.

Robert R. Youngs, PhD, a Principal Engineer at AMEC Geomatrix, Inc., has more than 35 years of consulting experience, with primary emphasis in hazard and decision analysis. He has pioneered approaches for incorporating earth sciences data and their associated uncertainties into probabilistic hazard analyses. The focus of this work has been on developing quantitative evaluations of hazard by combining statistical data and expert judgment. Dr. Youngs has considerable experience in assessing earthquake hazards in central and eastern North America and implementing SSHAC processes. He was a member of the research teams that developed EPRI’s seismic hazard assessment for nuclear power plants in the CEUS and EPRI-sponsored research projects to assess ground motions (1993) and maximum magnitudes (1994) for the CEUS. He was also a member of the project team for the NRC project to develop response spectral shapes for analysis of nuclear facilities (NUREG/CR-6728) in 2001 and the EPRI project to characterize ground motions in the CEUS for analysis of nuclear facilities in 2004. Dr. Youngs has completed seismic hazard analyses of existing and proposed nuclear power plants throughout the United States (including in Alabama, Florida, Louisiana, Michigan, and North Carolina) and internationally, including in Ontario, Canada and Switzerland (PEGASOS project). He earned his BS in civil engineering at California State Polytechnical University, Pomona (1969), and his MS and PhD in geotechnical engineering at the University of California, Berkeley (1982).

TECHNICAL SUPPORT

Serkan Bozkurt, MCP, is a Senior GIS Analyst and Information Manager at AMEC Geomatrix, Inc. He has 14 years of work experience in GIS, information management, and Internet technologies. The focus of his work has been the utilization of spatial models; 3-D visualizations; and GIS analysis and remote sensing technologies to support geosciences projects such as geohazards analysis for oil facilities, offshore platforms, pipelines, nuclear power plants, bridges dams, levees, and other critical facilities. Some of his recent project work includes GIS and information management services for SSHAC Level 2 studies and for sites in the United States, Canada, and the United Kingdom. Prior to joining AMEC, Mr. Bozkurt worked at the U.S. Geological Survey on the Earthquake Hazards Team as a GIS analyst and Web developer. He has contributed to more than 50 scientific publications related to seismic hazard studies. He earned a BS in urban and regional planning from Istanbul Mimar Sinan University (1996) and an M.C.P in GIS and city planning from the Istanbul Mimar Sinan University (2000).

Randolph J. Cumbest, PhD, is a Principal Geologist with Fugro William Lettis & Associates, Inc. (FWLA). He has 15 years experience with Westinghouse Savannah River Co., where he was engaged in various geological and geophysical characterization activities and was technical lead for the Savannah River Site fault characterization program. Dr. Cumbest has been with FWLA since 2007 and has been involved with studies for licensing commercial reactors. He earned his BS in geology from Auburn University (1976), his MS in geology from the University of Georgia (1987), and his PhD in geological sciences from Virginia Polytechnic Institute (1988). In addition, he has had postdoctoral positions as a research associate at Princeton University and as visiting scientist at the Institute of Advanced Studies, The Australian National University.

Valentina Montaldo Falero, PhD, is a Project Scientist for AMEC Geomatrix, Inc., with 10 years of research and consulting experience in probabilistic seismic hazard analysis. The focus of her work has been development and analysis of earthquake catalogs; assessment of recurrence parameters; and quantification of hazard. She has been involved in performing SSHAC Level 2 seismic hazard analyses for nuclear power plants in the CEUS, eastern Canada, and Europe, and in conducting probabilistic seismic hazard studies for dams and other facilities located in western North America (Oregon, Washington, Idaho, and British Columbia). Before joining AMEC Geomatrix, Dr. Montaldo Falero helped develop the national seismic hazard map of Italy and coauthored several scientific publications. She earned a BS/MS in geological sciences from the University of Milan, Italy (2000), and a PhD from the University of Milan-Bicocca, Italy (2006).

Roseanne C. Perman, PhD, a Senior Geologist at AMEC Geomatrix, Inc., has more than 30 years of experience as a consulting geologist with an emphasis on geologic hazards. She has managed and participated in a variety of multidisciplinary studies to evaluate potential geologic hazards to critical facilities for public agencies and private organizations and has assisted in developing hazard methodology and policy recommendations for state, federal, and professional organizations. For more than a decade, Dr. Perman's work was focused primarily on DOE studies for DOE to characterize uncertainties surrounding complex technical issues associated with the proposed high-level radioactive waste repository at Yucca Mountain. For the many DOE studies that involved expert elicitation, Dr. Perman had key roles in methodology development, coordination, and documentation. These included SSHAC Level 4 studies to complete a PSHA in 1998, a probabilistic volcanic hazard analysis conducted in 1996, and the update to that study completed in 2008. More recently, Dr. Perman has been involved in seismic source characterization for nuclear facilities located throughout the CEUS and in the Ontario region of Canada. For the CEUS SSC Project she had responsibilities for documentation, including coordination of report production. Dr. Perman earned a B.A. in both geography (1976) and earth science (1981), and an M.A. (1985) and Ph.D. (1988) in paleontology, all from the University of California, Berkeley.

Allison Shumway is a Senior Staff Geologist who joined Fugro William Lettis & Associates, Inc., in 2007. Ms. Shumway's experience in PSHA comes from working collaboratively with Risk Engineering, Inc., for the past 2 years on projects for the nuclear power industries. She earned her BA in geological sciences from the State University of New York at Geneseo (2005) and her MS in earth sciences from the University of Memphis (2007), where her graduate work focused on seismic hazard in the New Madrid seismic zone.

Frank H. Syms, PhD, is a Principal Engineering Geologist with Fugro William Lettis & Associates, Inc. He has been practicing in geology respective to nuclear applications for over 20 years. Much of this experience has been in the southeast respective to the DOE Savannah River site as well as serving in a review capacity for studies conducted for new facilities at Oak Ridge, Tennessee. During the past 4 years, Dr. Syms has concentrated on studies for the licensing of new commercial nuclear power reactors in the United States. His contributions to the CEUS SSC Project included the initial development of the database structure, selection of the data screening criteria, and participation in Workshop 1. Dr. Syms received his BS (1987), MS (1997), and PhD (2002) in geology from the University of South Carolina.

Martitia (Tish) Tuttle, PhD, is Director and Principal Investigator with M. Tuttle & Associates. She has been active in paleoseismology and earthquake hazards research since 1985, conducting studies of the geologic record of past earthquakes in the central, northeastern, and western United States; northeastern Caribbean; southeastern Canada; western Australia; and western Portugal. She has conducted paleoliquefaction studies in the central United States, including the New Madrid seismic zone and surrounding region since 1992, where she has played a pivotal role in identifying and dating earthquake-induced liquefaction features and assessing the earthquake potential of the region. Dr. Tuttle has participated in post-earthquake surveys of liquefaction features and related ground failures in California, Quebec, and India, and has collaborated in geotechnical studies of liquefaction sites in Massachusetts, Quebec, and the central United States. For the CEUS SSC Project, she served as a resource expert in earthquake-induced liquefaction and paleoseismology and participated in the development of a paleoliquefaction database and a report on uncertainties related to the collection and interpretation of paleoliquefaction data. Dr. Tuttle earned a BS in soil science from Oregon State University (1979), a BS in earth sciences from Portland State University (1983), an MS in earth sciences from University of California, Santa Cruz (1985), and PhD in geology from University of Maryland (1999).

DATABASE MANAGER

David L. Slayter, PG, is a Senior GIS Analyst at Fugro William Lettis & Associates, Inc. He has 19 years of experience in several roles involving the geologic and natural sciences, as a geologist and a GIS scientist. His professional background includes consulting and research, as well as local, state, and federal government experience on projects ranging from spatial analysis to GIS project design. Mr. Slayter has worked on the development of GIS databases for several proposed nuclear power plant license applications. He has also been involved in the development of quality assurance standards for GIS databases and quality control and validation of GIS software. He is a registered Professional Geologist in California and a certified GIS Professional. He currently serves on the Education Committee of the Geospatial Information & Technology Association and the Review Committee of the GIS Certification Institute. Mr. Slayter earned his BS in geology from California State University, Sacramento (1991), and his MA in geography from the University of Oklahoma (2003).

PARTICIPATORY PEER REVIEW PANEL

Jon P. Ake, PhD, is currently Senior Seismologist in the Office of Research, Division of Engineering of the NRC. His duties include overseeing research on a broad range of seismic related issues for hazard assessment and integration with risk analyses. Dr. Ake began his career conducting research on explosively generated ground motions, the dynamic response of earth media, and applications of signal analysis to ground shock problems. He subsequently worked as a consulting geophysicist with responsibility for operating a 21-station seismic network in central Colorado and performing high-resolution seismic refraction and reflection studies and other engineering geophysical investigations (magnetic, electrical, and gravity). In 1989 he joined the U.S. Bureau of Reclamation, where his responsibilities included conducting, reviewing, and coordinating probabilistic seismic hazard studies, integrating the results with engineering analyses, and incorporating them into quantitative risk assessments. Dr. Ake served as a member of the expert panel that characterized seismic sources for a PSHA for the proposed high-level waste repository at Yucca Mountain. He also served in a liaison role to the DOE on seismic hazard issues for the Yucca Mountain Project, in which he assisted in the coordination and preparation of documents on disruptive events that became part of the license application to the NRC.

Dr. Ake has served on the Dam Safety Advisory Team to the U.S. Bureau of Reclamation; the Federal Interagency Committee on Dam Safety; the U.S.-Japan Panel on Wind and Seismic Effects; the Consortium of Strong Motion Operators (COSMOS); and ANS/ANSI Committees 2.27 (Criteria for Investigations of Nuclear Facilities Sites for Seismic Hazard Assessments), 2.29 (Probabilistic Seismic Hazard Analysis), and 2.20 (Seismic Instrumentation for Nuclear Facilities). He has acted as a peer reviewer for the University of California Campus Earthquake Safety Program, BC Hydro, U.S. Army Corps of Engineers, DOE, California Department of Water Resources, Federal Energy Regulatory Commission, and the USGS, among others. He is currently a member of the DOE Seismic Lessons Learned Panel and Next Generation Attenuation–East projects. Dr. Ake obtained a BA in geology and physics from Western State College in Colorado and an MS and PhD in geophysics from the New Mexico Institute of Mining and Technology.

Walter J. Arabasz, PhD, is Co-Chairman of the PPRP for the CEUS SSC Project. He has worked since 1974 as a seismologist at the University of Utah, where he is now Research Professor Emeritus of Geology and Geophysics. From 1985 to June 2010 he was Director of the University of Utah Seismograph Stations. He has more than 40 years of professional experience in research, project management, consulting, and occasional teaching in seismology, seismotectonics, and earthquake hazard assessment. He is the author or co-author of 46 published papers, 94 published abstracts, and many technical reports. In addition, he has served on numerous national and state advisory and policy-making committees for earthquake risk reduction and U.S. network seismology.

Since 1977 Dr. Arabasz has routinely provided professional consulting services and peer review on earthquake hazard assessments for dams, nuclear facilities, and other critical construction, including services for engineering firms, the International Atomic Energy Agency, DOE, the U.S. Bureau of Reclamation, EPRI, Los Alamos National Laboratory, and the state of Utah, among others. He has had broad experience in implementing PSHA, beginning with participation as a member of the PSHA methodology team in the original EPRI seismic hazard characterization of the CEUS (1985–1987). As a member of the National Research Council's Panel on Seismic Hazard Evaluation (1992–1996), he observed the development of and formally reviewed recommendations for PSHA made by the Senior Seismic Hazard Analysis Committee (SSHAC). Honors include the U.S. Geological Survey's John Wesley Powell Award, the Western States Seismic Policy Council Lifetime Achievement Award in Earthquake Risk Reduction, and the [Utah] Governor's Medal for Science and Technology. Dr. Arabasz earned a BS in geology at Boston College (1964), an MS in geology at the California Institute of Technology (1966), and a PhD in geology and geophysics at the California Institute of Technology (1971).

William J. Hinze, PhD, is Emeritus Professor of Geophysics at Purdue University. Before coming to Purdue, where he taught for 26 years, he served at the U.S. Army Engineering Research and Development Laboratory, worked as an industrial exploration geophysicist, and later taught at Michigan State University for 13 years. He has supervised approximately 100 graduate students during his professional career. In addition to having extensive university teaching experience, Dr. Hinze has experience in research and industrial consulting on the geological and engineering applications of gravity and magnetic fields. He has authored or co-authored more than 130 journal publications and has co-edited or co-authored four books. He has been a member of numerous government and scientific panels dealing with gravity and magnetic fields, geophysics and geology of continents, continental drilling, digital geoscience data, seismotectonics, and nuclear waste disposal. From 1990 to 1996, he served as associate editor of geophysics and then senior editor of the *Journal of Geophysical Research–Solid Earth*. He served on the NRC's Advisory Committee on Nuclear Waste from 1989 to 1997 and from 2005 to 2008. He is recipient of the Institute on Lake Superior Geology's Goldich Medal and the American Geophysical Union's Kaula Award. Dr. Hinze is a member of the Society of Exploration Geophysicists and the American Geophysical Union, and he is a Fellow of the Geological Society of America. Currently he serves as Earth Science Consultant to the NRC's Advisory Committee on Reactor Safeguards. He obtained a PhD in geophysics from the University of Wisconsin–Madison.

Ann Marie (Annie) Kammerer, PhD, is currently a Senior Seismologist and Earthquake Engineer in the Office of Nuclear Regulatory Research at the NRC, where she coordinates and manages the Seismic Research Program. In this role, she is responsible for overseeing research on a broad range of seismic topics ranging from seismic hazard to seismic risk assessments for nuclear facilities. She is project manager for the NRC research project titled "Practical Procedures for the Implementation of the SSHAC Guidelines and for Updating Hazards," which will result in a new NUREG-series report intended as a companion document to the original SSHAC report. She is also the NRC project manager and representative on the Joint Management Committee for the Next Generation Attenuation–East project, which is developing ground-motion prediction equations for Central and Eastern North America for use with the CEUS SSC for Nuclear Facilities model.

In addition to her experience at the NRC, Dr. Kammerer has 15 years of experience in private consulting on seismic topics. Before joining the NRC in 2006, she was a consultant with the international design firm, Arup. As seismic hazard lead for the Americas, she was responsible for consulting in a wide variety of areas, including geotechnical earthquake engineering, seismology, and risk assessment. Dr. Kammerer has authored two dozen publications, including technical reports, journal articles, a book chapter, conference proceedings and papers, and an ASCE special publication. She was the project manager and a principal author of Regulatory Guide 1.208 and is assisting the International Atomic Energy Agency with the update of Safety Guide NS-G-3.5. She is also the project manager for the updates to regulatory guides on liquefaction assessments and determination of floor spectra and is responsible for the development of a new regulatory guidance on technology-neutral performance-based engineering of nuclear power plants. Dr. Kammerer holds three degrees, with minors in seismology and structural engineering, from the University of California, Berkeley: a BS in civil engineering, an MS in geotechnical engineering, and a PhD in geotechnical earthquake engineering.

Jeffrey K. Kimball is a Technical Specialist (Seismologist) on the staff of the Defense Nuclear Facilities Safety Board. He is responsible for technical issues involving natural phenomena hazards, nuclear facility safety and design, and general oversight of defense nuclear facilities. He has 30 years of experience with the evaluation and characterization of natural phenomena hazards and the design of critical facilities to resist these hazards. He has full knowledge of a wide range of nuclear facility regulations, regulatory guides, standards, manuals, guides, and review plans associated with nuclear facility design and evaluation. From 1990 to 2006, Mr.

Kimball was the group lead for engineering design in the DOE National Nuclear Security Administration. He supervised technical staff responsible for technical review of nuclear facility designs and safety analysis. He led the development of seismic site characterization at numerous DOE sites, including the definition of the design basis earthquake, and led preparation of DOE standards and guides to define requirements and procedures to complete assessment of natural phenomena hazards.

Mr. Kimball was the DOE sponsor for the program that led to the "Recommendations for Probabilistic Seismic Hazard Analysis: Guidance on Uncertainty and Use of Experts," commonly referred to as the SSHAC guidelines. From 1987 to 1990, he was a geophysicist in the DOE Office of Radioactive Waste, responsible for establishing the baseline site characterization plan for the Yucca Mountain high-level waste repository site. Before that, from 1984 to 1987, he was a senior geophysicist with Roy F. Weston Inc., participating in the review and development of environmental assessments for nine candidate high-level waste sites, and comparing and ranking sites for site characterization. From 1980 to 1984, he was a geophysicist with the NRC, participating in the review of safety analysis reports and developing appropriate sections of those reports. Mr. Kimball holds a BS in atmospheric and oceanic sciences and an MS in geosciences (geophysics/seismology), both from the University of Michigan.

Donald P. Moore, PE, is a Consulting Engineer with Southern Nuclear Operating Company. He has over 40 years experience in seismic analysis, seismic design, seismic qualification, and seismic hazard assessment of nuclear power plant structures, systems, and components. He has provided technical leadership through EPRI and NEI in many areas, such as implementation of seismic margin assessment methodology, the resolution of USI A-46 on equipment seismic qualification, the methodology for response to individual plant examination of external events (IPEEE) for seismic activity, and seismic analysis of unanchored spent fuel dry casks at independent spent-fuel storage facilities. He has participated in the development of industry codes and standards for nuclear facilities, such as ASCE-4, ASCE/SEI 43-05, IEEE-344, and ASME code revisions.

Mr. Moore was a member of the EPRI industry task group that provided NRC comments on new regulations and regulatory guides for ESPs and COLs. He also participated in the peer review of the seismic analysis of Westinghouse AP600, and in NRC research on the seismic response of unanchored spent-fuel casks. He is a member of the NEI Seismic Issues Task Force and the EPRI Technical Review and Advisory Group, which are involved in resolving seismic issues with ESPs and COLs. Mr. Moore has been a member of the Technical Advisory Group for a number of COL applicants for the Site Safety Analysis Report section 2.5 (Geology, Seismology, and Geotechnical Engineering). He has co-authored a number of technical papers on seismic analysis and design. He is currently the Technical Interface for Southern Nuclear for the seismic portion of the Vogtle ESP and COL. Mr. Moore holds a BS in civil engineering from University of Alabama and an MS in engineering from The University of Alabama at Birmingham. He is a licensed Professional Engineer.

Mark D. Petersen, PhD, is currently the Chief of the U.S. National Seismic Hazard Mapping Project of the U.S. Geological Survey in Golden, Colo., and also serves as a National Coordinator for the USGS Earthquake Hazards Program. Dr. Petersen was lead in developing the 1996 California state hazard maps (California Geological Survey) and the 2008 National Seismic Hazard Maps (USGS). He is responsible for the USGS seismic hazard maps that are applied in many modern building codes, implemented in earthquake insurance rates, and considered for public policy decisions. Dr. Petersen has served on several scientific committees, including the Working Group on California Earthquake Probabilities (1999, 2002, 2008); the Working Group on Utah Earthquake Probabilities (2010); the Science Advisory Board for the California Earthquake Authority (2003–2005); the Utah Seismic Safety Commission (2002–2010); the Global Earthquake Model (GEM) Modeling Advisory Group (2009–2010); the Advisory Board for the Swiss Seismological Service (2009); PEER Next Generation Attenuation Relations groups (2003–2010); and the PPRP for the CEUS SSC Project (2008–2010). In addition to the U.S. hazard analyses, he has conducted seismic hazard assessments for Europe (Turkey); central Asia; Southeast Asia (India, Thailand, Cambodia, Vietnam, Laos, Indonesia, Singapore, Malaysia); Central America and the Caribbean (Panama, Puerto Rico, Virgin Islands); and South America (all countries). Dr. Petersen has a BS and MS in geology from Brigham Young University, and an MPhil and PhD from Columbia University's Lamont-Doherty Earth Observatory.

J. Carl Stepp, PhD, of Earthquake Hazards Solutions, is Co-Chairman of the Participatory Peer Review Panel (PPRP) for the CEUS SSC Project. Dr. Stepp has more than 40 years experience developing PSHA methods and developing probabilistic seismic design bases, primarily for nuclear power generation plants and other critical facilities. During his professional career he has been a research seismologist for the U.S. Coast and Geodetic Survey for approximately 10 years; he was chief of the Geology, Seismology, and Geotechnical Engineering Branch at the NRC, in charge of the application of seismic hazard assessment in nuclear facilities seismic regulation for 7 years; he headed research and development of seismic hazard, seismic design, and seismic regulation technologies for 10 years as director of the Seismic Center at EPRI; and he provided consulting services in seismic hazard assessment and seismic safety regulation for approximately 20 years. At the NRC, he supervised early implementation of the nuclear seismic regulation 10 CFR, Part 100, Appendix A for reviews of 53 nuclear power plant construction and operating license applications, and the development of geology, seismology, and geotechnical engineering sections of the NRC's Standard Review Plan. At EPRI, Dr. Stepp managed a broad program of nuclear plant seismic safety research and technology development, including methods for probabilistic seismic hazard assessment and for predicting earthquake-generated ground motion. He was technical lead for EPRI, interacting with both the NRC and industry to incorporate the integrated results of EPRI's seismic research and technology development into seismic regulations, including the 10 CFR Part 100.23 rule making and the development of Regulatory Guide 1.165 and Revision 3 of the related Standard Review Plan sections.

Dr. Stepp directed development of the PSHA for the Yucca Mountain, Nevada, high-level nuclear waste site; he chaired the development of Preclosure Seismic Design Methodology for a Geologic Repository at Yucca Mountain, and he chaired the Seismic Review Panel for development of the Yucca Mountain license application. He served as a member of the EPRI Technical Review and Advisory Group, supporting the NEI/EPRI New Plant Seismic Issue Resolution Program and interacting with the NRC to update Regulatory Guide 1.208 and the related sections of the Standard Review Plan. Currently he is Chairman of the PPRP for the BC Hydro PSHA Project and a member of the Seismic Lessons Learned Panel that advises the DOE Nuclear Facility Safety Program. Dr. Stepp holds a BS in geology from Oklahoma State University, an MS in geophysics from the University of Utah, and a PhD in geophysics from Pennsylvania State University.

SPONSOR REVIEWERS

Brent Gutierrez, PhD, PE, CEM, is the Natural Phenomena Hazards Engineering Manager for DOE's Savannah River Operations Office located in Aiken, S.C. He has more than 22 years of engineering experience in the mitigation of natural phenomena hazards for nuclear facilities inclusive of hazard evaluation and geotechnical, structural, and mechanical engineering. His current responsibilities include developing mitigation policy for the Natural Phenomena Hazards Department and promulgating this policy into Savannah River's engineering standards and practice. Dr. Gutierrez received a BS and MS in mechanical engineering from Mississippi State University and a PhD in mechanical engineering from the University of South Carolina.

Clifford G. Munson, PhD, is Senior Technical Advisor in the Division of Site and Environmental Reviews, Office of New Reactors for the NRC. He is the principal reviewer of new nuclear plant siting applications in the areas of geology, seismology, and geotechnical engineering for the NRC. He has developed and updated several regulatory guidance documents pertaining to siting, including Chapter 2.5 of NUREG-0800, "Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants"; Regulatory Guide 1.206, "Combined License Applications for Nuclear Power Plants (LWR Edition)"; and Regulatory Guide 1.208, "A Performance-Based Approach to Define the Site-Specific Earthquake Ground Motion." Dr. Munson joined the NRC in 1995 as a geophysicist, becoming a senior geophysicist in 2003, then a branch chief in 2008 until he took his current position in November 2009. He has a BS in statistics (1987) from Brigham Young University and an MS (1991) and PhD in geophysics (1995) from the University of Wisconsin–Madison.

APPENDIX H

CEUS SSC Model Hazard Input Document (HID)

H

APPENDIX
CEUS SSC MODEL HAZARD INPUT DOCUMENT (HID)

H.1 Introduction

This appendix describes the CEUS SSC Model in the main report. The purpose of this document is to provide the necessary information so that an analyst experienced in PSHA can implement the seismic source model. The appendix contains the logic tree structure and descriptions of the parameters that define the frequency and spatial distribution of potential future earthquakes. The reader is referred to the main report for detailed descriptions of methods and rationale used to develop the model parameters. The digital files that contain the input parameters described in this appendix are contained on the project website. The area covered by this model is shown on Figure H-1-1 along with the locations of the test sites used for hazard sensitivity calculations presented in Chapter 8.

H.2 Seismic Source Model Structure and Master Logic Tree

The structure of the CEUS SSC model is described in Section 4. The CEUS SSC Model contains two general types of seismic sources. The first type of seismic source uses the recorded history of seismicity to model the frequency and spatial distribution of moderate to large earthquakes ($\mathbf{M} \geq 5$). These sources are denoted as distributed seismicity sources. They cover the entire region shown on Figure H-1-1. The second type of seismic source uses the paleo-earthquake record to model the frequency and spatial distribution of repeated large magnitude earthquakes (RLMEs) at specific locations.

Figure H-2-1 shows the master logic tree for the CEUS SSC model. The basis for this logic tree is described in Section 4.2. The first node addresses the conceptual approach used to characterize the distributed seismicity sources. Two approaches are used. The first is an approach in which distributed seismicity is modeled using seismicity rates that smoothly vary across the entire study region. The study region is subdivided only on the basis of differences in maximum magnitudes. The first branch is designated as the Mmax Zones approach. The second approach uses seismic source zones defined on a seismotectonic basis to model distributed seismicity. The second branch is designated as the Seismotectonic Zones approach. In both approaches specific seismic sources are used to model individual sources of RLMEs. The RLME sources represent additional sources of seismic hazard that are added to the hazard from the distributed seismicity sources.

The models developed for the various types of seismic sources are described in subsequent sections of this appendix.

H.3 Mmax Zones Distributed Seismicity Sources

Figure H-3-1 shows the logic tree structure to be used for the distributed seismicity sources on the Mmax Zones branch of the master logic tree. This logic tree is discussed in Section 4.2.3 of the main report.

H.3.1 Division of Study Region

The first node addresses whether or not the study region is divided into two zones that have different Mmax distributions. If “No” then the entire study region, shown on Figure H-1-1, is treated as a single source. If “Yes” then the study region is divided into Mesozoic and younger extended regions (MESE) and those regions that do not display such evidence (NMESE).

H.3.2 Location of Boundary of Mesozoic Extension

The second node of the Mmax Zones logic tree, which applies only to the Mesozoic and younger separation branch, addresses the alternative boundaries between the MESE and NMSES regions. Two alternatives are used. The first, labeled the “Wide Interpretation” has a broad interpretation of the extent of Mesozoic extension. Figure H-3-2 shows the location of this boundary. The second, labeled the “Narrow Interpretation” makes a narrow interpretation of the extent of Mesozoic extension. Figure H3-3 shows the location of this boundary.

H.3.3 Magnitude Interval Weights for Fitting Earthquake Occurrence Parameters

The third node addresses the issue of the weight assigned to smaller magnitudes in the estimation of seismicity parameters for the seismic source zones. Three cases are used, Cases A, B, and E. The weights assigned to individual magnitude intervals are discussed in Section 5.3.2.2.

H.3.4 Mmax Zones

The next element of the Mmax Zones logic tree (which is not a node but a listing) identifies the Mmax zone designations for each case. The vertical bar without a dot at the branching point designates the addition of hazard from all of the listed sources, as opposed to weighted alternatives that appear with a dot on the logic tree. The coordinates defining the boundaries of the Mmax Zones are contained in the file Source_Zones_Geometry.zip on the project web site. The boundary for each zone is contained in an ASCII file named for the source with the extension “zon” (e.g. “MESE-N.zon” for the MESE-N Mmax zone).

H.3.5 Seismogenic Crustal Thickness

The fifth node of the logic tree represents the uncertainty distribution for seismogenic crustal thickness. The distribution used for each Mmax zone is listed in Table H-3-1. These are epistemic uncertainties representing weighted alternative assessments of the seismogenic crustal thickness for each Mmax zone.

H.3.6 Future Earthquake Rupture Characteristics

The sixth node addresses the uncertainty distributions for the rupture characteristics of future earthquakes. In the CEUS SSC model a single aleatory distribution is applied to each Mmax zone. These aleatory distributions are listed in Table H-3-2.

The area of individual earthquake ruptures is modeled using the relationship:

$$\log_{10}(\text{A in km}^2) = \mathbf{M} - 4.366 \qquad \text{(H-1)}$$

The rupture aspect ratio is 1:1 until the rupture reaches maximum rupture width. For larger ruptures the width is fixed and the length is increased to obtain the area given by Equation H-1. This model is used for all earthquake sources described in this HID.

H.3.7 Assessment of Seismicity Rates

The seventh node of the Mmax Zones logic tree on Figure H-3-1 addresses the approach used for assessing seismicity rates and their spatial distribution. Allowing both the *a*-value and the *b*-value to vary spatially is the selected approach. The approach is described in Section 5.3.2. Seismicity parameters are estimated for ½° longitude by ½° latitude cells or partial cells.

H.3.8 Degree of Smoothing Applied in Defining Spatial Smoothing of Seismicity Rates

The eighth node of the logic tree addresses the degree of smoothing applied in the seismicity parameter estimation in each source region. A single approach, the “Objective” approach, is used to select the degree of smoothing. This is discussed in Section 5.3.2.2 of the main report.

H.3.9 Uncertainty in Earthquake Recurrence Rates

The ninth node of the logic tree addresses the epistemic uncertainty in earthquake recurrence parameters. The recurrence parameter distributions are represented by eight alternative spatial distributions developed from the fitted parameter distributions. These alternatives are described in Section 5.3.2. The result is eight equally weighted alternative sets of recurrence parameters for each Mmax Zone. The recurrence parameters are contained in the file “CEUS_SSC_All_xyab_Files.zip” on the project web site. The recurrence parameters are contained in ASCII files for each Mmax zone using the following file naming convention.

Zone_Case_Realization.ext

The *“Zone*” portion of the file name is the Mmax Zone name, MESE-W, MESE-N, NMESE-W, NMESE-N, and STUDY_R for the case when the entire study region is considered a single Mmax Zone. The “*Case*” portion of the file name refers to Case A, Case B, or Case E on Figure H-4. The “*Realization*” portion of the file name takes on the values “01”, “02”, “03”, “04”, “05”, “06”, “07”, and “08” to indicate the eight equally weighted alternative sets of recurrence parameters. The “*ext*” portion of the file name takes on two values. An extension of “*xyab*” indicates a file containing recurrence parameters for PSHA calculations that integrate over magnitude starting from a minimum magnitude, m_0, of **M** 5.0. An extension of “*xyab4*” indicates a file containing recurrence parameters for PSHA calculations that integrate over magnitude starting from a minimum magnitude, m_0, of **M** 4.0, which would typically be used for PSHA calculations incorporating the Cumulative Absolute Velocity (CAV) filter.

Each recurrence parameter file contains a header with the case description. The second record provides the number of individual cells and the nominal cell size in degrees (e.g 0.5 for ½° longitude by ½° latitude cells). The remaining records contain the following information in five columns:

- Longitude and latitude of the center of the cell or partial cell, in degrees.
- Recurrence rate of earthquakes of magnitude m_0 and larger per equatorial degrees^2. For the files with extension "*xyab*" this is the rate of **M** 5 and larger earthquakes and for files with extension "*xyab4*" this is the rate of **M** 4 and larger earthquakes.
- Beta value. This is the *b*-value expressed in natural log units $\{\beta = b \text{ x } \ln(10)\}$.
- Area of the cell in equatorial degrees^2. The absolute value of recurrence rate is the product of the values in the third and fifth columns.

H.3.10 Uncertainty in Maximum Magnitude

The tenth node of the logic tree addresses the uncertainty in the maximum magnitude for each Mmax Zone. These epistemic distributions are listed in Table H-3-3.

H.4 Seismotectonic Zones

Figure H-4-1 shows the logic tree structure for the seismotectonic source zones component of the master logic tree. The components of the source model logic tree are described below. Table H-4-1 lists the seismotectonic source zones.

H.4.1 Alternative Zonation Models

The first two nodes address the alternative zonation models. The first node addresses the uncertainty in the western boundary of the Paleozoic Extended Crust seismotectonic zone. The two alternatives are the narrow interpretation (0.8) and the wide interpretation (0.2). The second node of the logic tree addresses the uncertainty in the eastern extent of the Reelfoot Rift zone (RR) —whether or not it includes the Rough Creek Graben (RCG). These two logic tree levels lead to the four alternative seismotectonic zonation configurations shown on Figures H-4-2 through H-4-5. The discussion of this assessment and the associated weights is given in Section 7.3.6.3 of the main report. As shown on Figures H-4-1 though H-4-5, the alternative zonation models produce alternative versions of the Mid-Continent source zone. These are designated MidC-A, MidC-B, MidC-C, and MidC-D.

H.4.2 Magnitude Interval Weights for Fitting Earthquake Occurrence Parameters

The third node addresses the issue of the weight assigned to smaller magnitudes in the estimation of seismicity parameters for the seismic source zones. As in the Mmax Zones model, three cases are used, Cases A, B, and E. The weights assigned to individual magnitude intervals are discussed in Section 5.3.2.2.

H.4.3 Seismotectonic Zones

The next element of the logic tree is again a listing of the individual seismotectonic source zones for each zonation model. The vertical bar without a dot at the branching point designates the addition of hazard from all of the listed sources. The coordinates defining the boundaries of the source are contained in the file Source_Zones_Geometry.zip on the project web site. The boundary for each zone is contained in an ASCII file named for the source with the extension "zon" (e.g. "AHEX.zon" for the AHEX seismotectonic source zone).

H.4.4 Seismogenic Crustal Thickness

The fifth node of the logic tree represents the uncertainty distribution for seismogenic crustal thickness. The distribution used for each seismotectonic zone is listed in Table H-4-2. These are epistemic uncertainties representing weighted alternatives.

H.4.5 Future Earthquake Rupture Characteristics

The sixth node addresses the uncertainty distributions for the rupture characteristics of future earthquakes. In the CEUS SSC model a single aleatory distribution is applied to each seismotectonic zone. These aleatory distributions are listed in Table H-4-3.

The area of individual earthquake ruptures is modeled using the relationship given in Equation H-1 above. The rupture aspect ratio is 1:1 until the rupture reaches maximum rupture width. For larger ruptures the width is fixed and the length is increased to obtain the area given by Equation H-1. This model is used for all earthquake sources described in this HID.

H.4.6 Assessment of Seismicity Rates

The seventh node of the logic tree on Figure H-4-1 addresses the approach used for assessing seismicity rates and their spatial distribution. Allowing both the *a*-value and the *b*-value to vary spatially is the selected approach. The approach is described in Section 5.3.2. Seismicity parameters are estimated for ¼° longitude by ¼° latitude cells or partial cells for all sources except the Mid-Continent sources, for which the cell size ½° longitude by ½° latitude is used.

H.4.7 Degree of Smoothing Applied in Defining Spatial Smoothing of Seismicity Rates

The eighth node of the logic tree addresses the degree of smoothing applied in the seismicity parameter estimation in each source region. A single approach is used to select the degree of smoothing for each source. This is discussed in Section 5.3.2.2 of the main report. For all sources but the St. Lawrence Rift zone (SLR) the "Objective" approach is used.

H.4.8 Uncertainty in Earthquake Recurrence Rates

The ninth node of the logic tree addresses the epistemic uncertainty in earthquake recurrence parameters. As was the case for the Mmax zones, the recurrence parameter distributions are represented by eight alternative spatial distributions developed from the fitted parameter distributions. These alternatives are described in Section 5.3.2. The result is eight equally weighted alternative sets of recurrence parameters for each Seismotectonic Zone. The recurrence parameters are contained in the file "CEUS_SSC_All_xyab_Files.zip" on the project web site. The recurrence parameters are contained in ASCII files for each seismotectonic zone using the naming convention and file format described in Section H.3.9.

H.4.9 Uncertainty in Maximum Magnitude

The tenth node of the logic tree addresses the uncertainty in the maximum magnitude for each seismotectonic zone. These distributions are listed in Table H-4-4.

H.5 RLME Sources

This section describes the models for the RLME sources. As shown on Figure H-2-1, these sources are considered to be additional sources superimposed on the distributed seismicity sources on the seismotectonic branch of the master logic tree or on the Mmax Zones on the Mmax Zone branch of the master logic tree. Figure H-5-1 shows the overall structure of the RLME sources model. There are 10 RLME sources. Each source has a logic tree defining the uncertainty in characterization. Discussion of the each of the individual RLME sources is contained in Section H.5 of the main report. The locations of the RLME sources are shown on Figure H-5-2. The parameters for each of the RLME sources present in the following sections are contained in files located on the CEUS SSC Project website in the RLME directory.

H.5.1 Charlevoix RLME Seismic Source Model

The Charlevoix RLME source is described in Section 6.1.1 of the main text. The logic tree for the Charlevoix RLME source is shown on Figure H-5.1-1. The parameters are located on the CEUS SSC Project web site in the file "Charlevoix_RLME.xls."

H.5.1.1 Temporal Clustering

The first node of the logic tree addresses the issue of temporal clustering of earthquakes in the present tectonic stress regime. This node of the logic tree is not applicable to the Charlevoix RLME source.

H.5.1.2 Localizing Tectonic Features

Because the occurrence of RLMEs in the Charlevoix zone cannot be associated with a specific feature, future RLMEs are modeled as occurring randomly within the RLME source zone, as indicated on the second node of the logic tree (Figure H-5.1-1).

H.5.1.3 Geometry and Style of Faulting

The geometry of the Charlevoix RLME source is shown on Figure H-5.1-2. A single source zone geometry is used. The coordinates are contained on the "Geometry" tab of the file "Charlevoix_RLME.xls." Given the small source size and uncertain fault locations, the boundaries of the Charlevoix RLME source are leaky, allowing ruptures to extend beyond the source boundary by 50 percent.

The thickness of seismogenic crust is modeled with equal weight on 25 and 30 km (16 and 19 mi.), as shown on the fourth node of the logic tree (Figure H-5.1-1).

Future earthquake ruptures are modeled as reverse faulting earthquakes. Rupture geometry is modeled by a single aleatory distribution as shown by the fifth node of the logic tree. Strikes of ruptures are to be uniformly distributed over azimuths of 0 to 360 degrees. Fault dips are uniformly distributed between 45 and 60 degrees.

H.5.1.4 RLME Magnitude

Table H-5.1-1 lists the epistemic uncertainty distribution for the expected magnitude of future earthquakes associated with the Charlevoix RLME source. Aleatory variability in the size of an individual Charlevoix RLME is modeled as a uniform distribution of ±0.25 **M** units centered on the expected RLME magnitude value listed in Table H-5.1-1.

H.5.1.5 RLME Recurrence

The remaining nodes of the Charlevoix RLME logic tree address uncertainties in the specification of the annual frequency of RLMEs.

Recurrence Methods and Data

Two approaches are used to assess RLME recurrence. The “Earthquake Recurrence Intervals” approach is assigned a weight of 0.2. This approach leads to data set 1. The “Earthquake Count in a Time Interval” approach is assigned a weight of 0.8. There are two data sets associated with this branch. Data set 2 is assigned a conditional weight of 0.75 and data set 3 is assigned a conditional weight of 0.25.

Earthquake Recurrence Model

The Poisson model is used as the earthquake recurrence model, with a weight of 1.0.

RLME Annual Frequency

The final node of the logic tree addresses the uncertainty distributions for the annual frequency of RLMEs. These distributions are listed in Tables H-5.1-2, H-5.1-3, and H-5.1-4. The data are contained in the file “Charlevoix_RLME.xls.”

H.5.2 Charleston RLME Seismic Source Model

Charleston RLME source is described in Section 6.1.2 of the main text. Figure H-5.2-1 shows the logic tree for the Charleston RLME source. The parameters are located on the CEUS SSC Project web site in the file “Charleston_RLME.xls.”

H.5.2.1 Temporal Clustering

The first node of the logic tree (Figure H-5.2-1) addresses the issue of temporal clustering of earthquakes on the Charleston RLME source. The Charleston RLME seismic source is modeled as “in” a temporal cluster with a weight of 0.9 and “out” of a temporal cluster with a weight of 0.1. For the “in” branch, the remaining portion of the logic tree is used to define the hazard from this source. On the “out” branch the Charleston RLME source is not included in calculation of the total seismic hazard.

H.5.2.2 Localizing Feature

The second node of the Charleston RLME source logic tree indicates whether future earthquakes in the Charleston seismic zone will be associated with a specific localizing tectonic feature. The approach used for this source is to model future ruptures to occur randomly with the source.

H.5.2.3 Geometry and Style of Faulting

The third node of the Charleston RLME source logic tree addresses the alternative geometries of the parameters Charleston RLME source. Three alternative source zone geometries are included in the model. These are shown on Figure H-5.2-2. The coordinates of the three source geometries are given in the file "Charleston_RLME.xls."

The fourth node of the logic tree indicates the three values of seismogenic crustal thickness used for all source geometries.

The geometries and style of faulting for the three source geometries are specified as follows.

- Charleston Local source configuration: Future ruptures are oriented northeast, parallel to the long axis of the zone. Ruptures are modeled as occurring on vertical strike-slip faults. All boundaries of the Charleston Local source are strict, such that ruptures are not allowed to extend beyond the zone boundaries.
- Charleston Narrow source configuration: Future ruptures are oriented north-northeast, parallel to the long axis of the zone. Ruptures are modeled as occurring on vertical strike-slip faults. The northeast and southwest boundaries of the Charleston Narrow source are leaky, whereas the northwest and southeast boundaries of the Charleston Narrow source are strict.
- Charleston Regional source configuration: Future rupture orientations are represented by two alternatives: (1) future ruptures oriented parallel to the long axis of the source (northeast) with 0.80 weight, and (2) future ruptures oriented parallel to the short axis of the source (northwest) with 0.20 weight. In both cases, future ruptures are modeled as occurring on vertical strike-slip faults. All boundaries of the Charleston Regional source are strict.

H.5.2.4 RLME Magnitude

The sixth node of the Charleston RLME source logic tree defines the magnitude of future large earthquakes in the Charleston RLME source. The RLME magnitude distribution is given in Table H-5.2-1. Aleatory variability in the size of an individual Charleston RLME is modeled as a uniform distribution of ±0.25 **M** units centered on the expected RLME magnitude value.

H.5.2.5 RLME Recurrence

The remaining nodes of the Charleston RLME source logic tree address the uncertainty in modeling of the recurrence rare of Charleston RLMEs.

Recurrence Method

The recurrence data for the Charleston RLME source consists of ages of past RLMEs estimated from the paleoliquefaction record. Therefore, node seven of the logic tree indicates that recurrence for the Charleston RLME source is based solely on the "Earthquake Recurrence Intervals" approach.

Time Period

The eighth node of the Charleston RLME source logic tree assesses length and completeness of the paleoliquefaction record. Two alternatives are considered: the approximately 2,000-year record of Charleston earthquakes with 0.80 weight and the approximately 5,500-year record with 0.20 weight.

Earthquake Count

The ninth node of the Charleston logic tree addresses the uncertainty in the number of RLMEs that have occurred in the Charleston RLME source. For the 2,000-year record, a single model is used. For the 5.500-year, three alternatives are used as shown on Figure H-5.2-1.

Earthquake Recurrence Model

The tenth node of the Charleston RLME source logic tree defines the earthquake recurrence models used for the regional, local, and narrow source zones (Figure H-5.2-1). For the regional and local sources, only the Poisson model is used. For the more "fault-like" narrow source zone, the Poisson model is assigned 0.90 weight, and the BPT renewal model is assigned 0.10 weight. Use of the BPT renewal model requires specification of the coefficient of variation of the repeat time for RLMEs, parameter α. The uncertainty distribution for α is shown on the eleventh node of the Charleston RLME source logic tree.

RLME Annual Frequency

The final (twelfth) node of the logic tree addresses the uncertainty distributions for the annual frequency of RLMEs. There are 20 uncertainty distributions corresponding to the various approaches and data sets defined in Levels 8, 9, 10, and 11 of the logic tree. These are given in Tables H-5.2 -2 through H-5.2-21. Tables H-5.2-2 through H-5.2-6 provide the recurrence rate distributions for the Poisson Occurrence model and Tables H-5.2-7 through H-5.2-21 provide the recurrence rate distributions for the BPT Renewal model. Figure H-5.2-1 shows the relationship between the branches of the logic tree and the recurrence rate distribution tables.

H.5.3 Cheraw RLME Seismic Source Model

The Cheraw RLME source is described in Section 6.1.3 of the main report. Figure H-5.3-1 shows the logic tree for the Cheraw RLME source. The parameters are located on the CEUS SSC Project web site in the file "Cheraw_RLME.xls."

H.5.3.1 Temporal Clustering

The first node of the logic tree (Figure H-5.3-1) addresses the issue of temporal clustering of earthquakes in the present tectonic stress regime. The within-cluster branch of the logic tree is assigned a weight of 0.9, and the out-of-cluster branch is assigned a weight of 0.1. These two branches lead to different recurrence rates

H.5.3.2 Localizing Feature

The Cheraw RLME source is modeled as a single fault source.

H.5.3.3 Geometry and Style of Faulting

Two alternative lengths are used for the Cheraw RLME source. These are shown on Figure H-5.3-2. The mapped length is assigned a weight of 0.8 and the extended length is assigned a weight of 0.2. The coordinates for these two geometries are provided in the file “Cheraw_RLME.xls.”

The fourth node of the logic tree provides the uncertainty distribution for the thickness of seismogenic crust. The generic distribution of 13 km (weight of 0.4), 17 km (weight of 0.4), and 22 km (weight of 0.2) is used.

The fifth node of the logic tree addresses the uncertainty in the dip of the fault. The assigned uncertainty distribution is: 50°NW (0.6), 65°NW (0.4).

The style of faulting is assessed to be normal. Future ruptures are to be confined to the modeled fault surface.

H.5.3.4 RLME Magnitude

The magnitude distribution for the Cheraw RLME source is given in Table H-5.3-1. Aleatory variability in the size of an individual Cheraw RLME is modeled as a uniform distribution of ±0.25 **M** units centered on the expected RLME magnitude value.

H.5.3.5 RLME Recurrence

The remaining nodes of the Cheraw RLME logic tree address the uncertainties in modeling the recurrence rate of Cheraw RLMEs

Recurrence Method

Two types of data are used for assessing the recurrence frequency of Cheraw RLMEs. The first is the average slip rate of the fault and the second is the number and timing of previous RLMEs, allowing application of the “Earthquake Recurrence Intervals” approach. These two approaches are assigned equal weights.

Recurrence Data

Two data sets are used for the assessment of the in-cluster recurrence rate of Cheraw RLMEs based on the “Earthquake Recurrence Intervals” approach. The first is the occurrence of two earthquakes in 20-25 ka, with a weight of 0.4, and the second in the occurrence of three earthquakes in 20-25 ka, with a weight of 0.6. The total slip of the fault in the range of 3.2 to 4.1 m in 20-25 ka is used to assess the in-cluster slip rate.

The out-of-cluster recurrence rates for the “Earthquake Recurrence Intervals” approach are based on estimates of the time between in-cluster periods. Out-of-cluster slip rate is based on 7–8 m of offset in a time period ranging from 400 ka to 2 Ma.

Earthquake Recurrence Model

The Poisson model is used as the earthquake recurrence model with weight 1.0 for the Cheraw RLME source.

RLME Annual Frequency

The assessed RLME recurrence frequencies for the various data sets are given in Tables H-5.3-2 through H-5.3-6. Figure H-5.3-1 shows the relationship between the branches of the logic tree and the recurrence rate distribution tables.

H.5.4 Meers RLME Seismic Source Model

The Meers RLME source is described in Section 6.1.4 of the main report. The source logic tree is shown on Figure H-5.4-1. The data for the Meers RLME is located on the CEUS SSC Project web site contained in file "Meers_RLME.xls."

H.5.4.1 Temporal Clustering

The first node of the logic tree (Figure H-5.4-1) addresses the issue of temporal clustering. The in-cluster branch of the logic tree is given a weight of 0.8 and the out-of-cluster branch a weight of 0.2. These two alternatives affect both the recurrence rate of the RLMEs and their spatial distribution.

H.5.4.2 Localizing Feature

The second branch of the logic tree (Figure H-5.4-1) defined whether future earthquakes associated with the Meers RLME source are localized along the Meers fault scarp (designated "Fault" on the logic tree), or whether they may occur along other structures within the Oklahoma aulacogen ("Random in Zone" on the logic tree). For the in-cluster case, the "Fault" model is used and RLMEs are constrained to occur on the Meers fault. For the out-of-cluster case, RLMEs the two alternatives are the "Fault" model and the "Random in Zone" model.

H.5.4.3 Geometry and Style of Faulting

The third through fifth branches of the logic tree describe the source geometry and style of faulting (Figure H-5.4-1).

The alternative geometries for the "Fault" model consists of the mapped Quaternary trace of the Meers fault (weight 0.9) and an extended fault trace (weight 0.1). These two geometries are shown on Figure H-5.4-2.

For the "Random-in-Zone" model, the RLMEs are modeled as occurring uniformly distributed within the boundary of the OKA seismic source zone, also shown on Figure H-5.4-2.

The seismogenic thickness for the Meers RLME source is modeled as either 15 km or 20 km with equal weights.

For the "Fault" model, future earthquake ruptures are to be modeled as either oblique earthquakes on a vertical fault (weight 0.5) or reverse-oblique earthquakes dipping 40 degrees southwest. Ruptures are confined to the model fault surface.

For the "Random-in-Zone" model future ruptures are to be modeled as having a N60W strike and a random dip in the range of 90 to 40 degrees southwest.

H.5.4.4 RLME Magnitude

The sixth branch of the logic tree describes the earthquake magnitudes for the Meers RLME. The RLME magnitude distribution is given in Table H-5.4-1. Aleatory variability in the size of an individual Meers RLME is modeled as a uniform distribution of ±0.25 **M** units centered on the expected RLME magnitude value.

H.5.4.5 RLME Recurrence

The remaining branches of the logic tree define the uncertainty distributions for RLME recurrence rates.

Recurrence Method

The "Earthquake Recurrence Intervals" approach is used with weight 1.0 (Figure H-5.4-1).

Recurrence Data

The data used to assess the in-cluster recurrence rates consists of two earthquakes in 2.1 to 3 ka. The data used to assess the out-of-cluster case consist of the estimated time between clusters of activity on the fault.

Earthquake Recurrence Model

The Poisson model is used as the earthquake recurrence model with weight 1.0 for the Meers RLME source.

RLME Annual Frequency

The final node of the logic tree addresses the uncertainty distributions for the annual frequency of RLMEs (Figure H-5.4-1). These distributions are provided in Tables H-5.4-2 for the in-cluster case and Table H-5.4-3 for the out-of-cluster case. Note that the out-of-cluster model combined with the "Random-in-Zone" model for the spatial distribution is assigned the in-cluster recurrence rate distribution.

H.5.5 New Madrid Fault System RLME Seismic Source Model

The New Madrid Fault System (NMFS) RLME is discussed in Section 6.1.5 of the main report. Figure H-5.5-1 shows the logic tree for this source. The data for this source is on the CEUS SSC Project web site contained in file "NMFS_RLME.xls."

H.5.5.1 Temporal Clustering

The first node of the logic tree (Figure H-5.5-1) addresses the issue of temporal clustering. Three alternatives are modeled.

- With weight 0.9 the NMFS RLME is modeled as being in-cluster.

- With weight 0.05 the RLME is modeled as being out-of-cluster with no earthquake activity occurring on the source.
- With weight 0.05, the RLME is modeled as being out-of-cluster with a long term rate assigned to only the Reelfoot Thrust (described below).

H.5.5.2 Localizing Feature

The RLMEs associated with the NMFS are modeled as occurring on three fault sources: (1) the New Madrid South (NMS) fault; (2) the New Madrid North (NMN) fault; and (3) the Reelfoot Thrust (RFT).

H.5.5.3 Geometry and Style of Faulting

Each of the NMFS fault sources has two alternative geometries as shown on Figures H-5.5-2, H-5.5-3, and H-5.5-4, respectively. Future NMFS RLMEs are confined to occur on these modeled faults.

The seismogenic crustal thickness is modeled as being 13 km (weight of 0.3), 15 km (weight of 0.5), or 17 km (weight of 0.2).

The style of faulting for each of the fault sources is based on geologic and seismologic observations. The NMS fault is modeled as a vertical right-lateral strike-slip fault. The RFT fault is modeled as a reverse fault dipping an average of 40 degrees southwest. The NMN fault is modeled as a vertical right-lateral strike-slip fault.

H.5.5.4 RLME Magnitude

The magnitudes of RLMEs for the NMFS are assigned in terms of a joint distribution. Table H-5.5-1 lists the assigned distribution of rupture sets. Aleatory variability in the size of an individual RLME is modeled as a uniform distribution of ±0.25 **M** units centered on the expected RLME magnitude value for each fault source.

H.5.5.5 RLME Recurrence

The remaining nodes of the NMFS RLME source logic tree address the assessment of earthquake recurrence rates.

Recurrence Method

The "Earthquake Recurrence Intervals" approach is used with weight 1.0 (Figure H-5.5-1).

Recurrence Data

In-cluster case recurrence rates are based on the 1811-1812, 1450 AD, and 900 AD sequences. Out-of-cluster recurrence rates for the NMFS are based on timing between clusters.

Earthquake Recurrence Model

The Poisson and renewal recurrence models are assigned weights of 0.75 and 0.25, respectively, for the in-cluster case. For the renewal model the BPT model is used with a distribution for the parameter α shown on the twelfth node of the source logic tree.

RLME Annual Frequency

The final node of the logic tree addresses the uncertainty distributions for the annual frequency of RLMEs (Figure H-5.5-1). These distributions are contained in Table H-5.5-2 for the in-cluster Poisson case, Tables H-5.5-3, H-5.5-4, and H-5.5-5 for the in-cluster renewal model cases, and in Table H-5.5-5 for the out-of-cluster Poisson case.

For the in-cluster case, RLMEs are to be modeled as occurring on all three of the fault sources within a close period of time (e.g. similar to the 1811-1812 earthquake sequence).

H.5.6 Eastern Rift Margin Fault RLME Seismic Source Model

The Eastern Rift Margin (ERM) fault RLME sources are described in Section 6.1.6 in the main text. The source consists of southern and northern segments. Figure H-5.6-1 shows the logic tree for the southern segment, ERM-S and Figure H-5.6-2 shows the logic tree for the northern segment ERM-N. The data for these two sources are contained on the CEUS SSC Project web site in files “ERM-S_RLME.xls” and “ERM-N_RLME.xls.”

H.5.6.1 Temporal Clustering

The first node of the logic trees addresses the issue of temporal clustering of earthquakes in the present tectonic stress regime. This node of the logic tree is not applicable to the ERM-S and ERM-N RLME sources.

H.5.6.2 Localizing Feature

The ERM-S and ERM-N RLME sources are modeled as narrow zones. Figures H-5.6-3 and H-5.6-4 show the geometries of the sources. Earthquakes are modeled as uniformly distributed in the source zones.

H.5.6.3 Geometry and Style of Faulting

There are two alternative geometries for the ERM-S RLME source: ERM-SCC (weight of 0.6) and the ERM-SRP (weight 0.4). These are shown on Figure H-5.6-3. A single geometry is specified for the ERM-N RLME source.

The probability distribution used to model seismogenic thickness for the ERM-S and ERM-N RLME sources is: 13 km (weight of 0.3), 15 km (weight of 0.5), and 17 km (weight of 0.2).

Future ruptures are to be modeled as vertical strike slip ruptures aligned parallel with the long axis to the RLME source zones. Both the northeastern and southwestern ends of the zones are modeled as leaky to allow for uncertainty in the extent of possible reactivated faults along the rift margin.

H.5.6.4 RLME Magnitude

Tables H-5.6-1 and H-5.6-2 list the RLME magnitude distributions for the ERM-S and ERM-N RLMEs, respectively. Aleatory variability in the size of an RLME is modeled as a uniform distribution of ±0.25 **M** units centered on the expected RLME magnitude value given in the tables.

H.5.6.5 RLME Recurrence

The remaining nodes of the ERM-S and ERM-N logic trees address the estimation of recurrence rate of RLMEs.

Recurrence Method

The "Earthquake Count in a Time Interval" approach is used to assess RLME recurrence frequency for both the ERM-S and ERM-N sources.

Recurrence Data

For the ERM-S source, three alternative data sets are used to assess RLME recurrence rates: either two, three, or four earthquakes in a 17.7 to 21.7 ka period. The three alternatives have equal weight.

For the ERM-N source, two alternative data sets are use: either one (weight 0.9) or two (weight 0.1) earthquakes in a 12–35 ka period.

Earthquake Recurrence Model

The Poisson model is used as the default earthquake recurrence model with weight 1.0 for both the ERM-S and ERM-N sources.

RLME Annual Frequency

Tables H-5.6-3, H-5.6-4, and H-5.6-5 list the distribution of RLME recurrence frequencies for the ERM-S source. Tables H-5.6-6 and H-5.6-7 list the distribution of RLME recurrence frequencies for the ERM-N source.

H.5.7 Marianna Zone RLME Seismic Source Model

The Marianna Zone RLME is described in Section 6.1.7 of the main report. The logic tree for this source is shown on Figure H-5.7-1. The data for this source is contained on the CEUS SSC Project web site in file "Marianna_RLME.xls."

H.5.7.1 Temporal Clustering

The first node of the logic tree for the RLME source (Figure H-5.7-1) addresses the issue of temporal clustering of earthquakes. The in-cluster model is assigned a weight of 0.5 and the out-of-cluster model is assigned a weight of 0.5. For the "in" branch, the remaining portion of the logic tree is used to define the hazard from this source. On the "out" branch the Marianna RLME source is not included in calculation of the total seismic hazard.

H.5.7.2 Localizing Feature

RLMEs are modeled as occurring randomly with the boundary of the Marianna zone shown on Figure H-5.7-2.

H.5.7.3 Geometry and Style of Faulting

A single geometry for the Marianna RLME source is used. The geometry is shown on Figure H-5.7-2.

The probability distribution used to model seismogenic thickness is 13 km (weight of 0.3), 15 km (weight of 0.5), or 17 km (weight of 0.2).

Two equally weighted alternatives for future ruptures of RLMEs are modeled: either vertical strike-slip ruptures oriented northeast parallel to the sides of the Marianna zone or vertical strike-slip ruptures oriented northwest parallel to the sides of the Marianna zone. All boundaries to the MAR zone are leaky.

H.5.7.4 RLME Magnitude

The distribution for RLME magnitude for the Marianna RLME source is given in Table H-5.7-1. Aleatory variability in the size of an RLME is modeled as a uniform distribution of ±0.25 **M** units centered on the expected RLME magnitude value given in the table.

H.5.7.5 RLME Recurrence

The remaining branches of the logic tree describe the assessment of RLME recurrence rates.

Recurrence Method

The “Earthquake Recurrence Intervals” approach is used with weight 1.0 (Figure H-5.7-1).

Recurrence Data

The two equally weighted data sets consist of either three or four earthquakes with the oldest occurring approximately 9.9 ka.

Earthquake Recurrence Model

The Poisson model is used as the default earthquake recurrence model with weight 1.0 for the Marianna RLME source.

RLME Annual Frequency

The final node of the logic tree addresses the uncertainty distributions for the annual frequency of RLMEs. These distributions are given in Tables H-5.7-2 and H-5.7-3.

H.5.8 Commerce Fault RLME Seismic Source Model

The Commerce RLME source is described in Section 6.1.8 of the main text. The source logic tree is shown on Figure H-5.8-1. The data for this source is contained on the CEUS SSC Project web site in file “Commerce_RLME.xls.”

H.5.8.1 Temporal Clustering

This node of the logic tree is not applicable to this source.

H.5.8.2 Localizing Feature

RLMEs are modeled as occurring randomly with the boundary of the Commerce zone shown on Figure H-5.8-2.

H.5.8.2 Geometry and Style of Faulting

A single geometry for the Commerce RLME source is modeled.

The uncertainty distribution for seismogenic crustal thickness is: 13 km (weight of 0.3), 15 km (weight of 0.5), or 17 km (weight of 0.2).

The Commerce RLME source is modeled as a zone of vertical strike-slip faulting. Ruptures are to be oriented N47°E, subparallel to the Commerce zone boundary. The northeast and southwest boundaries of the zone are considered leaky boundaries.

H.5.8.4 RLME Magnitude

Table H-5.8-1 lists the uncertainty distribution for the Commerce RLME magnitude. Aleatory variability in the size of an RLME is modeled as a uniform distribution of ±0.25 **M** units centered on the expected RLME magnitude value given in the table.

H.5.8.5 RLME Recurrence

The remaining branches of the logic tree describe the assessment of RLME recurrence rates.

Recurrence Method

The “Earthquake Recurrence Intervals” approach is used with weight 1.0 (Figure H-5.8-1).

Recurrence Data

The preferred interpretation (weight 0.75) is that two earthquakes have occurred in the past 23 kyr with the possibility (weight 0.25) that the count is three earthquakes.

Earthquake Recurrence Model

The Poisson model is used as the earthquake recurrence model with weight 1.0 for the Commerce RLME source.

RLME Annual Frequency

Tables H-5.8-2 and H-5.8-3 list the alternative distributions for RLME frequency for the Commerce RLME source.

H.5.9 Wabash Valley RLME Seismic Source Model

The Wabash Valley RLME source is described in Section 6.1.9 of the main text. The source logic tree is shown on Figure H-5.9-1. The data for this source is contained on the CEUS SSC Project web site in file "Wabash_RLME.xls."

H.5.9.1 Temporal Clustering

This node of the logic tree is not applicable to this source.

H.5.9.2 Localizing Feature

RLMEs are modeled as occurring randomly with the boundary of the Wabash Valley zone shown on Figure H-5.9-2.

H.5.9.3 Geometry and Style of Faulting

A single zone geometry is used to model the Wabash Valley RLME. This geometry is shown on Figure H-5.9-2.

Two alternative estimates of the seismogenic thickness of the crust in the Wabash Valley RLME are used: 17 km (weight of 0.7) or 22 km (weight of 0.3).

The boundaries of the Wabash Valley RLME source zone are modeled as leaky. Earthquakes are to be modeled with a random strike (uniform 0º to 360º azimuth). The earthquakes are a mixture of 2/3 vertical strike-slip and 1/3 reverse (random dip in the range of 40º to 60º)

H.5.9.4 RLME Magnitude

Table H-5.9-1 lists the uncertainty distribution for the magnitude of Wabash Valley RLMEs. Aleatory variability in the size of an RLME is modeled as a uniform distribution of ±0.25 **M** units centered on the expected RLME magnitude value given in the table.

H.5.9.5 RLME Recurrence

The remaining branches of the logic tree describe the assessment of RLME recurrence rates.

Recurrence Method

The "Earthquake Recurrence Intervals" approach is used with weight 1.0 (Figure H-5.9-1).

Recurrence Data

The available data for characterizing the recurrence rate of Wabash Valley RLMEs are the estimated ages for the Vincennes-Bridgeport and Skelton paleoearthquakes.

Earthquake Recurrence Model

The Poisson model is used as the earthquake recurrence model with weight 1.0 for the Wabash Valley RLME source.

RLME Annual Frequency

The final node of the logic tree addresses the uncertainty distributions for the annual frequency of RLMEs. This distribution is listed in Table H-5.9-2.

Table H-3-1
Weighted Alternative Seismogenic Crustal Thickness Values for Mmax Zones

Mmax Zone	Crustal Thickness and [Weight]
Study Region	13 km [0.4], 17 km [0.4], 22 km [0.2]
MESE-W	13 km [0.4], 17 km [0.4], 22 km [0.2]
MESE-N	13 km [0.4], 17 km [0.4], 22 km [0.2]
NMESE-W	13 km [0.4], 17 km [0.4], 22 km [0.2]
NMESE-N	13 km [0.4], 17 km [0.4], 22 km [0.2]

Table H-3-2
Aleatory Distributions for Characterization of Future Earthquake Ruptures for Mmax Zones

Mmax Zone	Source Boundary Characteristics	Sense of Slip (Relative Frequency)	Rupture Strike (Relative Frequency)	Rupture Dip (Relative Frequency)
Study Region, MESE-N, MESE-W, NMESE-N, NMESE-W	Leaky[a]	Strike-slip (2/3)	N50W (0.2) N00E (0.2) N35E (0.4) N60E (0.1) N90E (0.1)	Uniformly distributed 60º to 90º, equally likely dip direction
		Reverse (1/3)	N50W (0.2) N00E (0.2) N35E (0.4) N60E (0.1) N90E (0.1)	Uniformly distributed 30º to 60º, equally likely dip direction

[a] Leaky boundary denotes the case were earthquake ruptures are centered on the earthquake epicenter, the epicenters are contained within the source boundary, but the rupture is allowed to extend beyond the source boundary.

Table H-3-3
Maximum Magnitude Distributions for Mmax Distributed Seismicity Sources

Weight Assigned to Mmax	Maximum Magnitude for:				
	Study Region	MESE_N	NMESE_N	MESE_W	NMESE_W
0.101	6.5	6.4	6.4	6.5	5.7
0.244	6.9	6.8	6.8	6.9	6.1
0.310	7.2	7.2	7.1	7.3	6.6
0.244	7.7	7.7	7.5	7.7	7.2
0.101	8.1	8.1	8.0	8.1	7.9

Table H-4-1
Seismotectonic Source Zones

Zone Acronym	Seismotectonic Source Zone
AHEX	Atlantic Highly Extended Crust
ECC-AM	Extended Continental Crust—Atlantic Margin
ECC-GC	Extended Continental Crust—Gulf Coast
GMH	Great Meteor Hotspot
IBEB	Illinois Basin Extended Basement
GHEX	Gulf Highly Extended Crust
MidC-A, MidC-B, MidC-C, MidC-D	Midcontinent-Craton alternatives
OKA	Oklahoma Aulacogen
PEZ-N and PEZ-W	Paleozoic Extended Crust narrow and Paleozoic Extended Crust wide
RR and RR-RCG	Reelfoot Rift and Reelfoot Rift including the Rough Creek Graben
SLR	St. Lawrence Rift, including the Ottawa and Saguenay grabens

Table H-4-2
Weighted Alternative Seismogenic Crustal Thickness Values for Seismotectonic Zones

Mmax Zone	Crustal Thickness and [Weight]
AHEX, GHEX	8 km [0.5], 15 km [0.5]
ECC-AM, ECC-GC, MidC-A, MidC-B, MidC-C, MidC-D, IBEB, NAP,PEZ-N, PEZ-W	13 km [0.4], 17 km [0.4], 22 km [0.2]
GMH, SLR	25 km [0.5], 30 km [0.5]
OKA	15 km [0.5] 20 km [0.5]
RR, RR-RCG	13 km [0.4], 15 km [0.4], 17 km [0.2]

Table H-4-3
Aleatory Distributions for Characterization of Future Earthquake Ruptures for Seismotectonic Zones

Seismotectonic Zone	Source Boundary Characteristics	Sense of Slip (Relative Frequency)	Rupture Strike (Relative Frequency)	Rupture Dip (Relative Frequency)
AHEX, ECC-AM, MidC-A, MidC-B, MidC-C, MidC-D, PEZ-N, PEZ-W	Leaky[a]	Strike-slip (2/3)	N50W (0.2) N00E (0.2) N35E (0.4) N60E (0.1) N90E (0.1)	Uniformly distributed 60º to 90º, equally likely dip direction
		Reverse (1/3)	N50W (0.2) N00E (0.2) N35E (0.4) N60E (0.1) N90E (0.1)	Uniformly distributed 30º to 60º, equally likely dip direction
ECC-GC, GHEX	Leaky[a]	Strike-slip (2/3)	Uniform 0º to 180º	Uniformly distributed 60º to 90º, equally likely dip direction
		Reverse (1/3)	Uniform 0º to 180º	Uniformly distributed 30º to 60º, equally likely dip direction
GMH	Leaky[a]	Strike-slip (0.2)	N40W (0.4) N20E (0.4) N90E (0.1)	Uniformly distributed 60º to 90º, equally likely dip direction
		Reverse (0.8)	N40W (0.4) N20E (0.4) N90E (0.1)	Uniformly distributed 30º to 60º, equally likely dip direction
IBEB	Leaky[a]	Reverse Oblique (0.1)	N20W (1.0)	75ºE (0.5) 75ºW (0.5)
		Reverse (0.3)	N00E (1.0)	40ºE (0.2) 40ºW (0.2) 75ºE (0.3) 75ºW (0.3)
		Strike-slip (0.6)	N50W (0.167) N90E (0.333) N40E (0.5)	90º (1.0)
NAP	Leaky[a]	Strike-slip (1/3)	N50W (0.2) N00E (0.2) N35E (0.4) N60E (0.1) N90E (0.1)	Uniformly distributed 60º to 90º, equally likely dip direction

Seismotectonic Zone	Source Boundary Characteristics	Sense of Slip (Relative Frequency)	Rupture Strike (Relative Frequency)	Rupture Dip (Relative Frequency)
		Reverse (2/3)	N50W (0.2) N00E (0.2) N35E (0.4) N60E (0.1) N90E (0.1)	Uniformly distributed 30º to 60º, equally likely dip direction
OKA	Leaky[a]	Reverse Oblique (1.0)	Parallel to Long Axis of Zone (1.0)	Uniform 45ºN to 75ºN (0.5) Uniform 45ºS to 75ºS (0.5)
RR, RR-RCG	Leaky[a]	Reverse (0.35)	N10W (1.0)	40ºE (0.25) 40ºW (0.25) 70ºE (0.25) 70ºE (0.25)
		Strike-slip (0.65)	N50W (0.3) N30E (0.3) N55E (0.3) N90E (0.1)	90º (1.0)
SLR	Leaky[a]	Strike-slip (1/3)	N25E (0.2) N40E (0.2) N70E (0.2) N50W (0.15) N70W (0.15) NS (0.05) EW (0.05)	Uniformly distributed 60º to 90º, equally likely dip direction
		Reverse (2/3)	N25E (0.2) N40E (0.2) N70E (0.2) N50W (0.15) N70W (0.15) NS (0.05) EW (0.05)	Uniformly distributed 30º to 60º, equally likely dip direction

[a] Leaky boundary denotes the case were earthquake ruptures are centered on the earthquake epicenter, the epicenters are contained within the source boundary, but the rupture is allowed to extend beyond the source boundary.

Table H-4-4
Maximum Magnitude Distributions for Seismotectonic Distributed Seismicity Sources

	Maximum Magnitude for:											
Weight	**AHEX**	**ECC-AM**	**ECC-GC**	**GHEX**	**GMH**	**IBEB**	**MidC-A, MidC-B, MidC-C, and MidC-D**	**NAP**	**OKA**	**PEZ-N and PEZ-W**	**RR**	**RR-RCG**	**SLR**
0.101	6.0	6.0	6.0	6.0	6.0	6.5	5.6	6.1	5.8	5.9	6.2	6.1	6.2
0.244	6.7	6.7	6.7	6.7	6.7	6.9	6.1	6.7	6.4	6.4	6.7	6.6	6.8
0.310	7.2	7.2	7.2	7.2	7.2	7.4	6.6	7.2	6.9	6.8	7.2	7.1	7.3
0.244	7.7	7.7	7.7	7.7	7.7	7.8	7.2	7.7	7.4	7.2	7.7	7.6	7.7
0.101	8.1	8.1	8.1	8.1	8.1	8.1	8.0	8.1	8.0	7.9	8.1	8.1	8.1

Table H-5.1-1
Charlevoix RLME Magnitude Distribution

Moment Magnitude	Weight
6.75	0.2
7.0	0.5
7.25	0.2
7.5	0.1

Table H-5.1-2
Annual Frequencies for Charlevoix RLME Events
Data Set 1: 1870 and 1663

RLME Frequency (Events/Year)	Weight
9.3E-03	0.101
6.7E-03	0.244
4.2E-03	0.310
2.2E-03	0.244
7.7E-04	0.101

Table H-5.1-3
Annual Frequencies for Charlevoix RLME Events
Data Set 2: 3 Earthquakes in 6–7 kyr BP

RLME Frequency (Events/Year)	Weight
1.3E-03	0.101
8.4E-04	0.244
5.7E-04	0.310
3.7E-04	0.244
1.9E-04	0.101

Table H-5.1-4
Annual Frequencies for Charlevoix RLME Events
Data Set 3: 4 Earthquakes in 9.5–10.2 kyr BP

RLME Frequency (Events/Year)	Weight
9.8E-04	0.101
6.7E-04	0.244
4.7E-04	0.310
3.2E-04	0.244
1.8E-04	0.101

Table H-5.2-1
Charleston RLME Magnitude Distribution

Moment Magnitude	Weight
6.7	0.10
6.9	0.25
7.1	0.30
7.3	0.25
7.5	0.10

Table H-5.2-2
Annual Frequencies for Charleston RLME Events
Poisson Model, 2,000-Year Time Period
Earthquakes 1886, A, B, and C

RLME Frequency (Events/Year)	Weight
4.7E-03	0.101
3.1E-03	0.244
2.1E-03	0.310
1.3E-03	0.244
6.8E-04	0.101

Table H-5.2-3
Annual Frequencies for Charleston RLME Events
Poisson Model, 5,500-Year Time Period
Earthquakes 1886, A, B, and C

RLME Frequency (Events/Year)	Weight
4.7E-03	0.101
3.1E-03	0.244
2.1E-03	0.310
1.3E-03	0.244
6.8E-04	0.101

Table H-5.2-4
Annual Frequencies for Charleston RLME Events
Poisson Model, 5,500-Year Time Period
Earthquakes 1886, A, B, C, and D

RLME Frequency (Events/Year)	Weight
2.7E-03	0.101
1.9E-03	0.244
1.3E-03	0.310
8.8E-04	0.244
5.0E-04	0.101

Table H-5.2-5
Annual Frequencies for Charleston RLME Events
Poisson Model, 5,500-Year Time Period
Earthquakes 1886, A, B, C, and E

RLME Frequency (Events/Year)	Weight
1.9E-03	0.101
1.3E-03	0.244
9.2E-04	0.310
6.4E-04	0.244
3.4E-04	0.101

Table H-5.2-6
Annual Frequencies for Charleston RLME Events
Poisson Model, 5,500-Year Time Period
Earthquakes 1886, A, B, C, D, and E

RLME Frequency (Events/Year)	Weight
2.2E-03	0.101
1.5E-03	0.244
1.1E-03	0.310
7.8E-04	0.244
4.6E-04	0.101

Table H-5.2-7
Annual Frequencies for Charleston RLME Events
BPT Renewal Model, α = 0.3, 2,000-Year Time Period
Earthquakes 1886, A, B, and C

RLME Frequency (Events/Year)	Weight
6.4E-05	0.101
7.6E-06	0.244
9.5E-07	0.310
8.5E-08	0.244
2.3E-09	0.101

Table H-5.2-8
Annual Frequencies for Charleston RLME Events
BPT Renewal Model, α = 0.5, 2,000-Year Time Period
Earthquakes 1886, A, B, and C

RLME Frequency (Events/Year)	Weight
1.4E-03	0.101
3.8E-04	0.244
9.5E-05	0.310
1.7E-05	0.244
1.0E-06	0.101

Table H-5.2-9
Annual Frequencies for Charleston RLME Events
BPT Renewal Model, α = 0.7, 2,000-Year Time Period
Earthquakes 1886, A, B, and C

RLME Frequency (Events/Year)	Weight
2.6E-03	0.101
9.8E-04	0.244
3.2E-04	0.310
7.1E-05	0.244
5.6E-06	0.101

Table H-5.2-10
Annual Frequencies for Charleston RLME Events
BPT Renewal Model, α = 0.3, 5,500-Year Time Period
Earthquakes 1886, A, B, and C

RLME Frequency (Events/Year)	Weight
6.8E-05	0.101
8.0E-06	0.244
1.0E-06	0.310
9.2E-08	0.244
2.5E-09	0.101

Table H-5.2-11
Annual Frequencies for Charleston RLME Events
BPT Renewal Model, α = 0.5, 5,500-Year Time Period
Earthquakes 1886, A, B, and C

RLME Frequency (Events/Year)	Weight
1.4E-03	0.101
3.9E-04	0.244
9.8E-05	0.310
1.7E-05	0.244
1.1E-06	0.101

Table H-5.2-12
Annual Frequencies for Charleston RLME Events
BPT Renewal Model, α = 0.7, 5,500-Year Time Period
Earthquakes 1886, A, B, and C

RLME Frequency (Events/Year)	Weight
2.7E-03	0.101
9.9E-04	0.244
3.3E-04	0.310
7.3E-05	0.244
5.8E-06	0.101

Table H-5.2-13
Annual Frequencies for Charleston RLME Events
BPT Renewal Model, α = 0.3, 5,500-Year Time Period
Earthquakes 1886, A, B, C, and D

RLME Frequency (Events/Year)	Weight
3.5E-07	0.101
2.5E-08	0.244
2.2E-09	0.310
1.4E-10	0.244
2.7E-12	0.101

Table H-5.2-14
Annual Frequencies for Charleston RLME Events
BPT Renewal Model, α = 0.5, 5,500-Year Time Period
Earthquakes 1886, A, B, C, and D

RLME Frequency (Events/Year)	Weight
2.2E-04	0.101
4.5E-05	0.244
9.3E-06	0.310
1.4E-06	0.244
7.6E-08	0.101

Table H-5.2-15
Annual Frequencies for Charleston RLME Events
BPT Renewal Model, α = 0.7, 5,500-Year Time Period
Earthquakes 1886, A, B, C, and D

RLME Frequency (Events/Year)	Weight
1.0E-03	0.101
3.3E-04	0.244
9.5E-05	0.310
2.0E-05	0.244
1.5E-06	0.101

Table H-5.2-16
Annual Frequencies for Charleston RLME Events
BPT Renewal Model, α = 0.3, 5,500-Year Time Period
Earthquakes 1886, A, B, C, and E

RLME Frequency (Events/Year)	Weight
4.5E-09	0.101
2.0E-10	0.244
1.2E-11	0.310
5.4E-13	0.244
6.4E-15	0.101

Table H-5.2-17
Annual Frequencies for Charleston RLME Events
BPT Renewal Model, α = 0.5, 5,500-Year Time Period
Earthquakes 1886, A, B, C, and E

RLME Frequency (Events/Year)	Weight
5.2E-05	0.101
8.2E-06	0.244
1.4E-06	0.310
1.7E-07	0.244
7.0E-09	0.101

Table H-5.2-18
Annual Frequencies for Charleston RLME Events
BPT Renewal Model, α = 0.7, 5,500-Year Time Period
Earthquakes 1886, A, B, C, and E

RLME Frequency (Events/Year)	Weight
5.2E-04	0.101
1.4E-04	0.244
3.4E-05	0.310
6.1E-06	0.244
3.9E-07	0.101

Table H-5.2-19
Annual Frequencies for Charleston RLME Events
BPT Renewal Model, α = 0.3, 5,500-Year Time Period
Earthquakes 1886, A, B, C, D, and E

RLME Frequency (Events/Year)	Weight
1.5E-08	0.101
8.7E-10	0.244
7.0E-11	0.310
4.4E-12	0.244
8.2E-14	0.101

Table H-5.2-20
Annual Frequencies for Charleston RLME Events
BPT Renewal Model, α = 0.5, 5,500-Year Time Period
Earthquakes 1886, A, B, C, D, and E

RLME Frequency (Events/Year)	Weight
7.0E-05	0.101
1.3E-05	0.244
2.5E-06	0.310
3.7E-07	0.244
2.1E-08	0.101

Table H-5.2-21
Annual Frequencies for Charleston RLME Events
BPT Renewal Model, α = 0.7, 5,500-Year Time Period
Earthquakes 1886, A, B, C, D, and E

RLME Frequency (Events/Year)	Weight
5.7E-04	0.101
1.6E-04	0.244
4.5E-05	0.310
9.2E-06	0.244
7.6E-07	0.101

Table H-5.3-1
Cheraw RLME Magnitude Distribution

Moment Magnitude	Weight
6.8	0.3
7.0	0.3
7.2	0.3
7.4	0.1

Table H-5.3-2
Annual Frequencies for Cheraw RLME Events
In-Cluster Case, Data Set: 2 Earthquakes in 20–25 kyr

RLME Frequency (Events/Year)	Weight
2.4E-04	0.101
1.3E-04	0.244
7.6E-05	0.310
3.8E-05	0.244
1.4E-05	0.101

Table H-5.3-3
Annual Frequencies for Cheraw RLME Events
In-Cluster Case, Data Set: 3 Earthquakes in 20–25 kyr

RLME Frequency (Events/Year)	Weight
3.1E-04	0.101
1.9E-04	0.244
1.2E-04	0.310
7.2E-05	0.244
3.2E-05	0.101

Table H-5.3-4
Slip Rates for Cheraw Fault
In-Cluster Case, Data Set: 3.2–4.1 m in 20–25 kyr

RLME Fault Slip Rate (mm/Year)	Weight
0.14	0.185
0.16	0.630
0.19	0.185

Table H-5.3-5
Annual Frequencies for Cheraw RLME Events
Out-of-Cluster Case, Time Between Clusters

RLME Frequency (Events/Year)	Weight
5.0E-06	0.333
2.9E-06	0.334
2.0E-06	0.333

Table H-5.3-6
Slip Rates for Cheraw Fault
Out-of-Cluster Case, Data Set: 7–8 m in 0.4–2.0 myr

RLME Fault Slip Rate (mm/Year)	Weight
0.0038	0.101
0.0043	0.244
0.0054	0.310
0.0072	0.244
0.011	0.101

Table H-5.4-1
Meers RLME Magnitude Distribution

Moment Magnitude	Weight
6.6	0.1
6.7	0.45
6.9	0.3
7.3	0.1
7.4	0.05

Table H-5.4-2
Annual Frequencies for Meers RLME Events
In-Cluster Case

RLME Frequency (Events/Year)	Weight
2.1E-03	0.101
1.2E-03	0.244
6.7E-04	0.310
3.4E-04	0.244
1.2E-04	0.101

Table H-5.4-3
Annual Frequencies for Meers RLME Events
Out-of-Cluster Case

RLME Frequency (Events/Year)	Weight
5.0E-06	0.333
2.9E-06	0.334
2.0E-06	0.333

Table H-5.5-1
NMFS RLME Magnitude Distribution

Moment Magnitude for:			Weight
NMS	RFT	NMN	
7.9	7.8	7.6	0.167
7.8	7.7	7.5	0.167
7.6	7.8	7.5	0.250
7.2	7.4	7.2	0.083
6.9	7.3	7.0	0.250
6.7	7.1	6.8	0.083

Table H-5.5-2
Annual Frequencies for NMFS RLME Events
In-Cluster Case, Poisson Model

RLME Frequency (Events/Year)	Weight
6.0E-03	0.101
3.7E-03	0.244
2.4E-03	0.310
1.4E-03	0.244
6.2E-04	0.101

Table H-5.5-3
Annual Frequencies for NMFS RLME Events
In-Cluster Case, BPT Model, α = 0.3

RLME Frequency (Events/Year)	Weight
3.5E-03	0.101
1.1E-03	0.244
3.2E-04	0.310
6.4E-05	0.244
4.7E-06	0.101

Table H-5.5-4
Annual Frequencies for NMFS RLME Events
In-Cluster Case, BPT Model, α = 0.5

RLME Frequency (Events/Year)	Weight
4.8E-03	0.101
2.2E-03	0.244
8.9E-04	0.310
2.6E-04	0.244
3.1E-05	0.101

Table H-5.5-5
Annual Frequencies for NMFS RLME Events
In-Cluster Case, BPT Model, α = 0.7

RLME Frequency (Events/Year)	Weight
4.4E-03	0.101
2.2E-03	0.244
1.0E-03	0.310
3.4E-04	0.244
4.7E-05	0.101

Table H-5.5-6
Annual Frequencies for NMFS RLME Events
Out-of-Cluster Case, Poisson Model

RLME Frequency (Events/Year)	Weight
1.3E-03	0.101
7.2E-04	0.244
4.2E-04	0.310
2.2E-04	0.244
8.0E-05	0.101

Table H-5.6-1
ERM-S RLME Magnitude Distribution

Moment Magnitude	Weight
6.7	0.15
6.9	0.2
7.1	0.2
7.3	0.2
7.5	0.2
7.7	0.05

Table H-5.6-2
ERM-N RLME Magnitude Distribution

Moment Magnitude	Weight
6.7	0.3
6.9	0.3
7.1	0.3
7.4	0.1

Table H-5.6-3
Annual Frequencies for ERM-S RLME Events
Data Set: 2 Earthquakes in 17.7–21.7 kyr

RLME Frequency (Events/Year)	Weight
3.5E-04	0.101
2.1E-04	0.244
1.4E-04	0.310
8.0E-05	0.244
3.6E-05	0.101

Table H-5.6-4
Annual Frequencies for ERM-S RLME Events
Data Set: 3 Earthquakes in 17.7–21.7 kyr

RLME Frequency (Events/Year)	Weight
4.3E-04	0.101
2.8E-04	0.244
1.9E-04	0.310
1.2E-04	0.244
6.2E-05	0.101

Table H-5.6-5
Annual Frequencies for ERM-S RLME Events
Data Set: 4 Earthquakes in 17.7–21.7 kyr

RLME Frequency (Events/Year)	Weight
5.0E-04	0.101
3.4E-04	0.244
2.4E-04	0.310
1.6E-04	0.244
9.0E-05	0.101

Table H-5.6-6
Annual Frequencies for ERM-N RLME Events
Data Set: 1 Earthquake in 12–35 kyr

RLME Frequency (Events/Year)	Weight
2.9E-04	0.101
1.5E-04	0.244
8.0E-05	0.310
4.0E-05	0.244
1.4E-05	0.101

Table H-5.6-7
Annual Frequencies for ERM-N RLME Events
Data Set: 2 Earthquakes in 12–35 kyr

RLME Frequency (Events/Year)	Weight
3.9E-04	0.101
2.2E-04	0.244
1.3E-04	0.310
7.2E-05	0.244
3.2E-05	0.101

Table H-5.7-1
Marianna RLME Magnitude Distribution

Moment Magnitude	Weight
6.7	0.15
6.9	0.2
7.1	0.2
7.3	0.2
7.5	0.2
7.7	0.05

Table H-5.7-2
Annual Frequencies for Marianna RLME Events
Data Set: 3 Earthquakes in 9.6–10.2 kyr

RLME Frequency (Events/Year)	Weight
6.9E-04	0.101
4.2E-04	0.244
2.7E-04	0.310
1.6E-04	0.244
7.2E-05	0.101

Table H-5.7-3
Annual Frequencies for Marianna RLME Events
Data Set: 4 Earthquakes in 9.6–10.2 kyr

RLME Frequency (Events/Year)	Weight
8.4E-04	0.101
5.5E-04	0.244
3.7E-04	0.310
2.4E-04	0.244
1.2E-04	0.101

Table H-5.8-1
Commerce RLME Magnitude Distribution

Moment Magnitude	Weight
6.7	0.15
6.9	0.35
7.1	0.35
7.3	0.10
7.7	0.05

Table H-5.8-2
Annual Frequencies for Commerce RLME Events
Data Set: 2 Earthquakes in 18.9–23.6 kyr

RLME Frequency (Events/Year)	Weight
2.5E-04	0.101
1.4E-04	0.244
8.0E-05	0.310
4.0E-05	0.244
1.4E-05	0.101

Table H-5.8-3
Annual Frequencies for Commerce RLME Events
Data Set: 3 Earthquakes in 18.9–23.6 kyr

RLME Frequency (events/Year)	Weight
3.3E-04	0.101
2.0E-04	0.244
1.3E-04	0.310
7.6E-05	0.244
3.4E-05	0.101

Table H-5.9-1
Wabash RLME Magnitude Distribution

Moment Magnitude	Weight
6.75	0.05
7.0	0.25
7.25	0.35
7.5	0.35

Table H-5.9-2
Annual Frequencies for Wabash RLME Events
Data Set: 2 Earthquakes in 11–13 kyr

RLME Frequency (Events/Year)	Weight
4.4E-04	0.101
2.5E-04	0.244
1.4E-04	0.310
7.2E-05	0.244
2.4E-05	0.101

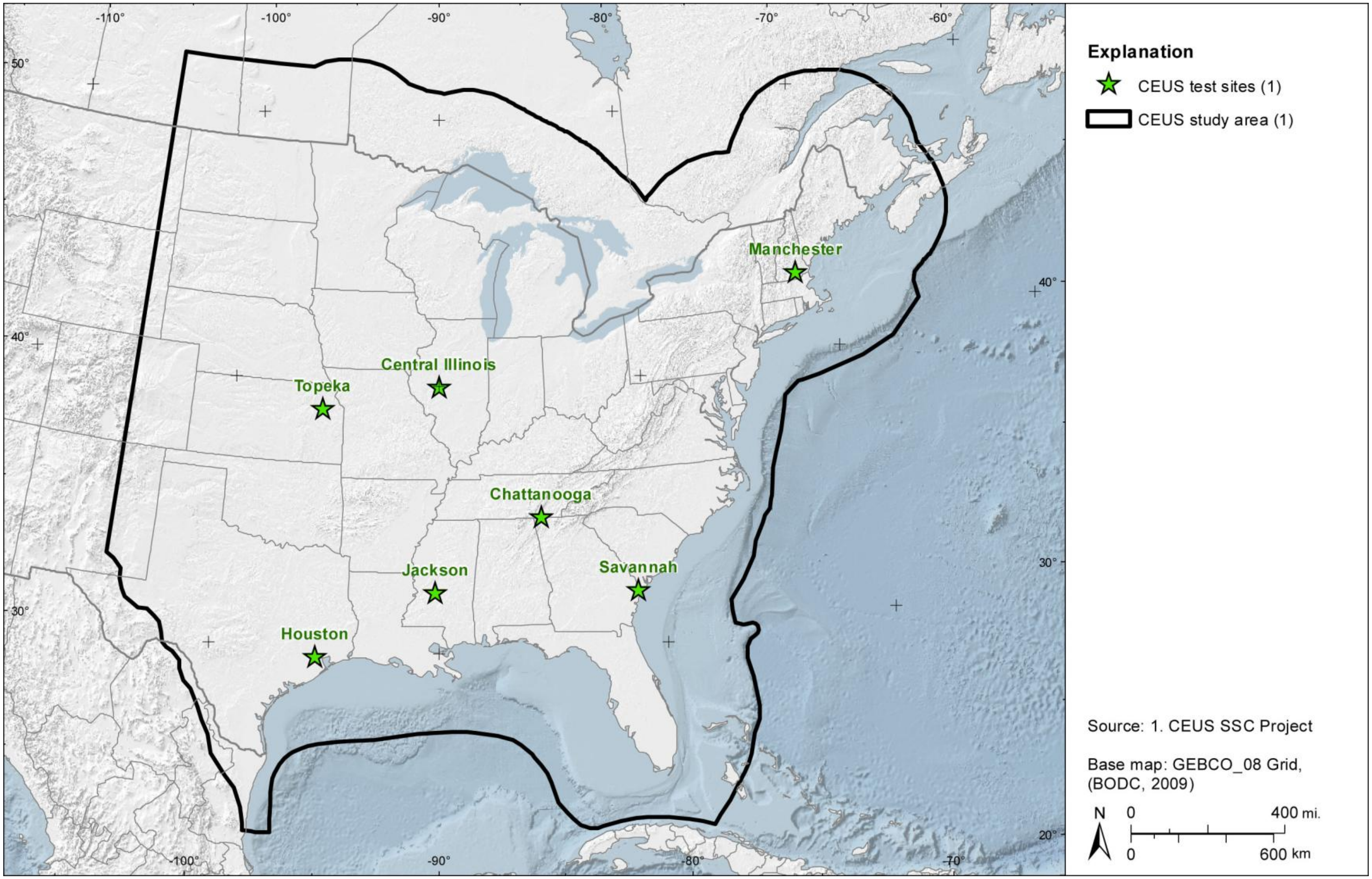

Figure H-1-1
Region covered by the CEUS SSC model

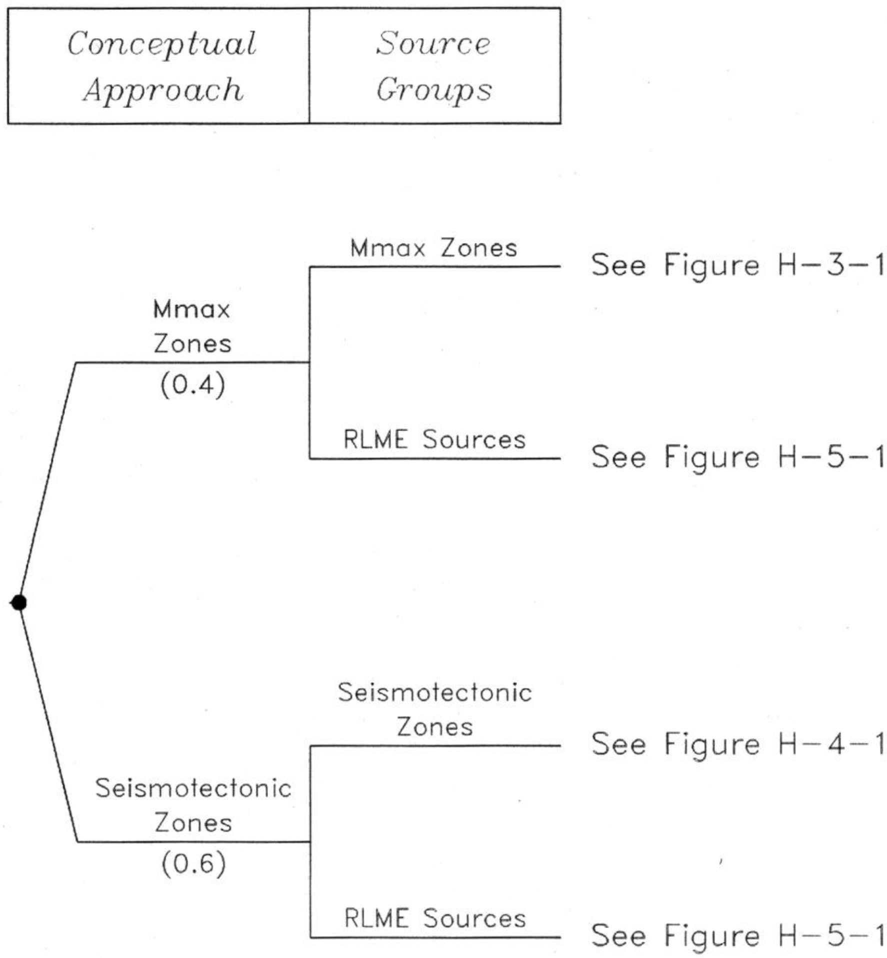

Figure H-2-1
Master logic tree for the CEUS SSC model

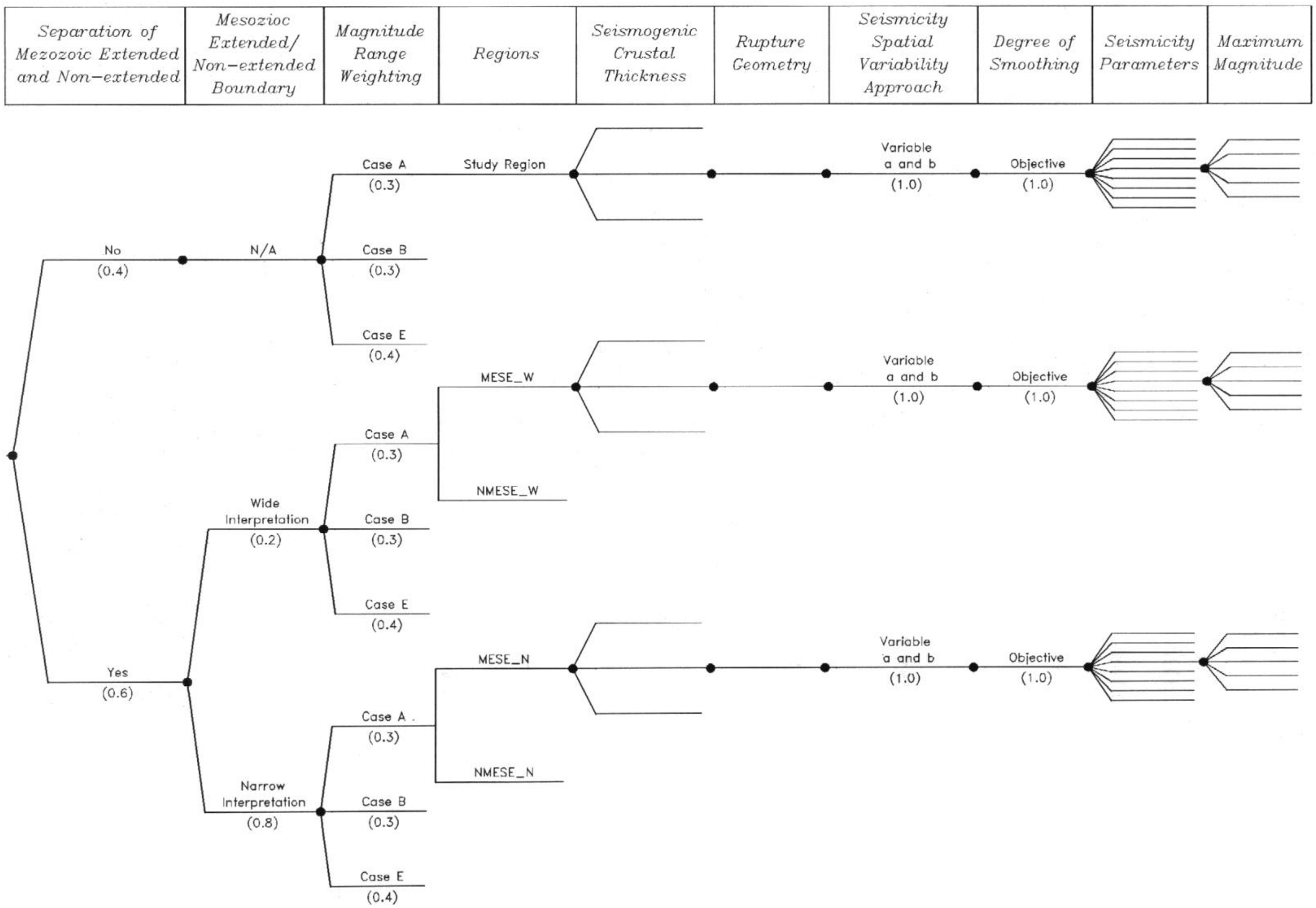

Figure H-3-1
Logic tree for the Mmax zones branch of the master logic tree

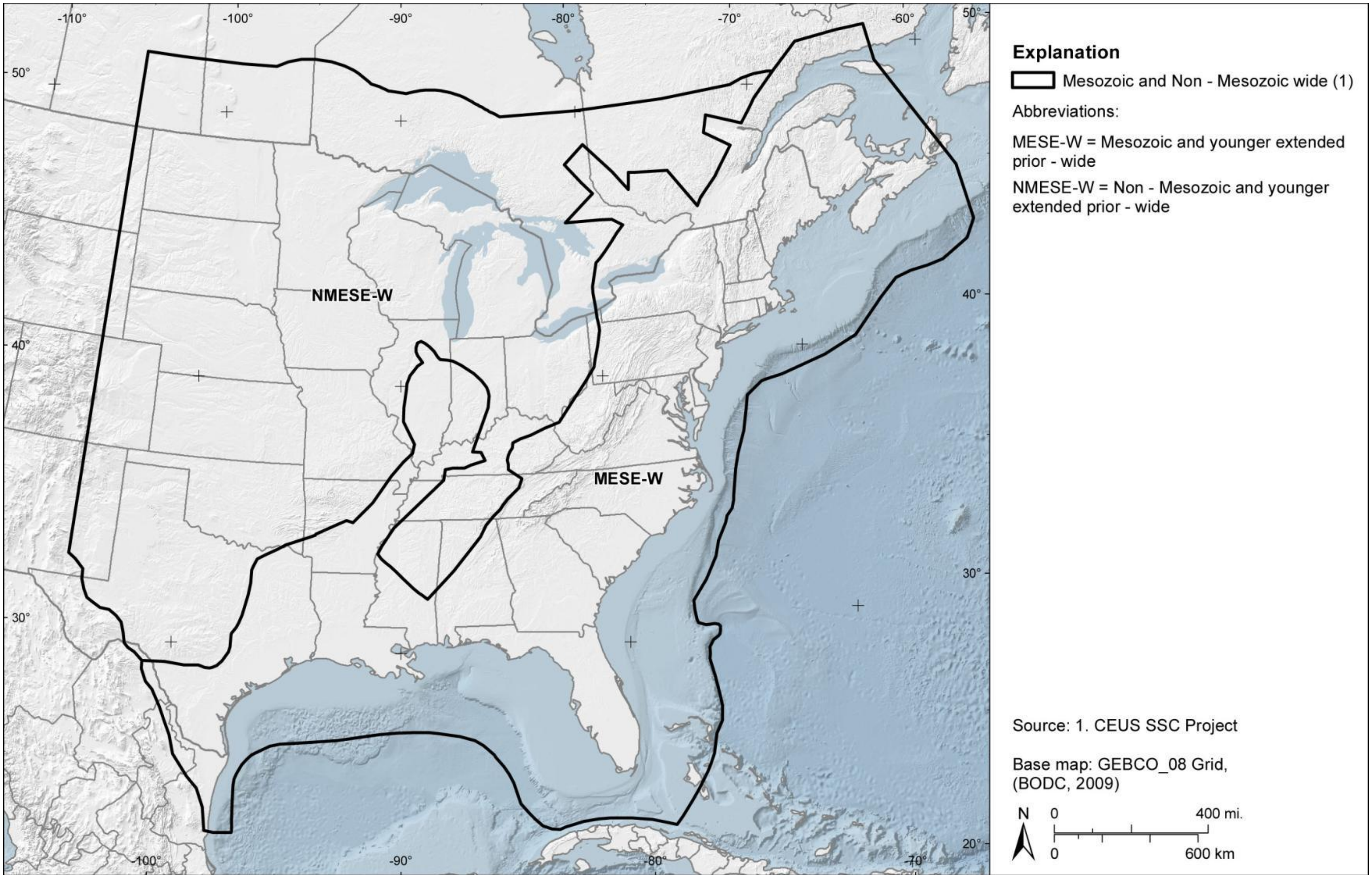

Figure H-3-2
Mesozoic extended (MESE-W) and non-extended (NMESE-W) Mmax zones for the "wide" interpretation

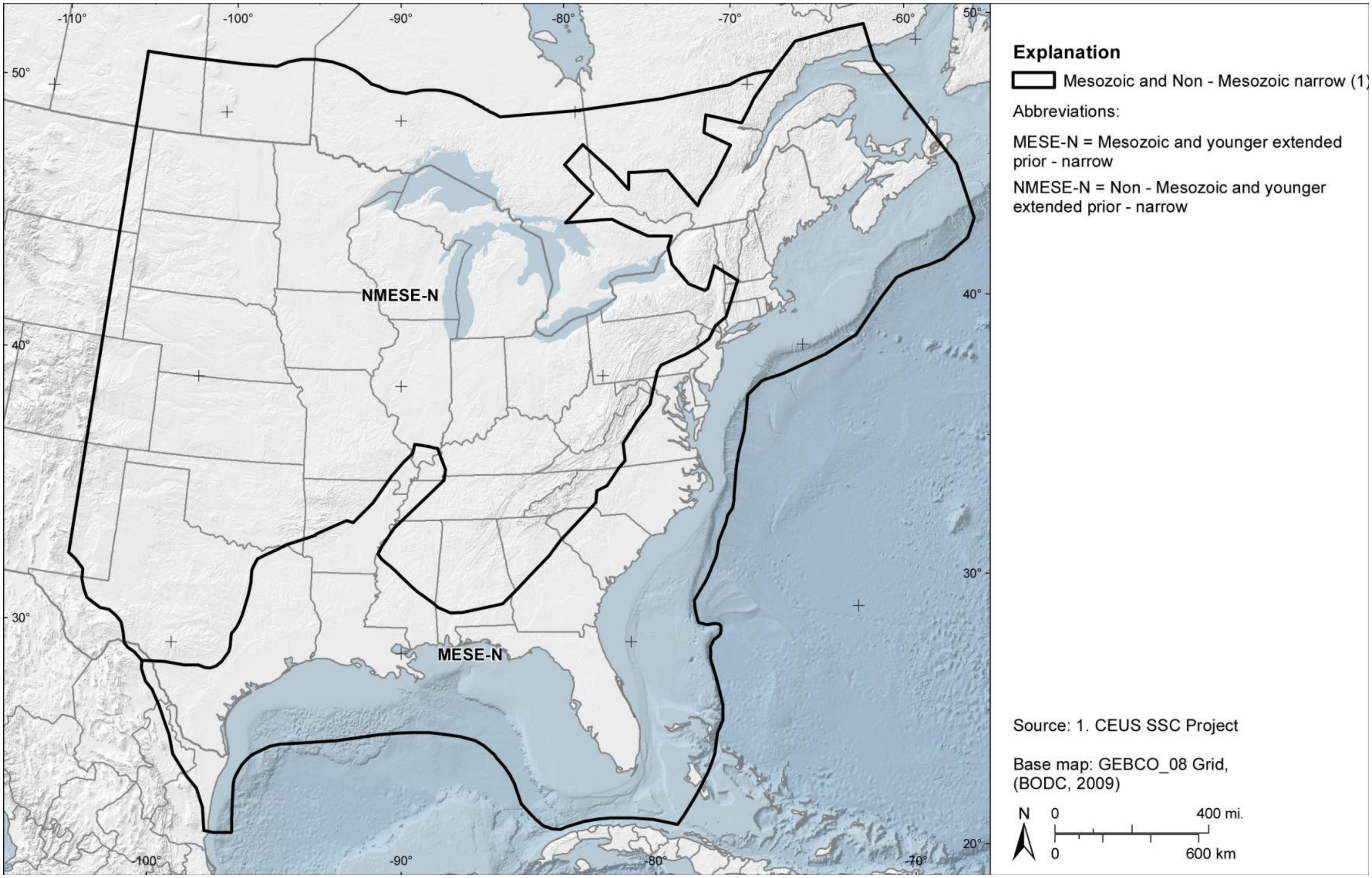

Figure H-3-3
Mesozoic extended (MESE-N) and non-extended (NMESE-N) Mmax zones for the "narrow" interpretation

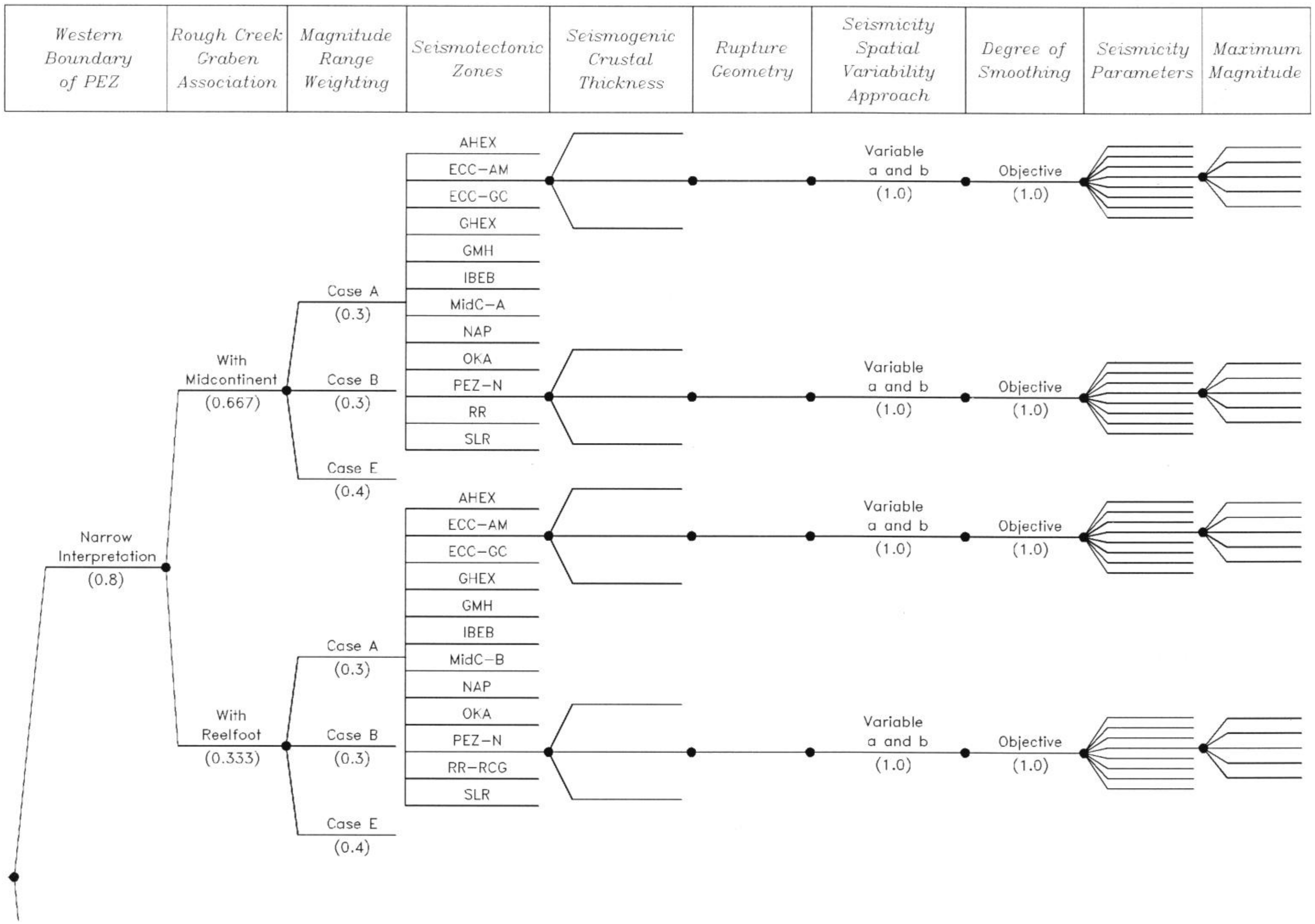

Figure H-4-1(a)
Logic tree for the seismotectonic zones branch of the master logic tree

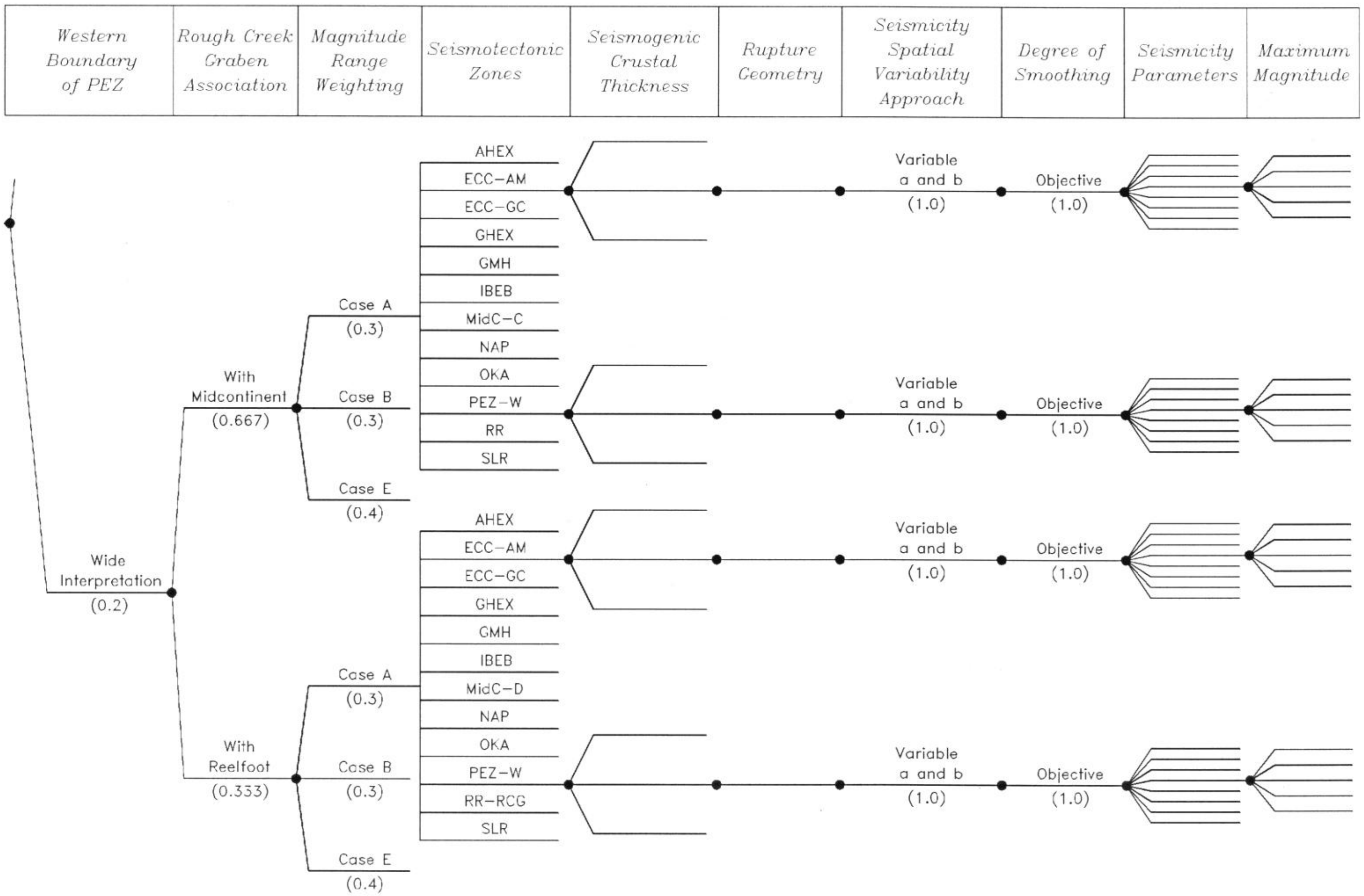

Figure H-4-1(b)
Logic tree for the seismotectonic zones branch of the master logic tree

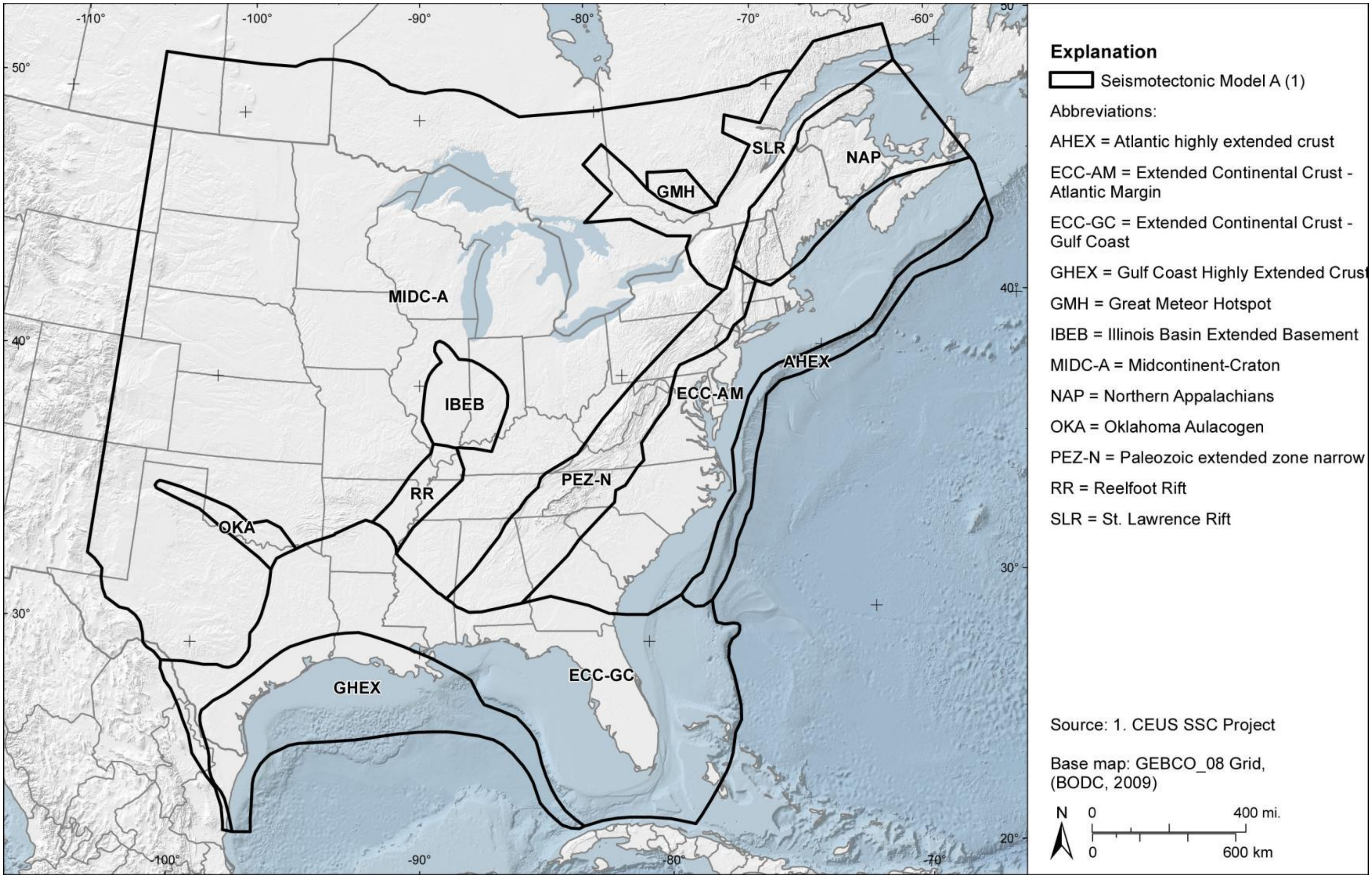

Figure H-4-2
Seismotectonic zones shown in the case where the Rough Creek Graben is not part of the Reelfoot Rift (RR) and the Paleozoic Extended zone is narrow (PEZ-N)

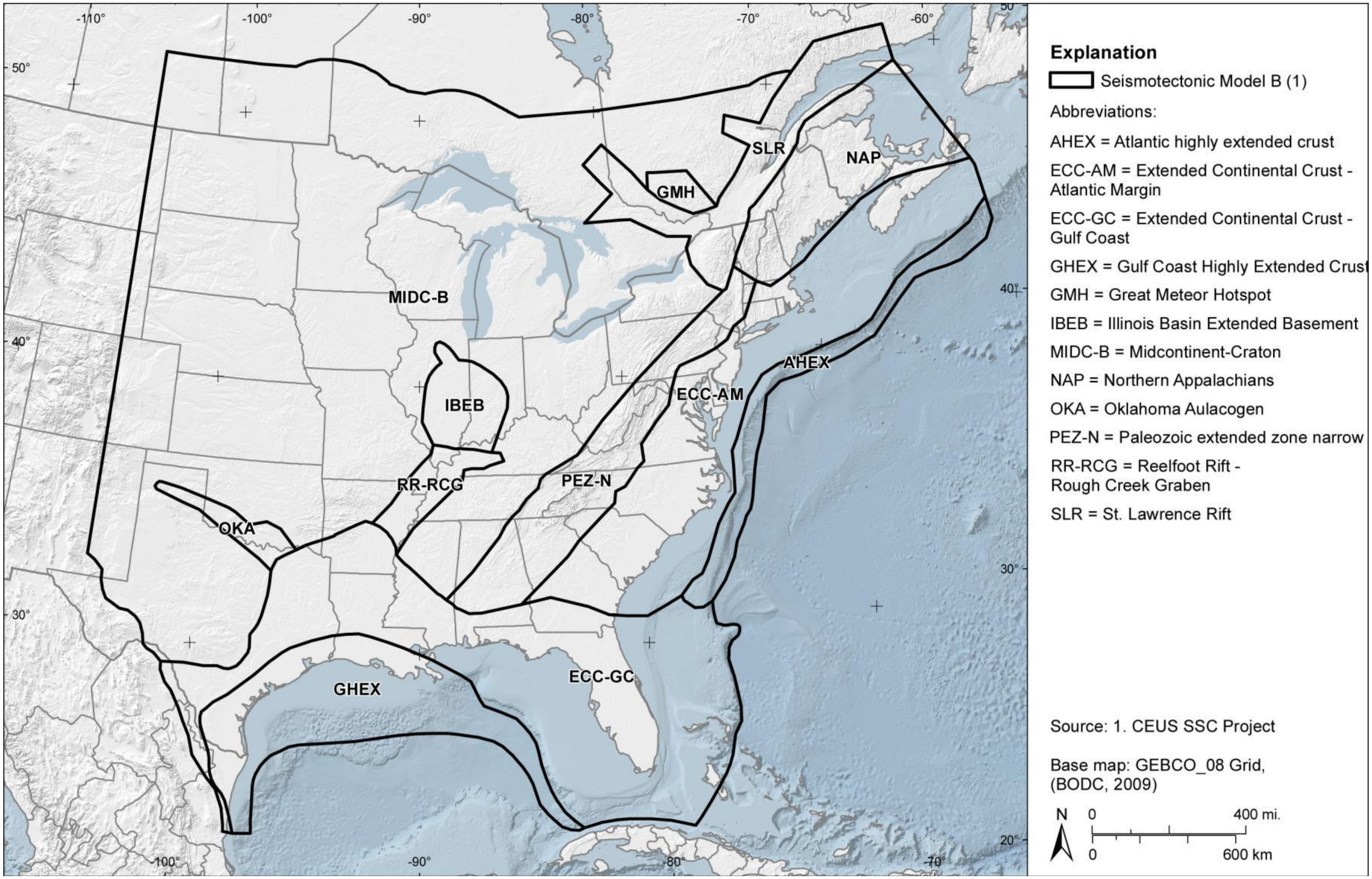

Figure H-4-3
Seismotectonic zones shown in the case where the Rough Creek Graben is part of the Reelfoot Rift (RR-RCG) and the Paleozoic Extended zone is narrow (PEZ-N)

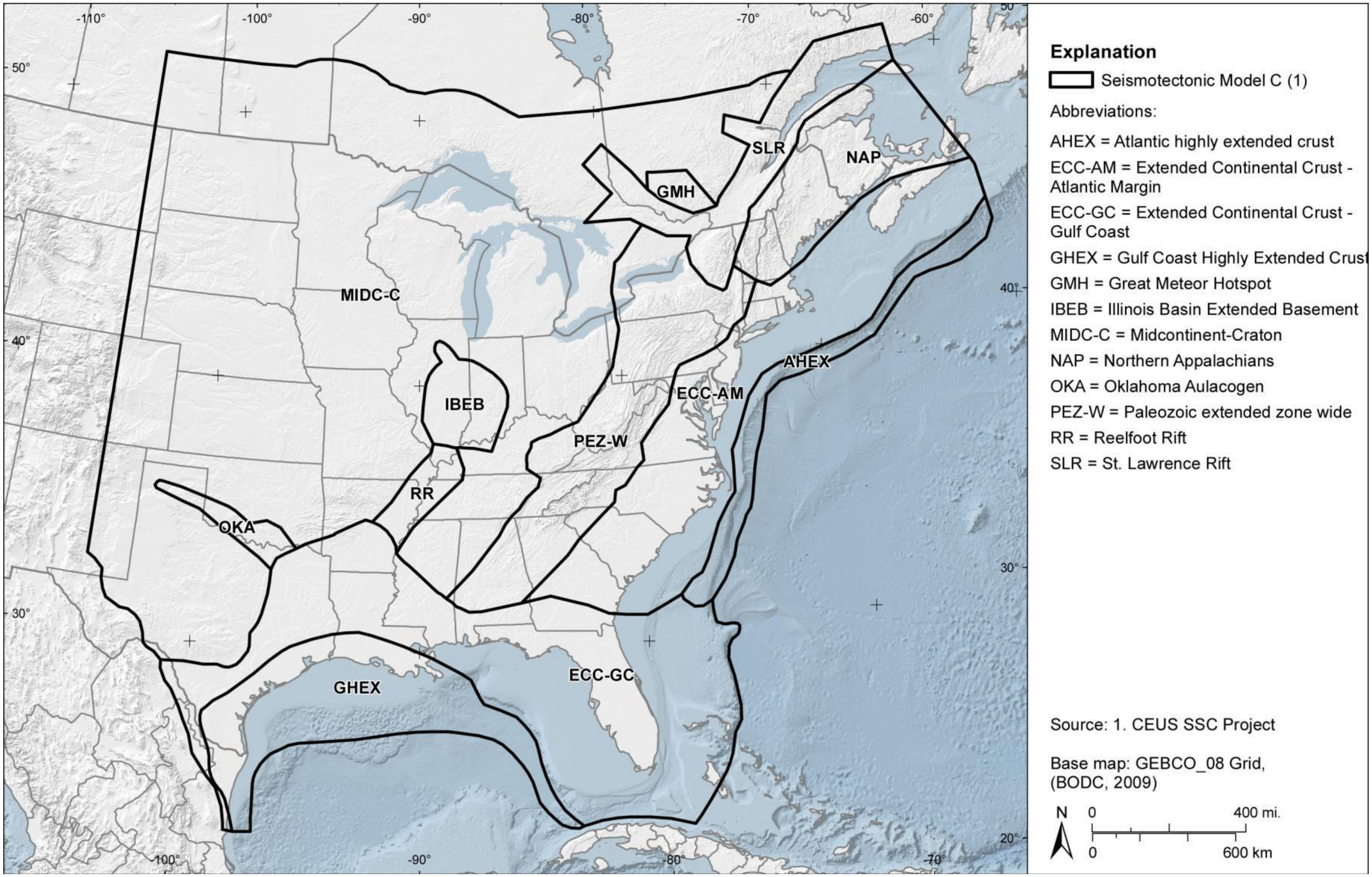

Figure H-4-4
Seismotectonic zones shown in the case where the Rough Creek Graben is not part of the Reelfoot Rift (RR) and the Paleozoic Extended zone is wide (PEZ-W)

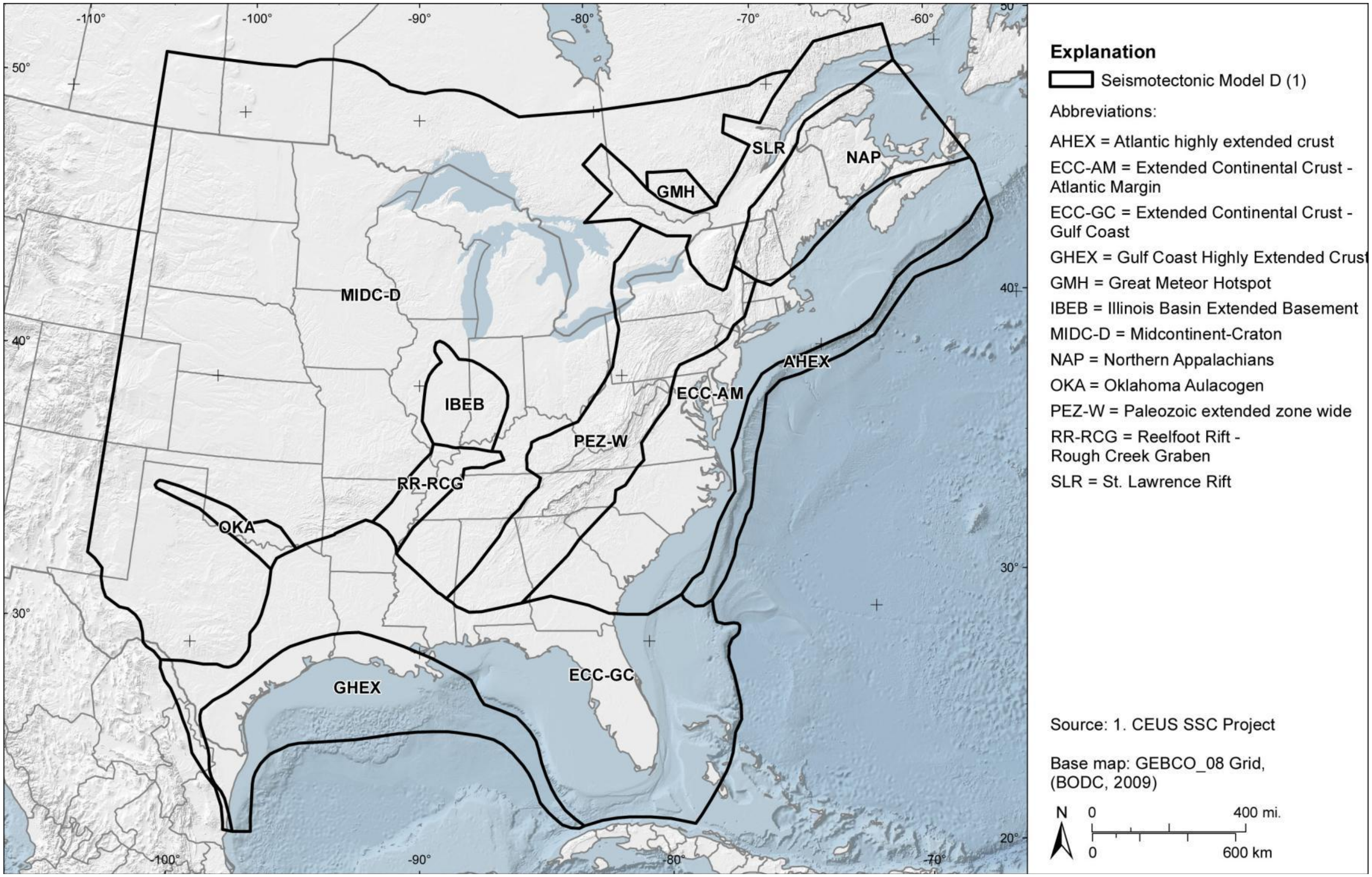

Figure H-4-5
Seismotectonic zones shown in the case where the Rough Creek Graben is part of the Reelfoot Rift (RR-RCG) and the Paleozoic Extended zone is wide (PEZ-W)

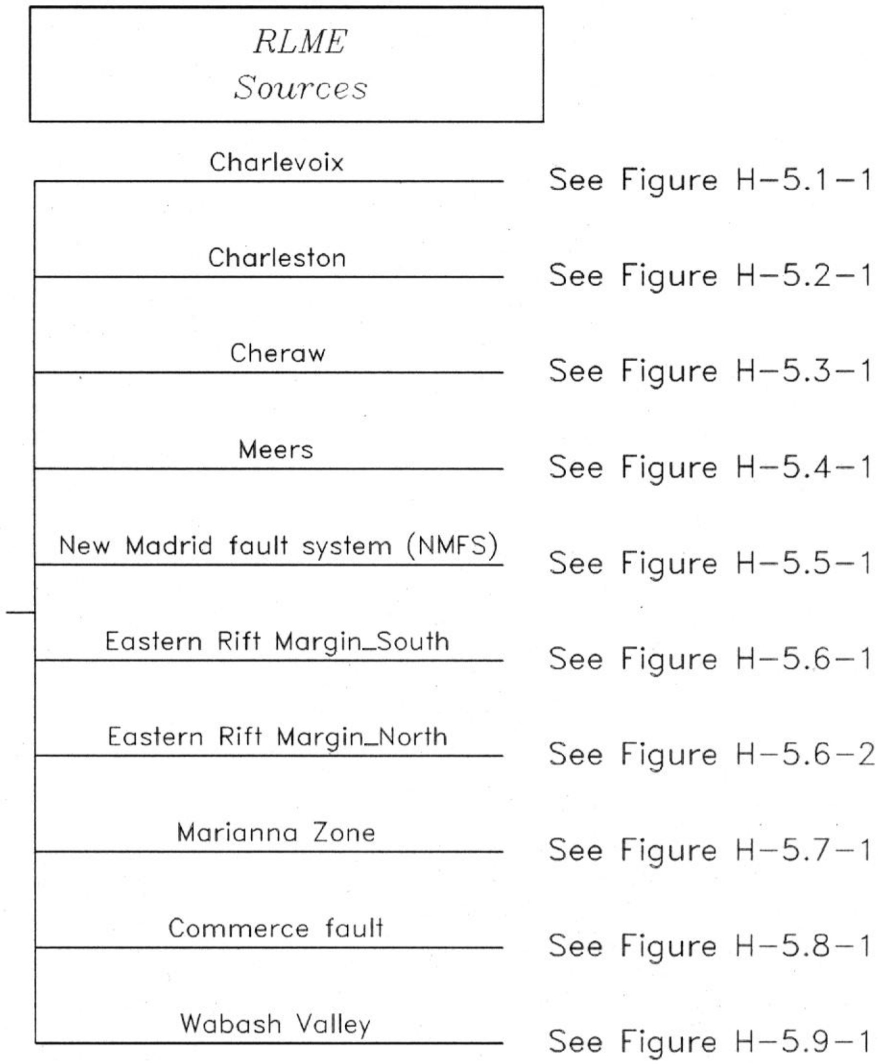

Figure H-5-1
Logic tree for the RLME source branch of the master logic tree

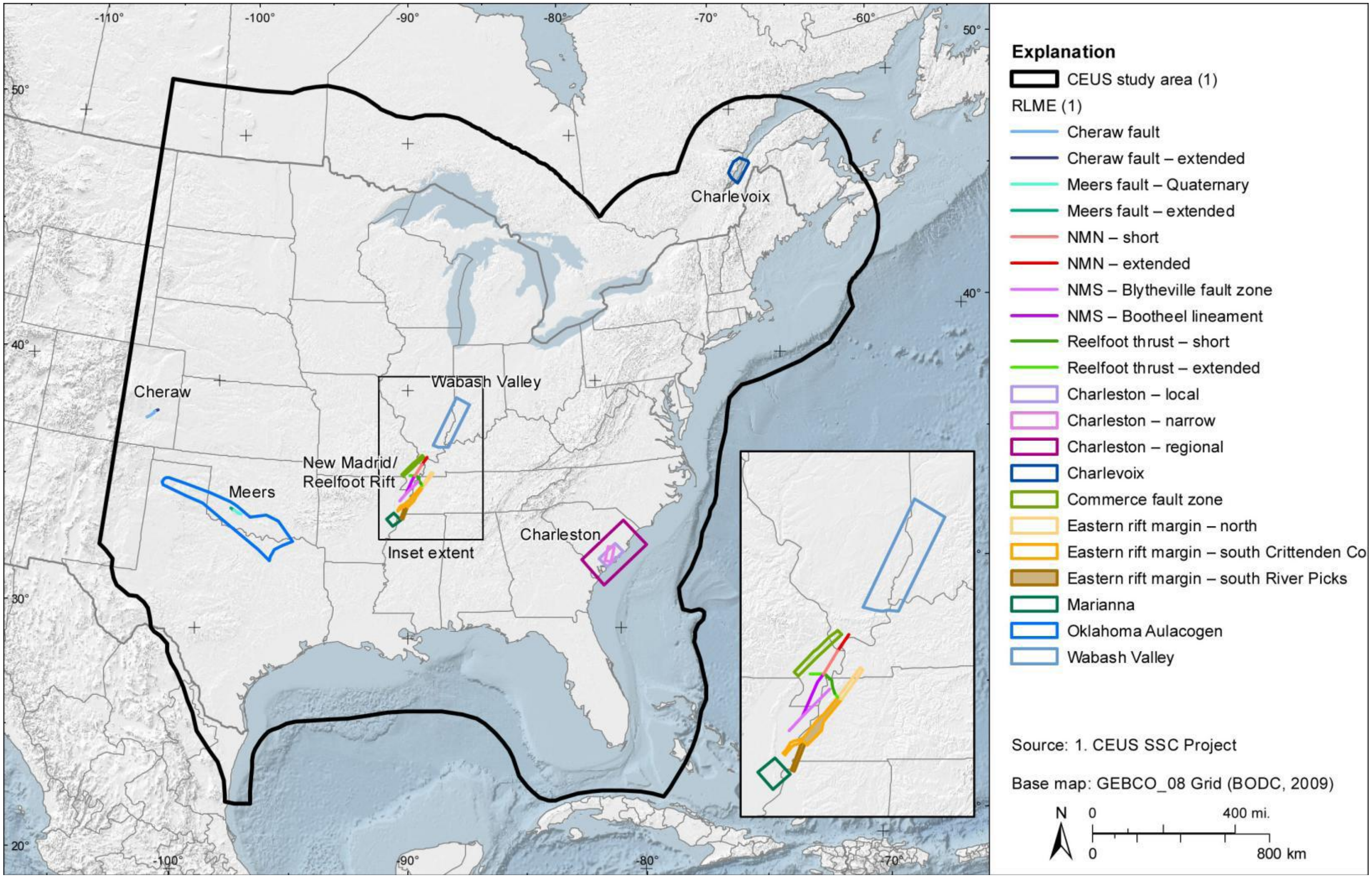

Figure H-5-2
Location of RLME sources in the CEUS SSC model

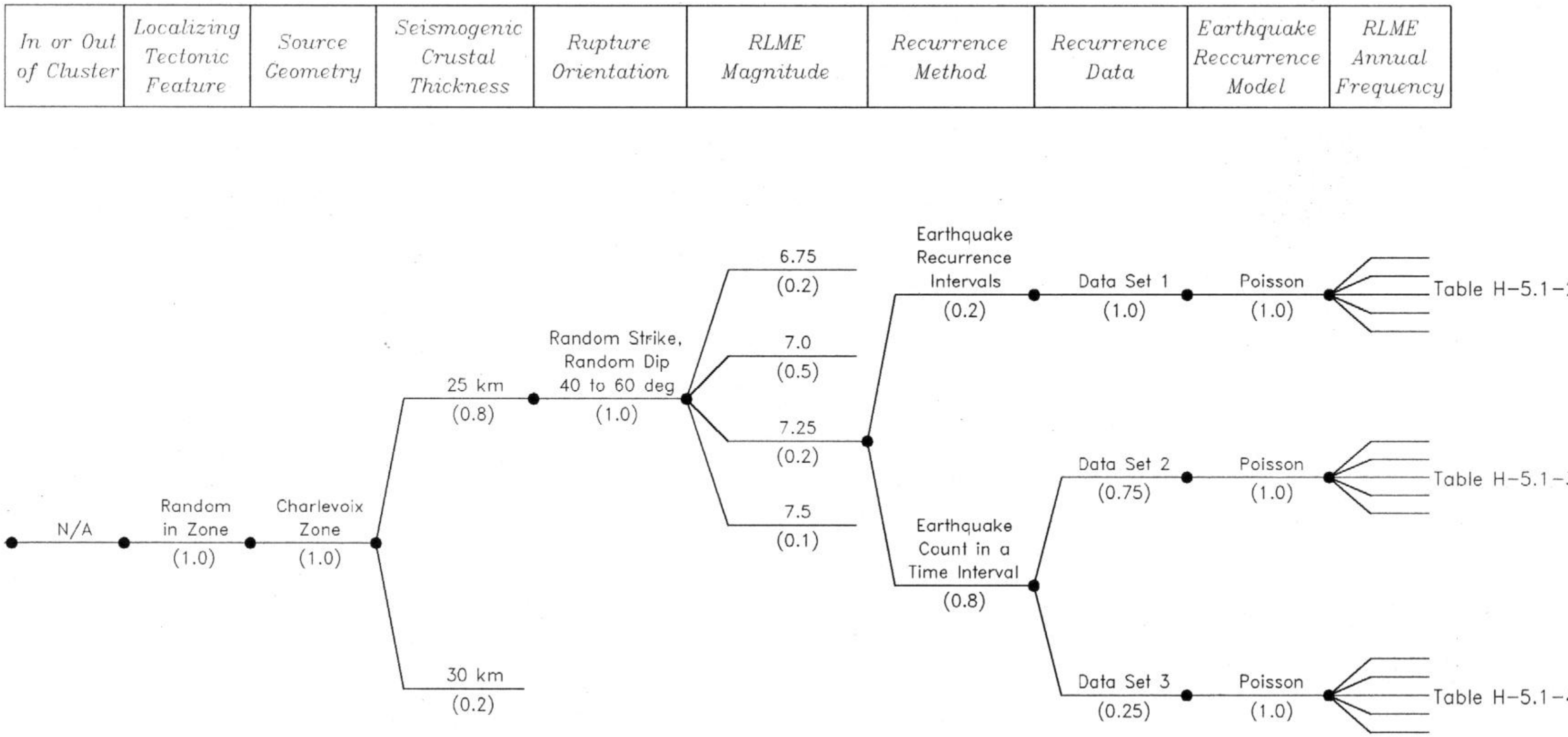

Figure H-5.1-1
Logic tree for Charlevoix RLME source

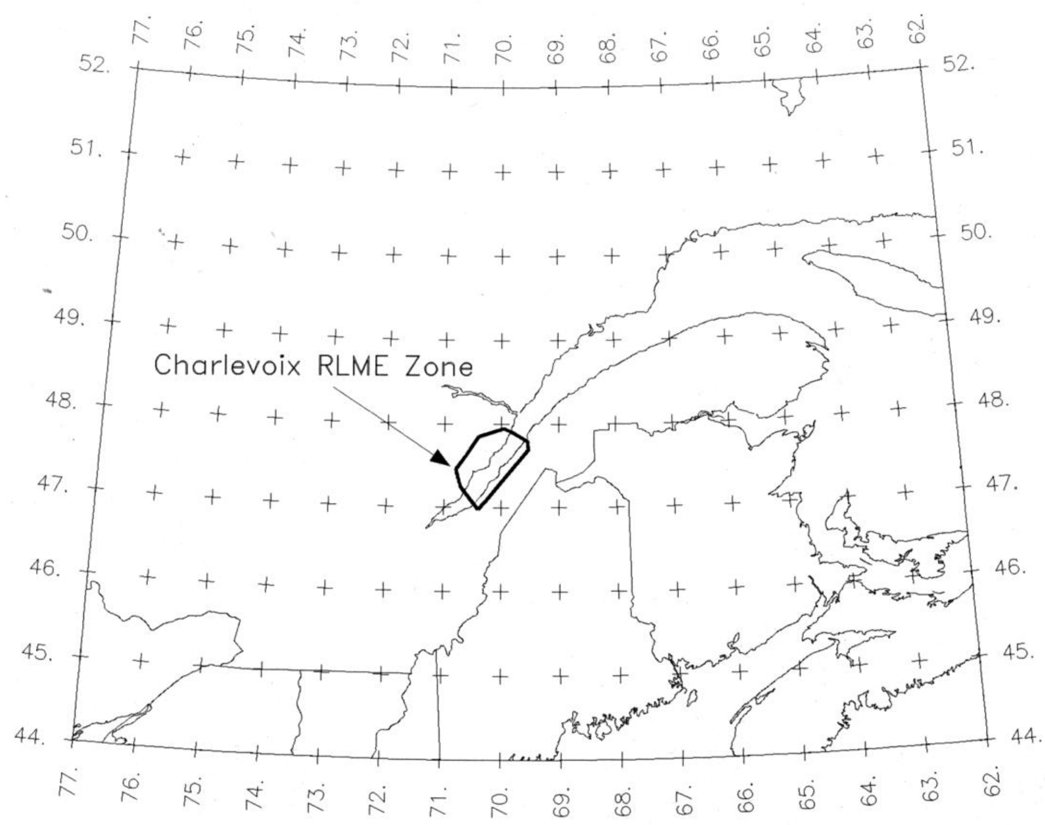

Figure H-5.1-2
Charlevoix RLME source geometry

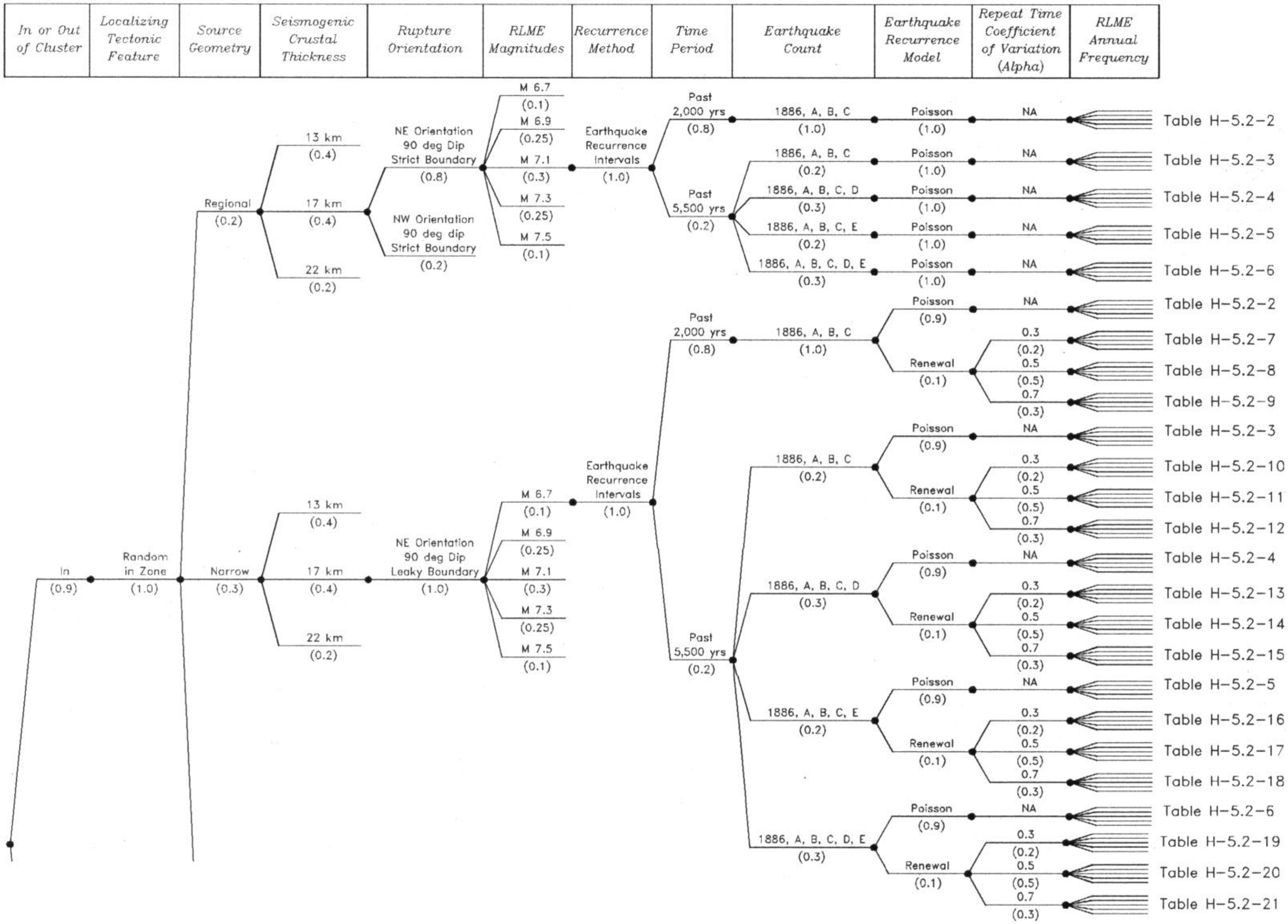

Figure H-5.2-1(a)
Logic tree for Charleston RLME source

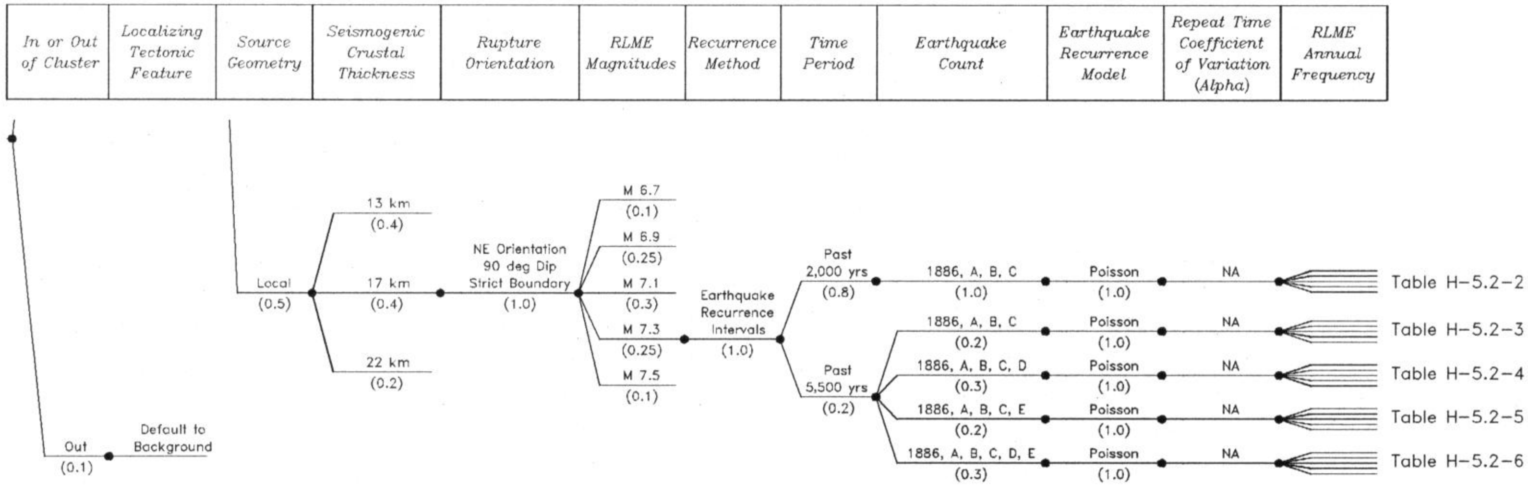

Figure H-5.2-1(b)
Logic tree for Charleston RLME source

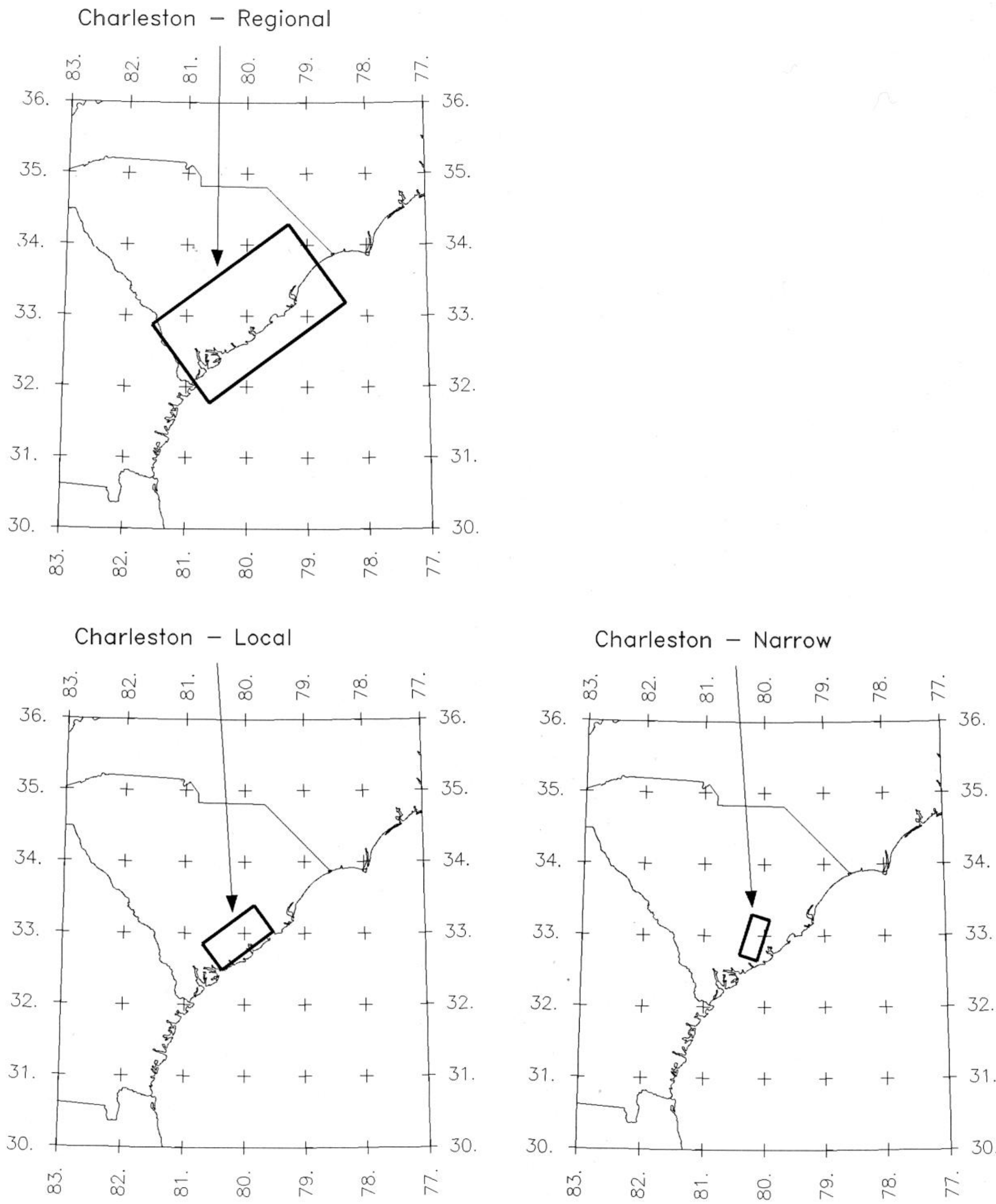

Figure H-5.2-2
Charleston RLME alternative source geometries

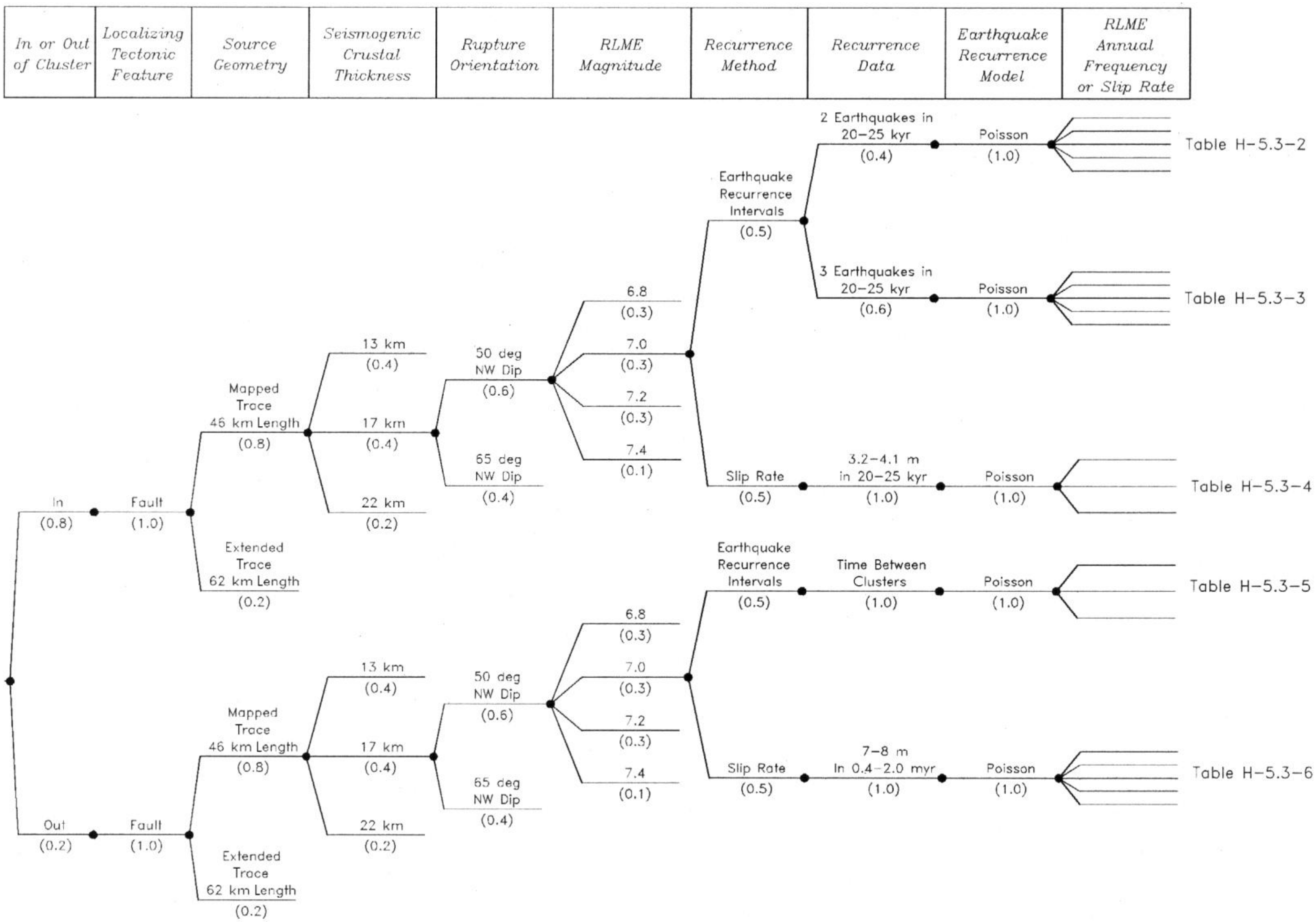

Figure H-5.3-1
Logic tree for Cheraw RLME source

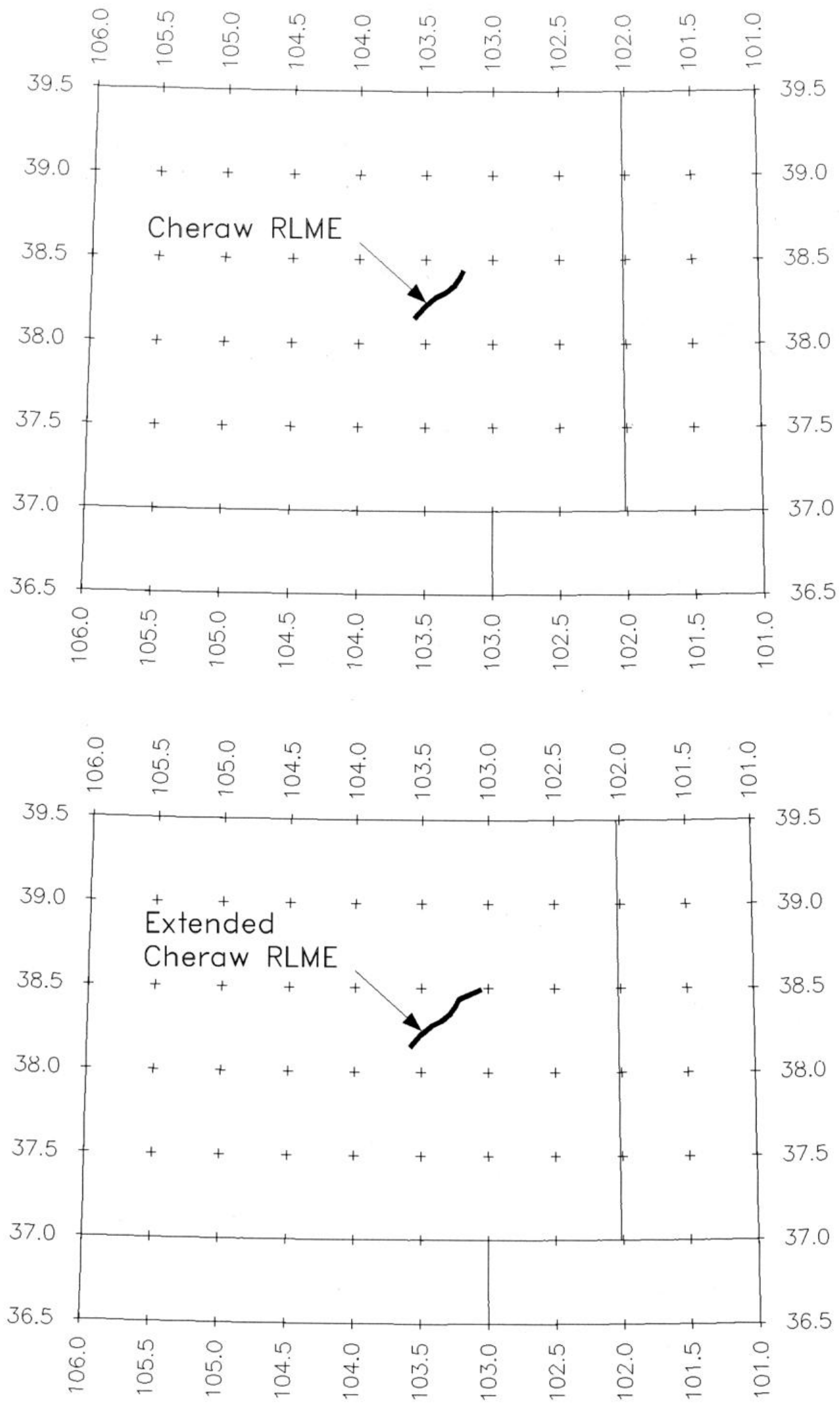

Figure H-5.3-2
Cheraw RLME source geometry

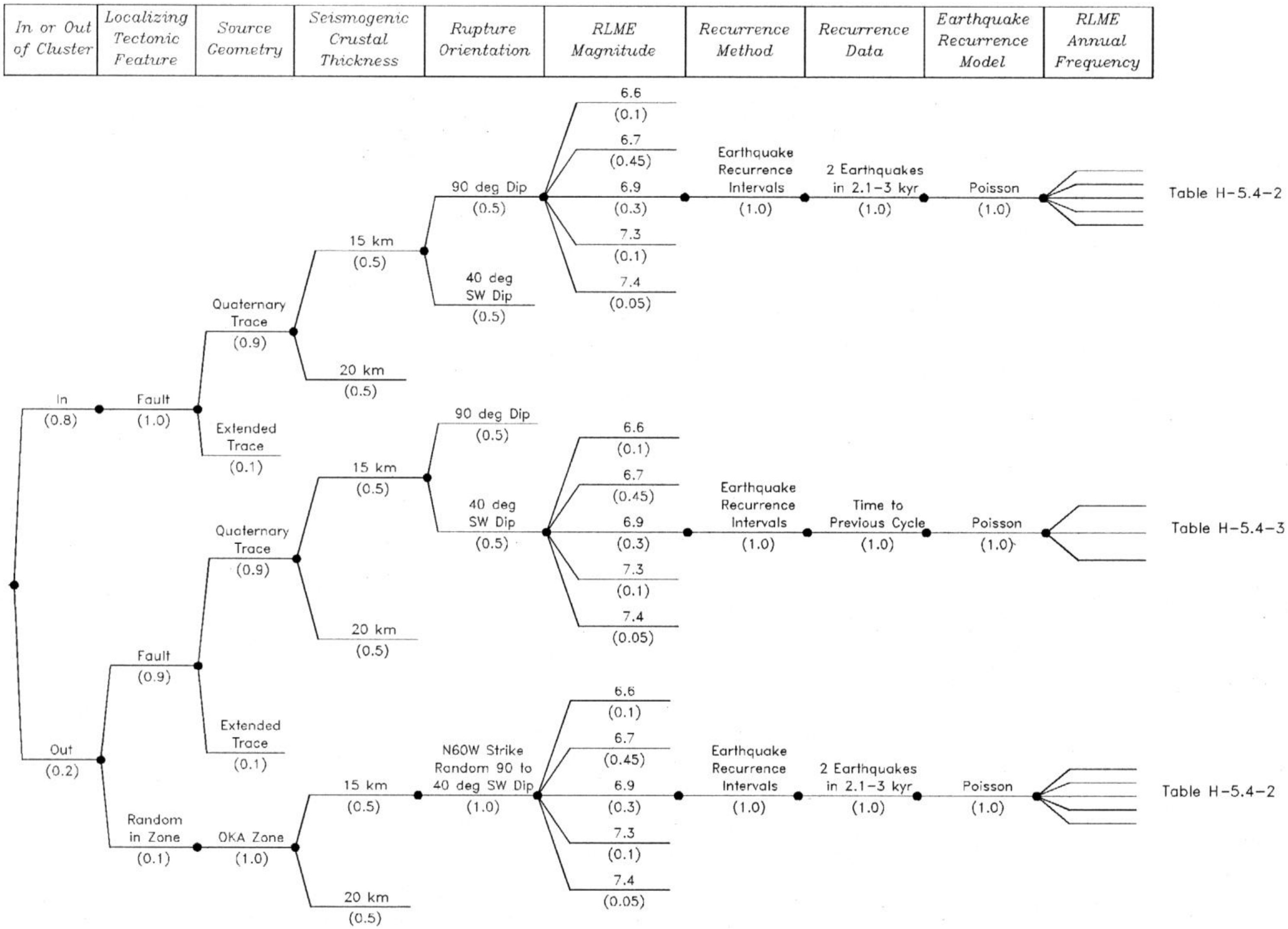

Figure H-5.4-1
Logic tree for Meers RLME source

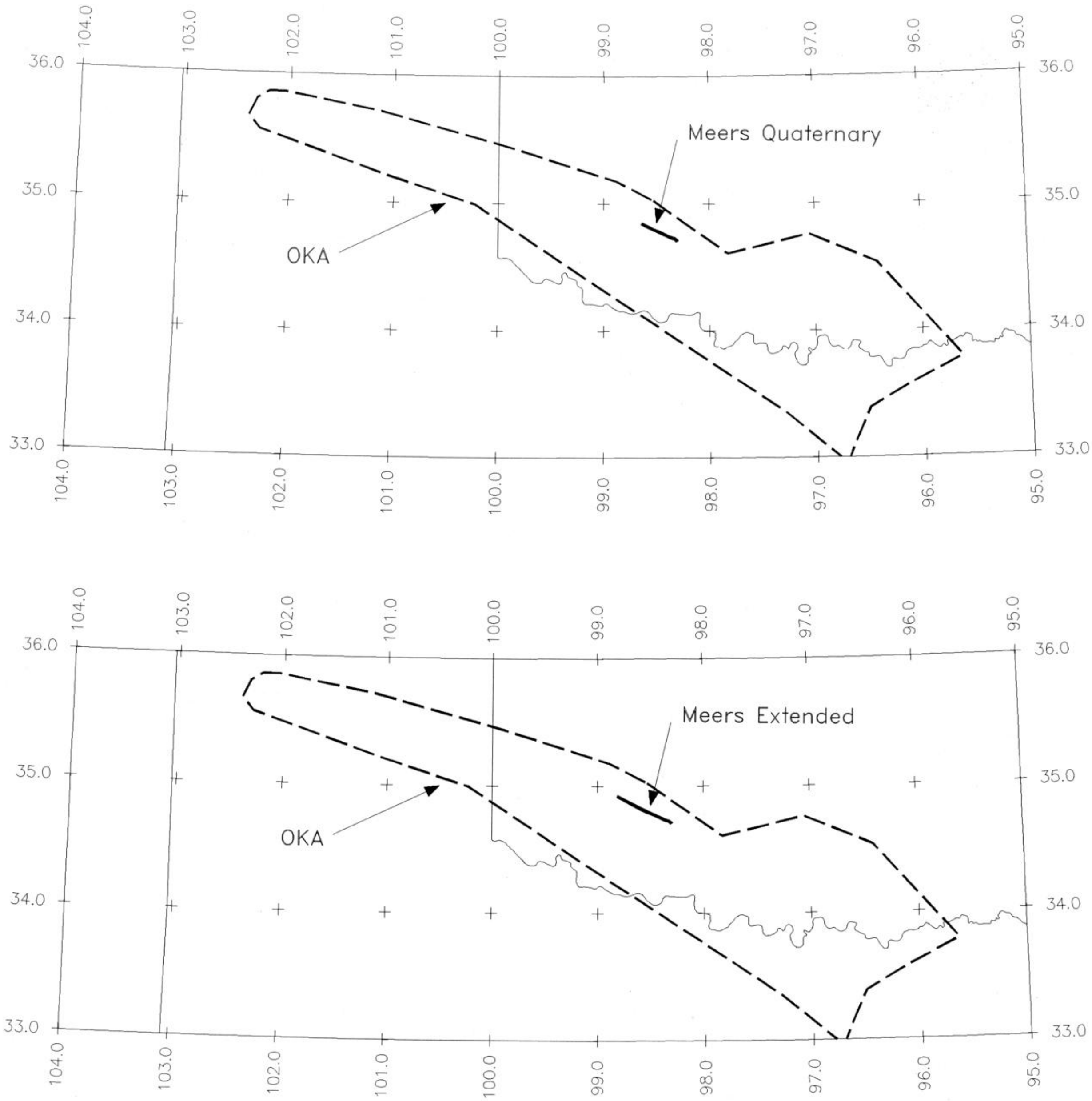

Figure H-5.4-2
Meers RLME source geometries

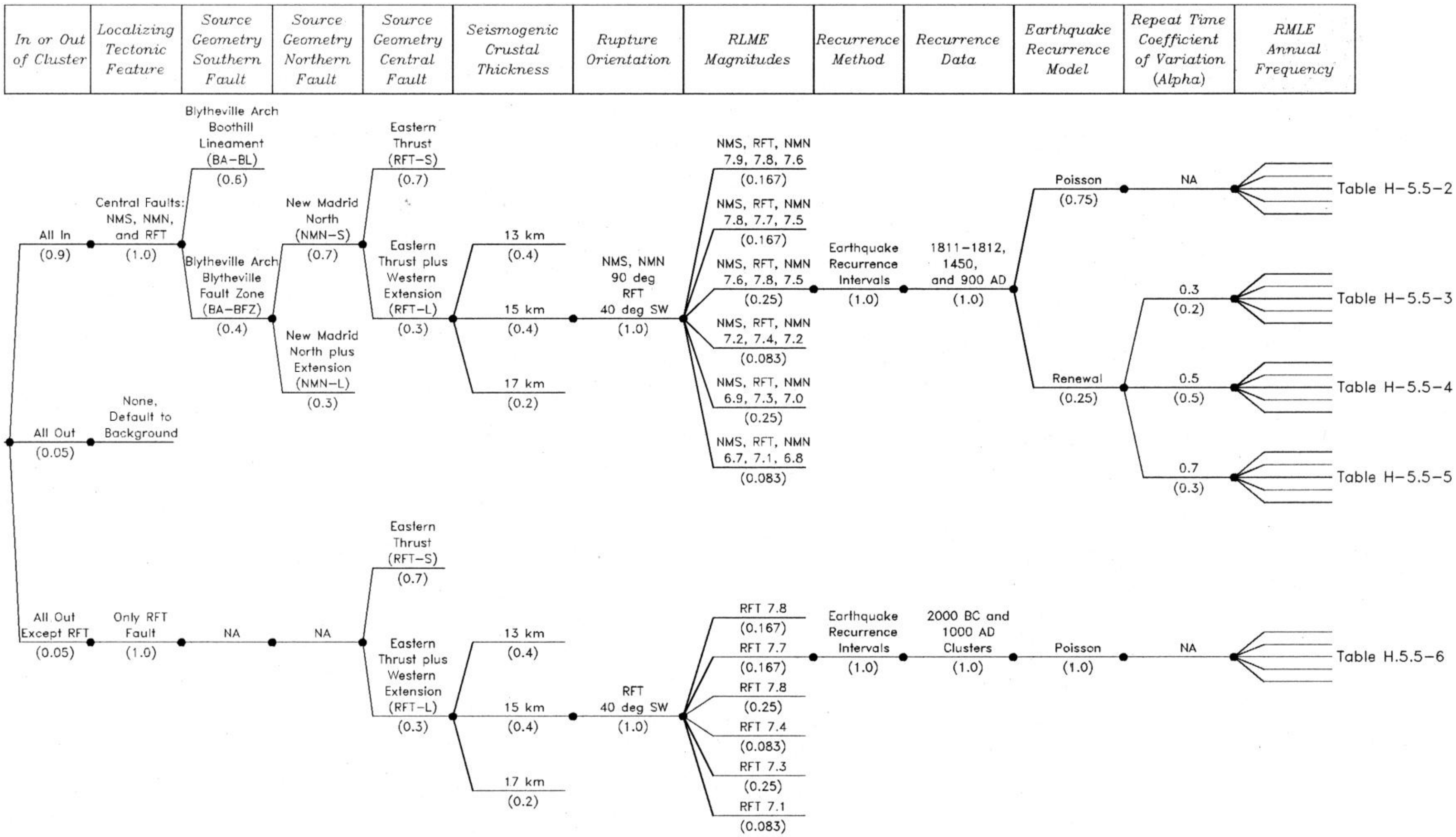

Figure H-5.5-1
Logic tree for NMFS RLME source

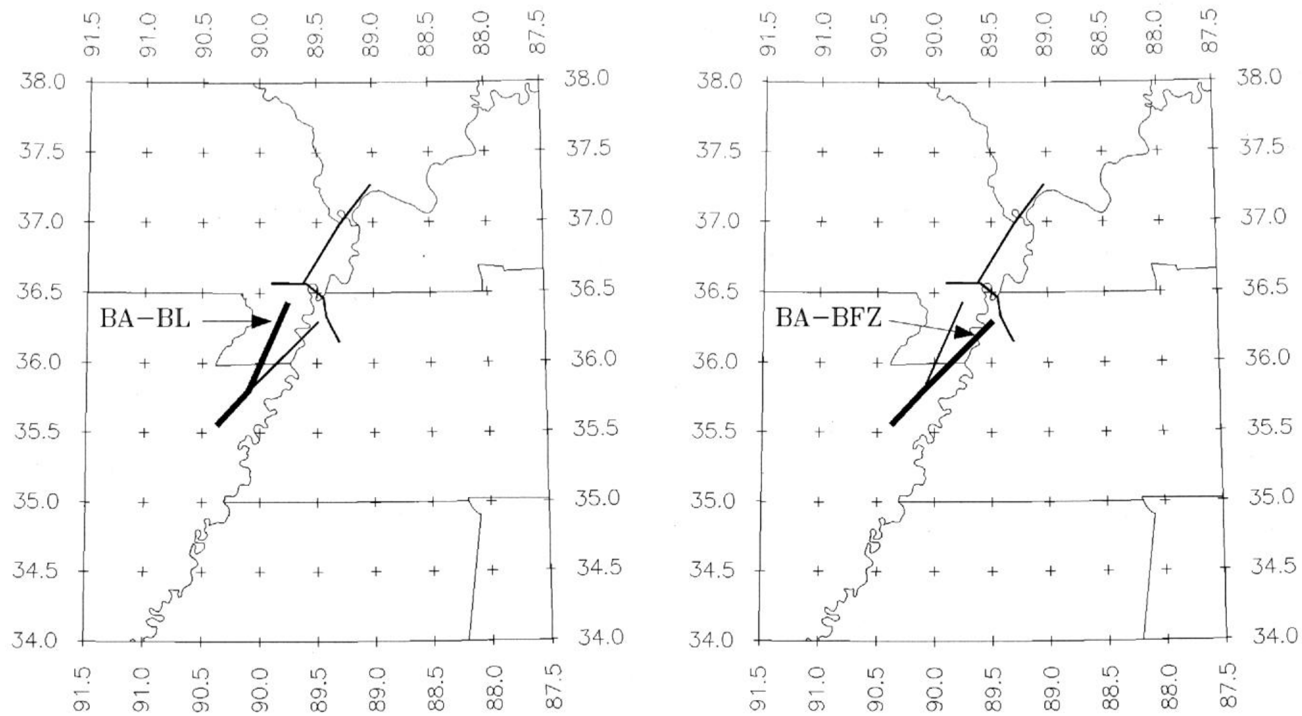

Figure H-5.5-2
New Madrid South (NMS) fault alternative RMLE source geometries: Blytheville Arch-Bootheel Lineament (BA-BL) and Blytheville Arch-Blytheville fault zone (BA-BFZ)

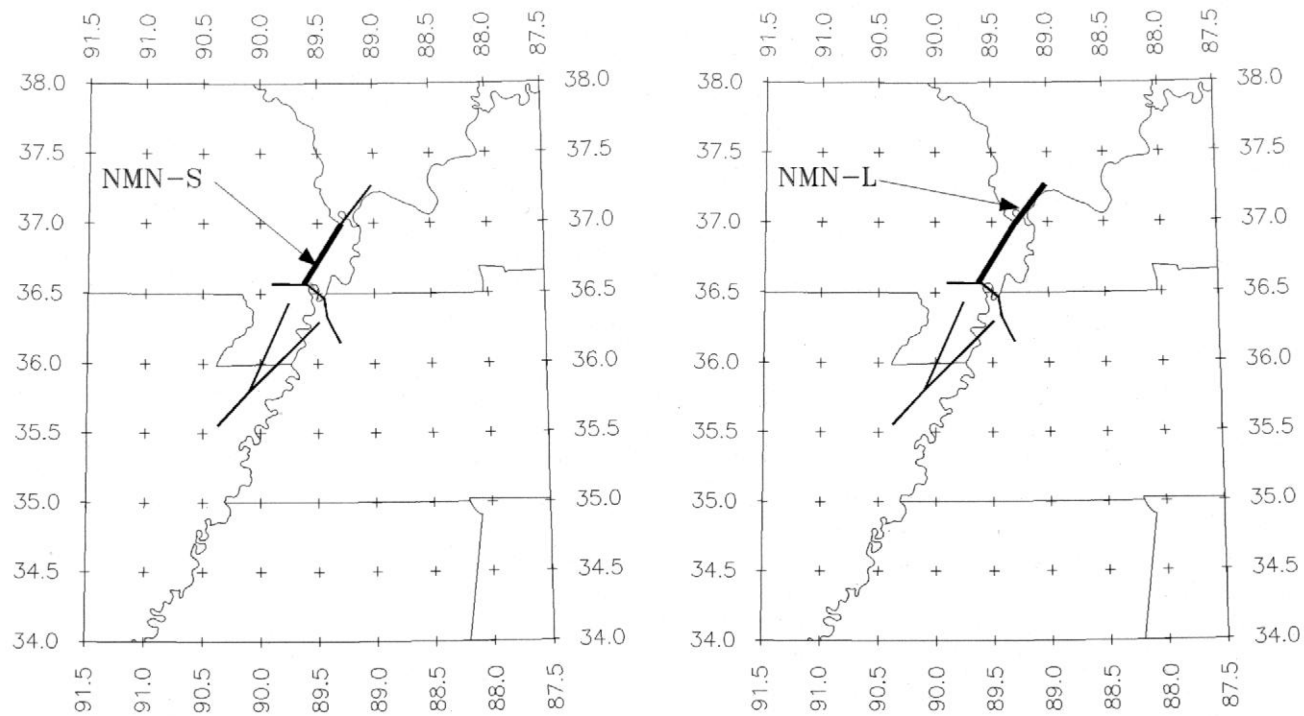

Figure H-5.5-3
New Madrid North (NMN) fault alternative RMLE source geometries: New Madrid North (NMN_S) and New Madrid North plus extension (NMN_L)

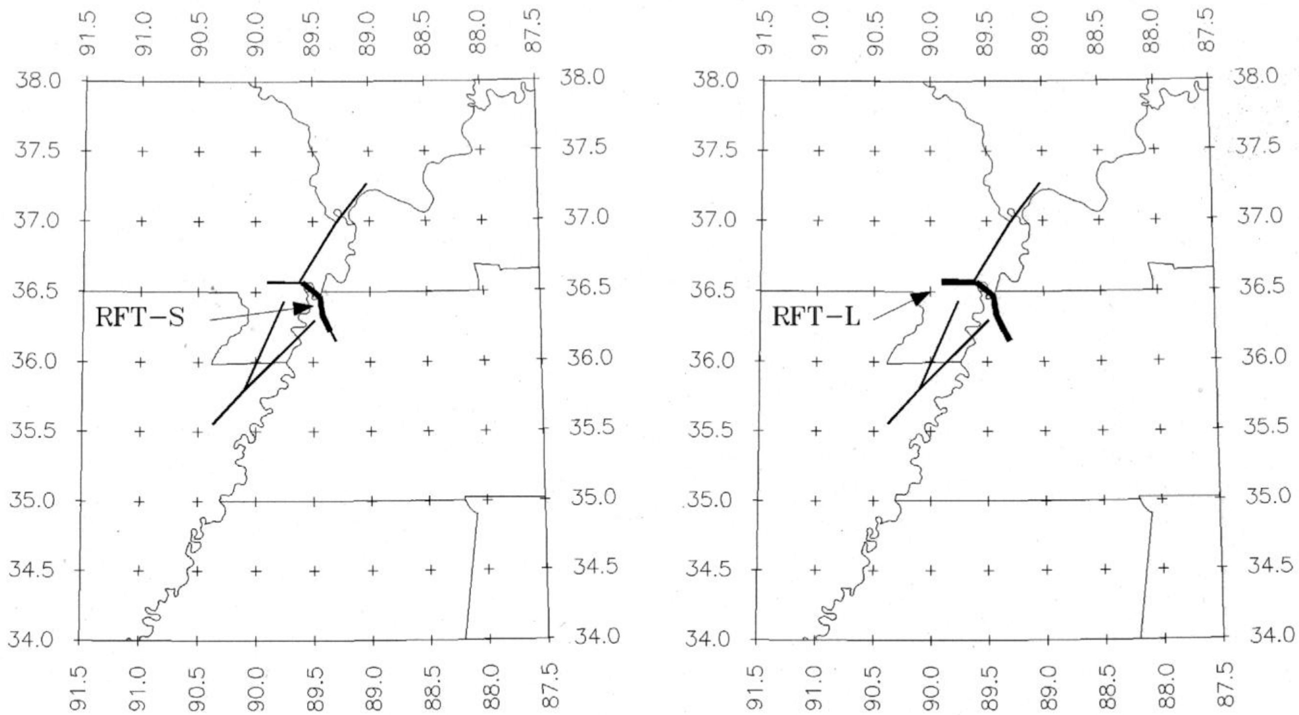

Figure H-5.5-4
Reelfoot Thrust (RFT) fault alternative RMLE source geometries: Reelfoot thrust (RFT_S) and Reelfoot thrust plus extensions (RFT_L)

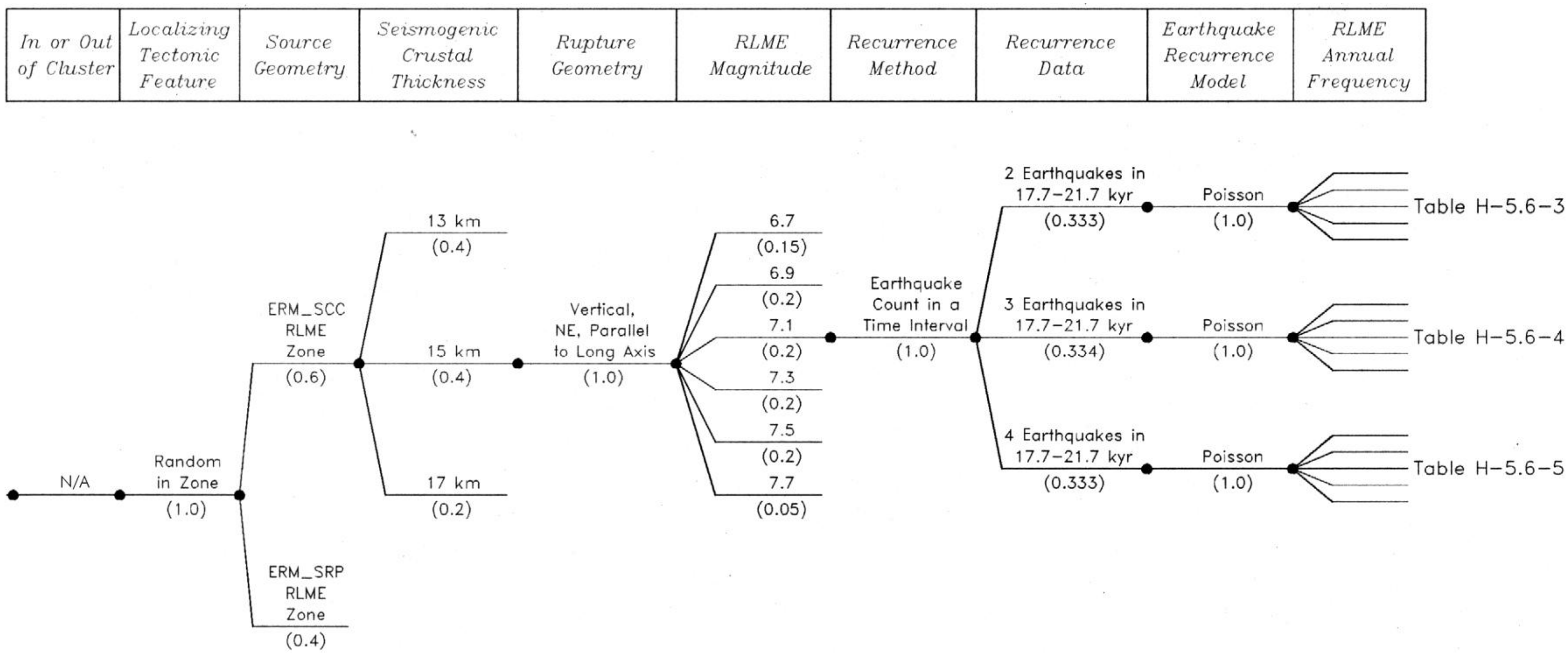

Figure H-5.6-1
Logic tree for ERM-S RLME source

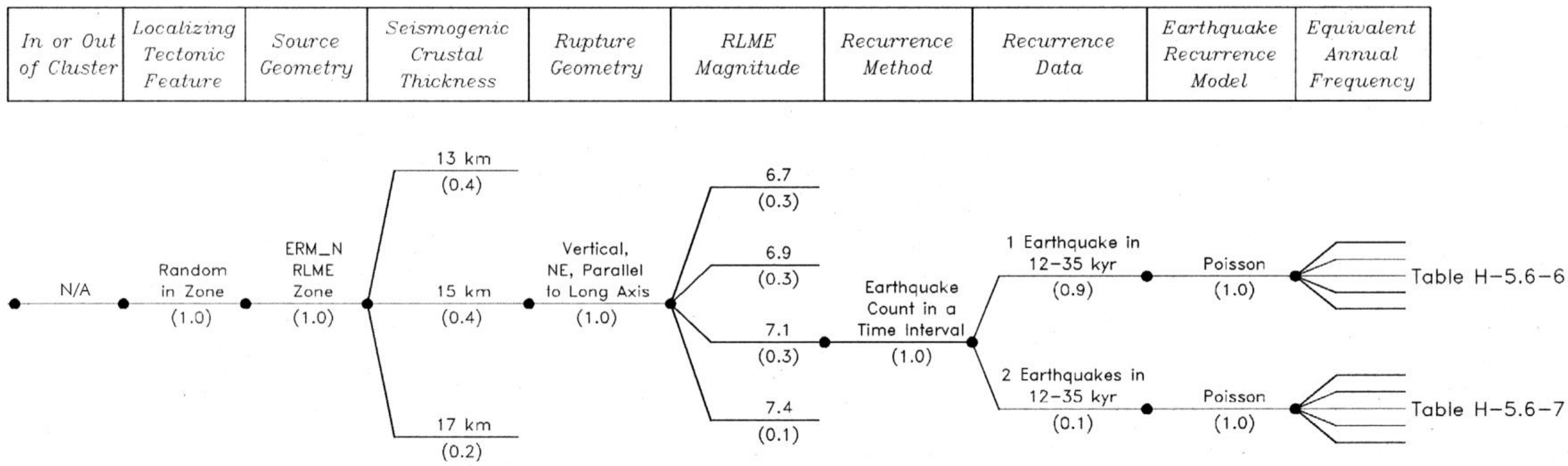

Figure H-5.6-2
Logic tree for ERM-N RLME source

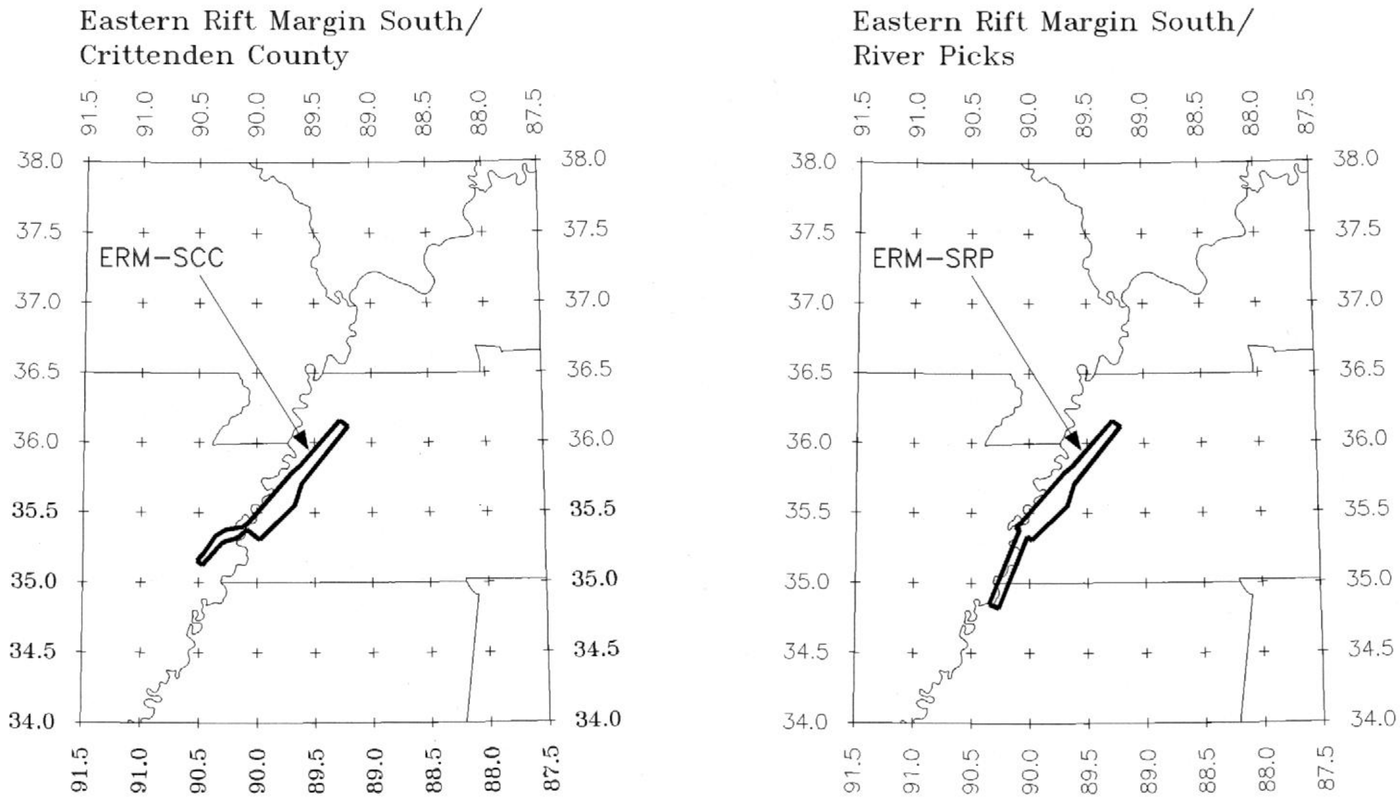

Figure H-5.6-3
ERM-S RLME source geometries

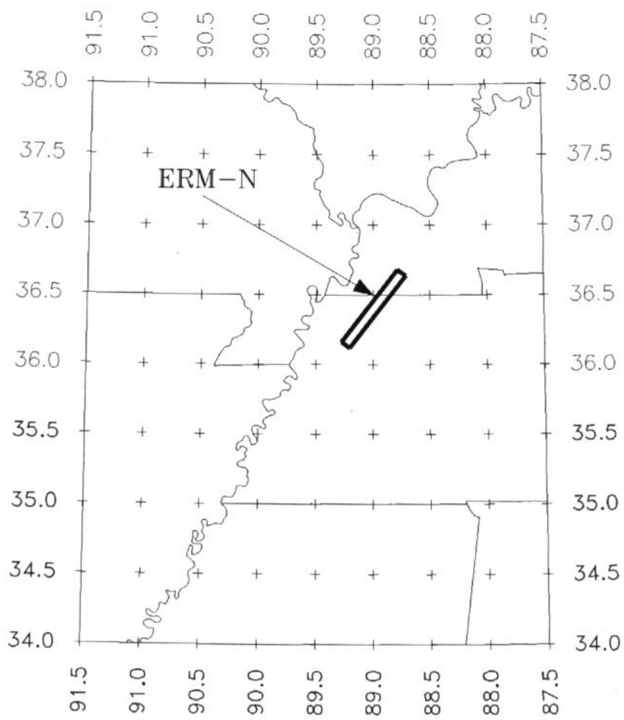

Figure H-5.6-4
ERM-N RLME source geometry

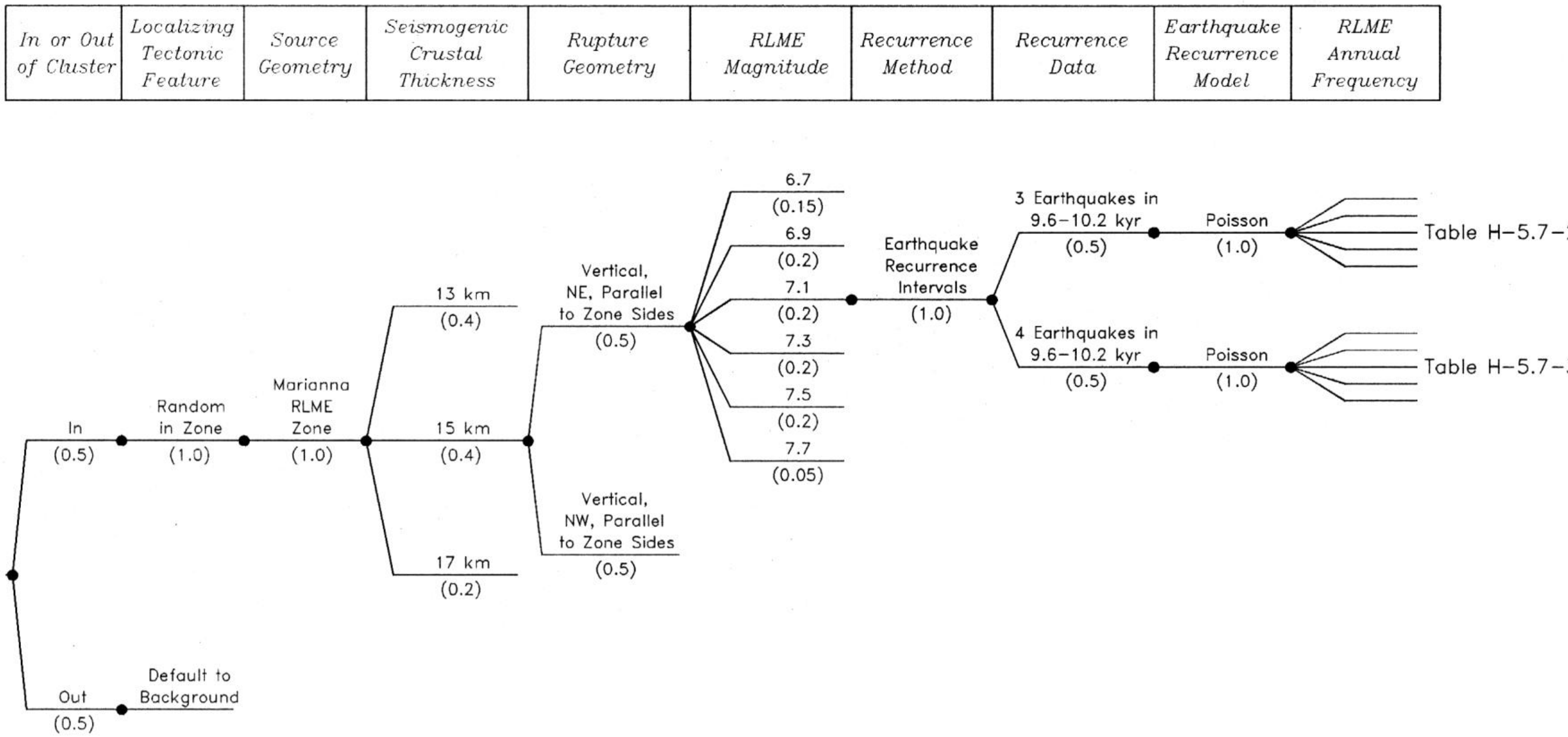

Figure H-5.7-1
Logic tree for Marianna RLME source

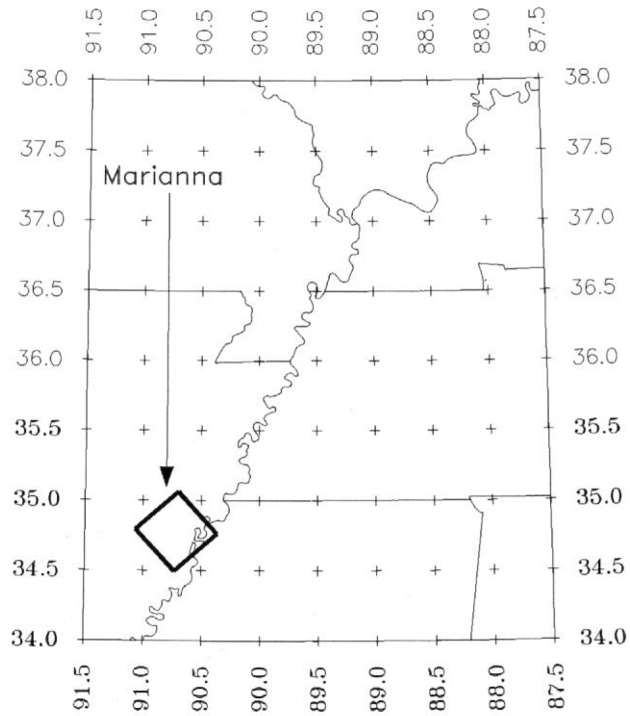

Figure H-5.7-2
Marianna RLME source geometry

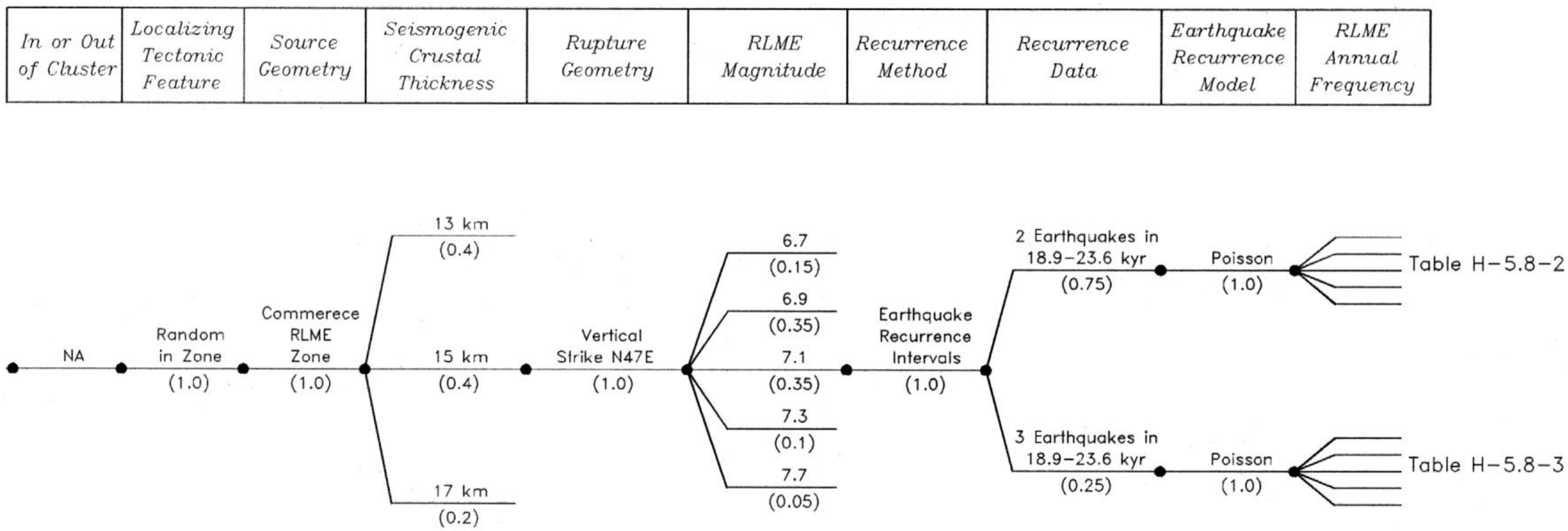

Figure H-5.8-1
Logic tree for Commerce Fault Zone RLME source

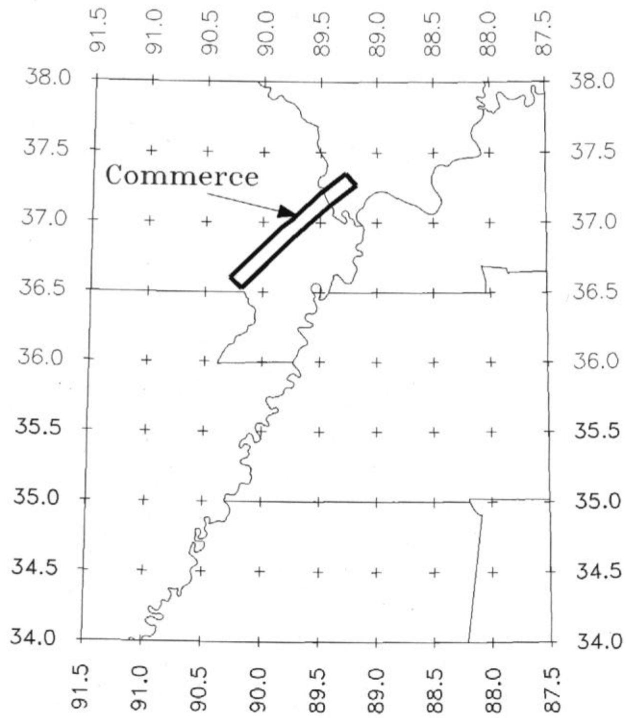

Figure H-5.8-2
Commerce RLME source geometry

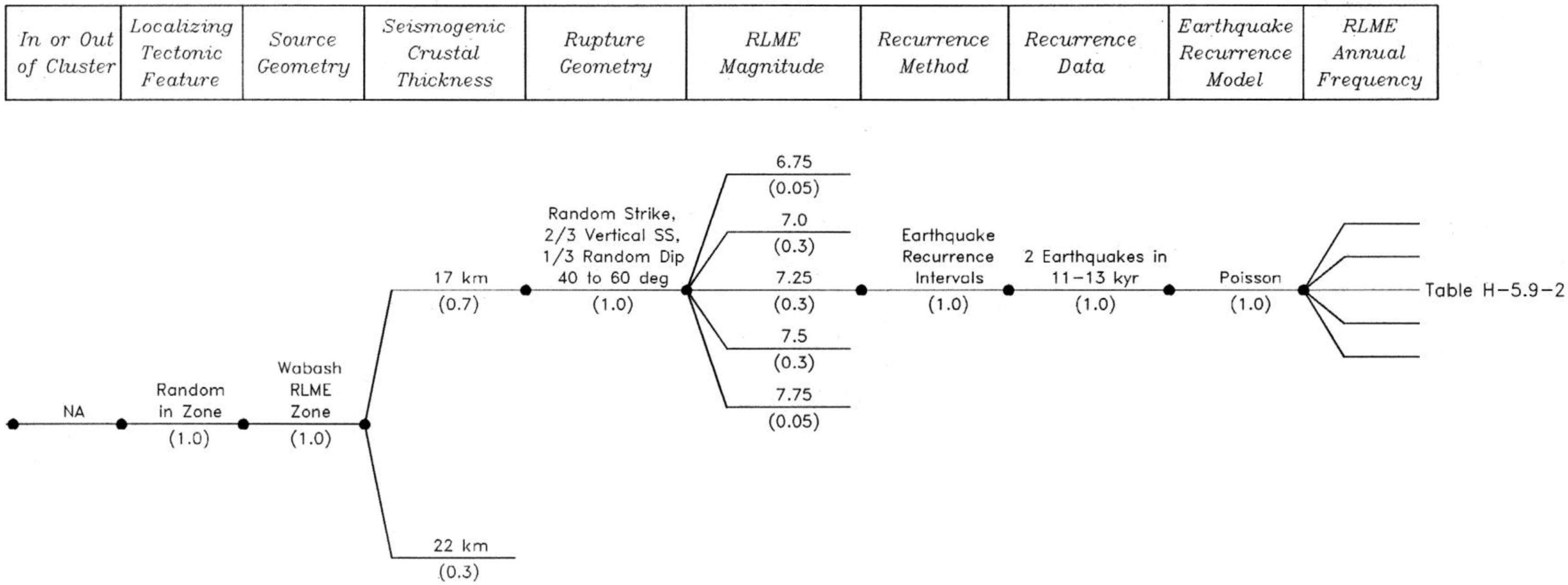

Figure H-5.9-1
Logic tree for Wabash Valley RLME source

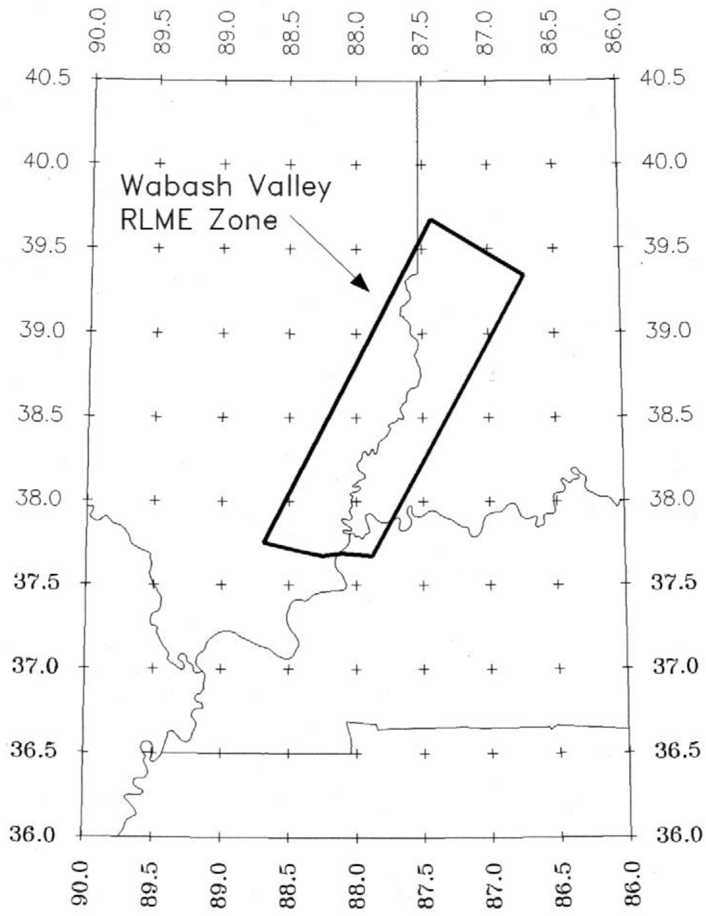

Figure H-5.9-2
Wabash Valley RLME source geometry

APPENDIX I

PPRP Review Comments

I

APPENDIX
PPRP REVIEW COMMENTS

CORRESPONDENCE—CONTENTS

Participatory Peer Review Panel (PPRP) Letters

1a) Letter dated May 22, 2008, to Mr. Salomone: *Central and Eastern United States Seismic Source Characterization for Nuclear Facilities, Draft Project Plan, Rev 00, April 14, 2008: Participatory Peer Review Panel review meeting, May 8, 2008*.

1b) *Attachment 1 (PPRP and Sponsor Representatives) dated May 22, 2008: CEUS SSC for Nuclear Facilities Participatory Peer Review Panel and Sponsor Representatives.*

1c) *Attachment 2 (Consolidated Written Comments on Draft Project Plan) dated May 22, 2008: Consolidated PPRP Comments on Draft Project Plan: Central and Eastern United States Seismic Source Characterization for Nuclear Facilities, Rev 00 04/14/08.*

2a) Letter dated August 15, 2008, to Mr. Salomone: *Central and Eastern United States Seismic Source Characterization for Nuclear Facilities: Participatory Peer Review Report on Workshop No. 1.*

2b) *Attachment A (PPRP Key Issues for CEUS SSC Relevant to Workshop #1 via e-mail dated June 3, 2008, including elaborated inputs from William J. Hinze, Jeffrey K. Kimball, and Jon P. Ake).*

3) Letter dated March 10, 2009, to Mr. Salomone: *Central and Eastern United States Seismic Source Characterization for Nuclear Facilities: Participatory Peer Review Report on Workshop No. 2*.

4) Letter dated September 18, 2009, to Mr. Salomone: *Central and Eastern United States Seismic Source Characterization for Nuclear Facilities: Participatory Peer Review Report on Workshop No. 3*.

5) Letter dated April 7, 2010, to Mr. Salomone: *Central and Eastern United States Seismic Source Characterization for Nuclear Facilities: Feedback on CEUS SSC Preliminary Model*.

6) Email dated October 4, 2010 to Mr. Salomone: *Central and Eastern United States Seismic Source Characterization for Nuclear Facilities—PPRP Review Comments on CEUS SSC Draft Report of July 31, 2010*

7) Email dated October 13, 2010, to Mr. Salomone: *Key Issues for TI Team to be Attentive to as They Revisit the CEUS SSC Model and Revise the Project Report (PPRP Informal Communication)*

8) Email dated February 23, 2011, to Mr. Salomone: *PPRP Feedback on CEUS SSC Working Meeting #9 (PPRP Informal Communication)*

9) Email dated September 26, 2011, to Mr. Salomone: *Central and Eastern United States Seismic Source Characterization for Nuclear Facilities—Mandatory PPRP Review Comments on the CEUS SSC Final Report*

10) Email dated September 26, 2011, to Mr. Salomone: *Central and Eastern United States Seismic Source Characterization for Nuclear Facilities—PPRP Non-Mandatory Review Comments on Installments 1 and 2 of Final Report*

11) PPRP Comment Response Table

Technical Integration (TI) Team and Project Manager (PM) Response to PPRP Letters

1) Letter dated September 16, 2008, to Drs. Arabasz and Stepp: *Response to Central and Eastern United States Seismic Source Characterization for Nuclear Facilities: Participatory Peer Review Report on Workshop No. 1, dated August 15, 2008*.

2) Letter dated March 20, 2009, to Drs. Arabasz and Stepp: *Response to Central and Eastern United States Seismic Source Characterization for Nuclear Facilities: Participatory Peer Review Report on Workshop No. 2, dated March 10, 2009*.

3) Letter dated September 25, 2009, to Drs. Arabasz and Stepp: *Response to Central and Eastern United States Seismic Source Characterization for Nuclear Facilities: Participatory Peer Review Report on Workshop No. 3, dated September 18, 2009.*

4) Letter dated April 19, 2010, to Drs. Arabasz and Stepp: *Central and Eastern United States Seismic Source Characterization for Nuclear Facilities: Feedback on CEUS SSC Preliminary Model dated April 7, 2010.*

1a

May 22, 2008

Lawrence A. Salomone
Washington Savannah River Company
Savannah River Site
Building 730-4B, Room 3125
Aiken, SC 29808

Dear Mr. Salomone:

Reference: *Central and Eastern United States Seismic Source Characterization for Nuclear Facilities*, Draft Project Plan, Rev 00, April 14, 2008: Participatory Peer Review Panel review meeting, May 8, 2008

This letter states the observations and recommendations of the designated Participatory Peer Review Panel (PPRP) for the referenced project relating to the draft project plan and the plan review meeting held in Palo Alto on May 8, 2008. The PPRP was able to review the draft project plan and provided its written comments prior to the meeting. Members of the Panel are listed in Attachment 1; the Panel's written comments on the draft project plan together with additional comments provided by sponsor agencies are in Attachment 2. We want to express our appreciation for the opportunity to meet with the Project Team and project sponsor representatives and for the responsive and thorough discussions of our written comments during the meeting. We believe the discussions and follow-on actions that grew out of them satisfactorily resolve our written comments.

The paramount goal of the project is to develop a seismic source characterization (SSC) model for the central and eastern United States (CEUS) that can be adopted by the sponsoring organizations as an accepted starting basis model for performing a site-specific probabilistic seismic hazard analysis (PSHA) at any geographic location within the region. In order to achieve this overarching goal the SSC model must have the stability of being broadly accepted by the informed scientific and technical community and must remain valid for a period into the future. The CEUS SSC assessment will implement current practice and guidance on the use of experts and assessment of uncertainty described in Budnitz, et al., 1997[1] (the SSHAC process). The planned approach is to use a SSHAC Level 3 process for assessing key SSC issues and a Level 2 process for assessing issues that have lesser hazard significance.

Our written comments on the draft project plan were satisfactorily resolved by discussions during the meeting and with planned revision of the plan. We have the following additional observations and recommendations following the meeting.

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[1] Budnitz, R. J., G. Apostolakis, D. M. Boore, L. S. Cluff, K. J. Coppersmith, C. A. Cornell, and P. A. Morris, 1997. *Recommendations for Probabilistic Seismic Hazard Analysis: Guidance on Uncertainty and Use of Experts.* NUREG/CR-6372, Washington, DC, U.S. Nuclear Regulatory Commission.

1. We endorse the planned use of a SSHAC Level 3 process for key issues of the CEUS SSC model. However, the planned use of Level 2 processes for "those issues having lesser hazard significance or are not subject to large uncertainty" is potentially problematic vis-à-vis desired stability. At a minimum, decisions to use Level 2 processes in developing aspects of the CEUS SSC model should be carefully scrutinized both by the Technical Integrator (TI) team and the PPRP. We recommend that consideration be given to using the Level 3 process for assessment of *all* SSC issues regardless of the level of uncertainty about the issue or its hazard significance. The planned early identification of the most hazard-significant issues should serve to more efficiently focus the workshops and assessments. However, a uniformly implemented Level 3 assessment will assure uniform thoroughness and completeness of the assessments and will raise scientific and public confidence in the result. Implemented this way, we are confident that the Level 3 assessment will result in a SSC model that properly reflects the uncertainty of the informed scientific community and that will serve as a stable starting basis for performing site-specific PSHA's.

2. The TI Team should make every effort to comprehensively address proponent positions on the various SSC issues and to thoroughly evaluate the issues in workshops. The workshop proceedings and the assessments of the issues should be thoroughly documented and summarized within the main body of the report, with more detail provided in the appendix of the report. It is clear that scientific investigations will continue to expand the available database and to improve scientific understanding of earthquake processes into the future. Organizations that adopt the SSC model should develop and implement procedures for evaluating the significance of such advances in scientific knowledge in order to fully achieve the desired longevity goal for use of the study results into the future. We consider the development of such procedures to be a user function beyond the scope of this project since the appropriate procedures and evaluations would be specific to each organization as required to meet its seismic regulations.

3. The TI Team is constituted of individuals who are among the most experienced available for implementation of the SSHAC process. However, considering that the paramount goal of the study is to develop a broadly accepted CEUS SSC model that will remain stable into the future, we strongly recommend expanding the TI Team. Specifically, we urge the inclusion of experts—either as full members of the Team or as heavily involved resource experts—who have expert knowledge about CEUS tectonic and earthquake processes and experience with other seismic source assessments for seismic hazard mapping programs that may elect to adopt the study results. We consider achievement of this level of participation across programs to be essential.

4. We understand that the project is limited by available resources and must be optimized to the extent achievable. Nevertheless, we consider six test sites for development of hazard results feedback to be minimum. We strongly endorse the plan to select locations for the test sites so as to optimally capture the sensitivity of hazard to elements and parameters of the CEUS SSC model. In order to optimize the benefit of the feedback workshop, arrangements should be made to

provide real-time analysis of the sensitivity of hazard to elements and parameters of the SSC model.

5. The project database is clearly fundamental for performing the assessments for development of the SSC model. A complete and well-qualified database should be the essential objective in order to reduce data uncertainty to the extent achievable. We recommend efficient open electronic access to the database by the project participants, to the extent achievable.
6. We endorse the planned briefings for the project sponsors on the SSC model and how to use the model to perform a site-specific PSHA. We recommend that the project prepare a document describing lessons learned at the end of the project and include this as part of the briefings and as an appendix to the final report.
7. In order to promote broad user community participation in, and subsequent use of, the CEUS SSC results, the PPRP was intentionally constituted to include qualified individuals from sponsoring organizations that expect to adopt the results and from other hazard mapping programs. Accordingly, the PPRP believes it is important to state the following. The PPRP intends to appropriately perform its function to provide critical review of procedural and technical aspects of the project. The Panel participants will focus their comments primarily on technical validity, technical completeness, and conformity to the SSHAC process. We expect the sponsoring organizations to communicate explicit statements of their views to the Project Team independently of the PPRP.

These observations and recommendations are our primary ones at this time. The Panel intends to provide, in a timely way, further comments regarding specific issues for consideration by the Project Team in planning Workshop 1.

Do not hesitate to contact us to discuss any of our observations and recommendations.

Sincerely,

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Attachments

- PPRP Members and Sponsor Representatives
- Consolidated Written Comments on Draft Project Plan

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CEUS SSC for Nuclear Facilities
Participatory Peer Review Panel and Sponsor Representatives

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Consolidated PPRP Comments on
DRAFT PROJECT PLAN: CENTRAL AND EASTERN UNITED STATES SEISMIC SOURCE CHARACTERIZATION FOR NUCLEAR FACILITIES, REV 00 04/14/08

For discussion and resolution at Project Planning Meeting #2, May 8, 2008

For discussions at the May 8, 2008 EPRI CEUS SSC Project meeting to address the PPRP review of the draft Project Plan, non-editorial PPRP review comments that require discussion are consolidated in this document. No effort has been made to integrate the comments; some address overlapping issues and can be grouped under a single agenda item. In addition, some comments go to details of implementation and may more appropriately be addressed in the detailed task implementation planning.

<u>Jon P. Ake, Annie Kammerer, Clifford Munson</u>

NRC staff generally has a positive response to the DPP. However, we do have a few specific comments, which are summarized below according to section of the DPP. Some high-level concerns we have identified include:

- The ability to fulfill the project objectives with only three workshops,
- The timeline, which seems fairly aggressive,
- The specific roles and responsibilities of the participatory peer review panel (PPRP) and the sponsor representatives. In particular the relationship between the PPRP, sponsors, and TI team needs to be clarified.
- In general the Project Plan needs more detail if the aggressive timeline laid out is to be met.
- The project documentation is to be captured as an EPRI Technical Report, it needs to be explicitly stated that this information will be readily available to the general public at nominal cost (i.e. for reproduction) or through download at the NRC or DOE website.
- The makeup of the TI team is entirely industry representatives, some thought should be given to the potential addition of an NRC or DOE person to the team.
- Given that the objective of this project is to produce a new seismic source characterization model, the role of the ESPs in this project is not clear. The ESPs focused on updating or modifying the EPRI-SOG model.

Executive Summary
On a philosophical note<u>, the purpose of the project is to produce an up-to-date, comprehensive, robust and defensible characterization of seismic sources in the CEUS</u>. As a result of following a disciplined, structured process (such as that in the SSHAC guidelines) we will achieve stability and longevity. However, stability and longevity is not the purpose in itself.

Given that the first meeting of project personnel, the peer review team and project sponsors will not occur until May 8th, it seems that scheduling the first workshop in July is somewhat optimistic. Perhaps more detailed discussion of exactly what needs to be done by the time of the meeting would make the basis for this timeline clearer.

After the review of the draft report by the PPRP it would be appropriate to have a final meeting (not necessarily a workshop) to close out any remaining comments from PPRP and project staff prior to production of the final report.

Introduction and Context of Study
The specification of six sites to be used in the seismic hazard calculations may be premature. To fully capture and understand the effects of certain source model assumptions or choices it may necessary to evaluate more than six sites. To assess the impact of seismicity boundaries and smoothing assumptions it may useful to look at a larger number of sites in a small area.

The discussion in this section (second paragraph on page 3) regarding Mmax leads to some questions regarding the conduct of a Level 3 versus Level 4 study. In a Level 4 study the experts/teams would each develop a distribution for Mmax and by integrating across the teams we have a measure of the range of technical interpretations of the broader informed community. Achieving that goal in a Level 3 study is somewhat more challenging. It appears that achieving the goal of broad community input will be a shared responsibility of the participatory peer review panel and TI team. This will lead to additional interactions between the PPRP and TI team. It would be beneficial to specifically schedule time before each of the workshops for the PPRP to meet and "get on the same page" and then to meet and debrief with the TI team immediately after each of the workshops. This additional meeting time would be an opportunity to effectively maximize the usefulness of participatory peer review. If this work is not performed in a thoughtful and thorough way, we will probably not achieve the goal of representing the full spectrum of community opinion.

Objectives
Please see the comment above regarding the philosophy of study objectives.

The specification of six sites to be chosen from next generation power plants and/or sites within the DOE complex for the sensitivity calculations needs to be carefully considered and justified.

Selection of SSHAC Study Level
In the first paragraph, there is discussion of the possibility of specification of lower levels of evaluation (SHAC Level 2) for some issues that are not as important. When will the importance of issues be defined? It seems like that will be done in Task 4 which should be done prior to Task 5 (Workshop #1), which is scheduled for July of 2008. Any decision making in this regard should be conducted with input from the PPRP.

Work Plan
Task 2: Database Development

Any literature compiled for use by the TI team should also be made available to the PPRP, and should ultimately be compiled into a publically available database.

Task 3: Seismicity Catalog Development
There is lots of good detailed discussion in this section. In the last bullet it seems an assessment of hazard sensitivity to catalog completeness estimates is needed (perhaps this will be done in Task 9?).

Task 4: Assessment of Hazard-Significant Issues
It is noted that three hypothetical site conditions will be assumed for each demonstration site to be evaluated (hard rock, shallow soil, and deep soil). Will these be the same conditions and amplification functions used in EPRI-6395 or will new functions be developed? If so, when will the PPRP be able to evaluate the choice of properties for the profiles?

Task 5: Workshop #1-Significant Issues and Databases
Please note the comment above regarding the timing of this workshop. It also not clear exactly who the resource experts will be and if it is possible to make arrangements (i.e. contract or travel or USGS support) to have them participate in a meeting in July.

Task 6: Workshop #2-Alternative Interpretations
This is the key task in the project. The objectives for this workshop described in the DPP are broad in scope and will be complex. The challenge of evaluating and incorporating alternative viewpoints into a hazard model that is flexible and broad enough to incorporate the evaluation of alternative conceptual models that might arise at a later date will be challenging. It seems that specifying a workshop duration of two days a priori is somewhat optimistic. This workshop should be of whatever duration is required to explore the reasonable alternative interpretations.

Task 7: Construct Preliminary SSC Model
Alternative methods for the assessment of maximum magnitude, such as those used in the PEGASOS Project, should also be evaluated. A current project for the evaluation of Mmax in the CEUS is being conducted by the USGS with support from the NRC. The results of that study should be considered or incorporated in Task #7.

Task 9: Perform Preliminary Hazard Calculations and Sensitivity Analyses
The DPP suggests that the sensitivity studies will show changes with respect to alternative source parameters, smoothing assumptions and relative to the EPRI-SOG sources. Since the objective of the project is to develop a SSC model that replaces the EPRI-SOG model, we assume this comparison is only of use to illustrate the change in hazard due to the evolution in our (the earthquake community) perceptions of hazard. Is this correct or is there another reason for this comparison?

Task 12: Document CEUS SSC Project in Draft Report
The discussion of the approach for documentation seems sound. Based on our reading of this section of the DPP it is not clear how many documents will be prepared. Will there

be a document that summarizes the technical bases for the assessments used in the hazard model and a separate Hazard Input Document or a single document? This is important from the standpoint of assessing how realistic the schedule and budget is. The development of complete and transparent documentation is essential for the longevity of the results by allowing for new information to be appropriately assessed.

Task 13: Review of Draft Report by PPRP
We assume the meeting described in this section will be between the TI team, PPRP, and Sponsor reviewers. What is not defined is when this meeting will take place (we find it hard to see from the spreadsheet) and exactly how the incorporation of comments will be done. There is a need to define the relationship between the various entities (TI team, PPRP, and Sponsor reviewers) and to consider how PPRP and Sponsor reviewer comments will be incoroporated. Some thought needs to be given to this beyond the box charts shown in Figures 1 and 2. We believe that the Sponsor reviewers should be treated as de facto members of the PPRP, in addition to the special responsibilities of representing the sponsor agencies.

Task 15: Brief NRC and DNFSB on CEUS SSC Study
DOE should be explicitly identified in the list of groups to be briefed.

Task 16: Participatory Peer Review Panel
Given the significant amount of material that will need to be reviewed and evaluated by the PPRP, and the responsibility that the PPRP has to assure that the breadth of the informed technical community is represented, it seems meetings of the PPRP beyond what is outlined in this section will be needed. This may or may not need to be physical meetings in all cases; teleconferences may work for some issues.

<u>Walter J. Arabasz</u>

1. The Draft Project Plan is well organized and structured—reflecting considerable thought and effort. Key information I lack as a reviewer is some indication of the qualifications of the individuals or teams or contractors who will perform some of the tasks (perhaps outside the scope of desired comment at this point). As an example, will some expert(s) in statistics be involved in Task 3 (Seismicity Catalog Development) or only seismologists? My confidence in the expected products and their stability and longevity depends not only on knowing task breakdowns but also on having some idea of who will be doing the work.

2. Will there be a Web-based resource (possibly managed by the database contractor) to facilitate controlled access to basic project information and data—e.g., project documents, bibliographic literature, data and/or information products associated with relevant data, PowerPoint presentations made at workshops, etc.? Given the complexity and duration of the project, participants (including the PPRP) will be able to function far more efficiently and incisively if they don't have to be their own information managers. (We've all been there!)

3. *Figure 1:* Given the long intervals between the activity points (stars) for the PPRP, I suggest there be <u>at least</u> one teleconference, or some other form of communication, for the PPRP between each milestone to keep them informed and reasonably engaged. Access to a well-designed project Web site would motivate them to stay engaged (even on unpaid time).

4. *Task 2 (Database Development), page 6:* Regarding "available data in the academic sector," expect the usual problem of quality control for data and peer-reviewed status for information that may be introduced. Guidelines will likely have to be established by the TI team for using unpublished data and information from the academic sector (a common source of "red herrings").

5. *Task 3 (Seismicity Catalog Development), page 8:* The task breakdown includes tasks that, in my judgment, need to be performed or overseen by one or more experts in statistics. The plan importantly states that alternative approaches will be examined for the identification of dependent events within the catalog. Various stochastic approaches have been developed by statisticians since the work of Veneziano and Van Dyck as part of the EPRI-SOG project, so stability and longevity are issues here. Similarly, other approaches have subsequently been developed for assessing catalog completeness, and alternative approaches should be considered in order to give confidence to other practitioners about the stability of results.

6. *Task 7 (Construct Preliminary SSC Model), page 10:* Many practitioners in seismic source characterization tend not to use terms identical to those defined in Appendix A of NRC Regulatory Guide 1.165 (e.g., *capable tectonic source, seismogenic source*). The project may want to consider adopting—or at least incorporating—terms consistent with NRC terminology to avoid having to translate later.

7. *Task 7 (Construct Preliminary SSC Model), Earthquake Recurrence, page 11:* Mention is made of "Where data are available, paleoseismic recurrence will be incorporated…" If fault sources are identified, moment balancing may need to be considered for fault rupture models.

8. *Task 11 (Finalize SSC Model), page 13, paragraph 1:* What does it mean that, "Alternative models considered will be discussed"? Draft documentation part of this task?

9. *Task 12 (Document CEUS SSC Project in Draft Report), page 13:* Apart from "documentation" of software, are there project requirements for validation or other forms of quality control?

10. *Project Organization, page 15:* Other than the Database Manager, it's not clear how other Specialty Contractors (mentioned in the Executive Summary) fit into the Project Organization.

<u>Brent J. Guetierrez</u> (DOE)

1. *Executive Summary, 2nd paragraph;* clarify the overall purpose of the CEUS SSC project is in achieving stability and longevity; e.g., in what? Isn't the real purpose of the project to develop a new and updated CEUS SSC model with the benefits of wide

acceptance in the technical community and with sufficient technical robustness that affords longevity of the SSC model?

2. *Executive Summary, 2nd paragraph;* the sentences defining stability and longevity at present appear somewhat incongruous as written. How can you achieve the longevity as defined and expect the technical underpinnings to remain valid when new scientific findings becomes generally accepted by the technical community?

3. Page 7, 2nd paragraph; make the copies of the key papers available to the project sponsors and agency technical representatives.

4. *Page 7, last paragraph before Task 3 and Page 16, Quality Assurance:* This paragraph describes the management and documentation of data in accordance with a data management procedure, data assessment, and data storage, yet the quality assurance "tone" for this project is described as that meeting or exceeding the quality assurance associated with publication in a peer reviewed technical journal without being under the auspices of a project quality assurance program. Given the apparent vast nature of the data to be complied across several existent databases and sources, a more defined quality assurance/quality control program should be implemented for this project.

5. *Page 3 and Page 9;* on both of these pages reference is made to the NGA East project. For completeness, suggest you add additional text describing how the results of the NGA East project will be incorporated into this project (as they are available) and what potential impacts the results may have on this project.

<u>William J. Hinze</u>

1. *Executive Summary:* The two sentences – "*Stability means that the study enjoys public and regulatory confidence that it is generally accepted by the technical community. Longevity means that the technical underpinnings will remain valid in the future, despite the development of new scientific findings.*" - are the lynchpin of the Project Plan. I understand the stability issue and this is well documented in the SSHAC report. However, I do have concerns about the "longevity" issue. Longevity is an ambiguous term. Its meaning will change depending on the user. I find no reference to longevity in the SSHAC report. The "experience" that shows longevity is " … best achieved…" needs to be documented to make this a credible statement. I am concerned that longevity will mean to some users of the results of the proposed study that we can anticipate no improvements in seismic source characterization in the central and eastern U.S in the foreseeable future. This is potentially dangerous because science and databases continue to improve. Examples are the perceived need for this study and DOE's Probabilistic Volcanic Hazard Analysis – Update of Yucca Mountain. I suggest that some constraints be placed on the longevity issue to clarify its meaning in this context. Furthermore the results of Earth Scope studies in the central and eastern US are likely to impact seismic source characterization.

2. *Selection of SSHAC Study Level: "Balancing the need for stability and longevity with the need to expedite the study, the CEUS SSC project will be conducted using a Study*

Level 3 process for the key SSC issues. Lesser emphasis and Level 2 processes will be given to those issues having lesser hazard significance or are not subject to large uncertainty." Is it possible that these two criteria may work contrary to each other, i. e., some regions of lesser hazard may have a larger uncertainty? Which will take precedence?

Jeffery W. Kimball

1. *CEUS SSC Objective:* The DPP states that the overall objective of this work is to achieve stability and longevity. It is suggested that stability and longevity should be desired attributes for the work being performed, but not the objective. The objective of the CEUS SSC Project should be to develop an up-to-date assessment of probabilistic seismic hazard analysis (PSHA) seismic source characterization for the CEUS that (1) includes full assessment and incorporation of uncertainties, (2) appropriately includes the range of diverse technical interpretations from the informed scientific community, (3) includes consideration of an up-to-date data base, (4) that is properly documented, and (5) peer reviewed. If these objectives are achieved then the product (CEUS SSC input) should have stability and longevity.

2. *Focus on replacing 1986 EPRI-SOG:* In a number of places the DPP speaks to replacing the 1986 EPRI-SOG PSHA work. It is not clear why this emphasis is necessary. The introduction properly notes that the project will take full advantage of data from several seismic hazard studies. If all participants agree that we should work towards developing a community based CEUS PSHA, then this effort becomes a key part of that goal. If that goal is achieved all users, including critical facility owners, would be comfortable with using the results.

3. *Role of the United States Geological Survey (USGS):* The DPP appropriately includes a representative from the USGS on the participatory peer review panel. To work towards a community based CEUS PSHA it may be good to add an appropriate USGS person to both the TI Team and TI Staff. That would work if the USGS would agree to support the time and travel of these people. This would have the added benefit of increasing USGS confidence that the CEUS SSC products should become the national map products (supporting a community based PSHA). While it is understood that USGS personnel are not "officially" representing their agency (neither am I, for example), getting the right people throughout the organizational framework of this effort will provide long term benefits.

4. *SSHAC Level:* The DPP states that the higher the Study Level, the higher the assurance that the views of the community have been captured and represented. While this tends to be true, the intent of the SSHAC guidance report would be to have adequate confidence with any Study Level, otherwise how could you support anything less than SSHAC Study Level 4? Following SSHAC guidelines, the responsibility for assuring that the views of the community have been captured and represented rests with the Technical Integrator (TI) or Technical Facilitator/Integrator (TFI). The DPP is based on the assumption that an overall SSHAC Study Level 3 is appropriate for this effort, thus the overall approach is based on using a TI. As a starting basis this approach is workable,

but this should be confirmed at the end of Task 5, once it is determined which CEUS SSC issues are most significant. While all PSHA's assign an overall SSHAC Study Level to the project, the SSHAC guidance can be read as intending that SSHAC Study Levels apply to issues, not projects. The DPP recognizes that some issues may be addressed at Study Level 2. It may be that certain issues require some aspects of a Study Level 4. They key is to manage this appropriately given the available resource and time constraints.

5. *Task 4 – Assessment of Hazard-Significant Issues:* While in concept the completion of sensitivity studies on PSHA parameters is an important aspect of assessing the significance of PSHA SSC issues, care must be taken to ensure that no bias is introduced into this assessment. It is assumed that the purpose of the sensitivity studies will be to prioritize PSHA issues, and that the CEUS SSC input will be a "complete" update; not relying on existing SSC input from the 1986 EPRI-SOG study. It may be appropriate for the TI Team to request that the participatory peer review panel provide their PSHA experience in listing those PSHA SSC issues that could be significant. For example, experience with CEUS PSHAs would suggest that the following issues may be potentially significant. Many of these issues represent state-of-practice advances since the EPRI-SOG work.

Potentially Significant CEUS PSHA SSC Issues:

- Relationship between moment magnitude and source dimension such as source area or fault length.
- Treating seismic sources as point sources versus extended sources, for both specific seismic source zones (such as New Madrid, Charleston), and within broader areas of lower seismicity.
- Magnitude distribution approach, such as characteristic magnitude distribution versus truncated magnitude distribution. When to use which relationship.
- Magnitudes assigned to earthquakes found via paleoliquefaction evidence. In particular, the proper assessment of site response impacts on assignment of magnitudes.
- Approach to establishing maximum magnitude for regions of low seismicity.
- The seismic source approach to areas of low seismicity, specifically defined source zones versus use of smoothed seismicity.
- Approach to modeling faults for well defined source zones such as New Madrid and Charleston. Should faults be oriented randomly, or with specific orientations?

6. *Project Documentation:* The DPP could be improved in terms of listing expected documentation for each of the tasks and/or expected from project participants. In terms of the participatory peer review panel, will it operate as a unit, with written comments provided from the panel as a whole?

<u>Donald P. Moore</u>

I have reviewed the draft project plan and find it to be an excellent document that provides sufficient detail of the tasks required. As a SSHAC Level 3 effort and issues related to QA I think it is very important to retain complete documentation of all tasks and interactions that will form the basis for the new seismic source characterization. Also this documentation should be stored in a controlled fashion to allow easy recover of information. Possiblely a procedure could be developed for this purpose.

Mark D. Petterson

The U.S. Geological Survey recently completed a national seismic hazard model considering many of the Central and Eastern U.S. hazard issues that will be discussed by the TI team. There has been some discussion about whether or not the USGS should participate on the TI team. After internal discussions, we feel that we should not be involved as technical integrators because of a perceived conflict of interest. The plan needs to make it clear that my participation on the review panel does not imply an endorsement by the USGS. I plan to contribute as an advisor to the NRC in reviewing this new source characterization.

The success of this project will depend on new databases of input data (e.g., moment magnitude catalogs, magnitude uncertainty and round-off estimates, liquefaction data, etc.); as well as objective and reproducible assessments of earthquake sources, rates, and magnitudes. We expect that all of this will be open to the public.

Section Objectives page 4 states: “the use of an appropriate ground motion model, which will be held constant” to isolate the relative importance of SSC issues will be required. Recent ground models vary by a factor of two between median ground motions for most magnitudes and distances. It seems like you may want to apply two equations that span the epistemic uncertainty within the relations.

Task 2: Database Development

The list of datasets should also include :

(1) the liquefaction dates from published literature. This is the basis for the recurrence models of the Wabash zone, New Madrid zone, and Charleston zones.

(2) Reflection data in localized or regional areas such as Charleston SC where the data indicated folded Miocene strata in the offshore region, Helena Banks fault zone.

(3) Bob Hermann’s catalog of regional earthquakes and the CMT catalogs that include moment calculations (to make the conversion between mblg and Mw – Task 3).

Task 7: Construct Preliminary SSC Model

Spatial distribution: I was confused by the meaning of item 2) identification of alternative conceptual models regarding spatial distribution and assignment of weights to the alternatives. How will zones be delineated?

Maximum magnitude Assessment: I am confused by the Baysian estimation procedure (i.e., how the prior distribution is obtained and how the short catalog gives information that can update the maximum magnitude prior distribution. Are other models going to be considered?

Earthquake Recurrence: I was confused by the statement that these codes will be updated to produce a- and b-values on a finer grid and in low historical activity rates. What methods will be used to determine rates?

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August 15, 2008 Via e-mail

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Dear Mr. Salomone:

Reference: *Central and Eastern United States Seismic Source Characterization for Nuclear Facilities:* Participatory Peer Review Report on Workshop No. 1.

Acronyms

CEUS	Central and Eastern United States
COLA	Combined Operating License Application
EPRI	Electric Power Research Institute
PPRP	Participatory Peer Review Panel
PSHA	Probabilistic Seismic Hazard Analysis
SOG	Seismicity Owners Group
SSC	Seismic Source Characterization
SSHAC	Senior Seismic Hazard Analysis Committee
TI	Technical Integrator
USGS	U.S. Geological Survey

This letter constitutes the report of the Participatory Peer Review Panel on Workshop No. 1 (WS-1), "Significant Issues and Databases," for the referenced project. The workshop was held July 22–23, 2008, at EPRI headquarters in Palo Alto, California.

Following guidance described in the implementation plan for the PPRP[1], and consistent with the expectations of the SSHAC process[2], the PPRP participated in WS-1 in order to be informed and to review both procedural and technical aspects of the workshop.

Five members of the PPRP (J. Ake , W. Arabasz, W. Hinze, A. Kammerer, and D. Moore) and one of the Sponsor Representatives (C. Munson) attended WS-1 and were able to fully observe all aspects of the workshop. The other three PPRP members (J. Kimball, M. Petersen, and C. Stepp) and the other Sponsor Representative (B. Gutierrez) were subsequently provided with electronic copies of all presentations made at WS-1.

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[1] *Implementation of the PPRP's Participation in the CEUS SSC Project*: Written statement communicated by J. Carl Stepp to L. Salomone and the TI Team on June 16, 2008.
[2] Budnitz, R. J., G. Apostolakis, D. M. Boore, L. S. Cluff, K. J. Coppersmith, C. A. Cornell, and P. A. Morris, 1997. *Recommendations for Probabilistic Seismic Hazard Analysis: Guidance on Uncertainty and Use of Experts.* NUREG/CR-6372, Washington, DC, U.S. Nuclear Regulatory Commission.

Based on our observations we offer the following comments and recommendations:

1. ***Basic goals of workshop*** — Under the pressure of an aggressive schedule, the Management and TI teams (hereafter "Project Team") organized a successful workshop that achieved many of the basic goals of WS-1. The TI Team effectively framed the CEUS SSC project and gave useful, informative introductory overviews to the project participants. Results of detailed sensitivity analyses were presented that provide a sound basis for initiating the identification and evaluation of issues that will be of primary significance to the SSC project. The resource experts that were convened described and discussed diverse databases pertinent to the assessments required for development of a CEUS SSC model, and they generated productive discussions.

   We concur in general with the important seismic hazard issues identified in the presentation on sensitivity results. However, evaluating these requires some fundamental considerations such as those elaborated in Item #3, below. These include a state-of-knowledge understanding of the mechanisms involved in earthquake occurrence in the CEUS, the definition of earthquake sources, the assessment of maximum earthquake magnitude, and the characterization of the New Madrid and Charleston seismic zones.[3]

   While the resource experts did a high-quality job of describing data sets, the uncertainty in the data sets was not generally described. Uncertainty involving both quality and quantity of data—including non-uniqueness of interpretation—is fundamentally important for assessing a SSC model, both for evaluating alternatives and for considering the longevity of the results of the study. Future improvements in the quantity and quality of the data being used in the analysis may have an important effect on uncertainty and thus the stability of seismic hazard assessment. Evaluation and understanding of the present uncertainty in the data sets should be a key element of the assessment. <u>In order to fully address this important need, we recommend that the TI Team continue to interact with the data resource experts to evaluate the uncertainty in their data.</u> In this connection, we emphasize the importance of obtaining germane reference lists from the resource experts.

2. ***How will data sets be used?*** — As the workshop unfolded, the tight schedule resulted in decoupling two aspects that were intended to be more integrated. The stated goal of WS-1 was "to identify the issues of highest significance to a SSC model for the CEUS and to identify the data and information that will be required

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[3] The considerations referred to in this paragraph were originally described in a memorandum from the PPRP to the Project Manager and the TI Team on June 3, 2008 to aid in planning WS-1. The memorandum was accompanied by elaborations on key issues for the CEUS SSC written by three individual PPRP members. We include a copy of these materials here as Attachment A, which serves simply as an information item and for useful documentation.

to address those issues."[4] The parts were presented, but the whole was not developed to the extent that it was clear how the data sets described and discussed, other than the earthquake catalog, will be used by the TI Team in assessing the SSC model. We recognize that evaluation and use of diverse databases will be the focus of efforts by the TI Team before Workshop #2, but we are concerned whether the schedule for data compilation will fully support these efforts.

We note the following potential scheduling conflicts and issues:

- The schedule for the project specifies that a preliminary SSC model be completed over the period December 2008 to August 2009. However, the data sets, including the earthquake catalog, that will be used to evaluate and assess sources are not scheduled to be completed until June 2009. We recommend prioritizing this work element to ensure that the critical data sets are completed early so that the assessment is not left until the final two months of the assessment effort**.**

  Use of the data sets would be very much enhanced if the quality and quantity of the data over the CEUS could be identified in the data maps and within the data sets and if the information is clearly documented. This concern arises because of the highly variable nature of data quality and quantity over the CEUS. Further, documentation of the quality of any data incorporated into the SSC will ultimately be a requisite for this and future PSHAs.

- A comprehensive data set of seismic reflection profiling over the CEUS was not presented at the Workshop, and it is not clear that procedures are in place to identify relevant seismic reflection profiles and to make them available to the project. A number of important reflection profiles, either acquired from industry or conducted by academic institutions, have been interpreted in terms of crustal structure and tectonic elements relevant to the CEUS SSC. Interpretations of these data that are in the public domain are spread throughout the geoscience literature. In view of the potential significance of the information from the seismic reflection profiles, not only for identifying seismic source zones and their properties but also for evaluating competing tectonic models, we recommend that interpretations of relevant seismic reflection profiles over the CEUS that are in the public domain be compiled for use in the project.

Experience from past projects shows that unless the scientific utility of diverse data sets is thought through at an early stage, the default will be heavy reliance on historical and instrumental seismicity. The issue of stationarity must be addressed—while keeping in mind that an implicit goal of the project is to achieve a good predictor of seismicity for the next 50 years.

[4] Task 5: Workshop #1 Significant Issues and Databases, *Project Plan: Central and Eastern United States Seismic Source Characterization for Nuclear Facilities*, EPRI, June 2008, p. 4-4.

3. ***Identifying key SSC issues and alternative viewpoints*** — The PPRP recognizes the difficulty of identifying the SSC issues and relevant alternative interpretations that will be central to achieving the goals of Workshop #2 (WS-2). <u>We recommend that the TI Team initiate identification and evaluation of these issues and interpretations as early as possible—to allow time for their full consideration prior to WS-2 and to ensure completeness vis-à-vis the diversity of views within the informed technical community.</u> To this end, the PPRP has identified some key issues that should be considered when preparing for WS-2; these are listed below.

   - **Seismotectonic Model** — A fundamental requirement for the CEUS SSC is a state-of-knowledge understanding of the tectonic mechanisms (i.e., processes that explain the occurrence of earthquakes in time and space) involved in the occurrence of earthquakes within the study region. Important issues related to elements of the model would include: (1) the origin, direction, and strength of ambient stress; (2) the potential influence of variations in tectonic structure and crustal material properties on variations in the stress field; (3) the time-frame over which the stress field can be considered stationary; (4) the current knowledge base for age of tectonic faulting and for the correlation of age of tectonic faulting with tectonic domains and tectonic history; and (5) properties of the intermediate crust at depths where most earthquakes nucleate and the spatial correlation of these properties with historic and instrumental seismicity.

   - **Definition of Earthquake Sources** — A systematic approach and procedure for defining earthquake sources would contribute to the consistency and transparency of the assessment. A transparent approach would be to develop a matrix of criteria that would be used to perform a weighted integrated assessment of the state of knowledge. This would apply to observed tectonic structures and tectonic structure domains, knowledge about the age of tectonic faulting, knowledge about the material properties of the crust, and knowledge about seismicity rates. All of this would be in the context of the seismotectonic model used for defining and characterizing tectonic structure-specific sources, area tectonic domain sources, and tectonic-based background sources.

   - **Approach to Establishing Earthquake Rates Using Smoothed Seismicity** — For a trial area source zone it may be useful to compare results using the USGS approach to smoothing seismicity (for the U.S. National Seismic Hazard Maps) versus the smoothing options used in the EPRI-SOG project[5]. Such a comparison could help in understanding

[5] Seismic Hazard Methodology for the Central and Eastern United States, 10 Volumes, EPRI NP-4726, July 1986.

differences between the two approaches and in establishing a suitable basis for assessing use of the two approaches in the current study.

- **Assessment of Maximum Earthquake Magnitude** — An approach is needed for assessing maximum magnitudes for earthquake sources that takes into account current knowledge and uses systematic procedures for assessing maximum magnitude based on the tectonic characteristics of an earthquake source—whether a structure-specific source, an area source, or a background source.

- **Characterization of New Madrid and Charleston Seismic Zones** — A fundamental issue relates to the interpreted repeat occurrence within the past few thousand years of large earthquakes in the CEUS (specifically, earthquakes associated with the New Madrid and Charleston seismic zones)—without evidence of substantial deformation in the near-surface rocks during post-Cretaceous time. The body of observed data and information (paleo-liquefaction mapping and interpretations) that form the basis for these interpreted repeat earthquakes should be critically evaluated. Also, the uncertainties in both the observations and interpretations need to be thoroughly understood. Further, interpretations of these data that postulate localized high rates of seismic strain release within the recent past—without observed significant surface deformation—require explanation in the context of a viable tectonic model.

We consider a comprehensive implementation of this step of the SSC assessment to be central and essential in order to achieve the shared goals of the Project Team and the Project Sponsors for (a) the stability of the SSC assessment and (b) its desired broad use into the future. Because of the key importance of WS-2, we recommend that the Project Team actively engage the PPRP in reviewing and commenting on the planning of WS-2 and in the development of the workshop agenda.

4. ***Longevity of the SSC and ability to update it in the future*** — In the Project Plan, *longevity* was defined to mean "that the technical underpinnings will remain valid in the future, despite the development of new scientific findings." Anticipating industry and regulatory needs, the PPRP urges careful attention to two aspects of the SSC process: (1) that there be transparency in the SSC model, the technical bases of the SSC model, the related uncertainties, and the SSC process—so that the resulting product can readily be updated in the future and (2) that front-end decisions not compromise the usefulness of the SSC product in the future.

   To explain what we mean by the second statement, consider the working criterion suggested at WS-1 to define a threshold of significance in the sensitivity analyses (namely, a specific percentage change in hazard). While such an approach is useful in focusing attention on what is important, we want to ensure that such a cutoff does not curtail analysis or documentation that may be important later. An example might be the elimination of logic-tree branches with an assigned low weighting (at this time). When users in the future ask how the SSC team would have treated a particular new development, the question should be answerable from the documentation of the CEUS SSC project.

5. ***Six test sites for hazard calculations*** **—** The PPRP believes that the six (or more) test sites to be selected for hazard calculations as part of the CEUS SSC project (Project Tasks 4 and 9) will be fundamentally important to the success of the project, both scientifically and vis-à-vis stakeholder interests. Accordingly, the PPRP has an ongoing interest in learning more about how the test sites will be selected and how hazard calculations at the selected sites will guide future stages of the project. The selection of sites can usefully be used "to challenge the process" of the SSC modeling, and it can test the influence of major seismic sources outside the study area.

   We note that the Project Plan called for the selection of six test sites (under Task 4) prior to WS-1 for sensitivity studies to assess key SSC issues, but this was not accomplished. Instead, sensitivity calculations were presented for a group of sites ("Group A sites") extending along a line roughly transverse to a major line source and for another group of sites ("Group B sites") at differing distances from a major areal source.

   Insofar as the planned test sites (a) have not yet been selected and (b) apparently will play an important role later in the SSC process, the criteria for site selection will be of great interest to the PPRP beyond the example given in the Project Plan. We note that in the discussion of the test site selection in the Project Plan (see p. 4-4) the provision is made that the sites should be "as generic as possible." We recommend that the sites should be *representative* of the range of seismogenesis over the region of applicability of the CEUS SSC model.

6. ***Applicable study region*** **—** The CEUS SSC model assessed in this study will be used for developing site-specific PSHAs for sites within the United States eastward of the Rocky Mountains. Regarding database coverage, the Project Plan issued in June 2008 (p. 4-1) states:

   > "The database will be designed to include the following regional data layers to provide coverage of the entire CEUS and extend a minimum of 200 miles beyond the coastline (or the edge of the continental slope if it is less) and 200 miles from the US borders with Canada and Mexico. The western boundary of the study region will be the foothills of the Rocky Mountains (about longitude 105° W), except that it will include the Rio Grande Rift system . . ."

   We observe that various discussions during WS-1 touched on the potential importance of large magnitude sources distant from a site, which might include, for example, seismic sources in the Caribbean or Canada beyond the planned 200-mile limit. Thus, in considering scoping issues for database and SSC coverage, the Project Team needs to be mindful of limitations that may result in the applicability of the project's products for future siting in some parts of the CEUS. Recent COLA applications regarding geographic areas of potential interest for future siting (e.g., Texas, Florida) and appropriate interactions with industry sponsors can help inform the decision-making about geographic scoping.

These observations and recommendations are our primary ones at this time. We thank you for facilitating our participation in WS-1 and for the opportunities to pursue discussions with you and other members of the Project Team.

Do not hesitate to contact us if you wish to discuss any of our observations and comments.

Sincerely,

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Attachment: Copy of memo (with three enclosures) from PPRP to L Salomone, K. Coppersmith, and TI Team, communicated by e-mail on June 3, 2008

Copy:
PPRP Members
Sponsor Representatives

2b

ATTACHMENT A

To: Lawrence Salomone [Via e-mail on June 3, 2008]
Kevin Coppersmith
CEUS SSC Project TI Team

From: CEUS SSC Project PPRP

Subject: Key Issues for CEUS SSC Relevant to Workshop #1

By this memorandum we are transmitting the PPRP's identification of some key tectonic and data evaluation issues for assessment of a seismic source model for the Central and Eastern United States. The intent is to aid the Project TI Team in planning Workshop #1. PPRP members in their informed resource expert role identified the key tectonic and data evaluation issues summarized in this memorandum. Thus, at this point the items herein represent thoughtful views rather than prescriptive recommendations by the PPRP. Some elaborations of individual PPRP members' inputs are enclosed.

Seismotectonic Model – A state-of-knowledge understanding of the mechanisms [processes that explain the occurrence of earthquakes in time and space] involved in the occurrence of earthquakes within the study region is a fundamental requirement for the assessment and characterization of seismic sources. Important issues related to elements of the model include:

- The origin, direction, and strength of ambient stress,
- The potential influence of variations in tectonic structure and crustal material properties on variations in the stress field,
- The time-frame over which the stress field can be considered stationary,
- Current knowledge base for age of tectonic faulting and the correlation of age of tectonic faulting with tectonic domains and tectonic history, and
- Properties of the intermediate crust at depths where most earthquakes nucleate and the spatial correlation with historic and instrumental seismicity.

Definition of Earthquake Sources – A systematic approach and procedure for defining earthquake sources would contribute to the consistency and transparency of the assessment. An optimum approach would be to develop a matrix of criteria that would be used to perform a weighted integrated assessment of the state of knowledge regarding observed tectonic structures, tectonic structure domains, knowledge about the age of tectonic faulting, knowledge about the material properties of the crust, and knowledge about seismicity rates in the context of the seismotectonic model for defining and characterizing tectonic structure-specific sources, area tectonic domain sources, and tectonic based background sources.

For both the development of a state of knowledge seismotectonic model for the study region and for the assessment of earthquake sources, the vertical and horizontal resolution of gravity and magnetic anomaly data for the CEUS is an important issue. These data are particularly important for evaluating the material properties of the crust and for determining the depth extent of tectonic features.

Assessment of Maximum Earthquake Magnitude – The approach to assessing maximum magnitudes for earthquake sources is perceived to be a significant issue. Development of current knowledge together with systematic procedures for assessing maximum magnitude based on tectonic characteristics of an earthquake source [structure-specific source, area source, or background source] are needed.

Characterization of New Madrid and Charleston Seismic Zones – A fundamental issue relates to the interpreted repeat occurrence of large earthquakes in the CEUS [specifically, associated with the New Madrid and Charleston seismic zones] within the past few thousand years without evidence of substantial deformation in post-Cretaceous time in the near-surface rocks. The body of observed data and interpretations [paleoliquefaction mapping and interpretations] that form the basis for these interpretations should be critically evaluated. A thorough understanding of the uncertainty in both the observations and interpretations is perceived to be a fundamental requirement. Equally importantly, interpretations of these data that postulate localized high rates of seismic strain release within the recent past in the absence of observed significant deformation require explanation in the context of a viable tectonic model.

Enclosures
1. William J. Hinze elaborated inputs
2. Jeffrey K. Kimball elaborated input
3. Jon P. Ake elaborated input

To: Carl Stepp, Walter Arbasz; PPRP
From: William J. Hinze
Subject: Hazard-Significant Seismic Site Characterization Issues
Date: May 29, 2008

The following outlines some thoughts on the hazard-significant seismic site characterization issues that may be considered during Workshop #1 of the CEUS SSC. The list is exclusive of consideration of the study's seismicity catalog and ground motion considerations.

The list includes issues of varying importance and level of detail. No attempt has been made to establish a priority ranking. Some are described as statements while others are more definitively considered as questions.

There are a variety of ways to subdivide the issues. I have chosen a four-fold division of *Earthquake Mechanisms*, *Earthquake Stresses*, *Earthquake Sources*, and *Earthquake Parameters*. Mechanism concerns potential processes leading to the origin of earthquakes, stresses involves the nature and origin of stresses that cause the structural development of the crust leading to earthquakes, sources considers the identification and bounding of local and regional seismic sources, and parameters relates to characteristics of the earthquakes in the identified seismic sources.

Earthquake Mechanisms – As in other intraplate terranes the mechanisms involved in the origin of earthquakes in the CEUS are not well known. Nonetheless numerous mechanisms have been suggested and considered in seismic hazard analysis (20 were identified in the EPRI/SOG study). They are generally based on spatial or temporal variations in prevailing stress field or spatial changes in the strength of the brittle crust. It is not necessary to establish the mechanism for earthquakes of the CEUS to perform a seismic hazard analysis, but the results of the analysis are much more credible and thus more stable when mechanisms for the activity can be identified.

- Numerous mechanisms have been identified for the origin of earthquakes in the CEUS including zones of weakness (e.g., tectonic faults, ancient plate boundaries, meteorite impact sites); inhomogeneities in crustal lithology; stress concentrations due to storage of strain energy associated with fault offsets or curvature, localized intrusions of the crust, and variations in crustal composition, thickness, and temperature; and elastic rebound of the lithosphere. The credibility of proposed earthquake mechanisms for intraplate earthquakes in the CEUS needs study and analysis.
- A fundamental issue relates to the occurrence of major earthquakes in the CEUS within the past few thousand years without evidence for substantial deformation in post-Cretaceous time in the topography and near-surface rocks of the region. This paradox should be evaluated considering for example that the major earthquake activity is very young, is episodic with recurrence times measured in tens or hundreds of million years, migrates over broad regions of the CEUS, or is mechanically decoupled from the observed surface sedimentary rocks.

- Another issue relating to earthquake mechanisms is the manner in which the mechanisms vary with spatial scales, magnitude, foci depth, etc.

Earthquake Stresses – Understanding the origin, direction, and strength of ambient stresses that cause strain leading to earthquake activity is important to the credibility and stability of seismic hazard analysis. Issues that relate to earthquake stresses in the CEUS include:

- The origin of stresses observed in the CEUS was largely related to ridge-push tectonic forces in the 1980's seismic hazard analysis. The importance of these forces is now open to question. Thus it is important to consider the origin of these forces and the resulting implications to seismic hazard analysis of the CEUS.
- Measurements of the azimuth of the observed stress field vary somewhat over the CEUS. The source of these variations should be considered. They may vary simply due to errors in measurement, but they may also have other origins including stress deflections as a result of local geologic structure and lithology and depth and stresses of local origin.
- Temporal changes in stress may take place at a range of time scales. Changes may occur in periods of thousands to hundreds of thousands of years due to elastic rebound of the earth due to Pleistocene glaciations and deglaciation especially in the northern part of the CEUS and loading of the crust by sediment concentrations in deltas at the shoreline of the continent or at time scales of minutes or hours due to the passage of seismic waves. The latter "far-field" triggering of earthquake activity with major earthquakes has been noted in recent years and should be evaluated in the CEUS.
- If major seismicity migrates over the CEUS the current seismic activity in some regions may simply be due to aftershocks. Thus it should be of interest to determine whether earthquakes in these regions, e.g., the New Madrid seismic zone, are Poissonian in nature or follow the aftershock law.

Earthquake Sources – A significant amount of effort has been put into identifying and bounding the seismic zones of the CEUS by mapping historical and pre-historical earthquake epicenters. These zones can be classified as either local or regional.

Local seismic zones (special seismic zones of the USGS) are restricted to a limited geographic region that has been the subject of relatively intense seismic activity in historic time. They are not related to the magnitude of the observed earthquakes. Generally they are marked by occurrence of relatively low magnitude earthquakes (< 5), but others such as the New Madrid seismic zone and the Charleston (SC) zone are noted for infrequent (order of hundreds to thousands of years) high magnitude earthquake(s) of the order of 7 and frequent smaller magnitude quakes. Analyses of the geology, geophysics, and Seismicity of these zones attempt to identify a source structure controlling the extent of the zone and its characteristic earthquakes.

Regional earthquake zones (seismotectonic zones or uniform background zones of the USGS) are broad expanses of the CEUS that are subject to infrequent, widely dispersed earthquake activity that have magnitudes commonly less than 5. They are not identified with any particular local structure but may be related to a specific crustal terrane based on age, tectonic history, and structure and composition. Identification of local and regional seismic zones leads to the following issue questions:

- What criteria identify local and regional seismic zones and their geographic limits?
- Seismic source zones are volumes rather than an area as depicted in surface maps. Accordingly surface geology, seismic activity, and geophysical data are used to define the character of source zones at depth. Geophysics is the primary investigative tool because of the paucity of earthquake data and the limited information derived from surface geology. As a result a significant issue is the resolution, both vertical and horizontal of geophysical methods, particularly of the extensively used regional gravity and magnetic anomaly data of the CEUS. This is particularly important in evaluating the ability to obtain information on the depth extent and surface area of fault faces.
- What is the significance of deep crustal expression in identifying seismic zones and their characteristics?
- Is the continental/oceanic transition (boundary) zone in both the Atlantic Ocean and the Gulf of Mexico a seismic zone?
- Smoothing of seismic source zones can be used to recognize that the specific boundaries of zones are seldom known to a high degree of accuracy because of insufficient information or inadequate resolution of the methodologies used to define them. Should smoothing be used and if so what criteria should be used to define the smoothing method?
- Although more is known about the New Madrid seismic source zone than any other seismic zone in the CEUS, several issues remain concerning its potential seismic hazard. For example, what is the origin of the zone of diffuse epicenters that is separated from but parallels the Reelfoot rift to the northwest? Why is there no such similar zone to the southeast? What is the origin and seismic hazard significance of linear trends of epicenters that parallel the Reelfoot rift north of the main seismic flux? Why does the axis of the rift have more seismic activity than the bounding fault margins?
- Should crustal structures that are potential zones of weakness oriented favorably for reactivation in the current regional stress field be identified as seismic source zones even if they have little or no record of historical or pre-historical earthquake activity? This should include basement structures that have been reactivated in Phanerozoic time as evidenced in sedimentary structures.
- Identified continental rifts that show evidence of tectonic activity in Mesozoic era to recent times are the source of roughly one-half the historical earthquake activity in the CEUS. What differentiates these rifts from older rifts as local seismic source zones?
- Are cross-structures to rifts capable of mechanically decoupling rifts so that local seismic zones can be restricted to only a portion of the rift bounded by the cross structure? Related to this is the question of the extension of the New Madrid seismic zone into the Wabash River Valley seismic zone.

- What establishes the potential seismicity of ancient (Precambrian faults) that are oriented favorably for reactivation in the current stress field?
- Should similar crustal geological features that are recognized in geophysical and geological data and that are roughly oriented in the same azimuth be considered a similar seismic hazard regardless of the historical seismic record? Are differences in the historical seismic record of these features simply a result of low Seismicity and long recurrence periods?

Earthquake Parameters of Local and Regional Seismic Zones –
The more active seismic zones of the CEUS provide useful information on the earthquake characteristics of the region. However, the low seismic flux limits this information leading to several important issues regarding the credibility of predicted earthquake parameters. These issues include the following:

- Aftershock sequences are observed following some of the more major earthquakes in the CEUS, the nature of these sequences can provide important information on the nature of the sources and the seismic strain.
- The temporal pattern of earthquakes of varying magnitude in a seismic zone are important to defining recurrence intervals and can be useful in defining maximum magnitudes anticipated in the zone. These patterns require definition and are particularly important in identifying the maximum magnitudes of earthquakes in zones. The problem of maximum magnitude is especially problematic in regional seismic zones.
- Pre-historical earthquakes identified by paleoseismology techniques have an important role in assessing the seismic hazard of the CEUS. However, there are numerous problems associated with the use of paleoliquefaction features including their recognition as associated with a particular earthquake event and calibrating them to the magnitude of the event.
- Earthquake wave attenuation is generally assumed to be constant over the CEUS. However, there are significant variations in crustal thickness, composition, and structure over this region and seismic anisotropy exists. As a result attenuation of seismic energy may vary across the area.
- “Slow” earthquakes are now identified in some regions. Do these occur in intraplate regions such as the CEUS and if so what are their impact on seismic hazards and what are their relation to ordinary earthquakes?
- Earthquake foci over the CEUS are at depths not exceeding a few tens of kilometers. Is the depth of foci an important parameter in identifying the origin of earthquakes and identifying seismic zones and their potential hazard?

Excerpts from Memo by Bill Hinze to PPRP Dated May 12, 2008
Relevant to Planning of CEUS SSC Workshop #1

Upon reflecting on issues and discussions at the CEUS SSC meeting on May 8, 2008 I have had some thoughts that I wish to share with Panel. Most of them are a result of asking myself how the credibility of the results of the study can be increased. . .

Data needs and related resource experts.

- The 300 km rind of data surrounding the study area should include the area to the west and south of 105^{o} W. This includes a seismically active region of for example the Rio Grande rift, the Rocky Mountain front, and northwestern Mexico. These will become more important in the future to central US nuclear facilities.
- The resource experts that will be invited to Workshop #1should be encouraged to discuss the metadata for the germane data sets, but they should also be encouraged to identify where appropriate the types of geologic sources that are portrayed in the data sets with examples, the horizontal and vertical resolution of the data, precision and accuracy, and the limitations of the data set. If possible they should also discuss competing data sets and their relative merits.
- There are several other data sets that should be made available to the TI team in addition to those listed in the draft plan. These should include derived data sets which emphasize particular attributes of the data. A map should be furnished with the location of crustal refraction and reflection profiles including those in the 320 km rind in Canada. The deep seismic reflection profiles will be more of a problem than the refraction profiles but review of COCORP, GLIMPCE, USGS, etc. data sets should capture the vast majority of the available profiles. These profiles that were generally not available at the time of the EPRI SOG study should be most useful in defining and characterizing seismic source zones. Note that current gas exploration renaissance in the Appalachian Mountains includes new reflection profiling that could be valuable to the SSC if they were available for the public sector.
- I learned . . . at the May 8th meeting that GPS data are not to be included in the data available to the TI team. . . . Neglecting [GPS] data at least to the point of evaluating their precision is a potentially serious error that will decrease the credibility of the findings of the SSC.
- It is likely in the analysis of data that there may be the need for additional data sets that will assist in interpretation and analysis beyond those identified prior to the study. Minimal resources should be made for adding a few additional data sets during the progress of the study.
- Mapping of prehistoric earthquakes by paleoliquefaction data is an important component of the SSC study. However, mapping of

paleoliquefaction features should also include maps which show stream valleys, etc. that have been mapped and show no liquefaction features although the surface materials are amenable to paleoliquefaction. Negative evidence is important as well as positive evidence in this situation.

- We were told at the May 8th meeting that no data would be assembled for higher resolution studies within the 40 km range around the sites selected for intensive analysis. Yet the reflection data within these regions would be used where available. Experience suggests that interpretation of seismic reflection profiles are enhanced, often significantly, by being integrated with potential field and other geophysical data. I suggest that the decision regarding the omission of higher resolution data in the specific study areas be reconsidered. Use of these data where available will decrease uncertainties.
- Unless stratigraphic studies of the sedimentary formations of the CEUS can be shown to be important to seismic properties (e.g., attenuation) there is no apparent compelling reason for exerting a good deal of effort on these studies.

Key Issues That Require Evaluation for Assessment of the CEUS Seismic Source Model as Input for Planning Workshop #1
Jeff Kimball, May 29, 2008

The issues are listed followed by a table which could be used to cross link the issues to the database. While I have not attempted to comprehensively fill out the table, review of the issues indicates that database focus may need to be adjusted to include more focus on paleoliquefaction data and seismic source dimension data {source inversions, stress drop}.

High Priority Seismic Source Issues:

1. Relationship between moment magnitude and source dimension such as source area or fault length.
2. Treating seismic sources as point sources versus extended sources. Needs consistency with ground motion modeling; larger {M>6} events should be treated as extended sources.
3. Seismic source approach to areas of low seismicity. Should large "open" sources be considered {extended margin, craton}?
4. Magnitude distribution approach, such as characteristic magnitude distribution versus truncated exponential magnitude distribution; when to use which approach.
5. Magnitudes assigned to earthquakes found via paleoliquefaction evidence.
6. Approach to establishing maximum magnitude for regions of low seismicity.

Other Seismic Source Issues:

1. New Madrid – source boundaries, approach to modeling faults, fault orientation.
2. New Madrid – assessing uncertainty in timing of paleoearthquakes.
3. Charleston – source boundaries, approach to modeling faults, fault orientation.
4. Charleston – assessing uncertainty in timing of paleoearthquakes.
5. Wabash Valley – source boundaries, approach to modeling faults, fault orientation.
6. Wabash – assessing uncertainty in timing of paleoearthquakes.
7. Identification of tectonic features and impact of seismicity; when features are identified but seismicity is not smoothed does this default to "smoothed seismicity"?
8. USGS smoothed seismicity versus EPRI approach to smoothing – which to use and why.
9. Areas of low seismicity – lower limit on maximum magnitude given implied source dimensions?

Seismic Source Related Issues		
	Key Issue	Database
General Issues	1. Relationship between moment magnitude and source dimension such as source area or fault length.	Earthquake source inversions, stress drop.
	2. Treating seismic sources as point sources versus extended sources. Needs consistency with ground motion modeling; larger {M>6} events should be treated as extended sources.	Workshop #2?
	1. New Madrid – source boundaries, approach to modeling faults, fault orientation.	GSG, paleoliquefaction data

Fault Source Issues	2. Charleston – source boundaries, approach to modeling faults, fault orientation.	GSG, paleoliquefaction data
	3. Wabash Valley – source boundaries, approach to modeling faults, fault orientation.	GSG, paleoliquefaction data
Area Source Issues	1. Seismic source approach to areas of low seismicity. Should large "open" sources be considered {extended margin, craton}?	Workshop #2?
	2. Identification of tectonic features and impact of seismicity; when features are identified but seismicity is not smoothed does this default to "USGS smoothed seismicity"?	GSG; Should we request sensitivity studies to address this issue {USGS vs. EPRI}?
Earthquake Occurrence – Magnitude Distribution Issues		
	Key Issue	Database
General Issues	1. Magnitude distribution approach, such as characteristic magnitude distribution versus truncated exponential magnitude distribution; when to use which approach.	Workshop #2?
	2. Magnitudes assigned to earthquakes found via paleoliquefaction evidence.	Critical review of published data, but this data should be compiled.
	3. Approach to establishing maximum magnitude for regions of low seismicity.	Seismicity catalog. Workshop #2?
	4. USGS smoothed seismicity versus EPRI approach to smoothing – which to use and why.	Should we request sensitivity studies to address this issue {USGS vs. EPRI}?
Specific Issues	1. Areas of low seismicity – lower limit on maximum magnitude given implied source dimensions?	Workshop #2?
	2. New Madrid – assessing uncertainty in timing of paleoearthquakes.	New Madrid Paleoliquefaction data
	3. Charleston – assessing uncertainty in timing of paleoearthquakes.	Charleston Paleoliquefaction data
	4. Wabash – assessing uncertainty in timing of paleoearthquakes.	Wabash Paleoliquefaction data

GSG = geologic, seismologic, geophysical data.

Key Issues for CEUS SSC Project
Jon Ake
6/1/2008

1. Source characterization for regions other than New Madrid, Wabash Valley and Charleston. Two end member scenarios are the very large zones (extended margin vs craton etc.) defined in the USGS approach and numerous very small zones defined in the EPRI-SOG study. If very large zones are used it implies little understanding of the seismotectonic differences across large areas. Conversely, the smaller zones often lack a sufficient number of earthquakes to allow for a stable estimate of rate.
2. The approach to use for computing rates using “gridded seismicity”. There at least two alternative approaches being used currently, the penalized likelihood EPRI model and the kernel smoothing approach used by the USGS. These probably need to be viewed as two proponent models and we need to evaluate the impact of the differences. There are also questions that need to be addressed with respect to the degree of smoothing applied (correlation distance in the kernel approach and Wa and Wb in the EPRI formulation).
3. The approach to be used for definition of maximum magnitude in source zones (i.e. not New Madrid, Charleston, Wabash Valley). Again there are several models available that should be considered. This is an area where the data set for estimating magnitude from paleo-liquefaction evidence probably needs to be reviewed to ensure there is not a systematic bias in the resultant magnitudes.
4. To ensure that appropriate source dimensions are assigned we need to re-examine the source scaling in the CEUS. This needs to be done for the revised ground motion models as well. Assigning source dimensions based on a WUS model is clearly inappropriate.
5. A detailed examination of hypocentral depths (and associated uncertainties) in the CEUS. This will need to be used with heat flow and potential field data to evaluate limits on seismogenic thickness.
6. Source boundaries for Wabash, Charleston, New Madrid etc. Will the boundaries be “hard” and no ruptures be allowed to extend outside, or will they be “soft” where the ends of fault ruptures may extend outside the source zone?
7. The uncertainty in the timing of paleoearthquakes needs to be evaluated more fully as this issue is “co-mingled” with any assessment that might be made relative to cluster models for sources like New Madrid.
8. Seismicity catalog updates. The need to compile the best possible catalog is a very high priority. The discussion in the Draft Project Plan (DPP) on this issue is very good. The need to convert the available data to moment magnitudes is discussed in the DPP, the techniques that will be applied to the historical data as well as the instrumental data is something that needs to be carefully considered.

3

March 10, 2009 Via e-mail

Lawrence A. Salomone
Washington Savannah River Company
Savannah River Site
Building 730-4B, Room 3125
Aiken, SC 29808

Dear Mr. Salomone:

Reference: *Central and Eastern United States Seismic Source Characterization for Nuclear Facilities:* Participatory Peer Review Report on Workshop No. 2.

Acronyms

CEUS	Central and Eastern United States
EPRI	Electric Power Research Institute
GPS	Global Positioning System
PPRP	Participatory Peer Review Panel
PSHA	Probabilistic Seismic Hazard Analysis
SSC	Seismic Source Characterization
SSHAC	Senior Seismic Hazard Analysis Committee
TI	Technical Integrator

This letter constitutes the report of the Participatory Peer Review Panel (PPRP) on Workshop No. 2 (WS-2), "Alternative Interpretations," for the referenced project. The workshop was held February 18–20, 2009, at EPRI headquarters in Palo Alto, California.

Following guidance described in the Project Implementation Plan for the PPRP[1], and consistent with the expectations of the SSHAC process[2], the PPRP participated in WS-2 in order to be informed and to review both procedural and technical aspects of the workshop. All eight members of the PPRP (J. P. Ake, W. J. Arabasz, W. J. Hinze, A. M. Kammerer, J. K. Kimball, D. P. Moore, M. D. Petersen, and J. C. Stepp) attended WS-2 and were able to fully observe all aspects of the workshop.

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[1] *Implementation of the PPRP's Participation in the CEUS SSC Project*: Written statement communicated by J. Carl Stepp to L. Salomone and the TI Team on June 16, 2008.
[2] Budnitz, R. J., G. Apostolakis, D. M. Boore, L. S. Cluff, K. J. Coppersmith, C. A. Cornell, and P. A. Morris, 1997. *Recommendations for Probabilistic Seismic Hazard Analysis: Guidance on Uncertainty and Use of Experts.* NUREG/CR-6372, Washington, DC, U.S. Nuclear Regulatory Commission.

General Observations

We observed that the workshop generally achieved the goal of compiling the range of basic data and proponent experts' interpretations that together constitute the current state of knowledge of the technical community, which the TI Team must evaluate for assessing the seismic source model for the CEUS region. We noted that potential field data remain to be compiled and incorporated into the TI Team's evaluation. We understand from the discussion of actions remaining to be taken prior to WS-3 that this important compilation and evaluation will be accomplished as part of planned working meetings of the TI Team prior to WS-3.

We observed that the skillful organization of the workshop stimulated lively inquiry and debate among proponent experts and members of the TI Team. The results will be useful for the TI Team in subsequent evaluations and assessments of uncertainties both in elements and parameters of the CEUS seismic source model. The questions provided by the TI Team to the proponent experts in advance of the workshop proved to be useful and effective. The questions focused the presentations by the invited experts and they stimulated interactions not only between the TI Team and proponents of specific hypotheses and interpretations of data but also among proponent experts.

Specific Comments and Recommendations

Provided below are comments and recommendations for follow-up actions by the TI Team for completing its evaluations and the CEUS seismic source model assessment. We note that many of these comments were touched on by Kevin Coppersmith in the final presentation of the workshop in which he described the actions that the TI Team already plans to take to complete its evaluations and the model assessment. If the TI Team successfully implements those actions, then most of the items described below would be adequately addressed.

1. *Need for a Tectonic Framework:* The range and complexity of alternative hypotheses and interpretations presented at WS-2 reinforce our previous recommendations concerning the need, first, to evaluate an overall tectonic framework for the study region and, second, to properly incorporate this evaluation into the CEUS seismic source model assessment. We consider a transparent evaluation of uncertainty to be a necessary element of the tectonic framework evaluation. The tectonic framework should have a universal role in the seismic source model assessment. This would establish the approach and scale for the seismic source model assessment, and it would provide a transparent, consistent assessment (weighting) of the complex alternative interpretations and hypotheses that constitute the current state of knowledge of the technical community.

We observed that some proponent interpretations regarding seismic sources and the origin of the seismicity in the CEUS pointed to the significance of evaluating the geological and seismological characteristics of the entire lithosphere—including the upper brittle crust, the ductile lower crust, and the upper mantle. Geological and geophysical evidence indicates that these various zones of the lithosphere are laterally heterogeneous, which could have profound impact on the seismicity of the brittle upper crust. As a result, we recommend that the TI Team should include the attributes of the entire lithosphere in their evaluation of the tectonic framework and their seismic source model assessment.

2. *Approach to Seismic Source Assessment and Scale:*

a) "Granularity" of Seismic Source Model (i.e., the scale of uniform scrutiny): During the workshop, geological structures ranging in scale from very local to continental-scale were described and discussed. We recommend that the TI Team provide early assurance, through assessment criteria that are explained and justified, that a systematic approach and procedure are being used for defining and assessing seismic sources in terms of scale. These assessment criteria will facilitate subsequent use of the model for a site-specific PSHA at any site in the study region. The assessment criteria should be at a level of detail that appropriately incorporates the state of knowledge of the sources and the current understanding of their inherent complexity. Using the criteria, one should be able to distinguish specific sources that have significant, identifiable, and relatively consistent seismic hazard potential. This systematic approach should be applied consistently across the study region.

b) Approach to Smoothing: We observed that there was little discussion or consideration of uncertainty involved in smoothing recorded seismicity versus deductive seismic source assessment, and there was no evaluation of alternative smoothing parameters. We consider this to be an important part of the assessment for the CEUS seismic source model and we recommend greater attention to the issue of smoothing and corresponding documentation.

3. *Integrated Evaluation of Paleoliquefaction and Interpretations of Paleo-Fault Displacements:*

a) Uncertainties in age dating: Multiple proponent experts discussed their interpretations of evidence for recent fault movement or the dating of geologic surfaces related to the formation of paleoliquefaction features. The proponents did not sufficiently describe the uncertainties in the age dating within their respective studies, and as such, the overall quality and reliability of this information is in question. The TI Team should strive to better understand the overall quality of these studies and develop a cohesive understanding of how the results can and cannot be used to establish recurrence information for various seismic sources. We recommend that the TI Team perform an integrated analysis of the body of paleoseismic investigation results in the vicinity of the New Madrid Seismic Zone using appropriate statistical methods. The study should incorporate uncertainty in the interpretations, to the extent that the uncertainty is described in or can be reasonably interpreted from the study results, in order to better correlate event times and rates of activity.

b) Size of paleoearthquakes: Paleoliquefaction is widely accepted to be a useful basis for assessing a seismic source model for the CEUS region; it is likely to gain even more importance in the future. The new approaches presented at WS-2 for assessing uncertainty in the observed data and interpretations and for using the interpretations for estimating the size of causal earthquakes have great promise and should be pursued in the future. At present, the uncertainties resulting from both the current and the newly presented methods are poorly constrained. We recommend that particular care be taken in estimating magnitude and in assigning corresponding uncertainties. We further recommend that the lack of evidence of paleoliquefaction not be used to determine maximum magnitude.

c) Time-dependent models: Given the importance of paleoliquefaction studies for evaluating the New Madrid and Charleston seismic zones, the TI Team should make a fundamental decision whether the incorporation and use of time-dependent recurrence models should be pursued. While this topic came up during the workshop, there was no discussion focused on what weight should be given to time-dependent recurrence models. It was not clear how the TI Team would assess the views of the technical community on this issue.

4. *Documentation of how alternative views are used:* At WS-2 a wide range of proponent views within the scientific community were presented about a number of important seismic source related issues. It is clear that, when assessed in detail, most CEUS locations are complex, with heterogeneities playing an important role in creating the data observed in the field. The TI Team needs to document how alternative views are accounted for in the assessment of the seismic source model to be presented in May 2009.

5. *The hypothesis of late aftershocks:* During the workshop, a proponent, using chiefly qualitative evidence, offered the view that much of the contemporary seismicity observed in the CEUS represents late aftershock activity of prior moderate to large earthquakes. If this view is used by the TI Team as a working hypothesis, it should first be critically examined. Standard seismological and statistical tools exist for verifying whether observed contemporary seismicity can plausibly be related to prior earthquakes, consistent with aftershock decay models such as the modified Omori model or Ogata's epidemic-type aftershock sequence (ETAS) model. Modern aftershock sequences in the CEUS, for example, can provide Omori parameters that can be used to test the hypothesis of long-lived aftershock sequences in the region.

6. *Temporal Clustering:* One uncertainty that was briefly discussed is whether the New Madrid seismic source zone is coming out of a cluster in terms of short repeat times for larger earthquakes. Some proponents cited GPS data that indicate little if any measurable strain in the New Madrid seismic zone region over the past 20 years, and one proponent presented geologic evidence that could be interpreted to indicate a history of clustering with very long geologic time intervals between clusters. The available data and overall lack of understanding of the mechanisms that may drive a clustering model for the New Madrid seismic source zone warrant caution about the supposition that a clustered sequence of higher recurrence behavior is ending.

7. *SSHAC process issues:* Under SSHAC guidelines, the makeup of the TI team has implications for ownership issues relating to the seismic source model and subsequent hazard results. As evident during the workshop, there are blurred boundaries between the TI Team specified in the CEUS SSC organization chart and the TI Staff. The working "TI

Team" appears to consider itself a larger group than listed in the Project Plan. The makeup of the "TI Team" in terms of individuals who will be responsible for ownership of the SSC inputs should be clarified.

We also note that in the SSHAC framework there conventionally is a distinction between the TI (or TI Team) and the hazard analyst. In the CEUS SSC project this distinction is blurred with Robin McGuire having a dual role as a member of the TI Team and as one of the key analysts responsible for computing hazard at seven demonstration sites. This is not a conflicting role and indeed adds strength to the project. We suggest, however, that this circumstance be explained in the final project report.

Do not hesitate to contact us if you wish to discuss any of our observations, comments, or recommendations.

Sincerely,

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Sponsor Representatives

4

September 18, 2009 Via e-mail

Lawrence A. Salomone
Savannah River Nuclear Solutions, LLC
Savannah River Site
Building 730-4B, Room 3125
Aiken, SC 29808

Dear Mr. Salomone:

Reference: *Central and Eastern United States Seismic Source Characterization for Nuclear Facilities:* Participatory Peer Review Report on Workshop No. 3.

This letter constitutes the report of the PPRP[1] on Workshop No. 3 ("WS-3") for the referenced project. The *Feedback* workshop was held August 25–26, 2009, at EPRI headquarters in Palo Alto, California. Following guidance described in the Project Implementation Plan for the PPRP[2], and consistent with the expectations of the SSHAC process[3], the PPRP participated in WS-3 in order to be informed and to review both procedural and technical aspects of the workshop.

Seven members of the PPRP (J. P. Ake, W. J. Arabasz, W. J. Hinze, A. M. Kammerer, D. P. Moore, M. D. Petersen, and J. C. Stepp) attended WS-3 and were able to fully observe all aspects of the workshop. The Panel's eighth member (J. K. Kimball) was unable to attend the workshop because of an unavoidable conflict but was provided with electronic copies of all presentations made at WS-3 together with other workshop materials to enable his participation in this review.

General Observations

The Project Manager and TI Team Leader worked together very effectively, executing their respective roles, and the TI team members were well prepared and effective in their respective contributions, all of which resulted in a successful workshop. The Panel commends the continuing effective leadership of the Project Manager and TI Team Leader and the professional preparation of the TI team members that were displayed in this workshop. We observed that the workshop accomplished the stated goals established for this important milestone of the CEUS SSC assessment.

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[1] Acronyms are explained in the Appendix.
[2] *Implementation of the PPRP's Participation in the CEUS SSC Project*: Written statement communicated by J. Carl Stepp to L. Salomone and the TI Team on June 16, 2008.
[3] Budnitz, R. J., G. Apostolakis, D. M. Boore, L. S. Cluff, K. J. Coppersmith, C. A. Cornell, and P. A. Morris, 1997. *Recommendations for Probabilistic Seismic Hazard Analysis: Guidance on Uncertainty and Use of Experts.* NUREG/CR-6372, Washington, DC, U.S. Nuclear Regulatory Commission.

WS-3 imposed a deadline for completing work tasks such as compilation of the seismicity catalog, the completion of a first-stage seismic source model for the CEUS termed "the SSC sensitivity model," and hazard sensitivity analyses based on the SSC sensitivity model. As such, WS-3 in effect was the TI Team's first opportunity to review and discuss its initial integrated evaluations of the range of the larger technical community's interpretations, although considering still incomplete data. The Panel recognizes that all of the evaluations reviewed in WS-3 constitute just a starting point for the TI Team to progressively build a seismic source model for the CEUS.

We observed that the informative presentations made by the TI Team Leader at the beginning and end of Day 2 effectively focused the Team's discussion on important evaluations remaining to be done going forward to support the SSC assessment. At the beginning of Day 2, Dr. Coppersmith summarized key conclusions he had extracted from the diverse feedback discussions during Day 1, and at the end of Day 2 he facilitated a lively discussion that actively engaged the TI Team in identifying additional feedback they required from the hazard analysts to effectively complete their SSC assessment. We found these discussions to be very informative and we consider them to have significant value for tracking how the TI Team is progressing with its implementation of the SSHAC guidelines.

Specific Comments and Recommendations

Provided below are comments and recommendations for consideration and follow-up action by the TI Team. The comments are not ranked in order of priority. Because the PPRP will not have another scheduled opportunity to comment on the CEUS SSC Project for a number of months, some of our comments extend beyond the content of WS-3.

1. *The Principal SSHAC Goal for a PSHA:* We appreciate Dr. Coppersmith's informative presentation of the background and context of the principal SSHAC goal for a PSHA: ***"to represent the center, the body, and the range of technical interpretations that the larger technical community would have if they were to conduct the study."*** His description of the historical context of the treatment of uncertainties in seismic regulation practice illustrates the critical importance to safety decision making of proper treatment of uncertainty, which formed the basis for the SSHAC's evolution of this important goal as well as the process that the SSHAC defined for achieving it. The SSHAC assessment process defines roles for participants as well as process activities that when properly implemented provide reasonable assurance that the goal for a PSHA established by the SSHAC is achieved. Based on Dr. Coppersmith's presentation and the follow-on discussions during the workshop, we concur that the assessment process activities being implemented for the CEUS SSC Project satisfy the SSHAC guidance. <u>We recommend that this important presentation be developed in the form of a white paper suitable for inclusion as a section in the project final report and that the white paper be distributed among the project participants, including the PPRP and sponsor technical representatives, for early review.</u>

2. *USGS Open-File Report on Maximum Magnitude:* Although briefly mentioned during the workshop, it was not clear to us how the soon-to-be issued USGS Open-File Report on estimation of maximum magnitude for seismic sources in the CEUS will be considered by the TI Team. <u>We recommend that the report be considered as part of the information base for assessment of the CEUS SSC model</u>.

3. *CEUS Earthquake Catalog:* The development and attendant analyses of the updated CEUS Earthquake Catalog are important contributions of the CEUS SSC Project that could potentially have high value for use in future PSHAs. The work summarized by Dr. Youngs on the catalog reflects a tremendous amount of work and represents a significant advancement in this important hazard data base. In order to be assured of the catalog's continuing high value, arrangements should be made to continually maintain this consensus catalog, and the analyses should be periodically updated as warranted by the addition of new data. Because multiple agencies and organizations will use the SSC Model, <u>we recommend that the Project suggest a plan for keeping the CEUS Earthquake Catalog current into the future as a companion product for use of the SSC Model</u>.

4. *Comments on Smoothing*:

   - We recognize that the concept of smoothing of seismicity is attractive from the standpoint of honoring the general location of past seismicity as well as allowing the TI Team a method to incorporate the uncertainty in the location of historical events. However, there needs to be careful consideration given to smoothing applied on a very small scale, especially in the "*b*-value". There are certainly implicit tectonic and/or structural assumptions associated with having the *b*-value changing over small distances. We believe a physical rationale should be supplied to support the Team's implementation of this approach. The examples shown at WS-3 utilized several different smoothing approaches but all were applied across very large regions or the entire CEUS. The use of a constant approach across the entire region may not be appropriate. It is not clear to us at this time whether that is the approach being planned by the TI team.

   - The smoothing methodologies discussed in the workshop are not described in any detail in the HID. It is not clear to us where the full documentation of the alternative smoothing procedures will appear. However, enough detail must be included in the HID to allow an experienced analyst to reasonably perform the hazard calculations for any point in the CEUS.

   - We consider the alternative procedures for smoothing seismicity that were presented and discussed during the workshop to be valuable tools for the TI Team to use to express uncertainty in its tectonic-based assessments of the spatial variation of seismicity. Accordingly, <u>we recommend that the use of these tools (i.e., the choice of smoothing method, the use of anisotropic kernels, priors on parameters, and so on) be justified in terms of the Team's evaluations of tectonic processes governing earthquake occurrence.</u>

5. *Independent Check*. The PPRP encourages the Project and the TI Team to perform the necessary independent checks of the analyses completed as part of developing the CEUS Earthquake Catalog and the Alternative Smoothing Procedures to ensure that this computational work is of the highest quality. It would be sufficient for the PPRP that this checking be performed using the TI Team participants so long as the "checker" is independent of the original work performed.

6. *Data Summary Table and Data Evaluation Table:* The **Data Summary Table** appears to be a highly valuable means of documenting the current range of the larger technical community's technical interpretations. We believe that the **Data Evaluation Table** also is an important part of the documentation of the CEUS SSC assessment that can serve the important need for transparent documentation of the TI Team's evaluations supporting its assessments of the center and body of uncertainty in the larger technical community's technical interpretations. The **Data Evaluation Table** also is potentially useful as a record of lessons learned and as such will be valuable in considering the need for and planning future investigations of the CEUS. This includes not only the utility of the various data most important in the SSC assessment, but also the nature and quality of data which imposed limitations on their use in identification and characterization of the seismic source zones. A summary of the various documents, their contents, and relationships would likely prove helpful and increase clarity for future implementation of the SSC Model. <u>We recommend that the Project and TI Teams give careful consideration to these important potential uses of the **Data Evaluation Table** as the assessment goes forward</u>.

7. *Sensitivity studies:* We consider the sensitivity studies to be highly valuable for providing insights and gaining understanding of the sensitivity of PSHA at a specific site to various elements of the SSC model. Additional sensitivity studies at a range of distances from the sources of frequent large earthquakes could add value for future use of the SSC model. However, <u>we recommend that the sensitivity studies not be used to justify devoting a reduced effort to assessing any fundamental element of the SSC model</u>. (See also Comment 11.)

8. *Lack of Consideration of Focal Depths:* There was a lack of discussion of earthquake focal depths in the workshop presentation on the updated CEUS seismicity catalog. This omission should be rectified. <u>Because focal depth is a potentially important contributor to our knowledge of seismic hazards, useful in characterizing and defining the limits of seismic source zones, and helpful in assessing potential ground motion, we recommend that greater consideration be made of this parameter in the CEUS SSC</u>.

9. *Plan for use of gravity and magnetic data.* Gravity and magnetic anomaly data and a variety of maps processed from these data are important in mapping largely hidden geological structures of the CEUS that may be useful in identifying seismic source zones and their geographic boundaries. We note that the contract for preparing the gravity anomaly data and associated maps has been let to the University of Oklahoma, but the contract has not been executed for preparing and processing the magnetic anomaly data. Furthermore, the Expanded Schedule for the CEUS project (7/14/09) set the completion date for both of these contracts as October 30, 2009, which we

learned at WS-3 has now been delayed until December 31, 2009. Despite the lack of the products from these contracts, the work of the TI team including the identification and delimiting of source zones must continue. As a result, we recommend that after December 31, 2009, once the new data sets and maps are available, a thorough review be conducted of decisions on identification and bounding of source zones that were reached prior to the availability of the gravity and magnetic anomaly data and related maps. This review may lead to modification of previous decisions.

10. *Preliminary Seismic Source Zones:* The seismic source zones used for the sensitivity evaluations and discussions during WS-3 are still tentative, but a cursory review of these zones raises several concerns:

- Where the evidence for the identified seismic source zones and their geographic limits are not described in referenced publications, we recommend that a comprehensive description be provided for the basis underlying the assessments of the source zones and their boundaries.
- It is unclear why certain regions were selected as "zones of elevated seismicity." What is their role? Why was the Clarendon-Linden region identified but not southeastern New York, the Niagara Peninsula, and other CEUS regions of above-normal seismicity in the historical record? We recommend that definitive criteria be cited for the selection of elevated seismicity zones.
- Earlier at Workshop No. 2, a scheduled presentation by Nano Seeber on seismicity and faulting in Ohio, Pennsylvania, New York State, and New York City was canceled and no similar presentation on this topic was made. Has anything been done to fill this void in the consideration and treatment of alternative interpretations? For example, a 2008 paper by Sykes and others[4] suggests an alternative view of seismicity in the New York City area that has not been cited in the Data Summary Table. We recommend that the list of alternative interpretations be updated to include those pertaining to the region that was to be discussed by Dr. Seeber at WS-2.
- There may be an inconsistency in the way that "extended zones" are used in the identification of seismic source zones. The area of the extended zone with normal faulting associated with the Iapetan Rift Margin is moved hundreds of kilometers west into the stable craton from the mapped rift margin. However, the limits of the seismic source zone associated with Iapetan (Cambrian) rifting in the midcontinent, including the New Madrid Rift Zone and its extensions, appear to be limited to mapped grabens without consideration of a bordering extended zone. Of particular note is the lack of an extended zone associated with the Grayville graben in southern Indiana. The "wide" interpretation of the seismic source zones is a step in the correct direction, but without further documentation on the factors defining the boundaries of this interpretation, it is difficult to determine if the broader extended zone is being captured in this interpretation. We recommend

[4] Sykes, L. R., Armbruster, J. G., Kim, W.-K., and Seeber, L., 2008, Observations and tectonic setting of historic and instrumentally located earthquakes in the greater New York City-Philadelphia area: *Bulletin of the Seismological Society of America*, v. 98, no. 4, pp. 1696–1719.

that the TI Team consider the possibility of an "extended zone" marginal to midcontinent seismic source zones.

11. *Pruning the Logic Tree and Need for Complete, Clear Documentation*. The use of an initial sensitivity model to inform evaluations to support the final model assessments is a sound and efficient approach. However, care must be taken to fully and clearly document the results of the sensitivity study, particularly as it impacts development of the final model and particularly in cases where alternative branches are removed. In a SSHAC level-3 study, the degree of credibility that the technical community grants the final model may be based heavily on the clarity and completeness of documentation and the ability of the technical community to understand the basis of assessments made by the TI team. In addition, robust documentation can more easily allow for the incorporation of new data and site-specific information into the model. In fact, specific guidance on how new or site-specific data should be evaluated could prove very valuable to the practitioner.

    The final model must represent the range of legitimate interpretations of the informed technical community in a scientifically defensible way. While some pruning of the tree based on the sensitivity study is desirable, we recommend that the sensitivity study not be used to trim branches that represented significant concepts or alternate hypotheses, even if the inclusion of alternate branches does not impact hazard. Some computational efficiencies could possibly be gained for the future hazard analyst if the study provides specific guidance as to the distance from the more significant sources at which the source no longer impacts hazard, and can be trimmed from the model.

12. *Evaluation and Assessment of Time-Dependent and In-vs.-Out-of-Cluster Models.* The approach to evaluating and assessing the time-dependent and in-vs.-out-of-cluster models need to be better explained. The time-dependent models require an aperiodicity parameter for use in the Brownian-Passage-Time calculations. Previous working groups in California determined a range of potential aperiodicity (or COV) parameters based on examining recurrence data with the associated uncertainties. It appears that the CEUS-SSC model may adopt this same range of parameters that was used in California. Since this is such an important parameter in determining the hazard, there should be some justification in the documentation regarding this choice considering the very different tectonic process that appears to be operative. The cluster models also need some further clarification. Sometimes the cluster models allow for activity in other nearby regions (migration of activity) when the primary source turns off and sometime they don't. In addition, different cluster-model weights for the Cheraw and Meers faults have been applied. It would be important to understand the basis for these weights and all other weights associated with these temporal models.

13. *Sanity Check for Seismic Sources Defined by Paleoliquefaction:* We recommend that the TI Team make a sanity check for those seismic sources defined by paleoliquefaction—that is, whether the source boundaries make sense, given the assumed magnitude versus area (or length) using relationships between magnitude and the maximum distance to liquefaction. For example, the magnitude-versus-area

relationship for the CEUS results in an assumed rupture length of ~21 km for M = 6.7. For the currently defined Charleston source options, can ruptures at the far ends of the source (e.g., the southeastern or northwestern corners of the large zone shown on Figure 15 in the HID) explain the observed paleoliquefaction at the opposite end of the source? The TI Team may need to factor in how they are modeling the recurrence of the source relative to the paleoliquefaction—but they need to make sure that the sources for the paleoliquefaction regions do not become too large when considering how rupture length is being modeled relative to paleoliquefaction.

14. *Integration with Ground-Motion Prediction Equations*. During the workshop there was discussion of the impact of the choice of ground-motion prediction equations on hazard results, particularly for sites in areas such as the Gulf region where the initiating seismic sources may be in other types of seismic-wave attenuation domains. It may be beneficial to consider recommendations to the practitioner with regard to the ground-motion prediction equations when different seismic-wave-propagation domains are involved in the PSHA.

15. *Need for Uniform Rigor in Assessing Rate-Information Inputs.* Examination of the SSC Sensitivity Model shows an apparent unevenness in rigor applied to assessing rate-information inputs in terms of significant figures and assessed distributions. This stands in contrast to the systematic rigor applied, say, to recurrence modeling. Because of the fundamental importance of rate information to hazard, we recommend careful uniform attention to the assessment of rate inputs. Such assessments should meet the basic expectations of a normative expert in a PSHA if one were overseeing the assessments.

16. *PPRP Observers in Remaining Working Meetings*. Under the CEUS SSC Project Expanded Schedule (dated July 14, 2009), the next face-to-face meeting of the PPRP with the TI Team will be in March 2010. Because this will be at a relatively late stage of shaping a near-final (albeit still "preliminary") SSC model, we recommend that the Project Manager facilitate participation of at least two PPRP members as observers in the TI Team's Working Meeting #6 (October 20–21, 2009) and Working Meeting #7 (January 12–13, 2010).

Do not hesitate to contact us if you wish to discuss any of our observations, comments, or recommendations.

Sincerely,

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Copy: PPRP Members
Sponsor Representatives

APPENDIX

Acronyms

CEUS	Central and Eastern United States
COV	Coefficient of Variation
EPRI	Electric Power Research Institute
HID	Hazard Input Document
PPRP	Participatory Peer Review Panel
PSHA	Probabilistic Seismic Hazard Analysis
SSC	Seismic Source Characterization
SSHAC	Senior Seismic Hazard Analysis Committee
TI	Technical Integrator
USGS	U.S. Geological Survey

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April 7, 2010 Via e-mail

Lawrence A. Salomone
Savannah River Nuclear Solutions, LLC
Savannah River Site
Building 730-4B, Room 3125
Aiken, SC 29808

Dear Mr. Salomone:

Reference: *Central and Eastern United States Seismic Source Characterization for Nuclear Facilities:* Feedback on CEUS SSC Preliminary Model.

This letter constitutes the report of the PPRP[1] ("the Panel") providing feedback on the CEUS SSC Preliminary Model. Our feedback is based on a one-day *PPRP and USGS Briefing Meeting* ("the Briefing Meeting") held on March 24, 2010, at EPRI headquarters in Palo Alto, California, and on materials provided to us beforehand. These materials included Draft Data Summary and Data Evaluation Tables, a Hazard Input Document for the CEUS SSC Preliminary Model, and a Draft CEUS SSC Report Outline.

All eight members of the PPRP (J. P. Ake, W. J. Arabasz, W. J. Hinze, A. M. Kammerer, J. K. Kimball, D. P. Moore, M. D. Petersen, and J. C. Stepp) attended the Briefing Meeting. On the following day (March 25), all eight members of the PPRP met privately for a half day to discuss observations and plan this feedback report.

General Observations

The Briefing Meeting was well organized, the TI team members were well prepared, and the Team members' respective presentations effectively stimulated discussion, all of which resulted in a successful meeting. The atmosphere of open discussion that prevailed throughout the briefing significantly enhanced the Panel's participation. We observed, however, that several elements of the model had not reached the stage of completeness of analysis and assessment that we had expected. These will be addressed more completely by Specific Comments.[2]

We commend the Project Manager and TI Team leader for their continuing effective leadership of the Project. This leadership continues to stimulate and maintain productive interactions among TI Team members and between the Project Team and the Panel. Actions required to complete the Project identified in "Path Forward" discussed at the end of the meeting appear to be well formed and achievable. The Panel noted, however, that the actions do not include a feedback interaction following completion of the Panel's review of the Draft Project Report to be delivered on September 1, 2010. <u>We recommend</u>

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[1] Acronyms are explained in the Appendix.
[2] As in earlier PPRP reports, recommendations are underlined for emphasis and ease of recognition.

that a process for resolving the Panel's comments and recommendations aimed at completing the Final Project Report be identified and scheduled.

Specific Comments and Recommendations

Provided below are comments and recommendations for consideration and follow-up action by the TI Team. The comments are not ranked in order of priority. We realize that this report is intended to represent the Panel's last formal opportunity to comment on the CEUS SSC Model before it moves ahead from "Preliminary" to "Final." However, because parts of the Model are still incomplete, some additional interactions between the TI Team and the Panel are desirable in the coming weeks to ensure the Panel's "buy-in" to the Final Model.

Among the diverse comments and recommendations contributed by the Panel members, two common themes will become apparent:

- Part of the Panel's responsibility in reviewing the Draft Technical Report in August will be to address the clarity and completeness of documentation of the SSC. So in this document we have included early advisories about potentially confusing terminology, missing pieces, and some expectations of what needs to be documented.
- The Master Logic Tree has progressively been contracted to characterize seismic sources in the CEUS in a way that eliminates elements that, in the judgment of the TI Team, do not contribute significantly to the resulting hazard—thus providing a simpler conceptual framework and allowing efficient computation of hazard. Where credible views of the Informed Technical Community ("ITC") do not appear to be included in the Master Logic Tree, there is a clear burden on the TI Team to address and document how those views have been considered and duly accounted for in the Model.

Because the Master Logic Tree includes major changes in characterizing earthquake potential in the CEUS, compared to past PSHAs, the Panel believes that the TI Team will need to be aggressive and pre-emptive in explaining these changes.

1. *Availability and completeness of work products for review:* The review period for the final report documentation is very short. It is critical that the PPRP be provided a complete final draft on August 2 so that Panel members can submit a set of complete and meaningful review comments. (Because of schedule constraints, some PPRP members need to begin their review immediately upon receipt of the Draft Technical Report on August 2.) In addition, the PPRP would find it beneficial to evaluate certain products that are finalized (after April 30) and at an early stage prior to the submittal of the Draft Final Project Report on August 2. Of particular interest would be the Mmax distribution and summary information used to develop the distribution for each seismic source zone (largest observed event, N, prior). Summary rate maps for individual source zones would also be useful for PPRP assessment prior to August 2.

2. *Differences Between Seismic Source Zones:* The TI Team stated that the conceptual approach used to define distributed seismic sources, specifically those defined on a seismotectonic basis, focused on four key factors: (1) earthquake recurrence rates; (2) maximum magnitude; (3) expected earthquake characteristics; and (4) tectonics. The Data Evaluation Tables provide information on some of these factors indicating some differences between seismic source zones. However, because the TI Team had not completed development of the final earthquake catalog, implementation of the approach to defining maximum magnitude and spatial smoothing of earthquake recurrence rates for each of the distributed seismic sources had not been finalized. As a result it is difficult for the PPRP to have high confidence that the preliminary seismic source characterization model captures the center, body, and range of the ITC. While some significant differences between distributed seismic sources may be anticipated (e.g., Mmax differences between Non-Extended crust relative to differences between the Illinois Basin Extended Basement (IBEB) and Mid-continent Crust seismic sources), it is not intuitive that such differences will fully support the seismotectonic zones that subdivide the Mesozoic Extended crust, and as a result the conceptual approach used to define distributed seismic sources. The PPRP had expected that the Hazard Input Document would have included information to justify the approach being used. The PPRP recommends that the TI Team provide this information for PPRP review concurrent with providing hazard input to the project's hazard analyst.

   We recommend the following with respect to maximum magnitude: (1) The TI Team should describe how paleoliquefaction evidence was used to define seismic source likelihood functions. (2) The TI Team should provide specific likelihood functions and posterior distributions for each of the Hybrid and Seismotectonic source zones, for each of the prior assumption cases considered.

   With respect to the application of the smoothed seismicity approach, we recommend that the PPRP be provided with sufficient activity rate maps for each hybrid and seismotectonic source zone (such as for M = 5) to appreciate the significance of recurrence rate differences between seismic sources.

3. *Organization of the Logic Trees:* We note that there are significant changes in the organization of the logic trees of the current CEUS SSC from previous PSHAs of the region. The Panel is generally supportive of these changes, but we recommend that the documentation of the design of the logic trees include a clear and detailed explanation of the reasoning involved in making the changes from previous studies. For example, the magnitude of the largest observed events (both historical and inferred from paleoliquefaction) is a major factor in isolating source zones for detailed characterization (the RLMEs), while regions of moderate to intense earthquake activity without moment magnitudes that exceed mid-5 values such as eastern Tennessee, northeastern Ohio, the Humboldt fault zone (Nemaha Ridge), and the Ramapo fault that have been included in earlier studies are not called out as specific seismic zones.

   Furthermore, we have the sense that some lines of evidence used by the ITC in identifying and characterizing the seismic source zones of the CEUS have not received the attention in the current study that they have been given by some members of the ITC and in former PSHAs of the region. For example, contrary to the present study, some investigators place considerable emphasis on recent strain (GPS) measurements and others give considerable weight to tectonic features of the CEUS that have been mapped directly or indirectly in the identification and characterization of seismic source zones. <u>The project would be well served by documented justification of the reasoning supporting minimization of these elements by the TI team in their decisions—and we recommend that the Draft Technical Report include such documentation</u>.

Lastly, it would be helpful if the TI Team paid particular attention to, and provided an appropriate level of discussion about, areas toward which the technical community is moving. For example, the use of strain rates is an area that will likely expand in the future. So, although these data may not have had a significant impact at this time, it is important for the study documentation to fully discuss the data available and how it was treated now.

4. *Clarity of terms in the Master Logic Tree:* In labeling and discussing branches of the Master Logic Tree, clarity can be improved. The TI Team may want to consider another term for "hybrid" at the very front end of the tree. The term is a vestige from labeling a former three-branch node (now collapsed to two), and many readers would expect a hybrid branch to be a combination of two other branches. Referring to "zoneless" seismicity sources is confusing insofar as these sources lie within demarcated areas of differently affected Mesozoic crust. <u>In general, we recommend that the TI Team examine jargon that has evolved in their internal discussions and evaluate whether terms used in their working discussions now help or hinder clear communication to others</u>. Labeling of Iapetan Extended/Non-extended as a different case from Mesozoic Extended/Non-extended may be confusing to those unfamiliar with the arcane term "Iapetan." Labeling of "Inter-event Times" as a Recurrence Method for the RLME logic tree branches is confusing because the method used in fact involves the use of both inter-event and event-interval paleoearthquake data. In source geometry branches for RLME sources (e.g., Figures 15 and 17 in the HID), "extended trace" should be used instead of just "extended" to avoid confusion with crustal extension.

5. *Assigning Weights to the Logic Trees:* As mentioned during the Briefing Meeting, <u>we recommend that TI Team describe the overall approach to assigning weights to the logic trees, and that this written description be included in the Draft Technical Report</u>. In some cases these weights represent an explicit statistical assumption or distribution while in other cases these weights are the TI's evaluated judgment of the informed technical community views. In these cases it would be useful to have an understanding of how the TI assigned weights from a generic perspective.

6. *Spatial Smoothing:* Conceptually, the PPRP endorses the direction the TI team is taking with respect to spatial smoothing approach and implementation. However, thus far there has been no written documentation provided to us that: (1) describes the

method in detail as it is being applied in this project, (2) describes the bases for choices of parameters of the model, or (3) justifies reliance entirely on the penalized likelihood method. We recommend that the eventual documentation not only describe the adopted technique in detail but also document any perceived advantages of this technique relative to simpler kernel techniques. Some discussion of "floor" values in regions of very low rates should also be included. It would benefit our review to receive this section for review as soon as is practicable.

7. *ALM Area Characterization:* The TI Team presented its independent evaluation of published field data, including original field copies of trench logs and field photographs of features that Randy Cox had described in WS #2 and interpreted as liquefaction features. "Project-specific *Criteria for Identifying Earthquake-Induced Liquefaction Features Used in Development of Paleoearthquake Chronologies"* were used to perform the evaluation. Discussions during the TI Team's presentation identified that these criteria are current state of practice for determining whether observed features are earthquake-induced liquefaction features or properly explained as depositional or due to another geologic process. First, given that the criteria are identified as representing the state of practice of the informed technical community, the "project-specific" qualification is confusing and misleading. We recommend that these criteria be clarified or removed.

   Second, the Team's evaluation appears to reasonably support their conclusion that the features do not satisfy the informed community's criteria for reasonably assessing that the features are earthquake-induced. However, this evaluation appears inconsistent with the highly qualified ALM area model assessment conclusion: "the paleoliquefaction data from the ALM region are immature and highly uncertain and, at the present time, do not provide strong evidence for a source of RLME in the ALM area." This highly qualified conclusion clearly conveys a level of uncertainty that would support giving some assessed weight to an interpretation that the ALM should be modeled as a RLME. Perhaps what is meant is that the information in the current dataset, when assessed using the criteria for determining whether features are indeed liquefaction features consistent with current state of practice, does not support the interpretation that these are paleoliquefaction features. We strongly support the TI Team's decision, as stated during the discussion, to revisit and clarify this assessment—and we recommend that the TI Team do so.

   To support this last point, it would be helpful if the discussion of the criteria include not only what the specific criteria are but the scientific and technical basis of each criterion. This would support not only this assessment, but would provide a valuable tool for projects in the future when datasets are not clear, or even as new information becomes available in the ALM area.

8. *Data Summary and Evaluation Tables:* The Panel finds the Data Summary and Data Evaluation tables to be highly important in supporting and annotating the decisions regarding identification and characterization of the seismic source zones of the CEUS. Every effort should be made to include in these tables documentation for the current,

complete center, body, and range of the ITC by seeking feedback from appropriate current investigators prior to finalizing the tables. A full description is warranted of the procedures used in selecting material for the Data Summary table. Additionally, both tables are essential in reviewing the basis for, and the assessments regarding, seismic source zones—but there remains the need for a full narrative that will allow the user of the CEUS SSC Model to completely understand the data evaluations that support the assessments made by the TI Team. We recommend that the Draft Technical Report include such a full narrative for the Data Summary and Data Evaluation tables.

9. *Earthquake Model for RLME Sources:* In the Master Logic Tree, full weight is given to the maximum-moment model as the "Earthquake Model" applicable to RLME seismic sources. In the western U.S., where detailed data are available to assess earthquake behavior on major active faults, increasing attention is being given to a variable-slip model—which allows the slip, rupture location, and length to change with each earthquake (see, for example, K. Scharer, "Changing views of the San Andreas fault": *Science*, vol. 327, 26 February 2010, p. 1089–1090). To defend a weight of 1.0 for the maximum-moment model vis-à-vis the ITC, the TI Team clearly has to demonstrate (if correct) that the choice is one of simplified methodology, which considers and accounts for other credible models of earthquake behavior.

10. *"Other" Reviews of the CEUS SSC Model:* At the Briefing Meeting, the Project Manager showed tracking milestones including "Review of Draft [Technical] Report by PPRP, USGS, and Sponsor Reviewers—August 2, 2010 to September 1, 2010." It seems appropriate to call attention to the following statement in *Implementation of the SSHAC Guidelines for Level 3 and 4 PSHAs—Experience Gained from Actual Applications* (USGS Open-File Report 2009-1093, p. 35:

    > The PPRP is the only legitimate review panel recognized by the SSHAC Guidelines; there is only one PPRP for a SSHAC Level 3 or 4 study, and its sole and unique obligation is to provide on-going commentary to TI/TFI as the project develops. All other "review panels" should be considered as observers, unless the project leadership agrees in advance to a different role/format for them.

    The Panel recognizes the prerogative of the Project Sponsors to request comments on the Draft Technical Report from other parties of its choosing for its own purposes. However, we recommend—and believe it is essential—that any comments on the CEUS SSC Model provided to the TI Team that result from a TI Team request be made available to the PPRP for its awareness and consideration.

11. *Comments on Draft Report Outline:* We recognize that the Draft Report Outline dated March 9, 2010, is preliminary (in its present form, the outline is a mix of topical phrases and explanations of what specific subsections will contain). As such, a detailed review is premature, and we only offer some general comments (not exhaustive). We recommend that the PPRP have another opportunity to review the

Draft Report Outline after the TI Team finalizes it. This could avoid some late-stage criticisms of the content of the Draft Technical Report during our August review.

- Because the Project Report will become a legal document with the authority of a regulatory guide, clarity is essential. As examples: do not use "seismicity catalog" for "earthquake catalog"; "event" for "earthquake"; "paleoseismicity" for "paleoearthquake"; "process" for "assessment."
- In providing guidance for future applications of the CEUS SSC Model, adhere to specific terminology of "refinement" for site-specific applications and "revision" for future updates of the Model.
- In section 2.1, consider a discussion of (1) the fundamental goal of safety regulation, i.e., "reasonable assurance based on current knowledge" and (2) the role of technical regulatory guidance for reasonably assuring the goal of safety regulations has been met.
- List of Acronyms needed.
- Need Glossary of key terms (e.g., seismic source, Conceptual SSC Framework, SSC Model, etc.) It will be essential to define "Conceptual SSC Framework" and its role in the assessment process. How does it support or frame the assessment? What weight is it given?
- Labeling section 2, which deals chiefly with process, as an apparent primary "Methodology" section is misleading. Either organize explanations of technical methodology into one section or guide the reader (as in the label for section 3.3) by prominently labeling, "Methodology for __________."
- Make the outline of sections/subsections reader-friendly. For example, the number of subsections in section 4 is too large. Subsections 4.5 and 4.6 appear to be distinct from earlier parts of section 4 (general characterization of seismic sources) and can be broken out into a separate section containing descriptions of specific sources in the logic tree.
- Missing discussion of GIS database, both under section 3.2 and in the Appendices.
- Missing discussion of metadata.
- In section 6, a subsection is needed relating to consideration of new data and/or information and determining when the SSC Model requires revision (updating).
- Declustering of the earthquake catalog was undertaken using methods described in the original EPRI study documentation. Because that study is not broadly accessible, it is important that a full discussion be included in the documentation. It should be complete enough to allow for members of the technical community to understand and repeat the work.
- Section 1.2.2 is currently titled "Conducted using SSHAC Level 3 approach." This section should discuss not only how the project met the standards for a level 3, but also WHY a level 3 was conducted instead of a level 4. It may also be useful to

discuss how this decision was made and what have been the benefits and drawbacks.

- Perhaps the PPRP review documents should be included as an Appendix. The form of the final report has not been clarified; but it could be a summary letter report that has the previous comment sets as attachments.

Closing Comment

The Panel is aware that, at the request of the Project, the USGS is preparing to deliver to the TI team independent feedback on the Project Earthquake Catalog and on the draft HID focusing on completeness of datasets, models, and tools being used in the CEUS SSC assessment. Based on telephone discussions between the PPRP and the Project Team on April 5, 2010, we understand that the TI Team will evaluate the USGS comments and will consider them in its final assessment and in its development of the final HID for the Project. We further understand that the TI Team's evaluation of the USGS comments will be finalized as part of its final working meeting scheduled to be held on April 12-13, 2010, in which one or more PPRP members will participate as observers.

Note: We may choose to provide additional PPRP feedback following the April 12-13 working meeting and receipt of information relating to completion of the TI Team's evaluation of the USGS comments and any modifications the Team may make to its datasets, models, or tools as a consequence.

Please contact us if you wish to discuss any of our observations, comments, or recommendations.

Sincerely,

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APPENDIX

Acronyms

ALM	Arkansas-Louisiana-Mississippi
CEUS	Central and Eastern United States
EPRI	Electric Power Research Institute
GIS	Geographic Information System
GPS	Global Positioning System
HID	Hazard Input Document
IBEB	Illinois Basin Extended Basement
ITC	Informed Technical Community
Mmax	Maximum Magnitude
PPRP	Participatory Peer Review Panel
PSHA	Probabilistic Seismic Hazard Analysis
RLME	Repeated Large Magnitude Earthquake
SSC	Seismic Source Characterization
SSHAC	Senior Seismic Hazard Analysis Committee
TI	Technical Integrator
USGS	U.S. Geological Survey

October 4, 2010 Via e-mail

Lawrence A. Salomone
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Dear Mr. Salomone:

Reference: *Central and Eastern United States Seismic Source Characterization for Nuclear Facilities:* PPRP Review Comments on CEUS SSC Draft Report of July 31, 2010

This letter constitutes the report of the PPRP[1] ("the Panel") providing review comments on the *Central and Eastern United States Seismic Source Characterization for Nuclear Facilities, Draft Report, July 31, 2010*.

All eight members of the PPRP (J. P. Ake, W. J. Arabasz, W. J. Hinze, A. M. Kammerer, J. K. Kimball, D. P. Moore, M. D. Petersen, and J. C. Stepp) participated in this peer review through written input, e-mail exchanges, and teleconference discussions. The General Comments and the Specific Comments (explained below) represent the consensus views of the Panel, arrived at through a process deliberately independent of any other review.[2]

Peer Review Responsibility of the PPRP

The Draft Report delivered to the PPRP was accompanied by a transmittal letter (dated July 31, 2010) signed by K. J. Coppersmith and L. A. Salomone, indicating that the Panel's review should focus on:

1) Identifying any data, models, methods that exist within the technical community that the TI Team may not have considered and that could substantively impact the result of the assessment
2) Reviewing the evaluation process in workshops and working meetings and offering advice regarding hypotheses and views put forward by members of the technical community
3) Reviewing the technical bases provided by the TI Team in the report, thereby substantiating their integration process of capturing the center, body, and range of the informed technical community

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[1] Participatory Peer Review Panel. For other acronyms, see the list of acronyms contained in the CEUS SSC Draft Report.

[2] A submission of review comments by the USGS, transmitted on August 30, 2010, was copied to W. J. Arabasz, co-chair of the PPRP. However, the review comments were not shared with the PPRP and were not considered by Dr. Arabasz in his contributions to the PPRP review. Input from Dr. J. Ake (NRC), Dr. A. M. Kammerer (NRC), and Dr. M. D. Petersen (USGS), represented their independent views as members of the PPRP.

Further, the PPRP was instructed that it should:

- Validate that there is reasonable assurance, based on a preponderance of evidence, that the views of the informed technical community have been properly captured in the final seismic source characterization model
- Provide assurance that uncertainties have been properly considered and incorporated
- Consider whether the guidelines for a SSHAC Level 3 assessment have been properly considered and incorporated

Additionally, the SSHAC guidelines require the PPRP to provide assurance that "the documentation of the study is clear and complete" (SSHAC, 1997, p. 48).

Format of Review Comments

For each chapter of the CEUS SSC Draft Report, we have organized our review comments into three categories: **General Comments** (numbered for tracking), **Specific Comments** (also numbered for tracking), and **Comments by Section**. The third category generally includes comments aimed at clarity and completeness of documentation; typographical errors are also noted. For the front matter and appendices, the categories may differ slightly but typically include **General Comments and Comments for Clarity and Completeness**.

Herein, we do not use the convention, adopted in earlier PPRP reports, of underlining specific recommendations for attention and response by the TI Team. Our review comments, particularly the *Specific Comments* (and some of the *General Comments*) for the main body of the report, inherently involve recommendations and suggestions that we believe are important to arrive at a final report that the PPRP can endorse. In many of our review comments, replacement text is liberally suggested. These should be viewed as suggested alternative wording for improved clarity—not a dictation of how the TI Team should word its report.

Please contact us if you have questions or need more information regarding the PPRP's review comments.

For the PPRP,

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PPRP REVIEW COMMENTS

Central and Eastern United States
Seismic Source Characterization for Nuclear Facilities
Draft Report, July 31, 2010

Format for Numbered Comments: **X Y-N**

X	Type of Comment:	G (General) or S (Specific)
Y	Part of Report:	1, 2, . . . , 11 (Chapter 1, 2, . . . , 11) A, B, . . . , K (Appendix A, B, . . . , K) Acr = Acronyms ES = Executive Summary FM = Front Matter
N	Sequence Number:	1, 2, . . . , n

Key to Characterization of Numbered Comments

CBR	Center, body, range (appropriate representation of the community distribution)
CC	Clarity and completeness of documentation
DMM	Data, models, and methods
NAR	No action required
SSHAC	SSHAC guidance
U	Uncertainties (proper consideration)

FRONT MATTER

EXECUTIVE SUMMARY

General Comments

G ES-1. **(CC)** The Executive Summary seems generally complete (see Specific Comment below). However, the PPRP's extensive comments on the body of the CEUS SSC Project report may lead to significant changes in the report. The Project Team will likely need to revise the Executive Summary to properly describe any such changes.

Specific Comments

S ES-1. **(CC)** *Emphasis on the Importance of Results Described in Chapters 8 and 9*

The critically important results described in Chapters 8 and 9 offer potentially valuable insights that could serve as guidance for future users of the CEUS SSC Model. Consequently, the significance of these results should be properly described in the Executive Summary. Specifically with regard to the results presented in Chapter 8, the differences in the CEUS SSC model, the USGS model, and COLA models that primarily cause the differences in computed hazard results at the seven test sites should be described in the Executive Summary. Similarly, the important results presented in Chapter 9 likely will have far reaching impact on resolution of seismic safety issues as well as on the formulation of criteria for updating the CEUS SSC model in the future as new data are acquired and scientific knowledge evolves. A perspective summary of this result and its potential value for regulatory decision-making should be included in the Executive Summary.

Comments for Clarity and Completeness

- p. v, par. 1, line 9.: Awkward word string — "Office of the Chief of the [sic] Nuclear Safety and the Office of Nuclear Regulatory Research of the Nuclear Regulatory Commission (NRC)"

  [Reviewer's note: The affiliations listed do not exactly match those in the Acknowledgements (e.g., in the Acknowledgements, the Office of the Chief of Nuclear Safety is part of DOE).]

- p. v, par. 2, line 8: Poor syntax and long awkward sentence —

  > The methodology for a SSHAC Level 3 Study as applied for the CEUS SSC Project is explained in the SSHAC report (Budnitz et al., 1997), which was written to discuss the evolution of expert assessment methodologies conducted during the previous three decades for purposed of probabilistic risk analyses.

Suggestion:

> The methodology for a SSHAC Level 3 Study, an important framework for the CEUS SSC Project, is explained in the SSHAC report (Budnitz et al., 1997). The SSHAC report was written to discuss the evolution of expert assessment methodologies conducted during the previous three decades for purposes of probabilistic risk and hazard analyses.
>
> [Reviewer's note: Prior analyses not only of risk but also hazard (e.g., EPRI-SOG and LLNL) were clearly considered by SSHAC.]

- p. v, par. 2, last sentence: As the only citation appearing in the Executive Summary, "(Coppersmith et al., 2010)" is unnecessary and can be deleted.
- p. v, par. 3, first sentence: The sentence structure including "then" and "finally" in this topical sentence misleadingly suggests a first-order summary of what the CEUS SSC report contains. Suggestion: "The CEUS SSC report presented here includes a review of the significant studies and case histories that led to the development of the SSHAC guidelines as well as projects conducted up to the present that have subsequently implemented those guidelines." [Original wording referring to "the SSHAC development process" is unclear and easily deleted.]
- p. v, last sentence (continuing onto p. vi): The important claim, beginning with "Based on the evidence presented in this report," warrants careful attention. Rewording should be consistent with any adopted changes in the second paragraph of Chapter 2 on p. 2-1 and the "Conclusion" paragraph of section 2.1.2.3 on p. 2-23 (see review comments for Chapter 2).
- p. vii, last paragraph, first sentence: Large-magnitude earthquakes are defined as ($\mathbf{M} \geq 6$). In the text (e.g., p. 4-14, 6-1), large-magnitude is defined as ($\mathbf{M} \geq 6.5$).

ACKNOWLEDGEMENTS

It is our understanding that the *Acknowledgements* were carefully vetted by the Project Manager in consultation with the named agencies and individuals. So we refrain from offering any comments on wording.

The Project Team may wish to consider using the more conventional spelling of "Acknowledgments" (preferred in American English) vs. "Acknowledgements" (preferred in British English).

SPONSORS' PERSPECTIVES

On p. xiii, par. 1, first sentence: We suggest changing "Probabilistic seismic hazard assessment (PSHA)" to Probabilistic seismic hazard analysis" to conform to the list of Acronyms and to usage of PSHA elsewhere in the report.

ACRONYMS

General Comments

G Acr-1. (CC) The inclusion of a list of acronyms is good practice, both for complete documentation and to help the reader. A decision needs to be made whether all acronyms, except for conventional abbreviations such BC or the designation of units, should be explained when first presented in the text (desirable). This is inconsistently done in the draft report. Note that many acronyms included in the appendices do not appear in the list.

Specific Comments for Clarity and Completeness

Identified corrections and additions to the list of acronyms are presented below. Not all missing acronyms may have been identified. We leave that to the technical editing of the final report.

Corrections

EPRI-SOG	Electric Power Research Institute- ~~Seismic~~ Seismicity Owners Group
SHmax	maximum horizontal ~~shortening~~ principal stress

Missing Acronyms and Terms (not exhaustive)

AFE	annual frequency of exceedance (p. 1-4)
ANSS	U.S. Advanced National Seismic System (p. 3-3)
BPT	Brownian passage time (p. 4-20)
CERI	University of Memphis Center for Earthquake Research and Information (p. 3-4)
ISC	International Seismological Centre (p. 3-3)
NEDP	_____ (p. 3-5)
NEIC	USGS National Earthquake Information Center (p. 3-1, 3-4)
NSHMP	USGS National Seismic Hazard Mapping Project (p. 1-3)
P_a	Probability of Activity
PDE	Preliminary Determination of Epicenters (p. 3-1)
SUSN	Southeastern United States Seismic Network (p. 3-1)

CHAPTER 1 — INTRODUCTION

General Comments

G 1-1. (NAR) This chapter is well structured and introduces the reviewer to all elements of this complex project report. The chapter usefully discusses the need for community-based studies and comparisons with other approaches. Here and throughout this Draft Report, we recognize the great effort that has gone into the writing and documentation, and we commend the TI Team for its diligent efforts to distill and report a massive amount of detail. Mindful of the criteria we have been given to guide our critical review (see cover letter), we proceed to specific comments.

Specific Comments

S 1-1. (SSHAC) *Justification for Using the SSHAC Level 3 Assessment Process*

A key issue related to the selection of the SSHAC assessment level, specifically a Level 4 assessment versus Level 3, relates to the ability of the selected experts to act as impartial evaluators—the perceived higher level of assurance provided by Level 4 comes with significant additional costs, some of which are associated with making sure the use of experts or expert teams as impartial evaluators is being done properly. The Hanks (2009) Open File reports notes, appropriately, that most geosciences experts are quite inexpert in one or more of several matters important to higher level SSHAC assessments. But generally, they are not experienced evaluators of uncertainty, given competing hypotheses and interpretations that require evaluation using diverse sets of geological, geophysical, and seismological data. This particular point needs to be brought out more in the draft report, both here and in Chapter 2.

Experience has shown, even for some projects that have claimed SSHAC Level 4 assessment, that the actual success of experts or expert teams as evaluators has been limited. At the present time for the CEUS it may be that the technical community is best able to implement a SSHAC Level 3 assessment (high confidence that a TI Team can be selected to act as impartial evaluator) versus a Level 4 assessment. While some could view this point as less important, it is a key point that those outside the project (other agencies, ACRS, others) must appreciate and understand.

Based on cumulative experience using the SSHAC Methodology, particularly given the time constraints, we have confidence that this project can be successfully implemented using a SSHAC Level 3 assessment versus Level 4.

S 1-2. (CC, SSHAC) *Clear Communication is Essential: Chapter 1 and Entire Report*

Keeping in mind that words are the stuff of thought and that clear communication of thought is essential, especially for regulatory guidance documents intended for long term use, usages of words and terms must clearly and accurately convey the concepts that are being described. It is also essential that the words and terms be used in their proper meaning consistently throughout the report.

The practice of using nuanced words as synonyms contributes to a lack of essential clarity. For example, throughout Chapter 1 the word “study” is used interchangeably in multiple meanings.

In most instances "study" is used to mean either "project" or "assessment"; it is used in its proper meaning in only a few instances, for example in subsection 1.4.4.4. Serious miscommunication will result from incorrectly using the word "study" to convey the activities that constitute a SSHAC assessment process—or that constitute a "SSHAC Study Level 3 Approach" or a "SSHAC Study Level 3 Methodology," which are alternatively used when referring to the SSHAC assessment process.

The word "study" does not properly communicate the complex activities and processes that constitute the SSHAC Methodology or SSHAC assessment process. These activities together constitute a structured assessment process that involves compilation of the state of scientific and technical knowledge, compilation of datasets, evaluations of state of practice, and finally, assessments that represent the integrated knowledge of the scientific community and the community's knowledge uncertainty as represented in the logic tree of the SSC model.

It should be kept in mind that the SSHAC assessment process is accepted by the Nuclear Regulatory Commission (NRC) as the current state of practice for a technical process whereby seismic hazard models are assessed. Thus, it has the same standing as a consensus standard (ASCE Standard 43-05, for example). It is incorporated into the Agency's accepted seismic regulatory procedures (Regulatory Guide 1.208) for demonstrating compliance with the seismic regulation 10 CFR Part 100.23; it also is accepted by the Department of Energy (DOE) as part of the Agency's seismic safety policies and regulatory procedures.

We emphasize that it is essential to clearly establish in Chapter 1 that the SSHAC Methodology is an assessment procedure that is accepted by the NRC and the DOE for developing seismic hazard models that are, in turn, accepted as providing reasonable assurance, consistent with these Agency's seismic safety decision-making practice, of compliance with their seismic safety regulations and policies. Reasonable assurance is expressed in the outcome of using the SSHAC Methodology as the representation of the center, body and range of scientific community knowledge. In order to clearly convey the fact that the assessment of the CEUS SSC model has been accomplished through implementation of an accepted structured assessment process, we believe that the terminology "SSHAC Level 3 assessment process" should be adopted and used consistently throughout the CEUS SSC Report, notwithstanding use of alternative terminology in other documents. This would require extensive technical editing.

Similarly, a careful edit should be performed, replacing the words "study/studies," which do not properly apply when describing the activities performed in the CEUS SSC Project, with "project" or "assessment," as appropriate. As examples, "LLNL study" and "EPRI-SOG study" are properly "LLNL Project" and EPRI-SOG Project." Although the term "SSHAC Study Level" has been used in past documents, we recommend use of the term "SSHAC assessment process" in order to clearly convey the complex activities performed in the CEUS SSC Project.

The word "event" is used confusingly to mean "earthquake" throughout this chapter and the report. While it can be argued that the usage is understood in context, regulatory documents, which are intended to be used for an extended time by many people having differing backgrounds, require clarity. Consider making a blanket change of the word "event" to "earthquake" where appropriate.

Comments by Section

Section 1.1

1st paragraph: Consider replacing the 2nd sentence with:

> "As such, the CEUS SSC model replaces regional seismic source models for this region that are currently accepted by the Nuclear Regulatory Commission (NRC) for satisfying the requirements of the seismic regulation, 10 CFR Part 100.23, for assessing uncertainty in seismic design bases. These include the Electric Power Research Institute–Seismicity Owners Group (EPRI-SOG) model (EPRI, 1988) and the Lawrence Livermore National Laboratory (LLNL) model (Bernreuter et al., 1989)."

This change would require some additional editing of the paragraph.

Note that the proper reference to the EPRI-SOG Project is EPRI (1988). The date should be corrected in the References. Note also, that EPRI (1989) contains hazard computations at the SOG utility's NPP sites. This report was not submitted to NRC for review. (See also *Comments by Section* for Chapter 3, under *References.*)

2nd paragraph: Consider replacing the 2nd sentence with:

> "The project used a SSHAC Level 3 assessment process in order to assure compliance with the requirements of seismic regulations that uncertainties in the model have been properly quantified, evaluating the range of views and interpretations of the technical community."

And add to the end of the paragraph: "These models are expected to be adopted as part of the seismic safety regulatory guidance, replacing the EPRI (2004, 2006) models."

Section 1.1.1

"Studies" should be replaced with "Projects" here and throughout the report when referring to the EPRI-SOG and LLNL projects.

Section 1.1.2

"Studies" should be replaced with "Expert Elicitation Projects." In the 1st paragraph, consider replacing sentences 4 through 6 with:

> "These included the EPRI-SOG and LLNL projects.[1] Although both of these large projects relied on assessments by multiple experts, there were significant technical and procedural differences between the two, and there were large differences in the hazard results obtained at many common sites compared by the two projects. The formation of SSHAC was motivated by the need to understand these differences and to develop guidance acceptable for meeting the requirements for seismic safety regulation of nuclear facilities for assessing uncertainty in seismic hazard models".

[1] See Section 2.1 for a discussion of the history of the SSHAC process.

This change would require editing of the subsection as needed to be consistent.

Typo: In the first sentence of paragraph 2, change "time if their issuance" to "time of their issuance"

Section 1.1.3

Suggested wording change in the first sentence: "just as important as the basis of the technical assessments." In the subsection heading: "SSHAC Methodology" or "SSHAC Guidance."

At the top of p 1-3, the sentence, "As will be discussed in Section 2.2, the roles and responsibilities that a SSHAC process defines for all project participants must be scrupulously adhered to throughout the process to ensure its success" is overstated. Section 2.2 makes no mention that "scrupulous adherence" is a condition for success. Suggestion:

> "The roles and responsibilities of participants in the CEUS SSC project were explicitly defined, consistent with SSHAC guidelines for a successful Level 3 assessment project (see Section 2.2), and were diligently followed."

Section 1.1.4

"Study" should be replaced with "Project" or "CEUS SSC Model"; edit the subsection as needed for consistency.

Suggested word change in paragraph 2, line 2: "The CEUS SSC model is based on a comprehensive, transparent, and traceable process, . . ."

In the last sentence of paragraph 1, given the purpose of the CEUS SSC project (as described in the following paragraph), it seems strange to mention the DNFSB explicitly but not the NRC in this first general statement. Suggestion:

> "Standardization at a regional level will provide a consistent basis for computing seismic hazard, which will assist regulators such as the NRC [acronym defined earlier in section 1.1] and the Defense Nuclear Facilities Safety Board (DNFSB) in their oversight of nuclear facilities."

Section 1.1.5

In the last line of paragraph 1 on p. 1-3, change "participated or observed the CEUS SSC Project" to "participated <u>in</u> or observed the CEUS SSC Project."

Differences from USGS National Seismic Hazard Mapping Project: In the 1st paragraph on p. 1-4, the quoted AFEs should be verified. The national seismic hazard maps and USGS PSHA work is for AFEs in the range of 10^{-2} to 10^{-4} (building code maps are developed for an AFE of 4.04×10^{-4}), and the CEUS SSC results will provide results for AFEs in the range of 10^{-3} to 10^{-6} for design purposes.

In the same paragraph, lines 6 and 7, suggested wording change: “critical safety requirements of these facilities” rather than “the robustness of these facilities.” [Delete comma preceding period at the end of this sentence.]

In the same paragraph, line 11, suggested wording change: “hypotheses and parameter values are included where appropriate”

In the same paragraph, line 12, consider changing “witnessed in the paleoseismic record” to “observed in the paleoseismic record”

Section 1.2.1

Consider replacing the section heading with “Regional Seismic Source Model that Represents Current Knowledge and Data Uncertainties of the Technical Community” (see Comment **S 1-1**).

In paragraph 2, line 1, consider changing “proper” to “appropriate.” The last sentence of this section discusses the possibility that local sources can be used to refine the CEUS SSC model for site-specific application. We suggest that this sentence be deleted. Any change to the CEUS SSC model will need to be evaluated in terms of the PSHA distance influence for that change. Thus, what constitutes a local SSC model change versus a regional SSC model change is somewhat vague. The SSC report should recognize that site-specific studies are required but be silent on what happens if these studies indicate an SSC model change. NRC and others will have to decide what to do with any recommended SSC change (the distance extent to which that change must apply) and whether updates to calculations for “regions” are necessary.

Section 1.2.2

The section heading should be changed to “Conducted Using the SSHAC Level 3 Assessment Process,” and edit the section to be consistent with the change (see Comment S 1-1).

In paragraph 1, consider replacing the 3rd sentence with: “For regional seismic hazard models intended for use at many sites, the higher assessment levels provide the level of assurance required by the regulators for future use in seismic safety decision-making.”

In paragraph 2, line 9, suggested wording change: “the success of these assessment levels is the implemented process followed, which . . .”

Third paragraph: Time and costs are issues that the regulatory agencies are committed to take into account, but reasonable assurance of safety as required by the seismic safety regulations and regulatory safety practice are primary. This section should be edited to reflect this understanding. Consider replacing the first sentence of this paragraph with: “Selection of a SSHAC assessment level depends on the scope and complexity of the required evaluations and the intended use of the assessed seismic hazard model.”

At the end of the paragraph consider adding the sentence: “Moreover, after several years experience using the SSHAC Methodology, a Level 3 assessment is now accepted for developing regionally-applicable seismic hazard models intended for use over an extended time as the starting basis for computing PSHAs at multiple sites.”

Section 1.2.3

In paragraph 1, line 3, suggested wording change: "a SSHAC process should not be subject to significant change without new hazard-critical scientific findings."

Suggested wording change in paragraph 2, line 2: "Although these findings may lead to"

Suggested wording change in paragraph 2, line 3: ". . . it is likely that the assessment will remain viable, avoiding the need for an extensive revision."

In paragraph 2, third sentence: The text states, "Longevity means that the model will last for several years before requiring a significant revision or update." The last sentence in the paragraph states, "It is expected that the longevity for studies such as the CEUS SSC Project will be at least 10 years before there will be the need for a significant revision." To avoid confusion, the wording defining *longevity* should be sharpened.

Section 1.2.4

The section heading should be changed to "Interface with Ground Motion Models"

Use of the words "debate" and "interaction" in the 2nd paragraph, do not properly convey the role of the workshops for implementing the assessment process. Consider replacing the last two sentences of the paragraph with:

> "The TI Team brought together a panel of ground motion experts constituted of proponents of the range of available models in a series of three workshops, structured to gain a common understanding of the uncertainties in the modeling approaches and to structure the evaluation and assessment process for representing the uncertainty distribution of the technical community."

The subsection should make clear that the Expert Panel represented the range of community ground motion modeling knowledge for the CEUS.

Suggested wording change in paragraph 2, line 8: "The TI Team interacted with the Expert Panel to . . ."

Section 1.3

As discussed in Comment S 1-1, the word "study" does not convey the activities and processes that constitute the SSHAC Methodology. The section heading should be changed to "CEUS SSC Model Region."

Regarding the 4th sentence of paragraph 1: Are there any contributing sources that are in oceanic crust?

In this same paragraph, the text incorrectly (or at least misleadingly) states that "On the north and southwest, the study region extends a minimum of 322 km (200 mi.) from the U.S. borders with Canada and Mexico." Examination of Figure 1.3.1 shows that the SSC model region extends 200 mi. into Mexico only along the Gulf Coast. It does not generally extend 200 miles into Mexico "on the southwest."

Section 1.4

"Study" should be changed to "Project" in the section heading (see Comment S 1-1).

Section 1.4.1

In the section heading, use of the word "Complete" is not clear, and the word "Study" is misleading. Section heading should be changed to "Seismic Source Model Region."

Need to introduce the three stages of the SSC Model assessment: In section 1.4.1, the reader should be informed that the SSC Model was developed in three stages—the sensitivity SSC Model, the preliminary SSC Model, and the final SSC Model. This can be done effectively at the end of this section—prior to Chapter 2 where the terms appear for the first time on p. 2-19 unexplained.

In paragraph 1 (see line 10), the text states, "sources of repeated large-magnitude earthquakes (**M** ≥ 6.5) earthquakes (RLMEs) are identified . . ." The rationale for selecting the threshold of **M** 6.5 for RLMEs should be explained.

In this same paragraph, next-to-last line, change "and the forecast future occurrences" to "and the forecast of future occurrences"

Kijko Methodology as "State-of-the-Art": On p. 1-9 in the first paragraph, the text describes "two methods for assessing Mmax: a Bayesian methodology . . . and the Kijko methodology that is state-of-the-art within the technical community." The latter assertion raises questions about the Kijko methodology vis-à-vis the project. If state-of-the-art, then why was the methodology only considered at a late stage of the project (see p. 2-44) and why was it not identified at the USGS Mmax workshop as state-of-the-art? Suggestion for a broad-brush statement needed here: ". . . and a well-founded mathematical procedure that estimates Mmax based on seismic data (where sufficient) only for the source being considered."

Section 1.4.2

In the 3rd line, consider changing "third party" to "future user"

In this same paragraph, lines 10–11, consider changing "for a project" to "for seismic hazard analysis at a specific site."

Section 1.4.4.2

In the 4th sentence, suggested word change: "Where applicable, GIS data layers were developed, and this included new geophysical data compilations developed specifically for the project."

Section 1.4.4.3

In line 4, change "all events up through 2009" to "all earthquakes through 2008." The project catalog (Chapter 3) extends through the end of 2008.

In line 7, suggested word change: "a number of historical earthquakes were reviewed in order to develop reliable moment magnitudes for these shocks."

Section 1.4.4.4

In the title of this section elsewhere in the report, *paleoseismicity data* tends to be used loosely as synonymous with *paleoliquefaction data*. Paleoliquefaction data are a <u>subset</u> of paleoseismicity data, which notably include results of geological trenching of active faults, such as for the Meers and Cheraw faults. The report includes varied types of paleoseismic data, and correct terminology is important for clarity.

Consider replacing the first sentence of this section with:

> "Because of the emerging use and significance of paleoliquefaction data in the CEUS, part of the scope of the project was a compilation of these data and development of written guidance for representing uncertainty in evaluations and interpretations of the data to estimate the locations, occurrence times, and magnitudes of causative earthquakes."

Section 1.4.4.5

The first sentence of the second paragraph is awkwardly worded. Suggestion: "This report contains an evaluation . . ."

CHAPTER 2 — SSHAC LEVEL 3 PROCESS AND IMPLEMENTATION

General Comments

G 2-1. (CBR, CC) This chapter contains generally informative and valuable background information, but it does not adequately achieve the goal of explaining the chapter heading for a number of reasons: (1) the chapter is not organized effectively, with too much discussion of history that, in its present form, distracts from a necessary focus on this project[1]; (2) there is not enough discussion of what the TI Team did to ensure that they were objective evaluators to "represent the center, body, and range of the technical interpretations that the larger informed technical community (ITC) would have if they were to conduct the study"; and (3) the discussion of the workshops needs to be enhanced to describe what the TI Team did to ensure that (a) the workshops focused on the right issues (completeness), (b) the workshop goals were met, and (c) the experts who attended the workshops were appropriate and sufficient for the purpose of defining the community knowledge and associated uncertainties.

G 2-2. (CC) The discussion regarding a "SSHAC Level 3 process" and the concept of the "informed technical community" (ITC) is of great importance for substantiating key claims about the implementation and results of the CEUS SSC project. But, it is marred by imprecise wording that may contribute to confusion or invite argument. Our Comment **S 1-2** (clear communication) applies equally to Chapter 2, and we offer additional specific comments to help strengthen the logic underpinning key claims in this chapter.

Specific Comments

S 2-1. (CC, SSHAC) *Explaining the Goals of the Chapter*

Writing always involves individual choice, and there are different ways to explain the goals of the Chapter at the outset. In the following example text[2] an attempt is made to give the reader a road map—intentionally with a regulatory framework in mind:

> The goals of this chapter are, first, to describe the SSHAC Level 3 assessment process and how it was implemented to assess the CEUS seismic source characterization (SSC) model and, second, to demonstrate that the implementation was accomplished in compliance with the SSHAC guidance. The SSHAC developed guidance for four levels

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[1] There are 16 pages of narrative before the reader finds out what this project did to ensure it was executed properly. The described history led to the SSHAC and Hanks reports, which this project uses. Understanding the history does not guarantee success. The text needs to focus on what this project specifically did to ensure success—Section 2.1.2.2 gets lost as organized.

[2] As stated in our cover letter, suggested text "should be viewed as suggested alternative wording for improved clarity—not a dictation of how the TI Team should word its report."

of implementing an assessment, depending on the degree of uncertainty and contention involved and the intended use of the seismic hazard model.[3]

The SSHC guidance emphasizes that, independent of the implementation level, the goal of a SSHAC assessment is “to represent the center, the body, and the range of the technical interpretations that the larger informed technical community would have if they were to conduct the study” (SSHAC, 1997, p. 21). The “center, the body, and the range” is taken to mean a representation of the uncertainty in the technical community’s knowledge, referred to by the SSHAC as “the community distribution.” The latter, as a representation of the uncertainty in the technical community’s knowledge, can be termed “the community uncertainty distribution.” A proper representation of the community uncertainty distribution appropriately meets the requirements of the NRC’s seismic regulation, 10 CFR 100.23

The SSHAC recommended that a Level 3 or a Level 4 assessment process be used for complex assessments, the products of which have high public importance and attract public scrutiny, such as regional seismic hazard models intended to be used over a sustained time period as base-case models for site-specific PSHAs. Such models require the highest level of assurance that the community uncertainty distribution has been properly represented. For this project, the decision was made to use a SSHAC Level 3 assessment process.[4] The CEUS SSC Project arrived at this decision based on experience gained with implementations of the SSHAC guidance, which has shown that a properly executed Level 3 assessment process can provide a level of assurance of meeting the SSHAC goals comparable to that of Level 4, which is much more costly to implement.

This chapter begins with a discussion of the fundamental SSHAC goal of representing the center, body, and range of the technical community’s knowledge, including why this goal was developed. This is followed by a discussion of how the SSHAC Level 3 assessment process has been implemented by the CEUS SSC Project, including the roles of key participants, project organization, key activities, and participation of the Participatory Peer Review Panel (PPRP).

S 2-2. (CC, SSHAC) *“Capture” and the Informed Technical Community*

We caution the TI Team that repeated use of the word “capture”—a highly nuanced term as it relates to the center, body, and range (CBR) of the technical interpretations of the ITC—may confound clear thinking.

[3] Seismic hazard model is used here and elsewhere in these comments to mean either an SSC model or a Ground Motion model.

[4] See Section 3 of the CEUS SSC Project Plan (June 2008).

In its 1997 report, the SSHAC most often uses the words "represent" or "a representation of" for actions relating to "the center, the body, and the range of technical interpretations that the larger informed technical community would have if they were to conduct the study" (SSHAC, p. 21).[5] In Chapter 2, the dominant action word used for the CBR is "capture," emphasized, for example, by the headings for sections 2.1.2 and 2.1.2.2. Coppersmith et al. (2010)[6] use "capture" (at least 17 times) in the context not only of the CBR but variously in terms of capturing uncertainty, capturing insights, capturing the community distribution, capturing rate of occurrence and randomness, and so on.

The problem with *capturing* the CBR of technical interpretations of the ITC, as opposed to *representing* them, is that it invites critical scrutiny of what may have been left out, not fully preparing the reader for the need to understand important concepts dispersed elsewhere in the report—notably, identification and due consideration of alternative views, allowance not to include views judged to have an insignificant effect on the hazard, and the *integration* function performed by the TI Team in its role of assessing and representing the CBR of the ITC.

S 2-3. (CC) *Claim that CEUS SSC Robustly Implemented SSHAC Guidance*

On p. 2-1, par. 2, the text states:

> "These sources, as well as projects conducted prior to the development of SSHAC guidance, offer confirmation that the CEUS SSC process was a robust implementation of both the "spirit" and the "letter" of the law, namely SSHAC."

It is illogical to say that prior sources "confirm" a later "robust implementation." And it is misleading to refer to SSHAC guidelines as "the law." The astute reader will compare the claim made in this introductory part of Chapter 2, with the conclusion eventually reached in section 2.1.2.3 (p. 2-23), where one finds wording such as "addressed adequately," "preponderance of evidence," and "reasonable assurance."

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[5] The PPRP anticipates discussion with the TI Team regarding terminology. The term "community distribution," used by the SSHAC (SSHAC, p. 22), may offer a useful compact term to avoid having repeatedly to refer to the center, body, and range of the informed technical community (ITC). It may also help avoid fixation on the ITC (see Comment **S 2-4**) by appropriately focusing on the distribution of the technical community's knowledge (and lack thereof), which the TI Team has the responsibility to represent through its evaluation and integration functions.

[6] Disclosure: Two members of the PPRP (J. Ake and A. M. Kammerer) are coauthors of Coppersmith et al. (2010), which is one of three sources cited and used in Chapter 2 as a basis for correctly interpreting SSHAC guidance.

Suggestion:

> "These sources, as well as projects conducted prior to the development of SSHAC guidance, provide a basis for concluding that the CEUS SSC assessment process followed in a robust way both the "spirit" and the "letter" of SSHAC guidance. The end result is reasonable assurance that the CEUS SSC final model achieves the primary goal intended by the SSHAC guidelines."

S 2-4. (SSHAC, CC) *Importance of "Site-Specific" Knowledge and Being "Informed"*

In section 2.1, p. 2-2, par. 2, the text emphasizes that, "what constitutes an 'informed' member of the technical community" is "knowledge of site-specific and other relevant data." The CEUS SSC model is described to be a *regional* seismic source model, to be modified by including local seismic sources, if needed, for site-specific application as required by the seismic regulatory guidance—Regulatory Guide 1.208. So the need for site-specific knowledge in the case of the CEUS SSC may confuse the reader. Overall the argument seems weak. Moreover, the notion itself of an informed community causes confusion and debate because it implies reliance on a subgroup with "specialized knowledge." The confusion and debate comes about because this notion conflicts with regulatory safety decision-making principles and practice and is distasteful to the larger scientific community.

The PPRP believes that defining the qualifications a person must have to be accepted as an "*informed member*" of the scientific/technical community is disruptive. While it is not possible to recover the thinking process of the SSHAC, it is possible and essential to consider the "*informed technical/scientific community*" within regulatory safety decision-making practice.

In all regulatory practice, all experts with equal subject-matter training are accepted as being equally informed for purposes of regulatory decision-making. Regulatory practice does not accept a special subset of the members of the scientific community as being more expert; it is counter-productive to promote such a designation. That is why standards of practice form the foundation for making regulatory safety decisions and why seismic safety decisions for nuclear facilities are made by means of *a structured regulatory process*. Implementation of such a process is accepted by the NRC for performing evaluations, analysis, and assessments to demonstrate compliance with the seismic safety regulations—and reasonable assurance of safety.

The SSHAC Methodology is one of the standards of practice that together constitute the NRC's seismic regulatory guidance. What will provide reasonable assurance that the CEUS SSC model represents the center, body, and range of the current scientific and technical knowledge is proper implementation of the SSHAC assessment process—not that the TI Team, whether large or small, was made up of special "*informed*" experts.

We recommend that the entire argument in Section 2.1, at least through Subsection 2.1.1.1, be changed and framed in the context of (a) the seismic safety decision-making process and practice and (b) the role of the SSHAC Guidance within the NRC's decision-making process for nuclear facilities. The terminology "*informed technical/scientific community*," coined by the SSHAC, has to be understood in this context.

S 2-5. (CC) *Historical Context and Evolution of Use of Expert Assessment (Section 2.1.1)*

The length of this subsection detracts from this chapter. While this section is informative, Sections 2.1.1 through 2.1.2.2 and Table 2-1 could be moved to an appendix, with a short summary provided here. Also, the text (specifically in Section 2.1.2) and Table 2-1 would be improved if the authors provided their thoughts on how well the experts or expert teams did as *evaluators* for those projects that were completed at a SSHAC Study Level 4. It is our impression that results are mixed in this regard. If the authors agree, this should be discussed and noted.

In order to completely chronicle the origins of the NRC's probabilistic seismic hazards program, it should be stated that during the mid to late 1970s, the Advisory Committee on Reactor Safeguards (ACRS) persistently urged the NRC to undertake research aimed at quantifying the uncertainty embodied in SSEs derived following the requirements of the seismic regulation 10 CFR Part 100, Appendix A, which had been adopted in 1973. The ACRS also urged the NRC to undertake a parallel program with the aim of quantifying the margin embodied in the NRC's seismic design criteria and procedures. In response, the NRC developed and funded a seismic margins research program and, a short time later, a seismic hazard research program, both conducted by the Lawrence Livermore National Laboratory (LLNL). The seismic hazard research program adopted from the decision analysis community the structure and formalism of classic expert elicitation processes.

S 2-6. (CC, SSHAC) *"Capturing" the Center, Body, and Range (Section 2.1.2)*

Consider changing "Capturing" to "Representing" in the section title.

As a lead-in to Section 2.1.2, consider this example text (see also Comment **S 2-4**):

> Reasonable assurance is the standard for reaching administrative decisions about public safety across the spectrum of hazards to which the public is exposed. Regulations, regulatory guidance, regulatory review, and administrative hearings all invoke the standard of reasonable assurance. Regulations state the safety requirements, regulatory guides provide guidance for technical methods and procedures that are accepted for demonstrating compliance with applicable regulations, regulatory review provides reasonable assurance that regulatory guidance has been properly implemented, and an administrative hearing determines whether the safety conclusions are supported by preponderance of the evidence developed by the regulatory review process.

> In this safety decision-making process the SSHAC assessment process is a technical process accepted in the NRC's seismic regulatory guidance for reasonably assuring that uncertainties in data and scientific knowledge (stated by the SSHAC as the center, body, and range of views of the informed scientific community) have been properly represented in seismic design ground motions consistent with the requirements of the seismic regulation 10 CFR Part 100.23.

S 2-7. (CC) *"Standard of Proof" (Section 2.1.2.1)*

Better wording for the title of section 2.1.2.1 would be "The Reasonable Assurance Standard," which is the primary focus of this subsection. The claim made in the fourth sentence of this subsection that, "there is no need for such proof" is out of place (the claim is explained later in the second paragraph).

Based on arguments made in our Comment S 2-5, we recommend deletion of the entire first paragraph of this subsection and revision of the remainder. The standard of proof is reasonable assurance, and reasonable assurance is demonstrated by proper implementation of the NRC's regulatory decision-making procedures. In the instance of the CEUS Project reasonable assurance that the CEUS SSC Model represents the center, body, and range of the views (prefer knowledge) of the scientific community is demonstrated by proper implementation of the SSHAC Level 3 assessment process.

S 2-8. (CBR, SSHAC) *Evidence That CEUS SSC Project Has Captured the Informed Technical Community (Section 2.1.2.2)*

Adherence to the SSHAC guidelines is necessary evidence, but it is not sufficient to show that the CBR of the technical community has been represented in the assessment. How can sufficient evidence be obtained? Certainly that is not easy, but sufficiency can be approached by peer review of the report. That is what the review of the draft report by the PPRP, the USGS, and supporting parties is doing. These parties are judging the completeness of the process carried out by the TI Team. The question is, do these reviews achieve the goal of evaluating the results of the process? This will be a subjective appraisal. It would be well for the report to discuss the subjectivity of the evaluation and the role of reviews in the evaluation.

This subjectivity is acknowledged in Section 2.1.2.1 [Standard of Proof] in the description of the technical community as a "hypothetical community" and the regulatory use of reasonable assurance. The idea that the technical community is hypothetical is contrary to seismic regulatory principles and practice (see our Comment S 2-5). There is a very real technical community that has developed the evidence and views regarding specific topics that are important to seismic source characterization and assessment in the CEUS. This community does not consider themselves to be hypothetical.

S 2-9. (CC) *PPRP Attendance at the Eight Working Meetings of the TI Team:*

The report contains differing statements about the attendance of PPRP observers at the TI Team Working Meetings:

> "All of the working meetings were observed by one or more members of the PPRP." (p. 2-20)
>
> "[The PPRP] participated in many TI Team working meetings to plan and review the process and progress of the project." (p. 2-36)
>
> "One to three representatives from the PPRP attended the working meetings in order to observe the deliberation and technical assessment processes." (p. 2-42)

For the record, PPRP attendance was as follows:

WM # 1	
WM # 2	Hinze, Kammerer, Kimball
WM # 3	Ake, Petersen
WM # 4	
WM # 5	
WM # 6	Ake, Stepp
WM # 7	Ake, Arabasz, Kimball
WM # 8	Kammerer

Comments by Section

Chapter 2 (Title)

In order to emphasize that the CEUS SSC Project implemented an assessment process, we recommend the Chapter title be changed to: SSHAC LEVEL 3 ASSESSMENT PROCESS AND IMPLEMENTATION (see Comments **S 1-1** and **S 1-2**).

Chapter 2 (Introductory Text)

Spell out PPRP when it is first used in report.

Section 2.1

p. 2-2, par. 3, line 3: "the data that applies" (inconsistency: data used as singular here; plural elsewhere in report)

Section 2.1.1

par. 1: The text states, “The SSHAC report was written in response to an evolution of expert risk assessment methodologies that had been conducted for purposes of probabilistic risk analyses during the previous three decades.” According to the footnote on p. 34, the only identified studies predating the SSHAC report that dealt with **risk** were the WASH-1400 study and the NUREG-1150 study; all the other studies dealt with **hazard**.

Section 2.1.1.1

p. 2-5, par. 3, line 1: Change “The EPRI-SOG study” to “In the EPRI-SOG Project”

p. 2-7, next-to-last par.: “and offered a prophecy for future guidance:” What exactly is prophesied in the subsequent quoted text? Suggestion: “and future guidance was envisioned”

Section 2.1.1.2

p. 2-10, par. 2, line 7: Suggest replacing “third party” with “future user”

p. 2-11, par. 2, line 3: Suggest replacing “gone up” with “increased”

p. 2-11, par. 2, second sentence: There is unclear phrasing in the second half of this critical sentence. The difference between the PEGASOS results and the older results were shown to be due to “an appropriate treatment of the ground motion aleatory variability and an error in the calculations in the previous hazard studies (NAGRA, 2004, Section 8.4.2).” Was the treatment appropriate in the older studies or in PEGASOS?

p. 2-11, par. 2, line7: “to discredit the study” — Clarify which study is being referred to.

p. 2-11, par. 3, line 11: Change “TI” to “TI Team”

p. 2-11, par. 3, line 2: Because ESP and COL appear in the list of Acronyms, consider writing, here at their first mention in the text, “Early Site Permits (ESPs) and Combined Construction and Operating License (COL) applications”

p. 2-11, par. 3: The narrative of what happened in the EPRI (2004) Level 3 process is confusing. The text describes that “A small TI Team was responsible for the assessments and a panel of resource experts/proponents provided their views of the existing ground motion models and their applicability to the CEUS.” Subsequent text describes the problem of the experts not taking ownership of the resulting composite model. As written, why would "resource experts/proponents" be expected to take ownership? In the EPRI (2004) Project, the TI Team requested that the Resource Expert Panel endorse the assessed model. The Panel did not challenge the implementation of the assessment process, but persisted in the role of proponent experts, insisting that their proponent model should have more weight.

Suggestion:

> "A lesson learned in the project was that if broad expertise is needed to perform the TI role of representing complex technical views of the informed technical community, then a small TI Team may not suffice. In the case of the EPRI (2004) assessment, the panel of ground-motion experts was not charged with the TI role, but they were asked to review and endorse the assessed ground motion model; individual members of the panel persisted in acting as proponents, advocating higher weighting of their individual proponent models. Subsequent Level 3 . . ."

p. 2-11, par. 3, last line: Suggest replacing "claim" with "accept:

p. 2-11, last paragraph, line 6: Suggest deleting "developing"

p. 2-12, line 1: Typo. Change "significance advances" to "<u>significant</u> advances"

Section 2.1.2

par. 1, third sentence: What is meant by "many of the technical issues that drive seismic hazard . . . are rare?" Suggestion: Delete "rare and"

Section 2.1.2.1

par. 1: See Comment **S 2-3** regarding the notion of "capturing the informed technical community." If the authors insist on using "capture," for clarity at least describe capturing the *views* or *technical interpretations* of the informed technical community—not the jargon of "capturing the informed technical community."

p. 2-17, par. 1, last line: Typo. "have the ~~like~~ highest likelihood"

p. 2-17, par. 3: It will be helpful to clarify for the reader that what is "not yet available" is not the article written by Coppersmith et al. (2010) but rather the NUREG document discussed in Coppersmith et al. (2010). Suggestion: "to develop a NUREG-series document (see Coppersmith et al., 2010)."

Section 2.1.2.2

In the discussion of Item 3 (Provide a uniform data base to all experts), mention should be made of the development of the seismicity catalog.

p. 2-19, par. 2, last sentence: What "will provide a valuable methodology step for future Study Level 3 projects" isn't "these tables" but rather something like "the structure of these tables."

On p. 2-19 near the end of the next-to-last paragraph, the reader encounters, for the first time, "the development of the sensitivity SSC model, the preliminary SSC model, and the final SSC model"—terms which aren't explained until the bottom of p. 2-20. These are fundamentally important for the reader to understand. A good place to introduce the reader to these terms would be at the end of Section 1.4.1, explaining that the SSC model was developed in three stages.

On p. 2-10, Item 5, 7th bullet: Typo. "Renewal vs. ~~Poison~~ Poisson recurrence models."

p. 2-19, last par.: For complete documentation (useful for future readers) give the dates of the maximum magnitude workshop in Golden, Colorado, and the CEUS workshop in Memphis, Tennessee.

p. 2-20, Item 5. *Elicit SSC judgments from experts*: The text describes eight working meetings of the TI Team and goes on to state that "Each working meeting was structured around a particular aspect of the project, as follows:"—but **ten** bullets follow, not eight. To compound the problem, a different list of eight bullets later appears on p.2-41 to describe the focus of the eight meetings. On p. 2-37 under the header TI Team, mention is made of **nine** working meetings.

Section 2.1.2.3

Where are the conclusions regarding the selection of the study level—an important part of the process?

Section 2.3

par. 3: Change "TI Lead" to "TI Team Lead" consistent with the organizational chart in Figure 2.3-1.

p. 2-37, par. 2: To soften jargon, consider replacing "Technical Integrator (TI) Team" with "Technical Integration (TI) Team"

Section 2.4.2

par. 1, line 9: Text states, "annual frequencies of interest (e.g., 10^{-4} to 10^{-7}/yr) for nuclear facilities." Executive Summary states 10^{-4} to 10^{-6}/yr.

Section 2.4.3

The text should describe what was done to identify resource experts for Workshop #1 and the approach used to ensure that the experts who participated in the workshop were appropriate and sufficient.

Sections 2.4.3 and 2.4.4

It would be helpful to have more references to the workshop information in the appendices, particularly the workshop summaries and the presentations.

Section 2.4.4

The text should describe what was done to identify proponent experts for Workshop #2 and the approach used to ensure that the experts who participated in the workshop were appropriate and sufficient.

Section 2.4.8

A short summary of the purpose of the Data Summary and Data Evaluation tables and the use that was made of them would be informative here.

Section 2.4.9.1

The HID is a valuable document. It would be useful here to expand on its purpose and to note specifically that this document is meant for the analyst—providing clarity about the model to be implemented and obviating the need to distill the model from the full report. This document helps assure that implementation of the model (which is sometime challenging) is as intended.

Section 2.4.9.2

First sentence: This sentence appears to be the objective of the report. Suggest that it be moved forward or reappear in an appropriate place in Chapter 1.

Table 2-2

Under "Other Technical Experts . . ." there are duplicate entries for Al-Shukri and Mueller

To avoid confusion about the listing of names in this table, delete "Other" in "~~Other~~ Technical Experts" because some of the experts are also listed in the first two categories of the table.

CHAPTER 3 — EARTHQUAKE CATALOG

General Comments

G 3-1. (NAR) This chapter summarizes the project approach to developing the earthquake catalog for use in the CEUS seismic source model. The process followed in this project is similar to many others in that it consists of three basic elements: (1) assembly of available, relevant sources of earthquake data into a single, magnitude-consistent earthquake catalog; (2) identification of dependent events; and (3) evaluation of catalog completeness.

G 3-2. (NAR) Chapter 3 is arranged logically as it describes the goals for earthquake catalog development (Section 3.1), the compilation of available data from continental and regional-scale catalogs as well as special studies (Section 3.2), development of various relationships to convert all earthquake size estimates to moment magnitude (Section 3.3), catalog declustering (Section 3.4), and catalog completeness (Section 3.5).

G 3-3. (NAR) It is appropriate to emphasize that, the comments below notwithstanding, the catalog that has been developed for this project represents a major achievement and is a real step forward for the entire seismic hazard community. It is a major improvement over previous catalogs in that it incorporates more regional catalogs and has developed moment magnitude estimates for all the earthquakes. The efforts of the TI Team, together those of collaborators from the USGS and the Geological Survey of Canada (GSC), are to be commended. The detailed and thorough approach followed has led to a product that will be widely used. The TI Team, USGS, and GSC staff should consider producing something in the open literature that documents this work. The development of a specific catalog for non-tectonic events in this region may not seem like an interesting product, but for practitioners in this field it will be very useful (especially if it is maintained over time).

Having said the above, in order to achieve a clear and complete description of the efforts that went into developing the catalog and of the results, Chapter 3 needs to be improved, as we proceed to explain.

G 3-4. (CC) The text and explanation of figures in Section 3.3 are too terse. The knowledgeable practitioner may be able to “read between the lines” or infer the meaning of unexplained dashed and dotted lines on many of the figures, but the documentation for this project report must be clear and complete for all readers.

G 3-5. (CC) This chapter would be enhanced by a description of the problems associated with obtaining useful focal depths in the region, limitations on focal-depth resolution, and general observations or conclusions regarding the depth of earthquake foci in the CEUS.

Specific Comments

S 3-1. (CC) *Non-PPRP Review Comments*

Section 3.1 documents the emphasis placed on the earthquake catalog as it provides the basic earthquake rate information that "drives" the seismic hazard model for most of the CEUS. This section describes the process of compiling the relevant catalogs and data sources and summarizes the rationale for returning to the basic data sources for magnitude or intensity data. A brief synopsis on review of the catalog by other interested and experienced seismologists is contained in Section 3.1.3. However, no mention is made of any results, comments, or changes due to those reviews (hence uncertainty whether suggested changes were implemented in the final catalog). Will those review comments (particularly those of the USGS) be part of the project documentation in any form? They do not appear as an Appendix. Will they be documented in project files in a form that could be retrieved by interested individuals?

S 3-2. (CC) *Clarity and Completeness in Figures*

The meaning of different line symbols is incompletely explained on several of the magnitude-conversion figures. On Figures 3.3.1-1 and 3.3.1-2, the addition of an added point to extend the regression to lower values needs more explanation and justification. On Figure 3.3.4-1, the labeling in the *Explanation* of "CEUS dependent catalog" makes the content on the figure ambiguous. The text on p. 3-11 states that "the catalog of earthquakes" is shown on the figure—but two sentences later, the text states, "Therefore, dependent earthquakes (foreshocks and aftershocks) must be identified . . . ." So "dependent catalog" can be read as the catalog of dependent events.

S 3-3. (CC) *Corrected Moment Magnitudes from Atkinson*

Section 3.3 provides the summary of the development of the various conversions of earthquake size measures (instrumental magnitude or macro-seismic observations) to moment magnitude. This step is essential to ensure consistent earthquake counts and compatibility with modern ground motion prediction equations. Section 3.3.1.1 describes the first of the specific instrumentally determined moment magnitude studies utilized (Atkinson, 2004). To make it clear to the reader how the conversion was carried out, additional detail should be added to 3.3.1.1. This additional discussion will ensure that the other 3.3.1.x sections are clear. For instance, for events that are used from Atkinson's study, our understanding is that her estimated **M** values are "corrected" to moment magnitudes consistent with the results of waveform inversion studies for those events. If this is not what was done, considerably more detail must be supplied as the correction process is not clear to the PPRP.

S 3-4. (CC) *Approximate vs. Instrumentally Determined Moment Magnitudes*

In Section 3.3.1, second paragraph, the text notes that some "moment magnitude estimates were obtained from three studies that determined **M** by approximate methods . . . ." As part of the project documentation, it would be helpful to identify these earthquakes in a table (presumably, the number involved is manageable). Also, to aid future users of the catalog, and for transparency, instrumentally determined moment magnitudes in the Earthquake Catalog should be flagged—ideally in Appendix B, or in files available to interested parties.

S 3-5. (DMM, U, CBR, CC) *Sensitivity of Recurrence or Hazard to Choice of Declustering Method*

Section 3.4 provides a discussion of the approach used to perform declustering of the magnitude-corrected earthquake catalog. Because the PSHA formulation used for area source zones relies on the assumption of earthquake occurrences following a Poisson process, it is necessary to identify any dependent events in the catalog and remove them prior to performing any rate calculations. A number of different approaches have been used in the past to perform declustering analyses in major seismic hazard studies. The work of Gardner and Knopoff (1974), Reasenberg (1984), and Reasenberg and Jones (1989) have been widely used. The Gardner and Knopoff technique, as well as similar region-specific methods (Urhammer, 1986; Gruenthal, 1985), rely on removing events within fixed magnitude-dependent time and distance windows about a "main" earthquake. The method developed by Reasenberg defines variable space-time windows for individual event clusters using statistical tests and related to a particular model of aftershock occurrence.

In contrast, the approach that has been used in the CEUS-SSC study is a stochastic approach developed in the mid-1980s as part of the EPRI-SOG Project. Section 4.3 cites EPRI (1988) as the source document for this approach to declustering, this reference is missing from the reference list (see note on EPRI references below). The EPRI approach begins by treating each earthquake as a main event and then evaluates the rate of earthquake occurrences within a "local window" about the main event and compares that rate to that within an "extended window," i.e., one larger in space-time dimension. If the rate of earthquakes within the local window is significantly higher (based on an un-specified statistical test) than within the extended window, then smaller events are removed within the local window until the rate approaches the extended window ("background") rate. However, in regions of low seismic activity, stable estimates of rate in the larger window can be problematic and hence lead to bias due to the unwarranted removal of events.

The PPRP has several specific concerns related to the approach taken to declustering of the catalog used in the CEUS SSC Project:

1. The lack of clear documentation. The discussion of declustering in Section 3.4 is less than one page long. The discussion and development of the EPRI declustering algorithm

contained in EPRI (1986, Vol. 1, Pt. 2, Sections 3 and 4) runs to more than 20 pages and is not trivial to follow. EPRI (1988) contains a thorough discussion of the various declustering approaches and the assumptions associated with each. The EPRI declustering method was designed to minimize the number of assumptions required about the clustering process. The description of the adopted declustering methodology in Chapter 3 needs to be significantly expanded.

2. Given that the declustering fundamentally alters the number of earthquakes in the catalog for calculations of recurrence—and thus hazard, more discussion is warranted about associated uncertainty. What are the implications if a different method were used (e.g., the Gardner and Knopoff method, which reportedly produces 15 percent fewer dependent events and thus more main events)? In the case of the EPRI-vs.-Gardner and Knopoff comparison, were smaller magnitude bins systematically more affected? This issue of uncertainty associated with declustering methodology could be addressed in one of two ways: (1) sensitivity studies displaying the impact that this assumption has on recurrence relationships or hazard results, or (2) explicit consideration of alternative declustering models each with an appropriate weight. If sensitivity calculations aren't explicitly made, can experience from other PSHAs be used to amplify on uncertainties associated with the choice of the declustering method? Also, because any declustering algorithm is sensitive to the choice of declustering parameters used, some discussion is warranted about the efforts made in the earlier EPRI Project to determine suitable parameters for the CEUS.

3. EPRI (1988) is in the open literature. However, it is difficult to obtain, not widely used outside a small number of individuals, and in the view of the PPRP, not uniquely representative of the CBR of the ITC. If it is the position of the TI Team that in fact the EPRI declustering approach is superior to all other approaches and the only approach that should be considered, then that needs to be more clearly articulated and documented. In point of fact, the EPRI approach has been used only by a few of the teams in the Yucca Mountain PSHA and in updates to the EPRI-SOG seismic source model used for recent COL/ESP applications. The seismic source characterization teams in the PEGASOS project used either the Gardner and Knopoff approach or variants thereof, or a modified version of the Reasenberg approach. Most other seismic hazard studies for critical facilities in the US have used similar approaches to those in PEGASOS. Alternative approaches to declustering should be examined, documented, and if warranted considered for inclusion in the present study to satisfy the goal of capturing the CBR of the ITC.

4. Figure 3.4-1 displays the results using the EPRI (1988) procedure, showing dependent event time and distance windows for events down to about $\mathbf{M}^* = 2.5$. Are these considered large events? Note: definition of main, large, and independent earthquakes needs to be clearly articulated in this section. If the PPRP is interpreting these figures properly the estimated time windows for many individual small ($\mathbf{M}^* < 4$) events are significantly longer than time windows for many individual larger ($\mathbf{M}^*$ from 5.5 to 6) events. For $\mathbf{M}^*$ just below

5, the time window ranges from 4 days to about 6.5 years. The PPRP questions if that range would be endorsed by the broader community of observational seismologists. Based on the information provided, it is not clear whether these outcomes are unique to the model selected, and whether the model properly models the uncertainty associated with identifying dependent events.

S 3-6. (DMM, CC, U) *Catalog Completeness*

Section 3.5 describes the approach used to assure catalog completeness in the CEUS SSC Project. The methodology used for catalog completeness is that developed in the EPRI-SOG Project and works with the uniform magnitude, **M***. The EPRI approach defines spatially discrete zones that have uniform levels of magnitude completeness and defines magnitude specific probabilities of detection (P_D) in each. For the CEUS SSC Project, the TI Team augmented the completeness regions used in the earlier EPRI study slightly to address additional catalog information and to properly cover the current study region.

Many of the same comments made regarding Section 3.4 can be made regarding Section 3.5. The lack of detail and clarity make a proper evaluation of this section virtually impossible. The sole reliance on reference to the EPRI documents as the technical basis fails to meet the standard of documentation required in a study of this scope. It is not discussed in this section, but the probability of detection thresholds defined and shown in Table 3.5-1 were derived by simultaneously maximizing the log likelihood functions for P_D as well as the “a” and “b” values in the earlier EPRI approach. Based on our reading of Section 5 it is not clear if the same approach was used in the current study. As with the discussion of declustering, there are alternative methods for performing completeness assessments in the literature and those should at least be discussed and evaluated. The P_D and equivalent time period of completeness methodology used is quite powerful as it maximizes the number of events used from the declustered catalog. However, it needs to be more completely described and evaluated against alternative methodologies if it is to be the sole approach used.

Comments by Section

Entire Chapter

The word “study” should be replaced with “project” throughout the chapter where used in as part of the designation of an integrated assessment project; e.g., “EPRI-SOG Project”, “this project”, and so on.

Section 3.1

Suggestion: The reader would find a summary preceding this to be helpful.

Sections 3.1.1 through 3.2.2

Numerous acronyms are unexplained and do not appear in the list of acronyms. These include: SUSN, NEIC, PDE (p. 3-1), ISC, ANSS (p. 3-3), CERI (p. 3-4), NEDB (p. 3-5)

Section 3.1.1

p. 3-1, par. 2, line 1: Change "CGS" to "GSC"

Section 3.1.3

line 3: Typo. "Therefore, ~~and~~ an important part of the catalog development process was review by ~~seismologist~~ seismologists with extensive knowledge . . ."

line 7: Affiliation for Martin Chapman as "Virginia Technological University" is incorrect. The school is called either Virginia Tech or Virginia Polytechnic Institute and State University (see http://www.vt.edu/).

Section 3.2

p. 3-3, 1st paragraph: It would be helpful to give an example of the numbering scheme as it is not entirely obvious how the scheme will appear in the summary catalog.

Section 3.2.1

p. 3-3, 1st paragraph, line 3: Typo. Change "and primary earthquake listing" to "and the primary earthquake listing")

p. 3-3, 2nd paragraph: EPRI (1988) reference is missing. (Please see comment on EPRI references below.)

Section 3.2.3

p. 3-4, 1st paragraph: Typo in line 3? ("locations and/or depths"?); in line 6, change "Boatwrigth" to "Boatwright"

p. 3-4, 2nd paragraph: Typos. Change "catalog" to "catalogs"; "are area" to "an area"); "The second is" to "the second was" (for consistency with tense in preceding sentence).

Section 3.2.4

p. 3-4, 3rd line: Reference to Section 3.2.4 should be to 3.2.3

Section 3.2.5

The scheme for assigning order of preference to events located south of the US-Canada border is not clear. We assume that all the regional networks have equal weight and events located near New Madrid would default to CERI or St Louis University, and if in New Jersey would default to Lamont Doherty. If not, this needs to be made clearer.

Section 3.3.1.1

line 5: Typo. Change "over estimates" to "overestimates"

Section 3.3.1.3

Typos. In line 2, change "an coda wave technique" to "a coda wave technique"); in line 4, change "abet" to "albeit"

Section 3.3.2.1

Define f_N, and F_N

Section 3.3.2.2

5th line and equation 3.3.2-3: Missing word and typo. "The Johnston (1996) relationship is reasonably consistent with the project data. Also, is Equation 3.3.2-3 the Johnston (1996) relationship, and is that what was actually used? Not clear as written.

Sections 3.3.3.1 and 3.3.3.2

Unclear whether the locally-weighted least-squares fit or a constant offset model was used in the conversions between M_N and m_{bLg} to moment magnitude **M**, as shown on Figures 3.3.3-1 and 3.3.3-2.

Section 3.3.3.2

Add a sentence after the equation indicating the variables Z_{CAN} and Z_{1995} are as defined in Section 3.3.3.1.

Section 3.3.3.3

Suggestion: "~~The~~ A third ~~mb~~ body-wave magnitude scale (m_b) is also more commonly used in the US than in Canada . . . ." Also note that m_{bLg} is used in this section when it should be m_b. Perhaps add a reference for robust regression.

Section 3.3.3.5

Typo in first sentence. Should be surface-wave magnitude (M_S) not "local magnitude M_L"; the same error is in equation 3.3.3-5.

Section 3.3.3.8

The discussion of unknown magnitude (M_U) is not clear. For any given earthquake, how was the decision made as to which conversion should be used?

Section 3.3.4

p. 3-10, line 3: Typo. Change "Section s" to "Sections"

p. 3-10: Following equation 3.3.4-1, the reference to $\sigma_{E[M|X]}$ should perhaps indicate this is illustrated by the confidence interval for the mean shown on Figures 3.3.1-1, 2, 3 etc. for example. We suggest that equations 3.3.4-2 and 3.3..4-3 be double checked as comparison with equations 3-8 and 3-9 in Vol.1. Pt.2 of the EPRI-SOG report indicates some discrepancies. Since the corrected magnitudes are ultimately used to derive the "b-value" one may wish to comment on the sensitivity (or hopefully lack thereof) to the "b-value" used in equation 3.3.4-3. In equation 3.3.4-4 the $\sigma^2_{M|M\ \mathrm{instrumental}}$ is not clear. Is it the 0.1 value assigned to the instrumentally determined values referenced in the paragraph above equation 3.3.4-1?

p. 3-10, last paragraph: The text states, "As discussed in EPRI (1988) uncertainty in the magnitude estimates and its propagation through the magnitude conversion process introduces a bias in the estimated earthquake recurrence rates." It would be helpful to the general reader to add some explanatory detail, rather than placing the burden on the reader seek another publication to understand the purpose or basis of the information that follows.

Section 3.4

p. 3-11, par.1,line 6: The text states, "The standard method of creating a catalog of independent earthquakes developed by Gardner and Knopoff . . . ." It is misleading to describe the Gardner and Knopoff procedure as "the standard method." Researchers in earthquake statistics outside the U.S. would likely use Ogata's well-established epidemic-type aftershock sequence (ETAS) model as the basis for declustering.

p. 3-11, par. 1, next-to-last sentence: In the report, "large" earthquakes are defined as $\mathbf{M} \geq 6.5$, so it is confusing to write "and distance interval about a large earthquake." Suggestion: "and distance interval about a relatively large earthquake."

p. 3-11, par. 1, last sentence: The text states, "If the rate of earthquakes is significantly higher than the background rate . . . , then earthquakes are removed until the rate becomes consistent with the background rate." Does this mean that a few earthquakes that would clearly be declared as aftershocks, say by Gardner and Knopoff, remain in the final catalog in order to match the background rate? In other words, is the declustered catalog not strictly a catalog of main shocks?

p. 3-11, par. 2, second sentence: For clarity (because Figure 3.4-1 contains two plots), consider writing, "The data points in the two plots represent the length in days of individual clusters and the maximum distance between earthquakes assigned to a cluster, respectively."

p. 3-11, par. 3, first sentence: Typo. Change "European earthquake" to "European earthquakes"

p. 3-11, par. 3, last sentence: The narrative describing that the EPRI procedure identifies about 15 percent more dependent events may confuse readers examining Figure 3.4-1. For clarity, consider cautioning the reader not to confuse numbers of dependent events with the number of data points for dependent-event parameters associated with individual clusters on Figure 3.4-1.

Section 3.5

First sentence: Typo. Change "EPRI SOG" to "EPRI-SOG"

p. 3-12, par. 2, line 6: Could not find Figure 8-1 in Report; what is the basis for the boundaries of the completeness regions? For example, how were the boundaries of Region 15 defined, which is one of the new regions? Is there a rationale for including both the Gulf of Mexico and Florida offshore in the same completeness region?

p. 3-12, 4th paragraph: The terms PENB, PENA and WEDT are not defined.

p. 3-12; 6th par., line 2: The text states, "in the time period 1995 to 2008" but in Table 3.5-1 the limiting year is 2009.

Figures

Labeling of page numbers on pp. 3-31, 3-32, and 3-33 needs to be corrected.

Figures 3.3.1-1 through 3.3.1-3

Add more detail to the figure captions, and indicate the 1:1 line and the 90% confidence interval for the mean. Typo in Figure 3.3.1-2: (1994) not (19944).

Figure 3.3.2-1

Lots of lines on the figure with no explanation in the figure caption. What exactly is approximate **M** in this figure?

Figure 3.3.4-1

Is the map of epicenters south of Florida complete to the shown boundary of the study region? If not, explain justification for neglecting these. Was the Caribbean seismicity catalog accessed to determine earthquakes in the study region?

Figure 3.4-1

The text should comment on the very large disparity in cluster duration and spatial dimension for similar magnitudes. Virtually all readers will be left with distrust of the methodology based on these results, absent any additional discussion.

References

EPRI (1988) is missing from reference list.

EPRI reports need to be properly referenced (see next page).

This is how the EPRI reports are referenced in the CEUS/SSC report:

Electric Power Research Institute (EPRI), 1986, Seismic Hazard Methodology for the Central and Eastern United States: Volume 1, Part 2, Methodology (Revision 1): Final Report, EPRI-NP-4726-A-1(1).

Electric Power Research Institute (EPRI), 1989, *Probabilistic Seismic Hazard Evaluations at Nuclear Power Plant Sites in the Central and Eastern United States: Resolution of the Charleston Earthquake Issue*: EPRI Technical Report EPRI NP-6935-D.

The references below are how the EPRI Project documents are referenced in the PEGASOS report.

EPRI-SOG 1986: Seismic Hazard Methodology for the Central and Eastern United States, Electric Power Research Institute NP-4726A, Volumes 1-11.

EPRI 1989: Probabilistic Seismic Hazard Evaluations at Nuclear Power Plant Sites in the Central and Eastern United States, Electric Power Research Institute NP-4726, 9 v.

The PPRP suggests the proper reference is the following:

EPRI-SOG 1988: Seismic Hazard Methodology for the Central and Eastern United States, Electric Power Research Institute NP-4726A, Revision 1, Volumes 1-11.

The EPRI-SOG Project was completed and submitted as “EPRI NP-4726” in 10 volumes to the NRC for review as a topical report. The review was completed in 1988. The report number designation “4726-A, Revision 1” identifies that the report has been revised in response to NRC’s review and that it is accepted by NRC for future use for licensing submittals and contains the NRC’s Review Report and Acceptance Letter. Volume 11 is the NRC’s requests for additional information and EPRI’s responses.

The above noted inconsistency is indicative of the problem with just broadly referencing the EPRI documents within this chapter of the report and the attendant issues with transparency and availability. The PPRP has two systemic recommendations regarding utilization of methods from the EPRI-SOG Project and citations. First, be much more specific when referencing the EPRI studies (i.e. volume, section etc.). Second, the TI Team should strongly consider reproducing and expanding the discussions and developments in the EPRI-SOG report in the CEUS-SSC report. This will enhance clarity and transparency and facilitate utilization of some of the methods by the broader community.

Other references either missing from Chapter 3 and/or that probably should have been cited

Gardener, J.K. & Knopoff, L. 1974: Is the sequence of earthquakes in Southern California, with aftershocks removed, Poissonian? Bull. Seism. Soc. Am. 64, 1363-1367.

Grünthal, G. 1985: The up-dated earthquake catalogue for the German Democratic Republic and adjacent areas – statistical data characteristics and conclusions for hazard assessment. *In:* Proceedings 3rd International Symposium on the Analysis of Seismicity and Seismic Risk, Czech. Ac. Sc., Prague, 19-25.

Reasenberg, P.A. 1985: Second-order moment of central California seismicity. J. Geophys. Res. 90, 5479-5495.

Reasenberg, P., and L. M. Jones (1989), Earthquake hazard after a mainshock in California, *Science* **243,** 1173–1176.

Stepp, J.C. 1972: Analysis of completeness of the earthquake sample in the Puget Sound area and its effect on statistical estimates of earthquake hazard. Proceedings of the International Conference on Microzonation 2, 897-910.

CHAPTER 4 — CONCEPTUAL SSC FRAMEWORK

General Comments

G 4-1. (CBR, CC) Chapter 4 describes the Conceptual SSC framework. This chapter is generally well-written, organized in a logical format, and responsive to early PPRP recommendations for creating a structured systematic approach to SSC, including the establishment of criteria for defining seismic sources. However, it is incumbent on the TI Team to document how these criteria were used to define seismic source zones. While the PPRP appreciates the role that informed judgment has on assessing weights for various branches of the logic tree, these weights must have a documented basis. In response to the PPRP April 7, 2010 letter, the TI agreed that project documentation must provide a detailed (emphasis added) discussion of the criteria that were used to identify seismic sources and a justification for all logic tree branches and weights.

G 4-2. (NAR) The development of Data Evaluation and Data Summary Tables has been extremely important with respect to making the seismic source characterization process more transparent and complete (see detailed comments on these tables). These types of tables represent a foundation upon which future SSC seismic hazard evaluations can be efficiently built. This is particularly true for seismic source characterization projects that have a broad regional extend. The TI Team is to be commended for taking the time to create these tables. The tables include an unprecedented level of information that external reviewers can use to understand the assessments that have been made and represented in the logic trees. An important point that was developed in Section 4.2.2 was that the Data Summary and Evaluation Tables are not intended to replace the documentation of the SSC effort but to supplement it.

Specific Comments

S 4-1. (CC) *Terminology*

The nuanced words “study,” “capture,” and “event” are used throughout Chapter 4, contributing to a lack of clarity. We recommend replacing with words that convey the specific contextual meaning: that is, replacing “study” with “project” or “assessment” as appropriate; “capture” with “represent” as appropriate; and “event” with “earthquake” as appropriate.

S 4-2. (CBR) *Master Logic Tree and Representing the Community Distribution*

The assessment of a conceptual tectonic framework is ultimately represented in the master logic tree as the weights applied to branches of this logic tree (major alternatives related to the overall tectonic framework). Interactions with the broad scientific community in Workshops #1 and #2, and the scientific knowledge base developed through these interactions, informed: (a) the TI Team’s assessments for the conceptual tectonic framework, (b) the TI Team’s evaluations of the hazard significance of various seismic source characterization issues (Section 4.3.2), and (c) development of criteria for defining seismic sources (Section 4.3.3).

For assessment of SSC models of this regional extent, it is now clear to the PPRP that it could have been useful to have additional feedback of the conclusions discussed in Section 4.3.2 and the criteria discussed in Section 4.3.3 to enhance confidence that this information can be used (i.e., appropriately represents the CBR of the ITC) to create a detailed SSC logic tree. From a generic perspective, this should be considered a lesson learned, recommended for Level 3 assessment projects of broad regional extent, to directly link the overall development of the seismic source assessment logic tree with a broader segment of the ITC. The TI Team is strongly encouraged to consider whether additional feedback with a targeted group of subject experts is warranted.

S 4-3. (SSHAC) *Level 3 Assessment Process*

In the first paragraph of Chapter 4, the text states that the justification for the use of a SSHAC Level 3 assessment process is given in the CEUS SSC Project Plan. While the project plan did discuss the selection of the assessment level, this project report must demonstrate that execution of this assessment level is appropriate, resulting in a high quality product consistent with the requirements for seismic regulatory decision-making. We suggest that this sentence be deleted.

S 4-4. (CBR, CC) *"Generic" Data Evaluation (Section 4.2.1)*

The development of Table 4-3 and the discussion of this table are beneficial to this report. The text would be strengthened if at the end of this section the TI Team discussed how they developed the numbers in the table. Specifically past PSHA experience, results from Workshop #2, and discussions with a wide range of people who are part of the ITC were all used to make these assessments (See Comment **S 4-2**). Finally, there should be discussion of how the numbers were or were not used to guide the weights ultimately assigned on the logic tress.

S 4-5. (CC) *Logic-Tree Branches and "Credible" Alternatives (Section 4.1.1.1)*

In Comment **S 1-2**, caution was raised about the use of particular wording that may lead to confusion or invite argument. We offer a similar caution here about declaring that only "credible" alternatives are included in the logic tree. Having to defend the assertion of <u>zero</u> credibility in the case of excluded alternatives can become a red herring. The nature of the TI Team's assessment of a representation of the views of the ITC is explained at great length in Chapter 2. Allowance is made for excluding an alternative view or parameter based on the judgment that its relative weighting would lead to an insignificant effect on the hazard. When discrete probability distributions are used to represent the center, body, and range of a continuous distribution, it is recognized that the distributions have tails of low-to-zero probability. Instead of having to assess exactly where the zero bounds are, acceptable practice allows representing the significant mass of the distribution. We recommend removing "credible" from the section title.

S 4-6. **(CC)** *Methodology for Identifying Seismic Sources (Section 4.3)*

This section would be improved if there were a discussion how Workshop #2 was used to guide the TI Team in terms of developing a methodology for identifying seismic sources.

S 4-7. **(CC, SSHAC)** *Hazard-Informed Approach: Section 4.3.1*

In the last paragraph on page 4-10, the following statement is very confusing, seemingly in conflict with SSHAC guidance, and likely to create controversy:

> "Rather, it reminds us that the purpose of the CEUS SSC Project is to develop a seismic source model to be used in a seismic hazard analysis, and not to attempt to answer or even capture the larger technical community's questions about SCR earthquake causative mechanisms. The exceptions are those cases where a hypothesis might have profound implications on the geometry, Mmax, or recurrence for a seismic source such that it would affect the hazard results."

Perhaps the intent is to convey the fact that the CEUS SSC Project is an assessment based on existing knowledge rather than an attempt of advance knowledge or resolve competing arguments. The two sentences could be removed without loss of continuity. In any case, some clarification is essential.

S 4-8. **(CC)** *Criteria for Defining Seismic Sources (Section 4.3.3)*

It would be appropriate and helpful here to note that geological and geophysical studies of the crust since the 1980s have provided little significant new information about tectonic features and the geological history of the region that may have a bearing on evaluation of seismic hazards. The only possible exception is the improved understanding of the Illinois basin extended zone and its features. However, paleoliquefaction studies have been useful in defining and characterizing seismic source zones.

S 4-9. **(CBR)** *Weights on the Two Conceptual Models (Section 4.4.1)*

One of the critical logic tree assessments is the weights on the two conceptual models used to represent classes of seismic sources. Section 4.3.3 establishes criteria for assessing seismic sources while Section 4.4.1 provides a description of the logic tree elements. This section does not develop a strong argument for the weights assigned, particularly the strong preference assigned to the seismotectonic zone branch. Additionally, it is not clear where the TI Team demonstrates that the development of seismotectonic zones leads to hazard significant changes in the model.

The text states that the development of seismotectonic zones allows for more relevant information on the characteristics of future earthquakes (the third criteria in the sequence defined in section 4.3.3)—but this seems to be a TI Team judgment, as opposed to a documented evaluation and assessment. Section 4.1 (Item #3) makes the point that a methodology for identifying seismic sources that takes into account defensible criteria is a critical attribute of this project, but the project must demonstrate that the TI Team has properly executed these criteria. Perhaps some type of summary table can be prepared to synthesize how the criteria distinguish between seismic sources.

The weight assessed for the seismotectonic branch has increased from 0.33 (August 2009, when three branches were considered) to 0.60 (March 2010) to 0.8 (July 2010 and the draft report). The PPRP notes that these weights could be viewed as somewhat counter to the overall ITC trend that has been documented in the USGS National Seismic Hazard Maps (three cycles including regional workshops) and not necessarily a logical outcome from Workshop #2 of this project. At a minimum, the TI Team needs to bolster their arguments for the weights assigned. The PPRP encourages careful consideration of this issue and the potential need for adjusting the weights toward more parity between the two overall SSC models.

S 4-10. (CBR, CC) *Mmax Zones Logic Tree (Section 4.4.1.2)*

The discussion of the magnitude weighting provides no explanation or basis for the weights. The same holds true for the approach to spatial distribution of seismicity rates (smoothing). PPRP comments on these weights are provided in Chapter 5. Once these comments are addressed these discussions should, at a minimum, refer to specific sections in Chapter 5, and be enhanced to summarize the basis as appropriate.

S 4-11. (DMM) *Table 4-3 (p. 4-41)*

Does "(4) Rift Basins" overlap with "(2) Extended Margins"? Does this include basins formed as a result of regional extension in a Highly Extended Terrain such as the Triassic grabens of the EUS? A comprehensive description of continental rift structures is presented by Olsen and Morgan (Continental Rifts: Evolution, Structure, Tectonics, Elsevier, 1995; Chapter 1). Does "(4) Rift Basins" also overlap with "(5) Failed Rift (Paleozoic and younger)" as in the Oklahoma aulacogen? A failed arm of a rift is a branch of a triple junction that did not develop into an ocean basin. A paleorift that has been reactivated by compressional deformation is an aulacogen, e.g., Oklahoma aulacogen. Does (4) include Precambrian continental rifts that were reactivated in later Precambrian time? Why is "(5) Failed Rift" rated lower than (4) if the Failed Rifts are limited to the Phanerozoic? The Oklahoma failed rift (aulacogen) has the Meers fault, while Recent faulting is not observed on Triassic graben faults, to the best of our knowledge.

Comments on Sections

Chapter 4 (title and introductory text)

Consider spelling out SSC in the title of chapter.

In the first sentence of par. 1, suggested wording change: "for use in future PSHAs."

In next-to-last line of par. 1: Typo. "how ~~that~~ the framework"

On p. 4-1, last sentence: Consider changing "the master logic tree that is the backbone of the SSC model" to "the master logic tree of the SSC model"

Section 4.1

In Item #3, line 1: Consider replacing "that takes into account" with "that is based on"; in

line 2, consider replacing "takes advantage of" with "incorporates"; in line 3, "identifies" instead of "captures."

Section 4.1.1

To more clearly represent the activities described in this section and in the report as a whole, we recommend changing the title of Section 4.1.1 to "*Logic Tree Approach to Representing Alternatives and Assessing Uncertainties,"* conveying that the alternatives represent the center, body, and range of scientific community's knowledge and that the assessed uncertainties represent the community uncertainty distribution.

On page 4-2, last paragraph, line 3: Consider replacing "identifying" with "representing; also in line 10 of the same paragraph.

On page 4-3, 1st paragraph, last line: Consider changing "that express the relative credibility of the alternatives" with "that represent an assessment of the relative credibility of the alternatives"

On page 4-3, last paragraph, line 7: Consider replacing "those assessments that are judged" with "those assessed alternatives"; see also Comment **S 4-5**).

On page 4-4, first full paragraph, line 1: Consider replacing "considered" with "assessed to be"; in line 2, consider replacing "degree of belief" with "assessment"; in line 7, consider replacing “and not worthy of” with “so did not warrant”; in the last line, consider replacing “assigned” with “assessed.”

On page 4-4, 2nd full paragraph, line 2: Consider replacing “assigned to” with “assessed for”; in line 6, consider replacing “the TI Team considered the available data” with “the TI Team evaluated the alternatives using available data”; in line 13, consider replacing “the weights assigned to” with “the weights assessed for.”

On page 4-4, 2nd full paragraph, line 5: When writing that “there is rarely a quantitative basis for assigning these weights,” it should be made clear that this refers to the assessment of subjective probabilities. The CEUS SSC methodology uses five-point distributions to represent quantified continuous distributions of selected parameters.

Section 4.2

On page 4-5, 2nd paragraph, line 1: Consider changing “an attempt was made to provide more structure and transparency” with “more structure and transparency has been provided”; in the next-to-last line, replace “study” with “evaluations and assessments of the TI Team”

Section 4.2.1

First paragraph, line 3: Consider replacing “as the technical community evolves its thinking regarding” to “as the knowledge of the technical community evolves regarding”

On page 4-5, first bullet, line 7-8: Consider replacing “which is an SCR” with “which geologically is constituted of SCR crust”

Section 4.2.2

On page 4-7, last paragraph, 2nd paragraph: The text states that “errors in the data generally exceed the signal” (data referring to geodetic data). It is suggested that this be changed to “errors in the data may exceed the signal.”

Section 4.3

First paragraph, line 2: Consider replacing “three decades in SSC” with “three decades in assessing SSCs”; in line 3: consider changing “community” to “scientific community”; in line 4, consider replacing “a regional PSHA that can be applied” with “a regional SSC assessment that can be applied; in line 5: consider replacing “requires that a methodology include” with “requires that the assessment include”; in the last line, consider replacing “across the study region” with “throughout the regional SSC model.”

In the last paragraph on p. 4-8, Regulatory Guide 1.208 is mentioned with respect to guidance for commercial reactors. ANS Standards 2.27 and 2.29 provide similar guidance for other nuclear facilities, and this should be recognized.

In the first paragraph on p. 4-9, the message conveyed by the first sentence is not clear. Consider replacing the word “intuitive” with “subjective” or “common practice.”

Section 4.3.1

The meaning of the first sentence is not clear and it seems to be inconsistent with the content of the paragraph. It could be deleted, as the following sentence seems to properly introduce the content of the paragraph.

Add P_a to List of Acronyms.

Section 4.3.3

On page 4-14, next-to-last paragraph, line 3: Consider replacing “captured by” with “obtained from”; in the last paragraph, line 7, replace “reasonable assessment” with “reasonable interpretation”

On page 4-15, 3rd full paragraph, line 4: Replace “PSHAs” with “seismic hazard models”

On page 4-16, first partial paragraph, lines 4-5: Consider replacing “Because the CEUS SSC Project is a regional study and not a site-specific study,” with “Because the CEUS SSC Project developed a regional SSC model rather than site-specific one,”

Section 4.4.1

It would be useful to start this discussion with recognition that RLME sources are identified based on well defined evidence for Late Quaternary or Holocene direct evidence of repeated large magnitude earthquakes. Also when discussing the 8th node of the logic tree, the discussion needs to be enhanced, consistent with the information shown on the logic tree figure.

Section 4.4.1.1

On page 4-18, the text refers to Table 4.4.1.1-3, which is not included in the report. Rather it appears to be labeled Table 4-6, which is included in the body of the text of the chapter. We suggest that this numbering be corrected, that the tables be numbered in a consistent manner, and that a List of Tables be included in the report.

On page 4-19, 1st paragraph: In the first sentence, make it clear that the issue is “the temporal clustering <u>of large magnitude earthquakes</u>.”

Section 4.4.1.2

Page 4-20, last paragraph: In the second sentence beginning, "For the CEUS SSC Project . . ." need a connector ("and" or a semi-colon) at the start of the last clause (e.g., "and the prior distributions from that study were reassessed.").

On page 4-21, second paragraph, suggest moving up the last sentence "As discussed in Section 6.2…" prior to the sentence that lists the weights assigned to the logic tree branches.

Four additional review comments relate to the discussion in the second paragraph on p. 4-21:

1. Two alternative locations of the Mesozoic and younger separation branch are identified: the wide and the narrow. Unfortunately, no map is provided for the location of the narrow zone. Reference is made to Figure 4.4.1.2-3 in line 6, which is presumably this map, but it is missing from the report as well as the List of Figures.
2. Figure 4.4.1.2-2 is labeled as showing the narrow Mesozoic alternative, but instead it shows the wide alternative.
3. Note that the caption of Figure 4.4.1.2-2 is not complete in the List of Figures. All captions in the List of Figures should be checked against those given on the figures.
4. The boundary of the project area shown on Figure 4.4.1.2-2 and subsequent figures of this chapter are not the same as shown in the defining figure of the boundary, Figure 1.3-1, and in Figure 4.4.1.1-2. Apparently the boundary in these figures has been modified to incorporate identified seismic source zones in Canada, which is the northeastern segment of the project area. Inconsistent project area boundaries should be avoided to prevent confusion.

Section 4.4.1.3

In the first paragraph, change "shown on Figures 4.4.1.3-2 through 4.4.1.3-7" to "shown on Figures 4.4.1.3-2 through 4.4.1.3-5"

Tables and Figures

The order of presentation of text, tables, and figures needs to be standardized in all chapters. In this chapter, the order is different than in preceding chapters.

Table 4-3

Page 4-39, last row: Assumed the intended wording is small r recent, not capital R Recent. Perhaps a more definitive and less confusing word could be used—perhaps Phanerozoic?

Page 4-42, first row: Suggest replacing "Orientation" with "Fault orientation"

Page 4-42, third row: Suggest adding "High-resolution seismic reflection" in third column.

CHAPTER 5 — SSC MODEL: OVERVIEW AND METHODOLOGY

General Comments

G 5-1. (CC) Chapter 5 provides an overview of the SSC model and some of the methodologies used within that model. This section is generally well written and provides a good description and summary of a number of the technical elements of the SSC model. The work that the TI Team completed to update the SCR database, performing new statistical analyses, and updating prior distributions is an important contribution to improving assessment of maximum magnitudes. However, some specific elements of the model and/or documentation thereof are problematic in the PPRP'S view. Significant changes or additional justifications may be warranted.

G 5-2. (CC) In addition to the PPRP review, to ensure thorough review of the many equations contained in the report, the PPRP recommends that all knowledgeable members of the TI Team carefully examine all equations, especially equations in sections that they were not tasked to write.

Specific Comments

S 5-1. (DMM, CC) *Implications of Kafka's Studies for Spatial Smoothing*

Section 5.1 provides a well-written overview of the approach to spatial and temporal models of earthquake occurrence in the current CEUS-SSC model. Section 5.1.1 describes the TI team interpretation that the spatial pattern of observed seismicity provides predictive information about the spatial distribution of future moderate-to-large magnitude earthquakes. The PPRP notes that the studies by Kafka (2007, 2009, and Workshop #2) indicate this is <u>generally</u> (emphasis added) the case. Various versions of the cellular seismology results presented by Kafka suggest that much (55–85%), <u>but not all</u>, seismicity is predicted by the spatial occurrence of past earthquakes. This suggests that the report should at least discuss the possibility of specifying a very high level of smoothing within source zones. This is utilization of subjective rather than objectively defined smoothing parameters that would specifically define a seismicity floor in some regions.

S 5-2. (SSHAC, CC) *Inconsistency With Principles of Seismic Hazard Model Assessment*

In Section 5.1.2, par. 3, second sentence, the statement: "The TI Team has taken a very cautious approach, however." conveys a clear violation of the SSHAC guidance principals for seismic hazard model assessment; namely the goal to represent the center, body, and range of the community scientific knowledge. An explanation is required. It would be made clearer if "assumed" were replaced with "used" in the last line of this paragraph (and if the awkward sentence were inverted).

S 5-3. (DMM, CC) *Inadequate Description of the Assessment Process*

In Section 5.1.2, the last paragraph on p. 5-3 (continuing on p. 5-4) is critically important, as it introduces the reviewer to the TI Team's assessment of temporal clustering, arguably the most uncertain assessment for the CEUS SSC model. For example, the topic is introduced with the weak statement, "consideration was given to" instead of wording such as "assessed," which links directly to the SSHAC guidance. With similar effect, "considered" is used in line 4, where the word "assessed" would more accurately convey the appropriate action and at the same time connect with the SSHAC guidance. In line 5 continuing on line 6, the physical process would be explained more clearly if the words "based on the concept of" were deleted, leaving the sentence to read: "The physical underpinning of a renewal model is a quasi steady state . . . ." In line 10, it would be clearer to change "concept" to "physical process." We recommend that this paragraph be rewritten, expanding the discussion to convey the state of scientific knowledge about an earthquake cycle in which strain is released as clustered large earthquakes. The most relevant data appear to be the absence of measurable levels of strain accumulation in the Charleston and New Madrid seismic zones, where the short-term geodetic strain rates are in apparent conflict with interpretations of "in-cluster" rates of occurrence of large earthquakes.

S 5-4. (CC) *Weak Support for Conclusion*

In the first paragraph of Section 5.1.3, the last two sentences, beginning with "The TI Team reviewed . . ." convey an evaluation and conclusion of the TI Team that is greatly important for the CEUS SSC model assessment. Yet support for the strong conclusion seems general and weak. Consider elaborating on the basis for the conclusion. For example, the last sentence begins with "With a few exceptions . . . ." Describe the data that permitted the exceptions and describe how the data were used in the assessments.

S 5-5. (DMM, CBR, CC) *Maximum Earthquake Magnitude Assessment*

Section 5.2 describes the methodology for assessing maximum magnitude (Mmax) that was used in the CEUS-SSC Project. The text notes that the maximum magnitude earthquake for any given source zone in regions of low-to-moderate seismicity (such as the CEUS) happens rarely, relative to the period of observation. As a result, the record of historical seismicity provides information, but rarely hard constraints, on the source-specific Mmax value. This fact has led to the investigation of global tectonic analogues to address this issue. The scheme for assessment of Mmax in the CEUS-SSC Project incorporated the uncertainties in both conceptual models and the parameters within models. The approach utilized in the CEUS-SSC Project provides a quantitative and repeatable process for estimating Mmax that is easily updatable if new information becomes available.

The discussion of the development of the Bayesian Mmax approach in Section 5.2.1.1 is generally clear and guides the reader through the development of the approach. The PPRP believes that the significant effort invested by the Project in the update and re-investigation of the global SCR database was worthwhile. This refinement represents a significant advancement for the community. However, the PPRP notes there are points that require further clarification and assessments that require additional justification as noted in the following two comments.

S 5-6. (DMM, CBR, CC) *USGS Mmax Workshop and Mmax Approaches Considered*

In Section 5.2.1, the discussion of the evaluation of alternative approaches to Mmax in the CEUS, lacks any meaningful discussion of the USGS workshop on this topic (Wheeler, 2009), and does not strongly support the TI Team's selection of Mmax approaches beyond the Bayesian approach. The approach developed by Kijko is not the only viable alternative discussed as part of the USGS workshop. Additionally, the approach developed by Kijko was not given much support in the USGS workshop, needing additional study before it becomes commonly used in PSHAs. This section should provide more discussion of the USGS Mmax workshop and the Mmax approaches considered by the TI Team, and why they are, or are not, selected for assessment.

S 5-7. (DMM, CC) *"Kijko Approach" — Terminology and Description*

Defining how this approach or procedure will be referred to in the report and appropriate attribution for its origin need to be established upon first mention. In section 5.2.1 (pg. 5-6, paragraph 3), two alternative approaches are described for estimating Mmax: the Bayesian procedure and "the Kijko (2004) procedure." Later in section 5.2.1-2 (pg. 5-15), the first sentence states: "The Kijko approach (Kijko and Graham, 1998; Kijko, 2004) . . ."

In referring to the "Kijko approach," misleading statements are made. On pg. 5-7 (paragraph 1, last sentence), the text states, "However, the approach relies on the assumption that the distribution of earthquake magnitudes follows a doubly truncated exponential distribution." Later on pg. 5-15 (section 5.2.1.2, paragraph 1, first sentence), the text repeats that the approach is based on the simple assumption that "the distribution of earthquakes in a region follows a doubly truncated exponential distribution." In Kijko (2004, pg. 1) the reader plainly finds:

> "This paper provides a generic equation for the evaluation of the maximum earthquake magnitude $m_{\max}$ for a given seismogenic zone or entire region. The equation is capable of generating solutions in different forms . . . . It includes the cases (i) when earthquake magnitudes are distributed according to the doubly-truncated Gutenberg-Richter relation, (ii) when the empirical magnitude distribution deviates moderately from the Gutenberg-Richter relation, and (iii) when no specific type of magnitude distribution is assumed."

S 5-8. (DMM, CBR) *"Kijko Approach" — Justification of Weighting*

Adding to Comment **S 5-**7 on the TI Team's use of the "Kijko approach" (Section 5.2.1.1), this is an approach that was not identified in the any of the CEUS-SSC workshops as a potential approach. Further, the approach was not discussed in detail at the 2009 USGS Mmax workshop. The Kijko approach is one that is represented by the form: Mmax = M_{max}^{obs} +Δ. At the USGS Mmax workshop this class of methods was given little credence. However, the discussion was mostly focused on models that specified a fixed magnitude increment for Δ (0.5 magnitude unit, for example). Kijko's approach is different in that it utilizes a statistical assessment of seismicity in the region of interest to obtain estimates of Δ (and uncertainties). The approach(es) developed by Kijko have not seen wide usage. The PPRP endorses the utilization of an alternative approach that uses zone-specific data for estimation of this important parameter, but notes that the assignment of equal weights to the Kijko KSB approach and the Bayesian global tectonic analog approach may be inconsistent with the CBR of the ITC. Inspection of the results suggests the Kijko method is only used when it agrees with the Bayesian results. (See also earlier Comment **S 5-5** and Comment **S 5-10** below regarding the justification of the relative weighting of approaches.)

The P(m^u>8.25) threshold of 0.5 does not seem unreasonable, but it does lead to the question of sensitivity of the final distribution to that choice. If P(m^u>8.25) were set to 0.25 or 0.75 what effect would that have on the number of zones for which the Kijko result would be used?

The choice of **M** 4.8 for the lower bound of the Kijko approach needs additional discussion. This leads in some cases (see Section 7) to non-zero probability assigned to Mmax branches of **M** < 5.25 in large source areas. The PPRP is not convinced this result is consistent with the ITC. It will certainly provoke discussion and hence should be justified to the maximum extent practicable.

S 5-9. (DMM, CBR, CC) *Bayesian Mmax Approach*

The discussion of the updated domain dataset analyses in Section 5.2.1.1 (and subsections) is confusing and lacks sufficient information to fully understand what was done. The text states that Table 5.2.1-1 list Mesozoic and younger extended superdomains, yet the table appears to list all ages of extended superdomains (and Table 5.2.1-2 is for all ages of non-extended superdomains). Without listing the actual p-values of the statistical tests it is difficult to appreciate the improvements that are being discussed as you assess subsets of the data. Given that Appendix K only provides tables of the SCR Mmax databases, more specifics should be provided in this section (see also Comments on Appendix K – more detail needs to be provided there also). It is suggested that there be a displayed, on one or more figures, the Mmax-obs distributions for the various classes being compared. Was an assessment made of the impact for using an alternative choice for the lower cutoff of magnitude for each of the domains (such as **M** 5 or **M** 5.5)?

Statistical analyses are good, but not necessarily the only basis for assigning weights to the prior distributions. It seems clear that the Mean Mmax between the two-priors is likely to be important from a PHSA perspective (7.1 versus 6.35). The text states that a stronger weight (0.6) is not assigned to the two priors because the statistical significance of the separation is not strong. Assignment of relative weights should consider the seismologic views of the ITC in addition to any statistical significance—based on the text, the TI Team seems to be making the statistics the primary consideration. Discussion at the USGS Mmax workshop and the public workshops held to support the National Seismic Hazard Maps could suggest that the ITC would put more emphasis on the "two-priors" model (the TI Team's intuitive judgment). The Open-File Report from the USGS Mmax workshop should be reviewed in this context, along with pertinent discussion from Workshop #2. A stronger basis for assigning relative weights is needed.

The description of the methodology to assess Mmax for all seismic sources contains a discussion of the role of the RLME sources in the assessment. The report suggests that a potential problem is that the global SCR database includes events from RLME sources (e.g., New Madrid) and that the Bayesian approach is being applied to non-RLME sources (p. 5-7). It seems that this methodology assumes that all RLME's have been identified in the current model. Otherwise, the model does not consider RLME's that may be found in the future. The report should explicitly describe how the model accounts for non-identified RLME's that may have maximum magnitudes the size of New Madrid or Charleston.

S 5-10. (CBR) *Weights for the Alternative Mmax Approaches (Section 5.3.1.3)*

Given the TI Team's noted high regard for the Bayesian approach, it is difficult to understand why the Kijko approach was assigned equal weight under any circumstances (large number of larger earthquakes). Discussion at the USGS Mmax workshop and the discussion at the regional workshops to support the National Seismic Hazard Maps would suggest that the ITC gives considerably more weight to the global tectonic analog/Bayesian approach. Beyond the Bayesian approach, there were several potential approaches considered at the USGS workshop, thus it is not clear why the TI Team selected the Kijko approach as the only alternative. The Mmax distributions shown in the report appear to be bi-modal in some cases. The TI Team has not properly discussed and justified the weights assigned to the alternative Mmax approaches.

S 5-11. (DMM, U, CC) *Approach to Earthquake Recurrence Assessment*

Section 5.3 describes the approach to earthquake recurrence assessment used in the Project. This section is generally well-written (given the complexity of the topic) but could certainly benefit from the inclusion of additional steps in the derivations and from additional discussion in some places (we elaborate in following comments).

A fundamental assumption of the methodology used in the CEUS-SSC Project (and most others as well) is that the magnitudes of earthquakes in the corrected catalog can be represented as exponential variables with a density function $f(m) = \beta * \exp(-\beta(m-m_0))$. Lombardi (BSSA, 2003, vol. 93, no. 5, pp. 2082–2088) argues that main shocks (i.e., those in the "corrected" catalog) do not satisfy this assumption. Lombardi suggests a different density function for the use with these main events that depends not only on β but on N (the number of events) as well. In fact, her comparisons utilizing Southern California data suggest much lower *b*-values for main shocks than for all the events in the catalog. The PPRP suggests that some discussion of these alternative assumptions be included in the report—and that the methodology used by the TI Team be checked, vis-à-vis implications of the Lombardi paper, to ensure that there is no systematic bias in the maximum-likelihood estimates of *b*-values.

S 5-12. (DMM, CBR, CC) *Smoothing to Represent Spatial Stationarity (Section 5.3.1)*

The argument is presented in this section that the penalized likelihood approach to spatial smoothing of seismicity is superior to other approaches and the only method to be considered in the CEUS-SSC Project. The PPRP does not find this argument to be adequately supported by the report as written in its present form. Keeping in mind that the objective of the SSHAC Level 3 process is to represent the CBR of the ITC, we note that, other than one or two members of the TI team, no other members of the technical community are utilizing the penalized likelihood approach to perform smoothing of observed seismicity. The overwhelming majority of the community is utilizing either a fixed-kernel or adaptive-kernel approach to smoothing. The kernel approaches are conceptually much simpler and easier to implement and, as a result, yield enhanced transparency.

The PPRP notes that in Section 5.2.1 (p. 5-7, 2nd paragraph) the report states, "[I]t was decided that for representing the center, body, and range of views of the informed technical community, the assessment would need to include alternative conceptual models for Mmax." The PPRP wonders if one were to replace "Mmax" with "smoothing technique" in this statement, why the argument presented in Section 5.2 would not apply in Section 5.3.

The penalized likelihood method, as developed in the EPRI-SOG Project and in the present report, possesses some very positive attributes. Some are briefly discussed in Section 5.3.1 but developed more fully in Section 5.3.2.4. It would enhance clarity to refer the reader to Section 5.3.2.4 in Section 5.3.1.

While the TI Team recognizes that the selection of the smoothing option requires expert judgment, the text goes on to note that "The smoothing operation within the distributed seismicity zones results in variations of *a*- and *b*-values over scales that were judged by the TI Team to be reasonable . . . ." The report has not provided an adequate basis for making this statement. The text does not compare the computed smoothing results to other studies, and does not point to any explicit data that indicates that the seismicity parameters fall within a reasonable range.

S 5-13. (DMM, CC) *Penalized Likelihood Function — Differences with EPRI-SOG?*

In Section 5.3.2.1 the model for the penalized likelihood function for recurrence parameters is formally developed. Many aspects of the approach appear to be similar to those of the EPRI-SOG Project. It would be useful to specify the differences in the present approach relative to the EPRI-SOG Project. The PPRP identifies the following differences (or at least this section of the current report is not clear enough to be sure if these are in fact differences relative to the EPRI-SOG Project):

1. One of the attributes of the EPRI-SOG model was the simultaneous solution of recurrence parameters and incompleteness. On pg. 5-23 the text states the probability of detection (P_D) values are calculated in Section 3.3.3 (typo-this should be Section 3.5). This statement plus the remainder of Section 5.3.2.1 give the appearance that P_D is calculated independently and no longer simultaneously solved for.
2. The smoothing functions are now analytically determined (objective estimates) as opposed to the general, judgment-based smoothing specified by the expert teams in the EPRI-SOG study.
3. The use of the Monte Carlo-Markov Chain simulation approach to develop alternative maps in the present study as opposed to the parametric bootstrapping used in the EPRI-SOG study.
4. The use of quarter-degree cells instead of one-degree cells and only using the cells that share sides (4 nearest neighbors instead of 8).

S 5-14. (DMM, CBR, CC) *Model for the Penalized Likelihood Function — Need for Scrutiny*

The development of the statistical approaches used in this Section 5.3.2.1.1 should undergo independent review either using an appropriately qualified member of the TI Team or an outside expert. It is not sufficient to simply provide a description of the approach used. To facilitate a thorough and transparent review, the software developed should be made available for use in the review process.

The text implies that selecting a small cell dimension, more cells, is an improvement relative to larger cell dimensions. It is not clear, from a seismologic perspective, considering the short historic record, why this would be the case. Review of the alternative recurrence maps (Appendix J) suggests that there are broad areas where the rates of **M** > 5 are effectively zero, there is wide variation (several orders of magnitude) in rates and *b*-values between alternatives, with generally lower *b*-values (< 0.8). It is not clear how the choice of cell dimension may have impacted these observations.

This section has not adequately demonstrated how the method chosen quantitatively compares to other methods such as the kernel approach. While section 5.3.2.4 provides some discussion, it is not sufficient by itself to support the sole use of the method chosen. It appears that the TI Team is using the argument that *b*-values are not constant within a “larger” seismic source. The variation (or lack of variation) of *b*-values is subject to considerable discussion within the ITC. What is the basis for supporting the position that the variation of *b*-values is consistent with the views of the ITC?

The weights on the reduced-weight option for the magnitude intervals listed on Table 5.3.2-1 are not properly discussed and justified. Presenting only two figures as a demonstration that the approach is not sensitive to these weights is not compelling. What was the basis for assigning these weights to each of the magnitude intervals?

A few additional aspects in Section 5.3.2.1 could certainly be clarified further to enhance readability and understanding:

- The reader is challenged to derive 5.3.2-11 from 5.3.2-9.
- What is the basis for eight alternative maps as opposed to four or ten?
- Section 5.3.2.3 is not clear enough to understand the generation of the alternative maps from the eigenvalues and eigenvectors of the covariance matrix **Sx**.

S 5-15. (CBR, CC) *Application of the Smoothing Model (Section 5.3.2.2)*

In Section 5.3.2.2, no basis is given for weights on *b*-value priors. The alternatives are shown to be unimportant later, indicate that fact in this section to avoid confusion over the lack of basis for weights.

S 5-16. (DMM,CBR, CC) *Constant b-value Kernel Approaches*

Section 5.3.2.4 discusses the constant *b*-value kernel approaches to smoothing of seismicity. The PPRP believes that significantly more discussion and comparisons are needed to justify the use of a sole unity-weighted branch in the logic tree for this important choice of model. We note that one of the strengths of the penalized likelihood approach, relative to the fixed *b*-value approaches, is the ability to allow for coupled rate and *b*-value behavior within sources. However, the results shown in Figures 5.3.2-3 and 5.3.2-5 suggest the penalized likelihood approach with the CEUS data yields very high smoothing levels on the *b*-value. In other words, the data may be insufficient to make a strong case between variable and fixed *b*-value approaches at the seismic source level—thus significantly reducing one of the strengths and justifications for the penalized likelihood approach. Additional comparisons with the fixed *b*-value kernel smoothing approaches are warranted.

S 5-17. (DMM, CC) *Seismogenic ~~Crustal~~ Thickness*

In the title and text of Section 5.4.1.4, the term should be "seismogenic thickness" not "seismogenic crustal thickness." The statement that the focal depth distributions of well-studied earthquakes established the basis for the assessment of seismogenic thickness is overly generalized. This section goes on to note that the base of the seismogenic zone is identified as lying near the base of observed focal depths at about the 95th-percentile depth; review of the depths listed in the updated earthquake catalog would suggest that a depth of 13 km may not be consistent with recorded data. If there are specific "well-studied" earthquakes used to establish the TI Team's assessment, these should be listed and summarized. Later in Chapter 6 when discussing the assignment of crustal thickness to specific seismic source zones, the report appears to ignore the stated intent that observed focal depths at about the 95th-percentile depth is an important consideration.

S 5-18. (CC) *Relationship of Rupture to Source Zone Boundaries*

In Section 5.4.1.7, the discussion of strict versus leaky source boundaries is not clear. While it is recognized that TI Team judgment is important here, it seems that some type of systematic approach would be appropriate. It may be important to note that the assumed rupture dimension relationships establish limits that must be explicitly considered in assigning strict versus leaky, and that this constraint is considered on a case-by-case basis. Otherwise it is not clear why some RLME sources move from strict to leaky, given the defined boundary. The same is true for difference between seismotectonic source zones—why are some leaky and some strict?

S 5-19. (CC) *Assessment of Future Earthquake Characteristic*

In Section 5.4, the introduction of Table 5.4-2 invites discussion before the reader has a chance to read the specifics related to each seismic source in Chapters 6 and 7. It is suggested that this table be split into two tables that can be provided as useful summaries at the end of Chapters 6 and 7, respectively, for the sources zones discussed in those chapters. In this way, the reader will have had the benefit of understanding the TI Team's basis for the source-specific weights that are assigned.

Comments by Section

Entire Chapter 5

Throughout Chapter 5, we recommend that "event" not be used as a synonym for "earthquake." In order to achieve the needed clarity for a regulatory document, we recommend making a blanket search to replace "event" with "earthquake" where that meaning is the case. Other instances of confusing uses of synonyms are identified elsewhere in the following comments.

Section 5.1.1

First sentence: Replacing "led to the belief" with "led to acceptance" would be clearer (note that in line 4 the word "conclusion" is used).

On p. 5-2, par. 2, line 9: Suggest replacing "secondary effects" with "liquefaction phenomena associated with them"

In the same paragraph, line 10: Suggest replacing "paleoseismic events" with "paleoearthquakes interpreted using the distribution of liquefaction phenomena"

In the same paragraph, last line: Replace "studies" with "SSC model assessments"

On p. 5-2, par. 3, line 3: Change "EPRI-SOG study" to "EPRI-SOG Project"

In the same paragraph, line 8: Suggest replacing "capturing" with "representing"

In the same paragraph, line 10: Change "in EPRI-SOG" to "in the EPRI-SOG Project"

Sections 5.1.2

In the first paragraph, line: Change "PSHA" to "SSC model assessments"

In the same paragraph, last line: Change "PSHAs" to "SSC model assessments"

On p. 5-3, par. 2, line 9: Change "CEUS SSC study" to "CEUS SSC Project"

Section 5.1.3

In the second paragraph, suggest rewording the first sentence to read: "Another area of ongoing research with potential implications for recurrence behavior relates to geodetic strain-rate measurements."

Section 5.2

In the first line of the second paragraph: Consider deleting "issue" and change "EPRI-SOG study" to "EPRI-SOG Project"

Section 5.2.1

In the first sentence of the first paragraph: Suggest replacing "calls for" with "incorporates"

Section 5.2.1.1

On p. 5-11, sequential paragraphs describe the results of performing Student's *t*-test as yielding "a very high probability (*p*-value)," then "a lower *p*-value," and then "a further reduction in the *p*-value." But the *p*-values are not given! Finally, the fourth paragraph reports the results of an additional step that "yielded a *p*-value of 0.14." The other *p*-values also need to be reported and documented for the reader to evaluate whether the extended and non-extended superdomain classifications are statistically significant.

Section 5.2.1.1.1

In the first paragraph, line 4: Consider replacing "known stress" with "known characteristics of tectonic stress"

In the next paragraph, first sentence: Change "study area" to "model region"

Section 5.2.1.1.2

In the first sentence: Consider replacing "applicable" with "appropriate"; change "study region" to "model region"

Section 5.2.1.1.3

In the first sentence: Replace "assigned" with "assessed"

In the same paragraph, line 3: Consider replacing "an intuitive" with "our subjective"

Section 5.2.1.1.4

In the second sentence, line 2, delete "likely"; in line 3, change "For this study" to "For this project"

Section 5.2.1.2

In the last line of the first paragraph: Consider deleting "*possible"* (or explain)

On p. 5-16, in the second full paragraph, line 4: Consider deleting "relatively" (or explain)

On p. 5-16, in the last full paragraph, line 6: Replace "decided" with "assessed"; in the last sentence of this same paragraph, consider replacing "the following key assumptions are made in the application of" with "the following constraints are placed on the application of"

On p. 5-17, first bullet: Replace "accounted for" with "assessed"

On p. 5-17, third bullet: Consider replacing "regard for" with "reliance on"

Section 5.2.1.3

In the first paragraph, line 3: Consider replacing "assigning weights to" with "weighting"

In the same paragraph, lines 4 and 6: Consider replacing "assigned" with "assessed"

Section 5.2.1.4

In the first paragraph, line 5: Consider replacing "assigned" with "assessed"

On p.5-18, in the partial paragraph at the top of the page: Consider replacing "assigned" with "assessed"

On p. 5-18, first full paragraph, lines 3 and 7: Consider replacing "assigned" with "assessed"

On p. 5-18, second full paragraph, line 3: Consider replacing "assigned to" with "assessed for"

Section 5.3.1

In the last paragraph on p. 5-19, line 9: Replace "study region" with "CEUS SSC model region"

On p. 5-20, first full paragraph, last sentence: Consider replacing: "were judged by the TI Team to be reasonable, given the technical community's views" to "were judged by the TI Team to represent the technical community's views"

Section 5.3.2.1.1

Regarding m_0 and the definition of v: Is v in fact calculated for $m > m_0$ or $m \geq m_0$ (e.g., McGuire, 2004; Weichert, 1980)? If calculated as the latter, then corrections should be made to equation 5.3.2-1 (and associated text on pg. 5-20), on pg. 5-29 (paragraph 2, line 2), and perhaps elsewhere.

On p. 5-21, third line from the top of the page: Change "This study" to "This project"

On p. 5-22, par. 4, line 2: Consider replacing "one may wish to assign lower weights to lower magnitudes" with "the assessment may result in a lower weight on lower magnitudes"

In this same paragraph, second sentence: Consider replacing this sentence with "For instance, the magnitude-recurrence law may deviate from exponential, or the magnitude-conversion models or completeness model may be less reliable for lower magnitudes."

On p. 5-22, last paragraph, line 1: Consider replacing "considered" with "incorporated"

On p.5-23, par. 1, line 5: Change reference to "Section 3.3.3" to "Section 3.5"

On p. 5-25, last full paragraph: Consider replacing "are specified by the expert teams on the basis of judgment" to "are assessed by the expert teams on the basis of their evaluations"

On p. 5-26, first text line at the top of the page: Change "study" to "project"

On p. 5-26, first full paragraph, line 4: Consider replacing "refer to" with "formulate"

On p. 5-26, par. 3: In line 1, change "Equation 13" to "Equation 5.3.2-13"; in line 2, consider changing "a characterization" to "an assessment"; in lines 7–8, consider replacing "An additional, practical requirement is that one must represent the epistemic uncertainty by means of a small number of " with "An additional practical requirement is that epistemic uncertainty must be represented. This can be accomplished by means of a small number of "

On p. 5-27, par. 3, line 4: Change "Equation 15" to "Equation 5.3.2-15"

On p. 5-27, par. 4, lines 7–8: Typo. "maps ~~of~~ to represent"

Section 5.3.2.2.1

On p. 5-29, second bullet: Change "in EPRI-SOG" to "in the EPRI-SOG Project" and change "study region" with "SSC model region"

Section 5.3.2.2.2

On p. 5-31, first full paragraph, line 6: Replace "assigned" with "assessed"; in line 7, consider deleting "reflected"

Section 5.3.2.3

Last line: Consider replacing "small-scale" with "local"

The first example used to examine model results in parameter space needs to be more explicit in describing how the expected earthquake counts in the polygons are derived. It would also be helpful to discuss the data error bars for the magnitude bins with no events. The figure captions for these figures need additional information.

Section 5.3.2.3.1

On p.5-32, par. 2, line 1: It is an overstatement to claim that Figures 5.3.2-20 and 5.3.2-21 show a "very close" agreement between model and data. In the following paragraph, "good agreement" is claimed between model and data for results shown on Figures 5.3.2-22 and 5.3.2-23. Admittedly, such statements are qualitative, but don't stretch the reader's credulity.

Section 5.3.2.4

In the first paragraph, first sentence, change "this study considered" to "this project evaluated"; in line 3, change "considered" to "evaluated"; in line 4, change "study" to "project"

In the second paragraph, line 2, change "has been specified subjectively" to "has been assessed subjectively"

On p. 5-34, next-to-last paragraph, line 6: Consider changing “idea” to “understanding”

Section 5.3.3.1

Equation 5.3.3-2 should be checked. The N! in the denominator appears to be an error. Because the normalization procedure used to generate the probability density function for λ isn’t explained, it’s not evident why the y-axis values are so low (0.00, 0.02, 0.04). Rescaling the x-axes of both plots would be helpful to avoid the awkward labeling of 5e-05, etc., making it easier to read the plots. Checking the five discrete levels on the CDF points to an error in Table 5.3.3-1: The value of cumulative probability in column 1, row 1 can’t be 0.304893 (other values in the table suggest it should be 0.034893).

Section 5.3.3.1.3

First paragraph: In the first sentence, consider replacing “is generally used to represent uncertainty in the inputs” to “is used to represent uncertainty in the SSC model “inputs”; in the last sentence, change “CEUS project” to “CEUS SSC Project”

Section 5.3.3.1.3

In the section title, consider changing “Estimation” to “Assessment”

Section 5.3.3.1.3

On p. 5-39, par. 3, line 1: Note that a 50-year life is stated elsewhere

On p. 5-39, last line: Missing word. Insert “on the time before present”

Section 5.3.4

In the section title, consider “Assessment of RLME Magnitude Distribution”

First paragraph: In the first sentence, consider deleting “are intended to”; in line 6, change “study” to “project; in line 7, consider deleting “set to be”; in the last sentence, consider substituting “is” for “was chosen as”

Section 5.4* (and *Tables 5.4-1 and 5.4-2

Some additional discussion is required to explain the bases for the development of weights for the characteristics (or improved cross-referencing).

On p. 5-41, par. 1, line 5: Consider deleting “a consideration of”

On p. 5-41, par 2, line 7: Consider replacing “considering” with “evaluating”

Section 5.4.1

First paragraph: In line 3, consider replacing “considered” with “evaluated”; in lines 7–8, consider rewording the last clause to read: “the assessed values in column 2 of the table are based on assessments by the TI Team of the default characteristics that represent the current state of scientific knowledge”

Section 5.4.1.3

In the first sentence: Consider rewording to read: “information about the characteristics of earthquake sources, modeled as finite faults in much the same manner as earthquake sources are modeled in the WUS.”

In line 6, consider replacing “in light of” with “using”

In the last line: Consider deleting “largely” (or explain) and replacing “consideration” by “evaluations”

Section 5.4.1.4

In line 2: Consider deleting “upper” (or explain)

In line 4: Replace “study” with CEUS SSC Model”

On p. 5-43, first partial paragraph at top of page: In line 1, consider replacing “some” with “a high”; in line 2, replace “study” with “CEUS SSC Model”

Section 5.4.1.5

In line 5: Replace “capture” with “represent”; in line 6, consider rewording to read: “The relationship used (Somerville et al., 2001)”

In the last line: Replace “study” with “assessment”

Section 5.4.1.6

In line 2: Consider replacing “a consideration” with “an evaluation”

In line 4: Replace “assumed to be equidimensional” to “assessed to be equidimensional” and change “For progressively larger areas” to “For progressively larger rupture areas”

In line 6: Consider deleting “it was assumed that”

In line 10: Consider deleting “assumed to be”

In line 11: The NAGRA approach should be explained, as reviewers are unlikely to have this report.

In the last line: Consider replacing “associated with” with “of”

Section 5.4.1.7

In line 1: Consider replacing “Assuming” with “For”, and “assumed to have” by “defined by”

In line 2: Replace “defined” with “represented”

In line 5: Replace “assigned to” with “assessed for”

Table 5.2.1.1

Does the last row contain numbers of earthquakes “Greater than **M** 4.5” or $\geq$ **M** 4.5?

Figures 5.2.1-7 and 5.2.1-8

Typo in legend. Change “Disribution” to “Distribution”

CHAPTER 6 — SSC MODEL: Mmax ZONES BRANCH

General Comments

G 6-1. (NAR) The core of the TI Team's assessment of the Mmax zones approach within the CEUS SSC model is described in this chapter. As such it is a critical chapter understanding of the assessment by future users. The TI Team has described an immense amount of data together with its evaluations of these data in characterizing and assessing this branch of the CEUS SSC model; in doing so the TI Team generally has described the assessment in sufficient scope and detail to inform future users of the model.

G 6-2. (CBR, U) Chapter 6 is generally well written. The discussion of each of the RLME sources is laid out logically providing a general description of the source, localizing feature(s), geometry, recurrence, and maximum magnitude. However, the basis for some of the assessments is not clearly articulated. Some specific examples are mentioned below, but the PPRP recommends the TI Team review all the subsections with an eye to improving the clarity and strength of the bases for assessments. For example, it is not always clear why one source is using the generic seismogenic crustal thickness assumptions while others are not. The same holds true for differences in assessed weights for clustered behavior. Another example is the empirical relationships used to derive magnitudes given assumed dimensions for seismic sources. To the extent possible, the TI Team needs to clearly establish their overall approach to assessing these weights; in some instances additions to Chapter 5 should be considered to establish the basic approach to how the TI Team decided to modify generic weights, or what generic data (discussed in Workshop #2?) influence the assignment of weights to individual seismic sources.

G 6-3. (CC) In the 3rd paragraph of Section 6.1 the report states: "By identifying the RLME sources and including them in the model, there is no implication that the set of RLME sources included is, in fact, the total set of RLME sources that might exist throughout the study region." This sentence and the remainder of the paragraph make a very important point about a fundamental assumption included in this model. This point needs to be articulated, specifically in Section 4 of the report as well.

Specific Comments

S 6-1. (CC, SSHAC) *Achieving Clarity Necessary for Future User*

The importance of Chapter 6 for informing future users of the CEUS SSC model places a heavy demand on the TI Team to clearly document its assessment. As a framework for achieving necessary clarity of documentation, it may be useful for the TI Team to keep in mind the steps involved in implementing the SSHAC assessment process: (1) compiling the community knowledge; (2) compiling the relevant data; (3) evaluating the community's knowledge, understanding the community's uncertainty, and characterizing alternatives for assessment; and (4) assessing weights for the alternatives representing the community uncertainty. Generally the TI Team has provided very thorough documentation of steps 1 and 2 in this chapter. Documentation of steps 3 and 4 is often less clear. Much of the lack of clear presentation can be attributed to misuse of terms. This is particularly evident in descriptions of the TI Team's assessments where many different words (define, characterize, modeled, given, constrain, allowed, chosen, assign, assumed …) are used for assessment. In addition to conflicting meanings, the impact of using words with such diverse meanings for the core SSHAC methodology requirement, namely "assessment," is that they undermine the essential discipline that a SSHAC assessment requires. Other instances of misuse of terms coupled with lack of completeness in descriptions detract from the reviewers' understanding of the evaluations performed and weaken the usefulness of the document for future users. Consider as an example the following edited first paragraph of Section 6.1 compared to the original.

> By definition, RLME sources are the locations of repeated (more than one) large-magnitude (**M** ≥ 6.5) earthquakes in the historic and (or) paleoearthquake record. Because of the rarity of repeated large-magnitude earthquakes relative to the period of historical observation, evidence for these earthquakes comes largely from the paleoearthquake record. For example, paleoearthquakes identified by interpretations of paleoliquefaction features and fault displacement (paleoseismic) studies combined with those in the historical record result in the catalog of large-magnitude earthquakes in the central New Madrid region and at Charleston. At Charlevoix, RLMEs are observed in the historical record and are supplemented by the paleoearthquake record. For the Meers and Cheraw faults as well as the Wabash Valley source, there are no large-magnitude earthquakes in the historical record. The RLMEs for these sources are characterized by evaluating repeated surface-faulting displacements identified in trenches across the faults and, for the Wabash Valley source, by interpretations of the geographic distribution of paleoliquefaction features.

S 6-2. **(CC)** *Improving the link to the Data Summary and Data Evaluation Tables*

Prior to discussing specific seismic sources, the reader should be reminded that the information in the Data Summary and Data Evaluation tables provides a comprehensive assessment of the current information related to each seismic source. It is the PPRP's view that external readers and reviewers of the CEUS report need to be at least familiar with those tables prior to objectively commenting on the TI Team's assessment. This section would also benefit from a brief discussion of how the earthquake recurrence for RLME sources was modeled, specifically how the lower-bound magnitude for integration for these sources was established by the TI Team.

S 6-3. **(DMM, CC, U)** *Earthquakes of **M** ≥ 6.5 in the Charlevoix RLME*

The first paragraph in Section 6.1.1 describes <u>two</u> historical earthquakes of **M** ≥ 6.5 (one of **M** 7 in 1663 and one of **M** 6.5 in 1870). The reader is then pointed to the Charlevoix RLME logic tree (Figure 6.1.1-2) which has branches for the "Events/Data" node that do <u>not</u> appear to include the two historical earthquakes in the stated event count for **M** ≥ 6.5 (e.g., "3 eqs in 9.5–11.2 kyr"). Section 6.1.1.2 goes on to describe paleoearthquakes, including one "historic" paleoearthquake with "a bracketed age of at least 540 yr BP." These descriptions need to be clarified for the reader to understand the basis of rate information.

To appearances, the RLME rate information and calculated uncertainties for Charlevoix in the HID (Appendix H, Section 5.2) <u>do not account for the two historical earthquakes</u> in 1663 and 1870—only the paleoearthquakes. (For an example of better clarity, see the logic tree and HID tables for the Charleston RLME, where the reader is explicitly informed with labeling such as

"1886, A, B, C" that the count includes one historical earthquake and three paleoearthquakes.) Adding to the problem of event counts, the text in Section 6.1.1.2 (first sentence of par. 2) states that "Tuttle and Atkinson (2010) provide evidence for at least three Holocene paleoearthquakes in Charlevoix with **M** ≥ 6.2 . . . ." If 6.2 is not a typo, then an assessment has to be made for how many of those events were of **M** ≥ 6.5 (or explain assumptions).

S 6-4. (U, DMM, CBR, CC) *Unclear Interpretation Impacting Uncertainty*

In Section 6.1.1.2, par. 3, the third sentence states, "Focal mechanisms for earthquakes of magnitude ≥ 3 show reverse faulting, whereas smaller-magnitude earthquakes indicate some strike-slip and normal faulting, suggesting that local stress conditions affect rupture style (Lamontagne and Ranalli, 1997)." This indicates that there is a local source of tectonic stress. If this is the intent, the interpretation would be in conflict with the community's knowledge and would require additional evaluation of uncertainty.

S 6-5. (CC, DMM) *Charlevoix—Geometry and Style of Faulting*

In the fourth paragraph of Section 6.1.1.2, while discussing the geometry and style of faulting for the Charlevoix RLME, the report indicates that future ruptures for this source are modeled as randomly-oriented thrust faults with dips between 45 and 60 degrees in either direction. Later on p. 6-6 the report indicates the RLME boundaries should be treated as leaky with ruptures permitted to extend beyond the source boundaries. There are a number of questions that arise in interpreting these statements that apply to several other RLME sources as well. The preceding paragraphs of the section describe fault orientations derived from small magnitude earthquakes. Keeping in mind the fact that a RLME source is for large (**M** ≥ 6.5) earthquakes and hence requires large rupture areas, the applicability of these results for small-magnitude earthquakes needs to be carefully explained.

For the RLME sources it is not clearly explained what assumptions are being made regarding the recurrence model, i.e. is it Mmax ± 0.25 magnitude unit about each of the four identified Mmax values (noted briefly in Section 5)? This would be a "perfectly characteristic" or maximum-moment type model. This represents the epistemic uncertainty in Mmax plus the aleatory variability in the future occurrence of each of the characteristic events. The "interaction" between the lower ranges of magnitudes for the characteristic RLME source that will overlap with the upper end of the truncated exponential distribution being applied for the Mesozoic Extended Mmax source zone needs to be explained. This point is true for all the RLME sources. Since Charlevoix is the first of the RLME sources described, the TI Team should clearly explain these issues in this section.

S 6-6. (CC) *Charlevoix—Maximum Magnitude*

In the last paragraph of Section 6.1.1.3, the discussion of boundary dimensions leading to the TI Team's conclusion that the boundary is leaky requires more discussion. Given the assigned Mmax values, are the boundary dimensions too small to fit these magnitudes fully within the boundaries? To the extent possible quantitative discussion should be provided.

S 6-7. (DMM, CC) *Unclear Logic for Performing Assessment*

In the first paragraph of Section 6.1.2.1, the meaning of "time periods of interest" as used is not clear. Is it the projected life of an NPP, the projected life of the CEUS SSC model, a geologic time period? In any case it is not clear how "time periods of interest" influences an assessment of whether tectonic strain release in the Charleston area is in or out of a cluster. Moreover, the TI Team must explain its evaluation, characterization, and assessment of the community's knowledge about tectonic driving forces and the physics of tectonic strain release in a clustered sequence of large earthquakes at about 500-year intervals in the absence of any measurable strain deformation. Otherwise, the reviewer and potential future user of this report will not be able to understand the basis for the assessment.

S 6-8. (CBR, U) *Charleston—Evidence for Clustered Behavior*

In Section 6.1.2.1, the TI Team's assessment of "in" or "out" of a cluster requires more justification. While the TI Team appropriately discusses the evidence of long-term versus short-term behavior, the fact remains that there is direct evidence of repeated large earthquakes in the Holocene and little if any direct evidence that we are at the end of a cluster. Perhaps there needs to be some type of generic discussion of this issue in Chapter 5, with Workshop #2 providing the ITC background to characterize and assess this issue. Otherwise the assessment that we are at the end of a cluster seems to come across as somewhat arbitrary versus informed assessment. What is different between Charleston and other RLME sources such as Cheraw?

S 6-9. (CC) *Charleston—Geometry and Style of Faulting*

In Section 6.1.2.3, the discussion of boundary dimensions leading to the TI Team's conclusion that the boundary for the three source geometries is either strict or leaky requires more discussion. Given the assessed Mmax values, are the boundary dimensions too small to fit these magnitudes fully within the narrow source boundary relative to the other two source definitions? To the extent possible, quantitative discussion should be provided. The TI Team's assessment of using the default values for seismogenic crustal thickness requires additional justification. While all of the references cited for seismogenic crustal thickness are within the range for the default values, several suggest more preference (higher weight?) for values between about 15 and 20 km. Given this, the basis for assessing a weight of 0.4 to a seismogenic crustal thickness of 13 km is not clear.

S 6-10. (CC) *Charleston—Weights for Charleston Narrow and Regional Sources*

In Section 6.1.2.3.1, the discussion of the basis for the weight assessed for the Charleston Local Source seems well developed. However, the discussion for the relative weighting of the Charleston Narrow and Regional sources is not clear.

S 6-11. (U, DMM, CBR, CC) *Contextual use of the term "microseismicity"*

In Section 6.1.2.3.1, first paragraph, the use of the term "microseismicity" potentially leads to confusion about tectonic processes. "Seismicity" is defined in terms of the spatial and temporal occurrence of earthquakes, a generally accepted measure of space-time tectonic strain release in earthquakes. The term "microearthquake" is now generally accepted to mean an earthquake of

M ≤ 3. But the PPRP is not aware of a community definition of the term "microseismicity." Consequently, the TI Team needs to explain its use of the term in the context of this evaluation. For example, is "microseismicity" used to mean "seismicity of microearthquakes," possibly implying a strain cycle process that is different from that implied by "seismicity"? The discussion should clearly convey how the TI Team evaluates "microseismicity" as one of the four observations cited as the basis for assessing the "Charleston Local source zone"?

S 6-12. (CC, DMM) *Charleston—Recurrence*

Given the uncertainty in length and completeness of the paleoliquefaction record and interpreted number of separate episodes, and the very general description of the process used to develop recurrence values contained in Section 5.3.3, the PPRP strongly encourages the TI Team to include a step-by-step example of the application of the procedure used for at least one of the RLME sources. This should include additional figures and text. This will significantly improve clarity and transparency. Consider the following criticisms, some of which apply to recurrence calculations and corresponding HID tables for other RLMEs:

In Section 6.1.2.5, the recurrence method is noted to be "based solely on inter-event times estimated from the paleoliquefaction record." What this section fails to communicate clearly to the reader—especially amid the elaborate analysis and description of those inter-event times—is that the methodology used to calculate the annual frequency of earthquakes of **M** ≥ 6.5 (Section 5.3.3.1.2) ultimately uses only <u>the elapsed time since the oldest event in the sequence</u> and the number of events counted. The Charleston RLME logic tree (12th node), for example, points the reader to the HID tables. Referring to those tables, it will not be readily evident to the reader that the key pieces of information are N and the elapsed time since the oldest earthquake in the sequence of N events. Also, given that the oldest earthquakes (Table 6.1.2-1) have an age specified by a <u>range</u>, an explanation is needed whether (or how) that uncertainty was addressed.

The unalert reader (or analyst) examining the HID tables for computed annual frequencies for the Charleston RLMEs may potentially be confused by: (1) the <u>inverted</u> order for the 5-point distributions compared to Table 5.3.3.-1, which was used to define the 5-point distribution; and (2) the need to refer to Tables 6.1.2-1 and 6.1.2-2 to discern the elapsed time since the oldest earthquake counted in the sequence. For example, examining "Table Charleston_HID-3," it may escape the reader's attention that the 5-point distribution is not for four events in 5500 years, but rather four events in 1,524–1,867 years (or possibly in 1,569–1,867 years). <u>To reproduce the results in the table (and for virtually all the Poisson-model tables in the HID), there is no explicit information about the exact elapsed time that was used</u>. To add to the confusion, the text does not explain what the age ranges listed in Tables 6.1.2-1 and 6.1.2-2 represent. Do they represent the mean ± 2 sigma from the probability distributions in Figure 5.3.3-2?

As the reader progresses to the BPT renewal model there are terse descriptions of the weighting (without justification of the weights) and cross reference to Section 5.3.3 for methodology—but the text does not provide any discussion of the results. How do the BPT results compare to those for a Poisson model? Do they make sense?

S 6-13. (CC) *Charleston—Time Period for Recurrence*

In Section 6.1.2.5.2 the discussion of the completeness period of the paleoliquefaction record (at least the last three sentences) seems equivocal. However, the weight assessed for the shorter completeness period, 0.8, indicates a strong preference; additional discussion seems required to justify the strong weighting.

S 6-14. (U, CC) *Clear Representation of the Community's Knowledge for Characterizing Alternatives and Uncertainties*

The discussion in Section 6.1.2.5.3 calls attention to the need for clear representation of the community's knowledge and uncertainty as the basis for characterizing alternatives in the logic tree and for assessing the community uncertainty. We offer the following edited paragraph as an example for comparison with the original paragraph:

> The ninth branch of the Charleston logic tree represents alternative characterizations of the community's knowledge and the TI Team's assessment of the community uncertainty for recurrence of large earthquakes in the Charleston Seismic Zone, developed as part of the CEUS SSC Project (Figure 6.1.2-1). Alternative interpretations of the distribution of liquefaction features include a total of four large earthquakes in the past approximately 2,000 years and between four and six large earthquakes in the past approximately 5,500 years. The alternative characterizations represented in the logic tree are based on (1) interpreted length of the paleoliquefaction record; (2) interpreted types of constraining ages; and (3) evaluations of the area distribution and interpretations of which prehistoric liquefaction features were caused by large-magnitude earthquakes centered in the Charleston area and which were caused by moderate-magnitude local earthquakes.

The clarity of this section could be greatly improved by technical editing to better link the descriptions of the current knowledge with characterizations of alternatives in the logic tree and with the assessment of the community uncertainty.

S 6-15. (CC) *Cheraw Fault—Evidence for Temporal Clustering*

In Section 6.1.3.1, the discussion of weights assigned to in or out of a cluster requires additional discussion given the statements that there is no evidence to indicate that this source is out of a cluster. It is not clear what the differences are for this source relative to other sources, such as Charleston as an example.

S 6-16. (CC, U) *Cheraw Fault—Magnitude*

In Section 6.1.3.3, p. 6-19, the discussion of relationships used to estimate magnitude from fault area includes "Somerville et al. (2001)." At various places in the Project report the citations for this relationship include Somerville et al. (2001), Somerville et al. (2005), and Somerville and Saika (2000). This needs to be double-checked and a validated reference cited (the Somerville references are in the gray literature and difficult to find, and the basis of the citation was not evident). A verifiable citation and reference need to be included in the Project database.

On page 6-20, in the discussion of maximum and average displacement for the Cheraw fault the report notes: "There is insufficient information to establish whether the displacement per event measured at the ***sole trench site*** (emphasis added) along the Cheraw fault represents average or maximum values." In the last sentence of this paragraph, the report concludes the values are maximum values. The conclusion does not seem to follow from the discussion in the paragraph as written.

S 6-17. (CC) *Meers Fault—Clustered Behavior*

In Section 6.1.4.1, the explanation of weights assessed for in or out of a cluster requires additional discussion, given the statements that there is no evidence to indicate that this source is out of a cluster. It is not clear what the differences are for this source relative to other sources such as Charleston as an example.

S 6-18. (DMM) *Meers Fault—Discussion of Potentially Relevant Data*

In Section 6.1.4.2, potentially relevant data for the assessment are not discussed. Specifically, the Meers fault is located on the sector of the boundary of the Wichita uplift that has greatest structural relief by a wide margin. The magnitude of the structural relief between the Wichita Mountains and the Anadarko Basin is the source of a very large gravity gradient indicating significant induced stress across the northern Wichita Mountains frontal fault system along this sector. A discussion of these potentially important data should be included for perspective.

Also, is "Arbuckle-Wichita-Amarillo uplift" a proper usage? A reference to the source of this usage is needed.

S 6-19. (CC, U) *Meers Fault—Localizing Feature*

In Section 6.1.4.2, it is not made clear in the discussion of the potential for the occurrence of Meers-like ruptures in the Oklahoma Aulacogen why "only one Meers-like structure is active within the aulocogen at a time."

S 6-20. (DMM, CC, U) *Meers Fault—Geometry and Style of Faulting*

In Section 6.1.4.3, on page 6-24: When Meers-like earthquakes are allowed to migrate off the fault they are limited to occurring within the OKA. How are the earthquakes within the OKA to be modeled? The next paragraph suggests the strike to be N60W (parallel to the Amarillo-Wichita-Arbuckle uplift) with a dip between 40 and 90 degrees. However (and this comment holds for several of the other RLME sources), it is not clear how the analyst should model this situation. As a series of fictitious parallel faults distributed throughout the appropriate portion of the OKA? If so, how many are appropriate? This answer will clearly be determined by the location of the site of interest relative to the source. What was assumed by the hazard analysts for the demonstration and sensitivity calculations?

On pages 6-24 and 6-25: The discussion indicates there is a significant amount of uncertainty in the appropriate H/V values to assign to the displacement observations. It does not seem as if this uncertainty is represented in the final recurrence values for the Meers RLME. Additional clarification seems necessary.

On p. 6-24, third paragraph: The assignment of seismogenic thickness for the Meers fault source based on one reference seems to be inconsistent with how this parameter has been assessed for other seismic sources including Charleston. Consistency in assessment of each of the branches of the logic tree is an important consideration. If outside reviewers see inconsistencies in the assessment of weights for the logic tree branches, then their confidence in the overall assessment may be weakened.

S 6-21. (CC, U) *Meers Fault—RLME Magnitude*

In Section 6.1.4.4, the use of four seismic source dimension relationships to characterize and assess magnitude for this seismic source contrasts with the approach to other seismic sources. It is not clear why the Meers source is any different than other seismic sources to justify these differences. A consistent approach to characterizing and assessing magnitude based on source dimensions seems to be appropriate. There does not appear to be any unique property of the Meers fault that would justify using rupture area relationships for the Meers fault but not other RLME sources such as Charlevoix, Charleston, or Cheraw.

S 6-22. (CBR, CC) *New Madrid—RLME Magnitude*

In Section 6.1.5.3, the use of unpublished information (Hough and Page) needs careful consideration. Has the paper been accepted for publication? Additionally, the text discusses the use of the characteristic earthquake recurrence model. Other sections of the text indicate that the characteristic earthquake recurrence model is not being used.

S 6-23. (CBR, CC) *New Madrid—Recurrence*

Section 6.1.5.4 presents an insufficient basis for the assessed weights for the two alternative recurrence models characterized. The text should refer to Workshop #2 for discussion of this topic and present more information to justify the weight assessed for the renewal recurrence model.

S 6-24. (CBR, CC) *Reelfoot Rift—Eastern Rift Margin Fault, Evidence for Temporal Clustering: Section 6.1.6.2*

In Section 6.1.6.1, for this seismic source, the TI Team has assessed non-clustered behavior with a weight of 1.0. The evidence for this assessment is stated to be insufficient information on the number or timing of earthquakes. This contrast with other RLME sources where the main issue pertained to evidence of short-term versus long-term behavior and the logic that short-term rates cannot extend through extended time frames. That logic also appears to apply to the ERMF. The TI Team needs to develop a consistent approach to assessing clustered versus non clustered behavior.

S 6-25. (CBR, CC) *Reelfoot Rift—Marianna Zone, Evidence for Temporal Clustering*

In Section 6.1.7.1, the text states, "It also is unclear whether some of the paleoliquefaction features are due to earthquakes on the Eastern Rift Margin (ERM, RLME) source . . . ." Given this statement, it is not clear why this seismic source has a probability of activity of 1.0. The discussion and justification of the weight for temporal clustering need to be strengthened.

Similarly, the basis for characterizing the seismic source boundary is “leaky” needs to be improved.

S 6-26. (CC) *Reelfoot Rift—Marianna Zone, Geometry and Style of Faulting*

In Section 6.1.7.2, last paragraph, the probability distribution on seismogenic thickness is different than the default distribution. Given this, the text should provide more details on the number of well-located earthquakes in this source and how they are used to establish a distribution on seismogenic thickness that is different than the default values.

S 6-27. (CBR, CC) *Reelfoot Rift—Commerce Fault, Evidence for Temporal Clustering*

In Section 6.1.8.1, the text notes that the liquefaction and secondary faulting used to document Holocene events may be related to strong ground motion from earthquakes occurring elsewhere in the Reelfoot Rift. Given this statement, it is not clear why this seismic source has a probability of activity of 1.0. The basis for assessing a weight of 1.0 to nonclustered behavior is not clear.

S 6-28. (CC) *Reelfoot Rift—Commerce Fault, Geometry and Style of Faulting*

In Section 6.1.8.2, last paragraph, the basis for characterizing the northwest and southeast boundaries of the seismic source as fixed and the northeast and southwest boundaries as “leaky” is not clear.

S 6-29. (CC) *Wabash Valley—Temporal Clustering: Section 6.1.9.1*

In Section 6.1.9.1, the basis for the weight of 1.0 on “in a cluster” needs to be improved and to be consistent with the bases for this assessment for all RLME seismic sources.

S 6-30. (DMM, CC) *Wabash Valley—Future Ruptures*

On pages 6-59 and 6-60 there is no specific discussion of how the future ruptures are to be modeled. The text refers to Table 5.4-1 (should be Table 5.4-1 and 5.4-2). But as noted previously, additional guidance for the hazard analyst would be useful.

S 6-31. (CC) *Wabash Valley—Alternative Mmax Zones*

In Section 6.2, the discussion of alternative Mmax zones only discusses the Bayesian approach to Mmax estimation and its relevance to source zone characterization. The consistency of the results using the Kijko method should be discussed as well.

S 6-32. (CC) *Criteria for Definition of Boundary—Mesozoic Extended Narrow Zone*

In the last sentence of Section 6.2.1.1 on p. 6-64, the text states: “These observations support the weight of 0.8 that this geometry represents crust extended in the Mesozoic.” The PPRP does not feel the section make the case well. A series of well written observations are presented, but the relevance of the observations to source characterization and specifically to a weight of 0.8 is not clearly articulated. This same comment applies to the other sections on Mmax zones.

S 6-33. (CBR, U) *Comparison of Recurrence Parameters to Catalog*

As discussed in Section 6.4.2, Figures 6.3-7 through 6.3-16 (should be corrected to read 6.4-7 through 6.4.16) show that the recurrence model for the large seismic source zones tends to overestimate the rates for magnitudes 5 or higher. What does this mean to the TI Team? A systematic trend such as the one discussed, should be questioned in detail by the TI Team in terms of evaluating whether all assumptions of the analysis are appropriate. The consistent overestimates of the rates suggest that assumptions related to smoothed seismicity may need to be adjusted to provide a better match between the recurrence model and observed seismicity. The PPRP strongly believes additional discussion and investigation is warranted regarding these results.

S 6-34. (CR, DMM, U) *Need for TI Team Assessment of Spatial Variation of Rate and b-values*

The results of the recurrence-rate analysis presented in Section 6.4 clearly show that TI Team assessments of priors on rate and *b*-values are required. The derived *b*-values in particular appear to be almost entirely below the range of values supported by studies world-wide over many years. We recommend that the Project arrange to further evaluate this analysis.

Comments by Section

Chapter 6 (Title)

Given that 60 of the 70 pages in this chapter deal with RLME sources, the chapter title should be changed to something like, SSC MODEL: MMAX ZONES BRANCH AND RLME SOURCES.

Chapter 6 (Introductory text)

In the introductory paragraph at the top of p. 6-1, after the second sentence, it would be helpful to most readers to repeat a very helpful description that appeared on p. 4-16f in Section 4.4.1:

The "Mmax zones" model involves the direct use of observed seismicity by spatial smoothing of distributed seismicity and the inclusion of RLMEs that are defined primarily by paleoseismic evidence. The "seismotectonic zones" model involves the use of additional tectonic data to define the spatial distribution of future events.

Section 6.1.1

p. 6-2, 2nd paragraph: Regarding "(source IRM in the R model)": we assume this refers to the Canadian study; clarification is needed.

p. 6-2, 3rd paragraph: The phrase "investigations undertaken for the . . ." probably should be "investigations evaluated . . . " The PPRP believes only evaluations were performed.

Section 6.1.1.2

Note: There are <u>two</u> sections labeled 6.1.1.2—one on p. 6.4 and one on p. 6-6.

On p. 6.4, in paragraphs 3 and 4, "thrust" and "reverse" are used inconsistently vis-à-vis the definition provided in the Glossary for "Fault, Thrust" (< 45°) and "Fault, Reverse" (> 45°).

On p. 6-6, 2nd paragraph, next-to-last sentence: ". . . favors three events to four based on field observations." A citation would be helpful.

Section 6.1.2.1

In last sentence of the first paragraph, the reader is referred to a non-existent Section 5.3.3.6. In scanning Chapter 5, it's not clear that there is a "definition" of the temporally clustered earthquake model.

On p. 6-8, 2nd full paragraph: No justification is given for weights on whether the Charleston RLME is "in" or "out" of a cluster.

Section 6.1.2.5.3

p. 6-14, last paragraph, line 10: Typo. (~~see~~ See Appendix E . . .).

Section 6.1.2.5.4

The use of "occurrence model" in the section title and text is at odds with "recurrence model" used predominantly throughout the text (easily verified by a global search for "recurrence model," which shows repeated instances of "Renewal vs. Poisson recurrence models") and in the Glossary. There is at least one other appearance of "occurrence model" in the text (Section 4-19, p. 4-20, beginning of second full paragraph). "Occurrence" rates/probability also appears in Section 5.3.3.2 and should be corrected globally.

Section 6.1.3.2

p. 6-19, 3rd paragraph: The weights assigned to the two dip cases sum to more than 1.0.

Section 6.1.3.4

p. 6-21, second full paragraph, line 3: The term "interval-based approach" is ambiguous and potentially misleading. The data used are the number of earthquakes in a specified time interval (e.g., Figure 6.1.1-2, 7th node), not the interval between earthquakes, as some readers might assume.

p. 6-21, fourth full paragraph, line 1: Consider replacing "occurrence rates" with "recurrence rates"

p. 6-21, 4th full paragraph: Typo in cited recurrence values: 200, 350, and 500 years, should be k-years.

Section 6.1.4.2

par. 1, lines 6–7: Suggested rewording. The text currently says "…have observed Quaternary faulting (e.g., Crone and Wheeler, 2001 . . . ." Suggest being specific and indicating observed Quaternary <u>surface</u> faulting.

Section 6.1.2.4.3

p. 6-13, 2nd paragraph: "The UCSS magnitudes and weights . . . ." UCSS not defined.

Section 6.1.4.5

2nd par., line 4: Typo. Change "500,00 years" to "500,000 years"

Section 6.1.5

In the Table on the top of p. 6-33: The note for the 1811-1812 earthquakes indicates 138 yr BP ± 100 yr. As written, suggests the uncertainty is 100 years; this needs to be clarified.

Section 6.1.5.3

p. 6-39, last paragraph: The text references Table 6.1.5-3 which appears to be missing.

Section 6.1.5.4

p. 6-41, first full paragraph, last sentence: Replace "only includes of all three" with "only includes the alternative of all three components"

p. 6-41: The paragraph containing equation 6.1.5-1 is not clear. The use of the equation needs to be explained within the source characterization scheme.

Section 6.2.1.2

p. 6-66, 2nd full paragraph line 9: Typo. (** mi)

Section 6.3

line 4: Typo. "source(described…"

Section 6.3.1

p. 6-69, first full paragraph, line 9: Reference is made to "the 1882 earthquake"; this event is not in the table on the previous page and there is no context. Adding a short descriptive sentence for clarity would help the reader.

Section 6.4.1

In the first line, change "Figures 6.3-1 through 6.3-6" to "Figures 6.4-1 through 6.4-6"

Section 6.4.2

In the first line, change "Figures 6.3-7 through 6.3-16" to "Figures 6.4-7 through 6.4-17"

Figure 6.1.1-1

Two of the large earthquakes are incorrectly labeled: 1663/2/5 is labeled **M**=3.71 (text in Section 6.1.1 says "**M** 7"; 1791/12/6 is labeled **M** 5.5 (text in Section 6.1.1 says "**M** 5.8). The labeled magnitude for only one of the other three large earthquakes corresponds exactly to the text in Section 6.1.1.

Figure 6.1.1-2

In the Charlevoix RLME logic tree, the header for the 10th node should be changed from "Earthquake Occurrence Model" to "Earthquake Recurrence Model" (see comment on Section 6.1.2.5.4).

Figure 6.1.2-1

In the Charleston RLME logic tree, the header for the 10th node should be changed from "Earthquake Occurrence Model" to "Earthquake Recurrence Model" (see comment on Section 6.1.2.5.4).

Figure 6.1.2.4

Figure 6.1.2-4 shows the three zones along with the magnitude and gravity anomalies. It is not clear how these zones were delineated based on these geophysical data.

Figure 6.1.3-1

In the Cheraw RLME logic tree, under Recurrence Method, the uppermost branch should more correctly be labeled "Earthquake Count in Time Interval" (as for the Charlevoix RLME logic tree instead of "Inter-event Times."

Figure 6.1.3-1

In the Meers RLME logic tree, under Recurrence Method, the upper and lower branches should more correctly be labeled "Earthquake Count in Time Interval" (as for the Charlevoix RLME logic tree) instead of "Inter-event Times." In the corresponding HID tables (Table MEERS_HID-2 and HID-3), information on the data set (N events, T time) should usefully be provided, as in Table Marianna_HID-2.

Figure 6.1.5-1

In the logic tree for the NMFS RLME source, under Equivalent Annual Frequency, references to the HID tables should be labeled NMFS instead of NMF. Under Events/Data, the labeling of "1811–1812, 1450 AD, and 900 AD" is difficult to relate to the dates in the table presented at the top of p. 6-33 (for example, 900 AD corresponds to 1110 yr BP—but in the table one finds "1,050 yr BP ± 150 yr). Exactly which elapsed time was used in Table NMFS_HID-2? (In that table, information on the data set (N events, T time) should usefully be provided, as in Table Marianna_HID-2.

Figure 6.1.6.2

What are the yellow stars on the figure? No explanation in legend or caption.

Figures 6.4-1 through 6.4-6

Consider adding a note to the caption explaining what the mean maps are.

Tables 6.1.5.1, 6.1.5.2, and 6.1.5.3 missing

Table 6.1.5-1 discussed on page 6-32 is missing. Table 6.1.5-2 discussed on page 6-37 is missing. Table 6.1.5-3 discussed on page 6-39 is missing.

CHAPTER 7 — SSC MODEL: SEISMOTECTONIC ZONES BRANCH

General Comments

G 7-1. (NAR) In this chapter, as in Chapter 6, the TI Team has described and evaluated an immense amount of data and information and deserves praise for its efforts. The chapter addresses the "seismotectonic zones" branch of the master logic tree, as developed in Chapter 4 and portrayed in Figure 4.4.1-1[1] (and companion figures referenced therein). The TI Team's assessment is supported by Data Evaluation and Data Summary tables in Appendices C and D. This conceptual branch of the logic tree splits into two source groups—seismotectonic zones and the independent RLME sources, described in Chapter 6. Chapter 7 deals only with the twelve seismotectonic zones and their seismic characteristics.

G 7-2. (CBR, CC) A significantly higher weight is assessed for the seismotectonic zones branch relative to the "Mmax zones" branch. As stated in Section 4.4.1 on p. 4-17: "A higher weight (0.8) is assigned to the seismotectonic zones branch than the Mmax zones branch (0.2) because the seismotectonic zones branch allows for more relevant information on the characteristics of future earthquakes to be included in the model." This information is the subject of the majority of Chapter 7. However, no full explanation or validation is presented in the introduction to this chapter to support the decision on the specific weights assessed for the two conceptual approaches at the front end of the master logic tree. A description of the justification of the weights would be an important and useful addition to the chapter.

G 7-3. (CC, DMM, U) Although the chapter provides an abundance of geological detail, it fails to make a compelling case for identifying many of the seismotectonic zones as separate sources distinct from the larger Mmax zones described in Chapter 6. Considering the weight that is given to this branch (0.8), it is especially important that the definition of each of the seismotectonic zones be very clear and well supported with convincing evidence. Unfortunately, a persuasive case is not developed for the identification of several of the zones described in this chapter.

G 7-4. (CC, DMM) The identification of the zones appears to be made largely on the basis of isolating regions of differing geological and tectonic histories that may have little direct relevance to the SSC characterization criteria that are specified in Section 4.3.3 (p. 4-14). These criteria are : (1) earthquake recurrence rate, (2) maximum earthquake magnitude, (3) expected future earthquake characteristics (e.g., style of faulting, rupture orientation, depth distribution), and (4) probability of activity of tectonic feature(s). The latter criterion was not used in developing the CEUS SSC model (Section 7.1, pg. 7-1), but no justification is given for not addressing this criterion. Furthermore, there is no uniform or systematic description of the application of the first three criteria which allow ready identification of the merits of the zones and which permit comparison among zones. Additional information pertaining to how the sources meet the defining criteria and more systematic organization of the content of the description of the zones would increase the rigor of the decisions reached in the report and their presentation. A summary table specifying the critical information that identifies each source zone based on criteria described in Chapter 4 would be helpful in organizing the information and comparing source zones.

[1] There are two figures labeled Figure 4.1.1-1; we refer to the one on p. 4-27.

G 7-5. (CC) Chapter 7 includes an impressive compilation of information and interpretations representing the range of relevant current knowledge of the scientific community. The scope and detail of this information are important in identifying and characterizing the seismotectonic zones and will be of great value to future users of the CEUS SSC Model. This information is well supported by comprehensive and timely references to the scientific literature. The level of detail is generally consistent throughout the description of the zones, but unfortunately the organization of the descriptions is not consistent. For example, some source zones have initial sections dealing with Background, others with Geologic Evidence, and still others with Basis for Defining Seismotectonic Zone. This lack of consistency in the description of the identified zones is an impediment to the review and comparison of the zones and needs to be corrected. The uneven descriptions appear to be due, in part, to multiple authorship, and some subsections apparently have not been updated since the application of the Kijko Mmax procedure in the Project. Some updating and rewriting appears warranted to alleviate these problems.

G 7-6. (CC) The level of detail in this chapter is high, which will be useful in future seismotectonic studies within the CEUS. However, this level of detail will make it difficult for those readers of the report not well versed in the geology and geography of the region or the geologic time scale to comprehend the significance of the detail. Thus, to support the detail it would be advisable to (1) add maps that identify the location of geologic features, (2) provide more geologic terms in the glossary, and (3) accompany the glossary with a geologic time scale. Additionally, the descriptions of the seismotectonic zones should be reviewed to determine if some of the more specialized terminology, e.g., essexite, T-axes, Neoproterozoic, can be eliminated or simplified so that they can be meaningful to the spectrum of users of the report.

G 7-7. (CC, SSHAC) As with previous chapters, this chapter could be greatly improved by a thorough technical edit. There are numerous editorial modifications required to achieve consistency in presentation, remove editorial errors, and improve clarity. Special attention should be given to clearly describing the bases for characterizing alternatives represented in alternative branches of the logic tree. Also, consideration should be given to describing the basis for the assessed weights for alternative characterizations representing the community uncertainty. Finally, care must be exercised to use words in their correct meaning, avoid casual terminology, and use terms that properly convey the essential activities of characterization of alternatives and assessment of the community uncertainty.

G 7-8. (DMM) The Data Summary Tables of Appendix D are an important supplement to the descriptions of the seismotectonic zones. Unfortunately there appear to be omissions in Appendix D so that supporting information is not consistently available for this draft chapter. This will need to be remedied in revision of the report. Additional comments on Appendix D are given in a review of that segment of the report.

Specific Comments

S 7-1. (CC) *Suggestion for Rewrite of Introductory Paragraph*

The introduction to Chapter 7 could be improved with significant editing. Consider the following as an example.

> As discussed in Section 4.3, the Conceptual Framework for assessing the CEUS SSC model is characterized by two alternative branches of the master logic tree: the Mmax zones branch and the seismotectonic zones branch. The seismotectonic zones branch, which is assessed a higher weight of 0.8 versus 0.2 for the Mmax zones branch, subdivides the CEUS SSC region according to differences in the seismic source assessment criteria described in Section 4.3.3. A common element of both the Mmax zones and the seismotectonic zones branches is the RLME sources. Because the paleoearthquake data that indicate the presence, location, and size of the RLMEs are essentially independent from data used to assess seismotectonic sources, the RLME branch is present in both models. An overview of the approaches for characterization and assessment of the zones is in Section 7.3.

S 7-2. (DMM) *Need for Specifics Regarding Geologic Conditions that Affect Mmax*

The first paragraph of Section 7.1 (p. 7-1) describes how the seismotectonic zones branch relates to Mmax. The basic premise is that regional differences in characteristics related to Mmax and/or future earthquake characteristics are best dealt with by identifying source zones of uniform properties. A region may possess characteristics that would lead to a different Mmax than adjacent regions, including a different prior distribution or different maximum observed earthquake. Mmax was described in Chapter 5, but it would be helpful to the users of the report for the authors to present examples of specific physical properties of the zones (e.g., thinner crust, lithospheric strength characteristics, aulacogens) and describe why these different conditions might result in different Mmax distributions. This information would help to sharpen the need for, and the significance of, the detailed information in the subsequent text which define Mmax and future earthquake characteristics.

S 7-3. (CC) *Description of Charlevoix RLME Source; Section 7.3.1.1.3, pg. 7-6.*

In Section 7.3.1.1.3 (p. 7-6), the description of the Charlevoix RLME seismic source (which is assumed to exist as a distinct seismic source) as part of justifying the St. Lawrence Rift (SLR), confuses the understanding of whether the SLR is a distinct seismotectonic zone. Part of the confusion relates to how the project is using historic earthquakes as part of the development of recurrence and maximum magnitudes. Are the historic earthquakes assigned to the SLR, even though they may be located within the boundaries of the Charlevoix RLME source?

S 7-4. (DMM) *Significance of V_p/V_s Ratio*

On p. 7-14 of Section 7.3.2, under *Geophysical Evidence*, what is the significance of results from teleseismic receiver functions described in last sentence of this section?

S 7-5. (DMM) *Evidence for Separating the Northern Appalachian Seismic Zone from the Paleozoic Extended Zone*

In Section 7.3.3.2 (p. 7-20), under *Basis for Zone Geometry*: The separation of the Northern Appalachian seismic zone (NAP) from the similar Paleozoic Extended zone (PEZ) to the south appears to be largely based on the location of the Triassic Hartford basin. However, a linear connection of the eastern boundaries of these zones would include only a small segment of the northern extent of the basin as shown in Figure 7.3.7-1 similar to the situation observed farther south along the boundary of the PEZ. Is the termination of the NAP being driven by the studies of Adams et al. in defining the seismic source zones of Canada?

S 7-6. (DMM) *Future Earthquake Characteristics;*

In Section 7.3.3.4 (p. 7-21), under *Future Earthquake Characteristics* for the Northern Appalachian seismotectonc zone, the text notes that all earthquakes with known depths are relatively shallow, but goes on to use the default depth distribution for the seismic source. The basis for assigning the depth distribution for distinct seismic sources, including the NAP, should be based on a common approach to using earthquakes with known depths. Otherwise, assignment of the default depth distribution lacks rigor. Also note that a search of Chapter 5 shows no "default depth" term.

S 7-7. (DMM) *Background of the Paleozoic Extended Zone*

In Section 7.3.4.1, the text needs to make clear that the Giles County Seismic Zone, the Eastern Tennessee Seismic Zone, and the Clarendon-Linden Fault System, are not unique from a seismotectonic perspective. Otherwise it is not clear why these features are not considered distinct seismic source zones.

S 7-8. (DMM) *Basis for Western Margin of the Paleozoic Extended Zone*

In Section 7.3.4.2 (p. 7-29), under *Basis for Zone Geometry*: A reentrant of the Paleozoic Extended seismic zone extends into the craton in the vicinity of Kentucky, moving the western margin of the zone farther west. There is no support for this feature in the text of the report. The reference in the report that is used most extensively in defining the western margin is Wheeler (1995), but his studies did not indicate this reentrant; rather his margin to this zone in essentially a straight line through this region. A strongly supported description of the cause of this feature is needed or it should be eliminated. No references are cited to provide an indication that this feature is present.

S 7-9. (DMM) *Basis for Identification of the Illinois Basin Extended Basement Zone.*

In Section 7.3.5.1 (p. 7-33), the justification for defining this region as a distinct seismotectonic zone and the discussion in this section are not consistent with the criteria defined in Section 4.3.3 for defining seismic source zones.

S 7-10. (CC, DMM) *Default Values of Future Earthquake Characteristics in the Eastern Continental Crust-Atlantic Margin; Section 7.3.7.4, pg. 7-48.*

In Section 7.3.7.4 (p. 7-48), the text discussing seismicity notes that most well located earthquakes of the Eastern Continental Crust-Atlantic Margin are distributed throughout the upper 13 km of crust. Given this information, the basis for assuming that the seismogenic thickness should be represented by the default values is not clear.

S 7-11. (DMM) *Additional Basis for Defining the Atlantic Highly Extended Crust*

In Section 7.3.8.1 (p.7-49), under *Basis for Defining Seismic Zone*: Canadian seismologists have recognized the zone of weakness at the Atlantic Ocean margin as defined by the continental slope as a zone of potential seismic activity based on the location of the magnitude 7.2 1929 Grand Banks earthquake, which occurred east of the northern tip of Nova Scotia. This earthquake, as well as the Baffin Bay earthquake in Canada, is supportive of the identification of this seismic zone.

S 7-12. (CC, SSHAC) *Clarification of Text Describing the Basis for Mmax of the Extended Continental Crust-Gulf Coast*

In Section 7.3.9.3 (p. 7-56), *Basis for Zone Mmax*: The characterization and assessment of Mmax described in this section is unclear. First, use of the term "scenario" (meaning imagined or possible) can convey a lack of disciplined evaluation of the available data for characterizing Mmax for the zone as required by the SSHAC assessment process. Replacing "scenario(s)" with "alternative characterization(s)" would properly convey that the characterizations represent the range of uncertainty based on evaluations of the available data. Second, the third alternative is described as follows: "The largest observed earthquake is the potential paleoearthquake identified from the studies of . . . ." The use of "largest observed earthquake" and "potential paleoearthquake" seems incompatible. In addition, the characterization described here clashes with the strong conclusion stated in Section 7.3.9.5. Elaboration is needed better explaining the evaluations performed supporting the third alternative characterization.

S 7-13. (DMM) *Additional Evidence for Defining the Gulf Highly Extended Crust*;

In Section 7.3.10.1 (p. 7-59), under *Basis for Defining Seismotectonic Zone*, is there evidence of faulting in this zone as anticipated in a highly extended zone? If so, that would be additional evidence for defining the zone.

S 7-14. (DMM) *Evidence Regarding Characterization of the Gulf Highly Extended Crust*

In Section 7.3.10.3 (p. 7-60), under *Basis for Zone Mmax*, there are substantive analyses that show the event of February 10, 2006, to have been a landslide. These analyses must be referenced and discussed as part of the data base for characterizing and assessing Mmax for this zone.

S 7-15. (CC,DMM) *Need to Strengthen the Basis for Defining the Oklahoma Aulacogen as a Distinct Seismic Source Zone*

In Section 7.3.11.1 (p. 7-62), under *Basis for Defining Seismotectonic Zone*, the text mentions "default future earthquake characteristics." This terminology has not been used systematically throughout Chapter 7 (with reference to Table 5.4-1), and in this section it is not clear why these are the primary basis for defining the seismotectonic zone versus the full set of criteria found in Section 4.3.3. While future earthquake characteristics are one of the criteria used to define distinct seismotectonic zones (see Section 4.3.3), there does not appear to be anything profoundly unique about the style of faulting or the strike of ruptures to support defining the Oklahoma Aulacogen as a distinct seismotectonic zone. The basis for defining the Oklahoma Aulacogen as a distinct seismotectonic zone is weak and needs to be improved.

S 7-16. (CC) *Significance of Statement in Description of Northeast Ohio Seismic Zone in the Midcontinent Seismic Zone*

In Section 7.3.12.1.4 (p. 7-68), for the Northeast Ohio Seismic Zone: The third bullet of the second paragraph is meaningless to the reader without additional description of its significance.

S 7-17. (DMM) *Effects of Smoothing on Recurrence Parameters*

In Section 7.5 (p.7-71), Recurrence Parameters: The objective smoothing results in *b*-values that are low, possibly below the range of values known from world-wide experience. Yet, no alternative is suggested. Additional elaboration of the analyses must be provided to adequately inform future users of the CEUS SSC model.

S 7-18. (DMM) *Full Explanation of the Results Shown in Figures 7.5.2-9 to 7.5.2-42*

Many of the data shown in Figures 7.5.2-9 to 7.5.2-42 indicate the poor fits of the realizations to the catalog. This is disturbing and needs to be more clearly explained in the text. Why doesn't the preferred model fit the catalog data better? Only the short text in section 7.5.2 describes these figures. The text should be enhanced to describe the fitting issues, and as a result there needs to be full justification of the rate and *b*-value maps for the seismotectonic zones.

Comments by Section

Section 7.3.1.2

This section never actually describes why the St. Lawrence Rift should be a distinct source zone. There is some discussion of geometry, but no well defined case for "why" (unless it is simply because the GSC did).

Section 7.3.1.3

At least some mention of the implications or importance of the observations to the Kijko model should be provided. This comment applies to all the individual zone sub-sections. Perhaps consider doing it at the beginning of Chapter 7.

Section 7.3.2

last bullet, p. 7-13: If the hotspot has been tracked farther **to** the northwest, why isn't the seismic source zone extended to the northwest?

Section 7.3.2.1

This is one of the few Seismotectonic Zone subsections that actually develop a clear summary for why this should be a separate zone.

Section 7.3.3.1

This section discusses the basis for proposing the NAP zone. It states: "The basis for defining the NAP seismotectonic zone centers primarily on the concept that terranes of this zone formed outboard of the Laurentian margin after Iapetan rifting and were subsequently accreted to the passive margin." This subsection is weak in terms of developing a basis for defining the NAP as a separate zone. The text focuses on geological arguments that are never specifically tied to the SSC criteria. The reader is left to infer this zone may or may not utilize a different Bayesian Mmax prior than adjacent regions.

Section 7.3.4

Use of the term "IRM" changes from describing a continental margin in the first sentence of the introductory paragraph of Section 7.3.4 to a seismic zone later in the paragraph. This is confusing. Similarly, note that the labeling of the PEZ in Figure 7.3.4-1 appears to be incorrectly labeled as IRM.

Section 7.3.4.1.4

Suggest that the reference to Steltenpohl et al. in Geology, June 2010, v. 38, p. 571-574 be added to the list in the second paragraph.

Section 7.3.4.1.6

p. 7-27: At the end of the second paragraph of this section reference is made to "a Class C tectonic feature." It would be helpful to the reader to cite where in this report the classes of the tectonic features are defined and thus the significance of this information to seismic source identification.

Section 7.3.4.1.6

p. 7-29, paragraph at top of page: The discussion of a lack of observed paleoliquefaction features should also be used with the appropriate qualification. Specifically, the observation that paleoliquefaction features provides strong evidence for past strong earthquake shaking, should be accompanied with a remark that failure to identify such features does not provide an equally strong a case for the absence of strong shaking.

Section 7.3.5

p. 7-32: The use of "Basement" in the title of this zone does not appear to be consistent with the titles given to other seismotectonic zones of the CEUS.

Section 7.3.5.1

p.7-33, 2nd bullet: In discussing the basis for defining the IBEBZ zone the text states, "The southern part of the Illinois basin is one of the most structurally complex areas of the Midcontinent." How this directly impacts the SSC needs to be more clearly elaborated, or deleted. On the following page in the next bullet the text states: "An extensive series of moderately dipping reflectors is present in the basement, part of which may have been reactivated by the 1968 mb 5.5 earthquake." Are the reflectors then interpreted to be faults? Also, the 1968 earthquake may have occurred <u>in response to reactivation</u> of the reflectors (if they are in fact faults), but not vice versa.

Section 7.3.5.2

p. 7-34: Suggest clarification of last sentence in second paragraph with something like: "The margins of the volcanic layered sequences, especially to the south and west, are marked by prominent coincident closed-contour magnetic and gravity anomalies which are derived at least in part from mafic volcanic rocks and intrusions . . . ."

Section 7.3.5.3

pg. 7-35: In considering the Mmax of this zone it may be useful to consider the presence of numerous late Paleozoic ultramafic intrusions (dikes and sills) into the sedimentary section of this region. See, for example, Sparlin and Lewis in Geophysics, v. 59, p. 1092-1099 (1994).

Section 7.3.6.5

(CC) ***Develop table for future earthquake characteristics in Reelfoot Rift zone;*** *pg. 7-42.*

p. 7-42, text box: The characteristics of future ruptures in the Reelfoot Rift zone listed in the text box at the end of Section 7.3.6.5 should be placed in a numbered table with headings.

Section 7.3.7

p.7-47, first full paragraph, line 5: The text refers to the unlikelihood of a maximum magnitude earthquake of greater than 7 because of the paucity of paleoliquefaction features in the region. Could Mmax be less than 7?

Section 7.3.7.1

In the second line of the first paragraph, "large" earthquakes are specified as $\mathbf{M} > 7$. Should be $\mathbf{M} \geq 6.5$ to be consistent with the value used elsewhere for the RLMEs.

Section 7.3.9.2.1

p. 7-52, last bullet: The point could be illustrated with reference to the appropriate magnetic anomaly figure.

Section 7.3.9.2.4

p. 7-55, first full paragraph: Suggest that the last sentence be modified to something like: "The source zone is extended north of the Southern Arkansas fault zone for several reasons:"

Section 7.3.10

In the title of this section, for consistency with previously described seismic source zone, suggest the title of this zone be "Gulf Coast Highly Extended Crust."

Section 7.3.11.3

This subsection is an example case where adding an additional sentence could improve the clarity, consistency and transparency of the document. The Bayesian approach is the only Mmax approach used for this zone. It would be helpful to the reader to note that specifically or state the Kijko approach was not used due to a high *p*-value. Some zones are explicit in describing the two approaches, some are not.

Section 7.3.12.1.2

pg. 7-65, first full paragraph, line 4: Suggest beginning sentence with, "The deformation during this interval is attributed to" instead of "It is attributed to"

Section 7.3.12.2

p. 7-69, par. 1, line 4: Suggest adding the phrase "and recurrence characteristics" after "maximum magnitude probability"

Figure 7.3.2-1

As on similar maps in the report, Figure 7.3.2.1 should show the magnitudes of the starred earthquakes.

Editorial Comments and Typographical Errors

<u>General Comment</u>:

To avoid repetition of editorial comments on repeated issues throughout the text of Chapter 7, the following issues are identified which should lead to necessary revisions throughout the chapter:

- The manner of describing compass directions and their hyphenation should be made consistent throughout the report. Note that sometimes the directions are spelled out and in other cases an abbreviation is used.
- Geologic time units are not used appropriately throughout the chapter. Ma is used by the scientific community for millions of years before the present and myr is used for millions of years of duration.
- Recommended that for each section that presents a different seismotectonic zone, the title include the acronym (e.g., Section 7.3.1 — St. Lawrence Rift (SLR). Some section headings already include the acronym, which is helpful to the reader in referring to maps and figures.
- "Aeromagnetic" is not a definitive term. Rather use "magnetic anomaly" and gravity should always be followed by "anomaly," e.g., gravity anomaly and magnetic anomaly. If

there is no adjective before either the gravity or magnetic anomaly, it is assumed that the gravity anomaly is the Bouguer gravity anomaly and the magnetic anomaly is the total intensity magnetic anomaly. Where possible, the type of anomaly should be specified.

- Mile should be abbreviated as "mi" without a period at the end, consistent with scientific context.
- The first time a term is used that will be identified by an acronym, the complete term should be given followed by the acronym in parentheses. There are numerous acronyms in this chapter that are not listed in the list of acronyms near the front of the report. These will not all be identified in the following comments.
- Reference to Adirondacks and Appalachians in place of Adirondack Mountains and Appalachian Mountains, respectively, is not editorially correct. This and similar casual terminology should be removed from the chapter.
- Several figures cited in this chapter are neither in the draft report nor in the List of Figures. All cited figures and tables should be carefully reviewed.
- Magnitudes of specific earthquakes should be consistent in number of significant figures throughout the text.
- Format for dates should be consistent throughout the text. Avoid 10 February 1999 rather use February 10, 1999.
- Listing of earthquakes, references, etc. should be in a prescribed order, e.g., date, magnitude, etc.

Specific Editorial ("E") Comments and Typographical Errors:

E 7-1 Section 7.1 Paragraph 1, line 5 – replace region with seismotectonic source zone

E 7-2 Section 7.1 Paragraph 1, line 7 – replace event with earthquake

E 7-3 Section 7.1 Paragraph 1, line 8 – insert tectonic between particular and province

E 7-4 Section 7.1 Paragraph 1, line 9 – insert faulting between slip and defining

E 7-5 Section 7.1 Paragraph 2, line 16 – replace eastern with western (?)

E 7-6 Section 7.1 Paragraph 3, line 1 – not all seismotectonic zones represented in Appendices C and D

E 7-7 Section 7.1 Paragraph 3, line 4 – replace provide an indication with specify

E 7-8 Section 7.1 Paragraph 3, line 7 – replace looking at any of the discussions with reviewing the descriptions

E 7-9 Section 7.1 Paragraph 4, line 16 – replace discussion with description

E 7-10 Section 7.1 Paragraph 5, line 6 – replace lie with occur

E 7-10 Section 7.1 Paragraph 6, line 5 – replace called out with identified

E 7-11 Section 7.1 Paragraph 5, line 9 – replace have been postulated as being with are postulated as

E 7-12 Section 7.1 Paragraph 5, line 11 – replace studies are judged to be too preliminary at the present time with assessments are judged to be without definitive support as a result of the preliminary nature of the investigations

E 7-13 Section 7.3 Paragraph 1, line 3 – replace Mid-Continent with Midcontinent

E 7-14 Section 7.3 Paragraph 1, line 6 – NMESE not in List of Acronyms

E 7-15 Section 7.3 Paragraph 1, line 7 – insert northwest boundary between the and Reelfoot

E 7-16 Section 7.3.1 Paragraph 2, line 2 – separate SCRs and correlate

E 7-17 Section 7.3.1.1.3 Paragraph 1, bullets – capitalize first word of bullets and place period after last bullet

E 7-17 Section 7.3.1.1.4, pg. 7-7, third bullet, separate A and third

E 7-18 Section 7.3.1.1.4 Paragraph 2, first bullet – separate The and oldest

E 7-19 Section 7.3.1.1.4 Paragraph 4, line 6 – remove space after hyphen

E 7-20 Section 7.3.1.1.5 Paragraph 1, line 3 – separate from and the

E 7-21 Section 7.3.1.1.7 Paragraph 1, line 11 – remove s between faults and associated

E 7-22 Section 7.3.1.1.7 Paragraph 1, line 13 – separate which and continued

E 7-23 Section 7.3.1.2 Paragraph 1, line 3 – replace has been with is

E 7-24 Section 7.3.1.2 Paragraph 1, line 6 – remove space after hyphen

E 7-24 Section 7.3.1.2, pg. 7-10, paragraph 1, line 3 and line 8 – separate States and faults

E 7-25 Section 7.3.1.2 Paragraph 1, line 19 – replace asterisks with 250

E 7-26 Section 7.3.1.1.4 Paragraph 2, line 2 – what is GSC R model??

E 7-27 Section 7.3.1.1.4 Paragraph 2, line 6 – remove space before Brompton

E 7-27 Section 7.3.1.1.7, pg. 7-9, line 13 – separate which and continued

E 7-28 Section 7.3.1.3 Paragraph 1, line 15 – separate subsidence and within

E 7-29 Section 7.3.1.3 Paragraph 1, line 28 – spell out first time GMH is used

E 7-29 Section 7.3.1.4, pg. 7-11, 1st line - suggest "Earthquakes in Canada are classified …." should be earthquakes in southeastern Canada

E 7-30 Section 7.3.1.4 Paragraph 1, line 13 – 5.8 is 5.75 elsewhere, use care in significant figures, similar problems elsewhere in report that need to be addressed

E 7-31 Section 7.3.1.4 Paragraph 2, line 2 – neither earthquake shown on Figure 7.3.1.1

E 7-32 Section 7.3.2, Geologic Evidence, Paragraph 1, bullet 2 – why refer to figure here?

E 7-33 Section 7.3.2, Geophysical Evidence, Paragraph 1, line 2 – Figure 7.3.2-3 is missing in report and List of Figures

E 7-34 Section 7.3.2, Evidence for Reactivation, Paragraph 1, several lines – Capitalize Late and Early when part of formal age

E 7-35 Section 7.3.2, Evidence for Reactivation, Paragraph 3, last line – replace / with and

E 7-36 Section 7.3.2.2 Paragraph 2, line 2 – Figure 7.3.2-4 is missing from report and List of Figures

E 7-37 Section 7.3.2.2 Paragraph 2, line 9 – can this information be related to a specific figure?

E 7-38 Section 7.3.2.3 Paragraph 2, line 5 – Figure 7.3.2-5 is missing from report and List of Figures

E 7-39 Section 7.3.2.4 Paragraph 2, line 15 – separate and20

E 7-40 Section 7.3.3 Paragraph 1, line 1 – remove s from Appalachian

E 7-41 Section 7.3.3 Tectonic Framework, Paragraph 3, line 5 – change to compressional event

E 7-42 Section 7.3.3 Tectonic Framework, Paragraph 7, line 2 – replace million-year with myr

E 7-43 Section 7.3.3 Seismicity Paragraph 1, line 10 – remove period after Ebel

E 7-44 Section 7.3.3 Paragraph 2, line 3 – magnitude of June 1638 earthquake is listed as 6.5 on page 7-19 and 5.67 on page 7-21

E 7-44 Section 7.3.3, pg. 7-19, Seismicity section - the 1904 earthquake referred to in terms of mblg, shouldn’t moment magnitude be indicated as well?

E 7-45 Section 7.3.3.3 Paragraph 2, line 5 – insert period after al

E 7-46 Section 7.3.4.1.1 Paragraph 1, line 3 – replace valley with rift

E 7-47 Section 7.3.4.1.2 Paragraph 1, line 3 – insert anomaly after gravity

E 7-48 Section 7.3.4.1.2 Paragraph 2, line 7 – remove any

E 7-49 Section 7.3.4.1.2 Paragraph 1, line 9 – replace Valley with rift

E 7-50 Section 7.3.4.1.3 Paragraph 3, line 9 – remove Recent

E 7-51 Section 7.3.4.1.3 Paragraph 4, last line – replace is with are

E 7-52 Section 7.3.4.1.5 Paragraph 1, line 6 – RTG not identified

E 7-53 Section 7.3.4.1.6 Paragraph 5, line 6 – insert space in front of Dineva

E 7-53 Section 7.3.2, pg. 7-13, 2nd line - currently states "This seismotectonic zone is largely defined by moderate seismicity, including …" As written this contradicts the stated position that the model accounts for differences in seismicity by spatial smoothing. It seems more appropriate to say "This seismotectonic zone is characterized by moderate seismicity,….."

E 7-54 Section 7.3.4.2 Paragraph 1, line 3 – remove unfiltered, add Bouguer gravity before anomaly

E 7-55 Section 7.3.4.2 Paragraph 1, line 5 – replace rise with anomaly gradient

E 7-56 Section 7.3.4.2 Paragraph 2, line 6 – should PEZ be PEZ-W??

E 7-57 Section 7.3.4.2 Paragraph 3, line 1 – spell out PEZ-N

E 7-58 Section 7.3.4.2 Paragraph 4, last line – replace IRM with PEZ

E 7-59 Section 7.3.4.3 Paragraph 1, line 2 – magnitude

E 7-59 Section 7.3.4.3, pg. 7-30, Paragraph 1 - mixed magnitudes in the section

E 7-60 Section 7.3.4.2 Paragraph 4, line 4 – replace IRM with PEZ

E 7-61 Section 7.3.4.4 Paragraph 4, line 4 – spelling of Pymatning??

E 7-62 Section 7.3.5 Paragraph 1, line 1 – delete The regions of

E 7-63 Section 7.3.5 Paragraph 1, line 2 – delete more distant, replace presented the with proposed that

E 7-64 Section 7.3.5 Paragraph 1, line 3 – delete concept and change extending to extend

E 7-65 Section 7.3.5 Paragraph 1, line 8 – delete d from indicated

E 7-66 Section 7.3.5 Paragraph 1, line 9 – delete of complexly deformed crust.

E 7-67 Section 7.3.5 Paragraph 4, line 4 – be consistent in use of term for LaSalle anticlinorium

E 7-68 Section 7.3.5 Paragraph 2, line 5 – insert anomaly after intensity

E 7-69 Section 7.3.5 Paragraph 2, line 6 – insert layered between volcanic and sequences

E 7-70 Section 7.3.6.1 Paragraph 1, bullet 1, line 4 – should be plume

E 7-71 Section 7.3.6.1.2 Paragraph 5, line 5 – FAFC, not defined

E 7-72 Section 7.3.6.1.2 Paragraph 8, line 8 – missing words??

E 7-73 Section 7.3.6. 2 Paragraph 8, bullet 3, line 5 – publication date of Pratt et al.

E 7-74 Section 7.3.7 Geophysical Anomalies, Paragraph 2, line 5 – replace runs with extends

E 7-75 Section 7.3.7 Geophysical Anomalies, Paragraph 2, line 10 – remove separately

E 7-76 Section 7.3.7 Seismicity, Paragraph 4, line 10 – should small be limited??

E 7-77 Section 7.3.7.2 Basis for Geometry, Paragraph 1, line 16 – BMA, identify

E 7-77 Section 7.3.7.4, Future Earthquake Characteristics, pg. 7-48, - text refers to ECC-AM having the same future rupture characteristics as the AHEX zone. However, the discussion of the AHEX follows the ECC-AM zone. Consider placing description of characteristics in this section

E 7-78 Section 7.3.8.1 Paragraph 2, line 5 – replace runs with extends

E 7-79 Section 7.3.9 Paragraph 1, line 6 – replace represents with is

E 7-80 Section 7.3.9.2.1 Paragraph 1, line 5 – remove any

E 7-81 Section 7.3.9.2.1 Paragraph 1, line 7 – replace think with thin

E 7-82 Section 7.3.9.2.1 Paragraph 2, line 6 – replace reflected with reflects

E 7-83 Section 7.3.9.2.3 Paragraph 2, line 1 – change to In spite of this tectonic interpretation,

E 7-84 Section 7.3.9.4 Paragraph 4, line 5 – change to that formed or were reactivated

E 7-85 Section 7.3.9.5 Paragraph 2, line 4 – replace since with because

E 7-86 Section 7.3.9.5 Paragraph 6, line 1 – insert the after comma

E 7-87 Section 7.3.10 Paragraph 1, line 6 – replace represents with is

E 7-88 Section 7.3.11.1 Paragraph 2, line 1 – replace first sentence with: The basis for defining the distinct future earthquake characteristics for the aulacogen is the observation of the characteristics of the Quaternary activity on the Meers fault, a fault within the Frontal Wichita fault system (see Section 6.1.4).

E 7-89 Section 7.3.11.2 Paragraph 2, line 5 – remove any

E 7-90 Section 7.3.12 Paragraph 1, line 2 – insert geologic between two and provinces

E 7-91 Section 7.3.12 Paragraph 2, line 1 – replace discussion with description

E 7-92 Section 7.3.12 Paragraph 2, line 2 – replace discussion with description

E 7-92 Section 7.3.12.1.4 Paragraph 1, line 6 – remove any of

E 7-93 Section 7.3.12.1.4 Paragraph 1, line 9 – replace could not with cannot

E 7-94 Section 7.3.12.1.4 Paragraph 1, last line – delete any of

E 7-95 Section 7.3.12.1.4 Northeast Ohio Seismic Zone, Paragraph 5, bullet 3, line 6 – change to consistent with one expected for a high pore-pressure…

E 7-96 Section 7.3.12.1.4 Northeast Ohio Seismic Zone, Paragraph 6, line 2 – replace very well with favorable

E 7-97 Figure 7.3.4-1 – Indicate 1929 Attica earthquake??

E 7-98 Figure 7.4.1-1 – scale and size used for displaying $m_{mzx\text{-}obs}$ for each seismic source needs to be modified to better illustrate the findings

E 7-99 – limits of information on all figures (e.g., 7.1-1 and 2) needs to be confined to the limits of the study area

CHAPTER 8 — DEMONSTRATION HAZARD CALCULATIONS USING CEUS SSC MODEL

General Comments

G 8-1. (CC) Chapter 8 is the opportunity for the TI Team to explain differences in hazard obtained using the CEUS SSC model, the USGS seismic source model, and the COLA seismic source models. This has been done to a degree, but more extensive evaluations relating the differences in hazard to elements of the CEUS SSC model would be very valuable for future users. Industry stakeholders and the scientific and technical community will be looking closely at the demonstration hazard calculations to gain an overall understanding of the CEUS SSC model and whether it yields reasonable results.

Figures such as Figures 8.2-5R through 8.2-5T for all test sites together with thorough evaluations of how the TI Team's assessments of smoothing parameters impact hazard would be very informative. Sensitivities to the Team's assessments of weights on the "in cluster" and "out of cluster" characterizations of RLME sources would also be very informative.

G 8-2. (CC, CBR) The CEUS SSC model rates are often by a factor of two or more higher than the USGS and COLA models rates, over a large range of ground motions. The slopes of the hazard curves are more similar because they all assume the same ground motion prediction equations. This higher rate of ground motions compared to earlier models is not clearly explained in the text. This higher hazard indicates that the CEUS SSC model predicts a rate of earthquakes that is considerably higher than the earthquake rate predicted in the USGS and COLA models. The basis of these higher rates can be seen in the figures of Chapter 5 to 7 (e.g., 6.4-7 to 6.4-16; 5.3.2-22), where the model realizations over-predicts the historical rate of earthquakes. These differences make one question whether the model encompasses the center, body, and range of the informed technical community.

Specific Comments

S 8-1. (CC) *Explanation of CEUS Ground Motion Attenuation Model Application*

The TI Team has used the 2004 EPRI ground motion attenuation model to complete probabilistic estimates of ground motion. Chapter 8 should provide a summary of the application steps that were implemented for the 2004 EPRI ground motion attenuation model. It is particularly important that the distance measure be explained. Application of the 2004 EPRI ground motion attenuation model could involve the use of either point source distance measures or extended source distance measures. If both distance measures were used, the text should provide an explanation of the criteria or considerations that resulted in the choice of the distance measure for each of the seismic sources. For those seismic sources that were modeled as extended ruptures, the text should describe what assumptions were made to model the extended rupture and to what extent epistemic uncertainty was considered (alternative extended rupture relationships). Without this explanation the information provided in Chapter 9 regarding the sensitivity to certain logic tree inputs is diminished.

S 8-2. (DMM, CC) *Questions Regarding Results of Demonstration Hazard Calculations*

In the subsection labeled "CENTRAL ILLINOIS SITE" (p. 8-6, 3rd paragraph): It would be informative to know how much higher and over what ground motion range the CEUS SSC model hazard is higher. Also, what characterizations and/or assessments contained in the model contribute to the higher seismic hazard.

The CEUS SSC model is almost a factor of 2 higher than USGS/EPRI-SOG models. The major contributor is the IBEB (Illinois Basin) zone. The New Madrid (NMFS) RLME is most important at 1 s SA. However, background seismicity dominates at shorter periods. Why does the background hazard from CEUS SSC model give significantly higher rates than were applied in the USGS and COLA models for short periods? At 1 s period the USGS and CEUS-SSC models are much more similar because the NMFS models are much more similar.

In the subsection labeled "CHATTANOOGA SITE" (addendum, 8/18/2010, 3rd paragraph): More complete evaluations and explanations relating the differences to elements of the CEUS SSC model would be very valuable. This comment applies to other sites as well; so, will not be repeated.

The CEUS SSC model hazard for the Chattanooga site is more than a factor of 2 higher in annual frequency of exceedance than the USGS and COLA models. At the Chattanooga site the ground motion hazard at e-3 to e-5 is more than a factor of 2 higher. Background sources contribute most to the hazard. However, the USGS ground motions are higher at 1 Hz for exceedances of e-4 to e-6. These results are not explained in the text.

In the subsection labeled "HOUSTON SITE": The CEUS-SSC model hazard at the Houston site is dominated by GHEX (Gulf of Mexico), which is the zone that encompasses the site. Contributions from other background sources are much lower. Hazard is dominated by background sources at all periods (except for very low ground motions at 1 s SA). The SSC model indicates about a factor of 2 higher annual frequency of exceedance than the USGS model frequencies for short periods (10 Hz and PGA) but is more similar at longer periods (1 Hz). This is probably because NMFS is significant at 1 Hz and the USGS and CEUS-SSC models are more similar for NMFS. However, the differences are not explained in the text.

In the subsection labeled "JACKSON SITE": For the Jackson Site, the NMFS is important at all frequencies. Therefore, the CEUS-SSC, COLA, and USGS models are quite similar for PGA, 10 Hz, and 1 Hz.

In the subsection labeled "MANCHESTER SITE": Similar to the other sites dominated by background hazard, the CEUS SSC hazard at the Manchester site is considerably higher than the hazard for the USGS and COLA models. The deaggregation for the Manchester site at 10 Hz is dominated by earthquakes with magnitudes less than 6.0 and distances less than 10 km. The CEUS SSC deaggregation for 10 Hz at e-4 is similar to that produced by the USGS for PGA at 4e-4. The higher rates for the Manchester Site should be explained in the text.

In the subsection labeled "SAVANNAH SITE": For the CEUS SSC model at the Savannah site, the major contributors to the ground motion hazard are the Charleston RLME source and the ACC_AM background source model. The CEUS-SSC, COLA, and USGS models are quite similar with the CEUS-SSC model showing a little higher ground motions for a large range of exceedances.

In the subsection labeled "TOPEKA SITE": The major contributor to the background source is MIDC-A which encompasses the site. The next important contributors are MIDC–B, MIDC-C, and MIDC-D. Background seismicity dominates the hazard at PGA and 10 Hz and the NMFS dominates hazard at 1 Hz. The hazard curves for the CEUS-SSC, COLA, and USGS and similar, especially at 1 Hz. The hazard is typically higher for the CEUS-SSC model with rates almost a factor of two higher for a large range of ground motions. This discrepancy should be explained in the text.

Comments by Section

Order of Text, Tables, and Figures

Material needs to be reorganized (including added materials transmitted on August 18, 2010) so that the order of presentation of text, tables, and figures is consistent with other chapters.

Section 8.1

3rd paragraph and elsewhere: The term "hard rock" can lead to confusion because it is unspecific and used in various meanings. Consider defining the term "CEUS Region generic rock," shear wave velocity of 9200 fps, and using this term consistently throughout the chapter. Similarly, using the term "soil" to mean the geologic section above "CEUS Region generic rock" can especially invite confusion because of the well-established use of this term in geotechnical engineering. Consider "stratigraphic column" instead.

4th paragraph: In the first line, would "generalized" or "representative" be more accurate than "hypothetical"? In the last line, would "dynamic response" be more descriptive than "parameters"?

Section 8.2 [including revised materials distributed on 8/18/2010]

In the subsection labeled "All site conditions" (p. 8-5): "EPRI-SOG (1989)" should be "EPRI-SOG (1988)"

Figures 8.1-4 and 8.1-5

Are the mean amplification factors independent of the mean AFEs (e.g., at 10^{-4}, 10^{-5}, and 10^{-6}) and the resulting site's mean uniform hazard spectra for hard rock?

Figures 8.2-5R and 8.2-5T (Manchester Site): These figures are very important for understanding how smoothing affects hazard. It would be particularly useful to know the estimated rates of **M** 5 earthquakes compared with estimated *b*-values for the 8 objective smoothing realizations.

CHAPTER 9 — USE OF THE CEUS SSC MODEL IN PSHA

General Comments

G 9-1. (NAR) Chapter 9 provides results that are potentially valuable for evaluating whether future new data or evolved knowledge require updating of the SSC model. In addition, the results are potentially valuable for resolving a number of seismic regulatory decision-making issues. The chapter is very well written, providing clear descriptions of the analyses performed and the results—a valuable contribution.

G 9-2. (NAR) PPRP review comments on Chapters 1–5 include suggestions that may lead to modification of weights in the Master Logic Tree and hence corresponding changes in calculated hazard results.

G 9-3. (NAR) It is noteworthy that, based on the comparisons provided in Chapter 8, differences with the USGS and EPRI-SOG (COLA) results are significantly larger than the precision defined in this chapter for the CEUS SSC model results at all seven test sites. Indeed, for ground motions in the range of 10^{-4} to 10^{-6}, the results in Chapter 8 indicate differences sometimes more than a factor of two between the USGS and CEUS SSC models in the rate of exceedances and the ground motion hazard. To avoid confusion, and because it might be argued that all experts have had essentially the same data and knowledge basis for assessing the various SSC models, the report should make abundantly clear how the uncertainty (precision or reproducibility) of the ± 25% should be understood—or not misinterpreted.

Specific Comments

S 9-1. (CC) *Figure References in Text Need to be Corrected*

Beginning in Section 9.4.2, the referencing of figures in the text needs to be corrected (the counting of figures appears to be off by 40 units—e.g. "Figure 9.4-1" in the text refers to Figure 9.4-41).

S 9-2. (DMM) *Possibility for Simplified HID*

Section 9.3.1 discusses simplifications "to increase efficiency in seismic hazard calculations." For each of the HID tables that involve five-point distributions for a Poisson recurrence model, it would seem that the five branches could be reduced by simply specifying the mean value of the gamma distribution, namely, (N + 1)/T (see Section 5.3.3.1, p. 5-36).

S 9-3. (CC) *Lack of Clarity in Notation in Section 9.4*

Some of the notation in section 9.4 is a little ambiguous. One PPRP reviewer commented that it took a while to understand that COV_K was for the parameters GEOM, Mmax, RATE, and RECORD. The difference between COV_T and SRSS was also found to be confusing and warrants clarification. Later in the chapter there are references to COVHAZ and COV_{HAZ} wts COV, and COV_{WT} , cl mean COV and σ_{CL} and σ_H. We suggest that these terms be clarified to be more consistent with the equations and figures.

Comments by Section

Order of Text, Tables, and Figures

Material needs to be reorganized so that the order of presentation of text, tables, and figures is consistent with other chapters.

Entire Chapter

Throughout, change “seismogenic crustal thickness” to “seismogenic thickness.”

Section 9.1

p. 9-1, par. 1: In line 6, change “Section 2” to “Chapter 2”; in line12, suggest replacing “that capture the community’s views” with “that represent the community’s views”

Because this section is intended to be a useful “overview,” in the last paragraph it would help to call the reader’s attention more explicitly to the key conclusions presented in Section 9.4.3—at the very end of the chapter and after 96 pages.

Section 9.2

In the first paragraph, line 10: Change “components - that is” to “components—that is”

Section 9.3.1

In the first sentence: “The HIDs describing seismic sources” is confusing. There is only one HID. Suggestion: “In the HID, the specifications for seismic sources . . .”

p. 9-3, first full paragraph, third sentence: Because the test sites are extensively referred to in the remainder of this chapter, it would be helpful at the end of this sentence to point the reader to a map of the seven test sites (say Figure 8.1-1).

p. 9-3, 3rd full paragraph, last sentence: Suggest replacing “Please refer to Section 9.4” with “See Section 9.4”

Section 9.3.1.10

p. 9-41, par. 2, first sentence: Text should be revised to eliminate reference to <u>internal</u> communications among the TI Team—“outlined in emails from Kathryn Hanson.”

Sections 9.3.2 and 9.3.3

No text provided, stated “to be written later.”

Section 9.4.1 and Table 9.4-1

The text and table contain inadequate documentation insofar as the column of "Available studies" in Table 9.4-1 includes a mix of citations, which can be tracked, and informally referenced studies such as "Charleston: WLA," "New Madrid: Youngs," "PEGASOS study," PEGASOS project."

Section 9.4.2

See Comment **S 9-1** regarding error in referencing figures, beginning in this section.

First paragraph (p. 9-49), last sentence: COV is defined here. Appropriate place to introduce symbols for the standard deviation of hazard (σ_H) and mean hazard (MH, or somesuch).

p. 9-66, line 2: Change "10-4 to 10-6" to "10^{-4} to 10^{-6}"

Section 9.4.3 and Table 9.4-1

The abbreviation "SSRS" appearing in Table 9.4-4 needs to be explained in the text. In the figure caption for Figure 9.4-44 one finds "srss" explained as "the square-root sum of squares calculation of the total COV." Neither srss nor SRSS appears in the list of acronyms.

Last paragraph: For clarity, it would be useful to explain where the statement "2/3 of the time" comes from—presumably from a normal distribution.

It is difficult to understand why the COVs decrease in annual frequencies of exceedance greater than 1E-5 on Figure 9.4-53 and 9.4-57.

The authors show at the Savannah, Chattanooga, and Columbia sites that the term "cl. Mean COV" is quite a bit different from the "wts COV." Because this is not intuitive, it would be helpful to provide some explanation to the reader.

CHAPTER 10 — REFERENCES

General Comments

G 10-1. (CC) *Content, Accuracy of List of References*

The PPRP leaves the technical editing of the list of References, including systematic cross-checking with the main body of the text to the TI Team and its support staff.

Some of our review comments on individual chapters of the main body of the text include specific comments on some references as either missing, to be added, or incorrectly cited (in particular, see PPRP review comments on Chapter 3, *References,* and Comment **S 6-16**).

G 10-2. (CC) *Single Place for All References*

The PPRP believes it would be desirable to have all references cited in the report—including those for the Appendices—in one place, and the reader should be informed to that effect.

CHAPTER 11 — GLOSSARY OF KEY TERMS

General Comments

G 11-1. (CC) *Content of Glossary*

A glossary of this type usefully serves the general reader, but more effort is needed to ensure that "key" terms specific to the CEUS SSC report are more systematically included. (It appears that someone simply extracted terms from the *Seismic Hazard Glossary* of the 1997 SSHAC report, modifying a few terms and adding several new ones.)

Ideally, the author of each chapter of the report should review his/her text and identify key terms for inclusion in the Glossary that would (a) help readers unfamiliar with the framework of the CEUS SSC project and (b) assist revisiting key concepts in the report.

<u>Candidate Key Terms</u>:

SSHAC Methodology
SSHAC Assessment Level
Stability
Longevity
Data Evaluation Table
Data Summary Table
Paleoseismic/Paleoseismicity
Liquefaction/Paleoliquefaction
Expert Assessment
Proponent Expert
Evaluator Expert
Reasonable Assurance Standard
Participatory Peer Review
Sensitivity Analysis
Declustering
Magnitude, Adjusted (**M***)
Conceptual SSC Framework
SSC Model
Probability of Activity
Future Earthquake Characteristics
Logic Tree
Weight
Hazard-Informed Approach
RLME Source
Bayesian Approach
Stable Continental Region
a-value
Spatial Stationarity
Smoothing
Fault Slip Rate
Hazard Calculation
Coefficient of Variation (COV)
[Recurrence Model—add Poisson, Renewal]
Probabilistic Seismic Hazard Analysis

G 11-2. (CC) *Geological and Other Relevant Technical Terms*

For numerous geological terms used in several of the chapters that do not appear in the *Glossary*, one might refer the general reader to a standard glossary of geological terms such as:

Neuendorf, K. K. E., Mehl, Jr., J. P., and Jackson, J. A., 2005, Glossary of Geology, 5th Edition, American Geological Institute, Alexandria, Virginia, 779 p.

Another valuable glossary for reference is:

Lee, W. H. K., and Aki, Keiiti, 2003, Glossary of Interest to Earthquake and Engineering Seismologists, *in*, Lee, W. H. K., Kanamori, H., Jennings, P. C., and Kisslinger, C., 2003, International Handbook of Earthquake and Engineering Seismology, Part B, Appendix 1.

Specific Comments

S 11-1. (CC) *Acknowledgment of Source*

Because more than 85 percent (45 of 54) of the entries in this Glossary either come directly or have been slightly modified from the *Seismic Hazard Glossary* of the 1997 SSHAC report, that source should be acknowledged.

S 11-2. (CC) *Disclaimer*

Given the sponsors of the CEUS SSC project, it may be prudent to caution the reader that definitions may not correspond exactly to those appearing in regulatory documents of NRC or DOE.

Comments for Clarity and Completeness

- **Active Fault, Active Source —** Active Fault and Active Source can have different definitions (consult Lee and Aki, 2003, cited in Comment **G 11-2**, for definition of Active Fault). Consider defining these two terms separately in the *Glossary*.
- **Aleatory Uncertainty/Variability** — The provided definition (not from SSHAC report) is a poor one for the uninformed reader. Revisit definition in SSHAC report and/or see definition in Robin McGuire's 2004 EERI monograph (p. 8).
- **Area Source and Background Source —** These two terms have very different characterization for representing uncertainty in an SSC model. To avoid confusion, cross references should not be made.
- **Distance Epistemic Uncertainty** — Typo and erroneous duplicate entry for Epistemic Uncertainty. Delete.

- **Epistemic Uncertainty** — As for *Aleatory Uncertainty*, the offered definition is a poor one for the uninformed reader. Revisit definition in SSHAC report and/or see definition in Robin McGuire's 2004 EERI monograph (p. 8).
- **Informed Technical (Scientific) Community —** Consider alternative definition:

  A construct of the SSHAC guidance that embodies the community distribution of uncertainty sought by the SSHAC Methodology, independent of the Assessment Level. Experience implementing the SSHAC Methodology has revealed a high level of confusion surrounding use of the word "informed" in this construct. For this reason, the word "informed" has been eliminated without loss of intent of the SSHAC construct.
- **Magnitude** — This general definition, unrelated to a specific scale, should be labeled as such—given the appearance of other magnitude definitions in the Glossary. The explanation included in this general definition applies to some, but not all, magnitude scales (e.g, it doesn't apply to coda-wave magnitude and Moment magnitude). Suggestion [see Bolt (1978,1988, 1993), the source that SSHAC obviously used] :

  Magnitude, General: A measure of earthquake size, classically determined by taking the common logarithm (base 10) of the largest ground motion recorded during the arrival of a seismic wave type and applying a standard correction for distance to the epicenter.
- **Maximum Magnitude —** Mmax is an assessment. Suggest replacing "that a seismic source is capable of generating" with "that a seismic source is assessed to be capable of generating"
- **Seismicity —** Consider the more informative definition contained in Lee and Aki, 2003, cited in Comment **G 11-2**.
- **Seismic Source** — Given the discussion on p. 4-13f, the offered definition (from the SSHAC report) is weak. Consider something like:

  Seismic Source: Traditionally, in a Probabilistic Seismic Hazard Analysis, a region or volume of the earth's crust that has uniform earthquake potential or uniform earthquake-generating characteristics. In this project, unique seismic sources (faults, regions) are spatially defined to account for distinct differences in earthquake recurrence rate, maximum earthquake magnitude, expected future earthquake characteristics, and probability of generating earthquakes of magnitude 5 or larger.
- **Technical Integrator (TI) —** Consider alternative definition:

  A SSHAC term for an individual or team responsible for characterizing the technical (scientific) community's knowledge and for assessing and representing the community uncertainty in a seismic hazard model. In this project, this was done using a SSHAC Level 3 assessment process.

APPENDIX A — DESCRIPTION OF THE CEUS SSC PROJECT DATABASE

General Comments

G A-1. (NAR) The CEUS SSC Project has assembled and archived a comprehensive suite of data sets of the CEUS that are important to the characterization and assessment of the SSC model of the region by the TI Team and that significantly contribute to the community knowledge-base. Compiling and providing these data sets in a common GIS data format required substantial effort, for which the Project Team is commended.

These data, for the entire CEUS SSC model region, as well as for specific subregions of special interest for the characterization and assessment of seismic source zones, have been obtained from existing data bases, digitized maps, data files, and original data. The data have been put into a GIS format to facilitate analysis, employing overlays of various data types, and they have been made available to the TI Team, the PPRP, and others in the project. The data files will be archived on a server that can be accessed in the future via a website. The data include maps of surface, bedrock, and crystalline basement geology, geophysical data (gravity, magnetic, and stress), results of seismic study of the crust, compilations of historic and pre-historic earthquake data, and previous seismic hazard analyses. Workshop #1 was focused on selecting the critical data sets required for the project and identifying the optimum data sets available to the project.

Appendix A describes the data included in the Database and the procedures for assembling the data sets and making them available to the project teams. In addition, summary metadata "sheets" are included for 32 of the identified data 72 CEUS data bases. As part of the review of Appendix A, consideration also has been given to the 60 metadata files describing the data sets of the Database. The 60 metadata descriptions are in a separate digital data file which is not part of the final report or its appendices, but has been on the EPRI data server which is no longer in service. Future access to the metadata files via the website needs to be clarified and explained. In general these files are helpful in understanding the source, capabilities, and limitations of the data sets that are important to all users of the CEUS SSC data compilation.

G A-2. (CC) The level of detail provided in Appendix A and the metadata files is generally satisfactory, but significant revisions are required to improve the text, update and complete the summary description of the data sets, complete the metadata a sheets for all data sets, synchronize the data sets, the metadata files, and the summary data sheets, and make numerous editorial changes. Suggestions are provided in the following general and specific comments for improving the Database and its description and the metadata files.

Specific Comments for Clarity and Completeness

S A-1. The Appendix does not describe the future website, or access to it, that will make the data sets and the metadata available to future users. This will need to be done to enable the report user to access the data and metadata files.

S A-2. There are several data sets dealing with gravity, magnetic, and geologic data of the same data type that are of various vintages. Data sets should be eliminated in the Database that have been superseded by more complete and accurate data sets. Including dated, out of date, data sets in the Database will cause confusion in determining which data set was and should be used in analyses. As a result the credibility of the results of the project will be enhanced by removing dated data sets.

S A-3. A total of 32 summary metadata sheets are presented in the Appendix for the CEUS SSC model region, but no summary metadata sheets are provided for the remaining 40 data sets listed in Table A-1 for specific subregions. Summary metadata sheets should be provided for all of the GIS layer data sets or an explanation for not preparing metadata for the data sets needs to be provided. Furthermore, there is not an obvious relationship between the summary metadata sheets and the metadata files. In the metadata file there are 60 separate files that do not synchronize with the summary metadata sheets. It is not clear why there are only 60 rather than 72 representing all the data layers as in Table A-1. Note also that the titles of the data sets are not necessarily the same as the titles in Appendix A and the metadata files. This causes confusion in using the files. It would be useful to have a column in Table A-1 that identifies the metadata file(s) of the specific data set as they exist in the metadata file.

S A-4. The prose in this appendix is in draft stage and needs clarification, reorganization, and improvement. A technical editor could help improve the appendix so that the resulting description of the efforts and the results associated with the Project Database reflect well on the major investment that was made.

S A-5. All pages of the appendix should be numbered consecutively.

S A-6. The page size maps of the data sets that are provided as part of the summary metadata sheets are very useful. They provide a view of the data set for use in qualitative analysis by the user of the report. In addition, they assist the user in making a decision about preparing small scale maps of the mapped parameter or in selecting regions of the maps for detailed analysis. Only one of the six magnetic anomaly data sets prepared for this project (Ravat et al., 2009) is shown, and only one of the fifteen gravity anomaly data sets (CEUS SSC, 2010) prepared for this project is illustrated. Please note that referring to the gravity anomaly data sets by CEUS SSC, 2010 as in the summary data sheets may lead to confusion. An alternative suggestion is to cite Keller, 2010, personal communication.

S A-7. Unfortunately a key to the contour interval and symbols used in several of the maps is not provided with the map. This seriously detracts from the usefulness of the maps. In the few maps that show a color bar of the mapped parameter amplitudes, the limits of the range are given to a precision unwarranted in the data set and have limited usefulness for the user. In addition, these color codes are too coarse for most uses of the data.

S A-8. The keywords of the metadata files need further attention. Most data sets do not have keywords, and keywords that are given are not consistent and comprehensive. Keywords are not critical but they can be helpful in directing the data user to the appropriate data set without laborious, extensive review of all the data sets. Will the user be able to search the data sets by keyword?

S A-9. "Aeromagnetic" in the title of maps should be changed to "magnetic anomaly." This is the general title that is applied to regional magnetic anomaly maps.

S A-10. Citations in tables are not in consistent format.

S A-11. A data file showing areas where reliable earthquake hypocenter depths are available would be useful. Or is it possible to show range of depths of foci for the CEUS?

S A-12. Headers for Metadata Sheets: The repetition of "CEUS SSC Project GIS Data Summary" in large point size and bolded is less important to guide the reader's eye than the title of what the sheet contains. Consider reformatting the header information. Example:

Sheet A-1 — CEUS SSC Project GIS Data Summary
NOAA DNAG MAGNETIC ANOMALY MAP OF NORTH AMERICA

S A-13. Remove bracketed comments in text from previous reviewers.

S A-14. Shaded-relief versions of selected gravity and magnetic anomaly maps (e.g., total magnetic intensity anomaly map, reduced to pole magnetic anomaly map, residual isostatic gravity anomaly map) are a significant aid in the interpretation of the geological sources of the anomalies, particularly the high wave-number components of the anomalies. Several of these shaded relief maps have been prepared, but they are not identified in the data sets. They should be included and the specifications of the azimuth and inclination of the light source used in preparing the maps should be specified on the maps and in the metadata.

Comments by Section, Table, and Sheet

Text: Unlabeled Introduction

First paragraph: The first two sentences are not clear as to the goals of the database and the method of achieving them. The use of "function" in the first sentence leads to confusion. Suggest a rewrite focusing on goals of the data sets and procedures used to achieve them.

Second paragraph: Strongly suggest that the term “aeromagnetic” throughout the titles of data sets be changed to “magnetic anomaly.” This is the appropriate title given to regional magnetic anomaly maps. Delete Free-air gravity and remove Bouguer and simply use the term “gravity anomaly.” Also, remove DNAG and USGS. These are data sets that have been superseded and should be removed from the Database. The Mesozoic rift basins data base cannot be found as an entity in the Database. Remove the parenthetical phrase in Earthquake Catalog.

In the bulleted list, note that there is no metadata file or summary for Mesozoic rift basins which was compiled for this study.

Last bullet of second paragraph: Will digital presentations of the crustal scale profiles be available? If not, where can they be obtained for analysis?

Last paragraph, last line: The last metadata summary sheet is A-32, rather than A-36.

Text: Section A.1

Last sentence of first paragraph: “The digital data compiled for the CEUS SSC Project are available to the public to provide transparency regarding the development of the CEUS SSC database.” Transparency does not seem to be an important reason for this. Rather it serves as a repository of data useful for largely regional seismic source zone characterization and assessment in the CEUS.

Second paragraph, first line: Figure A-1 is not in the appendix.

Second paragraph, second line: For example, some *public-domain* data sets cover…

Third paragraph, bullets: Change to “Magnetic anomaly data,” “Gravity anomaly data”

Add “Mesozoic rift basins within the ECC-AM” to the bullet list in third paragraph.

Third paragraph, fifth bullet: Add “data” after “Maximum horizontal compressive stress” to be consistent.

Third paragraph: Replace “sources” in first line by “types” or, less desirable, “class.” In second line, suggest: “These data layers include the following:”

Text: Section A-2

First paragraph: Suggest that definitions of data class, theme, etc. be provided or a figure showing hierarchy of data.

First paragraph: Spell out FWLA, point out that this server is no longer available

First paragraph, top of p. A-3: Instead of "theme," use "type of data"?

Fifth paragraph: All project data began at revision 0 (Rev0) and have been updated with consecutive revision numbers and made available via the project web site. Providing a full file name reference allows data to be identified if removed from the organization of the project Database.

Sixth (last) paragraph: Add this sentence at end: "This server is no longer in service for this project."

Sixth paragraph: Is the "Project GIS Manager" the same as "Database Manager" identified in Figure 2.3-1 and Appendix G? If so, be consistent.

Text: Section A-3.3

Second paragraph: If the steps to review GIS data produced from non-digital data were sequential, it would be better to present the steps using numbers or letters rather than bullets.

Second paragraph, fourth bullet: Clarify "Completion of attribute information"

Second paragraph, last bullet: Use of the term "topology" appears to be inappropriate here because the term is generally used to describe a branch of mathematics.

Text: Section A-4

Second paragraph, line 2:   ** are ??

Second paragraph, line 6: Summary sheet A-22 has no state boundaries.

Second paragraph, line 7: Why not "all" rather than "majority"? What criteria were used to omit some?

Second paragraph, last sentence: Why are there no metadata summary sheets for data covering specific regions of the study area? If they are important enough to include as a data set, they should be important enough to have a metadata file. Are all data sets included in the metadata file? If not, why not?

Text: Section A-5

Third paragraph, first line: Were the *original* or *source* data provided?

Third paragraph, last line: Typo: "into other coordinate systems."

Text: Section A-6

This section is out of place, place after A-5.

First paragraph, 3rd line: Add earthquake [information] to this list

Second paragraph, line 5: Typo: "to identify geologic relationships"

Table A-1

Page 1: Where are the citations located? Are they all in the same place in the report?

Page 1: Delete Row 1

Page 1: Delete Row 3

Page 1, Row 5: Need more complete description of this database and its preparation or refer to another section of report.

Page 2, Row 2: Replace "Geodesy" with "Strain (GPS)"

Page 3, Row 3: Why is this map being used, since it was replaced by Reed et al. (2005)? Delete.

Page 4, Row 3: Is this the basin map referred to in the data evaluation tables? If so use consistent titles.

Page 4, Row 7: Delete, superseded.

Page 5, Row 1: Refer to Keller, 2010, personal communication

Page 5, Rows 3 and 4: Delete, superseded

Page 5, Row 6: How are these tied to references? Where are the metadata for these layers?

Page 6, Row 2: This is also referred to as Zoback (2010). Determine appropriate reference and use consistently.

Page 7, Row header: Change "Mid-Continent" to "Midcontinent"

Page 7, Row 5: Replace "Geodesy" with "Strain (GPS)"

Page 7: Why does the numbering of Summary Sheets stop with A-32 (in the last row of page 6)?

Page 8, Rows 5 and 6: Need citations

Page 9, Row 2: Need citation

Page 9, Row 3: Change “Aeromagnetic” to “magnetic anomaly”

Sheet A-1 Delete, superseded

Sheet A-2

Replace “aeromagnetic” with “”

Contour interval should be given

Show page-size maps of six data sets with bar graph for amplitude and in shaded relief if possible

Differentially reduced to pole, tilt derivative, etc. may not be known entities to user; suggest a basic reference for each of these for the interested reader

Sheet A-3 Delete, superseded

Sheet A-4 Increase amplitude at least twice that being shown

Sheet A-5

Data description: Needs range of date, also key to map symbols; as throughout report, moment magnitude (**M**) should be bolded; which earthquake catalog is referred to? The raw catalog, the declustered catalog, or ?? Should refer to Appendix B if this is the same catalog.

Sheet A-6 Identify symbols

Sheet A-7 Brighter colors needed, no extended crust identified

Sheet A-8 Need brighter colors

Sheet A-9 Need key to colors

Sheet A-10 Need key to colors

Sheet A-11 How are they keyed to source (reference)?

Sheet A-12 Delete, superseded

Sheet A-13

Data description is misleading, the dashed line represents the mapped eastern limit of pre-1600 Ma crust. Why not show all of Figure 2 of this reference? It puts the boundary into the context of the basement terranes.

Sheet A-14 Brighten colors and provide key

Sheet A-15 Brighten colors and provide key

Sheet A-16 Brighten colors

Sheet A-17 Needs key

Sheet A-18

Needs contour interval, high range is given to 4 decimal points which is much greater than precision

Sheet A-19 Needs key

Sheet A-20 Legend of figure needs to be checked. What is basement thickness? Unclear.

Sheet A-21 Brighten colors and provide key

Sheet A-22 Delete, superseded

Sheet A-23

Brighten colors, color contour interval needed, show all figures at page size, preferably in shaded relief; suggest for Author that G.R. Keller be identified as the source of the data and derivative anomaly maps . . . as in A-2 for D. Ravat.

Sheet A-24

To be consistent, use residual isostatic; color contour interval without range beyond decimal point.

Sheet A-25 Delete, superseded

Sheet A-26 Delete, superseded

Sheet A-27 Tie to references?? Where will the metadata file be accessible?

Sheet A-28 Brighten colors

Sheet A-29 Needs key; this is also referenced as Zoback (2010) – select appropriate citation

APPENDIX B — EARTHQUAKE CATALOG

General Comments

G B-1. (NAR) Appendix B contains a listing of the earthquake catalog for the CEUS developed as part of this project. The development of the earthquake catalog is a major element of the source characterization and assessment in the project. The Appendix contains a single page of text that identifies the columnar entries in the catalog followed by a 273 page tabular listing of the 9800 earthquakes in the catalog. The table is well laid out and easy to follow.

G B-2. (CC) It is evident that monumental efforts were required to compile this catalog, and the Project Team is to be applauded for these efforts. Beyond its use by TI Team members familiar with its contents, careful documentation and explanation is needed for the contents of the catalog to be understood and appropriately used by others.

Specific Comments for Clarity and Completeness

S B-1. *Need for Introductory Text*

A brief summary discussion should be added to this Appendix. This discussion should describe what this catalog listing actually is (i.e., final catalog with dependent events flagged). It would also be useful to refer the reader back to relevant sections of Section 3 for a discussion of **M***, etc.

Additional notes on depths and how ERH was estimated would also be useful in the introduction to the catalog.

A pointer to the appropriate Database entry would be useful.

A catalog of non-tectonic events was developed as part of this project (mentioned in Section 3), where will this catalog be documented and maintained?

S B-2. *Clarity of Documentation in the Catalog Explanation*

For clarity of documentation, attention should be paid to the following:

1. Designation of time in an earthquake catalog should be explicit. Are the times/dates in UTC? Local time? A mix? This is non-trivial if one tries to find the events in another catalog. Also, the earthquake origin times are the basis for calculation of inter-event times in declustering algorithms.

2. How should the reader interpret the variable presentation of significant figures in the Earthquake Catalog for latitude, longitude, depth, **M**, and sig**M**? How does one discern available information on precision from the vagaries of spreadsheet display?

3. The meaning of Depth = 0 should be explained.

4. To avoid ambiguity, ERH should be explained as “Horizontal Location Uncertainty (km)”. If correct that the entries for ERH contain both rough estimates and statistical calculations, then ERH is better described as “Estimated Horizontal Location Uncertainty (km)”.

5. After ERH, entries in the Explanation change from having the first letter of all terms capitalized to just the first word capitalized.

6. **M** , **M***, and sig**M** should be bolded in Column 1 of the Explanation

7. In column 1, “Flag” should be written “FLAG” as it appears in the table.

APPENDIX C — DATA EVALUATION TABLES

General Comments

G C-1. (NAR) The tables of Appendix C summarize what data were used, how the data were used, and the source, quality, and significance of the data in defining, characterizing, and assessing the CEUS seismic sources. In addition, the tables specify the availability of the data in GIS format. These tables are a useful supplement to the documentation of the seismic source zone characterization and assessment of both the RLME sources and the seismotectonic source zones. They will be useful to users of the CEUS SSC report, and they will also provide a guide to potential application of various data sets in future evaluations of the CEUS SSC model. In general, the tables are well prepared and presented. However, they are not without problems, as we proceed to explain.

Specific Comments

S C-1. (CC, DMM) *Completeness of Tables and Ambiguity About Applicability*

Data Evaluation tables have been prepared for many of the identified seismic source zones, but not all. In Section 4.2.2 of the main report, the reader is informed (p. 4-6, first paragraph of the section) that, "Data Evaluation tables were developed . . . and the tables for <u>each source</u> (emphasis added) are included in Appendix C." Comparing a list of the RLME sources, the seismotectonic zones, and the Mmax source zones with the index of tables on the first page of Appendix C will leave the reader perplexed. Further, the treatment of some zones is handled within the Data Evaluation table for another zone (e.g., the Meers fault RLME source is included in the table for the OKA seismotectonic zone).

What criteria were used to select which zones were to have Data Evaluation tables? At the top of Table C-5.4, the labeling indicates "Default for entire CEUS SSC." Does this mean that if a table is not given for a specific zone, then Table C-5.4 is the applicable table? (If this is the intent, note that Table C-5.4 is incomplete with regard to several data sets.) Introductory text should be added to eliminate these and similar questions and concerns pertaining to the Data Evaluation tables. All seismic source zones including Mmax zones should have a Data Evaluation table.

S C-2. (CC) *Facilitating Use of the Data Evaluation Tables*

The Data Evaluation tables are explained in the text of the report (Section 4.2.2). However, consideration should be given to adding a short description of the objective, organization (including the keying of the table numbers to the main body of the report), preparation, and uses of the tables in an introductory paragraph to the appendix. This will facilitate the use of the tables. An explanation of the content of the columns used in the tables should be also included in this description for stand-alone reading. Also, all pages of Appendix C should be numbered consecutively, not separately for each table, to enable convenient reference—as opposed to having to point to a specific table and a page number within the table.

S C-3. (CC, DMM) *Inconsistencies in the Tables*

The Data Evaluation tables have numerous inconsistencies that should be eliminated because they diminish the quality and usefulness of the tables. We note the following:

1. The titles of the tables and the identified source in the notes at the top of each table should be consistent with the nomenclature of the text of the report, and tables should be in the same sequence as the identified source is described in the text (or keyed to a table in the text).

2. Although the majority of the Data Evaluation tables are also in the Data Summary tables (Appendix D), some are not included in the Data Summary tables and vice-versa. There is no explanation for this inconsistency among tables in the documentation of the report.

3. The level of information given in the tables is variable. This may be due in part to the information available, or it could be due to the detail that is provided by the individual preparing the table. Greater consistency in the level of information would be desirable.

4. All the tables have seven columns except for Tables 6.1.4 (OK aulacogen) and 7.3.9 (Gulf Coast), which have eight columns. Only seven columns are described in Section 4.2.2 (pages 4-6 and 4-7). Note that the fifth column should be "Description" rather than "Discussion" (there is no oral material here). Throughout the tables, references to "discussions" should be changed to "descriptions."

5. Numbers in the tables are inconsistently spelled out or given in numeric form. Numeric form should be used for data and scoring; otherwise, numbers should be spelled out when referring to counts of ten or less.

6. Geographic (compass) directions are inconsistently given in abbreviated (e.g., NE) and spelled-out form.

7. Some tables have the acronyms for the subdivisions of the seismic source zone identified in notes at the beginning of the tables, others do not. Also several acronyms are not given in the List of Acronyms.

8. Descriptions in cells are variously in sentence and non-sentence form. It may be useful to have both, but an effort to be consistent would be worthwhile.

9. The use of blanks in the tables is inconsistent. Every cell needs to have something in it; if nothing else, N/A for not applicable or some other notation to indicate intention. Otherwise, the meaning of a blank cell will be unclear.

10. There is inconsistency in the title of column 3 among the tables. Is it “data quality” or “data and quality” (as in “Notes on Quality or Data”)?

11. Use data as a plural word consistently throughout the tables.

12. Both the terms magnetic and aeromagnetic are used in the tables. The use of the term aeromagnetic should be changed to magnetic throughout. Aeromagnetic simply refers to the method of collecting the majority of the data in the file. Referring to “aeromagnetic” but only to “gravity” is inconsistent.

13. Where no data are available for a particular type of data, the tables deal with this in different ways—sometimes the wording indicates explicitly that no data are available (e.g., Table C-6.1.3, p. 4; r. 3); in other places, data are just not identified.

14. The evaluation of the quality of the data is not consistent; in some cases peer-reviewed publications are referred to and in others simple publications.

Comments by Table (for Clarity and Completeness)
(Notation: pg. = page, c = column of table, r = row of table)

Table C-5.4

- pg. 1, descriptor (title) of 5th c: Would “significance” be a more descriptive term than “reliance”?
- pg. 4, r. 3; c. 1: Is this the new data set from Zoback? If so, please put a date on it—and put dates in all tables for all the data sets prepared for this project so that in subsequent use there will be no question of date.
- pg. 1, r. 4, 5, & 6; c. 6: Add fault to slip
- pg. 1, r. 7; c. 3: In the Charlevoix area of the St.Lawrence Rift
- pg. 2, r. 1 & 2; c. 6: Add fault slip
- pg. 2, r. 5; c. 6: Could not find where depth as a function of magnitude is described in report

Table C-6.1.1

- pg. 1, r. 5; c. 6: Incomplete
- pg. 1, r. 6; c. 1: Change to magnetic from aeromagnetic, here and elsewhere in tables
- pg. 2, r. 2; c. 1: Give date

- pg. 3, r. 4; c. 1: Reinecher not in references…this holds true for many of the references cited in the tables…they should be included in Chapter 10 (References)

Table C-6.1.2

- pg. 2, r. 5 & 6; c. 3: What is the significance of the term “basic”?
- 6, r. 1; c. 3: What is meant by “plain sediments”?
- pg. 6, r. 5; c. 1: Should be bold and italics
- pg. 9, r. 5; c. 1: Should be bold and italics
- pg. 11, r. 3; c. 3: Replace to with two

Table C-6.1.3

- pg. 3, r. 2; c. 6: Reference to 2002 article is incomplete (author?)
- pg. 5, r. 1; c. 6: Change to “No measurements nearby to the . . .”
- pg. 6, r. 2; c. 6: Reference to 2002 article is incomplete (author?)

Table C-6.1.4

- Why add an eighth column? Y or N to be used in c. 8 to be consistent with rest of tables.
- pg. 1, r. 1; c. 4: How are faults due to hydrocarbon exploration? Change wording.
- pg. 1, r. 1; c. 5 and subsequent rows on page: What is OK aulacogen? Background?
- pg. 1, r. 2; c. 1: Bold and italics
- pg. 1, r. 3 & 4: Delete. These are data sets superseded by the EPRI data set.
- pg. 2, r. 2: Delete this data set, superseded by the EPRI data set
- pg. 3, r. 3; c. 7: Change to “within the Arbuckle”
- pg. 4; r. 2; c. 2: 1990
- pg. 4; r. 4; c. 2: What is BEG?
- pg. 7; r. 1; c. 7; “fault slip”

Table C-6.1.5

- pg. 1; r. 2; c. 6: Change to …are concentrated…; also …projects to surface..
- pg. 1; r. 5; c. 6: Change to …sequences provides…
- pg. 4; r. 1; c. 3: Give map #
- pg. 5; r. 5; c. 3: Is relatively short germane? Don’t know what short is. This is not used where abstracts are referenced.
- pg. 6; r. 2; c. 4: Define abbreviations
- pg. 6; r. 5; c. 6: Rationale or geophysical evidence?

- pg. 8; r. 1; c. 7: What is significance of ("?")

Table C-6.1.6

- pg. 5; r. 2; c. 6: What is RP and ERM-SRP? ; need period after parenthesis
- pg. 12; r. 1; c. 6: What is ERRM? ERM

Table C-6.1.7

- pg. 3; r. 5; c. 4; what is EMF_S? not in acronyms

Table C-6.1.8

- pg. 2; r. 1; c. 6: No CFZ in acronyms
- pg. 3; r. 5; c. 6: Explain A and B; replace

Table C-7.3.1

- pg. 2; r. 1; c. 6: Clarify the wording, "A general gradient in amplitude parallels"
- pg. 4; r. 8; c. 6: Entries; period at end of sentence
- pg. 5; r. 1; c. 6: Capitalize Mechanisms

Table C-7.3.3

- pg. 1: Shouldn't the title be Northern Appalachian zone, without the "s"?
- pg. 3; r. 2; c. 3: Parenthesis at end

Table C-7.3.4

- pg. 1: In notes beneath title, need to identify the acronyms of the subdivisions of the zone
- pg. 2; r. 4 & 5; c. 3 & 6: What is CLFS?

Table C-7.3.9

- pg. 1; r. 3 & 4; c. 7: If considered for defining boundaries, why 0 in column 6?

Table C-7.3.12

- pg. 1; r. 5; c. 3: Do not capitalize intensity
- pg. 2; r. 1; c. 6: Unfinished sentence
- pg. 2; r. 2; c. 6: Belongs in column 6 of row 3; why 2 in column 5 for row 2 and 1 in column 5 for row 3?
- pg. 5; r. 1; c. 6: Remove "yet"

APPENDIX D — DATA SUMMARY TABLES

General Comments

G D-1. (NAR) The Data Summary tables of Appendix D contain a massive amount of information on references that include data considered by the TI Team in identifying, characterizing, and assessing the CEUS seismic sources. These data include all types of information that have a potential use in achieving these objectives. The tables provide a benchmark of germane data at the time of the Project, which gives transparency to the efforts of the TI Team and which future evaluations can augment with new sources of information. The tables include the citation, the title, and the data included in the reference that are relevant to seismic source identification and characterization. The tables are thorough and, in general, reasonably well prepared and presented. We proceed to point out minor problems needing attention before finalizing the appendix.

Specific Comments

S D-1. (CC) *Difficulty in Relating the Appendix to the Main Body of the Report*

The labeling of the tables is not consistent with the titles and acronyms used in the main body of the report for the source zones, and source zone data summaries are grouped in a manner that makes it difficult to relate the tables to some of the specific zones. For example, the Gulf Highly Extended Crust zone is apparently included in Table D-7.3.9, Gulf Coast Data Summary. Similar situations occur in other tables of the appendix. This makes it very difficult to relate the tables to the source zones in the report and decreases the usefulness of the appendix. This inconsistency needs to be rectified.

S D-2. (CC) *Facilitating Use of the Data Summary Tables*

The Data Summary tables are explained in the text of the report (Section 4.2.2). However, consideration should be given to adding a short description of the objective, organization (including the keying of the table numbers to the main body of the report), preparation, and uses of the tables in an introductory paragraph to the appendix. This will facilitate the use of the tables. An explanation of the content of the columns used in the tables should be also included in this description for stand-alone reading. Also, all pages of Appendix D should be numbered consecutively, not separately for each table, to enable convenient reference—as opposed to having to point to a specific table and a page number within the table.

S D-3. (CC) *Inconsistencies in the Tables*

The Data Summary tables have numerous inconsistencies which should be eliminated because they diminish the quality and usefulness of the tables. We note the following:

1. The titles of the tables and the identified source in the notes at the top of each table should be consistent with the nomenclature of the text of the report, and tables should be in the same sequence as the identified source is described in the text (or keyed to a table in the text).

2. The level of information given in the third column, Relevance to SSC, is variable. This may be due in part to the information available or it could be due to the detail that is provided by the individual preparing the table. Greater consistency in the level of information would be desirable.

3. Geographic (compass) directions are inconsistently given in abbreviated (e.g., NE) and spelled-out form.

4. Dates are presented in different formats.

5. Some tables have the acronyms for the subdivisions of the seismic source zone identified in notes at the beginning of the tables, others do not.

6. Column 3 descriptors are sometimes in sentences, while others are not. It may be useful to have both, but an effort to be consistent would be worthwhile.

7. The use of blanks in the tables is inconsistent. Every cell needs to have something in it; if nothing else, N/A for not applicable or some other notation to indicate intention. Otherwise, the meaning of a blank cell will be unclear.

8. Both the terms magnetic and aeromagnetic are used in the tables. The use of the term aeromagnetic should be changed to magnetic throughout. Aeromagnetic simply refers to the method of collecting the majority of the data in the file. Referring to "aeromagnetic" but only to "gravity" is inconsistent.

9. The format of the references at the end of each table is inconsistent, and some references do not have complete information.

10. The ordering of the citations in the tables is not consistent. Some are listed chronologically, while others are listed alphabetically according to the first letter of the family name of the senior author.

11. Use of bold letters for subtitles in several of the tables is inconsistent.

12. Capitalization of type of feature is inconsistent in the tables. It is suggested that the type of feature should not be capitalized, e.g., Commerce lineament, not Commerce Lineament.

Comments by Table (for Clarity and Completeness)
(Notation: pg. = page, c = column of table, r = row of table)

Table D-5.4

- pg. 1, c. 1: Period after et al. on this page and throughout tables
- pg. 4: Should Petersen et al. be included?

Table D-6.1.1

- pg. 1, c. 3: Spell aulacogens

Table D-6.1.2

- pgs. 2 & 3, c. 3: No difference for Chapman and Beale, 2009 and 2010. Should there be a difference?
- pg. 5, c.3, r.2: Should be Appalachian Mountains not Appalachians, similar comment for other geographic features throughout tables.
- pg. 15, c.2, r.2: Why is journal listed?

Table D-6.1.3

- pg. 1, c.3, r.2: The abbreviation for miles should be mi without a period (not mi.) — change throughout tables

Table D-6.1.4

- pg. 3, c.3, r.1 & 2: Replace further with farther

Table D-6.1.5

- pg. 40, c.3, r.2: Blank—similar blanks in other tables

Table D-6.1.9

- pg. 4, c.3, r.4: Use of the casual Appalachians and Rockies should be avoided
- pg. 12: Has horizontal line between rows missing—this occurs elsewhere in tables

Table D-7.3.1

- pg. 4, c.2, r.2: Misspelled Quebec
- pg. 5, c.3, r.2: Is it Sutton Mountain or Sutton Mountains? Both are used in this table.

Table D-7.3.2

- pg. 10: Reference for N.H. Sleep; misspelled mantle

Table D-7.3.4

- pg. 9, c.3: No references for two subheadings

- pg. 15, r.: Geophysical Investigations should be bold; similar subheading concerns elsewhere in tables

Table D-7.3.7

- pg. 1: Horizontal lines needed between citations
- pg. 11: Misspelling of investigate

Table D-7.3.9

- pg. 1 and following: Why () around citations?

APPENDIX E — CEUS PALEOLIQUEFACTION DATABASE, UNCERTAINTIES ASSOCIATED WITH PALEOLIQUEFACTION DATA, AND GUIDANCE FOR SEISMIC SOURCE CHARACTERIZATION

General Comments

G E-1. (NAR) This appendix represents a thorough and well expressed compendium of methodology, data, and guidance related to paleoliquefaction studies in the CEUS. The written content and illustrations present the data and information clearly and with a high degree of technical quality. Generally the documentation of effort encompassed in this appendix supports the related assertions made in the CEUS SSC. This work is notable not only because it represents a new and productive field of study that was not included in the earlier EPRI-SOG and LLNL projects, but also because the effort has brought sets of information and data that were highly varied and inconsistent into a consistent and coherent framework. This appendix is likely to be used as a primer on the topic for future researchers in paleoliquefaction, and the fulfillment of the recommendations provided could significantly improve the understanding of RLMEs in areas of low to moderate seismicity areas in the U.S. and globally.

Specific Comments for Clarity and Completeness

S E-1. *Incorporation of the Digital Database*

It is unclear how the digital database is going to be incorporated into the final report and how it will be accessed in the future. It would be useful to the reader if the location was noted after the sentence, "The database itself is available in digital format."

S E-2. *Recommendations for Clarification of the Digital Database*

Because Section 1.1 (Database Structure) uses many technical terms related to dating that are very well discussed later in the document, it may be useful for many readers who are not well versed on the techniques if a sentence were added at the end of the first paragraph of the section that says, "A discussion of the various dating methods and their uncertainties can be found in Section 2.1.3."

In relation to the description of the database on page 2, a simplified figure illustrating parameters such as SB_THICK, SB_WIDTH, SB_LENGTH, etc. may be helpful to the reader.

Similarly, a simple figure illustrating the uncertainty estimates described in the last paragraph of Section 1.1 is not essential, but could be very useful for the reader.

S E-3. *Clarification of Data Contributors*

At the beginning of each of the "Data Description" subsections in the discussions of regional datasets in Section 1.2, the authors note that "Paleoliquefaction data have been contributed by . . . ." It is unclear to the reader if the contributors listed represent a complete list of the researchers who have worked in the area or if it is a subset of researchers who have provided additional information specifically for this project (e.g. by providing 2-sigma data that were not otherwise published).

Because this report is likely to be read by researchers not familiar with paleoliquefaction, it may be helpful to refer to Beta Analytic as "Beta Analytic Laboratories" or in similar terms. The way the text reads currently, those not familiar with the topic are likely to understand Beta Analytic to be a process or approach described in Talma and Vogel (1993) or Vogel et al. (1993).

S E-4. *Missing or Misnumbered Figures*

- There is a Figure 11a, followed by Figure 11. Presumably, the second should be Figure 11b.
- Figure E28 is missing.
- There is a Figure E-39 and a Figure E-39b. Only E-39 is noted in the text.
- There is a Figure E-44 and an E-44b. Only E-44 is noted in the text.
- On Figure E-50, it would be useful to note what the SL signifies in the description for those not familiar with that notation.
- Figure E-51 is sideways.
- Figures 53b and 55b are missing.

S E-5. *Additional Information and Clarification of Seismic Zones*

On page 8 in the first paragraph of Section 1.1.2, there is a discussion of a lineament throughout the paragraph. In the next paragraph there is reference to the "Daytona Beach" lineament at the end of the paragraph. It is unclear whether all the discussion relates to a single lineament called the Daytona Beach lineament. If so, perhaps the name should be noted at the start of the discussion.

The discussion of the Wabash Valley Seismic Zone should be expanded to make the report more complete. Neither the text, nor the figures, provides any actual dates, with the figure instead indicating "Event A Dates," "Event C Dates." The description of the dataset in the report should discuss these events and their dates rather than expecting the reader to go to the original papers.

On page 13, the report notes that "There is no evidence for repeated large earthquakes in the exposures." This statement needs to be further explained. In what way do the data not meet the criteria established by the project? Because this is a hazard-significant finding for sites in the ALM region, the line of evidence that the features do NOT represent seismically-generated features should be made clear. Also, it is unclear how this bullet and the following bullet are different statements.

From discussion of the Charleston Seismic Zone, it is unclear from both the text and the figures what the number of events and the dates of those events are. One can only tell that there is a historic event, and at least one other event happened. Clarification as to what the outcomes are in the text would be helpful to the reader.

S E-6. *Additional Guidance*

It would be appropriate to include a bullet point on considerations of completeness in Section 3 on guidance for the use of paleoliquefaction data in SSC.

Minor Editorial Comments and Typographical Errors

- TOC: The page number for 1.2.3 St. Louis Region is on the next line
- p. 1: There is an EPRI logo embedded on the middle of page
- Several of the page numbers have "Cited" included before the number
- p. 1: Consider changing sentence 3 as follows, "Under this task, a new paleoliquefaction database, including regional datasets, was created and this report was prepared, documentation and illustrating the database~~s~~, discussing . . ."
- p. 6 and other similar sections: Some sections make reference to "Beta Analytic" and others to "Beta Analytic Beta Analytic"
- p. 7, first paragraph: "…that may be capable of large earthquakes (e.g., Eastern Margin and Commerce faults), and migration of seismicity from one part of the Reelfoot Rift…"
- p. 5, Sand dikes, last bullet: Typo ("as well ~~we~~ as soft-sediment deformation")
- p. 19, second paragraph: "For the results of a paleoliquefaction study to be most useful in ~~accessing~~ assessing the long-term seismic hazards…"
- p. 34, par. 1, line 3: Typo (change "earthquakes parameters" to "earthquake parameters")
- p. 34, last paragraph: The text states that radiocarbon and OSL dating "provide age estimates with uncertainties of one hundred years in the best of circumstances. Dating

techniques that provide more precise results would help to improve age estimates of liquefaction features and their causative earthquakes." In section 2.1.3.2 (p. 24, par. 2), examples are given of reported "precision" of ± 80 radiocarbon years, ± 20 radiocarbon years, and ± 40 radiocarbon years.

- The figures start on page E2. Presumably the page numbers will be changed for the final report.

APPENDIX F — WORKSHOP SUMMARIES

General Comments

G F-1. (NAR) The summaries of the workshop provided in Appendix F are well-written accounts of the presentations and subsequent discussions that transpired. The workshop summaries, coupled with the agendas, participant lists, and presentations, provide sufficient documentation regarding the content of the workshops.

Specific Comments for Clarity and Completeness

S F-1. *Added Information for Each Workshop*

Information has been described as "what people need and want to know." Inclusion of the agenda for each workshop would give the reader a useful "road map" for navigating through the dense narratives. Also, the list of attendees for each workshop should be included for complete documentation (Table 2-2, p. 2-47, provides a partial list). As an additional step to help those wishing to review the project in the future, we assume that copies of visual presentations made at the workshops will be included as part of the project report and will become available either as part of this Appendix or on a project Website or in some other conveniently accessible form.

APPENDIX G — BIOGRAPHIES OF PROJECT TEAM

General Comments

G G-1. (NAR) This appendix is a straightforward compilation of biographical sketches for members of the CEUS SSC Project. As part of this review, individual members of the PPRP were asked to carefully examine their own biosketches.

Specific Comments for Clarity and Completeness

S G-1. *Correlation and Coordination of Appendix G with Figure 2.3-1*

For stand-alone reading of Appendix G, it would be useful to give the reader an overview of the Project Team by either pointing the reader to the CEUS SSC Project Organization diagram (Figure 2.3-1), say by using a footnote on p. G-1, or by reproducing the diagram in this appendix. The inclusion of biographies for the Sponsor Reviewers in Appendix G, as part of the Project Team, implies that their names should also be included in the Project Organization diagram.

The presentation of names in Appendix G is a mix of alphabetical and hierarchical ordering. If Figure 2.3-1 is to be a guide for the reader, consider ordering names in Appendix G as they appear in the various boxes on the figure.

In both the Project Organization diagram and in Appendix G, the TI Team (and support staff) is arguably a more important component of the "Project Team" than the PPRP. Consider moving the PPRP box on Figure 2.3-1 to the right of the TI Team and, correspondingly, presenting the PPRP names last in Appendix G. A box for the Sponsor Reviewers could be added in the organizational chart to the right of the PPRP (and their biosketches could follow those for the PPRP as in the draft).

Typographical Errors

- p. G-7: Ending period missing in last line at the end of Mark Petersen's biosketch.

APPENDIX H — EPRI/DOE/NRC CEUS SEISMIC SOURCE CHARACTERIZATION PROJECT: Draft Final Seismic Source Model Hazard Input Document (HID), Dated July 6, 2010

General Comments

G H-1. (NAR) The intent of the HID is to give future users details on how to implement the CEUS SSC model. It contains the logic tree structure that defines the frequency, locations, and sizes of future earthquakes in this region. The appendix describes how the zones are characterized. A description of why the TI Team chose a particular equation, occurrence rate, magnitude, or source geometry, or references is not given in this section of the report.

G H-2. (CC) The elements of the CEUS SSC model are clearly described in enough detail to support future users' implementation of the model for PSHA at any site in the CEUS. Gaps not described in the July 6, 2010 draft should be described in the final revision of the appendix.

G H-3. (CC) The PPRP's review of the 11 chapters of the main report identified many opportunities to achieve greater clarity in the TI Team's descriptions of the characterizations and assessments represented in the CEUS SSC model by proper and consistent use of terms. These comments apply as well to the descriptions contained in Appendix H.

Specific Comments

S H-1. (CC) *Title of Appendix H*

Consider changing the appendix title to: "CEUS SSC MODEL HAZARD INPUT DOCUMENT (HID)."

S H-2. (CC) *Implementing the Variable a- and b-value Routines*

To perform any hazard calculations using the HID, it would be difficult for most users to implement the variable *a*- and *b*-value routines described in Chapter 5. Therefore, the process is not open for most users to evaluate that methodology. It would be desirable that the computer codes be made available for these analyses. Alternatively, the TI Team could release the output gridded data. However, this is not the best alternative since most users would not understand how these numbers were generated. A third alternative is for the TI Team to revert to the smoothed seismicity kernel that is more intuitive to the user community.

S H-3. (CC) *Transparency of HID Tables for Recurrence*

The following excerpt is reproduced from PPRP Review Comment **S 6-**12:

> "The unalert reader (or analyst) examining the HID tables for computed annual frequencies for the Charleston RLMEs may potentially be confused by: (1) the <u>inverted</u> order for the 5-point distributions compared to Table 5.3.3.-1, which was used to define

the 5-point distribution; and (2) the need to refer to Tables 6.1.2-1 and 6.1.2-2 to discern the elapsed time since the oldest earthquake counted in the sequence. For example, examining "Table Charleston_HID-3," it may escape the reader's attention that the 5-point distribution is not for four events in 5500 years, but rather four events in 1,524–1,867 years (or possibly in 1,569–1,867 years). To reproduce the results in the table (and for virtually all the Poisson-model tables in the HID), there is no explicit information about the exact elapsed time that was used."

Comments for Clarity and Completeness

Figures 8 and 9 appear to be identical figures with different figure captions.

p. H-19, *Degree of Smoothing*: The text states that, "An "Objective" approach is used to select the degree of smoothing." It would be very helpful to refer back in the text where this approach is described.

APPENDIX I — PPRP REVIEW COMMENTS

General Comments

G I-1. (NAR) This compilation of review comments usefully provides a basis for tracking recommendations made by the PPRP and corresponding actions promised by the TI Team in response.

Specific Comments for Clarity and Completeness

S I-1. *Title of Appendix E*

Because this appendix contains both PPRP and USGS review comments, the title of the appendix should be changed.

S I-2. *Listing of Letters and Attachments*

In the summary of contents for the appendix, the separate listing of Attachments to PPRP Letter 1a as Items 1b and 1c poses a problem of consistency. PPRP Letter 2 (dated August 15, 2008) contains a substantive Attachment A ("Key Issues for CEUS SSC Relevant to Workshop #1) with three labeled enclosures. Also, USGS Letter 1 (dated April 8, 2010) contains five attachments. In the case of these three letters with attachments, one can either spell everything out or simply note that these letters have attachments (perhaps indicating their general nature).

S I-3. *Incorrect Date in Correspondence Contents*

p. I-2, TI Team Letter 1: Error in labeling the subject of the letter (change "dated August 12, 2008" to "dated August 15, 2008")

APPENDIX J — MAGNITUDE RECURRENCE MAPS

General Comments

G J-1. (NAR) Appendix J presents the recurrence maps developed for all of the alternative configurations of the distributed seismicity zones. A brief description of the organization of the maps within the Appendix is provided on the title page. Consistent with the care taken in the writing of Section 5.3.2 (*Smoothing Approach*), this appendix is well organized and explained—beginning with the text on the title page that provides helpful guidance to the reader.

Comments for Clarity and Completeness

- Page J-1: Consider adding additional reference to specific figures in Sections 6.4 and 7.5; suggested wording: "Mean maps and magnitude-recurrence for each source zone are shown in Sections 6.4 (Figures 6.4-1 through 6.4-16) and 7.5 (Figures 7.5.2-1 through 7.5.2-42)."
- Check: Were rates indeed calculated for $\mathbf{M} > 5$ or for $\mathbf{M} \geq 5$? If perchance they were calculated for the latter, then labels on the figures should be changed or an explanation can be added on the title page of the appendix.
- In figure caption for Figure J-1, need closing ["] for "no separation . . ." OR simply delete the ["], which doesn't appear in the captions for the following figures.
- On Figures J-17 through J-48, the header information incorrectly indicates "MES" vs. "MESE" (the correct acronym, according to the list of Acronyms) written in the figure captions.
- On Figures J-49 through J-112, the acronym "RCG" is used for Rough Creek graben vs. "RC" in the list of Acronyms.
- Page J-87: Realization 7 for the seismotectonic zone, wide interpretation, Rough Creek Graben in Mid-Continent, full magnitude weights is missing.

APPENDIX K — SCR DATABASES USED TO DEVELOP MMAX PRIOR DISTRIBUTIONS

General Comments

G K-1. (CC) This appendix provides the database used to develop the Mmax prior distributions. The work done to update and refine data for the global Stable Continental Regions has great value and importance. However, there is no explanatory text provided beyond the Notes and the two tables. To help future users, as well as to enhance transparency, this appendix could be improved by including additional information and a short description of the content being included in the appendix itself, or to a reference back to the relevant report text. It could also be noted whether or not the database is available in digital form elsewhere.

Specific Comments for Clarity and Completeness

K-1. *Information that should be considered for Appendix K*

Appendix K would benefit from including additional information for the reader to better appreciate where the domains and super domains are, and to better integrate with the text. The TI Team should considering adding the following:

- Maps showing domains and superdomains (useful files for the boundaries of these domains should also be included in the Project Database, with a pointer to those files)
- Figures displaying the Mmax-obs statistics for each of the superdomains
- Summary table of statistical analysis completed on the various superdomain classifications

K-2. *Clarity of Documentation*

For clarity of documentation, attention should be paid to the following:

1. Designation of time in an earthquake catalog should be explicit. Are the times/dates in UTC? Local time? A mix? This is non-trivial if one tries to find the events in another catalog.
2. How should the reader interpret the variable presentation of significant figures in Table K-1 for latitude, longitude, **M**, and sig**M**?
3. "Extensive stress" is an unorthodox descriptor for "extensional stress". (Google the two terms to see how most readers would interpret the first term.)
4. What are the units of "Area" in Table K-2?
5. Neither "Mx_obs" or "N > 4.5" is explicitly explained in Table K-2.

6. Check: Is N > 4.5 indeed the number of earthquakes greater than **M** 4.5? Or perchance is it **M** ≥ 4.5?
7. For the table to be self-contained, an explanation should be given for non-integer values of N > 4.5.
8. The wording used to explain SDNT and SDNC in Table K-2 will trip up most readers. Just add a few words to make it plain English. The acronyms certainly aren't intuitive, but given that they are what they are, suggestion:

SDNT	Indicates which Superdomain the domain is assigned to when TYPE <u>is</u> included in the classification
SDNC	Indicates which Superdomain the domain is assigned to when TYPE <u>is not</u> included in the classification

7

Via e-mail

INFORMAL COMMUNICATION

To: Larry Salomone

From: PPRP

Date: October 13, 2010

Subject: Key Issues for TI Team to be Attentive to as They Revisit the CEUS SSC Model and Revise the Project Report

This informal note is to highlight key issues raised in our review comments on the Draft Report—to help guide the TI Team as it revisits the CEUS SSC model and revises its report during the next few months. Because we apparently won't be interacting with the TI Team as it carries out this work, we want to communicate as clearly as possible to preclude, or at least minimize, any need for later corrective actions.

Short List of PPRP's Major Concerns

The endgame is a CEUS SSC model and report that the PPRP can endorse. Based on e-mail interactions and a teleconference, the following is a short list of the PPRP's major concerns (numbered for convenient reference, not for priority), embedded in our review comments[1]:

1. Approach to declustering and the impact on the catalog of earthquakes used to perform smoothing. Only one approach is used and it is not clear what impact this would or would not have on the catalog, and ultimately the seismicity parameters. [S 3-5; see also Attachment 1 here, *PPRP Commentary on New Methods (or Other Methods) with a Weight of 1.0 and SSHAC Guidance*]

2. The weights on the split between Mmax zones and Seismotectonic zones. [S 4-9]

Note: <u>To be clear</u>, the PPRP recognizes that ownership of the CEUS SSC model (and hence the weights on the master logic tree) belongs to the TI Team. The PPRP has the responsibility to ensure that the distribution of the technical community's views and corresponding uncertainties have been appropriately considered and reasonably represented in the model—and that thorough justification is provided for all weights in the model.

3. Statistical analysis of the SCR data base and how it is used to establish the weights on Mmax between the prior distributions. [S 5-9, S 5-10]

[1] We assume that the TI Team will do a responsible job of responding to our concerns regarding clarity, consistency, and the need for thorough technical editing.

4. The approaches used, and weights, for assignment of Mmax to seismic source zones. Specifically, the TI Team considers the Kijko approach in addition to the Bayesian approach, and has assigned relative weights to the two approaches. [S 5-6, S 5-7, S 5-8]

Note: Regarding Item 4, and some other important SSC model issues that did not have the benefit of being explicitly discussed in a workshop setting, the PPRP must judge whether the TI Team sufficiently understands and treats the proponent views (including the range of views and uncertainties).

5. The statistical analysis and approach to smoothing. Only one approach is used. The results from the statistical analysis directly impact the rates of seismicity considered and the proportion of larger to smaller events for each of the sources. [S 5-11, S 5-12, S5-13, S 5-14, S 5-16; see also Attachment 1 here, *PPRP Commentary on New Methods (or Other Methods) with a Weight of 1.0 and SSHAC Guidance*]

6. The criteria and basis for defining seismotectonic zones, and the application of these criteria so that a clear definition of each seismotectonic zone is supported. [S 4-2, G 7-2, G 7-4]

7. A full explanation of the causes, and implications for hazard calculations, of (a) the generally poor fit of the realizations of the modeled recurrence rate obtained from the earthquake catalog and (b) differences between the CEUS SSC model results and USGS and EPRI-SOG (COLA) findings. [G 8-2, S 8-2]

Note: The PPRP feels a responsibility to ensure that the characterization of earthquake sources is consistent with historical seismicity data, as well as with any other pertinent datasets, and that the final model spans the center, body, and range accepted by the technical community. The "best" model must not only be pleasing to the TI Team but must fit available data. Further, it is incumbent on the TI Team to fully understand the assumptions in the CEUS SSC model and to provide high confidence that the model truly represents the community distribution.

8. Explicit recognition of the issue raised by Lombardi (2003) regarding the incorrect use of the maximum likelihood method in estimating the *b*-value for mainshocks. The methodologies used by the TI Team for recurrence calculations should be carefully reviewed to ensure that there is no systematic bias in the maximum-likelihood estimates of *b*-values, such as criticized in the Lombardi paper. [S 5-11]

We understand your desire to let the TI Team do its work before having to respond to any of our PPRP review comments. If you or the TI Team have questions or would like clarification of any of our review comments or points in this communication, please contact us.

For the PPRP,

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Copy: PPRP Members

ATTACHMENT 1

PPRP Commentary on New Methods (or Other Methods) with a Weight of 1.0 and SSHAC Guidance

A principal focus of the SSHAC guidelines is the appropriate assessment of epistemic uncertainty in the current state of knowledge of technical issues of interest. The SSHAC guidelines, therefore, describe a process that is focused on accurately representing the "community distribution" through assessment and evaluation activities that include (1) a critical review of all scientifically viable alternative viewpoints and theories and (2) a series of structured interactive workshops, including a proponent workshop focused on assessing alternate methods, theories and approaches. These activities are included because it is an explicit goal (indeed requirement) of the SSHAC guidelines that the final model represents the community distribution (i.e. the center, body, and range of the viable alternatives). Typically, the representation of the community distribution is achieved through a logic-tree approach which weights the viable existing alternatives in a transparent and justifiable way.

The SSHAC guidelines do not preclude the use of new or different approaches beyond those already found in the technical community. Indeed, the guidelines specifically state that the guidelines themselves should not be a barrier to progress and development. The guidelines also allow for weighting of approaches that are not simply a representation of the current view of the technical community; the SSHAC approach allows for evolution of thinking and is not simply expert elicitation. Therefore, when new approaches are introduced, the questions should focus on how the alternative approach is implemented in the model, consistent with goals and requirements of the SSHAC guidelines, and how that consistency is demonstrated.

There are two ways in which new approaches can be incorporated into a SSHAC-based project. The first way is to introduce a new approach as a "proponent" approach and to add it to the logic tree and assign a weight based on its relative merit among the alternatives. In theory, this is relatively straightforward.

A second way, as chosen by the TI team in this project, is to adopt a new method and assign it a weight of 1.0, thereby replacing the range of alternative approaches used in the community with a single approach. Theoretically, this is allowable under the SSHAC guidelines as long as the requirement that the community distribution is effectively represented continues to be met. The use of a single approach must not artificially reduce the assessed epistemic uncertainty. In this case, the method used should not simply be another proponent model, because it is being treated as a "replacement" or "proxy" model that can represent the community distribution in a more elegant or computationally efficient way. The use of a "replacement" model comes with a high bar to reach in terms of showing that the SSHAC guidelines are being met. As a minimum, it should be demonstrated that the new approach is consistent with both the range of outcomes of traditionally accepted approaches (i.e., the community distribution), and also with the appropriate data that are available.

If the new method cannot be demonstrated to appropriately represent the community distribution, it is difficult to judge how it is not just another proponent model that should be incorporated with (and not replace) other proponent methods. To simply choose a proponent model approach and say that is the "best" one and give it a weight of 1.0 is inconsistent with the SSHAC guidelines. It is acceptable for any development team to develop a model (or approach) that they think is the "best"— but that is different than saying that a model (or approach) is consistent with the SSHAC process, and it must meet a high standard.

8

Via e-mail

INFORMAL COMMUNICATION

To: Larry Salomone

From: Walter Arabasz and Carl Stepp

Date: February 23, 2011

Subject: PPRP Feedback on CEUS SSC Working Meeting #9

This note provides some written feedback from the PPRP on CEUS SSC Working Meeting #9, held at EPRI Headquarters in Palo Alto, California, on February 7–8, 2011. It summarizes PPRP comments made at the end of the working meeting and adds some additional perspective.

General Comments

Based on the TI Team discussions, the PPRP was very encouraged that its major comments on the initial draft of the CEUS SSC report were being addressed in an appropriate manner. We commend the TI Team for taking the time to revise and enhance the earthquake catalog being used for this project. The PPRP anticipates that this catalog will represent a major advance forward for the technical community. The PPRP is also encouraged that the TI Team is working toward closure on addressing our comments related to *b*-value, the approach and method for smoothing and earthquake-recurrence assessment, and the derivation of maximum magnitudes.

Based on collective experience from the August–September 2010 review cycle of the CEUS SSC Draft Report, the PPRP urges the TI Team to be fully satisfied with the results and documentation for the next iteration of the Project report before releasing it for review. We expect that what we receive for review in the next cycle will have been carefully vetted, including careful attention to any significant discrepancies between model predictions and observed historical seismicity (for example, cases such as the area of St. Paul, Minnesota, in the July 2010, draft report).

We are pleased to learn that progress is being made on planning and arrangements for the Project's Public Website. The simultaneous activation of the Public Website with the release of the CEUS SSC Technical Report, scheduled for December 31, 2011 (*Revised CEUS SSC Schedule, 2/22/11*) will be greatly helpful to meet user needs.

Reminder Regarding Methods with a Weight of 1.0 and SSHAC Guidance

After listening to a detailed description of the Penalized Likelihood Approach, the PPRP calls the TI Team's attention to an attachment included in the PPRP's Informal Communication of October 13, 2010, in which we distilled our major concerns on the July 31, 2010, draft report. The attachment was labeled, *PPRP Commentary on New Methods (or Other Methods) with a Weight of 1.0 and SSHAC Guidance.* Replacing a range of alternative approaches used in the community with a single approach places a significant burden on the TI Team to show that SSHAC guidance is being met.

Approach to Smoothed Seismicity

The Penalized Likelihood Approach has evolved sufficiently to be accepted by the TI Team as the tool of choice for assessing the spatial variation of earthquake recurrence rate and *b*-value. Nevertheless, the influence of factors such as spatial incompleteness remains incompletely understood. Thus, while the Smoothing Model is a powerful tool, it seems prudent in assessing the spatial variation of earthquake recurrence to incorporate considerations of variations in tectonic histories and properties of the seismic sources to complete the TI Team's assessments. In other words, guidance by physical and tectonic insights is desirable.

The approach of establishing an initial *b*-value using the seismicity of the CEUS Model Region appears to be solid. We encourage the TI Team to consider discussing with a few selected seismologists their views on the variation in *b*-value as part of reviewing the smoothness of *b*-value maps and decisions by the TI Team related to the final sets of weights for smoothing parameters.

The TI Team has a number of difficult decisions to make in the very near future regarding recurrence assessment and especially the smoothing parameters. Although objective specification of these parameters is being considered, it appears likely from the presentations at the meeting that "analyst-specified" parameters will significantly influence the selection procedure. Accordingly, it is important for the purposes of developing a consensus among the TI team on these parameters—and for transparency in the decision process for the end user—that specific criteria be defined and used in the parameter-selection process so that the finally specified parameters be as objective as possible. We encourage vigorous internal interactions among the TI Team before the smoothing parameters are finalized.

Initial Branch of the Logic Tree

One issue that was not discussed in detail at Working Meeting #9 relates to the logic-tree weights applied to the initial branch in the logic tree—namely, maximum-magnitude zonation versus seismotectonic zonation. The tables that the TI Team described using the criteria for the definition of zonation will improve the basis for TI Team decisions. Having said this, the TI Team is encouraged to review all relevant information and data as part of developing its final set of weights for the initial branch of the logic tree. Without having seen sensitivity results on this weighting, we assume that the relative weights may be important in the overall determination of hazard. In any case, the weights need to be well justified, and their justification will be carefully reviewed by the PPRP.

Importance and Usefulness of Early Information to the PPRP

It was clear from the working meeting that closing on the earthquake catalog, finalizing and implementing the maximum-magnitude approach, and executing the final smoothing and recurrence calculations are on the critical path to completing Chapters 3 and 5—and ultimately completing the hazard calculations for the seven test sites. While the June 2011 Project Briefing will provide the opportunity to evaluate where the project stands, final versions of Chapters 3, 5, and 8 will not be available before that briefing. Given this, the PPRP encourages the project and TI Team to provide as much pertinent material to the PPRP before that briefing. Such material could include electronic versions of the earthquake catalog, final intensity and magnitude-conversion relationships, the final prior distribution being used to derive maximum magnitude distributions, a table displaying the final weighted maximum magnitudes for each of the seismic sources, a set of smoothing maps for each of the sources, and the final logic tree with weights.

The Stakeholder Briefing that was held February 9–10, 2011 (following Working Meeting #9) reinforced the expectation by the Project Sponsors that the PPRP stay engaged with the TI Team, as the team makes key decisions, so that the PPRP can efficiently perform their participatory review and potentially prevent delays in finalizing the CEUS SSC Model. Keeping the PPRP aware in a timely way concerning the specifics on completion of activities 8 (final smoothing), 9 (implementation of weights and conversions to hazard), and 10 (documentation of responses to comments on chapters 3, 5, and 8)—which are all to be completed well before the next scheduled Project Briefing in June 2011—will be important for arriving at that milestone with confidence in PPRP endorsement.

If you need more information or clarification, please contact either of us.

For the PPRP,

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Copy: PPRP Members

September 26, 2011 Via e-mail

Lawrence A. Salomone
Savannah River Nuclear Solutions, LLC
Savannah River Site
Building 730-4B, Room 3125
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Dear Mr. Salomone:
Reference: *Central and Eastern United States Seismic Source Characterization for Nuclear Facilities*: " Mandatory" PPRP Review Comments on the CEUS SSC Final Report

This letter constitutes the report of the PPRP[1] ("the Panel") providing selected review comments from both Installments 1 and 2 of the *Central and Eastern United States Seismic Source Characterization for Nuclear Facilities, Final Report* ("the Final Report"). As you requested, the selected comments are those identified by the Panel as "mandatory"—that is, review comments that must be addressed by the TI Team in their final documentation of the Final Report. These comments were discussed with the TI Team in draft form at the PPRP Closure Briefing on September 7, 2011.

Background to our PPRP Review Comments on the Final Project Report

On August 5, 2011, we provided in draft form all of our Panel's review comments on Installment 1 of the Final Report. Some of those comments were subsequently identified as mandatory and are now included in this formal PPRP report. The others have been incorporated into a separate PPRP Informal Communication that summarizes all of our Panel's "non-mandatory" review comments on both Installments 1 and 2 of the Final Report. Our non-mandatory comments are intended chiefly to help improve the quality of the final product.

All eight members of the PPRP (J. P. Ake, W. J. Arabasz, W. J. Hinze, A. M. Kammerer, J. K. Kimball, D. P. Moore, M. D. Petersen, and J. C. Stepp) participated in this peer review, and the review comments represent the Panel's consensus.

Our primary focus in reviewing Installments 1 and 2 of the Final Report has been: (1) to reach closure on comments made earlier on the Draft Report of July 2010; (2) to ensure that no substantive issues remain unresolved; and (3) to help the Project Team achieve a high-quality Final Report. Our overall evaluation of the CEUS SSC Project, including compliance with SSHAC guidance, will be addressed in our PPRP Final Letter Report in October 2011.

Kudos to the TI Team and Project Manager for the 2011 Version of the Project Report

The Panel praises the TI Team—and you as the Project Manager —for the impressive achievement of putting together the revised 2011 version of the Project report. We fully appreciate the massive amount of detail that had to be dealt with. Overall, the report is of high

[1] Participatory Peer Review Panel. For other acronyms, see the list of acronyms contained in the CEUS SSC Final Report.

quality, remarkably comprehensive, responsive to earlier PPRP review comments on the 2010 draft version, and clearly reflective of enormous efforts. The result is a high-quality project report that will support users' implementation of the CEUS SSC Model.

Please contact us if you have questions or need more information regarding the Panel's review comments.

For the PPRP,

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Sponsor Representatives

MANDATORY PPRP COMMENTS ON CEUS SSC FINAL REPORT
(not ordered in priority)

1. ***How SSHAC Level 3 was Selected***

   Although there is a comprehensive description of the use and difference between SSHAC Level 3 and 4 in Chapter 1, there are not explicit statements on why Level 3 was selected for the CEUS SSC Project, who made the decision, and at what stage in the project this was done. These are significant items of information that should be included. They are not discussed in Chapter 2.

2. ***Identification and Engagement of Experts***

   The report should provide additional discussion of how the spectrum of experts was selected for this project (several places within Chapter 2 and perhaps Chapter 1). While the report makes the point that all participants were reminded of their roles, and that many project participants have significant SSHAC experience, some could contend that this a closed process. Without additional discussion, the current text sounds like, "Trust us, we know what we are doing." Specifically, we suggest a description of the steps taken by TI Team, as supported by the PPRP, to ensure that the participation of Resource Experts and Proponent Experts in Workshops #1 and #2 was appropriate and complete in order to be representative of the range of current scientific community interpretations, for which awareness and knowledge were required.

   Additional discussion is required of the extended roles that certain resource experts played to develop explicit material for TI Team use (e.g., paleoliquefaction). Finally, the report should describe the extended role personnel from the U.S. Geological Survey (USGS) played in this project to ensure that all supportable interpretations of the scientific community were fully identified, evaluated and represented in the SSC model. Several USGS personnel provided detailed review and feedback on specific issues (e.g., the earthquake catalog, Mmax); these should be described.

3. ***Weights to Logic Tree Branches***

   Referring to the discussion in Section 4.1.1.2, while it is true that the final assignments of weights to logic tree branches are subjective, the report needs to make clear that the weights represent assessments informed by the totality of the SSHAC evaluation process. Before weights were assigned, the TI Team heard from a properly wide range of resource and proponent experts, reviewed extensive technical information, created the Data Summary and Data Evaluation tables, and evaluated a wide range of issues with members of the knowledgeable broader technical community. This is the critical message that needs to be emphasized for supporting the final informed subjective weights.

4. ***CBR of the ITC vs. CBR of the TDI***

   In the third sentence of Section 4.1.1.2 on p. 4-3, the text states that "the total set of logic tree branches and weights represent [sic] the team's assessment of the center, body, and range of views of the informed technical community (see Section 2.1 for a discussion of this concept)." In Section 2.1, however, the reader was informed of proposed alternative wording referring to "the CBR of the 'technically defensible interpretations' (TDI), instead of CBR of the ITC" citing the NRC (in review). If TDI is preferred, replace "of the informed technical community" with "of the technically-defensible interpretations."

In Section 2.1, in discussing the alternative wording of the TDI to replace the ITC, care should be taken to avoid the notion that "nothing has changed by way of perception of process; we have just used more acceptable wording." The text should convey that the change does indeed grow out of a deeper understanding of the process and is a more clear expression of the fundamental concept that the SSHAC intended to convey.

5. ***Evaluation of Cases A, B, and E***

In Section 7.5.1 (*Rate and b-Value Maps for Single Zone and Two Zones*), the bases for the three choices of magnitude weights represented by Cases A, B, and E, are discussed, but there is almost no discussion of the bases and considerations that went into the evaluation and integration that resulted in the assessed weights. Keeping in mind that observed seismicity is a direct measure of tectonic strain release and that the smoothing procedure is a tool for representing the TI Team's evaluation of this process—including issues such as uncertainty about spatial stationary of seismicity in space and time, uncertainty imposed by the limited observed record of earthquakes, as well as other uncertainties cited in Chapter 5 of the report—the report needs to clearly convey the Team's evaluation and integration activities that resulted in the weights on Cases A, B, and E as properly representing the TDI.

<u>Added commentary</u>: The following two comments on Chapter 8 are related to an understanding of the implications of weighting Cases A, B, and E.

1) The Central Illinois Site shows significantly higher hazard than from the COLA or USGS models (Figure 8.2-1j). It seems like the primary contributor is the IBEB source zone. Why is the seismicity rate high in this zone compared to the catalog used in the 2008 USGS maps?

2) For the Chattanooga site, Figures 8.2-2j to 8.2-2l show similar hazard between the USGS and CEUS SSC models for ground motion less than about 0.6 g for 10 Hz. However, for higher ground motions the curves diverge. For 1 Hz the USGS model is consistently higher than the CEUS SSC model. Is this difference because of the Eastern TN Seismic Zone, the Mmax distribution, or something else? This is the only site where the contribution from the Eastern TN Seismic Zone can be checked—hence, the interest in scrutinizing whether the CEUS SSC and USGS models are similar, or else the differences explained.

<u>Lack of table defining Cases A, B, and E</u>: The description of smoothing in Chapter 5 is well written. One lapse is that the report presently lacks a defining table for Cases A, B, and E for the weighting of magnitude bins—clearly a critical part of the report documentation. The discussion of weighting of magnitude bins begins in Section 5.3.2.2.1 on p. 5-36, and the reader is referred to Table 5.3.2.1 [sic]. Table 5.3.2-1 includes no information on Cases A, B, C, D, and E discussed in the text. This same table is also referenced in Section 5.3.2.6, pointing the reader to Cases A, B, and E.

6. ***Appendix A — Description of the CEUS SSC Project Database***

   One PPRP member who has special expertise relating to the subject matter of Appendix A has made extensive efforts in reviewing both the July 2010 draft version of this appendix and the June 2011 revision to help improve its accuracy and technical quality. We urge diligent attention to the totality of the review comments on Appendix A in our companion *non-mandatory* PPRP review comments. The following items of response are judged to be of greatest importance:

   - Item (e) in Comment **(FR) S A-1** regarding incorrect units on some of the figure legends must be dealt with because the units are incorrect.
   - Comment **(FR) S A-2** (*Lack of Suitable Information on Regional Heat Flow*) is important because of the role of these data in processes and seismogenic cristal thickness of the CEUS.
   - Comments **(FR) CC A-5**, **A-6**, and **A-8** relating to Figures A-13, A-14, and A-16, respectively, point out some basic problems with these figures.

7. ***Region of Applicability of the SSC Model***

   In the first sentence of Section 1.3, the statement, "The SSC model developed for this project is applicable to all sites within the project study region (Figure 1.3-1)" needs to be clarified. Sites within some distance (to be defined) of the boundary of the "study region" will require a site-specific SSC model that extends beyond the region boundary. A distinction must be made between "study region" and the region of applicability of the SSC model without the need to extend the model beyond the study region.

8. ***AFEs for Nuclear Facilities***

   In the second paragraph of Section 1.1.5, PSHAs for nuclear facilities must extend from 10^{-3} through 10^{-7} AFE (see also Section 2.4.2).

   Various sections of the report should be consistent in specifying this range of importance of AFEs for nuclear facilities; in Chapter 9, added wording should explain the focus on AFEs of 10^{-4} to 10^{-6} for COVs.

10

Via e-mail

INFORMAL COMMUNICATION

To: Larry Salomone

From: Walter Arabasz and Carl Stepp

Date: September 26, 2011

Subject: PPRP Non-Mandatory Comments on Installments 1 and 2 of Final Report

As an addition to our PPRP letter report to you on this same date, we are providing here a list of Non-Mandatory Comments on both Installments 1 and 2 of the *Central and Eastern United States Seismic Source Characterization for Nuclear Facilities, Final Report* (June–August 2011).

These non-mandatory comments are intended to help improve the Final Report. We understand that they will be handled by the TI Team as feasible and at their discretion.

Notes:

1. *August 5, 2011, document now obsolete:* All of our review comments on Installment 1 that we submitted in draft form on August 5, 2011, have subsequently been flagged as either "mandatory" or "non-mandatory." The former are included in our companion PPRP letter report and the latter have been incorporated into this Informal Communication. Hence, the August 5, 2011, document is obsolete.

2. *Comprehensive Technical Editing Not Done by the PPRP in this Review Cycle:* In reviewing the CEUS SSC Draft Report of July 31, 2010, the PPRP made diligent efforts to identify shortcomings in the clarity and completeness of documentation, and we offered numerous comments to help improve the reporting. In reviewing the revised 2011 version of the Final Report, we have not assumed responsibility for *comprehensive* technical editing, leaving that task to the Project Team's support staff. Our non-mandatory review comments do, however, include a significant number of minor editorial comments and point out some typographical errors. Also, individual members of the PPRP have provided added information to the Project Manager to help in final-stage editing.

If you need more information or clarification, please contact either of us.

For the PPRP,

Walter J. Arabasz	J. Carl Stepp
Tel: 801-554-1845	Tel: 830-833-5446
arabasz@seis.utah.edu	cstepp@moment.net

Copy: PPRP Members
Sponsor Representatives

KEY TO LABELING OF PPRP REVIEW COMMENTS

Central and Eastern United States
Seismic Source Characterization for Nuclear Facilities
Final Report, June–August, 2011

Format for Numbered Comments: **X Y-N**

(FR)	Final Report*	
X	Type of Comment:	G (General), S (Specific), or CC (comment relating to clarity, completeness, or error in documentation)
Y	Part of Report:	1, 2, . . . , 11 (Chapter 1, 2, . . . , 11) A, B, . . . , K (Appendix A, B, . . . , K) Acr = Acronyms ES = Executive Summary FM = Front Matter
N	Sequence Number:	1, 2, . . . , n

* The flag "(FR)" is included to indicate that the review comment applies to the CEUS SSC Final Report—to avoid confusion with similarly labeled PPRP review comments on the Draft Report of July 2010).

Example: Review Comment **(FR) G 3-1** applies to the Final Report, is a General Comment, applies to Chapter 3, and is the first comment of this type for that chapter.

FRONT MATTER

PRODUCT DESCRIPTION

Minor Editorial Comments and Typographical Errors

- In the third line of the first paragraph, the EPRI reference should be to the NRC-accepted report: EPRI Report EPRI-NP-4726-A (1988).
- Under **Keywords**, change “Probabilistic seismic hazard assessment (PSHA)” to “Probabilistic seismic hazard analysis (PSHA)” [e.g., see Glossary in Chapter 11].

EXECUTIVE SUMMARY

General Comments

(FR) G ES-1. In general, the Executive Summary is complete, very informative of the Project, and well written. However, because this part of the report will be read by the largest number of readers, and ideally written as a “stand-alone” part, it should (a) strive to use language that will be generally understandable , (b) eliminate acronyms or at least explain them (e.g., SCR is not explained), and (c) avoid references. Consider including subheadings to guide the reader, and consider referring to particular chapters or sections of the report (as is done in some parts of the Executive Summary) to make it easier for the reader to focus on a topic of particular interest.

Comments for Clarity and Completeness

(FR) CC ES-1. (Limitations of historical seismicity record): The sentence in the last paragraph of page xii dealing with the relationship of the locations of small- to moderate-magnitude earthquakes to locations of future large earthquakes is very important. In the initial description of this topic in the first paragraph of Section 5.1.1, limitations to this relationship are discussed. It would be useful in the Executive Summary to similarly note that there are limitations to this relationship and also note the importance of using geology and geophysics in identifying and characterizing seismic source zones in cratonic regions.

It would be informative to the reader if the Executive Summary stated that the CEUS SSC Model is based to a large extent on the assumption, typical in PSHA studies, that spatial stationarity of seismicity is expected to persist for a time period of approximately 50 years. The report has a definite lifetime.

(FR) CC ES-2. (“Reasonable” results): The third full paragraph of page xvi (regarding the seven demonstration sites) distills one of the most important parts of the report. The TI Team may wish to re-examine the conclusion in the last sentence that the CEUS SSC model provides “reasonable” seismic hazard results. Can a more definitive term be used?

Minor Editorial Comments and Typographical Errors

- Page ix, 1st para., last line: Consider changing “considered” to the more precise word (with respect to the SSHAC process), “represented”

- Page ix, 2nd para., line 6: EPRI (2006) . . . 2006a, 2006b, or both?
- Page xi, 1st partial para., line 2: Consider inserting "stresses in the crust and" following "near-surface indications of"; line 3: "stresses" should be "strains" and "identify" should be "quantify"; line 4: "future earthquakes"
- Page xii, 3rd para., line 1: In the word string: "the conceptual SSC framework and" change "and" to ", which"; line 2: instead of "identifies" use the more properly descriptive word "depicts"; line 3: use the more precisely descriptive word "interpretations" instead of "approaches"; replace "will be used" with "represent the range of defensible interpretations"; replace "establishes" with "depicts" and replace "assigned to" with "assessed for"; line 4: delete "main"
- Page xii, 1st bullet following the second full para.: Consider replacing "consideration" with the more properly descriptive word "representation"; 3rd bullet: Consider replacing "consideration of" with the more directly informative "representation of uncertainty in"; 4th bullet: replace "consideration" with "representation"
- Page xiii, top line: Insert "uncertainty in" following "assessment" and delete "have been relatively"; line 10 "uses"
- Page xiv, last full para., line 8: Replace "reflects the relative degree of belief" with "represents the uncertainty in the interpretation"; line 12: Delete first "resulting"
- Page xvi, 3rd full para., line 9: Change "characteristics for" to "characteristics of"; last line: change "adequately" to "appropriately"
- Page xvii, 3rd full para., next to last line: change "10^{-6}" to "10^{-7}" [Note: Per discussion at the PPRP Closure Briefing on September 7, 2011, the AFE of 10^{-6} is correct if the reason for focusing on 10^{-4} to 10^{-6} is explained in Chapter 9.]

ACKNOWLEDGMENTS

Depending on resolution among the sponsors for wording to be used on the title page, similar wording might be used for emphasis in the first sentence here. For example: "This study was jointly sponsored by the following three entities: . . ."

SPONSORS' PERSPECTIVES

No comment.

ACRONYMS

The revised 2011 version appears to be reasonably complete (not exhaustively checked).

CHAPTER 1 — INTRODUCTION

General Comments

(FR) G 1-1. Chapter 1 has been substantively revised from the July 31, 2010 draft. The current June 2011 version (Installment 1 of the Final Report) suitably responds to the PPRP's earlier review comments, as summarized in the TI Team's *PPRP Comment Resolution Table*. The chapter is now well structured and relatively complete in scope. However, the PPRP has some continuing concerns about clarity (see *Comments on Clarity and Completeness*, below). (See also PPRP Mandatory Comments Nos. 1, 2, 7, and 8.)

Comments on Clarity and Completeness

(FR) CC 1-1. (Clarity of wording in Section 1): Comments going to the issue of clarity of wording in Section 1, particularly Sections 1.1 through 1.2.2 are extensive. By agreement with the Project Manager, they have been made as edits in "Track Changes" format and have been submitted separately.

(FR) CC 1-2. (Adding helpful citations in Section 1.1.1): Although the USGS SSHAC implementation report and the NRC SSHAC implementation guidance (NUREG-XXXX, out for comment) are referenced later in the report, it would be helpful to reference them here.

(FR) CC 1-3. (Community-based model): Section 1.1.4 is titled "Community-Based Region SSC Model for Nuclear Facilities." While the concept of "community-based" has come up in several instances as part of broad PSHA efforts, these words could spark needless debate and are not necessary here.

(FR) CC 1-4. (Aid to locating key products in the report): In Section 1.4.4, consider referencing locations in the report where the identified key products are described.

(FR) CC 1-5. (Website "being developed"): Mention of the project website in Section 1.4.4.2 should not refer to development but rather the availability of the website at a specific address.

(FR) CC 1-6. (Use of earthquake catalog): In the last sentence of Section 1.4.4.3, we suggest describing that the project earthquake catalog was used in identifying and characterizing seismic source zones as well as for characterizing recurrence and Mmax parameters.

Minor Editorial Comments and Typographical Errors

- Throughout the report there is inconsistent style in the figure captions and table titles. In some cases, only the first letter of the first word is capitalized whereas in others the first letters of all major words are capitalized. There is similar inconsistency in using an ending period at the end of figure captions and table titles.

Some miscellaneous editorial comments and suggestions relating to Chapter 1 have been provided separately to the Project Manager. See also Comment **(FR) CC 1-1** regarding suggested edits provided separately to the Project Manager.

CHAPTER 2 — SSHAC LEVEL 3 ASSESSMENT PROCESS AND IMPLEMENTATION

General Comments

(FR) G 2-1. Chapter 2 has been extensively revised from the July 31, 2010 draft, and we commend the TI Team for this important effort and for diligently responding to the PPRP's earlier review comments, as summarized in the TI Team's *PPRP Comment Resolution Table*. The restructured chapter is greatly improved. To help with some further refinement, we offer one specific comment (see PPRP Mandatory Comment No. 2, "Identification and Engagement of Experts") together with a number of comments on clarity and completeness.

Comments on Clarity and Completeness

(FR) CC 2-1. (Meeting of May 28): In Section 2.2 (Table 2.2-1), the meeting of May 28, 2008, which played an important role in the project, is not included.

(FR) CC 2-2. (Section 2.3, PPRP): In describing the role of the PPRP in Section 2.3 on page 2-7, the last sentence should be revised to read, "PPRP responsibilities included review of both the Draft Project Report and the Final Technical Report developed by the TI Team." Also, it seems appropriate to mention the role of the PPRP in finalizing the Project Plan, which was a significant and important activity of the PPRP.

(FR) CC 2-3. (Section 2.3, TI Team): In describing the TI Team in Section 2.3, consider mentioning the size of the TI Team. Given the unique SSHAC role of an "evaluator," one of the key aspects of this project was to help train some new "evaluators," able to lead or participate in future PSHAs as needed.

(FR) CC 2-4. (AFEs for nuclear facilities): In the first paragraph of Section 2.4.2, the AFEs of interest for nuclear facilities should be 10^{-3} through 10^{-7} (see also Comment **(FR) CC 1-6)**.

(FR) CC 2-5. (PPRP involvement): The discussions in Sections 2.4.9 (*Finalization and Review of SSC Draft and Final Model*) and 2.5.2 (*Reviews and Feedback*) do not reflect the PPRP's participation in identifying key issues that required resolution. For example, while the TI Team did continue to refine the SSC Model associated with the initial Draft Report during the PPRP review, the PPRP independently identified a number of critical technical issues that required resolution. A few minor edits in these sections could convey a better sense of the PPRP's participation in the process.

(FR) CC 2-6. (Confusing descriptions in Section 2.4.10): The writing in Section 2.4.10 contains confusing descriptions, including tense, relating to the chronology of developments, and there is ambiguity as to whether products described relate to the draft or final versions of the project report. A markup of Chapter 2, provided separately to the Project Manager, contains numerous suggested edits for improving the clarity of Section 2.4.10.

(FR) CC 2-7. (Another key activity for Section 2.4.10): In Section 2.4.10, as part of the documentation of "Key Tasks and Activities" (title of Section 2.4), consider explicit mention of the development of a "Conceptual Seismic Source Characterization Framework"—now the subject of Chapter 4 in the Final Report.

(FR) CC 2-8. (Placement of PPRP closure letter in the report): The last sentence in Section 2.5.3 on p. 2-20 now reads, "The final activity conducted by the PPRP was the development of its closure letter, which is appended in this report." If our closure letter is placed after the Executive Summary (see Comment **(FR) S I-1**), this sentence will need to be revised.

(FR) CC 2-9. (Uniform data base to all experts): In Section 2.6, Item 3 (*Provide a uniform data base to all experts*) on p. 2-22, the text needs to make it clear that the Data Summary and Evaluation tables are viewed by both the TI Team and the PPRP as critical to the success of the project. This is the first project to rigorously and systematically document this information, and it is viewed by the PPRP as essential information to support the descriptions and discussion eventually found in Chapters 6 and 7. Early in the project, the PPRP encouraged the TI Team to create the Data Summary and Date Evaluation tables.

(FR) CC 2-10. (Confusing descriptions of the number of working meetings): In Section 2.6, in the first paragraph under Item 5 on p. 2-23, reference is made to "Nine multiple-day working meetings." To avoid confusing the reader (given the information in Table 2.2-1 and Section 2.4.5 describing 11 working meetings), consider writing: "Nine of the 11 working meetings (see Section 2.4.5) were multi-day meetings of the TI Team to review data and develop the SSC assessments." Similarly, the first sentence of the second paragraph can be clarified by writing, "One or more members of the PPRP participated as observers in six of the nine multi-day working meetings and in eight of the 11 total working meetings."

Minor Editorial Comments and Typographical Errors

- In the third subheading within Table 2-2.2 ("Technical Experts Contacted During Course of CEUS SSC Project"), would it be more descriptive to replace "Contacted" with "Who Contributed" or "Who Were Interviewed"?
- In Section 2.4.1, replace "aeromagnetic" with "magnetic"
- In the final paragraph of Section 2.4.1, it would be helpful to give the website address.
- In Section 2.4.8, first paragraph, the citation "(NRC, in review)" presumably will be updated, together with a corresponding entry in the list of references, to point the reader to an identifiable source of information.

In addition to the editorial comments listed above, a markup of Chapter 2 provided separately to the Project Manager includes many other editorial suggestions for improving the text.

CHAPTER 3 — EARTHQUAKE CATALOG

General Comments

(FR) G 3-1. Revisions made to Chapter 3 in the August 2011 installment of the Final Report, as summarized in the TI Team's *PPRP Comment Resolution Table*, suitably respond to the PPRP's earlier review comments. The revised chapter, with its 43 pages of text plus 87 pages of tables and figures, vastly improves the documentation in the 2010 draft version, which had 13 pages of text plus 20 pages of tables and figures to describe essentially the same subject matter. We commend the authors for their painstaking efforts, not only in developing the milestone Project catalog but also in effectively documenting and completely describing the many steps involved.

Comments on Clarity and Completeness

(FR) CC 3-1. (Units of Modified Mercalli Intensity): On pp. 3-6 and 3-7, differences in MMI are described in terms of "degrees." Richter (1958, p. 136) refers to "levels of intensity," which is a more common descriptor in connection with the MMI scale than "degrees of intensity." Consider substituting "level" for "degree" in the three occurrences on pp. 3-6 and 3-7.

(FR) CC 3-2. (Reduced standard errors): On p. 3-28, the text states: "The value of $\sigma_{\mathbf{M}|mb}$ = 0.24 reflects the value of 0.29 obtained from the regression reduced by the average value of $\sigma[\mathbf{M}|\mathbf{M}$ hat] = 0.16 for the earthquakes used in the regression (Equation 3.3.1-8)." Is the referenced equation indeed the correct one? To reproduce this result, does the reader need to know a value for *b*? In subsequent sections where a reduced standard error is described (§3.3.2.5, §3.3.2.6, §3.3.2.7, and §3.3.2.8) no similar reference is made to Equation 3.3.1-8 to guide the reader.

(FR) CC 3-3. (Seismic source zones): The caption, or legend, on Figure 3.2-7 should explain the bold lines outlining the seismic source zones. Also, because the seismic source zones and their geometries have neither been discussed nor presented prior to Chapter 3, the caption should contain a note to provide an advance reference informing the reader about them.

(FR) CC 3-4. (Description of declustering results): In the first full paragraph on page 3-39 describing Figure 3.4-3, the reader should be cautioned of pitfalls in interpreting the figure. For example, the data points from EQCLUSTER plotted in the right-hand part of the figure (described as "the maximum distance between earthquakes assigned to a cluster") represent a nearest-neighbor distance and not the same distance "window" used by Gardner and Knopoff (1974), i.e., the maximum distance between the largest shock in a sequence (the main shock) and one of its dependent events. Also, while the "average" space-time dimensions of the EPRI (1988) procedure can be compared with the space-time windows of Gardner and Knopoff (1974), the latter represent optimized *envelopes* to their data, not *average* dimensions.

The last sentence of the paragraph, referring to Figure 3.4-3, states: "The EPRI (1988) procedure does identify some clusters that have a much longer duration than the published time windows." Examining the left-hand side of Figure 3.4-3, this is clearly an understatement—particularly for parent events smaller than about **E**[**M**] 3.5. [The latter suggests that the EPRI approach is identifying significantly more events in the catalog as dependent events, compared to the Gardner and Knopoff approach—but the effects of "thinning" as opposed to "removal" have to be kept in mind.] A point that passes without comment is the fact that in their 1974 study, Gardner and Knopoff identified approximately one-third of their catalog as independent events. In contrast, more than three-fourths of the earthquakes in the CEUS SSC catalog are identified as independent events (Table 3.4-1). Bottom line: If correct, Table 3.4-1 is what it is, and attention to those results is appropriately emphasized in the subsequent paragraph.

(FR) CC 3-5. (McLaughlin et al., 1977, and USNSN): On p. 3-43, an analysis by McLaughlin et al. (1997) of the USNSN is described to address the probability of detection in the CEUS for 1995–2008. As a matter of up-to-date reporting, the USNSN is an obsolete term insofar as the network has been superseded by the ANSS national backbone network of nearly 100 stations (see http://earthquake.usgs.gov/monitoring/anss/backbone.php). The ANSS backbone network, including many of the original USNSN stations, was upgraded and expanded in 2004–2006, and many other ANSS regional network stations have been added in the CEUS during the last decade. Consider something like the following at the end of the first paragraph on p. 3-43: "During 2004–2006, the USNSN was upgraded and expanded to become the current ANSS backbone national network of nearly 100 stations, and many ANSS regional network stations have been added in the CEUS during the last decade. For our purposes, the USNSN analysis still serves as a useful baseline."

Minor Editorial Comments and Typographical Errors

- Pagination of the tables and figures should be sequential with the text.
- On p. 3-5, in line 5 of the last paragraph: consider changing "The magnitudes clearly line up" to "Nearly all the magnitudes line up"
- On p. 3-8, in the first line of the second paragraph: unclear word string: "the specific magnitude time reported"
- On p. 3-8, in line 5 of Section 3.2.4: change "SEUSSN, Lamont" to "SUSN, LDO"
- On p. 3-9, line 1: change "published in literature" to "published in the literature"
- On p. 3-9, in line 6 of Section 3.2.5: change "Dr. Chuck Mueller" to "Dr. Charles Mueller" for consistency elsewhere (e.g., p. 3-3); in this same paragraph, change "Dr.. Talwani" to "Dr. Talwani; also in this same paragraph, in the next-to-last line: change "the event is considered" to "the classification is considered"
- Search the chapter globally and change (where appropriate) M to **M**; also, N* to *N** (multiple corrections are needed on p. 3-17).
- In the table on p. 3-12, column 1 has incorrect symbols: e.g., change "Number 4.0 ≥ **M** > 4.5" to "Number 4.0 ≤ **M** < 4.5" and so on (see also a similarly incorrect occurrence on p. 3-16).
- On p. 3-20, in the next-to-last line of the first paragraph of Section 3.3.2.2: change "observe value" to "observed value"
- On p. 3-22, in line 2 of the second paragraph of Section 3.3.2.3: change "in northeastern United States" to "in the northeastern United States"
- On p. 3-23, in line 2 of the second paragraph: delete ")" after 1997.

- On p. 3-40, in the fifth line from the bottom: change “imposes the ideas that” to “imposes the idea that”
- In Table 3.3-1, in column 2 for M_L reported by GSC, should be $m_b = M_L - 0.21$ (not 21, typo).
- The figure captions on Figures 3.3-2 to 3.3-4 reference “Table B-X” in Appendix B; this should be Table B-2 (Moment Magnitudes).

CHAPTER 4 — CONCEPTUAL SEISMIC SOURCE CHARACTERIZATION FRAMEWORK

General Comments

(FR) G 4-1. Revisions made to Chapter 4 in the June 2011 installment of the Final Report, as summarized in the TI Team's *PPRP Comment Resolution Table*, suitably respond to the PPRP's earlier review comments. Comments on clarity and completeness for additional consideration are provided below. (See also PPRP Mandatory Comments Nos. 3 and 4.)

Comments on Clarity and Completeness

(FR) CC 4-1. (Potentially problematic statement): In the second paragraph of Chapter 4 on p. 4-1 it is stated that "nearly all of the PSHAs developed for nuclear facilities in the CEUS have been conducted by members of the TI Team . . . ." This part of the sentence is not needed and is not the critical aspect of why the TI Team was qualified to perform this study (we recommend avoiding language that could be read as a bias).

(FR) CC 4-2. (Need for conceptual SSC framework): In Section 4.1, consider noting that the need for a conceptual SSC framework was something the PPRP encouraged the TI Team to develop in order to strengthen the overall basis of the SSC model. Many of the operative words in the three items were voiced early by the PPRP.

(FR) CC 4-3. (GPS studies and crustal strain in the CEUS): One of the more important scientific advances in seismic hazard studies since the mid-1980s has been the use of GPS to investigate current strain in the CEUS. The studies available to date have been set aside in the report because of the immaturity of the science and the studies—that is, in the modeling and also the measurements. Justification for neglecting these studies (e.g., in Section 4.1.2.2) is based on a few declarative statements without supporting evidence from knowledgeable experts in the discipline. Neglecting GPS studies would have much more credence if the report cited some appropriate literature or reports, e.g., the recent report prepared for the USGS on the use of GPS in determining the hazard in the NMSZ.

(FR) CC 4-4. (Paleoliquefaction data compilation): In Section 4.1.3, the text should briefly mention that after Workshop 2, the Project and the TI Team were encouraged to develop and complete the paleoliquefaction task to help support the final TI Team assessments. The paleoliquefaction data compilation represents a major accomplishment that needs to be emphasized more in the text.

(FR) CC 4-5. (Significant differences in hazard): On page 4-10 in the last sentence of the first paragraph, the text discusses the consideration of site-specific refinement of the CEUS SSC model "only if such refinement would lead to significant differences in hazard." Consider referring the reader to the appropriate section(s) of Chapter 9 for insights on "significant differences" in hazard.

(FR) CC 4-6. (Four criteria for identifying seismic sources): In Section 4.1.3.3 four criteria are given that are used in the Project for identifying seismic sources. They are described as being used sequentially in the process, not simultaneously or without priority, and text on pages 4-15 through 4-17 provide useful details on the importance and use of these criteria. However, it is never explicitly explained why the order of the criteria as listed on page 4-15 is used. Is there a criterion used to establish the sequential order? If so, please explain.

(FR) CC 4-7. (Details relating to Table 4.1.3-1): In Section 4.1.3.3, in the second paragraph on page 4-17, reference is made to Table 4.1.3-1 serving as a summary of criteria used in the identification of each of the seismic source zones. Please explain that the X in the matrix indicates that this criterion was applied, if indeed that is the case, and identify somewhere on the table the significance of the X. Also, note that this table does not include the probability of activity of tectonic features, which is one of the criteria used to identify seismic source zones. This needs to be clarified where the table is introduced in the text, and it would be helpful to include a statement to that effect in a footnote to the table; otherwise, this criterion (probability of activity) is lost to the identifiable criteria in the table. (See also Comment **(FR) CC 7-2**).

(FR) CC 4-8. (Descriptions relating to draft vs. final model): Chapter 4 will need to be checked carefully for statements of technical detail that do not reflect the *final* model (described in Chapters of Installment 2, not yet available at the time of this review). For example, the third full paragraph on page 4-22, refers the reader to discussion in Section 5.3 and describes approaches that do not appear to correspond to cases A, B, and E for the weighting of magnitude bins.

Minor Editorial Comments and Typographical Errors

Some miscellaneous editorial comments and suggestions relating to Chapter 4 have been provided separately to the Project Manager.

CHAPTER 5 — SSC MODEL: OVERVIEW AND METHODOLOGY

General Comments

(FR) G 5-1. Revisions made to Chapter 5 in the August 2011 installment of the Final Report, as summarized in the TI Team's *PPRP Comment Resolution Table*, suitably respond to the PPRP's earlier review comments. (Besides the comments on clarity and completeness below, see also PPRP Mandatory Comment No. 5, "Evaluation of Cases A, B, and E.")

Specific Comments

(FR) S 5-1. *RLME Recurrence Rate Calculations*

In general, the description of the recurrence methodology is relatively brief compared to descriptions of methodology in other parts of the report. Given the supporting use of a single figure (incorrectly identified as a normalized probability density function), it's likely that only knowledgeable practitioners will fully understand the details of the recurrence-rate methodology, particularly for the recurrence-interval approach. Treating paleoearthquake information correctly to calculate earthquake rates is a common requirement in PSHA. As presently described, it is unclear whether the recurrence-interval approach used for the Poisson case is the most appropriate statistical method or just one alternative (e.g., when paleoearthquake dates are available, it is common to observe others calculating λ as the inverse of the mean inter-event time).

In scrutinizing the RLME rate calculations in Chapter 6 and the HID, some key information is unavailable for review, notably the distribution of numerical ages for the oldest paleoearthquakes that propagate into the RLME Poisson recurrence-frequency distributions when the earthquake-recurrence-interval approach is used. Tabulation of these data would be useful for future readers.

Comments on Clarity and Completeness

(FR) CC 5-1. (AFEs for nuclear facilities): In the first paragraph of Section 5.2, the text states: "However, at annual frequencies of interest for nuclear facilities ($\leq 10^{-4}$) . . ." Change the parenthetical statement to (10^{-3} to 10^{-7}). (See PPRP Mandatory Comment No. 8, "AFEs for Nuclear Facilities.")

(FR) CC 5-2. (Number of superdomains): In Section 5.2.1.1, in the last sentence of the second paragraph on page 5-11, the text states: "The result was 15 active (i.e., containing earthquakes) non-extended superdomains and 15 active extended superdomains." These values are inconsistent with those on Figure 5.2.1-4; the numbers on the figure appear to be correct.

(FR) CC 5-3. (Discrepancy between text and Figure 5.3.2-1): Text in the fourth paragraph on p. 5-36 is inconsistent with Table 5.3.2-1. (See PPRP Mandatory Comment No. 5, "Lack of table defining Cases A, B, and E.")

(FR) CC 5-4. (Error in Table 5.2.1-6?): The Mmax values listed in Table 5.2.1-6 for MESE-N appear to be a five-point distribution for the Kijko results and not for the Composite Distribution used in the hazard calculations, as stated in the text in the second paragraph on p. 5-21.

Minor Editorial Comments and Typographical Errors

- Pagination of the tables and figures should be sequential with the text.
- Search the chapter globally and change M and M_W to **M**.
- On p. 5-13, line 10: change “earthquaks” to “earthquakes”
- On p.5-13, in the next-to-last sentence of the second full paragraph: change “After evaluation the the results” to “After evaluating the results”
- On p. 5-15, in the first sentence of Section 5.2.1.1.5: change “criticiszed” to “criticized”
- On p. 5-16, in the next-to-last line of the first full paragraph: change “distributin” to “distribution”
- On p. 5-23 in introducing Equation 5.3.2-1, delete or change the ending words “with mean rate:” What follows the semi-colon is not a formulation for mean rate, it is a formulation for the number of earthquakes.
- On p. 5-24 in the paragraph beginning “In general”: The third sentence incorrectly states: “If the data are scarce, the likelihood function has a broad shape, indicating low uncertainty.” Substitute “high” or “large” uncertainty for “low uncertainty.”
- On p. 5-25, in the last line of the second paragraph: change “function for for” to “function for”
- On p. 5-26, first line: change “aren not” to “are not”
- On p. 5-26, in the last sentence of the second full paragraph: change “We note that expression” to “We note that the expression”
- Section 5.3.2.2.1: The zone acronym for Midcontinent-Craton defined in Table 4.2.4-1, and used in most of the figures in the report, is “MidC” as opposed to “Mid-C” or “MID-C” as written on p. 5-36. [Note: List of Abbreviations uses “Mid-C.”]
- On p. 5-32, in line 6 of Section 5.3.2.1.2: change “Equation 5.3.-18” to “Equation 5.3.2-18”
- On p. 5-35, line 3: in “latin hypercube sampling” note that Latin Hypercube is capitalized on p. 5-44.
- On p. 5-36, in the first line of the next-to-last paragraph: change “Table 5.3.2-1 shows the five cases were” to “Table 5.3.2-1 shows the five case that were”
- On p. 5-38, in line 4 of Section 5.3.2.2.2: change “mostlikely” to “most likely”
- On p. 5-40, in the last sentence of paragraph 3: change “Nonetheless, the the” to “Nonetheless, the”
- On p. 5-40 in the first sentence of Section 5.3.2.3.2: consider changing “has experienced multiple M > 5.0 earthquakes” to “has experienced two **M** > 5 earthquakes”

- On p. 5-41, in line 4 of the third paragraph of Section 5.3.2.3.3: It appears that "0.1 earthquake" should be "0.01 earthquake"
- On p. 5-43, in line 5 of the last paragraph: change "rate densitiy" to "rate density"
- On p.5-45, in line 3 of Section 5.3.2.6: change "but catalog of main shocks deviate from" to "but the catalog of main shocks deviates from"
- In Section 5.3.2.4, in the first paragraph on p. 5-43, the discussion cites Figures 5.2.3-1 and 5.2.3-2; these appear to be incorrect figure numbers.
- The figure caption for Figure 5.3.3-1 references Equation 5.3.3-1; however, it appears that the results are from Equation 5.3.3-2 (the Likelihood function).
- On the second line of p. 5-46, change "1900–2001" to "1990–2001"
- On p. 5-54, in line 6 of the second paragraph of Section 5.4.4: change "conept" to "concept"
- On p. 5-55, in line 5 of the first paragraph: change "the criterion of D_{90} is correct interpretation" to "the criterion of D_{90} is the correct interpretation"
- On p. 5-55, in line 3 of the second paragraph: change "resplved" to "resolved"
- On p. 5-55, in the next-to-last line of the third paragraph: change "reprenting" to "represent"

CHAPTER 6 — SSC MODEL: MMAX ZONES BRANCH

General Comments

(FR) G 6-1. Revisions made to Chapter 6 in the June 2011 installment of the Final Report, as summarized in the TI Team's *PPRP Comment Resolution Table*, suitably respond to the PPRP's earlier review comments—with one exception noted in a Specific Comment. The chapter is well written and complete. A few comments on clarity and completeness are provided below.

Specific Comments

(FR) S 6-1. *Remark on the TI Team's PPRP Comment Resolution Table*

In the top comment on page 30 of the *PPRP Comment Resolution Table,* the TI Team response is "Revision made as suggested." However, the title of Chapter 6 has not been changed, as suggested by the PPRP. The chapter title, which refers only to the Mmax zones branch, should recognize that the description of the RLME zones takes up ~74 of the total 79 pages of text. Only the final five pages of text deal with Mmax zones.

Comments on Clarity and Completeness

(FR) CC 6-1. (Variously described number of RLMEs): In Section 6.1, in the second paragraph on p. 6-1, the reader is informed: "Detailed maps of the RLME sources, along with their alternative geometries, are given in the individual subsections describing each of the **nine** [emphasis added] RLME sources (Sections 6.1.1 through 6.1.9)." Earlier in Chapter 4 the Conceptual SSC Framework is outlined for the reader to include **12** RLME sources (plus various alternatives, Table 4.2.2.-1, p. 4-40).

For understandable reasons, the TI Team assesses and depicts various combinations of RLMEs, but there needs to be a clear roadmap somewhere in the report to guide the reader and avoid confusion about something so fundamental as the number of RLMEs in the model. (The reader's first challenge is comparing the list of RLMEs in Table 4.2.2-1 to the map in Figure 4.2.2-2—even allowing for alternative source geometries.)

(FR) CC 6-2. (Presentation of logic trees): In Chapter 6, as well as elsewhere, figures showing complicated logic trees are shown with unduly small point size. In some cases, available white space may allow enlargement. Constraints are understood, but these nearly illegible figures detract from the quality of the report and will pose a challenge for many readers.

Minor Editorial Comments and Typographical Errors

Some miscellaneous editorial comments and suggestions relating to Chapter 6 have been provided separately to the Project Manager.

CHAPTER 7 — SSC MODEL: SEISMOTECTONIC ZONES BRANCH

General Comments

(FR) G 7-1. Revisions made to Chapter 7 in the June 2011 installment of the Final Report, as summarized in the TI Team's *PPRP Comment Resolution Table*, suitably respond to the PPRP's earlier review comments. The chapter is well written and overall an excellent presentation. Some comments to help improve clarity and completeness are provided below. (See also PPRP Mandatory Comment No. 5.)

Comments on Clarity and Completeness

(FR) CC 7-1. (Basis for slip rates): In Section 7.3.7 (*Extended Continental Crust—Atlantic Margin Zone*), on p. 7-52 the basis for the slip rates cited in the last sentence of the top paragraph is not clear. Are these post-Cretaceous rates based on total displacement Cretaceous to Miocene (5.3 Ma)? Logically, given no measurable displacement in the past 5.3 Ma, the displacement rate for purposes of SSC model characterization is zero.

(FR) CC 7-2. (Source zones and P_a): In the last sentence of the first paragraph of Section 7.1 (p. 7-1), the statement is made that "A seismotectonic zone may also be defined if tectonic features are identified that have a significant probability of activity (Section 4.1.3.3)." It would be useful to the reader if these tectonic features were identified and the probability of activity assigned them were described. Could this be included in Table 4.1.3-1? Are any of the source zones as indicated in Table 4.1.3-1 based in part on the probability of activity of identified tectonic features in the zone—that is, they are judged to have a $P_a > 0.5$?

(FR) CC 7-3. (Mid-C vs. MidC): In Section 7.2.12 (p. 7-71), the abbreviation "Mid-C" is used for the Midcontinent-Craton seismotectonic zone. This differs from "MidC" specified in Table 4.2.4-1 and used in most figures throughout the report.

(FR) CC 7-4. (Conflicting comparison): In the third sentence of Section 7.3.1.1.7 on p. 7-11, the title "Grenville-age dike swarms" conflicts with Cambrian age of 590 Ma of the Sutton Mountains.

(FR) CC 7-5. (Triggering threshold of paleoliquefaction): In the part of Section 7.3.12.1.4 on p. 7-77 dealing with the "Nemaha Ridge–Humboldt Fault Seismic Zone," reference is made in the second paragraph to the Olson et al., 2006 article indicating that available data suggest the triggering of paleoliquefaction features at magnitudes significantly lower than the threshold of **M** 6.5 used elsewhere in the project report for RLMEs. Should this be explained further?

(FR) CC 7-6. (Potentially confusing figures): Figures 7.1-5, 7.1-6, and 7.1-8 superpose one variation (unspecified) of seismotectonic source zones upon geophysical base maps. The text on p. 7-2 conveys that the figures are examples of how the TI Team examined available geophysical data sets as part of the process of defining source zones. However, the captions for these figures may mislead some readers to interpret that the underlying geophysical maps (particularly the magnetic and gravity maps) define the boundaries of the source zones that are shown.

(FR) CC 7-7. (Abbreviated figure captions): In the caption for Figure 7.5.2-1, important information in the second sentence is omitted in the captions for the following Figures 7.5.2-2 and 7.5.2-3. Similarly, in the caption for Figure 7.5.2-4, important information in the second sentence is omitted in the captions for the following Figures 7.5.2-5 through 7.5.2-51. Figure captions should stand alone. Readers will miss important information unless they examine the first figure in each of these series. For the second series, one could write, "Error bars as in Figure 7.5.2-4."

Minor Editorial Comments and Typographical Errors

- In the caption of Figure 7.1-5, "aeromagnetic" should be replaced with "total intensity magnetic anomaly." In the text of this section all instances of "aeromagnetic" should be replaced with "magnetic."
- Late, Early, and Middle used as adjectives to geologic time units (e.g., Paleozoic) should be capitalized. In the current draft the capitalization of these terms is inconsistent.
- In Section 7.1, the first sentence of the first paragraph on p. 7.1 should also include recurrence rate.
- "Appalachian Mountains" rather than "Appalachians" as in the second paragraph of Section 7.3.1.3.
- Should the title of Section 7.3.4 be "Paleozoic Extended Crust Zone" (as introduced in Table 4.2.4-1) rather than excluding the word "Crust"?
- Global search should be used to change M_w to $\mathbf{M}$.

In addition to the editorial comments listed above, some miscellaneous editorial comments and suggestions relating to Chapter 7 have been provided separately to the Project Manager.

CHAPTER 8 — DEMONSTRATION HAZARD CALCULATIONS

General Comments

(FR) G 8-1. Revisions made to Chapter 8 in the August 2011 installment of the Final Report, as summarized in the TI Team's *PPRP Comment Resolution Table*, suitably respond to the PPRP's earlier review comments. The revised chapter greatly improves the documentation in the 2010 draft version and provides helpful information for evaluating the CEUS SSC model. The reorganization of text and figures makes the chapter easy for the reader to navigate.

Specific Comments

(FR) S 8-1. *Observation Regarding Relative Hazard from the USGS and CEUS SSC Models*

There are several examples where hazard from the USGS model lies *above* the 85th-percentile fractile of hazard from the CEUS SSC model. For example, for the Chattanooga site, comparing Figures 8.2-2b and 8.2-2k for 1 Hz rock hazard shows that the USGS curve is much higher than the 85th-percentile fractile of the CEUS SSC model.

Comments on Clarity and Completeness

(FR) CC 8-1. (Terse information): On p. 8-2, in the last sentence of the top paragraph, how were the standard deviations ranging from 0.07 to 0.25 calculated to include "the effect of uncertainties in V_S versus depth and in soil parameters"?

Minor Editorial Comments and Typographical Errors

- In the captions for Figures 8.2-1c, 8.2-2c, 8.2-3c, etc., delete "Hz" in "PGA Hz rock hazard"
- The authors can consider whether they wish to report the V_S profiles (Figures 8.1-2 and 8.1-3) in units of ft and fps or in m and m/sec; the latter are used in the text (Section 8.1) as the primary units for V_S.
- As written, the last paragraph of Section 8.2 on p. 8-3 seems to apply to "*Figures ee, ff, and gg,"* To better guide the reader, insert a header before this important paragraph such as "*Sensitivity to in-cluster and out-of-cluster assumption:"*
- In the paragraph 4 of Section 8.2.2 on p. 8-5, change "but at approximately 0.6 g and 0.3 g" to "but above approximately 0.6 g and 0.3 g"

CHAPTER 9 — USE OF THE CEUS SSC MODEL IN PSHA

General Comments

(FR) G 9-1. Revisions made to Chapter 9 in the August 2011 installment of the Final Report, as summarized in the TI Team's *PPRP Comment Resolution Table*, suitably respond to the PPRP's earlier review comments. The revised chapter adds helpful information for implementing the CEUS SSC model and for understanding sensitivities in the model.

(FR) G 9-2. The revised Section 9.4.3 markedly improves guidance on understanding the precision in seismic hazard estimates and how the results presented should be interpreted. After going through extensive detail on COVs, presented in about 9½ pages of text and 34 figures, the reader arrives at Section 9.4.3 to learn that the critical information for the conclusions is contained in the *minimum* observed COV_{MH} values. The reader should be prepared at the outset for this detail in order to pay attention as the relevant information unfolds. For example, a simple informative statement could be added at the end of Section 9.4.1.

Comments on Clarity and Completeness

(FR) CC 9-1. (Precision and weights): In the second paragraph of Section 9.4.2.2, there is the statement: "It is notable that weights on alternatives are generally given to one-decimal-place precision, and that while these weights indicate quantitative preferences on alternatives, an independent evaluation by another investigator might assign somewhat different weights." This sentence leaves unclear whether it is the precision with which weights are quantified or the different weights that different evaluators would assess, or both that are being evaluated. The distinction is conceptually important since the precision of the weights is a matter of how precise qualitative assessments typically are or can be quantified, while the difference in weights assessed by two TIs using the same data and SSHAC process is a matter of the limiting precision of the SSHAC Methodology itself.

(FR) CC 9-2. (Basis for following SSHAC guidelines): In the first paragraph of Section 9.1 on p. 9-1, the text refers to a SSHAC Level 3 process and states that "all the required steps were taken to implement the letter and the spirit of the SSHA guidelines (Budnitz et al., 1997)." The next sentence then refers the reader to [Chapter] 2. Consistent with Chapter 2, consider expanding the sentence containing "all the required steps were taken" to refer not only to Budnitz et al. (1997) but also to the draft NUREG.

(FR) CC 9-3. (Sections 9.3.2 and 9.3.3): Sections 9.3.2 and 9.3.3 are missing—for reasons explained in the text ("to be written later").

(FR) CC 9-4. (Section 9.4.2.2): The addition of Equation 9-5 and associated discussion on p. 1-13 is particularly helpful. On this same page, the cluster model is referred to. It seems like the authors should at least provide a reference (e.g., Toro and Silva) and possibly an equation.

(FR) CC 9-5. (Seismogenic crustal thickness and hazard calculations): The text and figures (e.g., Figure 9.3-18 through 20) address sensitivity to seismogenic crustal thickness. Revisiting Section 5.4.4, there does not appear to be discussion of how seismogenic crustal thickness is used in the calculation of hazard. How are ruptures distributed with depth? [Reviewer's note: If this is clearly stated somewhere else in the report, then this comment can be disregarded. Otherwise, some discussion is appropriate.]

(FR) CC 9-6. (Description of figures vs. actual content): The amount of text and the number of figures devoted to COVs invites the interested reader to carefully examine the material presented. When reference is made to a figure, the reader will be confused if he/she observes something different than described. Two examples:

- In the last paragraph of Section 9.4.2.1 appearing on p. 9-11, the conclusion is drawn from Figures 9.4-1 through 9.4-3—for area sources—that "typical COV_{MH} will range from 0.15 at a mean annual frequency of 10^{-4} **to perhaps 0.25** [emphasis added] at a mean annual frequency of 10^{-6}, with a wide variation in that range." This statement cannot be squared with the *range* of values observed on Figures 9.4-1 through 9.4-3 unless "typical" is explained. On Figure 9.4-2, there are many COV values at 10^{-6} in the 0.3 to 0.45 range, and in Figure 9.4-3 (bottom), half the COV values at 10^{-6} are > 0.25.
- Text in the middle of p. 9-13 states: "From Figures 9.4-4 through 9.4-6, the COV_{MH} for annual frequencies in the range of 10^{-4} to 10^{-6} is 0.25 to 0.4, with a minimum of 0.25." Given the curves on Figure 9.4-4 and 9.4-6, why not "0.25 to 0.45"?

Minor Editorial Comments and Typographical Errors

- In Section 9.1, in line 6 of the first paragraph on p. 9-1, change "Section 2 describes" to "Chapter 2 describes"
- On p. 9-1, at the end of line 1 in the second paragraph: consider changing "to calculate seismic hazard at locations of nuclear facilities" to "calculate seismic hazard for nuclear facilities"
- The second sentence of Section 9.4 states: "Once a PSHA is completed, it is expected that new data, models, and methods will emerge within the technical community." [This makes is sound like new information is expected to arise *immediately*, once the PSHA is completed.] Suggestion: "After a PSHA is completed, it is expected that new data, models, and methods will subsequently emerge within the technical community."
- In Table 9.4-1, in column 3 relating to site response: Clarify whether EPRI (2005) refers to EPRI (2005a), EPRI (2005b), or both in the list of references.
- In Section 9.4.2.1, the last paragraph on p. 9-10 (continuing on p. 9-11) refers to Figures 9.4-3a and 9.4-3b. However, Figure 9.4-3 contains no "a" and "b" parts; the figure caption refers only to "top" and "bottom." Text needs to be revised to avoid confusion.
- In Section 9.4.2.3, on p. 9-15 (third paragraph, line 2): change the parenthetical reference from "Figure 9.4-13" to "Figure 9.4-12." In the following sentence, consider writing: "The reason is that the 1 Hz hazard curves (Figure 9.4-13) show . . ."
- In Section 9.4.2.3 the abbreviation GMPE [presumably, for ground-motion prediction equations] is used on pp. 9-16 and 9-17. The abbreviation is not included in the list of Abbreviations and Symbols, and a prior definition of the abbreviation couldn't be found in either Chapter 9 or Chapter 8.

CHAPTER 10 — REFERENCES

General Comments

(FR) G 10-1. *Content, Accuracy of List of References*

The PPRP leaves the technical editing of the list of References, including systematic cross-checking with the main body of the text to the TI Team and its support staff.

Comments on Clarity and Completeness

(FR) CC 10-1. (Some missing references): The following citations encountered in the text of Installment 2 are not included in list of references in Chapter 10. No systematic attempt was made to identify missing references.

- p. ix: (NRC, 2011)
- p. 3-37: (Reasenberg, 1985)
- p. 5-25: Utsu (1965)
- p. 5-29: (Fukuda and Johnson, 2008)
- ubiquitous in Chapter 5: EPRI-SOG (1986)
- p. 5-37, p. 5-44, and elsewhere: EPRI-SOG (1988); [a 1988 citation abbreviated (EPRI) appears in the list of references, but not (EPRI-SOG).]

CHAPTER 11 — GLOSSARY OF KEY TERMS

General Comments

(FR) G 11-1. Revisions made to Chapter 11 in the August 2011 installment of the Final Report suitably respond to the PPRP's earlier review comments. The revised glossary is a great improvement over the 2010 draft version and will provide helpful information for many readers.

Comments for Clarity and Completeness

(FR) CC 11-1. (Definitions still to be added): The following definitions still need to be added to the Glossary:

- ***a*-value** (This term is used in many places in the final report; the companion term, *b*-value, is suitably described.)
- **Database, Data Set** (There was agreement at the PPRP Closure Briefing on September 7, 2011, that these terms would be added to the Glossary.)

APPENDIX A — DESCRIPTION OF THE CEUS SSC PROJECT DATABASE

General Comments

(FR) G A-1. The PPRP stated in its review of the July 2010 draft of this appendix (see the TI Team's *PPRP Comment Resolution Table*) that "The CEUS SSC Project has assembled and archived a comprehensive suite of data sets of the CEUS that are important to the characterization and assessment of the SSC model of the region by the TI Team and that significantly contribute to the community knowledge-base." In our July 2010 review, numerous general and specific comments were made aimed at helping to improve Appendix A.

Appendix A in the June 2011 installment of the Final Report is notably improved, both editorially and with regard to clarity and completeness. Nonetheless, further improvements in quality can still be made. To this end, we offer a few specific comments, and we also offer numerous editorial comments on the metadata summary sheets that accompany the figures of the CEUS-scale data layers.[1]

Specific Comments

(FR) S A-1. *Remarks on the TI Team's PPRP Comment Resolution Table*

The TI Team's *PPRP Comment Resolution Table* pertaining to Appendix A generally provides a useful and positive summary of the revisions made to the report in response to the PPRP comments on the July 2010 draft report. However, there are the following exceptions:

a. In our original Comment **S A-1** the suggestion was made to clarify for the reader the availability of and access to datasets and metadata on the Project website. This suggestion is not commented upon or adopted in the revision. The website address of the project and links to the metadata files should be presented in the introduction to this appendix.

b. In our original Comment **S A-4** the suggestion was made to have a technical editor review Appendix A. However, the response to this suggestion apparently did not extend in the revision to the metadata summary sheets. These sheets still need review by a technical editor.

c. Our original Comment **S A-10** noted that the citations in the tables were not in consistent format. This has not been addressed in the metadata summary sheets. Note the varied use of italics.

d. In our original Comment **S A-11** a suggestion was made to include a data file showing areas where reliable earthquake hypocenter depths are available. No response to this comment is given in the resolution table. Such a data file (or map) would be useful in validating the probabilities placed on the seismogenic crust thickness in Table 5.4-2 (July 2010 draft

[1] In order to help the Project Team in its technical editing of Appendix A, a fundamentally important appendix, we include the complete comments made by one diligent PPRP reviewer. Separately, additional editorial comments on Appendix A, made by this same reviewer, are being provided to the Project Manager.

report). The seismogenic crustal thickness is identified in Section 7.1 of the June 2011 version of the report as a criterion for defining seismotectonic zones. Thus, supporting information on this criterion is particularly important.

e. In our original comment on **Sheet A-20** the suggestion was made to check the legend of the figure. Here and in the case of other sheets, this has generally been done, but problems still remain. For example, the units used in the horizontal and vertical derivatives of the gravity anomalies are incorrect. The units have to be mGals/length unit, either km or m. The units of the similar magnetic anomaly maps should also be checked to be certain that the nT/length unit is correct. Other editorial suggestions for Appendix A are being provided separately to the Project Manager.

(FR) S A-2. *Lack of Suitable Information on Regional Heat Flow*

A regional heat flow dataset, which can provide important information on crustal properties and tectonic activity, is not included in the data compilation of the CEUS SSC, despite being identified as a potential database in the preliminary evaluation of data significant to recognizing and mapping seismic source zones in the CEUS. For example, the January 9, 2009, file of database status recognizes both the University of Michigan (Henry Pollack) and the Southern Methodist University (David Blackwell) maps of the heat flow of North America that include the CEUS region, but neither of these are included in the final datasets. What is included is the heat flow point data in the USGS Crustal Database (Sheet A-13, Figure A-15). Unfortunately, this database includes only six heat flow values in the entire CEUS. Thus, this database is of limited value, if any, to mapping seismic source zones. It can be assumed that the data points in this file are relatively recent updates to the US heat flow database.

It needs to be emphasized that even a heat flow map that shows minimal variation over a region has tectonic significance. Thus, even though heat flow over the CEUS is not highly variable, the dataset should be included in the project. A metadata file was prepared in the CEUS SSC project for the University of Michigan's global 1993 heat flow dataset (File: NorthAmerica_HeatFlow_R0_20080617). However, the Southern Methodist University map is dated 2004 (it is an update of the GSA DNAG heat flow map, 1993) and thus should be used if possible because it is the most recent dataset. It is recommended that Figure A-15 be removed because of its limited utility.

Comments on Clarity and Completeness[2]

(FR) CC A-1. (Consistent labeling desirable): The GIS Layer/File Name in column 2 of Table A-1 should be consistent with titles of the Metadata Summary Sheets. They are not for at least two of the Data Theme entries for Tectonic Features.

(FR) CC A-2. (Reference to Ravat et al., 2009): In Table A-1 for Data Theme entitled Magnetic on page A-11 and the associated Metadata Summary Sheets and Figures, the reference is to the Ravat et al.'s USGS Open-File Report dated 2009. That reference is only appropriate for the original total magnetic intensity anomaly data as shown on Figure A-40, page A-80, and the associated shaded relief maps. All subsequent derived magnetic anomaly

[2] See footnote 1 for additional information.

data sets and figures (e.g., differentially reduced to pole magnetic anomaly data shown on Figure A-42) should refer to personal communication from Ravat. The processed derived data as provided by Ravat is not included in the USGS Open-File Report.

(FR) CC A-3. (Geon): The term Geon is used in the legend of a figure in Appendix A. Because, this is not a widely known term, we suggest that Geon be added to Glossary.

(FR) CC A-4. (Figure A-6): The addition of a Source number reference on the cross-sections shown in Figure A-6 would greatly help the user of the dataset.

(FR) CC A-5. (Figure A-13): Just what is shown on Figure A-13 is unclear. Is crustal thickness or basement thickness presented? The statement is made in the legend that the labels are basement thickness, but the title of the figure refers to crustal thickness. Which are the symbols for the sediment thickness? The label indicates that the sediment thickness is not given, but the symbol identification indicates that they are. The legend and title are confusing.

(FR) CC A-6. (Figure A-14): Referring to Figure A-14 (and Summary Sheet A-13), why does the title refer to both P- and S-wave velocity, but the legend indicates that only P-wave velocities are shown. One can presume that the velocities refer to average velocity of the crust. Is that correct? If so, modification of the title to indicate this would be appropriate.

(FR) CC A-7. (Figure A-49): On Figure A-49 there is no indication of the COCORP lines in south Texas. Should they be there as in a preliminary copy of this figure?

(FR) CC A-8. (Figure A-16): Comparison between Figure A-16 (Sediment thickness derived from USGS Crustal Database), page A-52, and the figure of the same data presented by Walter Mooney on page 6 of his handout at Workshop #1 indicates significant discrepancies. Are these only caused by differences in contour interval? This should be checked to verify the information shown in Figure A -16 and the associated dataset.

APPENDIX B — EARTHQUAKE CATALOG

General Comments

(FR) G B-1. Revisions made to Appendix B in the August 2011 installment of the Final Report suitably respond to the PPRP's earlier review comments. Once again, the PPRP commends the TI Team on the monumental efforts that went into compiling the earthquake catalog.

Minor Editorial Comments and Typographical Errors

- Section B.3, Page B-3, cites Equations 3.3-9 and 3.3-10; the correct citation is Equations 3.3.1-9 and 3.3.1-10.

APPENDIX C — DATA EVALUATION TABLES

General Comments

(FR) G C-1. Revisions made to Appendix C in the June 2011 installment of the Final Report, as summarized in the TI Team's *PPRP Comment Resolution Table*, suitably respond to the PPRP's earlier review comments, with one exception, noted below as a Specific Comment. A few items for improved clarity are offered for consideration by the Project Team.

Specific Comments

(FR) S C-1. *Remark on the TI Team's PPRP Comment Resolution Table*

Our original Comment **S C-1**, reproduced on p. 50–51 in the *PPRP Comment Resolution Table*, stated in its final sentence that "All seismic source zones including Mmax zones should have a Data Evaluation table." The corresponding resolution column in the table states that "All seismic sources have an applicable Data Evaluation table." Nonetheless, no evaluation tables could be found in Appendix C for the Mmax zones, and these tables are not identified in the listing of tables in the introductory text to Appendix C.

Comments on Clarity and Completeness

(FR) CC C-1. (Explanation of labeling of the Data Evaluation tables): It would be helpful to explain that the labeling of the Data Evaluation tables is keyed to a specific chapter and section where the corresponding source zone is described and discussed—e.g., Table C-7.3.3 is keyed to Section 7.3.3, *Northern Appalachian Zone (NAP)*.

(FR) CC C-2. (Potential confusion about "No Table"): The entry in the index on page C-1 indicating "[No Table C-7.3.11]" may confuse some readers. An explanation of the labeling scheme for the tables, suggested in Comment **(FR) CC C-1** above, would help clarify the matter.

(FR) CC C-3. (Reader-friendly guide to locating information): To help the reader locate a specific Data Evaluation table, it would be helpful if the index on page C-1 (and perhaps also the Table of Contents) included page numbers for finding the table for a specific source zone.

APPENDIX D — DATA SUMMARY TABLES

General Comments

(FR) G D-1. Revisions made to Appendix D in the June 2011 installment of the Final Report, as summarized in the TI Team's *PPRP Comment Resolution Table*, suitably respond to the PPRP's earlier review comments. A few items for improved clarity are noted below for consideration by the Project Team.

Comments on Clarity and Completeness

(FR) CC D-1. (Explanation of labeling of the Data Summary tables): It would be helpful to explain that the labeling of the Data Summary tables is keyed to a specific chapter and section where the corresponding source zone is described and discussed—e.g., Table D-7.3.3 is keyed to Section 7.3.3, *Northern Appalachian Zone (NAP)*.

(FR) CC D-2. (Potential confusion about "No Table"): The entries in the index on page D-1 indicating "[No Table . . .]" may confuse some readers. An explanation of the labeling scheme for the tables, suggested in Comment **(FR) CC D-1** above, would help clarify the matter.

(FR) CC D-3. (Absence of Data Summary tables for the Mmax source zones): Why are there no Data Summary tables for the Mmax seismic source zones? Include or explain their omission in appropriate text in an introduction to Appendix D (see also Comment **(FR) S C-1**).

(FR) CC D-4. (Reader-friendly guide to locating information): To help the reader locate a specific Data Summary table, it would be helpful if the index on page D-1 (and perhaps also the Table of Contents) included page numbers for finding the table for a specific source zone.

(FR) CC D-5. (Intentional or accidental repetition?) Page D-34 repeats pages D-31, and D-36 repeats D-33.

(FR) CC D-6. (Mix-up in Tables D-7.3.1 and D-6.1.9): Pages D-119 to D-145, ostensibly Table D-7.3.1 and identified in the header as a Data Summary table for the St. Lawrence Rift, are a repeat of pages for the Wabash Valley RLME given in Table D-6.1.9.

(FR) CC D-7. (Inconsistent labeling of magnitude): Both **M** and M_w appear in the table descriptions. For consistency with the rest of the report, **M** should be used (unless some magnitude scale other than moment magnitude is referred to).

APPENDIX E— CEUS PALEOLIQUEFACTION DATABASE, UNCERTAINTIES ASSOCIATED WITH PALEOLIQUEFACTION DATA, AND GUIDANCE FOR SEISMIC SOURCE CHARACTERIZATION

General Comments

(FR) G E-1. This appendix represents a thorough and well expressed compendium of methodology, data, and guidance related to paleoliquefaction studies in the CEUS. Revisions made to Appendix E in the June 2011 installment of the Final Report, as summarized in the TI Team's *PPRP Comment Resolution Table*, fully address the PPRP's earlier review comments. The only need for further attention is the item noted below.

Comments on Clarity and Completeness

(FR) CC E-1. (Figure E-6): Incorrect figure? It appears that the figure provided as Figure E-6 is Figure E-5 repeated. The two figures have different captions.

Minor Editorial Comments and Typographical Errors

Miscellaneous editorial comments and suggestions, provided separately to the Project Manager, include several comments on Appendix E.

APPENDIX F — WORKSHOP SUMMARIES

General Comments

(FR) G F-1. This appendix remains basically unchanged from the July 2010 draft. As the PPRP commented in its earlier review (see the TI Team's *PPRP Comment Resolution Table*), "The summaries of the workshop provided in Appendix F are well-written accounts of the presentations and subsequent discussions that transpired." The only remaining issue is a clear instruction to the reader about the availability and location of companion materials for understanding the summaries (see Comment **(FR) S F-1** below).

Specific Comments

(FR) S F-1. *Remark on the TI Team's PPRP Comment Resolution Table*

In our review comments on the July 2010 draft (see TI the TI Team's *PPRP Comment Resolution Table*), the PPRP suggested that it would be helpful to add the agenda and list of participants for each workshop, and we noted our assumption that copies of visual presentations made at the workshops would become available in some conveniently accessible form. The TI Team's Comment Resolution Table (response to Comment **S F-1**) states: "No change. The workshop agendas and lists of participants, as well as copies of all presentations, will be provided on the Project website."

Because the extra information is important for understanding of context, as well as for completeness of documentation, there should be a clear instruction to the reader—perhaps as a footnote to the title of Appendix F—that for each workshop the agenda, list of participants, and copies of all presentations can be accessed on the Project website.

Minor Editorial Comments and Typographical Errors

Because tables consistently appear *at the end* of all other parts of the report, the placement of Table 1 after the narrative for Workshop and #2 and before the narrative for Workshop #3 may confuse some readers. Perhaps a footnote to the Appendix title on p. C-1 could be added stating something like: "Note that references and any tables for each workshop appear at the end of that workshop's summary."

APPENDIX G — BIOGRAPHIES OF PROJECT TEAM

General Comments

(FR) G G-1. The revised Appendix G suitably responds to the PPRP's review comments on the July 2010 draft, as summarized in the TI Team's *PPRP Comment Resolution Table*. Appendix G remains a straightforward compilation of biographical sketches for members of the CEUS SSC Project. The addition of an introduction gives the reader a helpful overview and provides guidance for understanding the grouping and ordering of the individual biographies.

Minor Editorial Comments and Typographical Errors

- In the biographical sketch for Tom J. Mulford, there is the following word string:

  "... has had extensive interface with utilities around the world, including the U.S. Nuclear Regulatory Commission (NRC) . . ."

  In the syntax, "including" refers to "utilities"; because the NRC is not a utility, this sentence needs to be reworded.

APPENDIX H — CEUS SSC MODEL HAZARD INPUT DOCUMENT (HID)

General Comments

(FR) G H-1. The revised HID usefully includes more cross-references to text and figures in the report to help guide the user, and it appears to be complete. Three members of the PPRP will eventually be using the HID at their respective agencies (USGS, NRC, and DFNSB), but it wasn't feasible for them to implement the HID before completing this review. The adequacy of the HID remains to be verified by these and other users in the near future.

APPENDIX I — PPRP AND USGS REVIEW COMMENTS[1]

General Comments

(FR) G I-1. Revisions made to Appendix I in the June 2011 installment of the Final Report, as summarized in the TI Team's *PPRP Comment Resolution Table*, suitably respond to the PPRP's earlier review comments. Three matters needing further attention are described below.

Specific Comments

(FR) S I-1. *Placement of PPRP Closure Letter in CEUS SSC Final Report*

As discussed with the Project Team at the PPRP Briefing on June 22, 2011, the PPRP recommends that its Final Letter Report, to be delivered to the Project Manager in October 2011, appear in the CEUS SSC Final Report immediately following the Executive Summary. We believe that executive readers will be eager to know how the PPRP views the project and its outcome, and that this information should be readily accessible—rather than in Appendix I. (Note that the last sentence on p. 2-20, referring to the location of the PPRP's closure letter in the report, would need to be revised.)

(FR) S I-2. *PPRP Review Comments to be Included in Appendix I*

As also discussed with the Project Team at the PPRP Briefing on June 22, 2011, it is our expectation that the following PPRP report be included in Appendix I:

> Letter dated October 4, 2010, to Mr. Salomone: *Central and Eastern United States Seismic Source Characteristics for Nuclear Facilities:* PPRP Review Comments on CEUS SSC Draft Report of July 31, 2010.

The above letter, although lengthy, provides full context for our review comments and gives the reader a sense of the extent and incisiveness of the PPRP's review. Insofar as the TI Team's *PPRP Comment Resolution Table* is partly repetitious, the latter might appear only on the Project website. We assume that, after they are finalized in September 2011, the PPRP's combined review comments on Installments 1 and 2 of the CEUS SSC Final Report will also be included in Appendix I.

(FR) S I-3. *Inclusion of Two PPRP Informal Communications in Appendix I*

Despite their designation, we request that two specific PPRP "Informal Communications" be included in Appendix I. The following two communications contain important perspectives at critical junctures of the project, and we believe that they warrant inclusion in the Project's formal documentation:

- Memorandum dated October 13, 2010, to Mr. Salomone: Key Issues for TI Team to be Attentive to as They Revisit the CEUS SSC Model and Revise the Project Report.
- Memorandum dated February 23, 2011, to Mr. Salomone: PPRP Feedback on CEUS SSC Working Meeting #9.

[1] Some comments here regarding the content of Appendix I are superseded by later decisions made with the Project Team after the PPRP Closure Briefing on September 7–8, 2011.

APPENDIX J — MAGNITUDE-RECURRENCE MAPS FOR ALL REALIZATIONS AND ALL SOURCE-ZONE CONFIGURATIONS

General Comments

(FR) G J-1. Revisions made to Appendix B in the August 2011 installment of the Final Report suitably respond to the PPRP's earlier review comments. Reviewers cannot be certain that each map is the correct one corresponding to the caption, but the maps appear to be logical in terms of degree of smoothing, and so on.

APPENDIX K — SCR DATABASES USED TO DEVELOP MMAX PRIOR DISTRIBUTIONS

General Comments

(FR) G K-1. The addition of explanatory text, figures, and cross-references to relevant sources of information all greatly improve this revised 2011 version of the Appendix K. No further comments.

APPENDIX L — QUALITY ASSURANCE

General Comments

(FR) G L-1. Appendix L is a new appendix that was not contained in the 2010 version of the Draft Project Report. The PPRP offers one specific comment that deals with the transparency (or lack thereof) in merely citing the previous EPRI-SOG verification efforts as adequate verification for several key pieces of software.

Specific Comments

(FR) S L-1. *Adequate Verification of Software*

On page L-4, a discussion of the use of Verified Computer Programs indicates that the two principal computer codes used in the development of the earthquake catalog are EQCLUST and EQPARAM. The text asserts that "both of these programs were part of the verification program of the EPRI-SOG" study. These programs and the associated results/documentation of the EPRI-SOG verification effort have not been publicly available. The CEUS SSC Project Team should strongly consider reproducing/placing the relevant portions of the EPRI-SOG verification documentation on the Project website. This would significantly improve the transparency and completeness of the CEUS SSC documentation.

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PPRP Comment Response Table

Comment	Summary of Revisions to Report
CHAPTER 1—INTRODUCTION	
General Comments **G 1-1. (NAR)** This chapter is well structured and introduces the reviewer to all elements of this complex project report. The chapter usefully discusses the need for community-based studies and comparisons with other approaches. Here and throughout this Draft Report, we recognize the great effort that has gone into the writing and documentation, and we commend the TI Team for its diligent efforts to distill and report a massive amount of detail. Mindful of the criteria we have been given to guide our critical review (see cover letter), we proceed to specific comments.	Comment noted and appreciated.
S 1-1. (SSHAC) *Justification for Using the SSHAC Level 3 Assessment Process* A key issue related to the selection of the SSHAC assessment level, specifically a Level 4 assessment versus Level 3, relates to the ability of the selected experts to act as impartial evaluators—the perceived higher level of assurance provided by Level 4 comes with significant additional costs, some of which are associated with making sure the use of experts or expert teams as impartial evaluators is being done properly. The Hanks (2009) Open File reports notes, appropriately, that most geosciences experts are quite inexpert in one or more of several matters important to higher level SSHAC assessments. But generally, they are not experienced evaluators of uncertainty, given competing hypotheses and interpretations that require evaluation using diverse sets of geological, geophysical, and seismological data. This particular point needs to be brought out more in the draft report, both here and in Chapter 2. Experience has shown, even for some projects that have claimed SSHAC Level 4 assessment, that the actual success of experts or expert teams as evaluators has been limited. At the present time for the CEUS it may be that the technical community is best able to implement a SSHAC Level 3 assessment (high confidence that a TI Team can be selected to act as impartial evaluator) versus a Level 4 assessment. While some could view this point as less important, it is a key point that those outside the project (other agencies, ACRS, others) must appreciate and understand. Based on cumulative experience using the SSHAC Methodology, particularly given the time constraints, we have confidence that this project can be successfully implemented using a SSHAC Level 3 assessment versus Level 4.	Explanation added regarding why Level 4 projects cost more and take more time than Level 3 studies. We are unaware of any Level 4 projects that have not been successful with regard to the experts acting as evaluators.
S 1-2. (CC, SSHAC) *Clear Communication is Essential: Chapter 1 and Entire Report* Keeping in mind that words are the stuff of thought and that clear communication of thought is essential, especially for regulatory guidance documents intended for long term use, usages of words and terms must clearly and accurately convey the concepts that are being described. It is also essential that the words and terms be used in their proper meaning consistently throughout the report. The practice of using nuanced words as synonyms contributes to a lack of essential clarity. For example, throughout Chapter 1 the word “study” is used interchangeably in multiple meanings. In most instances “study” is used to mean either “project” or “assessment”; it is used in its proper meaning in only a few instances, for example in subsection 1.4.4.4. Serious miscommunication will result from incorrectly using the word “study” to convey the activities that constitute a SSHAC assessment process—or that constitute a “SSHAC Study Level 3 Approach” or a “SSHAC Study Level 3 Methodology,”	Changes made to clarify the use of “study,” “project,” and “assessment.” We agree with the term “SSHAC assessment process” and text has been revised accordingly. However, the term “Study Level” is given in the SSHAC Guidelines and cannot be easily changed by this report without confusion. For clarity, SSHAC Study Levels are always indicated with capital letters. Use of “event” has been clarified or revised.

PPRP Comment Response Table

Comment	Summary of Revisions to Report
which are alternatively used when referring to the SSHAC assessment process. The word "study" does not properly communicate the complex activities and processes that constitute the SSHAC Methodology or SSHAC assessment process. These activities together constitute a structured assessment process that involves compilation of the state of scientific and technical knowledge, compilation of datasets, evaluations of state of practice, and finally, assessments that represent the integrated knowledge of the scientific community and the community's knowledge uncertainty as represented in the logic tree of the SSC model. It should be kept in mind that the SSHAC assessment process is accepted by the Nuclear Regulatory Commission (NRC) as the current state of practice for a technical process whereby seismic hazard models are assessed. Thus, it has the same standing as a consensus standard (ASCE Standard 43-05, for example). It is incorporated into the Agency's accepted seismic regulatory procedures (Regulatory Guide 1.208) for demonstrating compliance with the seismic regulation 10 CFR Part 100.23; it also is accepted by the Department of Energy (DOE) as part of the Agency's seismic safety policies and regulatory procedures. We emphasize that it is essential to clearly establish in Chapter 1 that the SSHAC Methodology is an assessment procedure that is accepted by the NRC and the DOE for developing seismic hazard models that are, in turn, accepted as providing reasonable assurance, consistent with these Agency's seismic safety decision-making practice, of compliance with their seismic safety regulations and policies. Reasonable assurance is expressed in the outcome of using the SSHAC Methodology as the representation of the center, body and range of scientific community knowledge. In order to clearly convey the fact that the assessment of the CEUS SSC model has been accomplished through implementation of an accepted structured assessment process, we believe that the terminology "SSHAC Level 3 assessment process" should be adopted and used consistently throughout the CEUS SSC Report, notwithstanding use of alternative terminology in other documents. This would require extensive technical editing. Similarly, a careful edit should be performed, replacing the words "study/studies," which do not properly apply when describing the activities performed in the CEUS SSC Project, with "project" or "assessment," as appropriate. As examples, "LLNL study" and "EPRI-SOG study" are properly "LLNL Project" and EPRI-SOG Project." Although the term "SSHAC Study Level" has been used in past documents, we recommend use of the term "SSHAC assessment process" in order to clearly convey the complex activities performed in the CEUSSSC Project. The word "event" is used confusingly to mean "earthquake" throughout this chapter and the report. While it can be argued that the usage is understood in context, regulatory documents, which are intended to be used for an extended time by many people having differing backgrounds, require clarity. Consider making a blanket change of the word "event" to"earthquake" where appropriate.	
Comments by Section ***Section 1.1*** 1st paragraph: Consider replacing the 2nd sentence with: "As such, the CEUS SSC model replaces regional seismic source models for this region that are currently accepted by the Nuclear Regulatory Commission (NRC) for satisfying the requirements of the seismic regulation, 10 CFR Part 100.23, for assessing uncertainty	Revisions made to text as suggested.

PPRP Comment Response Table

Comment	Summary of Revisions to Report
in seismic design bases. These include the Electric Power Research Institute–Seismicity Owners Group (EPRI-SOG) model (EPRI, 1988) and the Lawrence Livermore National Laboratory (LLNL) model (Bernreuter et al., 1989).” This change would require some additional editing of the paragraph. Note that the proper reference to the EPRI-SOG Project is EPRI (1988). The date should be corrected in the References. Note also, that EPRI (1989) contains hazard computations at the SOG utility’s NPP sites. This report was not submitted to NRC for review. (See also *Comments by Section* for Chapter 3, under *References.*) 2nd paragraph: Consider replacing the 2nd sentence with: “The project used a SSHAC Level 3 assessment process in order to assure compliance with the requirements of seismic regulations that uncertainties in the model have been properly quantified, evaluating the range of views and interpretations of the technical community.” And add to the end of the paragraph: “These models are expected to be adopted as part of the seismic safety regulatory guidance, replacing the EPRI (2004, 2006) models.”	
Section 1.1.1 “Studies” should be replaced with “Projects” here and throughout the report when referring to the EPRI-SOG and LLNL projects.	Revisions made as suggested.
Section 1.1.2 “Studies” should be replaced with “Expert Elicitation Projects.” In the 1st paragraph, consider replacing sentences 4 through 6 with: “These included the EPRI-SOG and LLNL projects.1 Although both of these large projects relied on assessments by multiple experts, there were significant technical and procedural differences between the two, and there were large differences in the hazard results obtained at many common sites compared by the two projects. The formation of SSHAC was motivated by the need to understand these differences and to develop guidance acceptable for meeting the requirements for seismic safety regulation of nuclear facilities for assessing uncertainty in seismic hazard models”. This change would require editing of the subsection as needed to be consistent. Typo: In the first sentence of paragraph 2, change “time if their issuance” to “time of their issuance”	Revisions made as suggested.
Section 1.1.3 Suggested wording change in the first sentence: “just as important as the basis of the technical assessments.” In the subsection heading: “SSHAC Methodology” or “SSHAC Guidance.” At the top of p 1-3, the sentence, “As will be discussed in Section 2.2, the roles and responsibilities that a SSHAC process defines for all project participants must be scrupulously adhered to throughout the process to ensure its success” is overstated. Section 2.2 makes no mention that “scrupulous adherence” is a condition for success. Suggestion: “The roles and responsibilities of participants in the CEUS SSC project were explicitly defined, consistent with SSHAC guidelines for a successful Level 3 assessment project (see Section 2.2), and were diligently followed.”	Revisions made as suggested.

PPRP Comment Response Table

Comment	Summary of Revisions to Report
Section 1.1.4 “Study” should be replaced with “Project” or “CEUS SSC Model”; edit the subsection as needed for consistency. Suggested word change in paragraph 2, line 2: “The CEUS SSC model is based on a comprehensive, transparent, and traceable process, . . .” In the last sentence of paragraph 1, given the purpose of the CEUS SSC project (as described in the following paragraph), it seems strange to mention the DNFSB explicitly but not the NRC in this first general statement. Suggestion: “Standardization at a regional level will provide a consistent basis for computing seismic hazard, which will assist regulators such as the NRC [acronym defined earlier in section 1.1] and the Defense Nuclear Facilities Safety Board (DNFSB) in their oversight of nuclear facilities.”	Revisions made as suggested.
Section 1.1.5 In the last line of paragraph 1 on p. 1-3, change “participated or observed the CEUS SSC Project” to “participated in or observed the CEUS SSC Project.” Differences from USGS National Seismic Hazard Mapping Project: In the 1st paragraph on p. 1-4, the quoted AFEs should be verified. The national seismic hazard maps and USGS PSHA work is for AFEs in the range of 10-2 to 10-4 (building code maps are developed for an AFE of 4.04 x 10-4), and the CEUS SSC results will provide results for AFEs in the range of 10-3 to 10-6 for design purposes. In the same paragraph, lines 6 and 7, suggested wording change: “critical safety requirements of these facilities” rather than “the robustness of these facilities.” [Delete comma preceding period at the end of this sentence.] In the same paragraph, line 11, suggested wording change: “hypotheses and parameter values are included where appropriate” In the same paragraph, line 12, consider changing “witnessed in the paleoseismic record” to “observed in the paleoseismic record”	Revisions made as suggested.
Section 1.2.1 Consider replacing the section heading with “Regional Seismic Source Model that Represents Current Knowledge and Data Uncertainties of the Technical Community” (see Comment **S 1-1**). In paragraph 2, line 1, consider changing “proper” to “appropriate.” The last sentence of this section discusses the possibility that local sources can be used to refine the CEUS SSC model for site-specific application. We suggest that this sentence be deleted. Any change to the CEUS SSC model will need to be evaluated in terms of the PSHA distance influence for that change. Thus, what constitutes a local SSC model change versus a regional SSC model change is somewhat vague. The SSC report should recognize that site-specific studies are required but be silent on what happens if these studies indicate an SSC model change. NRC and others will have to decide what to do with any recommended SSC change (the distance extent to which that change must apply) and whether updates to calculations for “regions” are necessary.	Consideration given to suggested revisions; revisions made to text to reflect the intent of the suggestions.
Section 1.2.2 The section heading should be changed to “Conducted Using the SSHAC Level 3 Assessment Process,” and edit the section to be consistent with the change (see	Revisions made to text as suggested, except that terminology of SSHAC Study Levels is kept for clarity.

Comment	Summary of Revisions to Report
Comment S 1-1). In paragraph 1, consider replacing the 3rd sentence with: "For regional seismic hazard models intended for use at many sites, the higher assessment levels provide the level of assurance required by the regulators for future use in seismic safety decision-making." In paragraph 2, line 9, suggested wording change: "the success of these assessment levels is the implemented process followed, which . . ." Third paragraph: Time and costs are issues that the regulatory agencies are committed to take into account, but reasonable assurance of safety as required by the seismic safety regulations and regulatory safety practice are primary. This section should be edited to reflect this understanding. Consider replacing the first sentence of this paragraph with: "Selection of a SSHAC assessment level depends on the scope and complexity of the required evaluations and the intended use of the assessed seismic hazard model." At the end of the paragraph consider adding the sentence: "Moreover, after several years experience using the SSHAC Methodology, a Level 3 assessment is now accepted for developing regionally-applicable seismic hazard models intended for use over an extended time as the starting basis for computing PSHAs at multiple sites."	
Section 1.2.3 In paragraph 1, line 3, suggested wording change: "a SSHAC process should not be subject to significant change without new hazard-critical scientific findings." Suggested wording change in paragraph 2, line 2: "Although these findings may lead to" Suggested wording change in paragraph 2, line 3: ". . . it is likely that the assessment will remain viable, avoiding the need for an extensive revision." In paragraph 2, third sentence: The text states, "Longevity means that the model will last for several years before requiring a significant revision or update." The last sentence in the paragraph states, "It is expected that the longevity for studies such as the CEUS SSC Project will be at least 10 years before there will be the need for a significant revision." To avoid confusion, the wording defining *longevity* should be sharpened.	Revisions made as suggested.
Section 1.2.4 The section heading should be changed to "Interface with Ground Motion Models" Use of the words "debate" and "interaction" in the 2nd paragraph, do not properly convey the role of the workshops for implementing the assessment process. Consider replacing the last two sentences of the paragraph with: "The TI Team brought together a panel of ground motion experts constituted of proponents of the range of available models in a series of three workshops, structured to gain a common understanding of the uncertainties in the modeling approaches and to structure the evaluation and assessment process for representing the uncertainty distribution of the technical community." The subsection should make clear that the Expert Panel represented the range of community ground motion modeling knowledge for the CEUS. Suggested wording change in paragraph 2, line 8: "The TI Team interacted with the Expert Panel to . . ."	Revisions made to text as suggested.
Section 1.3 As discussed in Comment S 1-1, the word "study" does not convey the activities and	The term "study region" is commonly used for seismic hazard analyses, while "model region" is not clear and not common. We will continue to use the term

Comment	Summary of Revisions to Report
processes that constitute the SSHAC Methodology. The section heading should be changed to "CEUS SSC Model Region." Regarding the 4th sentence of paragraph 1: Are there any contributing sources that are in oceanic crust? In this same paragraph, the text incorrectly (or at least misleadingly) states that "On the north and southwest, the study region extends a minimum of 322 km (200 mi.) from the U.S. borders with Canada and Mexico." Examination of Figure 1.3.1 shows that the SSC model region extends 200 mi. into Mexico only along the Gulf Coast. It does not generally extend 200 miles into Mexico "on the southwest."	study region when talking about the region depicted on the figure. Change made to sentence regarding boundary.
Section 1.4 "Study" should be changed to "Project" in the section heading (see Comment S 1-1).	Revision made as suggested.
Section 1.4.1 In the section heading, use of the word "Complete" is not clear, and the word "Study" is misleading. Section heading should be changed to "Seismic Source Model Region." Need to introduce the three stages of the SSC Model assessment: In section 1.4.1, the reader should be informed that the SSC Model was developed in three stages—the sensitivity SSC Model, the preliminary SSC Model, and the final SSC Model. This can be done effectively at the end of this section—prior to Chapter 2 where the terms appear for the first time on p. 2-19 unexplained. In paragraph 1 (see line 10), the text states, "sources of repeated large-magnitude earthquakes (**M** ≥ 6.5) earthquakes (RLMEs) are identified . . ." The rationale for selecting the threshold of **M** 6.5 for RLMEs should be explained. In this same paragraph, next-to-last line, change "and the forecast future occurrences" to "and the forecast of future occurrences" Kijko Methodology as "State-of-the-Art": On p. 1-9 in the first paragraph, the text describes "two methods for assessing Mmax: a Bayesian methodology . . . and the Kijko methodology that is state-of-the-art within the technical community." The latter assertion raises questions about the Kijko methodology vis-à-vis the project. If state-of-the-art, then why was the methodology only considered at a late stage of the project (see p. 2-44) and why was it not identified at the USGS Mmax workshop as state-of-the-art? Suggestion for a broad-brush statement needed here: ". . . and a well-founded mathematical procedure that estimates Mmax based on seismic data (where sufficient) only for the source being considered."	"Complete" deleted; term Study Region is specific to the mapped area (see comment response to Section 1.3) Discussion of the three stages added to Section 1.4.4. Explanation added by M6.5 used for RLME. Revisions regarding the Kijko method made as suggested.
Section 1.4.2 In the 3rd line, consider changing "third party" to "future user" In this same paragraph, lines 10–11, consider changing "for a project" to "for seismic hazard analysis at a specific site."	Revisions made to text as suggested.
Section 1.4.4.2 In the 4th sentence, suggested word change: "Where applicable, GIS data layers were developed, and this included new geophysical data compilations developed specifically for the project."	Revisions made to text as suggested.
Section 1.4.4.3 In line 4, change "all events up through 2009" to "all earthquakes through 2008." The	Revisions made to text as suggested.

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project catalog (Chapter 3) extends through the end of 2008. In line 7, suggested word change: “a number of historical earthquakes were reviewed in order to develop reliable moment magnitudes for these shocks.”	
Section 1.4.4.4 In the title of this section elsewhere in the report, *paleoseismicity data* tends to be used loosely as synonymous with *paleoliquefaction data*. Paleoliquefaction data are a subset of paleoseismicity data, which notably include results of geological trenching of active faults, such as for the Meers and Cheraw faults. The report includes varied types of paleoseismic data, and correct terminology is important for clarity. Consider replacing the first sentence of this section with: “Because of the emerging use and significance of paleoliquefaction data in the CEUS, part of the scope of the project was a compilation of these data and development of written guidance for representing uncertainty in evaluations and interpretations of the data to estimate the locations, occurrence times, and magnitudes of causative earthquakes.”	Revisions made to text as suggested.
Section 1.4.4.5 The first sentence of the second paragraph is awkwardly worded. Suggestion: “This report contains an evaluation . . .”	Revisions made to text as suggested.
CHAPTER 2—SSHAC LEVEL 3 PROCESS AND IMPLEMENTATION	
General Comments **G 2-1. (CBR, CC)** This chapter contains generally informative and valuable background information, but it does not adequately achieve the goal of explaining the chapter heading for a number of reasons: (1) the chapter is not organized effectively, with too much discussion of history that, in its present form, distracts from a necessary focus on this project1; (2) there is not enough discussion of what the TI Team did to ensure that they were objective evaluators to “represent the center, body, and range of the technical interpretations that the larger informed technical community (ITC) would have if they were to conduct the study”; and (3) the discussion of the workshops needs to be enhanced to describe what the TI Team did to ensure that (a) the workshops focused on the right issues (completeness), (b) the workshop goals were met, and (c) the experts who attended the workshops were appropriate and sufficient for the purpose of defining the community knowledge and associated uncertainties.	History discussion removed. Additional discussion provided of the activities associated with the evaluation process, including the need for all TI Team members to assume the role of expert evaluators, and the potential for removal of Team members who were not able or willing to assume the evaluator role Additional discussion provided regarding workshops and approaches to ensuring their success, including providing the proponent experts with a list of questions prior to the workshop to ensure that the proponents focused on the hazard-significant issues.
G 2-2. (CC) The discussion regarding a “SHAC Level 3 process” and the concept of the “informed technical community” (ITC) is of great importance for substantiating key claims about the implementation and results of the CEUS SSC project. But, it is marred by imprecise wording that may contribute to confusion or invite argument. Our Comment **S 1-2** (clear communication) applies equally to Chapter 2, and we offer additional specific comments to help strengthen the logic underpinning key claims in this chapter.	Extensive revisions to the discussion of the ITC made throughout to make it consistent with NRC (2011), which will be issued shortly.
Specific Comments **S 2-1. (CC, SSHAC)** *Explaining the Goals of the Chapter* Writing always involves individual choice, and there are different ways to explain the goals of the Chapter at the outset. In the following example text2 an attempt is made to give the reader a road map—intentionally with a regulatory framework in mind:	Most of the suggested passage was included in the revised text. Use of the term “community distribution” is maintained in this discussion because it is specifically defined in the SSHAC guidelines.

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The goals of this chapter are, first, to describe the SSHAC Level 3 assessment process and how it was implemented to assess the CEUS seismic source characterization (SSC) model and, second, to demonstrate that the implementation was accomplished in compliance with the SSHAC guidance. The SSHAC developed guidance for four levels of implementing an assessment, depending on the degree of uncertainty and contention involved and the intended use of the seismic hazard model.3 The SSHC guidance emphasizes that, independent of the implementation level, the goal of a SSHAC assessment is "to represent the center, the body, and the range of the technical interpretations that the larger informed technical community would have if they were to conduct the study" (SSHAC, 1997, p. 21). The "center, the body, and the range" is taken to mean a representation of the uncertainty in the technical community's knowledge, referred to by the SSHAC as "the community distribution." The latter, as a representation of the uncertainty in the technical community's knowledge, can be termed "the community uncertainty distribution." A proper representation of the community uncertainty distribution appropriately meets the requirements of the NRC's seismic regulation, 10 CFR 100.23 The SSHAC recommended that a Level 3 or a Level 4 assessment process be used for complex assessments, the products of which have high public importance and attract public scrutiny, such as regional seismic hazard models intended to be used over a sustained time period as base-case models for site-specific PSHAs. Such models require the highest level of assurance that the community uncertainty distribution has been properly represented. For this project, the decision was made to use a SSHAC Level 3 assessment process.4 The CEUS SSC Project arrived at this decision based on experience gained with implementations of the SSHAC guidance, which has shown that a properly executed Level 3 assessment process can provide a level of assurance of meeting the SSHAC goals comparable to that of Level 4, which is much more costly to implement. This chapter begins with a discussion of the fundamental SSHAC goal of representing the center, body, and range of the technical community's knowledge, including why this goal was developed. This is followed by a discussion of how the SSHAC Level 3 assessment process has been implemented by the CEUS SSC Project, including the roles of key participants, project organization, key activities, and participation of the Participatory Peer Review Panel (PPRP).	
S 2-2. (CC, SSHAC) *"Capture" and the Informed Technical Community* We caution the TI Team that repeated use of the word "capture"—a highly nuanced term as it relates to the center, body, and range (CBR) of the technical interpretations of the ITC—may confound clear thinking. In its 1997 report, the SSHAC most often uses the words "represent" or "a representation of" for actions relating to "the center, the body, and the range of technical interpretations that the larger informed technical community would have if they were to conduct the study" (SSHAC, p. 21).5 In Chapter 2, the dominant action word used for the CBR is "capture," emphasized, for example, by the headings for sections 2.1.2 and 2.1.2.2. Coppersmith et al. (2010)6 use "capture" (at least 17 times) in the context not only of the CBR but variously in terms of capturing uncertainty, capturing insights, capturing the community distribution, capturing rate of occurrence and randomness, and so on. The problem with *capturing* the CBR of technical interpretations of the ITC, as opposed to	Capture replaced by represent, although both terms are used interchangeably in the SSHAC report. One downside to the use of "represent" is the mistaken notion that the TI Team merely attempts to reflect or mirror the views of the community (i.e., a poll), in the same way that a politician represents his constituency. The "informed" aspect of the definition of the ITC is important, was defined specifically in SSHAC, and is emphasized in the text. All of the discussion of these issues has been made consistent with NRC (2011), which will be issued in the near future.

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representing them, is that it invites critical scrutiny of what may have been left out, not fully preparing the reader for the need to understand important concepts dispersed elsewhere in the report—notably, identification and due consideration of alternative views, allowance not to include views judged to have an insignificant effect on the hazard, and the *integration* function performed by the TI Team in its role of assessing and representing the CBR of the ITC.	
S 2-3. (CC) *Claim that CEUS SSC Robustly Implemented SSHAC Guidance* On p. 2-1, par. 2, the text states: "These sources, as well as projects conducted prior to the development of SSHAC guidance, offer confirmation that the CEUS SSC process was a robust implementation of both the "spirit" and the "letter" of the law, namely SSHAC." It is illogical to say that prior sources "confirm" a later "robust implementation." And it is misleading to refer to SSHAC guidelines as "the law." The astute reader will compare the claim made in this introductory part of Chapter 2, with the conclusion eventually reached in section 2.1.2.3 (p. 2-23), where one finds wording such as "addressed adequately," "preponderance of evidence," and "reasonable assurance." Suggestion: "These sources, as well as projects conducted prior to the development of SSHAC guidance, provide a basis for concluding that the CEUS SSC assessment process followed in a robust way both the "spirit" and the "letter" of SSHAC guidance. The end result is reasonable assurance that the CEUS SSC final model achieves the primary goal intended by the SSHAC guidelines."	Revisions made to merely state that the SSHAC assessment process, as given in the SSHAC guidelines, was followed.
S 2-5. (CC) *Historical Context and Evolution of Use of Expert Assessment (Section 2.1.1)* The length of this subsection detracts from this chapter. While this section is informative, Sections 2.1.1 through 2.1.2.2 and Table 2-1 could be moved to an appendix, with a short summary provided here. Also, the text (specifically in Section 2.1.2) and Table 2-1 would be improved if the authors provided their thoughts on how well the experts or expert teams did as *evaluators* for those projects that were completed at a SSHAC Study Level 4. It is our impression that results are mixed in this regard. If the authors agree, this should be discussed and noted. In order to completely chronicle the origins of the NRC's probabilistic seismic hazards program, it should be stated that during the mid to late 1970s, the Advisory Committee on Reactor Safeguards (ACRS) persistently urged the NRC to undertake research aimed at quantifying the uncertainty embodied in SSEs derived following the requirements of the seismic regulation 10 CFR Part 100, Appendix A, which had been adopted in 1973. The ACRS also urged the NRC to undertake a parallel program with the aim of quantifying the margin embodied in the NRC's seismic design criteria and procedures. In response, the NRC developed and funded a seismic margins research program and, a short time later, a seismic hazard research program, both conducted by the Lawrence Livermore National Laboratory (LLNL). The seismic hazard research program adopted from the decision analysis community the structure and formalism of classic expert elicitation processes.	The entire section has been removed. A comparable section appears in the NUREG on SSHAC implementation (NRC, 2011), which is a more appropriate venue.
S 2-6. (CC, SSHAC) *"Capturing" the Center, Body, and Range (Section 2.1.2)* Consider changing "Capturing" to "Representing" in the section title. As a lead-in to Section 2.1.2, consider this example text (see also Comment **S 2-4**):	Much of the suggested wording has been added in the text.

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Reasonable assurance is the standard for reaching administrative decisions about public safety across the spectrum of hazards to which the public is exposed. Regulations, regulatory guidance, regulatory review, and administrative hearings all invoke the standard of reasonable assurance. Regulations state the safety requirements, regulatory guides provide guidance for technical methods and procedures that are accepted for demonstrating compliance with applicable regulations, regulatory review provides reasonable assurance that regulatory guidance has been properly implemented, and an administrative hearing determines whether the safety conclusions are supported by preponderance of the evidence developed by the regulatory review process. In this safety decision-making process the SSHAC assessment process is a technical process accepted in the NRC's seismic regulatory guidance for reasonably assuring that uncertainties in data and scientific knowledge (stated by the SSHAC as the center, body, and range of views of the informed scientific community) have been properly represented in seismic design ground motions consistent with the requirements of the seismic regulation 10 CFR Part 100.23.	
S 2-7. (CC) *"Standard of Proof" (Section 2.1.2.1)* Better wording for the title of section 2.1.2.1 would be "The Reasonable Assurance Standard," which is the primary focus of this subsection. The claim made in the fourth sentence of this subsection that, "there is no need for such proof" is out of place (the claim is explained later in the second paragraph). Based on arguments made in our Comment S 2-5, we recommend deletion of the entire first paragraph of this subsection and revision of the remainder. The standard of proof is reasonable assurance, and reasonable assurance is demonstrated by proper implementation of the NRC's regulatory decision-making procedures. In the instance of the CEUS Project reasonable assurance that the CEUS SSC Model represents the center, body, and range of the views (prefer knowledge) of the scientific community is demonstrated by proper implementation of the SSHAC Level 3 assessment process.	The entire section has been removed.
S 2-8. (CBR, SSHAC) *Evidence That CEUS SSC Project Has Captured the Informed Technical Community (Section 2.1.2.2)* Adherence to the SSHAC guidelines is necessary evidence, but it is not sufficient to show that the CBR of the technical community has been represented in the assessment. How can sufficient evidence be obtained? Certainly that is not easy, but sufficiency can be approached by peer review of the report. That is what the review of the draft report by the PPRP, the USGS, and supporting parties is doing. These parties are judging the completeness of the process carried out by the TI Team. The question is, do these reviews achieve the goal of evaluating the results of the process? This will be a subjective appraisal. It would be well for the report to discuss the subjectivity of the evaluation and the role of reviews in the evaluation. This subjectivity is acknowledged in Section 2.1.2.1 [Standard of Proof] in the description of the technical community as a "hypothetical community" and the regulatory use of reasonable assurance. The idea that the technical community is hypothetical is contrary to seismic regulatory principles and practice (see our Comment S 2-5). There is a very real technical community that has developed the evidence and views regarding specific topics that are important to seismic source characterization and assessment in the CEUS. This community does not consider themselves to be hypothetical.	Section has been modified extensively. The remaining section is intended to show that the recommended steps in a SSHAC assessment process (as given in the SSHAC guidelines) have been followed.

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S 2-9. (CC) *PPRP Attendance at the Eight Working Meetings of the TI Team:* The report contains differing statements about the attendance of PPRP observers at the TI Team Working Meetings: "All of the working meetings were observed by one or more members of the PPRP." (p. 2-20) "[The PPRP] participated in many TI Team working meetings to plan and review the process and progress of the project." (p. 2-36) "One to three representatives from the PPRP attended the working meetings in order to observe the deliberation and technical assessment processes." (p. 2-42) For the record, PPRP attendance was as follows: WM # 1 WM # 2 Hinze, Kammerer, Kimball WM # 3 Ake, Petersen WM # 4 WM # 5 WM # 6 Ake, Stepp WM # 7 Ake, Arabasz, Kimball WM # 8 Kammerer	Revisions made to indicate PPRP attendance at seven of the ten working meetings.
Comments by Section ***Chapter 2 (Title)*** In order to emphasize that the CEUS SSC Project implemented an assessment process, were commend the Chapter title be changed to: SSHAC LEVEL 3 ASSESSMENT PROCESS AND IMPLEMENTATION (see Comments **S 1-1** and **S 1-2**). ***Chapter 2 (Introductory Text)*** Spell out PPRP when it is first used in report. ***Section 2.1*** p. 2-2, par. 3, line 3: "the data that applies" (inconsistency: data used as singular here; plural elsewhere in report) ***Section 2.1.1*** par. 1: The text states, "The SSHAC report was written in response to an evolution of expert risk assessment methodologies that had been conducted for purposes of probabilistic risk analyses during the previous three decades." According to the footnote on p. 34, the only identified studies predating the SSHAC report that dealt with **risk** were the WASH-1400 study and the NUREG-1150 study; all the other studies dealt with **hazard**. ***Section 2.1.1.1*** p. 2-5, par. 3, line 1: Change "The EPRI-SOG study" to "In the EPRI-SOG Project" p. 2-7, next-to-last par.: "and offered a prophecy for future guidance:" What exactly is prophesied in the subsequent quoted text? Suggestion: "and future guidance was envisioned" ***Section 2.1.1.2*** p. 2-10, par. 2, line 7: Suggest replacing "third party" with "future user"	All specific comments led to text revisions, except as noted: Sections 2.1.1, 2.1.1.1, 2.1.1.2, 2.1.2, and 2.1.2.1 have been deleted. Comment regarding Sections 2.4.3 and 2.4.4: the workshop summaries are included in the report in Appendix F; the presentations will be made available on the project website after issuance of the final report

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p. 2-11, par. 2, line 3: Suggest replacing “gone up” with “increased” p. 2-11, par. 2, second sentence: There is unclear phrasing in the second half of this critical sentence. The difference between the PEGASOS results and the older results were shown to be due to “an appropriate treatment of the ground motion aleatory variability and an error in the calculations in the previous hazard studies (NAGRA, 2004, Section 8.4.2).” Was the treatment appropriate in the older studies or in PEGASOS? p. 2-11, par. 2, line7: “to discredit the study” — Clarify which study is being referred to. p. 2-11, par. 3, line 11: Change “TI” to “TI Team” p. 2-11, par. 3, line 2: Because ESP and COL appear in the list of Acronyms, consider writing, here at their first mention in the text, “Early Site Permits (ESPs) and Combined Construction and Operating License (COL) applications” p. 2-11, par. 3: The narrative of what happened in the EPRI (2004) Level 3 process is confusing. The text describes that “A small TI Team was responsible for the assessments and a panel of resource experts/proponents provided their views of the existing ground motion models and their applicability to the CEUS.” Subsequent text describes the problem of the experts not taking ownership of the resulting composite model. As written, why would “resource experts/proponents” be expected to take ownership? In the EPRI (2004) Project, the TI Team requested that the Resource Expert Panel endorse the assessed model. The Panel did not challenge the implementation of the assessment process, but persisted in the role of proponent experts, insisting that their proponent model should have more weight. Suggestion: “A lesson learned in the project was that if broad expertise is needed to perform the TI role of representing complex technical views of the informed technical community, then a small TI Team may not suffice. In the case of the EPRI (2004) assessment, the panel of ground-motion experts was not charged with the TI role, but they were asked to review and endorse the assessed ground motion model; individual members of the panel persisted in acting as proponents, advocating higher weighting of their individual proponent models. Subsequent Level 3 . . .” p. 2-11, par. 3, last line: Suggest replacing “claim” with “accept: p. 2-11, last paragraph, line 6: Suggest deleting “developing” p. 2-12, line 1: Typo. Change “significance advances” to “significant advances” ***Section 2.1.2*** par. 1, third sentence: What is meant by “many of the technical issues that drive seismic hazard . . . are rare?” Suggestion: Delete “rare and” ***Section 2.1.2.1*** par. 1: See Comment **S 2-3** regarding the notion of “capturing the informed technical community.” If the authors insist on using “capture,” for clarity at least describe capturing the *views* or *technical interpretations* of the informed technical community— not the jargon of “capturing the informed technical community.” p. 2-17, par. 1, last line: Typo. “have the like highest likelihood” p. 2-17, par. 3: It will be helpful to clarify for the reader that what is “not yet available” is not the article written by Coppersmith et al. (2010) but rather the NUREG document discussed in Coppersmith et al. (2010). Suggestion: “to develop a NUREG-series	

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document (see Coppersmith et al., 2010)." ***Section 2.1.2.2*** In the discussion of Item 3 (Provide a uniform data base to all experts), mention should be made of the development of the seismicity catalog. p. 2-19, par. 2, last sentence: What "will provide a valuable methodology step for future Study Level 3 projects" isn't "these tables" but rather something like "the structure of these tables." On p. 2-19 near the end of the next-to-last paragraph, the reader encounters, for the first time, "the development of the sensitivity SSC model, the preliminary SSC model, and the final SSC model"—terms which aren't explained until the bottom of p. 2-20. These are fundamentally important for the reader to understand. A good place to introduce the reader to these terms would be at the end of Section 1.4.1, explaining that the SSC model was developed in three stages. p. 2-19, last par.: For complete documentation (useful for future readers) give the dates of the maximum magnitude workshop in Golden, Colorado, and the CEUS workshop in Memphis, Tennessee. p. 2-20, Item 5. *Elicit SSC judgments from experts*: The text describes eight working meetings of the TI Team and goes on to state that "Each working meeting was structured around a particular aspect of the project, as follows:"—but **ten** bullets follow, not eight. To compound the problem, a different list of eight bullets later appears on p.2-41 to describe the focus of the eight meetings. On p. 2-37 under the header TI Team, mention is made of **nine** working meetings. ***Section 2.1.2.3*** Where are the conclusions regarding the selection of the study level—an important part of the process? ***Section 2.3*** par. 3: Change "TI Lead" to "TI Team Lead" consistent with the organizational chart in Figure 2.3-1. p. 2-37, par. 2: To soften jargon, consider replacing "Technical Integrator (TI) Team" with "Technical Integration (TI) Team" ***Section 2.4.2*** par. 1, line 9: Text states, "annual frequencies of interest (e.g., 10–4 to 10–7/yr) for nuclear facilities." Executive Summary states 10–4 to 10–6/yr. ***Section 2.4.3*** The text should describe what was done to identify resource experts for Workshop #1 and the approach used to ensure that the experts who participated in the workshop were appropriate and sufficient. ***Sections 2.4.3 and 2.4.4*** It would be helpful to have more references to the workshop information in the appendices, particularly the workshop summaries and the presentations. ***Section 2.4.4*** The text should describe what was done to identify proponent experts for Workshop #2 and the approach used to ensure that the experts who participated in the workshop were	

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appropriate and sufficient. ***DRAFT*** Installment 2, PPRP Review Comments, page 2-11 ***Section 2.4.8*** A short summary of the purpose of the Data Summary and Data Evaluation tables and the use that was made of them would be informative here. ***Section 2.4.9.1*** The HID is a valuable document. It would be useful here to expand on its purpose and to note specifically that this document is meant for the analyst—providing clarity about the model to be implemented and obviating the need to distill the model from the full report. This document helps assure that implementation of the model (which is sometimes challenging) is as intended. ***Section 2.4.9.2*** First sentence: This sentence appears to be the objective of the report. Suggest that it be moved forward or reappear in an appropriate place in Chapter 1. ***Table 2-2*** Under “Other Technical Experts . . .” there are duplicate entries for Al-Shukri and Mueller To avoid confusion about the listing of names in this table, delete “Other” in “Other Technical Experts” because some of the experts are also listed in the first two categories of the table.	
CHAPTER 3 — EARTHQUAKE CATALOG	
General Comments **G 3-1. (NAR)** This chapter summarizes the project approach to developing the earthquake catalog for use in the CEUS seismic source model. The process followed in this project is similar to many others in that it consists of three basic elements: (1) assembly of available, relevant sources of earthquake data into a single, magnitude-consistent earthquake catalog; (2) identification of dependent events; and (3) evaluation of catalog completeness.	No response required.
G 3-2. (NAR) Chapter 3 is arranged logically as it describes the goals for earthquake catalog development (Section 3.1), the compilation of available data from continental and regional scale catalogs as well as special studies (Section 3.2), development of various relationships to convert all earthquake size estimates to moment magnitude (Section 3.3), catalog declustering (Section 3.4), and catalog completeness (Section 3.5).	No response required.
G 3-3. (NAR) It is appropriate to emphasize that, the comments below notwithstanding, the catalog that has been developed for this project represents a major achievement and is a real step forward for the entire seismic hazard community. It is a major improvement over previous catalogs in that it incorporates more regional catalogs and has developed moment magnitude estimates for all the earthquakes. The efforts of the TI Team, together those of collaborators from the USGS and the Geological Survey of Canada (GSC), are to be commended. The detailed and thorough approach followed has led to a product that will be widely used. The TI Team, USGS, and GSC staff should consider producing something in the open literature that documents this work. The development of a specific catalog for non-tectonic events in this region may not seem like an interesting product,	Listing of non-tectonic events included in Appendix B

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but for practitioners in this field it will be very useful (especially if it is maintained over time). Having said the above, in order to achieve a clear and complete description of the efforts that went into developing the catalog and of the results, Chapter 3 needs to be improved, as we proceed to explain.	
G 3-4. (CC) The text and explanation of figures in Section 3.3 are too terse. The knowledgeable practitioner may be able to "read between the lines" or infer the meaning of unexplained dashed and dotted lines on many of the figures, but the documentation for this project report must be clear and complete for all readers.	Section 3.3 greatly expanded
G 3-5. (CC) This chapter would be enhanced by a description of the problems associated with obtaining useful focal depths in the region, limitations on focal-depth resolution, and general observations or conclusions regarding the depth of earthquake foci in the CEUS.	Section on focal depth data added
Specific Comments **S 3-1. (CC)** *Non-PPRP Review Comments* Section 3.1 documents the emphasis placed on the earthquake catalog as it provides the basic earthquake rate information that "drives" the seismic hazard model for most of the CEUS. This section describes the process of compiling the relevant catalogs and data sources and summarizes the rationale for returning to the basic data sources for magnitude or intensity data. A brief synopsis on review of the catalog by other interested and experienced seismologists is contained in Section 3.1.3. However, no mention is made of any results, comments, or changes due to those reviews (hence uncertainty whether suggested changes were implemented in the final catalog). Will those review comments (particularly those of the USGS) be part of the project documentation in any form? They do not appear as an Appendix. Will they be documented in project files in a form that could be retrieved by interested individuals?	Section 3.1.3 added to describe main review comments and actions taken as a result
S 3-2. (CC) *Clarity and Completeness in Figures* The meaning of different line symbols is incompletely explained on several of the magnitude conversion figures. On Figures 3.3.1-1 and 3.3.1-2, the addition of an added point to extend the regression to lower values needs more explanation and justification. On Figure 3.3.4-1, the labeling in the *Explanation* of "CEUS dependent catalog" makes the content on the figure ambiguous. The text on p. 3-11 states that "the catalog of earthquakes" is shown on the figure—but two sentences later, the text states, "Therefore, dependent earthquakes (foreshocks and aftershocks) must be identified . . . ." So "dependent catalog" can be read as the catalog of dependent events.	Text greatly expanded in Section 3.3 to clarify figures.
S 3-3. (CC) *Corrected Moment Magnitudes from Atkinson* Section 3.3 provides the summary of the development of the various conversions of earthquake size measures (instrumental magnitude or macro-seismic observations) to moment magnitude. This step is essential to ensure consistent earthquake counts and compatibility with modern ground motion prediction equations. Section 3.3.1.1 describes the first of the specific instrumentally determined moment magnitude studies utilized (Atkinson, 2004). To make it clear to the reader how the conversion was carried out, additional detail should be added to 3.3.1.1. This additional discussion will ensure that the other 3.3.1.x sections are clear. For instance, for events that are used from Atkinson's study, our understanding is that her estimated **M** values are "corrected" to moment magnitudes consistent with the results of waveform inversion studies for those events. If this is not what was done, considerably more detail must be supplied as the correction process is not clear to the PPRP.	Additional discussion added to explain process

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S 3-4. (CC) *Approximate vs. Instrumentally Determined Moment Magnitudes* In Section 3.3.1, second paragraph, the text notes that some "moment magnitude estimates were obtained from three studies that determined **M** by approximate methods . . . ." As part of the project documentation, it would be helpful to identify these earthquakes in a table (presumably, the number involved is manageable). Also, to aid future users of the catalog, and for transparency, instrumentally determined moment magnitudes in the Earthquake Catalog should be flagged—ideally in Appendix B, or in files available to interested parties.	Listing of approximate moment magnitudes added to Appendix B
S 3-5. (DMM, U, CBR, CC) *Sensitivity of Recurrence or Hazard to Choice of Declustering Method* Section 3.4 provides a discussion of the approach used to perform declustering of the magnitude-corrected earthquake catalog. Because the PSHA formulation used for area source zones relies on the assumption of earthquake occurrences following a Poisson process, it is necessary to identify any dependent events in the catalog and remove them prior to performing any rate calculations. A number of different approaches have been used in the past to perform declustering analyses in major seismic hazard studies. The work of Gardner and Knopoff (1974), Reasenberg (1984), and Reasenberg and Jones (1989) have been widely used. The Gardner and Knopoff technique, as well as similar region-specific methods (Urhammer, 1986; Gruenthal, 1985), rely on removing events within fixed magnitude-dependent time and distance windows about a "main" earthquake. The method developed by Reasenberg defines variable space-time windows for individual event clusters using statistical tests and related to a particular model of aftershock occurrence. In contrast, the approach that has been used in the CEUS-SSC study is a stochastic approach developed in the mid-1980s as part of the EPRI-SOG Project. Section 4.3 cites EPRI (1988) as the source document for this approach to declustering, this reference is missing from the reference list (see note on EPRI references below). The EPRI approach begins by treating each earthquake as a main event and then evaluates the rate of earthquake occurrences within a "local window" about the main event and compares that rate to that within an "extended window," i.e., one larger in space-time dimension. If the rate of earthquakes within the local window is significantly higher (based on an un-specified statistical test) than within the extended window, then smaller events are removed within the local window until the rate approaches the extended window ("background") rate. However, in regions of low seismic activity, stable estimates of rate in the larger window can be problematic and hence lead to bias due to the unwarranted removal of events. The PPRP has several specific concerns related to the approach taken to declustering of the catalog used in the CEUS SSC Project: 1. The lack of clear documentation. The discussion of declustering in Section 3.4 is less than one page long. The discussion and development of the EPRI declustering algorithm contained in EPRI (1986, Vol. 1, Pt. 2, Sections 3 and 4) runs to more than 20 pages and is not trivial to follow. EPRI (1988) contains a thorough discussion of the various declustering approaches and the assumptions associated with each. The EPRI declustering method was designed to minimize the number of assumptions required about the clustering process. The description of the adopted declustering methodology in Chapter 3 needs to be significantly expanded. 2. Given that the declustering fundamentally alters the number of earthquakes in the catalog for calculations of recurrence—and thus hazard, more discussion is warranted	1. Explanation of declustering method expanded 2. The effect of the declustering method is examined by including a comparison with results obtained by Gardner Knopoff as implemented by USGS. Differences are small. 3.More discussion added to declustering section 4. That is correct, there is variability in cluster length as a function of magnitude. The "classical" methods ignore this effect while the EPRi approach recognizes it 5. There are assessments/conjectures in the literature for very long aftershock sequences for earthquakes in the CEUS in the literature, but these do not enjoy widespread support in the technical community. The comparisons shown in the revised report indicate similar results to the Gardner-Knopoff approach

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about associated uncertainty. What are the implications if a different method were used (e.g., the Gardner and Knopoff method, which reportedly produces 15 percent fewer dependent events and thus more main events)? In the case of the EPRI-vs.-Gardner and Knopoff comparison, were smaller magnitude bins systematically more affected? This issue of uncertainty associated with declustering methodology could be addressed in one of two ways: (1) sensitivity studies displaying the impact that this assumption has on recurrence relationships or hazard results, or (2) explicit consideration of alternative declustering models each with an appropriate weight. If sensitivity calculations aren't explicitly made, can experience from other PSHAs be used to amplify on uncertainties associated with the choice of the declustering method? Also, because any declustering algorithm is sensitive to the choice of declustering parameters used, some discussion is warranted about the efforts made in the earlier EPRI Project to determine suitable parameters for the CEUS. 3. EPRI (1988) is in the open literature. However, it is difficult to obtain, not widely used outside a small number of individuals, and in the view of the PPRP, not uniquely representative of the CBR of the ITC. If it is the position of the TI Team that in fact the EPRI declustering approach is superior to all other approaches and the only approach that should be considered, then that needs to be more clearly articulated and documented. In point of fact, the EPRI approach has been used only by a few of the teams in the Yucca Mountain PSHA and in updates to the EPRI-SOG seismic source model used for recent COL/ESP applications. The seismic source characterization teams in the PEGASOS project used either the Gardner and Knopoff approach or variants thereof, or a modified version of the Reasenberg approach. Most other seismic hazard studies for critical facilities in the US have used similar approaches to those in PEGASOS. Alternative approaches to declustering should be examined, documented, and if warranted considered for inclusion in the present study to satisfy the goal of capturing the CBR of the ITC. 4. Figure 3.4-1 displays the results using the EPRI (1988) procedure, showing dependent event time and distance windows for events down to about **M*** = 2.5. Are these considered large events? Note: definition of main, large, and independent earthquakes needs to be clearly articulated in this section. If the PPRP is interpreting these figures properly the estimated time windows for many individual small (**M*** < 4) events are significantly longer than time windows for many individual larger (**M*** from 5.5 to 6) events. For **M*** just below 5, the time window ranges from 4 days to about 6.5 years. The PPRP questions if that range would be endorsed by the broader community of observational seismologists. Based on the information provided, it is not clear whether these outcomes are unique to the model selected, and whether the model properly models the uncertainty associated with identifying dependent events.	
S 3-6. (DMM, CC, U) *Catalog Completeness* Section 3.5 describes the approach used to assure catalog completeness in the CEUS SSC Project. The methodology used for catalog completeness is that developed in the EPRI-SOG Project and works with the uniform magnitude, **M***. The EPRI approach defines spatially discrete zones that have uniform levels of magnitude completeness and defines magnitude specific probabilities of detection (PD) in each. For the CEUS SSC Project, the TI Team augmented the completeness regions used in the earlier EPRI study slightly to address additional catalog information and to properly cover the current study region.	Additional description of the completeness approach is provided. Discussion of the alternative approaches is included

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Many of the same comments made regarding Section 3.4 can be made regarding Section 3.5. The lack of detail and clarity make a proper evaluation of this section virtually impossible. The sole reliance on reference to the EPRI documents as the technical basis fails to meet the standard of documentation required in a study of this scope. It is not discussed in this section, but the probability of detection thresholds defined and shown in Table 3.5-1 were derived by simultaneously maximizing the log likelihood functions for PD as well as the "a" and "b" values in the earlier EPRI approach. Based on our reading of Section 5 it is not clear if the same approach was used in the current study. As with the discussion of declustering, there are alternative methods for performing completeness assessments in the literature and those should at least be discussed and evaluated. The PD and equivalent time period of completeness methodology used is quite powerful as it maximizes the number of events used from the declustered catalog. However, it needs to be more completely described and evaluated against alternative methodologies if it is to be the sole approach used.	
Comments by Section ***Entire Chapter*** The word "study" should be replaced with "project" throughout the chapter where used in as part of the designation of an integrated assessment project; e.g., "EPRI-SOG Project", "this project", and so on. ***Section 3.1*** Suggestion: The reader would find a summary preceding this to be helpful. ***Sections 3.1.1 through 3.2.2*** Numerous acronyms are unexplained and do not appear in the list of acronyms. These include: SUSN, NEIC, PDE (p. 3-1), ISC, ANSS (p. 3-3), CERI (p. 3-4), NEDB (p. 3-5) ***Section 3.1.1*** p. 3-1, par. 2, line 1: Change "CGS" to "GSC" ***Section 3.1.3*** line 3: Typo. "Therefore, and an important part of the catalog development process was review by seismologist seismologists with extensive knowledge . . ." line 7: Affiliation for Martin Chapman as "Virginia Technological University" is incorrect. The school is called either Virginia Tech or Virginia Polytechnic Institute and State University (see http://www.vt.edu/). ***Section 3.2*** p. 3-3, 1st paragraph: It would be helpful to give an example of the numbering scheme as it is not entirely obvious how the scheme will appear in the summary catalog. ***Section 3.2.1*** p. 3-3, 1st paragraph, line 3: Typo. Change "and primary earthquake listing" to "and the primary earthquake listing") p. 3-3, 2nd paragraph: EPRI (1988) reference is missing. (Please see comment on EPRI references below.) ***Section 3.2.3*** p. 3-4, 1st paragraph: Typo in line 3? ("locations and/or depths"?); in line 6, change "Boatwrigth" to "Boatwright" p. 3-4, 2nd paragraph: Typos. Change "catalog" to "catalogs"; "are area" to "an area"); "The second is" to "the second was" (for consistency with tense in preceding sentence). ***Section 3.2.4*** p. 3-4, 3rd line: Reference to Section 3.2.4 should be to 3.2.3	Correction made 3.1 Brief summary added at beginning of chapter 3.1.1-3.2.2 Acronyms explained as introduced CGS fixed Fixed Numbering scheme explained Section rewritten Fixed Scheme explained.

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Section 3.2.5 The scheme for assigning order of preference to events located south of the US-Canada border is not clear. We assume that all the regional networks have equal weight and events located near New Madrid would default to CERI or St Louis University, and if in New Jersey would default to Lamont Doherty. If not, this needs to be made clearer. ***Section 3.3.1.1*** line 5: Typo. Change “over estimates” to “overestimates” ***Section 3.3.1.3*** Typos. In line 2, change “an coda wave technique” to “a coda wave technique”); in line 4, change “abet” to “albeit” ***Section 3.3.2.1*** Define fN, and FN ***Section 3.3.2.2*** 5th line and equation 3.3.2-3: Missing word and typo. “The Johnston (1996) relationship is reasonably consistent with the project data. Also, is Equation 3.3.2-3 the Johnston (1996) relationship, and is that what was actually used? Not clear as written. ***Sections 3.3.3.1 and 3.3.3.2*** Unclear whether the locally-weighted least-squares fit or a constant offset model was used in the conversions between MN and mbLg to moment magnitude **M**, as shown on Figures 3.3.3-1 and 3.3.3-2. ***Section 3.3.3.2*** Add a sentence after the equation indicating the variables ZCAN and Z1995 are as defined in Section 3.3.3.1. ***Section 3.3.3.3*** Suggestion: “The A third mb body-wave magnitude scale (mb) is also more commonly used in the US than in Canada . . . .” Also note that mbLg is used in this section when it should be mb. Perhaps add a reference for robust regression. ***Section 3.3.3.5*** Typo in first sentence. Should be surface-wave magnitude (MS) not “local magnitude ML”; the same error is in equation 3.3.3-5. ***Section 3.3.3.8*** The discussion of unknown magnitude (MU) is not clear. For any given earthquake, how was the decision made as to which conversion should be used? ***Section 3.3.4*** p. 3-10, line 3: Typo. Change “Section s” to “Sections” p. 3-10: Following equation 3.3.4-1, the reference to σE[M|X] should perhaps indicate this is illustrated by the confidence interval for the mean shown on Figures 3.3.1-1, 2, 3 etc. for example. We suggest that equations 3.3.4-2 and 3.3..4-3 be double checked as comparison with equations 3-8 and 3-9 in Vol.1. Pt.2 of the EPRI-SOG report indicates some discrepancies. Since the corrected magnitudes are ultimately used to derive the “b-value” one may wish to comment on the sensitivity (or hopefully lack thereof) to the “b-value” used in equation 3.3.4- 3. In equation 3.3.4-4 the σ2 M|M instrumental is not clear. Is it the 0.1 value assigned to the instrumentally determined values referenced in the paragraph above equation 3.3.4-1? p. 3-10, last paragraph: The text states, “As discussed in EPRI (1988) uncertainty in the magnitude estimates and its propagation through the magnitude conversion process introduces a bias in the estimated earthquake recurrence rates.” It would be helpful to the general reader to add some explanatory detail, rather than placing the burden on the reader seek another publication to understand the purpose or basis of the information that	Section 3.3 rewritten to address comments and add additional clarification

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follows. ***Section 3.4*** p. 3-11, par.1,line 6: The text states, "The standard method of creating a catalog of independent earthquakes developed by Gardner and Knopoff . . . ." It is misleading to describe the Gardner and Knopoff procedure as "the standard method." Researchers in earthquake statistics outside the U.S. would likely use Ogata's well-established epidemic-type aftershock sequence (ETAS) model as the basis for declustering. p. 3-11, par. 1, next-to-last sentence: In the report, "large" earthquakes are defined as **M** ≥ 6.5, so it is confusing to write "and distance interval about a large earthquake." Suggestion: "and distance interval about a relatively large earthquake." p. 3-11, par. 1, last sentence: The text states, "If the rate of earthquakes is significantly higher than the background rate . . . , then earthquakes are removed until the rate becomes consistent with the background rate." Does this mean that a few earthquakes that would clearly be declared as aftershocks, say by Gardner and Knopoff, remain in the final catalog in order to match the background rate? In other words, is the declustered catalog not strictly a catalog of main shocks? p. 3-11, par. 2, second sentence: For clarity (because Figure 3.4-1 contains two plots), consider writing, "The data points in the two plots represent the length in days of individual clusters and the maximum distance between earthquakes assigned to a cluster, respectively." p. 3-11, par. 3, first sentence: Typo. Change "European earthquake" to "European earthquakes" p. 3-11, par. 3, last sentence: The narrative describing that the EPRI procedure identifies about 15 percent more dependent events may confuse readers examining Figure 3.4-1. For clarity, consider cautioning the reader not to confuse numbers of dependent events with the number of data points for dependent-event parameters associated with individual clusters on Figure 3.4-1.	Section rewritten 3.4 to better explain the EPRI method and address comments
Section 3.5 First sentence: Typo. Change "EPRI SOG" to "EPRI-SOG" p. 3-12, par. 2, line 6: Could not find Figure 8-1 in Report; what is the basis for the boundaries of the completeness regions? For example, how were the boundaries of Region 15 defined, which is one of the new regions? Is there a rationale for including both the Gulf of Mexico and Florida offshore in the same completeness region? p. 3-12, 4th paragraph: The terms PENB, PENA and WEDT are not defined. p. 3-12; 6th par., line 2: The text states, "in the time period 1995 to 2008" but in Table 3.5-1 the limiting year is 2009.	Section 3.5 rewritten to address comments and add greater explanation
Figures Labeling of page numbers on pp. 3-31, 3-32, and 3-33 needs to be corrected. ***Figures 3.3.1-1 through 3.3.1-3*** Add more detail to the figure captions, and indicate the 1:1 line and the 90% confidence interval for the mean. Typo in Figure 3.3.1-2: (1994) not (19944). ***Figure 3.3.2-1*** Lots of lines on the figure with no explanation in the figure caption. What exactly is approximate **M** in this figure? ***Figure 3.3.4-1*** Is the map of epicenters south of Florida complete to the shown boundary of the study region? If not, explain justification for neglecting these. Was the Caribbean seismicity catalog accessed to determine earthquakes in the study region?	Figures for section 3.3 have been redone Caribbean seismicity not included
Figure 3.4-1	

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The text should comment on the very large disparity in cluster duration and spatial dimension for similar magnitudes. Virtually all readers will be left with distrust of the methodology based on these results, absent any additional discussion.	
References EPRI (1988) is missing from reference list. EPRI reports need to be properly referenced (see next page). **This is how the EPRI reports are referenced in the CEUS/SSC report:** Electric Power Research Institute (EPRI), 1986, Seismic Hazard Methodology for the Central and Eastern United States: Volume 1, Part 2, Methodology (Revision 1): Final Report, EPRI-NP-4726-A-1(1). Electric Power Research Institute (EPRI), 1989, *Probabilistic Seismic Hazard Evaluations at Nuclear Power Plant Sites in the Central and Eastern United States: Resolution of the Charleston Earthquake Issue*: EPRI Technical Report EPRI NP-6935-D. **The references below are how the EPRI Project documents are referenced in the PEGASOS report.** EPRI-SOG 1986: Seismic Hazard Methodology for the Central and Eastern United States, Electric Power Research Institute NP-4726A, Volumes 1-11. EPRI 1989: Probabilistic Seismic Hazard Evaluations at Nuclear Power Plant Sites in the Central and Eastern United States, Electric Power Research Institute NP-4726, 9 v. **The PPRP suggests the proper reference is the following**: EPRI-SOG 1988: Seismic Hazard Methodology for the Central and Eastern United States, Electric Power Research Institute NP-4726A, Revision 1, Volumes 1-11. The EPRI-SOG Project was completed and submitted as "EPRI NP-4726" in 10 volumes to the NRC for review as a topical report. The review was completed in 1988. The report number designation "4726-A, Revision 1" identifies that the report has been revised in response to NRC's review and that it is accepted by NRC for future use for licensing submittals and contains the NRC's Review Report and Acceptance Letter. Volume 11 is the NRC's requests for additional information and EPRI's responses. The above noted inconsistency is indicative of the problem with just broadly referencing the EPRI documents within this chapter of the report and the attendant issues with transparency and availability. The PPRP has two systemic recommendations regarding utilization of methods from the EPRI-SOG Project and citations. First, be much more specific when referencing the EPRI studies (i.e. volume, section etc.). Second, the TI Team should strongly consider reproducing and expanding the discussions and developments in the EPRI-SOG report in the CEUS-SSC report. This will enhance clarity and transparency and facilitate utilization of some of the methods by the broader community.	EPRI reference fixed to 1988
Other references either missing from Chapter 3 and/or that probably should have been cited Gardener, J.K. & Knopoff, L. 1974: Is the sequence of earthquakes in Southern California, with aftershocks removed, Poissonian? Bull. Seism. Soc. Am. 64, 1363-1367. Grünthal, G. 1985: The up-dated earthquake catalogue for the German Democratic Republic and adjacent areas – statistical data characteristics and conclusions for hazard assessment. *In:* Proceedings 3rd International Symposium on the Analysis of Seismicity and Seismic Risk, Czech. Ac. Sc., Prague, 19-25. Reasenberg, P.A. 1985: Second-order moment of central California seismicity. J. Geophys. Res. 90, 5479-5495. Reasenberg, P., and L. M. Jones (1989), Earthquake hazard after a mainshock in California, *Science* **243,** 1173–1176.	Additional references cited as appropriate

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Stepp, J.C. 1972: Analysis of completeness of the earthquake sample in the Puget Sound area and its effect on statistical estimates of earthquake hazard. Proceedings of the International Conference on Microzonation 2, 897-910.	
CHAPTER 4—CONCEPTUAL SSC FRAMEWORK	
General Comments **G 4-1. (CBR, CC)** Chapter 4 describes the Conceptual SSC framework. This chapter is generally well-written, organized in a logical format, and responsive to early PPRP recommendations for creating a structured systematic approach to SSC, including the establishment of criteria for defining seismic sources. However, it is incumbent on the TI Team to document how these criteria were used to define seismic source zones. While the PPRP appreciates the role that informed judgment has on assessing weights for various branches of the logic tree, these weights must have a documented basis. In response to the PPRP April 7, 2010 letter, the TI agreed that project documentation must provide a detailed (emphasis added) discussion of the criteria that were used to identify seismic sources and a justification for all logic tree branches and weights.	To aid in the description of the criteria for identifying seismic sources, Table 4.1.3-1 has been added. Also, text has been added in Section 4.1.3 stating where the detailed descriptions are given of the technical bases for identifying each source (in Chapters 6 and 7). Also, each discussion of alternatives in the logic tree and their associated weights has been reviewed to ensure that it provides ample detail for the reader to understand the technical bases for the branches and weights of the logic tree.
G 4-2. (NAR) The development of Data Evaluation and Data Summary Tables has been extremely important with respect to making the seismic source characterization process more transparent and complete (see detailed comments on these tables). These types of tables represent a foundation upon which future SSC seismic hazard evaluations can be efficiently built. This is particularly true for seismic source characterization projects that have a broad regional extend. The TI Team is to be commended for taking the time to create these tables. The tables include an unprecedented level of information that external reviewers can use to understand the assessments that have been made and represented in the logic trees. An important point that was developed in Section 4.2.2 was that the Data Summary and Evaluation Tables are not intended to replace the documentation of the SSC effort but to supplement it.	No revisions necessary.
Specific Comments **S 4-1. (CC)** *Terminology* The nuanced words “study,” “capture,” and “event” are used throughout Chapter 4, contributing to a lack of clarity. We recommend replacing with words that convey the specific contextual meaning: that is, replacing “study” with “project” or “assessment” as appropriate; “capture” with “represent” as appropriate; and “event” with “earthquake” as appropriate.	Revisions made to text, as appropriate.
S 4-2. (CBR) *Master Logic Tree and Representing the Community Distribution* The assessment of a conceptual tectonic framework is ultimately represented in the master logic tree as the weights applied to branches of this logic tree (major alternatives related to the overall tectonic framework). Interactions with the broad scientific community in Workshops #1 and #2, and the scientific knowledge base developed through these interactions, informed: (a) the TI Team’s assessments for the conceptual tectonic framework, (b) the TI Team’s evaluations of the hazard significance of various seismic source characterization issues (Section 4.3.2), and (c) development of criteria for defining seismic sources (Section 4.3.3). For assessment of SSC models of this regional extent, it is now clear to the PPRP that it	Evidence that the data evaluation process developed for this project and the methodology for identifying seismic sources can result in a full SSC model is the CEUS SSC model itself. Linkages are made (or enhanced) between the use of the data tables to assist in the evaluation and integration process, as well as the linkage between the seismic source criteria and their application for the sources identified in the assessment. The PPRP is the fundamental group in a SSHAC assessment process to provide feedback on all technical and process issues, including whether or not the conceptual SSC framework advanced in this project is reasonable. Importantly, the SSC process is a hazard-related activity and, in addition to the PPRP, the TI Team received

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could have been useful to have additional feedback of the conclusions discussed in Section 4.3.2 and the criteria discussed in Section 4.3.3 to enhance confidence that this information can be used (i.e., appropriately represents the CBR of the ITC) to create a detailed SSC logic tree. From a generic perspective, this should be considered a lesson learned, recommended for Level 3 assessment projects of broad regional extent, to directly link the overall development of the seismic source assessment logic tree with a broader segment of the ITC. The TI Team is strongly encouraged to consider whether additional feedback with a targeted group of subject experts is warranted.	valuable input from the USGS regarding potentially applicable data and approaches to identifying seismic sources.
S 4-3. (SSHAC) *Level 3 Assessment Process* In the first paragraph of Chapter 4, the text states that the justification for the use of a SSHAC Level 3 assessment process is given in the CEUS SSC Project Plan. While the project plan did discuss the selection of the assessment level, this project report must demonstrate that execution of this assessment level is appropriate, resulting in a high quality product consistent with the requirements for seismic regulatory decision-making. We suggest that this sentence be deleted.	Sentence has been deleted, as suggested.
S 4-4. (CBR, CC) ***"Generic" Data Evaluation (Section 4.2.1)*** The development of Table 4-3 and the discussion of this table are beneficial to this report. The text would be strengthened if at the end of this section the TI Team discussed how they developed the numbers in the table. Specifically past PSHA experience, results from Workshop #2, and discussions with a wide range of people who are part of the ITC were all used to make these assessments (See Comment S 4-2). Finally, there should be discussion of how the numbers were or were not used to guide the weights ultimately assigned on the logic tress.	Additional discussion added to clarify the dual purposes of data identification and evaluation. The generic table is described more fully and its role of helping to document the identification of data based on potential indicators of seismic sources. The bases for the weights are discussed and they provide a basis for documenting the current thinking regarding the relative importance of potential indicators and the relative usefulness of various types of data to address the indicators. They also provided a means of prioritizing the data compilation efforts toward those data that have the highest potential usefulness in the SSC process. They are not used in any quantitative sense, nor do they have a direct relationship to the weights given in the logic trees.
S 4-5. (CC) ***Logic-Tree Branches and "Credible" Alternatives (Section 4.1.1.1)*** In Comment S 1-2, caution was raised about the use of particular wording that may lead to confusion or invite argument. We offer a similar caution here about declaring that only "credible" alternatives are included in the logic tree. Having to defend the assertion of zero credibility in the case of excluded alternatives can become a red herring. The nature of the TI Team's assessment of a representation of the views of the ITC is explained at great length in Chapter 2. Allowance is made for excluding an alternative view or parameter based on the judgment that its relative weighting would lead to an insignificant effect on the hazard. When discrete probability distributions are used to represent the center, body, and range of a continuous distribution, it is recognized that the distributions have tails of low-to-zero probability. Instead of having to assess exactly where the zero bounds are, acceptable practice allows representing the significant mass of the distribution. We recommend removing "credible" from the section title.	"Credible" is not used in the section title. The term "non-credible" is replaced by "alternatives that are not technically defensible." The discussion of the exclusion of non-credible branches of the logic tree is motivated by problems that have emerged in PSHA projects where it was felt that including very low-weighted alternatives would provide a means of handling outlier and controversial models and parameter values. In one such project, the total number of end branches exceeded 10^{27}, thus leading to excessive run times for calculations (~one month) and limited sensitivity analyses. Analysis of the hazard significance of the branches allowed for the vast majority of them to be "pruned" or "pinched" based on a lack of hazard significance. It is felt that, rather than trim branches after the fact, making an attempt to eliminate non-credible alternatives could lead to similar reductions in scale during the development of the trees.
S 4-6. (CC) *Methodology for Identifying Seismic Sources (Section 4.3)* This section would be improved if there were a discussion how Workshop #2 was used to guide the TI Team in terms of developing a methodology for identifying seismic sources.	Text added to explain usefulness of WS2 to source identification process.
S 4-7. (CC, SSHAC) *Hazard-Informed Approach: Section 4.3.1* In the last paragraph on page 4-10, the following statement is very confusing, seemingly in conflict with SSHAC guidance, and likely to create controversy: "Rather, it reminds us that the purpose of the CEUS SSC Project is to develop a seismic	The point of the sentences is to indicate that the SSC process is part of a hazard analysis and is not a mechanism for answering research questions. First sentence was modified and second sentence deleted.

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source model to be used in a seismic hazard analysis, and not to attempt to answer or even capture the larger technical community's questions about SCR earthquake causative mechanisms. The exceptions are those cases where a hypothesis might have profound implications on the geometry, Mmax, or recurrence for a seismic source such that it would affect the hazard results." Perhaps the intent is to convey the fact that the CEUS SSC Project is an assessment based on existing knowledge rather than an attempt of advance knowledge or resolve competing arguments. The two sentences could be removed without loss of continuity. In any case, some clarification is essential.	
S 4-8. (CC) *Criteria for Defining Seismic Sources (Section 4.3.3)* It would be appropriate and helpful here to note that geological and geophysical studies of the crust since the 1980s have provided little significant new information about tectonic features and the geological history of the region that may have a bearing on evaluation of seismic hazards. The only possible exception is the improved understanding of the Illinois basin extended zone and its features. However, paleoliquefaction studies have been useful in defining and characterizing seismic source zones.	Sentences added as suggested.
S 4-9. (CBR) *Weights on the Two Conceptual Models (Section 4.4.1)* One of the critical logic tree assessments is the weights on the two conceptual models used to represent classes of seismic sources. Section 4.3.3 establishes criteria for assessing seismic sources while Section 4.4.1 provides a description of the logic tree elements. This section does not develop a strong argument for the weights assigned, particularly the strong preference assigned to the seismotectonic zone branch. Additionally, it is not clear where the TI Team demonstrates that the development of seismotectonic zones leads to hazard significant changes in the model. The text states that the development of seismotectonic zones allows for more relevant information on the characteristics of future earthquakes (the third criteria in the sequence defined in section 4.3.3)—but this seems to be a TI Team judgment, as opposed to a documented evaluation and assessment. Section 4.1 (Item #3) makes the point that a methodology for identifying seismic sources that takes into account defensible criteria is a critical attribute of this project, but the project must demonstrate that the TI Team has properly executed these criteria. Perhaps some type of summary table can be prepared to synthesize how the criteria distinguish between seismic sources. The weight assessed for the seismotectonic branch has increased from 0.33 (August 2009, when three branches were considered) to 0.60 (March 2010) to 0.8 (July 2010 and the draft report). The PPRP notes that these weights could be viewed as somewhat counter to the overall ITC trend that has been documented in the USGS National Seismic Hazard Maps (three cycles including regional workshops) and not necessarily a logical outcome from Workshop #2 of this project. At a minimum, the TI Team needs to bolster their arguments for the weights assigned. The PPRP encourages careful consideration of this issue and the potential need for adjusting the weights toward more parity between the two overall SSC models.	Table 4.1.3-1 has been added, along with associated text, to summarize the criteria that have been used to identify each seismic source. Reference is made to hazard sensitivity studies (which will be included in Section 8) that show little sensitivity to the choice of the "seismotectonic zones" or the "Mmax zones" branches of the logic trees. The comment regarding changes to the weights of the alternative models are misleading and irrelevant. As discussed in the report, refinements to all components and weights in the model were encouraged throughout the project and there was no imposed requirement that weights not change or that alternative branches not be added or removed as the model integration process progresses. The weights on the alternative branches for the conceptual approach are, in fact, a judgment made by the TI Team. Similar approaches have been used by the SSC community for various hazard studies, but the weights are not intended to reflect a poll of what others have done. Rather, the important consideration is the ability of each model to incorporate important seismic source information. Additional text has been added explaining the bases for the weights on these alternative models.
S 4-10. (CBR, CC) *Mmax Zones Logic Tree (Section 4.4.1.2)* The discussion of the magnitude weighting provides no explanation or basis for the weights. The same holds true for the approach to spatial distribution of seismicity rates (smoothing). PPRP comments on these weights are provided in Chapter 5. Once these	These assessments are addressed in the applicable sections of Chapter 5 and applicable cross-references are made.

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comments are addressed these discussions should, at a minimum, refer to specific sections in Chapter 5, and be enhanced to summarize the basis as appropriate.	
S 4-11. (DMM) *Table 4-3 (p. 4-41)* Does "(4) Rift Basins" overlap with "(2) Extended Margins"? Does this include basins formed as a result of regional extension in a Highly Extended Terrain such as the Triassic grabens of the EUS? A comprehensive description of continental rift structures is presented by Olsen and Morgan (Continental Rifts: Evolution, Structure, Tectonics, Elsevier, 1995; Chapter 1). Does "(4) Rift Basins" also overlap with "(5) Failed Rift (Paleozoic and younger)" as in the Oklahoma aulacogen? A failed arm of a rift is a branch of a triple junction that did not develop into an ocean basin. A paleorift that has been reactivated by compressional deformation is an aulacogen, e.g., Oklahoma aulacogen. Does (4) include Precambrian continental rifts that were reactivated in later Precambrian time? Why is "(5) Failed Rift" rated lower than (4) if the Failed Rifts are limited to the Phanerozoic? The Oklahoma failed rift (aulacogen) has the Meers fault, while Recent faulting is not observed on Triassic graben faults, to the best of our knowledge.	No doubt many of the items identified "overlap" and should not be considered as mutually exclusive. The goal of Table 4-3 (now Table 4.1.2-3) is to identify potential indicators of seismic sources (all of those shown have been proposed in the community) for the purpose of identifying the types of data that can address them. Thus, fine-scale definitions of each indicator are not necessary for purposes of defining the applicable data.
Comments on Sections ***Chapter 4 (title and introductory text)*** Consider spelling out SSC in the title of chapter. In the first sentence of par. 1, suggested wording change: "for use in future PSHAs." In next-to-last line of par. 1: Typo. "how that the framework" On p. 4-1, last sentence: Consider changing "the master logic tree that is the backbone of the SSC model" to "the master logic tree of the SSC model" ***Section 4.1*** In Item #3, line 1: Consider replacing "that takes into account" with "that is based on"; in line 2, consider replacing "takes advantage of" with "incorporates"; in line 3, "identifies" instead of "captures." ***Section 4.1.1*** To more clearly represent the activities described in this section and in the report as a whole, we recommend changing the title of Section 4.1.1 to "*Logic Tree Approach to Representing Alternatives and Assessing Uncertainties,"* conveying that the alternatives represent the center, body, and range of scientific community's knowledge and that the assessed uncertainties represent the community uncertainty distribution. On page 4-2, last paragraph, line 3: Consider replacing "identifying" with "representing; also in line 10 of the same paragraph. On page 4-3, 1st paragraph, last line: Consider changing "that express the relative credibility of the alternatives" with "that represent an assessment of the relative credibility of the alternatives" On page 4-3, last paragraph, line 7: Consider replacing "those assessments that are judged" with "those assessed alternatives"; see also Comment **S 4-5**). On page 4-4, first full paragraph, line 1: Consider replacing "considered" with "assessed to be"; in line 2, consider replacing "degree of belief" with "assessment"; in line 7, consider replacing "and not worthy of" with "so did not warrant"; in the last line, consider replacing "assigned" with "assessed."	Revisions made to text as suggested except as noted here. Section 4.2 (now Section 4.1.2) has been rewritten for clarity. SCR is defined per Johnston et al. (1994)

PPRP Comment Response Table

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On page 4-4, 2nd full paragraph, line 2: Consider replacing “assigned to” with “assessed for”; in line 6, consider replacing “the TI Team considered the available data” with “the TI Team evaluated the alternatives using available data”; in line 13, consider replacing “the weights assigned to” with “the weights assessed for.” On page 4-4, 2nd full paragraph, line 5: When writing that “there is rarely a quantitative basis for assigning these weights,” it should be made clear that this refers to the assessment of subjective probabilities. The CEUS SSC methodology uses five-point distributions to represent quantified continuous distributions of selected parameters. ***Section 4.2*** On page 4-5, 2nd paragraph, line 1: Consider changing “an attempt was made to provide more structure and transparency” with “more structure and transparency has been provided”; in the next-to-last line, replace “study” with “evaluations and assessments of the TI Team” ***Section 4.2.1*** First paragraph, line 3: Consider replacing “as the technical community evolves its thinking regarding” to “as the knowledge of the technical community evolves regarding” On page 4-5, first bullet, line 7-8: Consider replacing “which is an SCR” with “which geologically is constituted of SCR crust” ***Section 4.2.2*** On page 4-7, last paragraph, 2nd paragraph: The text states that “errors in the data generally exceed the signal” (data referring to geodetic data). It is suggested that this be changed to “errors in the data may exceed the signal.” ***Section 4.3*** First paragraph, line 2: Consider replacing “three decades in SSC” with “three decades in assessing SSCs”; in line 3: consider changing “community” to “scientific community”; in line 4, consider replacing “a regional PSHA that can be applied” with “a regional SSC assessment that can be applied; in line 5: consider replacing “requires that a methodology include” with “requires that the assessment include”; in the last line, consider replacing “across the study region” with “throughout the regional SSC model.” In the last paragraph on p. 4-8, Regulatory Guide 1.208 is mentioned with respect to guidance for commercial reactors. ANS Standards 2.27 and 2.29 provide similar guidance for other nuclear facilities, and this should be recognized. In the first paragraph on p. 4-9, the message conveyed by the first sentence is not clear. Consider replacing the word “intuitive” with “subjective” or “common practice.” ***Section 4.3.1*** The meaning of the first sentence is not clear and it seems to be inconsistent with the content of the paragraph. It could be deleted, as the following sentence seems to properly introduce the content of the paragraph. Add Pa to List of Acronyms. ***Section 4.3.3*** On page 4-14, next-to-last paragraph, line 3: Consider replacing “captured by” with “obtained from”; in the last paragraph, line 7, replace “reasonable assessment” with “reasonable interpretation” On page 4-15, 3rd full paragraph, line 4: Replace “PSHAs” with “seismic hazard models”	

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On page 4-16, first partial paragraph, lines 4-5: Consider replacing "Because the CEUS SSC Project is a regional study and not a site-specific study," with "Because the CEUS SSC Project developed a regional SSC model rather than site-specific one," ***Section 4.4.1*** It would be useful to start this discussion with recognition that RLME sources are identified based on well defined evidence for Late Quaternary or Holocene direct evidence of repeated large magnitude earthquakes. Also when discussing the 8th node of the logic tree, the discussion needs to be enhanced, consistent with the information shown on the logic tree figure. ***Section 4.4.1.1*** On page 4-18, the text refers to Table 4.4.1.1-3, which is not included in the report. Rather it appears to be labeled Table 4-6, which is included in the body of the text of the chapter. We suggest that this numbering be corrected, that the tables be numbered in a consistent manner, and that a List of Tables be included in the report. On page 4-19, 1st paragraph: In the first sentence, make it clear that the issue is "the temporal clustering of large magnitude earthquakes." ***Section 4.4.1.2*** Page 4-20, last paragraph: In the second sentence beginning, "For the CEUS SSC Project . . ." need a connector ("and" or a semi-colon) at the start of the last clause (e.g., "and the prior distributions from that study were reassessed."). On page 4-21, second paragraph, suggest moving up the last sentence "As discussed in Section 6.2…" prior to the sentence that lists the weights assigned to the logic tree branches. Four additional review comments relate to the discussion in the second paragraph on p. 4-21: 1. Two alternative locations of the Mesozoic and younger separation branch are identified: the wide and the narrow. Unfortunately, no map is provided for the location of the narrow zone. Reference is made to Figure 4.4.1.2-3 in line 6, which is presumably this map, but it is missing from the report as well as the List of Figures. 2. Figure 4.4.1.2-2 is labeled as showing the narrow Mesozoic alternative, but instead it shows the wide alternative. 3. Note that the caption of Figure 4.4.1.2-2 is not complete in the List of Figures. All captions in the List of Figures should be checked against those given on the figures. 4. The boundary of the project area shown on Figure 4.4.1.2-2 and subsequent figures of this chapter are not the same as shown in the defining figure of the boundary, Figure 1.3-1, and in Figure 4.4.1.1-2. Apparently the boundary in these figures has been modified to incorporate identified seismic source zones in Canada, which is the northeastern segment of the project area. Inconsistent project area boundaries should be avoided to prevent confusion. ***Section 4.4.1.3*** In the first paragraph, change "shown on Figures 4.4.1.3-2 through 4.4.1.3-7" to "shown on Figures 4.4.1.3-2 through 4.4.1.3-5" ***Tables and Figures*** The order of presentation of text, tables, and figures needs to be standardized in all	

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chapters. In this chapter, the order is different than in preceding chapters. ***Table 4-3*** Page 4-39, last row: Assumed the intended wording is small r recent, not capital R Recent. Perhaps a more definitive and less confusing word could be used—perhaps Phanerozoic? Page 4-42, first row: Suggest replacing "Orientation" with "Fault orientation" Page 4-42, third row: Suggest adding "High-resolution seismic reflection" in third column.	
CHAPTER 5—SSC MODEL: OVERVIEW AND METHODOLOGY	
General Comments **G 5-1. (CC)** Chapter 5 provides an overview of the SSC model and some of the methodologies used within that model. This section is generally well written and provides a good description and summary of a number of the technical elements of the SSC model. The work that the TI Team completed to update the SCR database, performing new statistical analyses, and updating prior distributions is an important contribution to improving assessment of maximum magnitudes. However, some specific elements of the model and/or documentation thereof are problematic in the PPRP'S view. Significant changes or additional justifications may be warranted.	No revisions necessary. Significant changes have been made throughout the chapter.
G 5-2. (CC) In addition to the PPRP review, to ensure thorough review of the many equations contained in the report, the PPRP recommends that all knowledgeable members of the TI Team carefully examine all equations, especially equations in sections that they were not tasked to write.	Reviewed as suggested.
Specific Comments **S 5-1. (DMM, CC)** *Implications of Kafka's Studies for Spatial Smoothing* Section 5.1 provides a well-written overview of the approach to spatial and temporal models of earthquake occurrence in the current CEUS-SSC model. Section 5.1.1 describes the TI team interpretation that the spatial pattern of observed seismicity provides predictive information about the spatial distribution of future moderate-to-large magnitude earthquakes. The PPRP notes that the studies by Kafka (2007, 2009, and Workshop #2) indicate this is generally (emphasis added) the case. Various versions of the cellular seismology results presented by Kafka suggest that much (55–85%), but not all, seismicity is predicted by the spatial occurrence of past earthquakes. This suggests that the report should at least discuss the possibility of specifying a very high level of smoothing within source zones. This is utilization of subjective rather than objectively defined smoothing parameters that would specifically define a seismicity floor in some regions.	Sentences added to Section 5.1.1 indicating that a range of smoothing parameters has been included in the logic tree in order to represent a range of variations in the spatial distribution of future recurrence rates, including an option that leads to relatively uniform rates throughout the seismic source. It is also noted that the penalized maximum likelihood approach used does not require a floor in rate, unlike the kernel approach.
S 5-2. (SSHAC, CC) *Inconsistency With Principles of Seismic Hazard Model Assessment* In Section 5.1.2, par. 3, second sentence, the statement: "The TI Team has taken a very cautious approach, however." conveys a clear violation of the SSHAC guidance principals for seismic hazard model assessment; namely the goal to represent the center, body, and range of the community scientific knowledge. An explanation is required. It would be made clearer if "assumed" were replaced with "used" in the last line of this paragraph (and if the awkward sentence were inverted).	The sentence has been removed. Other sentences modified to indicate that distributed seismic source zones are modeled using exponential distribution of magnitudes and Poissonian recurrence behavior.
S 5-3. (DMM, CC) *Inadequate Description of the Assessment Process* In Section 5.1.2, the last paragraph on p. 5-3 (continuing on p. 5-4) is critically important, as it introduces the reviewer to the TI Team's assessment of temporal clustering,	Revisions made as suggested. Clarification is added to indicated that the TI Team evaluated the data that exists for each RLME and then assessed the appropriate approach to modeling recurrence. Because this section is

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arguably the most uncertain assessment for the CEUS SSC model. For example, the topic is introduced with the weak statement, “consideration was given to” instead of wording such as “assessed,” which links directly to the SSHAC guidance. With similar effect, “considered” is used in line 4, where the word “assessed” would more accurately convey the appropriate action and at the same time connect with the SSHAC guidance. In line 5 continuing on line 6, the physical process would be explained more clearly if the words “based on the concept of” were deleted, leaving the sentence to read: “The physical underpinning of a renewal model is a quasi steady state . . . .” In line 10, it would be clearer to change “concept” to “physical process.” We recommend that this paragraph be rewritten, expanding the discussion to convey the state of scientific knowledge about an earthquake cycle in which strain is released as clustered large earthquakes. The most relevant data appear to be the absence of measurable levels of strain accumulation in the Charleston and New Madrid seismic zones, where the short-term geodetic strain rates are in apparent conflict with interpretations of “in-cluster” rates of occurrence of large earthquakes.	intended to be merely an introduction to key concepts, the reader is referred to the applicable sections regarding RLME recurrence methodology and the specific assessments regarding Charleston and New Madrid RLME recurrence.
S 5-4. (CC) *Weak Support for Conclusion* In the first paragraph of Section 5.1.3, the last two sentences, beginning with “The TI Team reviewed . . .” convey an evaluation and conclusion of the TI Team that is greatly important for the CEUS SSC model assessment. Yet support for the strong conclusion seems general and weak. Consider elaborating on the basis for the conclusion. For example, the last sentence begins with “With a few exceptions . . . .” Describe the data that permitted the exceptions and describe how the data were used in the assessments.	Additional discussion added to indicate that there are no exceptions and the appropriate model given the limited data in the CEUS is recurrence of RLMEs and that of distributed seismicity sources.
S 5-5. (DMM, CBR, CC) *Maximum Earthquake Magnitude Assessment* Section 5.2 describes the methodology for assessing maximum magnitude (Mmax) that was used in the CEUS-SSC Project. The text notes that the maximum magnitude earthquake for any given source zone in regions of low-to-moderate seismicity (such as the CEUS) happens rarely, relative to the period of observation. As a result, the record of historical seismicity provides information, but rarely hard constraints, on the source-specific Mmax value. This fact has led to the investigation of global tectonic analogues to address this issue. The scheme for assessment of Mmax in the CEUS-SSC Project incorporated the uncertainties in both conceptual models and the parameters within models. The approach utilized in the CEUS-SSC Project provides a quantitative and repeatable process for estimating Mmax that is easily updatable if new information becomes available. The discussion of the development of the Bayesian Mmax approach in Section 5.2.1.1 is generally clear and guides the reader through the development of the approach. The PPRP believes that the significant effort invested by the Project in the update and re-investigation of the global SCR database was worthwhile. This refinement represents a significant advancement for the community. However, the PPRP notes there are points that require further clarification and assessments that require additional justification as noted in the following two comments.	No response required.
S 5-6. (DMM, CBR, CC) *USGS Mmax Workshop and Mmax Approaches Considered* In Section 5.2.1, the discussion of the evaluation of alternative approaches to Mmax in the CEUS, lacks any meaningful discussion of the USGS workshop on this topic (Wheeler, 2009), and does not strongly support the TI Team’s selection of Mmax approaches beyond the Bayesian approach. The approach developed by Kijko is not the only viable alternative discussed as part of the USGS workshop. Additionally, the approach developed by Kijko was not given much support in the USGS workshop,	Additional reference made to the Wheeler (2004) to indicate the problems with statistical approaches that rely on large sample sizes. Although the TI Team considered the summary of approaches given in the Wheeler report, the Team was charged with doing more than merely identifying the pros and cons of any given approach. The Team’s conclusion was that there are only two viable approaches: those that rely on analogues and those that use the observed seismicity. The Bayesian approach formalizes the use of analogues, and

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needing additional study before it becomes commonly used in PSHAs. This section should provide more discussion of the USGS Mmax workshop and the Mmax approaches considered by the TI Team, and why they are, or are not, selected for assessment.	provides for updating using observed seismicity. The Kijko approach (the option choosen for application to the CEUS project) uses observed seismicity and an assumption of exponentiality.
S 5-7. (DMM, CC) *"Kijko Approach" — Terminology and Description* Defining how this approach or procedure will be referred to in the report and appropriate attribution for its origin need to be established upon first mention. In section 5.2.1 (pg. 5-6, paragraph 3), two alternative approaches are described for estimating Mmax: the Bayesian procedure and "the Kijko (2004) procedure." Later in section 5.2.1-2 (pg. 5-15), the first sentence states: "The Kijko approach (Kijko and Graham, 1998; Kijko, 2004) . . ." In referring to the "Kijko approach," misleading statements are made. On pg. 5-7 (paragraph 1, last sentence), the text states, "However, the approach relies on the assumption that the distribution of earthquake magnitudes follows a doubly truncated exponential distribution." Later on pg. 5-15 (section 5.2.1.2, paragraph 1, first sentence), the text repeats that the approach is based on the simple assumption that "the distribution of earthquakes in a region follows a doubly truncated exponential distribution." In Kijko (2004, pg. 1) the reader plainly finds: "This paper provides a generic equation for the evaluation of the maximum earthquake magnitude *m*max for a given seismogenic zone or entire region. The equation is capable of generating solutions in different forms . . . . It includes the cases (i) when earthquake magnitudes are distributed according to the doubly-truncated Gutenberg-Richter relation, (ii) when the empirical magnitude distribution deviates moderately from the Gutenberg-Richter relation, and (iii) when no specific type of magnitude distribution is assumed."	The report modified to refer consistently to the Kijko (2004) approach. While many of the concepts were introduced in Kijko and Graham (1998), Kijko (2004) introduces the methodology for developing a distribution for Mmax that was used in the CEUS SSC Project. The PPRP is correct. Kijko indicated that multiple magnitude distribution forms can be accommodated. The report was modified to indicate this and to justify why the selection option was utilized.
S 5-8. (DMM, CBR) *"Kijko Approach" — Justification of Weighting* Adding to Comment **S 5-**7 on the TI Team's use of the "Kijko approach" (Section 5.2.1.1), this is an approach that was not identified in the any of the CEUS-SSC workshops as a potential approach. Further, the approach was not discussed in detail at the 2009 USGS Mmax workshop. The Kijko approach is one that is represented by the form: Mmax = Mmax obs +Δ. At the USGS Mmax workshop this class of methods was given little credence. However, the discussion was mostly focused on models that specified a fixed magnitude increment for Δ (0.5 magnitude unit, for example). Kijko's approach is different in that it utilizes a statistical assessment of seismicity in the region of interest to obtain estimates of Δ (and uncertainties). The approach(es) developed by Kijko have not seen wide usage. The PPRP endorses the utilization of an alternative approach that uses zone-specific data for estimation of this important parameter, but notes that the assignment of equal weights to the Kijko KSB approach and the Bayesian global tectonic analog approach may be inconsistent with the CBR of the ITC. Inspection of the results suggests the Kijko method is only used when it agrees with the Bayesian results. (See also earlier Comment **S 5-5** and Comment **S 5-10** below regarding the justification of the relative weighting of approaches.) The P(mu>8.25) threshold of 0.5 does not seem unreasonable, but it does lead to the question of sensitivity of the final distribution to that choice. If P(mu>8.25) were set to 0.25 or 0.75 what effect would that have on the number of zones for which the Kijko result would be used? The choice of **M** 4.8 for the lower bound of the Kijko approach needs additional discussion. This leads in some cases (see Section 7) to non-zero probability assigned to Mmax branches of **M** < 5.25 in large source areas. The PPRP is not convinced this result is consistent with the ITC. It will certainly provoke discussion and hence should be justified to the maximum extent practicable.	The statement that the Kijko approach is a Max observed plus delta is an over simplification. The Kikjo approach defines a distribution for Mmax. The basic formulation produces equations for the mean of that distribution, which could be considered a max_obs plus delta. However, looking at it in this way, one could also consider the Bayesian approach to be a mean plus delta if one computed the mean of the posterior. The PPRP is correct in that the Kijko approach has not seen wide usage. However, as discussed in the response to comment S-5-10, there do not appear to be many options for a repeatable and readily updatable Mmax assessment method for large source zones. The TI team selected the ones that were judged viable for application in this context. It is true that the weight on the Kijko approach is correlated with the similarity in the Kijko and Bayesian results. This has to do with data. The more data there is in a source zone, the more the Bayesian prior is modified by the likelihood function. That likelihood function has a shape similar to the distribution for Mmax produced by the Kijko method implemented in the CEUS SSC project. Also as the amount of data increases in a source, the Kijko method gets more weight. Therefore, when there is a lot of data, it is not surprising that the two methods produce similar results. The revised model imposed a minimum Mmax of 5.5 for all sources

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S 5-9. (DMM, CBR, CC) *Bayesian Mmax Approach* The discussion of the updated domain dataset analyses in Section 5.2.1.1 (and subsections) is confusing and lacks sufficient information to fully understand what was done. The text states that Table 5.2.1-1 list Mesozoic and younger extended superdomains, yet the table appears to list all ages of extended superdomains (and Table 5.2.1-2 is for all ages of non-extended superdomains). Without listing the actual p-values of the statistical tests it is difficult to appreciate the improvements that are being discussed as you assess subsets of the data. Given that Appendix K only provides tables of the SCR Mmax databases, more specifics should be provided in this section (see also Comments on Appendix K – more detail needs to be provided there also). It is suggested that there be a displayed, on one or more figures, the Mmax-obs distributions for the various classes being compared. Was an assessment made of the impact for using an alternative choice for the lower cutoff of magnitude for each of the domains (such as **M** 5 or **M** 5.5)? Statistical analyses are good, but not necessarily the only basis for assigning weights to the prior distributions. It seems clear that the Mean Mmax between the two-priors is likely to be important from a PHSA perspective (7.1 versus 6.35). The text states that a stronger weight (0.6) is not assigned to the two priors because the statistical significance of the separation is not strong. Assignment of relative weights should consider the seismologic views of the ITC in addition to any statistical significance—based on the text, the TI Team seems to be making the statistics the primary consideration. Discussion at the USGS Mmax workshop and the public workshops held to support the National Seismic Hazard Maps could suggest that the ITC would put more emphasis on the "two-priors" model (the TI Team's intuitive judgment). The Open- File Report from the USGS Mmax workshop should be reviewed in this context, along with pertinent discussion from Workshop #2. A stronger basis for assigning relative weights is needed. The description of the methodology to assess Mmax for all seismic sources contains a discussion of the role of the RLME sources in the assessment. The report suggests that a potential problem is that the global SCR database includes events from RLME sources (e.g., New Madrid) and that the Bayesian approach is being applied to non-RLME sources (p. 5-7). It seems that this methodology assumes that all RLME's have been identified in the current model. Otherwise, the model does not consider RLME's that may be found in the future. The report should explicitly describe how the model accounts for non-identified RLME's that may have maximum magnitudes the size of New Madrid or Charleston.	More details on the development of the priors are provided in the revised report. No impact was made of the choice of lower cutoff for each domain. However, a minimum Mmax is now used for all applications to assess of Mmax The USGS Mmax workshop did not deal explicitly with the issue of the relative weights that should be applied to alternative prior distributions using the Bayesian approach. Nor was there any formal "consensus" in exactly what prior distributions should or could be used with the Bayesian approach. As noted in the text, the lack of strong statistical significance between the separate and the combined priors provides input to the judgment that there is not a strong technical basis for giving either alternative strong weight. The updated distributions all contain the possibility that Mmax values could be as large as 1811,1812 or 1886
S 5-10. (CBR) *Weights for the Alternative Mmax Approaches (Section 5.3.1.3)* Given the TI Team's noted high regard for the Bayesian approach, it is difficult to understand why the Kijko approach was assigned equal weight under any circumstances (large number of larger earthquakes). Discussion at the USGS Mmax workshop and the discussion at the regional workshops to support the National Seismic Hazard Maps would suggest that the ITC gives considerably more weight to the global tectonic analog/Bayesian approach. Beyond the Bayesian approach, there were several potential approaches considered at the USGS workshop, thus it is not clear why the TI Team selected the Kijko approach as the only alternative. The Mmax distributions shown in the report appear to be bi-modal in some cases. The TI Team has not properly discussed and justified the weights assigned to the alternative Mmax approaches.	The TI team is not aware of other quantitative and repeatable procedures for estimation of Mmax other than the Bayesian approach or the Kijko approach other than assigning an arbitrary delta value to the observed Mmax or developing a direct subjective assessment. The Team is not opposed to use of a direct subjective assessment but felt that methods that could readily be updated in the future when new information becomes available are preferable.
S 5-11. (DMM, U, CC) ***Approach to Earthquake Recurrence Assessment***	An effort was made to improve the clarity in section 5.3.2 by providing more

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Section 5.3 describes the approach to earthquake recurrence assessment used in the Project. This section is generally well-written (given the complexity of the topic) but could certainly benefit from the inclusion of additional steps in the derivations and from additional discussion in some places (we elaborate in following comments). A fundamental assumption of the methodology used in the CEUS-SSC Project (and most others as well) is that the magnitudes of earthquakes in the corrected catalog can be represented as exponential variables with a density function $f(m) = \beta * \exp(-\beta(m-m0))$. Lombardi (BSSA, 2003, vol. 93, no. 5, pp. 2082–2088) argues that main shocks (i.e., those in the "corrected" catalog) do not satisfy this assumption. Lombardi suggests a different density function for the use with these main events that depends not only on β but on N (the number of events) as well. In fact, her comparisons utilizing Southern California data suggest much lower *b*-values for main shocks than for all the events in the catalog. The PPRP suggests that some discussion of these alternative assumptions be included in the report—and that the methodology used by the TI Team be checked, vis-à-vis implications of the Lombardi paper, to ensure that there is no systematic bias in the maximum-likelihood estimates of *b*-values.	background. We have also examined the Lombardi paper and concluded that the issues identified in that paper do not affect the results of this study. A section was added (Section 5.3.2.6) that discusses the paper and its practical implications.
S 5-12. (DMM, CBR, CC) *Smoothing to Represent Spatial Stationarity (Section 5.3.1)* The argument is presented in this section that the penalized likelihood approach to spatial smoothing of seismicity is superior to other approaches and the only method to be considered in the CEUS-SSC Project. The PPRP does not find this argument to be adequately supported by the report as written in its present form. Keeping in mind that the objective of the SSHAC Level 3 process is to represent the CBR of the ITC, we note that, other than one or two members of the TI team, no other members of the technical community are utilizing the penalized likelihood approach to perform smoothing of observed seismicity. The overwhelming majority of the community is utilizing either a fixed-kernel or adaptive-kernel approach to smoothing. The kernel approaches are conceptually much simpler and easier to implement and, as a result, yield enhanced transparency. The PPRP notes that in Section 5.2.1 (p. 5-7, 2nd paragraph) the report states, "[I]t was decided that for representing the center, body, and range of views of the informed technical community, the assessment would need to include alternative conceptual models for Mmax." The PPRP wonders if one were to replace "Mmax" with "smoothing technique" in this statement, why the argument presented in Section 5.2 would not apply in Section 5.3. The penalized likelihood method, as developed in the EPRI-SOG Project and in the present report, possesses some very positive attributes. Some are briefly discussed in Section 5.3.1 but developed more fully in Section 5.3.2.4. It would enhance clarity to refer the reader to Section 5.3.2.4 in Section 5.3.1. While the TI Team recognizes that the selection of the smoothing option requires expert judgment, the text goes on to note that "The smoothing operation within the distributed seismicity zones results in variations of *a*- and *b*-values over scales that were judged by the TI Team to be reasonable . . . ." The report has not provided an adequate basis for making this statement. The text does not compare the computed smoothing results to other studies, and does not point to any explicit data that indicates that the seismicity parameters fall within a reasonable range.	Discussion added to justify the use of the penalized maximum likelihood approach to smoothing and to present the argument that all smoothing approaches are based on the same conceptual model of spatial stationarity. The penalized maximum likelihood approach developed for the CEUS SSC project is a refinement of the EPRI-SOG approach, which is part of an SSC model endorsed in Reg Guide 1.208 and has seen common use throughout the technical community in every Combined Operating License application filed to date. Section 5.3.2.4 provides the bases for selecting the approach over the other kernel approaches and reference to it is added to Section 5.3.1. The point of the quoted statement is that the selection of smoothing parameters is subjective and an assessment made by the TI Team. The technical considerations that were part of that assessment are given in Section 5.3.2.4. Calculations were also performed for a few source zones using a kernel approach with objectively selected adaptive kernel size (using a completely different objective approach). The resulting map is presented in Section 5.3.2.4. Visual comparisons indicate a very good agreement, except in regions of very low seismicity, where Gaussian kernel approaches are known to be problematic.
S 5-13. (DMM, CC) *Penalized Likelihood Function — Differences with EPRI-SOG?* In Section 5.3.2.1 the model for the penalized likelihood function for recurrence parameters is formally developed. Many aspects of the approach appear to be similar to those of the EPRISOG Project. It would be useful to specify the differences in the present	The new Section 5.3.2.5 contains a detailed comparison of the approach used in this study and the penalized likelihood. This discussion covers all the differences identified by the PPRP.

Comment	Summary of Revisions to Report
approach relative to the EPRI-SOG Project. The PPRP identifies the following differences (or at least this section of the current report is not clear enough to be sure if these are in fact differences relative to the EPRI-SOG Project): 1. One of the attributes of the EPRI-SOG model was the simultaneous solution of recurrence parameters and incompleteness. On pg. 5-23 the text states the probability of detection (PD) values are calculated in Section 3.3.3 (typo-this should be Section 3.5). This statement plus the remainder of Section 5.3.2.1 give the appearance that PD is calculated independently and no longer simultaneously solved for. 2. The smoothing functions are now analytically determined (objective estimates) as opposed to the general, judgment-based smoothing specified by the expert teams in the EPRI-SOG study. 3. The use of the Monte Carlo-Markov Chain simulation approach to develop alternative maps in the present study as opposed to the parametric bootstrapping used in the EPRISOG study. 4. The use of quarter-degree cells instead of one-degree cells and only using the cells that share sides (4 nearest neighbors instead of 8).	
S 5-14. (DMM, CBR, CC) *Model for the Penalized Likelihood Function — Need for Scrutiny* The development of the statistical approaches used in this Section 5.3.2.1.1 should undergo independent review either using an appropriately qualified member of the TI Team or an outside expert. It is not sufficient to simply provide a description of the approach used. To facilitate a thorough and transparent review, the software developed should be made available for use in the review process. The text implies that selecting a small cell dimension, more cells, is an improvement relative to larger cell dimensions. It is not clear, from a seismologic perspective, considering the short historic record, why this would be the case. Review of the alternative recurrence maps (Appendix J) suggests that there are broad areas where the rates of **M** > 5 are effectively zero, there is wide variation (several orders of magnitude) in rates and *b*-values between alternatives, with generally lower *b*-values (< 0.8). It is not clear how the choice of cell dimension may have impacted these observations. This section has not adequately demonstrated how the method chosen quantitatively compares to other methods such as the kernel approach. While section 5.3.2.4 provides some discussion, it is not sufficient by itself to support the sole use of the method chosen. It appears that the TI Team is using the argument that *b*-values are not constant within a “larger” seismic source. The variation (or lack of variation) of *b*-values is subject to considerable discussion within the ITC. What is the basis for supporting the position that the variation of *b*-values is consistent with the views of the ITC? The weights on the reduced-weight option for the magnitude intervals listed on Table 5.3.2-1 are not properly discussed and justified. Presenting only two figures as a demonstration that the approach is not sensitive to these weights is not compelling. What was the basis for assigning these weights to each of the magnitude intervals? A few additional aspects in Section 5.3.2.1 could certainly be clarified further to enhance readability and understanding: • The reader is challenged to derive 5.3.2-11 from 5.3.2-9. • What is the basis for eight alternative maps as opposed to four or ten? • Section 5.3.2.3 is not clear enough to understand the generation of the alternative maps from the eigenvalues and eigenvectors of the covariance matrix **Sx**.	The software will be made available to the reviewers, as already indicated in the project plan. In principle, smaller cell dimensions are preferable because they allow finer spatial resolution. The absence of earthquakes in an individual cell does not create a problem because the penalty functions that promote smoothness in fact create a larger “effective cell size.” Tests on the MIDC_A zone with objective smoothing indicate similar results for cell sizes of 0.25, 0.5, and 1 degree. The objective smoothing compensates for the cell size by arriving at solutions with smaller $\sigma_{\Delta\nu}$ (i.e., smaller differences between adjacent cells) for the smaller cell sizes. In the opinion of the TI team, the source-level comparisons shown in Chapters 6 and 7, the comparisons for smaller regions shown in Sections 5.3.2.3, and the comparison to the kernel approach in Section 5.3.2.4 provide sufficient support for the decision to adopt the penalized likelihood approach as the sole method for source-zone recurrence calculations. In addition, the choice of cases A, B, and E samples a broad range of assumptions regarding degree of smoothness or roughness. As indicated earlier, the choice between the penalized-likelihood approach and kernel approach is a choice between statistical tools; the conceptual model for both approaches is the same. The spatial variation of the b value is indeed a topic of much discussion. The TI Lead canvassed several seismologists who have thought about b and its spatial variation, but did not receive any useful guidance in this regard. The TI team felt that, given the large size of some of these source zones, it was preferable not to adopt a constant b as an a-priori assumption. In the end, the objective-smoothing approach arrived at maps with a mild spatial variation in b (except in SLR). The choice of magnitude weights has changed: we now use cases A, B, and E. The revised report contains a discussion in Section 5.3.2.2.1 of why other

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	cases were eliminated and how the weights to cases A, B, and E were assigned by the TI Team. Regarding Eqs. 5.3.2-11 and 5.3.2-9 (now 5.3.2-15 and 5.3.2-13), 5.3.2-11 is not derived from 5.3.2-9. The latter represents the likelihood of the recurrence parameters in all cells, while the former represents one of the penalty functions that are introduced to promote smoothness between cells. Regarding the choice of eight alternative maps, the following paragraph was added at the end of Section 5.3.2.1.3: "The initial implementation of this approach required that the number of realizations be a power of 2 because the first few epsilons were sampled using two-point distributions. This number was set to 8 because 4 was considered insufficient and 16 imposed a high computational burden for the hazard calculations. In the present Latin Hypercube implementation, the restriction of a power of 2 no longer exists, but the choice of eight realizations was retained. Tests indicate that 8 realizations, together with Latin Hypercubes, provide an adequate representation of the mean and fractiles of the hazard." Regarding the eigenvalue decomposition, Section 5.3.2.1.3, the text was modified in the hope that it will improve clarity. In essence, the eigenvalue analysis and the Karhunen –Loève expansion are utilized to generate realizations of a random vector with the desired covariance properties. This technique is used in many disciplines.
S 5-15. (CBR, CC) ***Application of the Smoothing Model (Section 5.3.2.2)*** In Section 5.3.2.2, no basis is given for weights on *b*-value priors. The alternatives are shown to be unimportant later, indicate that fact in this section to avoid confusion over the lack of basis for weights.	Those weights were preliminary weights, simply for the purpose of the sensitivity analysis. This potential misunderstanding was removed in the revised report.
S 5-16. (DMM,CBR, CC) *Constant b-value Kernel Approaches* Section 5.3.2.4 discusses the constant *b*-value kernel approaches to smoothing of seismicity. The PPRP believes that significantly more discussion and comparisons are needed to justify the use of a sole unity-weighted branch in the logic tree for this important choice of model. We note that one of the strengths of the penalized likelihood approach, relative to the fixed *b*-value approaches, is the ability to allow for coupled rate and *b*-value behavior within sources. However, the results shown in Figures 5.3.2-3 and 5.3.2-5 suggest the penalized likelihood approach with the CEUS data yields very high smoothing levels on the *b*-value. In other words, the data may be insufficient to make a strong case between variable and fixed *b*-value approaches at the seismic source level—thus significantly reducing one of the strengths and justifications for the penalized likelihood approach. Additional comparisons with the fixed *b*value kernel smoothing approaches are warranted.	As indicated earlier, the TI team felt that, given the large size of some of these source zones, it was preferable not to adopt a constant b as an a-priori assumption. As indicated in Section 5.3.2.4, the penalized likelihood approach has other advantages over the kernel approach (besides the spatial variation in b). The most important of these are the ability to produce spatially varying estimates of the uncertainty in b and the presence of a natural floor in areas of very low seismicity. A comparison to the kernel approach was added in Section 5.3.2, and it shows a good agreement. Please see the response to 5.5-14 for additional discussion of the issues raised in this comment.
S 5-17. (DMM, CC) *Seismogenic Crustal Thickness* In the title and text of Section 5.4.1.4, the term should be "seismogenic thickness" not "seismogenic crustal thickness." The statement that the focal depth distributions of well studied earthquakes established the basis for the assessment of seismogenic thickness is overly generalized. This section goes on to note that the base of the seismogenic zone is identified as lying near the base of observed focal depths at about the 95th-percentile depth; review of the depths listed in the updated earthquake catalog would suggest that a	The term "seismogenic crust" is commonly used and text is added to indicate that it is synonymous with seismogenic layer or seismogenic zone. The approach used has been modified to be based on the D90 of high-quality focal depths for all seismic sources. Text is added to present the approach and to define its technical basis.

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depth of 13 km may not be consistent with recorded data. If there are specific “well-studied” earthquakes used to establish the TI Team’s assessment, these should be listed and summarized. Later in Chapter 6 when discussing the assignment of crustal thickness to specific seismic source zones, the report appears to ignore the stated intent that observed focal depths at about the 95th-percentile depth is an important consideration.	Chapters 6 and 7 will be made consistent with this approach and reported values consistent with those in Table 5.4.1-2.
S 5-18. (CC) *Relationship of Rupture to Source Zone Boundaries* In Section 5.4.1.7, the discussion of strict versus leaky source boundaries is not clear. While it is recognized that TI Team judgment is important here, it seems that some type of systematic approach would be appropriate. It may be important to note that the assumed rupture dimension relationships establish limits that must be explicitly considered in assigning strict versus leaky, and that this constraint is considered on a case-by-case basis. Otherwise it is not clear why some RLME sources move from strict to leaky, given the defined boundary. The same is true for difference between seismotectonic source zones—why are some leaky and some strict?	Explanation added regarding the bases for leaky versus strict boundaries. It is also noted that all sources have sufficient dimensions to accommodate the ruptures consistent with their assessed magnitudes.
S 5-19. (CC) *Assessment of Future Earthquake Characteristic* In Section 5.4, the introduction of Table 5.4-2 invites discussion before the reader has a chance to read the specifics related to each seismic source in Chapters 6 and 7. It is suggested that this table be split into two tables that can be provided as useful summaries at the end of Chapters 6 and 7, respectively, for the sources zones discussed in those chapters. In this way, the reader will have had the benefit of understanding the TI Team’s basis for the source-specific weights that are assigned.	Having all of the assessed characteristics for all seismic sources directly in the section where the approach is discussed has value and Table 5.4.1-2 is retained. Chapters 6 and 7 have been structured so that they are consistent in format and discuss the bases for the future earthquake characteristics. All of those discussions now refer the reader to Table 5.4.1-2, for clarity.
Comments by Section ***Entire Chapter 5*** Throughout Chapter 5, we recommend that “event” not be used as a synonym for “earthquake.”In order to achieve the needed clarity for a regulatory document, we recommend making a blanket search to replace “event” with “earthquake” where that meaning is the case. Other instances of confusing uses of synonyms are identified elsewhere in the following comments. ***Section 5.1.1*** First sentence: Replacing “led to the belief” with “led to acceptance” would be clearer (note that in line 4 the word “conclusion” is used). On p. 5-2, par. 2, line 9: Suggest replacing “secondary effects” with “liquefaction phenomena associated with them” In the same paragraph, line 10: Suggest replacing “paleoseismic events” with “paleoearthquakes interpreted using the distribution of liquefaction phenomena” In the same paragraph, last line: Replace “studies” with “SSC model assessments” On p. 5-2, par. 3, line 3: Change “EPRI-SOG study” to “EPRI-SOG Project” In the same paragraph, line 8: Suggest replacing “capturing” with “representing” In the same paragraph, line 10: Change “in EPRI-SOG” to “in the EPRI-SOG Project” ***Sections 5.1.2*** In the first paragraph, line: Change “PSHA” to “SSC model assessments” In the same paragraph, last line: Change “PSHAs” to “SSC model assessments” On p. 5-3, par. 2, line 9: Change “CEUS SSC study” to “CEUS SSC Project” ***Section 5.1.3*** In the second paragraph, suggest rewording the first sentence to read: “Another area of ongoing research with potential implications for recurrence behavior relates to geodetic strain rate measurements.”	Event changed to earthquake in most cases. Revisions made as suggested.
Section 5.2	Revised as suggested.

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Comment	Summary of Revisions to Report
In the first line of the second paragraph: Consider deleting “issue” and change “EPRI-SOG study” to “EPRI-SOG Project”	
Section 5.2.1	
In the first sentence of the first paragraph: Suggest replacing “calls for” with “incorporates”	Revised as suggested.
Section 5.2.1.1	
On p. 5-11, sequential paragraphs describe the results of performing Student’s *t*-test as yielding “a very high probability (*p*-value),” then “a lower *p*-value,” and then “a further reduction in the *p*-value.” But the *p*-values are not given! Finally, the fourth paragraph reports the results of an additional step that “yielded a *p*-value of 0.14.” The other *p*-values also need to be reported and documented for the reader to evaluate whether the extended and non-extended superdomain classifications are statistically significant.	P values given in revised report
Section 5.2.1.1.1	
In the first paragraph, line 4: Consider replacing “known stress” with “known characteristics of tectonic stress”	Revised as suggested.
In the next paragraph, first sentence: Change “study area” to “model region”	
Section 5.2.1.1.2	
In the first sentence: Consider replacing “applicable” with “appropriate”; change “study region” to “model region”	Revised as suggested.
Section 5.2.1.1.3	
In the first sentence: Replace “assigned” with “assessed”	
In the same paragraph, line 3: Consider replacing “an intuitive” with “our subjective”	Revised as suggested.
Section 5.2.1.1.4	
In the second sentence, line 2, delete “likely”; in line 3, change “For this study” to “For this project”	Revised as suggested.
Section 5.2.1.2	
In the last line of the first paragraph: Consider deleting “*possible”* (or explain)	
On p. 5-16, in the second full paragraph, line 4: Consider deleting “relatively” (or explain)	Revised as suggested.
On p. 5-16, in the last full paragraph, line 6: Replace “decided” with “assessed”; in the last sentence of this same paragraph, consider replacing “the following key assumptions are made in the application of” with “the following constraints are placed on the application of”	Revised as suggested.
On p. 5-17, first bullet: Replace “accounted for” with “assessed”	
On p. 5-17, third bullet: Consider replacing “regard for” with “reliance on”	
Section 5.2.1.3	Revised as suggested.
In the first paragraph, line 3: Consider replacing “assigning weights to” with “weighting”	
In the same paragraph, lines 4 and 6: Consider replacing “assigned” with “assessed”	
Section 5.2.1.4	
In the first paragraph, line 5: Consider replacing “assigned” with “assessed”	Revised as suggested.
On p.5-18, in the partial paragraph at the top of the page: Consider replacing “assigned” with“assessed”	
On p. 5-18, first full paragraph, lines 3 and 7: Consider replacing “assigned” with “assessed”	Revised as suggested.
On p. 5-18, second full paragraph, line 3: Consider replacing “assigned to” with “assessed for”	
Table 5.2.1.1	Revised as suggested.
Does the last row contain numbers of earthquakes “Greater than **M** 4.5” or ≥ **M** 4.5?	
Figures 5.2.1-7 and 5.2.1-8	
Typo in legend. Change “Disribution” to “Distribution”	≥ **M** 4.5
	Revised as suggested.

Comment	Summary of Revisions to Report
Section 5.3.1 In the last paragraph on p. 5-19, line 9: Replace "study region" with "CEUS SSC model region"	The term "study region" is common usage and well-understood, so it is retained.
On p. 5-20, first full paragraph, last sentence: Consider replacing: "were judged by the TI Team to be reasonable, given the technical community's views" to "were judged by the TI Team to represent the technical community's views"	Considerable additional discussion added on the issue of the community's views regarding spatial stationarity and smoothing. During the evaluation phase, the larger community's views were evaluated. During the integration phase, the SSC model was built and that includes the smoothing decisions. So, it is correct to say that the assessment belongs to the TI Team, having given due consideration to the community's views.
Section 5.3.2.1.1 Regarding m0 and the definition of *v*: Is *v* in fact calculated for $m > m0$ or $m \geq m0$ (e.g., McGuire, 2004; Weichert, 1980)? If calculated as the latter, then corrections should be made to equation 5.3.2-1 (and associated text on pg. 5-20), on pg. 5-29 (paragraph 2, line 2), and perhaps elsewhere.	We use m$\geq$mo and we corrected the equations and text accordingly. In theory, this is not important for a continuous random variable. Because magnitude are not quite continuous, it has a moderate effect in practice (note: most changes to 5.3.2 were made after Aug. 7 version)
On p. 5-21, third line from the top of the page: Change "This study" to "This project"	Change made in a number of places
On p. 5-22, par. 4, line 2: Consider replacing "one may wish to assign lower weights to lower magnitudes" with "the assessment may result in a lower weight on lower magnitudes"	Change made
In this same paragraph, second sentence: Consider replacing this sentence with "For instance, the magnitude-recurrence law may deviate from exponential, or the magnitude-conversion models or completeness model may be less reliable for lower magnitudes."	Change made.
On p. 5-22, last paragraph, line 1: Consider replacing "considered" with "incorporated"	Change was considered but it was not incorporated.
On p.5-23, par. 1, line 5: Change reference to "Section 3.3.3" to "Section 3.5"	
On p. 5-25, last full paragraph: Consider replacing "are specified by the expert teams on the basis of judgment" to "are assessed by the expert teams on the basis of their evaluations"	Change made.
On p. 5-26, first text line at the top of the page: Change "study" to "project"	Change made.
On p. 5-26, first full paragraph, line 4: Consider replacing "refer to" with "formulate"	"refer to" was changed to "write"
On p. 5-26, par. 3: In line 1, change "Equation 13" to "Equation 5.3.2-13"; in line 2, consider changing "a characterization" to "an assessment"; in lines 7–8, consider replacing "An additional, practical requirement is that one must represent the epistemic uncertainty by means of a small number of " with "An additional practical requirement is that epistemic uncertainty must be represented. This can be accomplished by means of a small number of "	Change made using slightly different wording.
On p. 5-27, par. 3, line 4: Change "Equation 15" to "Equation 5.3.2-15"	Change made.

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Comment	Summary of Revisions to Report
On p. 5-27, par. 4, lines 7–8: Typo. “maps of to represent”	Change made.
Section 5.3.2.2.1 On p. 5-29, second bullet: Change “in EPRI-SOG” to “in the EPRI-SOG Project” and change “study region” with “SSC model region”	Change made.
Section 5.3.2.2.2 On p. 5-31, first full paragraph, line 6: Replace “assigned” with “assessed”; in line 7, consider deleting “reflected”	N/A. Section was almost entirely re-written.
Section 5.3.2.3 Last line: Consider replacing “small-scale” with “local”	Change made.
The first example used to examine model results in parameter space needs to be more explicit in describing how the expected earthquake counts in the polygons are derived. It would also be helpful to discuss the data error bars for the magnitude bins with no events. The figure captions for these figures need additional information.	Explanations added. Error bars no longer shown for bins with no data.
Section 5.3.2.3.1 On p.5-32, par. 2, line 1: It is an overstatement to claim that Figures 5.3.2-20 and 5.3.2-21 show a “very close” agreement between model and data. In the following paragraph, “good agreement” is claimed between model and data for results shown on Figures 5.3.2-22 and 5.3.2-23. Admittedly, such statements are qualitative, but don’t stretch the reader’s credulity.	Statements are consistent with revised results.
Section 5.3.2.4 In the first paragraph, first sentence, change “this study considered” to “this project evaluated”; in line 3, change “considered” to “evaluated”; in line 4, change “study” to “project” In the second paragraph, line 2, change “has been specified subjectively” to “has been assessed subjectively”	Change made.
On p. 5-34, next-to-last paragraph, line 6: Consider changing “idea” to “understanding”	Change made.
Section 5.3.3.1 Equation 5.3.3-2 should be checked. The N! in the denominator appears to be an error. Because the normalization procedure used to generate the probability density function for λ isn’t explained, it’s not evident why the y-axis values are so low (0.00, 0.02, 0.04). Rescaling the x-axes of both plots would be helpful to avoid the awkward labeling of 5e-05, etc., making it easier to read the plots. Checking the five discrete levels on the CDF points to an error in Table 5.3.3-1: The value of cumulative probability in column 1, row 1 can’t be 0.304893(other values in the table suggest it should be 0.034893).	Other changes made as suggested.
Section 5.3.3.1.3 First paragraph: In the first sentence, consider replacing “is generally used to represent uncertainty in the inputs” to “is used to represent uncertainty in the SSC model “inputs”; in the last sentence, change “CEUS project” to “CEUS SSC Project”	
Section 5.3.3.1.3 In the section title, consider changing “Estimation” to “Assessment”	

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Comment	Summary of Revisions to Report
Section 5.3.3.1.3 On p. 5-39, par. 3, line 1: Note that a 50-year life is stated elsewhere On p. 5-39, last line: Missing word. Insert “on the time before present” ***Section 5.3.4*** In the section title, consider “Assessment of RLME Magnitude Distribution” First paragraph: In the first sentence, consider deleting “are intended to”; in line 6, change “study” to “project; in line 7, consider deleting “set to be”; in the last sentence, consider substituting “is” for “was chosen as”	
Section 5.4* (and *Tables 5.4-1 and 5.4-2 Some additional discussion is required to explain the bases for the development of weights for the characteristics (or improved cross-referencing). On p. 5-41, par. 1, line 5: Consider deleting “a consideration of” On p. 5-41, par 2, line 7: Consider replacing “considering” with “evaluating” ***Section 5.4.1*** First paragraph: In line 3, consider replacing “considered” with “evaluated”; in lines 7–8, consider rewording the last clause to read: “the assessed values in column 2 of the table are based on assessments by the TI Team of the default characteristics that represent the current state of scientific knowledge” ***Section 5.4.1.3*** In the first sentence: Consider rewording to read: “information about the characteristics of earthquake sources, modeled as finite faults in much the same manner as earthquake sources are modeled in the WUS.” In line 6, consider replacing “in light of” with “using” In the last line: Consider deleting “largely” (or explain) and replacing “consideration” by “evaluations” ***Section 5.4.1.4*** In line 2: Consider deleting “upper” (or explain) In line 4: Replace “study” with CEUS SSC Model” On p. 5-43, first partial paragraph at top of page: In line 1, consider replacing “some” with “a high”; in line 2, replace “study” with “CEUS SSC Model” ***Section 5.4.1.5*** In line 5: Replace “capture” with “represent”; in line 6, consider rewording to read: “The relationship used (Somerville et al., 2001)” In the last line: Replace “study” with “assessment” ***Section 5.4.1.6*** In line 2: Consider replacing “a consideration” with “an evaluation” In line 4: Replace “assumed to be equidimensional” to “assessed to be equidimensional” and change “For progressively larger areas” to “For progressively larger rupture areas” In line 6: Consider deleting “it was assumed that” In line 10: Consider deleting “assumed to be” In line 11: The NAGRA approach should be explained, as reviewers are unlikely to have this report. In the last line: Consider replacing “associated with” with “of” ***Section 5.4.1.7*** In line 1: Consider replacing “Assuming” with “For”, and “assumed to have” by “defined	Referencing to Chapters 6 and 7 has been added to indicate that the technical bases for the weights are included in those chapters. Also, Chapters 6 and 7 have been made consistent and each section refers to applicable future earthquake characteristics. “Study region” is common terminology and has been kept. All other revisions made as suggested.

Comment	Summary of Revisions to Report
by" In line 2: Replace "defined" with "represented" In line 5: Replace "assigned to" with "assessed for"	
CHAPTER 6—SSC MODEL: Mmax ZONES BRANCH	
General Comments **G 6-1. (NAR)** The core of the TI Team's assessment of the Mmax zones approach within the CEUS SSC model is described in this chapter. As such it is a critical chapter understanding of the assessment by future users. The TI Team has described an immense amount of data together with its evaluations of these data in characterizing and assessing this branch of the CEUS SSC model; in doing so the TI Team generally has described the assessment in sufficient scope and detail to inform future users of the model.	No revision necessary.
G 6-2. (CBR, U) Chapter 6 is generally well written. The discussion of each of the RLME sources is laid out logically providing a general description of the source, localizing feature(s), geometry, recurrence, and maximum magnitude. However, the basis for some of the assessments is not clearly articulated. Some specific examples are mentioned below, but the PPRP recommends the TI Team review all the subsections with an eye to improving the clarity and strength of the bases for assessments. For example, it is not always clear why one source is using the generic seismogenic crustal thickness assumptions while others are not. The same holds true for differences in assessed weights for clustered behavior. Another example is the empirical relationships used to derive magnitudes given assumed dimensions for seismic sources. To the extent possible, the TI Team needs to clearly establish their overall approach to assessing these weights; in some instances additions to Chapter 5 should be considered to establish the basic approach to how the TI Team decided to modify generic weights, or what generic data (discussed in Workshop #2?) influence the assignment of weights to individual seismic sources.	The bases for all assessments have been reviewed and revised as necessary for clarity. Explanation has been added for the assessed future earthquake characteristics and for assessed weights for clustered behavior. Dimensions of seismic sources have been checked to be sure they are compatible with the dimensions implied by the empirical relationships. The technical bases for all weights have been reviewed to ensure completeness and clarity. There are no "generic weights" for the assessments; all weights must be discussed and supported. Perhaps the comment refers to the "default" future earthquake characteristics; Discussion added to Section 5.4 regarding the use of the default characteristics or source-specific assessments and Table 5.4-2 added summarizing the source assessments.
G 6-3. (CC) In the 3rd paragraph of Section 6.1 the report states: "By identifying the RLME sources and including them in the model, there is no implication that the set of RLME sources included is, in fact, the total set of RLME sources that might exist throughout the study region." This sentence and the remainder of the paragraph make a very important point about a fundamental assumption included in this model. This point needs to be articulated, specifically in Section 4 of the report as well.	The point is made in Section 4 of the report, as suggested.
Specific Comments **S 6-1. (CC, SSHAC)** *Achieving Clarity Necessary for Future User* The importance of Chapter 6 for informing future users of the CEUS SSC model places a heavy demand on the TI Team to clearly document its assessment. As a framework for achieving necessary clarity of documentation, it may be useful for the TI Team to keep in mind the steps involved in implementing the SSHAC assessment process: (1) compiling the community knowledge; (2) compiling the relevant data; (3) evaluating the community's knowledge, understanding the community's uncertainty, and characterizing alternatives for assessment; and (4) assessing weights for the alternatives representing the	Documentation of the technical bases for the assessments has been reviewed and revised as appropriate. Suggested wording for Section 6.1 incorporated as suggested.

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community uncertainty. Generally the TI Team has provided very thorough documentation of steps 1 and 2 in this chapter. Documentation of steps 3 and 4 is often less clear. Much of the lack of clear presentation can be attributed to misuse of terms. This is particularly evident in descriptions of the TI Team's assessments where many different words (define, characterize, modeled, given, constrain, allowed, chosen, assign, assumed …) are used for assessment. In addition to conflicting meanings, the impact of using words with such diverse meanings for the core SSHAC methodology requirement, namely "assessment," is that they undermine the essential discipline that a SSHAC assessment requires. Other instances of misuse of terms coupled with lack of completeness in descriptions detract from the reviewers' understanding of the evaluations performed and weaken the usefulness of the document for future users. Consider as an example the following edited first paragraph of Section 6.1 compared to the original. By definition, RLME sources are the locations of repeated (more than one) large magnitude (**M** ≥ 6.5) earthquakes in the historic and (or) paleoearthquake record. Because of the rarity of repeated large-magnitude earthquakes relative to the period of historical observation, evidence for these earthquakes comes largely from the paleoearthquake record. For example, paleoearthquakes identified by interpretations of paleoliquefaction features and fault displacement (paleoseismic) studies combined with those in the historical record result in the catalog of large-magnitude earthquakes in the central New Madrid region and at Charleston. At Charlevoix, RLMEs are observed in the historical record and are supplemented by the paleoearthquake record. For the Meers and Cheraw faults as well as the Wabash Valley source, there are no large magnitude earthquakes in the historical record. The RLMEs for these sources are characterized by evaluating repeated surface-faulting displacements identified in trenches across the faults and, for the Wabash Valley source, by interpretations of the geographic distribution of paleoliquefaction features.	
S 6-2. (CC) *Improving the link to the Data Summary and Data Evaluation Tables* Prior to discussing specific seismic sources, the reader should be reminded that the information in the Data Summary and Data Evaluation tables provides a comprehensive assessment of the current information related to each seismic source. It is the PPRP's view that external readers and reviewers of the CEUS report need to be at least familiar with those tables prior to objectively commenting on the TI Team's assessment. This section would also benefit from a brief discussion of how the earthquake recurrence for RLME sources was modeled, specifically how the lower-bound magnitude for integration for these sources was established by the TI Team.	Discussion added to Section 6.1 as suggested.
S 6-3. (DMM, CC, U) *Earthquakes of **M** ≥ 6.5 in the Charlevoix RLME* The first paragraph in Section 6.1.1 describes two historical earthquakes of **M** ≥ 6.5 (one of **M** 7 in 1663 and one of **M** 6.5 in 1870). The reader is then pointed to the Charlevoix RLME logic tree (Figure 6.1.1-2) which has branches for the "Events/Data" node that do not appear to include the two historical earthquakes in the stated event count for **M** ≥ 6.5 (e.g., "3 eqs in 9.5– 11.2 kyr"). Section 6.1.1.2 goes on to describe paleoearthquakes, including one "historic" paleoearthquake with "a bracketed age of at least 540 yr BP." These descriptions need to be clarified for the reader to understand the basis of rate information. To appearances, the RLME rate information and calculated uncertainties for Charlevoix in	Text clarified to indicate that the 1663 and 1870 earthquakes are RLMEs. Tuttle's historical paleoearthquake could be either of these. Therefore two prehistoric earthquakes occurring at 5,000 and 10,000 years B.P. are the other two RLME events. Updated and revised recurrence calculation section clarifies how the historical earthquakes are used.

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the HID (Appendix H, Section 5.2) do not account for the two historical earthquakes in 1663 and 1870—only the paleoearthquakes. (For an example of better clarity, see the logic tree and HID tables for the Charleston RLME, where the reader is explicitly informed with labeling such as "1886, A, B, C" that the count includes one historical earthquake and three paleoearthquakes.) Adding to the problem of event counts, the text in Section 6.1.1.2 (first sentence of par. 2) states that "Tuttle and Atkinson (2010) provide evidence for at least three Holocene paleoearthquakes in Charlevoix with **M** ≥ 6.2 . . . ." If 6.2 is not a typo, then an assessment has to be made for how many of those events were of **M** ≥ 6.5 (or explain assumptions).	
S 6-4. (U, DMM, CBR, CC) *Unclear Interpretation Impacting Uncertainty* In Section 6.1.1.2, par. 3, the third sentence states, "Focal mechanisms for earthquakes of magnitude ≥ 3 show reverse faulting, whereas smaller-magnitude earthquakes indicate some strike-slip and normal faulting, suggesting that local stress conditions affect rupture style (Lamontagne and Ranalli, 1997)." This indicates that there is a local source of tectonic stress. If this is the intent, the interpretation would be in conflict with the community's knowledge and would require additional evaluation of uncertainty.	Current literature (Baird et al., 2009) indicates that the Charlevoix RLME is attributed to the interaction of the impact crater and rift faults. Introductory text clarifies the local stress discussion.
S 6-5. (CC, DMM) *Charlevoix—Geometry and Style of Faulting* In the fourth paragraph of Section 6.1.1.2, while discussing the geometry and style of faulting for the Charlevoix RLME, the report indicates that future ruptures for this source are modeled as randomly-oriented thrust faults with dips between 45 and 60 degrees in either direction. Later on p. 6-6 the report indicates the RLME boundaries should be treated as leaky with ruptures permitted to extend beyond the source boundaries. There are a number of questions that arise in interpreting these statements that apply to several other RLME sources as well. The preceding paragraphs of the section describe fault orientations derived from small magnitude earthquakes. Keeping in mind the fact that a RLME source is for large (**M** ≥ 6.5) earthquakes and hence requires large rupture areas, the applicability of these results for small magnitude earthquakes needs to be carefully explained. For the RLME sources it is not clearly explained what assumptions are being made regarding the recurrence model, i.e. is it Mmax ± 0.25 magnitude unit about each of the four identified Mmax values (noted briefly in Section 5)? This would be a "perfectly characteristic" or maximum-moment type model. This represents the epistemic uncertainty in Mmax plus the aleatory variability in the future occurrence of each of the characteristic events. The "interaction" between the lower ranges of magnitudes for the characteristic RLME source that will overlap with the upper end of the truncated exponential distribution being applied for the Mesozoic Extended Mmax source zone needs to be explained. This point is true for all the RLME sources. Since Charlevoix is the first of the RLME sources described, the TI Team should clearly explain these issues in this section.	Text clarified to use reverse for dips between 45 and 60 degrees. Paragraph added at end of section 6.1 to address issue of combining RLMEs with their host seismic source.
S 6-6. (CC) *Charlevoix—Maximum Magnitude* In the last paragraph of Section 6.1.1.3, the discussion of boundary dimensions leading to the TI Team's conclusion that the boundary is leaky requires more discussion. Given the assigned Mmax values, are the boundary dimensions too small to fit these magnitudes fully within the boundaries? To the extent possible quantitative discussion should be provided.	The discussion of the boundary amplified to provide quantitative reasons for assigning them as leaky

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S 6-7. (DMM, CC) *Unclear Logic for Performing Assessment* In the first paragraph of Section 6.1.2.1, the meaning of "time periods of interest" as used is not clear. Is it the projected life of an NPP, the projected life of the CEUS SSC model, a geologic time period? In any case it is not clear how "time periods of interest" influences an assessment of whether tectonic strain release in the Charleston area is in or out of a cluster. Moreover, the TI Team must explain its evaluation, characterization, and assessment of the community's knowledge about tectonic driving forces and the physics of tectonic strain release in a clustered sequence of large earthquakes at about 500-year intervals in the absence of any measurable strain deformation. Otherwise, the reviewer and potential future user of this report will not be able to understand the basis for the assessment.	Text revised for clarity and to delete phrase "time periods of interest".
S 6-8. (CBR, U) *Charleston—Evidence for Clustered Behavior* In Section 6.1.2.1, the TI Team's assessment of "in" or "out" of a cluster requires more justification. While the TI Team appropriately discusses the evidence of long-term versus short-term behavior, the fact remains that there is direct evidence of repeated large earthquakes in the Holocene and little if any direct evidence that we are at the end of a cluster. Perhaps there needs to be some type of generic discussion of this issue in Chapter 5, with Workshop #2 providing the ITC background to characterize and assess this issue. Otherwise the assessment that we are at the end of a cluster seems to come across as somewhat arbitrary versus informed assessment. What is different between Charleston and other RLME sources such as Cheraw?	Generic discussion added to Ch. 5 regarding the issue of assessing clustered behavior.
S 6-9. (CC) *Charleston—Geometry and Style of Faulting* In Section 6.1.2.3, the discussion of boundary dimensions leading to the TI Team's conclusion that the boundary for the three source geometries is either strict or leaky requires more discussion. Given the assessed Mmax values, are the boundary dimensions too small to fit these magnitudes fully within the narrow source boundary relative to the other two source definitions? To the extent possible, quantitative discussion should be provided. The TI Team's assessment of using the default values for seismogenic crustal thickness requires additional justification. While all of the references cited for seismogenic crustal thickness are within the range for the default values, several suggest more preference (higher weight?) for values between about 15 and 20 km. Given this, the basis for assessing a weight of 0.4 to a seismogenic crustal thickness of 13 km is not clear.	Seismogenic crustal thickness distribution revised. Discussion expanded to provide additional rationale and justification for Narrow and Local source configurations.
S 6-10. (CC) *Charleston—Weights for Charleston Narrow and Regional Sources* In Section 6.1.2.3.1, the discussion of the basis for the weight assessed for the Charleston Local Source seems well developed. However, the discussion for the relative weighting of the Charleston Narrow and Regional sources is not clear.	Text revised to provide additional rationale for weights on Narrow and Regional source configurations.
S 6-11. (U, DMM, CBR, CC) *Contextual use of the term "microseismicity"* In Section 6.1.2.3.1, first paragraph, the use of the term "microseismicity" potentially leads to confusion about tectonic processes. "Seismicity" is defined in terms of the spatial and temporal occurrence of earthquakes, a generally accepted measure of space-time tectonic strain release in earthquakes. The term "microearthquake" is now generally accepted to mean an earthquake of **M** ≤ 3. But the PPRP is not aware of a community definition of the term "microseismicity." Consequently, the TI Team needs to explain its use of the term in the context of this evaluation. For example, is "microseismicity" used to	The term "microseismicity" has been removed from section.

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mean “seismicity of microearthquakes,” possibly implying a strain cycle process that is different from that implied by “seismicity”? The discussion should clearly convey how the TI Team evaluates “microseismicity” as one of the four observations cited as the basis for assessing the “Charleston Local source zone”?	
S 6-12. (CC, DMM) *Charleston—Recurrence* Given the uncertainty in length and completeness of the paleoliquefaction record and interpreted number of separate episodes, and the very general description of the process used to develop recurrence values contained in Section 5.3.3, the PPRP strongly encourages the TI Team to include a step-by-step example of the application of the procedure used for at least one of the RLME sources. This should include additional figures and text. This will significantly improve clarity and transparency. Consider the following criticisms, some of which apply to recurrence calculations and corresponding HID tables for other RLMEs: In Section 6.1.2.5, the recurrence method is noted to be “based solely on inter-event times estimated from the paleoliquefaction record.” What this section fails to communicate clearly to the reader—especially amid the elaborate analysis and description of those inter-event times— is that the methodology used to calculate the annual frequency of earthquakes of **M** ≥ 6.5 (Section 5.3.3.1.2) ultimately uses only the elapsed time since the oldest event in the sequence and the number of events counted. The Charleston RLME logic tree (12th node), for example, points the reader to the HID tables. Referring to those tables, it will not be readily evident to the reader that the key pieces of information are N and the elapsed time since the oldest earthquake in the sequence of N events. Also, given that the oldest earthquakes (Table 6.1.2-1) have an age specified by a range, an explanation is needed whether (or how) that uncertainty was addressed. The unalert reader (or analyst) examining the HID tables for computed annual frequencies for the Charleston RLMEs may potentially be confused by: (1) the inverted order for the 5-point distributions compared to Table 5.3.3.-1, which was used to define the 5-point distribution; and (2) the need to refer to Tables 6.1.2-1 and 6.1.2-2 to discern the elapsed time since the oldest earthquake counted in the sequence. For example, examining “Table Charleston_HID-3,” it may escape the reader’s attention that the 5-point distribution is not for four events in 5500 years, but rather four events in 1,524–1,867 years (or possibly in 1,569–1,867 years). To reproduce the results in the table (and for virtually all the Poisson-model tables in the HID), there is no explicit information about the exact elapsed time that was used. To add to the confusion, the text does not explain what the age ranges listed in Tables 6.1.2-1 and 6.1.2-2 represent. Do they represent the mean ± 2 sigma from the probability distributions in Figure 5.3.3- 2? As the reader progresses to the BPT renewal model there are terse descriptions of the weighting (without justification of the weights) and cross reference to Section 5.3.3 for methodology—but the text does not provide any discussion of the results. How do the BPT results compare to those for a Poisson model? Do they make sense?	Discussion of these issues added to Ch. 5 on the methodology for assessing recurrence for RMLE sources.
S 6-13. (CC) *Charleston—Time Period for Recurrence* In Section 6.1.2.5.2 the discussion of the completeness period of the paleoliquefaction record (at least the last three sentences) seems equivocal. However, the weight assessed for the shorter completeness period, 0.8, indicates a strong preference; additional	Text revised to provide additional clarity and rationale for relatively high weight on shorter completeness period.

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discussion seems required to justify the strong weighting.	
S 6-14. (U, CC) *Clear Representation of the Community's Knowledge for Characterizing Alternatives and Uncertainties* The discussion in Section 6.1.2.5.3 calls attention to the need for clear representation of the community's knowledge and uncertainty as the basis for characterizing alternatives in the logic tree and for assessing the community uncertainty distribution. We offer the following edited paragraph as an example for comparison with the original paragraph: The ninth branch of the Charleston logic tree represents alternative characterizations of the community's knowledge and the TI Team's assessment of the community uncertainty for recurrence of large earthquakes in the Charleston Seismic Zone, developed as part of the CEUS SSC Project (Figure 6.1.2-1). Alternative interpretations of the distribution of liquefaction features include a total of four large earthquakes in the past approximately 2,000 years and between four and six large earthquakes in the past approximately 5,500 years. The alternative characterizations represented in the logic tree are based on (1) interpreted length of the paleoliquefaction record; (2) interpreted types of constraining ages; and (3) evaluations of the area distribution and interpretations of which prehistoric liquefaction features were caused by large magnitude earthquakes centered in the Charleston area and which were caused by moderate-magnitude local earthquakes. The clarity of this section could be greatly improved by technical editing to better link the descriptions of the current knowledge with characterizations of alternatives in the logic tree and with the assessment of the community uncertainty distribution.	Text revised for clarity as recommended.
S 6-15. (CC) *Cheraw Fault—Evidence for Temporal Clustering* In Section 6.1.3.1, the discussion of weights assigned to in or out of a cluster requires additional discussion given the statements that there is no evidence to indicate that this source is out of a cluster. It is not clear what the differences are for this source relative to other sources, such as Charleston as an example.	Text modified to change weights from 0.8 to 0.9 for 'in cluster' and 0.2 to 0.1 for 'out of cluster' based on the lack of evidence to support a 'out of cluster' behavior.
S 6-16. (CC, U) *Cheraw Fault—Magnitude* In Section 6.1.3.3, p. 6-19, the discussion of relationships used to estimate magnitude from fault area includes "Somerville et al. (2001)." At various places in the Project report the citations for this relationship include Somerville et al. (2001), Somerville et al. (2005), and Somerville and Saika (2000). This needs to be double-checked and a validated reference cited (the Somerville references are in the gray literature and difficult to find, and the basis of the citation was not evident). A verifiable citation and reference need to be included in the Project database.On page 6-20, in the discussion of maximum and average displacement for the Cheraw fault the report notes: "There is insufficient information to establish whether the displacement per event measured at the ***sole trench site*** (emphasis added) along the Cheraw fault represents average or maximum values." In the last sentence of this paragraph, the report concludes the values are maximum values. The conclusion does not seem to follow from the discussion in the paragraph as written.	There is uncertainty regarding whether the displacement/event recorded at the site represents an average or maximum value for the fault as a whole. Revisions to text have been made to clarify uncertainty in the estimated range of average and maximum slip per event at the site. The Mmax distribution assigned to the Cheraw encompasses the range of **M** (6.8-7.2) suggested by displacements suggested by these revised estimates. Table 6.1.3-1 has been added to show the range of estimated magnitudes from different empirical relationships.
S 6-17. (CC) *Meers Fault—Clustered Behavior* In Section 6.1.4.1, the explanation of weights assessed for in or out of a cluster requires additional discussion, given the statements that there is no evidence to indicate that this	Additional discussion was added to Chapter 5 regarding the evaluation of clustering behavior for RLMEs.

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source is out of a cluster. It is not clear what the differences are for this source relative to other sources such as Charleston as an example.	
S 6-18. (DMM) *Meers Fault—Discussion of Potentially Relevant Data* In Section 6.1.4.2, potentially relevant data for the assessment are not discussed. Specifically, the Meers fault is located on the sector of the boundary of the Wichita uplift that has greatest structural relief by a wide margin. The magnitude of the structural relief between the Wichita Mountains and the Anadarko Basin is the source of a very large gravity gradient indicating significant induced stress across the northern Wichita Mountains frontal fault system along this sector. A discussion of these potentially important data should be included for perspective. Also, is "Arbuckle-Wichita-Amarillo uplift" a proper usage? A reference to the source of this usage is needed.	The section in question discusses the "localizing feature" branch of the logic tree. The presence of a gravity gradient was not used to argue whether the Meers-like activity should be localized on the fault or allowed to occur throughout the aulacogen. Also, a gravity gradient does not necessarily say anything about the state of stress on a fault system. The gravity gradient is used in helping to define the geometry of the zone and is discussed elsewhere in the section. A-W-A is a name used in the literature. See references in data summary table (e.g., Perry 1989). There is no need to cite a reference in the text just for this naming convention; the intention and meaning of the name is clear in the existing text.
S 6-19. (CC, U) *Meers Fault—Localizing Feature* In Section 6.1.4.2, it is not made clear in the discussion of the potential for the occurrence of Meers-like ruptures in the Oklahoma Aulacogen why "only one Meers-like structure is active within the aulocogen at a time."	Added "This interpretation is based on the fact that there is no evidence of Quaternary activity on other faults within the aulacogen."
S 6-20. (DMM, CC, U) *Meers Fault—Geometry and Style of Faulting* In Section 6.1.4.3, on page 6-24: When Meers-like earthquakes are allowed to migrate off the fault they are limited to occurring within the OKA. How are the earthquakes within the OKA to be modeled? The next paragraph suggests the strike to be N60W (parallel to the Amarillo- Wichita-Arbuckle uplift) with a dip between 40 and 90 degrees. However (and this comment holds for several of the other RLME sources), it is not clear how the analyst should model this situation. As a series of fictitious parallel faults distributed throughout the appropriate portion of the OKA? If so, how many are appropriate? This answer will clearly be determined by the location of the site of interest relative to the source. What was assumed by the hazard analysts for the demonstration and sensitivity calculations? On pages 6-24 and 6-25: The discussion indicates there is a significant amount of uncertainty in the appropriate H/V values to assign to the displacement observations. It does not seem as if this uncertainty is represented in the final recurrence values for the Meers RLME. Additional clarification seems necessary. On p. 6-24, third paragraph: The assignment of seismogenic thickness for the Meers fault source based on one reference seems to be inconsistent with how this parameter has been assessed for other seismic sources including Charleston. Consistency in assessment of each of the branches of the logic tree is an important consideration. If outside reviewers see inconsistencies in the assessment of weights for the logic tree branches, then their confidence in the overall assessment may be weakened.	Details of the source model implementation are provided in the HID. Recurrence for the Meers fault is based on the record of discrete faulting offsets in the trenches and does not depend on H/V ratios. The methodology for assessing seismogenic thickness for all seismic sources is the same and is discussed in Section 5.4
S 6-21. (CC, U) *Meers Fault—RLME Magnitude* In Section 6.1.4.4, the use of four seismic source dimension relationships to characterize and assess magnitude for this seismic source contrasts with the approach to other seismic sources. It is not clear why the Meers source is any different than other seismic sources to justify these differences. A consistent approach to characterizing and assessing magnitude based on source dimensions seems to be appropriate. There does not appear to be any unique property of the Meers fault that would justify using rupture	Unlike most of the other RLME sources, the Meers fault is a discrete mapped fault, thus allowing fault-specific characteristics to assist in the assessment of RLME magnitude.

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area relationships for the Meers fault but not other RLME sources such as Charlevoix, Charleston, or Cheraw.	
S 6-22. (CBR, CC) *New Madrid—RLME Magnitude* In Section 6.1.5.3, the use of unpublished information (Hough and Page) needs careful consideration. Has the paper been accepted for publication? Additionally, the text discusses the use of the characteristic earthquake recurrence model. Other sections of the text indicate that the characteristic earthquake recurrence model is not being used.	The Hough and Page manuscript has now been published: Hough, S. E., and M. Page (2011), Toward a consistent model for strain accrual and release for the New Madrid Seismic Zone, central United States, J. Geophys. Res., 116, B03311. References to the characteristic model have been deleted from this discussion. The model includes epistemic uncertainty in the average size of the RLME earthquakes, plus aleatory variability in the size of next earthquake of one-quarter magnitude unit. Section 5.3.3 has been modified to clarify this approach.
S 6-23. (CBR, CC) *New Madrid—Recurrence* Section 6.1.5.4 presents an insufficient basis for the assessed weights for the two alternative recurrence models characterized. The text should refer to Workshop #2 for discussion of this topic and present more information to justify the weight assessed for the renewal recurrence model.	Additional discussion of the basis for the weights added to the discussion of recurrence models in Section 5.3.
S 6-24. (CBR, CC) *Reelfoot Rift—Eastern Rift Margin Fault, Evidence for Temporal Clustering: Section 6.1.6.2* In Section 6.1.6.1, for this seismic source, the TI Team has assessed non-clustered behavior with a weight of 1.0. The evidence for this assessment is stated to be insufficient information on the number or timing of earthquakes. This contrast with other RLME sources where the main issue pertained to evidence of short-term versus long-term behavior and the logic that short-term rates cannot extend through extended time frames. That logic also appears to apply to the ERMF. The TI Team needs to develop a consistent approach to assessing clustered versus non clustered behavior.	The text has been revised to state… "The available data regarding number and timing of recent earthquakes and long term slip rates for the ERM sources are not sufficient to evaluate whether the ERM RLME sources exhibit evidence for temporal clustering. Therefore, this branch of the tree is not applicable to the Reelfoot Rift ERM_S and ERM_N RLME sources.
S 6-25. (CBR, CC) *Reelfoot Rift—Marianna Zone, Evidence for Temporal Clustering* In Section 6.1.7.1, the text states, "It also is unclear whether some of the paleoliquefaction features are due to earthquakes on the Eastern Rift Margin (ERM, RLME) source . . . ." Given this statement, it is not clear why this seismic source has a probability of activity of 1.0. The discussion and justification of the weight for temporal clustering need to be strengthened. Similarly, the basis for characterizing the seismic source boundary is "leaky" needs to be improved.	The size and number of features in the Marianna area suggest that most if not all of the liquefaction features are due to a local source rather than a more distant ERM source. It is acknowledged however that some of the paleoliquefaction features in the Marianna area could be related to an earthquake on the ERM. The text has been modified to clarify that there is evidence of a local source. Tuttle (WS #2) and others have suggested that seismicity migrates within the RRZ on a 5-15 kyr time frame. The apparent clustering of events in the early Holocene and lack of recognized events in the late Holocene has been postulated to support this concept (i.e., that the locus of activity is currently in the NMSZ rather than in the Marianna region). A statement regarding this concept has been added to support the 0.5 (in versus out) of a cluster weight assigned to this source. The 'leaky' boundary acknowledges that the location of the source of the earthquakes giving rise to the Marianna features is uncertain.

PPRP Comment Response Table

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S 6-26. (CC) R*eelfoot Rift—Marianna Zone, Geometry and Style of Faulting* In Section 6.1.7.2, last paragraph, the probability distribution on seismogenic thickness is different than the default distribution. Given this, the text should provide more details on the number of well-located earthquakes in this source and how they are used to establish a distribution on seismogenic thickness that is different than the default values.	The seismogenic thickness distribution in the Reelfoot rift is based on recent analysis and relocation of earthquakes using an improved velocity models for the northeastern part of the rift (Shumway, 2008) and along the eastern margin (Chiu et al., 1997). These studies indicate that the best located events lie within the upper 16-17 km of the crust. Therefore, this distribution rather than the default distribution was used.
S 6-27. (CBR, CC) *Reelfoot Rift—Commerce Fault, Evidence for Temporal Clustering* In Section 6.1.8.1, the text notes that the liquefaction and secondary faulting used to document Holocene events may be related to strong ground motion from earthquakes occurring elsewhere in the Reelfoot Rift. Given this statement, it is not clear why this seismic source has a probability of activity of 1.0. The basis for assessing a weight of 1.0 to nonclustered behavior is not clear.	The text has been revised to state… "The available data regarding number and timing of recent earthquakes and long term slip rates for the Commerce RLME source is not sufficient to evaluate whether the Commerce RLME source exhibits evidence for temporal clustering. Therefore, this branch of the tree is not applicable to this source.
S 6-28. (CC) *Reelfoot Rift—Commerce Fault, Geometry and Style of Faulting* In Section 6.1.8.2, last paragraph, the basis for characterizing the northwest and southeast boundaries of the seismic source as fixed and the northeast and southwest boundaries as "leaky" is not clear.	The northwest and southeast boundaries, which are defined by the general limits of the CGL as defined by Hildenbrand are sufficiently wide enough to cover the zone of surface faulting that has been identified by various researchers. There has been less work to define the northeastern and southwestern extent of the zone of Quaternary deformation and the geophysical lineament can be traced in both of these directions beyond the limits of the paleoseismic investigations. Therefore, the TI team judged that leaky boundaries would serve to represent the greater uncertainty in the possible extension of ruptures along the CGL.
S 6-29. (CC) *Wabash Valley—Temporal Clustering: Section 6.1.9.1* In Section 6.1.9.1, the basis for the weight of 1.0 on "in a cluster" needs to be improved and to be consistent with the bases for this assessment for all RLME seismic sources.	The last sentence of Section 6.1.9-1 has been revised to read…"Therefore, this branch of the tree is not applicable to the Wabash Valley RLME source."
S 6-30. (DMM, CC) *Wabash Valley—Future Ruptures* On pages 6-59 and 6-60 there is no specific discussion of how the future ruptures are to be modeled. The text refers to Table 5.4-1 (should be Table 5.4-1 and 5.4-2). But as noted previously, additional guidance for the hazard analyst would be useful.	The appropriate table callout should be Table 5.4-2 (not both Tables 5.4.1 and 5.4-2). The text is modified accordingly. The information provided in Table 5.4-2 and the associated discussion in the Section 5.4 text should be sufficient input for the hazard analyst.
S 6-31. (CC) *Wabash Valley—Alternative Mmax Zones* In Section 6.2, the discussion of alternative Mmax zones only discusses the Bayesian approach to Mmax estimation and its relevance to source zone characterization. The consistency of the results using the Kijko method should be discussed as well.	The results derived from the Kijko approach are now discussed.
S 6-32. (CC) *Criteria for Definition of Boundary—Mesozoic Extended Narrow Zone* In the last sentence of Section 6.2.1.1 on p. 6-64, the text states: "These observations support the weight of 0.8 that this geometry represents crust extended in the Mesozoic." The PPRP does not feel the section make the case well. A series of well written observations are presented, but the relevance of the observations to source characterization and specifically to a weight of 0.8 is not clearly articulated. This same comment applies to the other sections on Mmax zones.	Section 6.2 has been rewritten to better outline criteria used to differentiate MESE versus NMESE crust and more directly relate the weight assigned to the wide versus narrow geometries to these criteria.
S 6-33. (CBR, U) *Comparison of Recurrence Parameters to Catalog*	Two additional cycles of model-building and hazard feedback were conducted

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As discussed in Section 6.4.2, Figures 6.3-7 through 6.3-16 (should be corrected to read 6.4-7 through 6.4.16) show that the recurrence model for the large seismic source zones tends to overestimate the rates for magnitudes 5 or higher. What does this mean to the TI Team? A systematic trend such as the one discussed, should be questioned in detail by the TI Team in terms of evaluating whether all assumptions of the analysis are appropriate. The consistent overestimates of the rates suggest that assumptions related to smoothed seismicity may need to be adjusted to provide a better match between the recurrence model and observed seismicity. The PPRP strongly believes additional discussion and investigation is warranted regarding these results.	following the draft report, thus providing the TI Team the opportunity to question and review the recurrence results, both those related to recurrence plots and to spatial smoothing of recurrence parameters. The PPRP was an observer during these working meetings and briefings. The results are now judged by the TI Team to be reasonable relative to the observed rates from the catalog.
S 6-34. (CR, DMM, U) *Need for TI Team Assessment of Spatial Variation of Rate and bvalues* The results of the recurrence-rate analysis presented in Section 6.4 clearly show that TI Team assessments of priors on rate and *b*-values are required. The derived *b*-values in particular appear to be almost entirely below the range of values supported by studies world-wide over many years. We recommend that the Project arrange to further evaluate this analysis.	As suggested, such analyses occurred and changes were made to the recurrence model. Discussion of the recurrence methodology is given in Chapter 5.3.
Comments by Section ***Chapter 6 (Title)*** Given that 60 of the 70 pages in this chapter deal with RLME sources, the chapter title should be changed to something like, SSC MODEL: MMAX ZONES BRANCH AND RLME SOURCES.	Revision made as suggested.
Chapter 6 (Introductory text) In the introductory paragraph at the top of p. 6-1, after the second sentence, it would be helpful to most readers to repeat a very helpful description that appeared on p. 4-16f in Section 4.4.1: The "Mmax zones" model involves the direct use of observed seismicity by spatial smoothing of distributed seismicity and the inclusion of RLMEs that are defined primarily by paleoseismic evidence. The "seismotectonic zones" model involves the use of additional tectonic data to define the spatial distribution of future events.	Revision made as suggested.
Section 6.1.1 p. 6-2, 2nd paragraph: Regarding "(source IRM in the R model)": we assume this refers to the Canadian study; clarification is needed. p. 6-2, 3rd paragraph: The phrase "investigations undertaken for the . . ." probably should be "investigations evaluated . . . " The PPRP believes only evaluations were performed. ***Section 6.1.1.2*** Note: There are two sections labeled 6.1.1.2—one on p. 6.4 and one on p. 6-6. On p. 6.4, in paragraphs 3 and 4, "thrust" and "reverse" are used inconsistently vis-à-vis the definition provided in the Glossary for "Fault, Thrust" (< 45°) and "Fault, Reverse" (> 45°). On p. 6-6, 2nd paragraph, next-to-last sentence: ". . . favors three events to four based on field observations." A citation would be helpful.	Revisions and clarifications made as suggested.
Section 6.1.2.1 In last sentence of the first paragraph, the reader is referred to a non-existent Section	- Text revised to provide correct subsection call-out (5.1.2).

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5.3.3.6. In scanning Chapter 5, it's not clear that there is a "definition" of the temporally clustered earthquake model. On p. 6-8, 2nd full paragraph: No justification is given for weights on whether the Charleston RLME is "in" or "out" of a cluster. ***Section 6.1.2.5.3*** p. 6-14, last paragraph, line 10: Typo. (see See Appendix E . . .). ***Section 6.1.2.5.4*** The use of "occurrence model" in the section title and text is at odds with "recurrence model" used predominantly throughout the text (easily verified by a global search for "recurrence model," which shows repeated instances of "Renewal vs. Poisson recurrence models") and in the Glossary. There is at least one other appearance of "occurrence model" in the text (Section 4-19, p. 4-20, beginning of second full paragraph). "Occurrence" rates/probability also appears in Section 5.3.3.2 and should be corrected globally. ***Section 6.1.2.4.3*** p. 6-13, 2nd paragraph: "The UCSS magnitudes and weights . . . ." UCSS not defined.	- Generic discussion of in vs. out of cluster to be added to Ch 5. - Typo corrected - Text revised to replace term "occurrence model" with "recurrence model". - "UCSS" is typo. Deleted.
Section 6.1.3.2 p. 6-19, 3rd paragraph: The weights assigned to the two dip cases sum to a value greater than one. ***Section 6.1.3.4*** p. 6-21, second full paragraph, line 3: The term "interval-based approach" is ambiguous and potentially misleading. The data used are the number of earthquakes in a specified time interval (e.g., Figure 6.1.1-2, 7th node), not the interval between earthquakes, as some readers might assume. p. 6-21, fourth full paragraph, line 1: Consider replacing "occurrence rates" with "recurrence rates" p. 6-21, 4th full paragraph: Typo in cited recurrence values: 200, 350, and 500 years, should be k-years.	Change (0.5) to (0.4). The approach used to model recurrence for the Cheraw fault is interval-based. The text and description in this section have been modified to clarify this. Years changed to kyr
Section 6.1.4.5 2nd par., line 4: Typo. Change "500,00 years" to "500,000 years"	Changed
Section 6.1.5 In the Table on the top of p. 6-33: The note for the 1811-1812 earthquakes indicates 138 yr BP ± 100 yr. As written, suggests the uncertainty is 100 years; this needs to be clarified. ***Section 6.1.5.3*** p. 6-39, last paragraph: The text references Table 6.1.5-3 which appears to be missing. ***Section 6.1.5.4*** p. 6-41, first full paragraph, last sentence: Replace "only includes of all three" with "only includes the alternative of all three components" p. 6-41: The paragraph containing equation 6.1.5-1 is not clear. The use of the equation needs to be explained within the source characterization scheme.	Text (and table will be modified to discuss in detail the analysis, data used, and results Table 6.1.5-3 will be included in the final report p. 6-41 (first full paragraph) sentence corrected as suggested. p. 6-41—deleted the last paragraph that included the equation.
Section 6.2.1.2	Section 6.2.1.2 has been rewritten. Typo comment is thus obsolete See

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p. 6-66, 2nd full paragraph line 9: Typo. (** mi) ***Section 6.3*** line 4: Typo. “source(described…” ***Section 6.3.1*** p. 6-69, first full paragraph, line 9: Reference is made to “the 1882 earthquake”; this event is not in the table on the previous page and there is no context. Adding a short descriptive sentence for clarity would help the reader. ***Section 6.4.1*** In the first line, change “Figures 6.3-1 through 6.3-6” to “Figures 6.4-1 through 6.4-6” ***Section 6.4.2*** In the first line, change “Figures 6.3-7 through 6.3-16” to “Figures 6.4-7 through 6.4-17” ***Figure 6.1.1-1*** Two of the large earthquakes are incorrectly labeled: 1663/2/5 is labeled **M**=3.71 (text in Section 6.1.1 says “**M** 7”; 1791/12/6 is labeled **M** 5.5 (text in Section 6.1.1 says “**M** 5.8). The labeled magnitude for only one of the other three large earthquakes corresponds exactly to the text in Section 6.1.1. ***Figure 6.1.1-2*** In the Charlevoix RLME logic tree, the header for the 10th node should be changed from “Earthquake Occurrence Model” to “Earthquake Recurrence Model” (see comment on Section 6.1.2.5.4). ***Figure 6.1.2-1*** In the Charleston RLME logic tree, the header for the 10th node should be changed from “Earthquake Occurrence Model” to “Earthquake Recurrence Model” (see comment on Section 6.1.2.5.4). ***Figure 6.1.2.4*** Figure 6.1.2-4 shows the three zones along with the magnitude and gravity anomalies. It is not clear how these zones were delineated based on these geophysical data. ***Figure 6.1.3-1*** In the Cheraw RLME logic tree, under Recurrence Method, the uppermost branch should more correctly be labeled “Earthquake Count in Time Interval” (as for the Charlevoix RLME logic tree instead of “Inter-event Times.” ***Figure 6.1.3-1*** In the Meers RLME logic tree, under Recurrence Method, the upper and lower branches should more correctly be labeled “Earthquake Count in Time Interval” (as for the Charlevoix RLME logic tree) instead of “Inter-event Times.” In the corresponding HID tables (Table MEERS_HID-2 and HID-3), information on the data set (N events, T time) should usefully be provided, as in Table Marianna_HID-2. ***Figure 6.1.5-1*** In the logic tree for the NMFS RLME source, under Equivalent Annual Frequency, references to the HID tables should be labeled NMFS instead of NMF. Under Events/Data, the labeling of “1811–1812, 1450 AD, and 900 AD” is difficult to relate to the dates in the table presented at the top of p. 6-33 (for example, 900 AD corresponds to 1110 yr BP—but in the table one finds “1,050 yr BP ± 150 yr). Exactly which elapsed time was used in Table NMFS_HID-2? (In that table, information on the data set (N events, T	revised Section 6.2.1.2 Figure 6.1.1-1 labeled modified. Figure 6.1.6-2 The star represents paleoseismic investigation sites. This will be added to the explanation. Tables 6.1.5-1, 6.1.5-2, and 6.1.5-3 will be included in the final draft. Logic tree labeling of approaches made consistent throughout Clear descriptions of the data used for each RLME recurrence calculations are provided in each section along with tables of the results.

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time) should usefully be provided, as in Table Marianna_HID-2. ***Figure 6.1.6.2*** What are the yellow stars on the figure? No explanation in legend or caption. ***Figures 6.4-1 through 6.4-6*** Consider adding a note to the caption explaining what the mean maps are. ***Tables 6.1.5.1, 6.1.5.2, and 6.1.5.3 missing*** Table 6.1.5-1 discussed on page 6-32 is missing. Table 6.1.5-2 discussed on page 6-37 is missing. Table 6.1.5-3 discussed on page 6-39 is missing.	
CHAPTER 7—SSC MODEL: SEISMOTECTONIC ZONES BRANCH	
General Comments **G 7-1. (NAR)** In this chapter, as in Chapter 6, the TI Team has described and evaluated an immense amount of data and information and deserves praise for its efforts. The chapter addresses the "seismotectonic zones" branch of the master logic tree, as developed in Chapter 4 and portrayed in Figure 4.4.1-11 (and companion figures referenced therein). The TI Team's assessment is supported by Data Evaluation and Data Summary tables in Appendices C and D. This conceptual branch of the logic tree splits into two source groups—seismotectonic zones and the independent RLME sources, described in Chapter 6. Chapter 7 deals only with the twelve seismotectonic zones and their seismic characteristics.	No revisions required.
G 7-2. (CBR, CC) A significantly higher weight is assessed for the seismotectonic zones branch relative to the "Mmax zones" branch. As stated in Section 4.4.1 on p. 4-17: "A higher weight (0.8) is assigned to the seismotectonic zones branch than the Mmax zones branch (0.2) because the seismotectonic zones branch allows for more relevant information on the characteristics of future earthquakes to be included in the model." This information is the subject of the majority of Chapter 7. However, no full explanation or validation is presented in the introduction to this chapter to support the decision on the specific weights assessed for the two conceptual approaches at the front end of the master logic tree. A description of the justification of the weights would be an important and useful addition to the chapter.	The discussion of the basis for weights has been bolstered in Section 4.2.1. It is not appropriate to repeat that discussion in Chapter 7, but reference is made back to Section 4.2.1.
G 7-3. (CC, DMM, U) Although the chapter provides an abundance of geological detail, it fails to make a compelling case for identifying many of the seismotectonic zones as separate sources distinct from the larger Mmax zones described in Chapter 6. Considering the weight that is given to this branch (0.8), it is especially important that the definition of each of the seismotectonic zones be very clear and well supported with convincing evidence. Unfortunately, a persuasive case is not developed for the identification of several of the zones described in this chapter.	Each section of Chapter 7 includes a summary of the bases for identifying the seismotectonic zone, and the criteria that define each zone are summarized in Table 4.1.3-1. Each section has been reviewed and revised, as necessary, to ensure that the bases for the seismotectonic zones are adequate and clear.
G 7-4. (CC, DMM) The identification of the zones appears to be made largely on the basis of isolating regions of differing geological and tectonic histories that may have little direct relevance to the SSC characterization criteria that are specified in Section 4.3.3 (p. 4-14). These criteria are : (1) earthquake recurrence rate, (2) maximum earthquake magnitude, (3) expected future earthquake characteristics (e.g., style of faulting, rupture orientation, depth distribution), and (4) probability of activity of tectonic feature(s). The latter criterion was not used in developing the CEUS SSC model (Section 7.1, pg. 7-1), but no	The bases for identifying the seismic source zones in the CEUS SSC model indeed come from the four criteria. The statement that the fourth criterion was not used is incorrect and has been removed. Examples of the application of the criterion are the Meers fault and Cheraw fault. Discussions of the bases for identifying each of the seismotectonic zones have been revised to tie the discussion back to the four criteria, as applicable. As suggested, Table 4.1.3-1 has been added to summarize how the Mmax zones and the seismotectonic

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justification is given for not addressing this criterion. Furthermore, there is no uniform or systematic description of the application of the first three criteria which allow ready identification of the merits of the zones and which permit comparison among zones. Additional information pertaining to how the sources meet the defining criteria and more systematic organization of the content of the description of the zones would increase the rigor of the decisions reached in the report and their presentation. A summary table specifying the critical information that identifies each source zone based on criteria described in Chapter 4 would be helpful in organizing the information and comparing source zones.	zones relate to the four seismic source identification criteria.
G 7-5. (CC) Chapter 7 includes an impressive compilation of information and interpretations representing the range of relevant current knowledge of the scientific community. The scope and detail of this information are important in identifying and characterizing the seismotectonic zones and will be of great value to future users of the CEUS SSC Model. This information is well supported by comprehensive and timely references to the scientific literature. The level of detail is generally consistent throughout the description of the zones, but unfortunately the organization of the descriptions is not consistent. For example, some source zones have initial sections dealing with Background, others with Geologic Evidence, and still others with Basis for Defining Seismotectonic Zone. This lack of consistency in the description of the identified zones is an impediment to the review and comparison of the zones and needs to be corrected. The uneven descriptions appear to be due, in part, to multiple authorship, and some subsections apparently have not been updated since the application of the Kijko Mmax procedure in the Project. Some updating and rewriting appears warranted to alleviate these problems.	The sections have been organized to be comparable section to section.
G 7-6. (CC) The level of detail in this chapter is high, which will be useful in future seismotectonic studies within the CEUS. However, this level of detail will make it difficult for those readers of the report not well versed in the geology and geography of the region or the geologic time scale to comprehend the significance of the detail. Thus, to support the detail it would be advisable to (1) add maps that identify the location of geologic features, (2) provide more geologic terms in the glossary, and (3) accompany the glossary with a geologic time scale. Additionally, the descriptions of the seismotectonic zones should be reviewed to determine if some of the more specialized terminology, e.g., essexite, T-axes, Neoproterozoic, can be eliminated or simplified so that they can be meaningful to the spectrum of users of the report.	Locations referred to in the text have been added to the maps, terms have been added to the glossary, and a geologic time scale has been added to the glossary. Terminology has been simplified wherever possible to avoid unnecessary jargon. Figures 7.3.1-2, 7.3.2-2, -3 added. Labels for places discussed in text added to all relevant figures; deleted mention of specific alkaline rocks, including essexite in Section 7.3.2.1. Deleted mention of T-axes in section 7.3.1.4
G 7-7. (CC, SSHAC) As with previous chapters, this chapter could be greatly improved by a thorough technical edit. There are numerous editorial modifications required to achieve consistency in presentation, remove editorial errors, and improve clarity. Special attention should be given to clearly describing the bases for characterizing alternatives represented in alternative branches of the logic tree. Also, consideration should be given to describing the basis for the assessed weights for alternative characterizations representing the community uncertainty. Finally, care must be exercised to use words in their correct meaning, avoid casual terminology, and use terms that properly convey the essential activities of characterization of alternatives and assessment of the community uncertainty.	All sections have been reviewed and revised relative to describing all branches of the logic tree and the technical bases for the weights assigned to each branch.
G 7-8. (DMM) The Data Summary Tables of Appendix D are an important supplement to the descriptions of the seismotectonic zones. Unfortunately there appear to be omissions in Appendix D so that supporting information is not consistently available for this draft	All Data Summary tables are now included in Appendix D.

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chapter. This will need to be remedied in revision of the report. Additional comments on Appendix D are given in a review of that segment of the report.	Added key references from text to Date Evaluation tables.
Specific Comments **S 7-1. (CC)** *Suggestion for Rewrite of Introductory Paragraph* The introduction to Chapter 7 could be improved with significant editing. Consider the following as an example. As discussed in Section 4.3, the Conceptual Framework for assessing the CEUS SSC model is characterized by two alternative branches of the master logic tree: the Mmax zones branch and the seismotectonic zones branch. The seismotectonic zones branch, which is assessed a higher weight of 0.8 versus 0.2 for the Mmax zones branch, subdivides the CEUS SSC region according to differences in the seismic source assessment criteria described in Section 4.3.3. A common element of both the Mmax zones and the seismotectonic zones branches is the RLME sources. Because the paleoearthquake data that indicate the presence, location, and size of the RLMEs are essentially independent from data used to assess seismotectonic sources, the RLME branch is present in both models. An overview of the approaches for characterization and assessment of the zones is in Section 7.3.	Revision made using most of suggested example.
S 7-2. (DMM) *Need for Specifics Regarding Geologic Conditions that Affect Mmax* The first paragraph of Section 7.1 (p. 7-1) describes how the seismotectonic zones branch relates to Mmax. The basic premise is that regional differences in characteristics related to Mmax and/or future earthquake characteristics are best dealt with by identifying source zones of uniform properties. A region may possess characteristics that would lead to a different Mmax than adjacent regions, including a different prior distribution or different maximum observed earthquake. Mmax was described in Chapter 5, but it would be helpful to the users of the report for the authors to present examples of specific physical properties of the zones (e.g., thinner crust, lithospheric strength characteristics, aulacogens) and describe why these different conditions might result in different Mmax distributions. This information would help to sharpen the need for, and the significance of, the detailed information in the subsequent text which define Mmax and future earthquake characteristics.	Examples and discussion added to Section 7.1 to illustrate the manner in which the zones were identified and how they differ from one another. The methodologies for assessing Mmax are described in Section 5.2. As discussed therein, the only physical characteristic that is important for the Mmax assessment is whether or not the zones show evidence of Mesozoic or younger extension. Otherwise, the differences in future earthquake characteristics of the various zones are described in Section 5.4 and summarized in Table 5.4-2. There is no explicit connection between these characteristics and Mmax.
S 7-3. (CC) *Description of Charlevoix RLME Source; Section 7.3.1.1.3, pg. 7-6.* In Section 7.3.1.1.3 (p. 7-6), the description of the Charlevoix RLME seismic source (which is assumed to exist as a distinct seismic source) as part of justifying the St. Lawrence Rift (SLR), confuses the understanding of whether the SLR is a distinct seismotectonic zone. Part of the confusion relates to how the project is using historic earthquakes as part of the development of recurrence and maximum magnitudes. Are the historic earthquakes assigned to the SLR, even though they may be located within the boundaries of the Charlevoix RLME source?	Text in Section 6.1.1 and 7.3.1 clarified to indicate which earthquakes are considered RLMEs. Text in Section 7.3.1.1 introduces Charlevoix and other portions of the SLR seismotectonic zone such as the Ottawa-Bonnechere graben, Saguenay graben, and lower St. Lawrence as crust within SLR that exhibits varying rates of seismicity.
S 7-4. (DMM) *Significance of Vp/Vs Ratio* On p. 7-14 of Section 7.3.2, under *Geophysical Evidence*, what is the significance of results from teleseismic receiver functions described in last sentence of this section?	Eaton et al. (2006) do not interpret the result of variable Vp-Vs ratio: "Finally, region 3 is an area of thin crust (<38km) and variable VP/VS ratio. This area is entirely located northeast of the Ottawa–Bonnechere graben, a post-Grenvillian extensional feature that formed during the opening of the Iapetus ocean (ca. 0.7Ga; Kamo et al., 1995). It is interesting to note that region 3 appears to coincide with the Western Quebec Seismic Zone (Fig. 14), an area

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	of relatively intense intraplate seismicity." It could be judged that variable Vp-Vs ratio could be attributed to intrusion of mafic rocks into felsic host rock, but the authors have not made that interpretation.
S 7-5. (DMM) *Evidence for Separating the Northern Appalachian Seismic Zone from the Paleozoic Extended Zone* In Section 7.3.3.2 (p. 7-20), under *Basis for Zone Geometry*: The separation of the Northern Appalachian seismic zone (NAP) from the similar Paleozoic Extended zone (PEZ) to the south appears to be largely based on the location of the Triassic Hartford basin. However, a linear connection of the eastern boundaries of these zones would include only a small segment of the northern extent of the basin as shown in Figure 7.3.7-1 similar to the situation observed farther south along the boundary of the PEZ. Is the termination of the NAP being driven by the studies of Adams et al. in defining the seismic source zones of Canada?	Boundaries of PEZ-N modified on the west to follow the NY-AL lineament and the western boundary of the Hartford Basin. The southern boundary of the NAP seismotectonic zone follows the northern boundary of the Hartford basin.
S 7-6. (DMM) *Future Earthquake Characteristics;* In Section 7.3.3.4 (p. 7-21), under *Future Earthquake Characteristics* for the Northern Appalachian seismotectonc zone, the text notes that all earthquakes with known depths are relatively shallow, but goes on to use the default depth distribution for the seismic source. The basis for assigning the depth distribution for distinct seismic sources, including the NAP, should be based on a common approach to using earthquakes with known depths. Otherwise, assignment of the default depth distribution lacks rigor. Also note that a search of Chapter 5 shows no "default depth" term.	All estimates of seismogenic crustal thickness have been assessed using the same approach, as described in Section 5.4.
S 7-7. (DMM) *Background of the Paleozoic Extended Zone* In Section 7.3.4.1, the text needs to make clear that the Giles County Seismic Zone, the Eastern Tennessee Seismic Zone, and the Clarendon-Linden Fault System, are not unique from a seismotectonic perspective. Otherwise it is not clear why these features are not considered distinct seismic source zones.	Text reorganized to include large regional data and conceptual framework in the background section and specific seismological characteristics of zones of historically elevated seismicity within subsections.
S 7-8. (DMM) *Basis for Western Margin of the Paleozoic Extended Zone* In Section 7.3.4.2 (p. 7-29), under *Basis for Zone Geometry*: A reentrant of the Paleozoic Extended seismic zone extends into the craton in the vicinity of Kentucky, moving the western margin of the zone farther west. There is no support for this feature in the text of the report. The reference in the report that is used most extensively in defining the western margin is Wheeler (1995), but his studies did not indicate this reentrant; rather his margin to this zone in essentially a straight line through this region. A strongly supported description of the cause of this feature is needed or it should be eliminated. No references are cited to provide an indication that this feature is present.	Geometry of PEZ alternatives have been redrawn. The western boundary of PEZ_N follows the NY-AL. Crust northwest of the NY-AL lineament appears to have behaved as a rigid, somewhat coherent block, and its sharp boundary against the anomaly implies the edge of this competent block (Steltenpoh et al., 2010). Crust of the reentrant in the vicinity of Kentucky consists of the Rome Trough and is now included in the PEZ-W alternative geometry. The Rome trough is an Cambrian graben that appears to be related to reactivation of the NY-AL lineament (Stetlenpohl et al., 2010) or the East Continent Rift Basin (Drahovzal, 1997; Stark, 1997).
S 7-9. (DMM) *Basis for Identification of the Illinois Basin Extended Basement Zone.* In Section 7.3.5.1 (p. 7-33), the justification for defining this region as a distinct seismotectonic zone and the discussion in this section are not consistent with the criteria defined in Section 4.3.3 for defining seismic source zones.	The arguments for defining the IBEB as previously stated primarily address magnitude and future earthquake characteristics (i.e., allows for use of both MESE and NMESE Mmax priors; specification of future earthquake characteristics based on analysis of seismicity in southern Illinois, basement and Paleozoic structural trends). The higher rate of seismicity in this region may stem from some of the same

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	mechanisms proposed for the adjacent NMSZ/Reelfoot rift region to the south. This also suggests that the IBEB is different from the surrounding craton regions.
S 7-10. (CC, DMM) *Default Values of Future Earthquake Characteristics in the Eastern Continental Crust-Atlantic Margin; Section 7.3.7.4, pg. 7-48.* In Section 7.3.7.4 (p. 7-48), the text discussing seismicity notes that most well located earthquakes of the Eastern Continental Crust-Atlantic Margin are distributed throughout the upper 13 km of crust. Given this information, the basis for assuming that the seismogenic thickness should be represented by the default values is not clear.	The weights on the default values of 13, 17, and 22 km have been modified to place a higher weight on shallower depths for the ECC-AM. The weights of 0.6, 0.3, and 0.1 result in a slightly shallower mean seismogenic depth than the default weights of 0.4, 0.4, and 0.2.
S 7-11. (DMM) *Additional Basis for Defining the Atlantic Highly Extended Crust* In Section 7.3.8.1 (p.7-49), under *Basis for Defining Seismic Zone*: Canadian seismologists have recognized the zone of weakness at the Atlantic Ocean margin as defined by the continental slope as a zone of potential seismic activity based on the location of the magnitude 7.2 1929 Grand Banks earthquake, which occurred east of the northern tip of Nova Scotia. This earthquake, as well as the Baffin Bay earthquake in Canada, is supportive of the identification of this seismic zone.	We agree that the occurrence of the two mentioned earthquakes could be used to argue for the presence of a zone of weak crust. However, following our methodology for defining seismic zones, the occurrence of the earthquakes, and/or the arguments for a weaker crust, are not criteria for defining zones, so they are not discussed within this section of the report.
S 7-12. (CC, SSHAC) *Clarification of Text Describing the Basis for Mmax of the Extended Continental Crust-Gulf Coast* In Section 7.3.9.3 (p. 7-56), *Basis for Zone Mmax*: The characterization and assessment of Mmax described in this section is unclear. First, use of the term "scenario" (meaning imagined or possible) can convey a lack of disciplined evaluation of the available data for characterizing Mmax for the zone as required by the SSHAC assessment process. Replacing "scenario(s)" with "alternative characterization(s)" would properly convey that the characterizations represent the range of uncertainty based on evaluations of the available data. Second, the third alternative is described as follows: "The largest observed earthquake is the potential paleoearthquake identified from the studies of . . . ." The use of "largest observed earthquake" and "potential paleoearthquake" seems incompatible. In addition, the characterization described here clashes with the strong conclusion stated in Section 7.3.9.5. Elaboration is needed better explaining the evaluations performed supporting the third alternative characterization.	Revised as suggested with the exception of comments regarding paleoliquefaction. There is no strong evidence of repeated earthquakes in the ALM area, but there is potential evidence of one paleoliquefaction event. Also, we don't see the incompatibility in using a potential paleoearthquake as the largest observed earthquake. Including this possibility is part of capturing the uncertainty in the largest observed earthquake. Changed to "alternate characterizations"
S 7-13. (DMM) *Additional Evidence for Defining the Gulf Highly Extended Crust*; In Section 7.3.10.1 (p. 7-59), under *Basis for Defining Seismotectonic Zone*, is there evidence of faulting in this zone as anticipated in a highly extended zone? If so, that would be additional evidence for defining the zone.	There is no evidence of seismogenic Quaternary faulting within this zone.
S 7-14. (DMM) *Evidence Regarding Characterization of the Gulf Highly Extended Crust* In Section 7.3.10.3 (p. 7-60), under *Basis for Zone Mmax*, there are substantive analyses that show the event of February 10, 2006, to have been a landslide. These analyses must be referenced and discussed as part of the data base for characterizing and assessing Mmax for this zone.	Added discussion of this event, but note that there has not been any research published in peer-reviewed journals that demonstrates that the event was a landslide, and all available literature is listed in the data summary tables.
S 7-15. (CC,DMM) *Need to Strengthen the Basis for Defining the Oklahoma Aulacogen as a* *Distinct Seismic Source Zone* In Section 7.3.11.1 (p. 7-62), under *Basis for Defining Seismotectonic Zone*, the text mentions "default future earthquake characteristics." This terminology has not been used	The basis for defining the zone follows from the methodology outlined in Section 4.1.3.3. The description of this methodology has been modified for clarity.

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systematically throughout Chapter 7 (with reference to Table 5.4-1), and in this section it is not clear why these are the primary basis for defining the seismotectonic zone versus the full set of criteria found in Section 4.3.3. While future earthquake characteristics are one of the criteria used to define distinct seismotectonic zones (see Section 4.3.3), there does not appear to be anything profoundly unique about the style of faulting or the strike of ruptures to support defining the Oklahoma Aulacogen as a distinct seismotectonic zone. The basis for defining the Oklahoma Aulacogen as a distinct seismotectonic zone is weak and needs to be improved.	
S 7-16. (CC) *Significance of Statement in Description of Northeast Ohio Seismic Zone in the Midcontinent Seismic Zone* In Section 7.3.12.1.4 (p. 7-68), for the Northeast Ohio Seismic Zone: The third bullet of the second paragraph is meaningless to the reader without additional description of its significance.	Text added to clarify this statement. Additional discussion provided of age and location (significance) of the sand pit exposure.
S 7-17. (DMM) *Effects of Smoothing on Recurrence Parameters* In Section 7.5 (p.7-71), Recurrence Parameters: The objective smoothing results in *b*-values that are low, possibly below the range of values known from world-wide experience. Yet, no alternative is suggested. Additional elaboration of the analyses must be provided to adequately inform future users of the CEUS SSC model.	Recurrence has been reassessed based on the Final SSC model and there is a reasonable match between the observed recurrence and the predicted recurrence based on the objective model.
S 7-18. (DMM) *Full Explanation of the Results Shown in Figures 7.5.2-9 to 7.5.2-42* Many of the data shown in Figures 7.5.2-9 to 7.5.2-42 indicate the poor fits of the realizations to the catalog. This is disturbing and needs to be more clearly explained in the text. Why doesn't the preferred model fit the catalog data better? Only the short text in section 7.5.2 describes these figures. The text should be enhanced to describe the fitting issues, and as a result there needs to be full justification of the rate and *b*-value maps for the seismotectonic zones.	The recurrence based on the Final SSC model shows reasonable fits between the realizations from the model and the observed counts.
Comments by Section ***Section 7.3.1.2*** This section never actually describes why the St. Lawrence Rift should be a distinct source zone. There is some discussion of geometry, but no well defined case for "why" (unless it is simply because the GSC did). ***Section 7.3.1.3*** At least some mention of the implications or importance of the observations to the Kijko model should be provided. This comment applies to all the individual zone sub-sections. Perhaps consider doing it at the beginning of Chapter 7.	SLR seismotectonic crust separates crust initially rifted in the Paleozoic and subsequently reactivated during the Mesozoic into one zone with a maximum magnitude distribution derived from a Mesozoic and younger prior. Text in section 7.3.1.1 better introduces subsections describing portions of the SLR seismotectonic zone that display different geological or seismological characteristics and seismicity rates. Text added giving results from Kijko approach. Discussions of the Kijko approach are a part of section 5.2.
Section 7.3.2 last bullet, p. 7-13: If the hotspot has been tracked farther **to** the northwest, why isn't the seismic source zone extended to the northwest? ***Section 7.3.2.1*** This is one of the few Seismotectonic Zone subsections that actually develop a clear summary for why this should be a separate zone. ***Figure 7.3.2-1*** As on similar maps in the report, Figure 7.3.2.1 should show the magnitudes of the starred earthquakes.	Moved discussion of Ma and Eaton (2007) indicating that seismic portion of the hotspot track corresponds to the transition from kimberlitic dikes to plutons. Also, Figure 7.3.2-2 shows that the hotspot track northwest of the seismic zone is aseismic. Labels added.

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Section 7.3.3.1 This section discusses the basis for proposing the NAP zone. It states: "The basis for defining the NAP seismotectonic zone centers primarily on the concept that terranes of this zone formed outboard of the Laurentian margin after Iapetan rifting and were subsequently accreted to the passive margin." This subsection is weak in terms of developing a basis for defining the NAP as a separate zone. The text focuses on geological arguments that are never specifically tied to the SSC criteria. The reader is left to infer this zone may or may not utilize a different Bayesian Mmax prior than adjacent regions.	Clarified section to illustrate why a Paleozoic and younger Mmax prior does not apply and why a Mesozoic and younger prior does. Further tectonic and seismological arguments are used to distinguish between ECC-AM which also has a Mesozoic and younger prior.
Section 7.3.4 Use of the term "IRM" changes from describing a continental margin in the first sentence of the introductory paragraph of Section 7.3.4 to a seismic zone later in the paragraph. This is confusing. Similarly, note that the labeling of the PEZ in Figure 7.3.4-1 appears to be incorrectly labeled as IRM. ***Section 7.3.4.1.4*** Suggest that the reference to Steltenpohl et al. in Geology, June 2010, v. 38, p. 571-574 be added to the list in the second paragraph. ***Section 7.3.4.1.6*** p. 7-27: At the end of the second paragraph of this section reference is made to "a Class C tectonic feature." It would be helpful to the reader to cite where in this report the classes of the tectonic features are defined and thus the significance of this information to seismic source identification. ***Section 7.3.4.1.6*** p. 7-29, paragraph at top of page: The discussion of a lack of observed paleoliquefaction features should also be used with the appropriate qualification. Specifically, the observation that paleoliquefaction features provides strong evidence for past strong earthquake shaking, should be accompanied with a remark that failure to identify such features does not provide an equally strong a case for the absence of strong shaking.	Restricted usage of IRM as a concept of the Iapetan rifted margin. Discussions based on this reference have been added throughout the section. Statement deleted. Statement added.
Section 7.3.5 p. 7-32: The use of "Basement" in the title of this zone does not appear to be consistent with the titles given to other seismotectonic zones of the CEUS. ***Section 7.3.5.1*** p.7-33, 2nd bullet: In discussing the basis for defining the IBEBZ zone the text states, "The southern part of the Illinois basin is one of the most structurally complex areas of the Midcontinent." How this directly impacts the SSC needs to be more clearly elaborated, or deleted. On the following page in the next bullet the text states: "An extensive series of moderately dipping reflectors is present in the basement, part of which may have been reactivated by the 1968 mb 5.5 earthquake." Are the reflectors then interpreted to be faults? Also, the 1968 earthquake may have occurred in response to reactivation of the reflectors (if they are in fact faults), but not vice versa. ***Section 7.3.5.2*** p. 7-34: Suggest clarification of last sentence in second paragraph with something like: "The margins of the volcanic layered sequences, especially to the south and west, are marked by prominent coincident closed-contour magnetic and gravity anomalies which	p. 7-32: The names applied to the various zones reflect both geographic and geologic information. The IBEB zone is defined in part on its structural and tectonic setting that influenced our characterization of Mmax priors. Evidence for reactivation of extensional structures in the Precambrian basement was considered in this assessment; hence, this was included in the name assigned to the zone. p. 7-33: Additional text has been added to the observations used to define the IBEB as a seismotectonic zone. The mid-crustal reflectors are interpreted to be faults and the revised text clarifies the terminology. p. 7.34 Sentence modified as suggested. p. 7-35: A summary of the article to the Data Summary table for the Illinois Basin-Wabash Valley has been added. The Omaha intrusive mentioned is

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are derived at least in part from mafic volcanic rocks and intrusions . . . ." ***Section 7.3.5.3*** pg. 7-35: In considering the Mmax of this zone it may be useful to consider the presence of numerous late Paleozoic ultramafic intrusions (dikes and sills) into the sedimentary section of this region. See, for example, Sparlin and Lewis in Geophysics, v. 59, p. 1092-1099 (1994).	actually in the WV RLME source zone.
Section 7.3.6.5 **(CC)** ***Develop table for future earthquake characteristics in Reelfoot Rift zone;*** *pg. 7-42.*p. 7-42, text box: The characteristics of future ruptures in the Reelfoot Rift zone listed in the text box at the end of Section 7.3.6.5 should be placed in a numbered table with headings.	This table is being deleted from the revised text. Reference made instead to Table 5.4-2.
Section 7.3.7 p.7-47, first full paragraph, line 5: The text refers to the unlikelihood of a maximum magnitude earthquake of greater than 7 because of the paucity of paleoliquefaction features in the region. Could Mmax be less than 7? ***Section 7.3.7.1*** In the second line of the first paragraph, "large" earthquakes are specified as **M** > 7. Should be **M** ≥ 6.5 to be consistent with the value used elsewhere for the RLMEs.	p. 7-47: The statement reflects the interpretations made by Obermeier and McNulty (1998). It is possible that the paucity of paleoliquefaction data could suggest that the largest mid-late Holocene event could be even smaller than **M**7, but it would more difficult to support that conclusion. 7.3.7.1: In this context, "large" earthquakes refer to the M≥7 events in Mesozoic and younger extended crust observed in the global earthquake catalog compiled as part of the Johnston et al (1994) EPRI study. At the time of that study, the only stable continental earthquakes of M≥7 had occurred in Mesozoic and younger extended crust. The use of "large" was not intended to reflect the same definition of RLME. To avoid any confusion the text is modified and the term "large" is removed.
Section 7.3.9.2.1 p. 7-52, last bullet: The point could be illustrated with reference to the appropriate magnetic anomaly figure. ***Section 7.3.9.2.4*** p. 7-55, first full paragraph: Suggest that the last sentence be modified to something like: "The source zone is extended north of the Southern Arkansas fault zone for several reasons:"	Reference to figure added. Suggested change made.
Section 7.3.10 In the title of this section, for consistency with previously described seismic source zone, suggest the title of this zone be "Gulf Coast Highly Extended Crust."	Revision made as suggested.
Section 7.3.11.3 This subsection is an example case where adding an additional sentence could improve the clarity, consistency and transparency of the document. The Bayesian approach is the only Mmax approach used for this zone. It would be helpful to the reader to note that specifically or state the Kijko approach was not used due to a high *p*-value. Some zones are explicit in describing the two approaches, some are not.	Revision made as suggested.
Section 7.3.12.1.2 pg. 7-65, first full paragraph, line 4: Suggest beginning sentence with, "The deformation during this interval is attributed to" instead of "It is attributed to" ***Section 7.3.12.2***	The text modified as suggested. p. 7-69 This suggestion was not adopted. The Mmax prior is the primary

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p. 7-69, par. 1, line 4: Suggest adding the phrase "and recurrence characteristics" after "maximum magnitude probability"	distinguishing characteristic for delineating this zone.
Editorial Comments and Typographical Errors General Comment: To avoid repetition of editorial comments on repeated issues throughout the text of Chapter 7, the following issues are identified which should lead to necessary revisions throughout the chapter: • The manner of describing compass directions and their hyphenation should be made consistent throughout the report. Note that sometimes the directions are spelled out and in other cases an abbreviation is used. • Geologic time units are not used appropriately throughout the chapter. Ma is used by the scientific community for millions of years before the present and myr is used for millions of years of duration. • Recommended that for each section that presents a different seismotectonic zone, the title include the acronym (e.g., Section 7.3.1 — St. Lawrence Rift (SLR). Some section headings already include the acronym, which is helpful to the reader in referring to maps and figures. • "Aeromagnetic" is not a definitive term. Rather use "magnetic anomaly" and gravity should always be followed by "anomaly," e.g., gravity anomaly and magnetic anomaly. If there is no adjective before either the gravity or magnetic anomaly, it is assumed that the gravity anomaly is the Bouguer gravity anomaly and the magnetic anomaly is the total intensity magnetic anomaly. Where possible, the type of anomaly should be specified. • Mile should be abbreviated as "mi" without a period at the end, consistent with scientific context. • The first time a term is used that will be identified by an acronym, the complete term should be given followed by the acronym in parentheses. There are numerous acronyms in this chapter that are not listed in the list of acronyms near the front of the report. These will not all be identified in the following comments. • Reference to Adirondacks and Appalachians in place of Adirondack Mountains and Appalachian Mountains, respectively, is not editorially correct. This and similar casual terminology should be removed from the chapter. • Several figures cited in this chapter are neither in the draft report nor in the List of Figures. All cited figures and tables should be carefully reviewed. • Magnitudes of specific earthquakes should be consistent in number of significant figures throughout the text. • Format for dates should be consistent throughout the text. Avoid 10 February 1999 rather use February 10, 1999. • Listing of earthquakes, references, etc. should be in a prescribed order, e.g., date, magnitude, etc. Specific Comments: **E 7-1** Section 7.1 Paragraph 1, line 5 – replace region with seismotectonic source zone **E 7-2** Section 7.1 Paragraph 1, line 7 – replace event with earthquake **E 7-3** Section 7.1 Paragraph 1, line 8 – insert tectonic between particular and province	Revisions made as suggested unless otherwise noted below: **E 7-63:** Text deleted or modified as suggested, replaced with 'adjacent' **E 7-67:** Text checked—La Salle anticlinal belt is used throughout **E 7-71:** no change needed. FAFC explained in paragraph 2 of this section **E 7-72:** Sentence revised to add 'Pleistocene deformation' after the word 'late' **E 7-73:** Reference corrected to Pratt (2009) **E 7-91** no change needed. Discussion is an appropriate term

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E 7-4 Section 7.1 Paragraph 1, line 9 – insert faulting between slip and defining **E 7-5** Section 7.1 Paragraph 2, line 16 – replace eastern with western (?) **E 7-6** Section 7.1 Paragraph 3, line 1 – not all seismotectonic zones represented in Appendices C and D **E 7-7** Section 7.1 Paragraph 3, line 4 – replace provide an indication with specify **E 7-8** Section 7.1 Paragraph 3, line 7 – replace looking at any of the discussions with reviewing the descriptions **E 7-9** Section 7.1 Paragraph 4, line 16 – replace discussion with description **E 7-10** Section 7.1 Paragraph 5, line 6 – replace lie with occur **E 7-10** Section 7.1 Paragraph 6, line 5 – replace called out with identified ***DRAFT*** Installment 3, PPRP Review Comments, page 7-11 **E 7-11** Section 7.1 Paragraph 5, line 9 – replace have been postulated as being with are postulated as **E 7-12** Section 7.1 Paragraph 5, line 11 – replace studies are judged to be too preliminary at the present time with assessments are judged to be without definitive support as a result of the preliminary nature of the investigations **E 7-13** Section 7.3 Paragraph 1, line 3 – replace Mid-Continent with Midcontinent **E 7-14** Section 7.3 Paragraph 1, line 6 – NMESE not in List of Acronyms **E 7-15** Section 7.3 Paragraph 1, line 7 – insert northwest boundary between the and Reelfoot **E 7-16** Section 7.3.1 Paragraph 2, line 2 – separate SCRs and correlate **E 7-17** Section 7.3.1.1.3 Paragraph 1, bullets – capitalize first word of bullets and place period after last bullet **E 7-17** Section 7.3.1.1.4, pg. 7-7, third bullet, separate A and third **E 7-18** Section 7.3.1.1.4 Paragraph 2, first bullet – separate The and oldest **E 7-19** Section 7.3.1.1.4 Paragraph 4, line 6 – remove space after hyphen **E 7-20** Section 7.3.1.1.5 Paragraph 1, line 3 – separate from and the **E 7-21** Section 7.3.1.1.7 Paragraph 1, line 11 – remove s between faults and associated **E 7-22** Section 7.3.1.1.7 Paragraph 1, line 13 – separate which and continued **E 7-23** Section 7.3.1.2 Paragraph 1, line 3 – replace has been with is **E 7-24** Section 7.3.1.2 Paragraph 1, line 6 – remove space after hyphen **E 7-24** Section 7.3.1.2, pg. 7-10, paragraph 1, line 3 and line 8 – separate States and faults **E 7-25** Section 7.3.1.2 Paragraph 1, line 19 – replace asterisks with 250 **E 7-26** Section 7.3.1.1.4 Paragraph 2, line 2 – what is GSC R model?? **E 7-27** Section 7.3.1.1.4 Paragraph 2, line 6 – remove space before Brompton **E 7-27** Section 7.3.1.1.7, pg. 7-9, line 13 – separate which and continued **E 7-28** Section 7.3.1.3 Paragraph 1, line 15 – separate subsidence and within **E 7-29** Section 7.3.1.3 Paragraph 1, line 28 – spell out first time GMH is used **E 7-29** Section 7.3.1.4, pg. 7-11, 1st line - suggest "Earthquakes in Canada are classified	

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….” should be earthquakes in southeastern Canada	
E 7-30 Section 7.3.1.4 Paragraph 1, line 13 – 5.8 is 5.75 elsewhere, use care in significant figures, similar problems elsewhere in report that need to be addressed	
E 7-31 Section 7.3.1.4 Paragraph 2, line 2 – neither earthquake shown on Figure 7.3.1.1	
E 7-32 Section 7.3.2, Geologic Evidence, Paragraph 1, bullet 2 – why refer to figure here?	
E 7-33 Section 7.3.2, Geophysical Evidence, Paragraph 1, line 2 – Figure 7.3.2-3 is missing in report and List of Figures	
E 7-34 Section 7.3.2, Evidence for Reactivation, Paragraph 1, several lines – Capitalize Late and Early when part of formal age	
E 7-35 Section 7.3.2, Evidence for Reactivation, Paragraph 3, last line – replace / with and	
E 7-36 Section 7.3.2.2 Paragraph 2, line 2 – Figure 7.3.2-4 is missing from report and List of Figures	
E 7-37 Section 7.3.2.2 Paragraph 2, line 9 – can this information be related to a specific figure?	
E 7-38 Section 7.3.2.3 Paragraph 2, line 5 – Figure 7.3.2-5 is missing from report and List of Figures	
E 7-39 Section 7.3.2.4 Paragraph 2, line 15 – separate and20	
E 7-40 Section 7.3.3 Paragraph 1, line 1 – remove s from Appalachian	
E 7-41 Section 7.3.3 Tectonic Framework, Paragraph 3, line 5 – change to compressional event	
E 7-42 Section 7.3.3 Tectonic Framework, Paragraph 7, line 2 – replace million-year with myr	
E 7-43 Section 7.3.3 Seismicity Paragraph 1, line 10 – remove period after Ebel	
E 7-44 Section 7.3.3 Paragraph 2, line 3 – magnitude of June 1638 earthquake is listed as 6.5 on page 7-19 and 5.67 on page 7-21	
E 7-44 Section 7.3.3, pg. 7-19, Seismicity section - the 1904 earthquake referred to in terms of mblg, shouldn't moment magnitude be indicated as well?	
E 7-45 Section 7.3.3.3 Paragraph 2, line 5 – insert period after al	
E 7-46 Section 7.3.4.1.1 Paragraph 1, line 3 – replace valley with rift	
E 7-47 Section 7.3.4.1.2 Paragraph 1, line 3 – insert anomaly after gravity	
E 7-48 Section 7.3.4.1.2 Paragraph 2, line 7 – remove any	
E 7-49 Section 7.3.4.1.2 Paragraph 1, line 9 – replace Valley with rift	
E 7-50 Section 7.3.4.1.3 Paragraph 3, line 9 – remove Recent	
E 7-51 Section 7.3.4.1.3 Paragraph 4, last line – replace is with are	
E 7-52 Section 7.3.4.1.5 Paragraph 1, line 6 – RTG not identified	
E 7-53 Section 7.3.4.1.6 Paragraph 5, line 6 – insert space in front of Dineva	
E 7-53 Section 7.3.2, pg. 7-13, 2nd line - currently states "This seismotectonic zone is largely defined by moderate seismicity, including …" As written this contradicts the stated position that the model accounts for differences in seismicity by spatial smoothing. It	

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seems more appropriate to say "This seismotectonic zone is characterized by moderate seismicity,….." **E 7-54** Section 7.3.4.2 Paragraph 1, line 3 – remove unfiltered, add Bouguer gravity before anomaly **E 7-55** Section 7.3.4.2 Paragraph 1, line 5 – replace rise with anomaly gradient **E 7-56** Section 7.3.4.2 Paragraph 2, line 6 – should PEZ be PEZ-W?? **E 7-57** Section 7.3.4.2 Paragraph 3, line 1 – spell out PEZ-N **E 7-58** Section 7.3.4.2 Paragraph 4, last line – replace IRM with PEZ **E 7-59** Section 7.3.4.3 Paragraph 1, line 2 – magnitude **E 7-59** Section 7.3.4.3, pg. 7-30, Paragraph 1 - mixed magnitudes in the section **E 7-60** Section 7.3.4.2 Paragraph 4, line 4 – replace IRM with PEZ **E 7-61** Section 7.3.4.4 Paragraph 4, line 4 – spelling of Pymatning?? **E 7-62** Section 7.3.5 Paragraph 1, line 1 – delete The regions of **E 7-63** Section 7.3.5 Paragraph 1, line 2 – delete more distant, replace presented the with proposed that **E 7-64** Section 7.3.5 Paragraph 1, line 3 – delete concept and change extending to extend **E 7-65** Section 7.3.5 Paragraph 1, line 8 – delete d from indicated **E 7-66** Section 7.3.5 Paragraph 1, line 9 – delete of complexly deformed crust. **E 7-67** Section 7.3.5 Paragraph 4, line 4 – be consistent in use of term for LaSalle anticlinorium **E 7-68** Section 7.3.5 Paragraph 2, line 5 – insert anomaly after intensity **E 7-69** Section 7.3.5 Paragraph 2, line 6 – insert layered between volcanic and sequences **E 7-70** Section 7.3.6.1 Paragraph 1, bullet 1, line 4 – should be plume **E 7-71** Section 7.3.6.1.2 Paragraph 5, line 5 – FAFC, not defined **E 7-72** Section 7.3.6.1.2 Paragraph 8, line 8 – missing words?? **E 7-73** Section 7.3.6. 2 Paragraph 8, bullet 3, line 5 – publication date of Pratt et al. **E 7-74** Section 7.3.7 Geophysical Anomalies, Paragraph 2, line 5 – replace runs with extends **E 7-75** Section 7.3.7 Geophysical Anomalies, Paragraph 2, line 10 – remove separately **E 7-76** Section 7.3.7 Seismicity, Paragraph 4, line 10 – should small be limited?? **E 7-77** Section 7.3.7.2 Basis for Geometry, Paragraph 1, line 16 – BMA, identify **E 7-77** Section 7.3.7.4, Future Earthquake Characteristics, pg. 7-48, - text refers to ECC-AM having the same future rupture characteristics as the AHEX zone. However, the discussion of the AHEX follows the ECC-AM zone. Consider placing description of characteristics in this section **E 7-78** Section 7.3.8.1 Paragraph 2, line 5 – replace runs with extends **E 7-79** Section 7.3.9 Paragraph 1, line 6 – replace represents with is **E 7-80** Section 7.3.9.2.1 Paragraph 1, line 5 – remove any **E 7-81** Section 7.3.9.2.1 Paragraph 1, line 7 – replace think with thin	

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E 7-82 Section 7.3.9.2.1 Paragraph 2, line 6 – replace reflected with reflects **E 7-83** Section 7.3.9.2.3 Paragraph 2, line 1 – change to In spite of this tectonic interpretation, **E 7-84** Section 7.3.9.4 Paragraph 4, line 5 – change to that formed or were reactivated **E 7-85** Section 7.3.9.5 Paragraph 2, line 4 – replace since with because **E 7-86** Section 7.3.9.5 Paragraph 6, line 1 – insert the after comma **E 7-87** Section 7.3.10 Paragraph 1, line 6 – replace represents with is **E 7-88** Section 7.3.11.1 Paragraph 2, line 1 – replace first sentence with The basis for defining the distinct future earthquake characteristics for the aulacogen is the observation of the characteristics of the Quaternary activity on the Meers fault, a fault within the Frontal Wichita fault system (see Section 6.1.4). **E 7-89** Section 7.3.11.2 Paragraph 2, line 5 – remove any **E 7-90** Section 7.3.12 Paragraph 1, line 2 – insert geologic between two and provinces **E 7-91** Section 7.3.12 Paragraph 2, line 1 – replace discussion with description **E 7-92** Section 7.3.12 Paragraph 2, line 2 – replace discussion with description **E 7-92** Section 7.3.12.1.4 Paragraph 1, line 6 – remove any of **E 7-93** Section 7.3.12.1.4 Paragraph 1, line 9 – replace could not with cannot **E 7-94** Section 7.3.12.1.4 Paragraph 1, last line – delete any of **E 7-95** Section 7.3.12.1.4 Northeast Ohio Seismic Zone, Paragraph 5, bullet 3, line 6 – change to consistent with one expected for a high pore-pressure… **E 7-96** Section 7.3.12.1.4 Northeast Ohio Seismic Zone, Paragraph 6, line 2 – replace very well with favorable **E 7-97** Figure 7.3.4-1 – Indicate 1929 Attica earthquake?? **E 7-98** Figure 7.4.1-1 – scale and size used for displaying mmzx-obs for each seismic source needs to be modified to better illustrate the findings **E 7-99 –** limits of information on all figures (e.g., 7.1-1 and 2) needs to be confined to the limits of the study area	
CHAPTER 8 — DEMONSTRATION HAZARD CALCULATIONS USING CEUS SSC MODEL	
General Comments **G 8-1. (CC)** Chapter 8 is the opportunity for the TI Team to explain differences in hazard obtained using the CEUS SSC model, the USGS seismic source model, and the COLA seismic source models. This has been done to a degree, but more extensive evaluations relating the differences in hazard to elements of the CEUS SSC model would be very valuable for future users. Industry stakeholders and the scientific and technical community will look be looking closely at the demonstration hazard calculations to gain an overall understanding of the CEUS SSC model and whether it yields reasonable results. Figures such as Figures 8.2-5R through 8.2-5T for all test sites together with thorough evaluations of how the TI Team's assessments of smoothing parameters impact hazard would be very informative. Sensitivities to the Team's assessments of weights on the "in cluster" and "out of cluster" characterizations of RLME sources would also be very informative.	Additional discussion of releases for differences at each site

PPRP Comment Response Table

Comment	Summary of Revisions to Report
G 8-2. (CC, CBR) The CEUS SSC model rates are often by a factor of two or more higher than the USGS and COLA models rates, over a large range of ground motions. The slopes of the hazard curves are more similar because they all assume the same ground motion prediction equations. This higher rate of ground motions compared to earlier models is not clearly explained in the text. This higher hazard indicates that the CEUS SSC model predicts a rate of earthquakes that is considerably higher than the earthquake rate predicted in the USGS and COLA models. The basis of these higher rates can be seen in the figures of Chapter 5 to 7 (e.g., 6.4-7 to 6.4-16; 5.3.2-22), where the model realizations over-predicts the historical rate of earthquakes. These differences make one question whether the model encompasses the center, body, and range of the informed technical community.	Hazard curves for CEUS SSC model match other curves better.
Specific Comments **S 8-1. (CC)** *Explanation of CEUS Ground Motion Attenuation Model Application* The TI Team has used the 2004 EPRI ground motion attenuation model to complete probabilistic estimates of ground motion. Chapter 8 should provide a summary of the application steps that were implemented for the 2004 EPRI ground motion attenuation model. It is particularly important that the distance measure be explained. Application of the 2004 EPRI ground motion attenuation model could involve the use of either point source distance measures or extended source distance measures. If both distance measures were used, the text should provide an explanation of the criteria or considerations that resulted in the choice of the distance measure for each of the seismic sources. For those seismic sources that were modeled as extended ruptures, the text should describe what assumptions were made to model the extended rupture and to what extent epistemic uncertainty was considered (alternative extended rupture relationships). Without this explanation the information provided in Chapter 9 regarding the sensitivity to certain logic tree inputs is diminished.	Text modified to include this revision
S 8-2. (DMM, CC) *Questions Regarding Results of Demonstration Hazard Calculations* In the subsection labeled "CENTRAL ILLINOIS SITE" (p. 8-6, 3rd paragraph): It would be informative to know how much higher and over what ground motion range the CEUS SSC model hazard is higher. Also, what characterizations and/or assessments contained in the model contribute to the higher seismic hazard. The CEUS SSC m del is almost a factor of 2 higher than USGS/EPRI-SOG models. The major contributor is the IBEB (Illinois Basin) zone. The New Madrid (NMFS) RLME is most important at 1 s SA. However, background seismicity dominates at shorter periods. Why does the background hazard from CEUS SSC model give significantly higher rates than were applied in the USGS and COLA models for short periods? At 1 s period the USGS and CEUS SSC models are much more similar because the NMFS models are much more similar. In the subsection labeled "CHATTANOOGA SITE" (addendum, 8/18/2010, 3rd paragraph): More complete evaluations and explanations relating the differences to elements of the CEUS SSC model would be very valuable. This comment applies to other sites as well; so, will not be repeated. The CEUS SSC model hazard for the Chattanooga site is more than a factor of 2 higher in annual frequency of exceedance than the USGS and COLA models. At the Chattanooga site the ground motion hazard at e-3 to e-5 is more than a factor of 2 higher. Background sources contribute most to the hazard. However, the USGS ground motions are higher at 1 Hz for exceedances of e-4 to e-6. These results are not explained in the text.	Revised comparisons are described Explained revised comparison

PPRP Comment Response Table

Comment	Summary of Revisions to Report
In the subsection labeled “HOUSTON SITE”: The CEUS-SSC model hazard at the Houston site is dominated by GHEX (Gulf of Mexico), which is the zone that encompasses the site. Contributions from other background sources are much lower. Hazard is dominated by background sources at all periods (except for very low ground motions at 1 s SA). The SSC model indicates about a factor of 2 higher annual frequency of exceedance than the USGS model frequencies for short periods (10 Hz and PGA) but is more similar at longer periods (1 Hz). This is probably because NMFS is significant at 1 Hz and the USGS and CEUS-SSC models are more similar for NMFS. However, the differences are not explained in the text.	Explained revised comparison
In the subsection labeled “JACKSON SITE”: For the Jackson Site, the NMFS is important at all frequencies. Therefore, the CEUS-SSC, COLA, and USGS models are quite similar for PGA, 10 Hz, and 1 Hz.	No comment required
In the subsection labeled “MANCHESTER SITE”: Similar to the other sites dominated by background hazard, the CEUS SSC hazard at the Manchester site is considerably higher than the hazard for the USGS and COLA models. The deaggregation for the Manchester site at 10 Hz is dominated by earthquakes with magnitudes less than 6.0 and distances less than 10 km. The CEUS SSC deaggregation for 10 Hz at e-4 is similar to that produced by the USGS for PGA at 4e-4. The higher rates for the Manchester Site should be explained in the text.	No comment required
In the subsection labeled “SAVANNAH SITE”: For the CEUS SSC model at the Savannah site, the major contributors to the ground motion hazard are the Charleston RLME source and the ACCAM background source model. The CEUS-SSC, COLA, and USGS models are quite similar with the CEUS-SSC model showing a little higher ground motions for a large range off exceedances.	No comment required
In the subsection labeled “TOPEKA SITE”: The major contributor to the background source is MIDC-A which encompasses the site. The next important contributors are MIDC–B, MIDC-C, and MIDC-D. Background seismicity dominates the hazard at PGA and 10 Hz and the NMFS dominates hazard at 1 Hz. The hazard curves for the CEUS-SSC, COLA, and USGS and similar, especially at 1 Hz. The hazard is typically higher for the CEUS-SSC model with rates almost a factor of two higher for a large range of ground motions. This discrepancy should be explained in the text.	Explained revised comparison
Comments by Section	
Order of Text, Tables, and Figures	
Material needs to be reorganized (including added materials transmitted on August 18, 2010) so that the order of presentation of text, tables, and figures is consistent with other chapters.	Revised accordingly
Section 8.1	
3rd paragraph and elsewhere: The term “hard rock” can lead to confusion because it is unspecific and used in various meanings. Consider defining the term “CEUS Region generic rock,” shear wave velocity of 9200 fps, and using this term consistently throughout the chapter.	No revision required
Similarly, using the term “soil” to mean the geologic section above “CEUS Region generic rock” can especially invite confusion because of the well-established use of this term in geotechnical engineering. Consider “stratigraphic column” instead.	No revision required

Comment	Summary of Revisions to Report
4th paragraph: In the first line, would “generalized” or “representative” be more accurate than “hypothetical”? In the last line, would “dynamic response” be more descriptive than “parameters”? ***Section 8.2 [including revised materials distributed on 8/18/2010]*** In the subsection labeled “All site conditions” (p. 8-5): “EPRI-SOG (1989)” should be “EPRISOG (1988)” ***Figures 8.1-4 and 8.1-5*** Are the mean amplification factors independent of the mean AFEs (e.g., at 10–4, 10–5, and 10–6) and the resulting site’s mean uniform hazard spectra for hard rock? ***Figures 8.2-5R and 8.2-5T (Manchester Site):*** These figures are very important for understanding how smoothing affects hazard. It would be particularly useful to know the estimated rates of **M** 5 earthquakes compared with estimated *b*-values for the 8 objective smoothing realizations.	No revision required Discuss revised comparisons
CHAPTER 9 — USE OF THE CEUS SSC MODEL IN PSHA	
General Comments **G 9-1. (NAR)** Chapter 9 provides results that are potentially valuable for evaluating whether future new data or evolved knowledge require updating of the SSC model. In addition, the results are potentially valuable for resolving a number of seismic regulatory decision-making issues. The chapter is very well written, providing clear descriptions of the analyses performed and the results—a valuable contribution.	So noted.
G 9-2. (NAR) PPRP review comments on Chapters 1–5 include suggestions that may lead to modification of weights in the Master Logic Tree and hence corresponding changes in calculated hazard results.	Changes in logic trees, such as the weights associated with the seismotectonic zones versus the Mmax zones approach, have been propagated into the seismic hazard results.
G 9-3. (NAR) It is noteworthy that, based on the comparisons provided in Chapter 8, differences with the USGS and EPRI-SOG (COLA) results are significantly larger than the precision defined in this chapter for the CEUS SSC model results at all seven test sites. Indeed, for ground motions in the range of 10-4 to 10-6, the results in Chapter 8 indicate differences sometimes more than a factor of two between the USGS and CEUS SSC models in the rate of exceedances and the ground motion hazard. To avoid confusion, and because it might be argued that all experts have had essentially the same data and knowledge basis for assessing the various SSC models, the report should make abundantly clear how the uncertainty (precision or reproducibility) of the ± 25% should be understood—or not misinterpreted.	Paragraph added at end of Section 9.3
Comments by Section ***Order of Text, Tables, and Figures*** Material needs to be reorganized so that the order of presentation of text, tables, and figures is consistent with other chapters. ***Entire Chapter*** Throughout, change “seismogenic crustal thickness” to “seismogenic thickness.” ***Section 9.1*** p. 9-1, par. 1: In line 6, change “Section 2” to “Chapter 2”; in line12, suggest replacing “that capture the community’s views” with “that represent the community’s views” Because this section is intended to be a useful “overview,” in the last paragraph it would help to call the reader’s attention more explicitly to the key conclusions presented in Section 9.4.3—at the very end of the chapter and after 96 pages. ***Section 9.2*** In the first paragraph, line 10: Change “components - that is” to “components—that is”	Order is consistent with presentation in Chapters 6 and 7. As discussed in Section 5.4, the use of the term “seismogenic crustal thickness” is consistent with common usage and is maintained. Changes made as suggested.

PPRP Comment Response Table

Comment	Summary of Revisions to Report
Section 9.3.1 In the first sentence: “The HIDs describing seismic sources” is confusing. There is only one HID. Suggestion: “In the HID, the specifications for seismic sources . . .” p. 9-3, first full paragraph, third sentence: Because the test sites are extensively referred to in the remainder of this chapter, it would be helpful at the end of this sentence to point the reader to a map of the seven test sites (say Figure 8.1-1). p. 9-3, 3rd full paragraph, last sentence: Suggest replacing “Please refer to Section 9.4” with “See Section 9.4” ***Section 9.3.1.10*** p. 9-41, par. 2, first sentence: Text should be revised to eliminate reference to internal communications among the TI Team—“outlined in emails from Kathryn Hanson.” ***Sections 9.3.2 and 9.3.3*** No text provided, stated “to be written later.” ***Section 9.4.1 and Table 9.4-1*** The text and table contain inadequate documentation insofar as the column of “Available studies” in Table 9.4-1 includes a mix of citations, which can be tracked, and informally referenced studies such as “Charleston: WLA,” “New Madrid: Youngs,” “PEGASOS study,” PEGASOS project.” ***Section 9.4.2*** See Comment **S 9-1** regarding error in referencing figures, beginning in this section. First paragraph (p. 9-49), last sentence: COV is defined here. Appropriate place to introduce symbols for the standard deviation of hazard (σH) and mean hazard (MH, or some such). p. 9-66, line 2: Change “10-4 to 10-6” to “10–4 to 10–6” ***Section 9.4.3 and Table 9.4-1*** The abbreviation “SSRS” appearing in Table 9.4-4 needs to be explained in the text. In the figure caption for Figure 9.4-44 one finds “srss” explained as “the square-root sum of squares calculation of the total COV.” Neither srss nor SRSS appears in the list of acronyms. Last paragraph: For clarity, it would be useful to explain where the statement “2/3 of the time” comes from—presumably from a normal distribution. It is difficult to understand why the COVs decrease in annual frequencies of exceedance greater than 1E-5 on Figure 9.4-53 and 9.4-57. The authors show at the Savannah, Chattanooga, and Columbia sites that the term “cl. Mean COV” is quite a bit different from the “wts COV.” Because this is not intuitive, it would be helpful to provide some explanation to the reader.	Revised as suggested Revised as suggested Revised as suggested Revised as suggested Others responsible. Text must be written by MACTEC or EPRI for how to ftp access information Citations were corrected to specify the sources Figures renumbered. Introduction of symbols was added Superscripts changed Abbreviation was removed from text Statement removed Revised as suggested Revised as suggested

Comment	Summary of Revisions to Report
APPENDIX A—DESCRIPTION OF THE CEUS SSC PROJECT DATABASE	
General Comments The CEUS SSC Project has assembled and archived a comprehensive suite of data sets of the CEUS that are important to the characterization and assessment of the SSC model of the region by the TI Team and that significantly contribute to the community knowledgebase. Compiling and providing these data sets in a common GIS data format required substantial effort, for which the Project Team is commended. These data, for the entire CEUS SSC model region, as well as for specific subregions of special interest for the characterization and assessment of seismic source zones, have been obtained from existing data bases, digitized maps, data files, and original data. The data have been put into a GIS format to facilitate analysis, employing overlays of various data types, and they have been made available to the TI Team, the PPRP, and others in the project. The data files will be archived on a server that can be accessed in the future via a website. The data include maps of surface, bedrock, and crystalline basement geology, geophysical data (gravity, magnetic, and stress), results of seismic study of the crust, compilations of historic and pre-historic earthquake data, and previous seismic hazard analyses. Workshop #1 was focused on selecting the critical data sets required for the project and identifying the optimum data sets available to the project. Appendix A describes the data included in the Database and the procedures for assembling the data sets and making them available to the project teams. In addition, summary metadata “sheets” are included for 32 of the identified data 72 CEUS data bases. As part of the review of Appendix A, consideration also has been given to the 60 metadata files describing the data sets of the Database. The 60 metadata descriptions are in a separate digital data file which is not part of the final report or its appendices, but has been on the EPRI data server which is no longer in service. Future access to the metadata files via the website needs to be clarified and explained. In general these files are helpful in understanding the source, capabilities, and limitations of the data sets that are important to all users of the CEUS SSC data compilation. The level of detail provided in Appendix A and the metadata files is generally satisfactory, but significant revisions are required to improve the text, update and complete the summary description of the data sets, complete the metadata a sheets for all data sets, synchronize the data sets, the metadata files, and the summary data sheets, and make numerous editorial changes. Suggestions are provided in the following general and specific comments for improving the Database and its description and the metadata files.	Report was revised to clarify that data will be part of future project website for delivery of data/metadata.
Specific Comments for Clarity and Completeness **S A-1.** The Appendix does not describe the future website, or access to it, that will	This will be provided.

make the data sets and the metadata available to future users. This will need to be done to enable the report user to access the data and metadata files.	
S A-2. There are several data sets dealing with gravity, magnetic, and geologic data of the same data type that are of various vintages. Data sets should be eliminated in the Database that have been superseded by more complete and accurate data sets. Including dated, out of date, data sets in the Database will cause confusion in determining which data set was and should be used in analyses. As a result the credibility of the results of the project will be enhanced by removing dated data sets.	Older data sets removed from the database, as suggested.
S A-3. A total of 32 summary metadata sheets are presented in the Appendix for the CEUS SSC model region, but no summary metadata sheets are provided for the remaining 40 data sets listed in Table A-1 for specific subregions. Summary metadata sheets should be provided for all of the GIS layer data sets or an explanation for not preparing metadata for the data sets needs to be provided. Furthermore, there is not an obvious relationship between the summary metadata sheets and the metadata files. In the metadata file there are 60 separate files that do not synchronize with the summary metadata sheets. It is not clear why there are only 60 rather than 72 representing all the data layers as in Table A-1. Note also that the titles of the data sets are not necessarily the same as the titles in Appendix A and the metadata files. This causes confusion in using the files. It would be useful to have a column in Table A-1 that identifies the metadata file(s) of the specific data set as they exist in the metadata file.	Report was revised to provide metadata summary sheets for only the CEUS-scale data. Summary sheets for zone-specific data were not prepared because these data were typically digitized from a published figure.
S A-4. The prose in this appendix is in draft stage and needs clarification, reorganization, and improvement. A technical editor could help improve the appendix so that the resulting description of the efforts and the results associated with the Project Database reflect well on the major investment that was made.	Updated text.
S A-5. All pages of the appendix should be numbered consecutively. **S A-6.** The page size maps of the data sets that are provided as part of the summary metadata sheets are very useful. They provide a view of the data set for use in qualitative analysis by the user of the report. In addition, they assist the user in making a decision about preparing small scale maps of the mapped parameter or in selecting regions of the maps for detailed analysis. Only one of the six magnetic anomaly data sets prepared for this project (Ravat et al., 2009) is shown, and only one of the fifteen gravity anomaly data sets (CEUS SSC, 2010) prepared for this project is illustrated. Please note that referring to the gravity anomaly data sets by CEUS SSC, 2010 as in the summary data sheets may lead to confusion. An alternative suggestion is to cite Keller, 2010, personal communication.	The goal of the summary sheets was to provide an easily-accessible review of the database contents and individual regional-scale data layers rather than a detailed presentation of every derivative of every layer. However, we have developed figures for each of the data layers in the CEUS and their derivatives where there is a metadata summary sheet.
S A-7. Unfortunately a key to the contour interval and symbols used in several of the maps is not provided with the map. This seriously detracts from the usefulness of the maps. In the few maps that show a color bar of the mapped parameter amplitudes, the limits of the range are given to a precision unwarranted in the data set and have limited usefulness for the user. In addition, these color codes are too coarse for most uses of the data.	Explanations, labels, scale bars and other typical map elements have been provided for the figures in the appendix where appropriate. Because of the scale of information presented in the figures not all features can be shown clearly, or exhaustive legends developed.
S A-8. The keywords of the metadata files need further attention. Most data sets do not have keywords, and keywords that are given are not consistent and comprehensive. Keywords are not critical but they can be helpful in directing the data	A keyword dictionary will not be available as part of the metadata for each data layer.

user to the appropriate data set without laborious, extensive review of all the data sets. Will the user be able to search the data sets by keyword?	
S A-9. "Aeromagnetic" in the title of maps should be changed to "magnetic anomaly." This is the general title that is applied to regional magnetic anomaly maps.	Updated text.
S A-10. Citations in tables are not in consistent format.	Updated text.
S A-11. A data file showing areas where reliable earthquake hypocenter depths are available would be useful. Or is it possible to show range of depths of foci for the CEUS?	
S A-12. Headers for Metadata Sheets: The repetition of "CEUS SSC Project GIS Data Summary" in large point size and bolded is less important to guide the reader's eye than the title of what the sheet contains. Consider reformatting the header information. Example: **Sheet A-1 — CEUS SSC Project GIS Data Summary** **NOAA DNAG MAGNETIC ANOMALY MAP OF NORTH AMERICA**	Updated sheets.
S A-13. Remove bracketed comments in text from previous reviewers.	Updated text.
S A-14. Shaded-relief versions of selected gravity and magnetic anomaly maps (e.g., total magnetic intensity anomaly map, reduced to pole magnetic anomaly map, residual isostatic gravity anomaly map) are a significant aid in the interpretation of the geological sources of the anomalies, particularly the high wave-number components of the anomalies. Several of these shaded relief maps have been prepared, but they are not identified in the data sets. They should be included and the specifications of the azimuth and inclination of the light source used in preparing the maps should be specified on the maps and in the metadata.	Hillshades (shaded relief) were created for the magnetic and gravity anomaly derivatives where possible to provide an added visual aid to the interpretation of these data. Some of the data layers have limited data ranges and were not appropriate for hillshade creation without significant exaggeration. Summary sheet text for gravity and magnetic data, were modified to note that the hillshades (shaded relief) layers exist and their parameters. This information was also included on the figures where a hillshade was displayed.
Comments by Section, Table, and Sheet ***Text: Unlabeled Introduction*** First paragraph: The first two sentences are not clear as to the goals of the database and the method of achieving them. The use of "function" in the first sentence leads to confusion. Suggest a rewrite focusing on goals of the data sets and procedures used to achieve them. Second paragraph: Strongly suggest that the term "aeromagnetic" throughout the titles of data sets be changed to "magnetic anomaly." This is the appropriate title given to regional magnetic anomaly maps. Delete Free-air gravity and remove Bouguer and simply use the term "gravity anomaly." Also, remove DNAG and USGS. These are data sets that have been superseded and should be removed from the Database. The Mesozoic rift basins data base cannot be found as an entity in the Database. Remove the parenthetical phrase in Earthquake Catalog. In the bulleted list, note that there is no metadata file or summary for Mesozoic rift basins which was compiled for this study. Last bullet of second paragraph: Will digital presentations of the crustal scale profiles be available? If not, where can they be obtained for analysis? Last paragraph, last line: The last metadata summary sheet is A-32, rather than A-36.	Updated text. Mesozoic basins have been included as five separate data layers, each corresponding to the interpretation of the source author. Metadata and a metadata summary sheet have been included for these layers. Digital representations of the crustal scale profiles are not included in the database.
Text: Section A.1 Last sentence of first paragraph: "The digital data compiled for the CEUS SSC Project	Updated text.

are available to the public to provide transparency regarding the development of the CEUS SSC database." Transparency does not seem to be an important reason for this. Rather it serves as a repository of data useful for largely regional seismic source zone characterization and assessment in the CEUS. Second paragraph, first line: Figure A-1 is not in the appendix. Second paragraph, second line: For example, some *public-domain* data sets cover… Third paragraph, bullets: Change to "Magnetic anomaly data," "Gravity anomaly data" Add "Mesozoic rift basins within the ECC-AM" to the bullet list in third paragraph. Third paragraph, fifth bullet: Add "data" after "Maximum horizontal compressive stress" to be consistent. Third paragraph: Replace "sources" in first line by "types" or, less desirable, "class." In second line, suggest: "These data layers include the following:"	
Text: Section A-2 First paragraph: Suggest that definitions of data class, theme, etc. be provided or a figure showing hierarchy of data. First paragraph: Spell out FWLA, point out that this server is no longer available First paragraph, top of p. A-3: Instead of "theme," use "type of data"? Fifth paragraph: All project data began at revision 0 (Rev0) and have been updated with consecutive revision numbers and made available via the project web site. Providing a full file name reference allows data to be identified if removed from the organization of the project Database. Sixth (last) paragraph: Add this sentence at end: "This server is no longer in service for this project." Sixth paragraph: Is the "Project GIS Manager" the same as "Database Manager" identified in Figure 2.3-1 and Appendix G? If so, be consistent.	Updated text. Notes added regarding the class/theme as used in database and text. The FWLA server was only for project use, not long-term use. No need to note this in the text as requested in the comment. Title renamed as "Database Manager" as originally noted in the project work plan.
Text: Section A-3.3 Second paragraph: If the steps to review GIS data produced from non-digital data were sequential, it would be better to present the steps using numbers or letters rather than bullets. Second paragraph, fourth bullet: Clarify "Completion of attribute information" Second paragraph , last bullet: Use of the term "topology" appears to be inappropriate here because the term is generally used to describe a branch of mathematics.	Updated text. The term "topology" used in GIS refers to data layers with defined relationships between their component points, lines and polygon features.
Text: Section A-4 Second paragraph, line 2: ** are ?? Second paragraph, line 6: Summary sheet A-22 has no state boundaries. Second paragraph, line 7: Why not "all" rather than "majority"? What criteria were used to omit some? Second paragraph, last sentence: Why are there no metadata summary sheets for data covering specific regions of the study area? If they are important enough to include as a data set, they should be important enough to have a metadata file. Are all data sets included in the metadata file? If not, why not?	Updated text. See above comments about metadata *summary* sheets vs. layer metadata.

Text: Section A-5 Third paragraph, first line: Were the *original* or *source* data provided? Third paragraph, last line: Typo: “into other coordinate systems.”	Updated text.
Text: Section A-6 This section is out of place, place after A-5. First paragraph, 3rd line: Add earthquake [information] to this list Second paragraph, line 5: Typo: “to identify geologic relationships”	Updated text.
Table A-1 Page 1: Where are the citations located? Are they all in the same place in the report? Page 1: Delete Row 1 Page 1: Delete Row 3 Page 1, Row 5: Need more complete description of this database and its preparation or refer to another section of report. Page 2, Row 2: Replace “Geodesy” with “Strain (GPS)” Page 3, Row 3: Why is this map being used, since it was replaced by Reed et al. (2005)? Delete. Page 4, Row 3: Is this the basin map referred to in the data evaluation tables? If so use consistent titles. Page 4, Row 7: Delete, superseded. Page 5, Row 1: Refer to Keller, 2010, personal communication Page 5, Rows 3 and 4: Delete, superseded Page 5, Row 6: How are these tied to references? Where are the metadata for these layers? Page 6, Row 2: This is also referred to as Zoback (2010). Determine appropriate reference and use consistently. Page 7, Row header: Change “Mid-Continent” to “Midcontinent” Page 7, Row 5: Replace “Geodesy” with “Strain (GPS)” Page 7: Why does the numbering of Summary Sheets stop with A-32 (in the last row of page 6)? Page 8, Rows 5 and 6: Need citations Page 9, Row 2: Need citation Page 9, Row 3: Change “Aeromagnetic” to “magnetic anomaly”	Text has been updated. Citations are presented in the report. Citations used in Table A-1 are the same, or same style, as those in the report. Older data that have been superseded with new data in this database have been removed. Data layers that were incorporated into the CEUS paleoliquefaction database have been removed from the rest of the database where earlier presented as separate layers.
Sheet A-1 Delete, superseded ***Sheet A-2*** Replace “aeromagnetic” with “” Contour interval should be given Show page-size maps of six data sets with bar graph for amplitude and in shaded relief if possible Differentially reduced to pole, tilt derivative, etc. may not be known entities to user; suggest a basic reference for each of these for the interested reader ***Sheet A-3*** Delete, superseded	Updated sheets as appropriate.

Sheet A-4 Increase amplitude at least twice that being shown ***Sheet A-5*** Data description: Needs range of date, also key to map symbols; as throughout report, moment magnitude (**M**) should be bolded; which earthquake catalog is referred to? The raw catalog, the declustered catalog, or ?? Should refer to Appendix B if this is the same catalog. ***Sheet A-6*** Identify symbols ***Sheet A-7*** Brighter colors needed, no extended crust identified ***Sheet A-8*** Need brighter colors ***Sheet A-9*** Need key to colors ***Sheet A-10*** Need key to colors ***Sheet A-11*** How are they keyed to source (reference)? ***Sheet A-12*** Delete, superseded ***Sheet A-13*** Data description is misleading, the dashed line represents the mapped eastern limit of pre- 1600 Ma crust. Why not show all of Figure 2 of this reference? It puts the boundary into the context of the basement terranes. ***Sheet A-14*** Brighten colors and provide key ***Sheet A-15*** Brighten colors and provide key ***Sheet A-16*** Brighten colors ***Sheet A-17*** Needs key ***Sheet A-18*** Needs contour interval, high range is given to 4 decimal points which is much greater than precision ***Sheet A-19*** Needs key ***Sheet A-20*** Legend of figure needs to be checked. What is basement thickness? Unclear. ***Sheet A-21*** Brighten colors and provide key ***Sheet A-22*** Delete, superseded ***Sheet A-23*** Brighten colors, color contour interval needed, show all figures at page size, preferably in shaded relief; suggest for Author that G.R. Keller be identified as the source of the data and derivative anomaly maps . . . as in A-2 for D. Ravat. ***Sheet A-24*** To be consistent, use residual isostatic; color contour interval without range beyond decimal point. ***Sheet A-25*** Delete, superseded ***Sheet A-26*** Delete, superseded ***Sheet A-27*** Tie to references?? Where will the metadata file be accessible? ***Sheet A-28*** Brighten colors ***Sheet A-29*** Needs key; this is also referenced as Zoback (2010) – select appropriate citation	

APPENDIX B — EARTHQUAKE CATALOG	
General Comments Appendix B contains a listing of the earthquake catalog for the CEUS developed as part of this project. The development of the earthquake catalog is a major element of the source characterization and assessment in the project. The Appendix contains a single page of text that identifies the columnar entries in the catalog followed by a 273 page tabular listing of the 9800 earthquakes in the catalog. The table is well laid out and easy to follow. It is evident that monumental efforts were required to compile this catalog, and the Project Team is to be applauded for these efforts. Beyond its use by TI Team members familiar with its contents, careful documentation and explanation is needed for the contents of the catalog to be understood and appropriately used by others.	Greater detail on contents of catalog added to Chapter 3 and to Appendix B
Specific Comments for Clarity and Completeness **S B-1.** *Need for Introductory Text* A brief summary discussion should be added to this Appendix. This discussion should describe what this catalog listing actually is (i.e., final catalog with dependent events flagged). It would also be useful to refer the reader back to relevant sections of Section 3 for a discussion of **M***, etc. Additional notes on depths and how ERH was estimated would also be useful in the introduction to the catalog. A pointer to the appropriate Database entry would be useful. A catalog of non-tectonic events was developed as part of this project (mentioned in Section 3), where will this catalog be documented and maintained?	Summary added, including description of list of non-tectonic event Catalog will be on Project web site. Maintenance in the future is beyond the scope of this project, but discussions with the USGS as a possible repository are in progress
S B-2. *Clarity of Documentation in the Catalog Explanation* For clarity of documentation, attention should be paid to the following: 1. Designation of time in an earthquake catalog should be explicit. Are the times/dates in UTC? Local time? A mix? This is non-trivial if one tries to find the events in another catalog. 2. How should the reader interpret the variable presentation of significant figures in the Earthquake Catalog for latitude, longitude, depth, **M**, and sig**M**? How does one discern available information on precision from the vagaries of spreadsheet display? 3. The meaning of Depth = 0 should be explained. 4. To avoid ambiguity, ERH should be explained as “Horizontal Location Uncertainty (km)”. If correct that the entries for ERH contain both rough estimates and statistical calculations, then ERH is better described as “Estimated Horizontal Location Uncertainty (km)”. 5. After ERH, entries in the Explanation change from having the first letter of all terms capitalized to just the first word capitalized. 6. **M** , **M***, and sig**M** should be bolded in Column 1 of the Explanation 7. In column 1, “Flag” should be written “FLAG” as it appears in the table.	Discussion added of entries
APPENDIX C—DATA EVALUATION TABLES	
General Comments **G C-1. (NAR)** The tables of Appendix C summarize what data were used, how the data were used, and the source, quality, and significance of the data in defining,	Comment noted and appreciated.

characterizing, and assessing the CEUS seismic sources. In addition, the tables specify the availability of the data in GIS format. These tables are a useful supplement to the documentation of the seismic source zone characterization and assessment of both the RLME sources and the seismotectonic source zones. They will be useful to users of the CEUS SSC report, and they will also provide a guide to potential application of various data sets in future evaluations of the CEUS SSC model. In general, the tables are well prepared and presented. However, they are not without problems, as we proceed to explain.	
Specific Comments **S C-1. (CC, DMM)** *Completeness of Tables and Ambiguity About Applicability* Data Evaluation tables have been prepared for many of the identified seismic source zones, but not all. In Section 4.2.2 of the main report, the reader is informed (p. 4-6, first paragraph of the section) that, "Data Evaluation tables were developed . . . and the tables for each source (emphasis added) are included in Appendix C." Comparing a list of the RLME sources, the seismotectonic zones, and the Mmax source zones with the index of tables on the first page of Appendix C will leave the reader perplexed. Further, the treatment of some zones is handled within the Data Evaluation table for another zone (e.g., the Meers fault RLME source is included in the table for the OKA seismotectonic zone). What criteria were used to select which zones were to have Data Evaluation tables? At the top of Table C-5.4, the labeling indicates "Default for entire CEUS SSC." Does this mean that if a table is not given for a specific zone, then Table C-5.4 is the applicable table? (If this is the intent, note that Table C-5.4 is incomplete with regard to several data sets.) Introductory text should be added to eliminate these and similar questions and concerns pertaining to the Data Evaluation tables. All seismic source zones including Mmax zones should have a Data Evaluation table.	Data Evaluation for Meers fault / OKA RLME combined because when Meers is out of cluster, RLME allowed within larger OKA source. The list of tables on the cover sheet for Appendix C was expanded to indicate the applicable table for each RLME and Seismotectonic zone. All seismic sources have an applicable Data Evaluation table. In some cases, the same table is used for multiple sources and the applicable sources are listed at the top of the table. Table C-5.4 is different from the other tables because it is referring specifically to the assessment of future earthquake characteristics (Section 5.4). Thus, the reference to "Default for entire CEUS SSC" is specifically for future earthquake characteristics, as discussed in Section 5.4.
S C-2. (CC) *Facilitating Use of the Data Evaluation Tables* The Data Evaluation tables are explained in the text of the report (Section 4.2.2). However, consideration should be given to adding a short description of the objective, organization (including the keying of the table numbers to the main body of the report), preparation, and uses of the tables in an introductory paragraph to the appendix. This will facilitate the use of the tables. An explanation of the content of the columns used in the tables should be also included in this description for stand-alone reading. Also, all pages of Appendix C should be numbered consecutively, not separately for each table, to enable convenient reference—as opposed to having to point to a specific table and a page number within the table.	Revisions made as suggested.
S C-3. (CC, DMM) *Inconsistencies in the Tables* The Data Evaluation tables have numerous inconsistencies that should be eliminated because they diminish the quality and usefulness of the tables. We note the following: 1. The titles of the tables and the identified source in the notes at the top of each table should be consistent with the nomenclature of the text of the report, and tables should be in the same sequence as the identified source is described in the text (or keyed to a table in the text). 2. Although the majority of the Data Evaluation tables are also in the Data Summary tables (Appendix D), some are not included in the Data Summary tables and vice versa. There is no explanation for this inconsistency among tables in the documentation of the	1. Revisions made as suggested. 2. Explanation added in Section 7.1; a new Table 7.1-1 shows which Appendix C and D table numbers are associated with each of the seismotectonic zones. 3. Modifications made with an objective of achieving greater consistency in the level of information. 4. Modifications made so that all tables have seven columns. "Discuss" is defined as "to consider or examine by argument, comment, etc." and is the

report. 3. The level of information given in the tables is variable. This may be due in part to the information available, or it could be due to the detail that is provided by the individual preparing the table. Greater consistency in the level of information would be desirable. 4. All the tables have seven columns except for Tables 6.1.4 (OK aulacogen) and 7.3.9 (Gulf Coast), which have eight columns. Only seven columns are described in Section 4.2.2 (pages 4-6 and 4-7). Note that the fifth column should be “Description” rather than “Discussion” (there is no oral material here). Throughout the tables, references to “discussions” should be changed to “descriptions.” 5. Numbers in the tables are inconsistently spelled out or given in numeric form. Numeric form should be used for data and scoring; otherwise, numbers should be spelled out when referring to counts of ten or less. 6. Geographic (compass) directions are inconsistently given in abbreviated (e.g., NE) and spelled-out form. 7. Some tables have the acronyms for the subdivisions of the seismic source zone identified in notes at the beginning of the tables, others do not. Also several acronyms are not given in the List of Acronyms. 8. Descriptions in cells are variously in sentence and non-sentence form. It may be useful to have both, but an effort to be consistent would be worthwhile. 9. The use of blanks in the tables is inconsistent. Every cell needs to have something in it; if nothing else, N/A for not applicable or some other notation to indicate intention. Otherwise, the meaning of a blank cell will be unclear. 10. There is inconsistency in the title of column 3 among the tables. Is it “data quality” or “data and quality” (as in “Notes on Quality or Data”)? 11. Use data as a plural word consistently throughout the tables. 12. Both the terms magnetic and aeromagnetic are used in the tables. The use of the term aeromagnetic should be changed to magnetic throughout. Aeromagnetic simply refers to the method of collecting the majority of the data in the file. Referring to “aeromagnetic” but only to “gravity” is inconsistent. 13. Where no data are available for a particular type of data, the tables deal with this in different ways—sometimes the wording indicates explicitly that no data are available (e.g., Table C-6.1.3, p. 4; r. 3); in other places, data are just not identified. 14. The evaluation of the quality of the data is not consistent; in some cases peer-reviewed publications are referred to and in others simple publications.	formal treatment of a topic in speech or writing. We believe that the term “Discussion”, as used in the Data Evaluation tables, is more accurate than the term “Description”, so no change has been made. 5.Revisions made as suggested 6. Modifications were made to abbreviate compass directions in the tables. 7. Modifications made for consistency; List of Acronyms has been expanded. 8. Modifications made with an objective of achieving greater consistency in using non-sentence (or notes) form. 9. Modifications made with an objective of achieving greater consistency. 10. Revisions made; the proper heading for column 3 is “Notes on Quality of Data” 11. Revisions made as suggested. 12. Revisions made as suggested. 13. Modifications made with an objective of achieving greater consistency. 14. Modifications made with an objective of achieving greater consistency.
Comments by Table (for Clarity and Completeness) (Notation: pg. = page, c = column of table, r = row of table) ***Table C-5.4*** • pg. 1, descriptor (title) of 5th c: Would “significance” be a more descriptive term than “reliance”? • pg. 4, r. 3; c. 1: Is this the new data set from Zoback? If so, please put a date on it—and put dates in all tables for all the data sets prepared for this project so that in subsequent use there will be no question of date. • pg. 1, r. 4, 5, & 6; c. 6: Add fault to slip • pg. 1, r. 7; c. 3: In the Charlevoix area of the St. Lawrence Rift	Reliance is a better descriptor; “significance” would be some measure of importance, but “reliance” describes how much the TI Team used the information in their assessments. Revisions made as suggested or to clarify.

• pg. 2, r. 1 & 2; c. 6: Add fault slip • pg. 2, r. 5; c. 6: Could not find where depth as a function of magnitude is described in report	
Table C-6.1.1 • pg. 1, r. 5; c. 6: Incomplete • pg. 1, r. 6; c. 1: Change to magnetic from aeromagnetic, here and elsewhere in tables • pg. 2, r. 2; c. 1: Give date • pg. 3, r. 4; c. 1: Reinecher not in references…this holds true for many of the references cited in the tables…they should be included in Chapter 10 (References)	• Removed reference to specific value from project catalog • changed to magnetic • no date given for gravity dataset; • Replaced reference with Heidbach et al., 2008 as a global change.
Table C-6.1.2 • pg. 2, r. 5 & 6; c. 3: What is the significance of the term “basic”? • 6, r. 1; c. 3: What is meant by “plain sediments”? • pg. 6, r. 5; c. 1: Should be bold and italics • pg. 9, r. 5; c. 1: Should be bold and italics • pg. 11, r. 3; c. 3: Replace to with two	Revised as suggested.
Table C-6.1.3 • pg. 3, r. 2; c. 6: Reference to 2002 article is incomplete (author?) • pg. 5, r. 1; c. 6: Change to “No measurements nearby to the . . .” • pg. 6, r. 2; c. 6: Reference to 2002 article is incomplete (author?)	Revised to address comments
Table C-6.1.4 • Why add an eighth column? Y or N to be used in c. 8 to be consistent with rest of tables. • pg. 1, r. 1; c. 4: How are faults due to hydrocarbon exploration? Change wording. • pg. 1, r. 1; c. 5 and subsequent rows on page: What is OK aulacogen? Background? • pg. 1, r. 2; c. 1: Bold and italics • pg. 1, r. 3 & 4: Delete. These are data sets superseded by the EPRI data set. • pg. 2, r. 2: Delete this data set, superseded by the EPRI data set • pg. 3, r. 3; c. 7: Change to “within the Arbuckle” • pg. 4; r. 2; c. 2: 1990 • pg. 4; r. 4; c. 2: What is BEG? • pg. 7; r. 1; c. 7; “fault slip”	Revised as suggested
Table C-6.1.5 • pg. 1; r. 2; c. 6: Change to …are concentrated…; also …projects to surface.. • pg. 1; r. 5; c. 6: Change to …sequences provides… • pg. 4; r. 1; c. 3: Give map # • pg. 5; r. 5; c. 3: Is relatively short germane? Don’t know what short is. This is not used where abstracts are referenced. • pg. 6; r. 2; c. 4: Define abbreviations • pg. 6; r. 5; c. 6: Rationale or geophysical evidence? • pg. 8; r. 1; c. 7: What is significance of (“?”)	Revised to address comments

Table C-6.1.6 • pg. 5; r. 2; c. 6: What is RP and ERM-SRP? ; need period after parenthesis • pg. 12; r. 1; c. 6: What is ERRM? ERM	Revised to address comments: RP deleted. ERM-SRP Eastern Rift Margin-Seismic river picks; ERRM, which stands for Eastern Reelfoot rift margin, is an acronym used in a publication
Table C-6.1.7 • pg. 3; r. 5; c. 4; what is EMF_S? not in acronyms	EMF_S has been changed to ERM_S
Table C-6.1.8 • pg. 2; r. 1; c. 6: No CFZ in acronyms • pg. 3; r. 5; c. 6: Explain A and B; replace	Revised to address comments.
Table C-7.3.1 • pg. 2; r. 1; c. 6: Clarify the wording, “A general gradient in amplitude parallels” • pg. 4; r. 8; c. 6: Entries; period at end of sentence • pg. 5; r. 1; c. 6: Capitalize Mechanisms	• Deleted statement. • Entry carries onto next page so no period was added • Entry not capitalized because sentence continues from the previous page.
Table C-7.3.3 • pg. 1: Shouldn’t the title be Northern Appalachian zone, without the “s”? • pg. 3; r. 2; c. 3: Parenthesis at end	S deleted from header; Parenthesis added.
Table C-7.3.4 • pg. 1: In notes beneath title, need to identify the acronyms of the subdivisions of the zone • pg. 2; r. 4 & 5; c. 3 & 6: What is CLFS?	Clarified acronyms for source zone; Spelled out Clarendon-Linden fault system
Table C-7.3.9 • pg. 1; r. 3 & 4; c. 7: If considered for defining boundaries, why 0 in column 6?	A “0” was used when a data set was considered but not used
Table C-7.3.12 • pg. 1; r. 5; c. 3: Do not capitalize intensity • pg. 2; r. 1; c. 6: Unfinished sentence • pg. 2; r. 2; c. 6: Belongs in column 6 of row 3; why 2 in column 5 for row 2 and 1 in column 5 for row 3? • pg. 5; r. 1; c. 6: Remove “yet”	Revised to address comments.
APPENDIX D—DATA SUMMARY TABLES	
General Comments **G D-1. (NAR)** The Data Summary tables of Appendix D contain a massive amount of information on references that include data considered by the TI Team in identifying, characterizing, and assessing the CEUS seismic sources. These data include all types of information that have a potential use in achieving these objectives. The tables provide a benchmark of germane data at the time of the Project, which gives transparency to the efforts of the TI Team and which future evaluations can augment with new sources of information. The tables include the citation, the title, and the data included in the reference that are relevant to seismic source identification and characterization. The tables are thorough and, in general, reasonably well prepared and presented. We proceed to point out minor problems needing attention before finalizing the appendix.	No revision necessary.

Specific Comments **S D-1. (CC)** *Difficulty in Relating the Appendix to the Main Body of the Report* The labeling of the tables is not consistent with the titles and acronyms used in the main body of the report for the source zones, and source zone data summaries are grouped in a manner that makes it difficult to relate the tables to some of the specific zones. For example, the Gulf Highly Extended Crust zone is apparently included in Table D-7.3.9, Gulf Coast Data Summary. Similar situations occur in other tables of the appendix. This makes it very difficult to relate the tables to the source zones in the report and decreases the usefulness of the appendix. This inconsistency needs to be rectified.	The list of tables on the cover sheet for Appendix D was expanded to indicate the applicable table for each RLME and Seismotectonic zone. Modifications have been made to the tables with an objective of achieving greater consistency. Explanation added in Section 7.1; a new Table 7.1-1 shows which Appendix C and D table numbers are associated with each of the seismotectonic zones.
S D-2. (CC) *Facilitating Use of the Data Summary Tables* The Data Summary tables are explained in the text of the report (Section 4.2.2). However, consideration should be given to adding a short description of the objective, organization (including the keying of the table numbers to the main body of the report), preparation, and uses of the tables in an introductory paragraph to the appendix. This will facilitate the use of the tables. An explanation of the content of the columns used in the tables should be also included in this description for stand-alone reading. Also, all pages of Appendix D should be numbered consecutively, not separately for each table, to enable convenient reference—as opposed to having to point to a specific table and a page number within the table.	Revisions made as suggested.
S D-3. (CC) *Inconsistencies in the Tables* The Data Summary tables have numerous inconsistencies which should be eliminated because they diminish the quality and usefulness of the tables. We note the following: 1. The titles of the tables and the identified source in the notes at the top of each table should be consistent with the nomenclature of the text of the report, and tables should be in the same sequence as the identified source is described in the text (or keyed to a table in the text). 2. The level of information given in the third column, Relevance to SSC, is variable. This may be due in part to the information available or it could be due to the detail that is provided by the individual preparing the table. Greater consistency in the level of information would be desirable. 3. Geographic (compass) directions are inconsistently given in abbreviated (e.g., NE) and spelled-out form. 4. Dates are presented in different formats. 5. Some tables have the acronyms for the subdivisions of the seismic source zone identified in notes at the beginning of the tables, others do not. 6. Column 3 descriptors are sometimes in sentences, while others are not. It may be useful to have both, but an effort to be consistent would be worthwhile. 7. The use of blanks in the tables is inconsistent. Every cell needs to have something in it; if nothing else, N/A for not applicable or some other notation to indicate intention. Otherwise, the meaning of a blank cell will be unclear. 8. Both the terms magnetic and aeromagnetic are used in the tables. The use of the term aeromagnetic should be changed to magnetic throughout. Aeromagnetic simply refers to the method of collecting the majority of the data in the file. Referring to “aeromagnetic” but only to “gravity” is inconsistent. 9. The format of the references at the end of each table is inconsistent, and some	1. Revisions made as suggested. 2. Modifications made with an objective of achieving greater consistency in the level of information. 3. Modifications made to abbreviate compass directions in the tables. 4. Modifications made with an objective of achieving greater consistency. 5. Modifications made with an objective of achieving greater consistency. 6. Modifications made with an objective of achieving greater consistency in using non-sentence (or notes) form. 7. Modifications made with an objective of achieving greater consistency. 8. Revisions made as suggested. 9. References have been deleted from the tables; all references are included in Chapter 10 References. 10. Modifications made with an objective of achieving greater consistency. 11. Modifications made with an objective of achieving greater consistency.

references do not have complete information. 10. The ordering of the citations in the tables is not consistent. Some are listed chronologically, while others are listed alphabetically according to the first letter of the family name of the senior author. 11. Use of bold letters for subtitles in several of the tables is inconsistent. 12. Capitalization of type of feature is inconsistent in the tables. It is suggested that the type of feature should not be capitalized, e.g., Commerce lineament, not Commerce Lineament.	12. Modifications made with an objective of achieving greater consistency.
Comments by Table (for Clarity and Completeness) (Notation: pg. = page, c = column of table, r = row of table) ***Table D-5.4*** • pg. 1, c. 1: Period after et al. on this page and throughout tables • pg. 4: Should Petersen et al. be included?	Revised as suggested. Petersen et al. was not used to assess future earthquake characteristics.
Table D-6.1.1 • pg. 1, c. 3: Spell aulacogens	Revised as suggested.
Table D-6.1.2 • pgs. 2 & 3, c. 3: No difference for Chapman and Beale, 2009 and 2010. Should there be a difference? • pg. 5, c.3, r.2: Should be Appalachian Mountains not Appalachians, similar comment for other geographic features throughout tables. • pg. 15, c.2, r.2: Why is journal listed?	Revised as suggested.
Table D-6.1.3 • pg. 1, c.3, r.2: The abbreviation for miles should be mi without a period (not mi.) — change throughout tables	Modifications were made to the tables to achieve consistency – English units are abbreviated and include a period at the end (e.g., mi. and ft.); metric units do not have a period at the end (e.g., km, cm)
Table D-6.1.4 • pg. 3, c.3, r.1 & 2: Replace further with farther	Replaced
Table D-6.1.5 • pg. 40, c.3, r.2: Blank—similar blanks in other tables	Revised to fill in blanks
Table D-6.1.9 • pg. 4, c.3, r.4: Use of the casual Appalachians and Rockies should be avoided • pg. 12: Has horizontal line between rows missing—this occurs elsewhere in tables	Revised as suggested.
Table D-7.3.1 • pg. 4, c.2, r.2: Misspelled Quebec • pg. 5, c.3, r.2: Is it Sutton Mountain or Sutton Mountains? Both are used in this table.	Revised as suggested.
Table D-7.3.2 • pg. 10: Reference for N.H. Sleep; misspelled mantle	Revised.
Table D-7.3.4 • pg. 9, c.3: No references for two subheadings • pg. 15, r.: Geophysical Investigations should be bold; similar subheading concerns	Entries added. Headings formatted.

elsewhere in tables	
Table D-7.3.7 • pg. 1: Horizontal lines needed between citations • pg. 11: Misspelling of investigate	Modifications made
Table D-7.3.9 • pg. 1 and following: Why () around citations?	Removed
APPENDIX E—CEUS PALEOLIQUEFACTION DATABASE, UNCERTAINTIES ASSOCIATED WITH PALEOLIQUEFACTION DATA, AND GUIDANCE FOR SEISMIC SOURCE CHARACTERIZATION	
General Comments This appendix represents a thorough and well expressed compendium of methodology, data, and guidance related to paleoliquefaction studies in the CEUS. The written content and illustrations present the data and information clearly and with a high degree of technical quality. Generally the documentation of effort encompassed in this appendix supports the related assertions made in the CEUS SSC. This work is notable not only because it represents a new and productive field of study that was not included in the earlier EPRI-SOG and LLNL projects, but also because the effort has brought sets of information and data that were highly varied and inconsistent into a consistent and coherent framework. This appendix is likely to be used as a primer on the topic for future researchers in paleoliquefaction, and the fulfillment of the recommendations provided could significantly improve the understanding of RLMEs in areas of low to moderate seismicity areas in the U.S. and globally.	No revisions required.
Specific Comments for Clarity and Completeness ***S E-1.*** *Incorporation of the Digital Database* It is unclear how the digital database is going to be incorporated into the final report and how it will be accessed in the future. It would be useful to the reader if the location was noted after the sentence, "The database itself is available in digital format."	Text modified to indicate that the database will be available on the CEUS SSC project website.
S E-2. *Recommendations for Clarification of the Digital Database* Because Section 1.1 (Database Structure) uses many technical terms related to dating that are very well discussed later in the document, it may be useful for many readers who are not well versed on the techniques if a sentence were added at the end of the first paragraph of the section that says, "A discussion of the various dating methods and their uncertainties can be found in Section 2.1.3." In relation to the description of the database on page 2, a simplified figure illustrating parameters such as SB_THICK, SB_WIDTH, SB_LENGTH, etc. may be helpful to the reader. Similarly, a simple figure illustrating the uncertainty estimates described in the last paragraph of Section 1.1 is not essential, but could be very useful for the reader.	Text modified as recommended. Added two figures illustrating measured size parameters of liquefaction features and age data used to estimate ages and related uncertainty of liquefaction features.
S E-3. *Clarification of Data Contributors* At the beginning of each of the "Data Description" subsections in the discussions of regional datasets in Section 1.2, the authors note that "Paleoliquefaction data have been contributed by . . . ." It is unclear to the reader if the contributors listed represent a complete list of the researchers who have worked in the area or if it is a subset of	Text revised for clarity as recommended. Clarified who contributed directly to the database and new maps produced for the report showing rivers searched. Changed Beta Analytic to Beta Analytic Radiocarbon Laboratory.

researchers who have provided additional information specifically for this project (e.g. by providing 2-sigma data that were not otherwise published). Because this report is likely to be read by researchers not familiar with paleoliquefaction, it may be helpful to refer to Beta Analytic as "Beta Analytic Laboratories" or in similar terms. The way the text reads currently, those not familiar with the topic are likely to understand Beta Analytic to be a process or approach described in Talma and Vogel (1993) or Vogel et al. (1993).	
S E-4. *Missing or Misnumbered Figures* — There is a Figure 11a, followed by Figure 11. Presumably, the second should be Figure 11b. — Figure E28 is missing. — There is a Figure E-39 and a Figure E-39b. Only E-39 is noted in the text. — There is a Figure E-44 and an E-44b. Only E-44 is noted in the text. — On Figure E-50, it would be useful to note what the SL signifies in the description for those not familiar with that notation. — Figure E-51 is sideways. — Figures 53b and 55b are missing.	
S E-5. *Additional Information and Clarification of Seismic Zones* On page 8 in the first paragraph of Section 1.1.2, there is a discussion of a lineament throughout the paragraph. In the next paragraph there is reference to the "Daytona Beach" lineament at the end of the paragraph. It is unclear whether all the discussion relates to a single lineament called the Daytona Beach lineament. If so, perhaps the name should be noted at the start of the discussion. The discussion of the Wabash Valley Seismic Zone should be expanded to make the report more complete. Neither the text, nor the figures, provides any actual dates, with the figure instead indicating "Event A Dates," "Event C Dates." The description of the dataset in the report should discuss these events and their dates rather than expecting the reader to go to the original papers. On page 13, the report notes that "There is no evidence for repeated large earthquakes in the exposures." This statement needs to be further explained. In what way do the data not meet the criteria established by the project? Because this is a hazard-significant finding for sites in the ALM region, the line of evidence that the features do NOT represent seismically-generated features should be made clear. Also, it is unclear how this bullet and the following bullet are different statements. From discussion of the Charleston Seismic Zone, it is unclear from both the text and the figures what the number of events and the dates of those events are. One can only tell that there is a historic event, and at least one other event happened. Clarification as to what the outcomes are in the text would be helpful to the reader.	Daytona lineament: The Daytona Beach lineament is named in the first paragraph of Section 1.1.2. Additional text added. Wabash Valley seismic zone: Text and figures describing the Wabash Valley seismic zone have been revised to provide additional detail. ALM: Text revised for clarity, including brief summary of how the ALM features do not meet the criteria for earthquake-induced liquefaction features. Charleston seismic zone: Text modified to provide cross-reference to Subsection 6.1.2 of the main report, which presents detailed discussions and figures for Charleston earthquake chronology.
S E-6. *Additional Guidance* It would be appropriate to include a bullet point on considerations of completeness in Section 3 on guidance for the use of paleoliquefaction data in SSC.	Text revised as suggested to include bullet about completeness in Section 3.
Minor Editorial Comments and Typographical Errors • TOC: The page number for 1.2.3 St. Louis Region is on the next line • p. 1: There is an EPRI logo embedded on the middle of page	These and other minor editorial issues have been corrected. - Deleted EPRI logo - p. 1, sentence 3 edited.

• Several of the page numbers have “Cited” included before the number • p. 1: Consider changing sentence 3 as follows, “Under this task, a new paleoliquefaction database, including regional datasets, was created and this report was prepared, documentation and illustrating the databases, discussing . . .” • p. 6 and other similar sections: Some sections make reference to “Beta Analytic” and others to “Beta Analytic Beta Analytic” • p. 7, first paragraph: “…that may be capable of large earthquakes (e.g., Eastern Margin and Commerce faults), and migration of seismicity from one part of the Reelfoot Rift…” • p. 5, Sand dikes, last bullet: Typo (“as well we as soft-sediment deformation”) • p. 19, second paragraph: “For the results of a paleoliquefaction study to be most useful in accessing assessing the long-term seismic hazards…” • p. 34, par. 1, line 3: Typo (change “earthquakes parameters” to “earthquake parameters”) • p. 34, last paragraph: The text states that radiocarbon and OSL dating “provide age estimates with uncertainties of one hundred years in the best of circumstances. Dating techniques that provide more precise results would help to improve age estimates of liquefaction features and their causative earthquakes.” In section 2.1.3.2 (p. 24, par. 2), examples are given of reported “precision” of ± 80 radiocarbon years, ± 20 radiocarbon years, and ± 40 radiocarbon years. • The figures start on page E2. Presumably the page numbers will be changed for the final report.	- Deleted “Cited” from footer. - Beta Analytic changed to Beta Analytic Radiocarbon Laboratory. - p. 7. Added references regarding the Commerce and Eastern Reelfoot Rift margin faults being earthquake sources. - p. 5. Changed to “as well as” - p. 19. Corrected typographical error. - p. 34, par.1. “s deleted from “earthquakes” - p. 34, last par. Explained the difference between sample dates and age estimates of liquefaction features and earthquakes responsible for their formation and referenced Figure E-3.
APPENDIX F — WORKSHOP SUMMARIES	
General Comments The summaries of the workshop provided in Appendix F are well-written accounts of the presentations and subsequent discussions that transpired. The workshop summaries, coupled with the agendas, participant lists, and presentations, provide sufficient documentation regarding the content of the workshops.	None required
S F-1. *Added Information for Each Workshop* Information has been described as “what people need and want to know.” Inclusion of the agenda for each workshop would give the reader a useful “road map” for navigating through the dense narratives. Also, the list of attendees for each workshop should be included for complete documentation (Table 2-2, p. 2-47, provides a partial list). As an additional step to help those wishing to review the project in the future, we assume that copies of visual presentations made at the workshops will be included as part of the project report and will become available either as part of this Appendix or on a project Website or in some other conveniently accessible form.	No change. The workshop agendas and lists of participants, as well as copies of all presentations, will be provided on the Project website.
APPENDIX G — BIOGRAPHIES OF PROJECT TEAM	
General Comments This appendix is a straightforward compilation of biographical sketches for members of the CEUS SSC Project. As part of this review, individual members of the PPRP were	None required

asked to carefully examine their own biosketches.	
Specific Comments for Clarity and Completeness **S G-1.** *Correlation and Coordination of Appendix G with Figure 2.3-1* For stand-alone reading of Appendix G, it would be useful to give the reader an overview of the Project Team by either pointing the reader to the CEUS SSC Project Organization diagram (Figure 2.3-1), say by using a footnote on p. G-1, or by reproducing the diagram in this appendix. The inclusion of biographies for the Sponsor Reviewers in Appendix G, as part of the Project Team, implies that their names should also be included in the Project Organization diagram. The presentation of names in Appendix G is a mix of alphabetical and hierarchical ordering. If Figure 2.3-1 is to be a guide for the reader, consider ordering names in Appendix G as they appear in the various boxes on the figure. In both the Project Organization diagram and in Appendix G, the TI Team (and support staff) is arguably a more important component of the "Project Team" than the PPRP. Consider moving the PPRP box on Figure 2.3-1 to the right of the TI Team and, correspondingly, presenting the PPRP names last in Appendix G. A box for the Sponsor Reviewers could be added in the organizational chart to the right of the PPRP (and their biosketches could follow those for the PPRP as in the draft).	New introduction added that points the reader to the CEUS Reference made to the SSC Project Organization diagram (Fig. 2.3-1) and discussion in Sec. 2.3. Sponsor Reviewer box added to Fig. 2.3-1. Fig 2.3-1 names are in hierarchical order for Project management team. For all other boxes, order of names is alphabetical, except for TI and PPRP groups where the lead or chairman is first in box, followed by members of team in alphabetical order. Boxes for TI Team and PPRP rearranged. Appendix G bios reorganized consistent with order of names shown in Fig 2.3-1.
Typographical Errors • p. G-7: Ending period missing in last line at the end of Mark Petersen's biosketch.	Change made
APPENDIX H — EPRI/DOE/NRC CEUS SEISMIC SOURCE CHARACTERIZATION	
PROJECT: Draft Final Seismic Source Model Hazard Input Document (HID), Dated July 6, 2010 **General Comments** **G H-1. (NAR)** The intent of the HID is to give future users details on how to implement the CEUS SSC model. It contains the logic tree structure that defines the frequency, locations, and sizes of future earthquakes in this region. The appendix describes how the zones are characterized. A description of why the TI Team chose a particular equation, occurrence rate, magnitude, or source geometry, or references is not given in this section of the report.	No revisions required.
G H-2. (CC) The elements of the CEUS SSC model are clearly described in enough detail to support future users' implementation of the model for PSHA at any site in the CEUS. Gaps not described in the July 6, 2010 draft should be described in the final revision of the appendix.	Full model including seismicity inputs for distributed sources included
G H-3. (CC) The PPRP's review of the 11 chapters of the main report identified many opportunities to achieve greater clarity in the TI Team's descriptions of the characterizations and assessments represented in the CEUS SSC model by proper and consistent use of terms. These comments apply as well to the descriptions contained in Appendix H.	HID review for consistency with Chapters 4, 6, and 7
Specific Comments **S H-1. (CC)** *Title of Appendix H* Consider changing the appendix title to: "CEUS SSC MODEL HAZARD INPUT DOCUMENT (HID)."	Change made
S H-2. (CC) *Implementing the Variable a- and b-value Routines*	Calculation of the variable a and b values is not part the use of the CEUS

To perform any hazard calculations using the HID, it would be difficult for most users to implement the variable *a*- and *b*-value routines described in Chapter 5. Therefore, the process is not open for most users to evaluate that methodology. It would be desirable that the computer codes be made available for these analyses. Alternatively, the TI Team could release the output gridded data. However, this is not the best alternative since most users would not understand how these numbers were generated. A third alternative is for the TI Team to revert to the smoothed seismicity kernel that is more intuitive to the user community.	SSC model for application in PSHAs, the purpose of the HID, but rather is an issue for future updates to the model.
S H-3. (CC) *Transparency of HID Tables for Recurrence* The following excerpt is reproduced from PPRP Review Comment **S 6-**12: "The unalert reader (or analyst) examining the HID tables for computed annual frequencies for the Charleston RLMEs may potentially be confused by: (1) the inverted order for the 5-point distributions compared to Table 5.3.3.-1, which was used to define the 5-point distribution; and (2) the need to refer to Tables 6.1.2-1 and 6.1.2-2 to discern the elapsed time since the oldest earthquake counted in the sequence. For example, examining "Table Charleston_HID-3," it may escape the reader's attention that the 5-point distribution is not for four events in 5500 years, but rather four events in 1,524–1,867 years (or possibly in 1,569–1,867 years). To reproduce the results in the table (and for virtually all the Poisson-model tables in the HID), there is no explicit information about the exact elapsed time that was used."	Documentation of calculation process was expanded in Chapter 6, HID revised to be consistent with main chapters and to add pointers to specific sections of the main report
Comments for Clarity and Completeness Figures 8 and 9 appear to be identical figures with different figure captions. p. H-19, *Degree of Smoothing*: The text states that, "An "Objective" approach is used to select the degree of smoothing." It would be very helpful to refer back in the text where this approach is described.	References to main chapters added to HID as appropriate
APPENDIX I — PPRP AND USGS REVIEW COMMENTS	
Specific Comments for Clarity and Completeness **S I-1.** *Title of Appendix E* Because this appendix contains both PPRP and USGS review comments, the title of the appendix should be changed.	Title changed
Specific Comments for Clarity and Completeness **S I-2.** *Listing of Letters and Attachments* In the summary of contents for the appendix, the separate listing of Attachments to PPRP Letter 1a as Items 1b and 1c poses a problem of consistency. PPRP Letter 2 (dated August 15, 2008) contains a substantive Attachment A ("Key Issues for CEUS SSC Relevant to Workshop #1) with three labeled enclosures. Also, USGS Letter 1 (dated April 8, 2010) contains five attachments. In the case of these three letters with attachments, one can either spell everything out or simply note that these letters have attachments (perhaps indicating their general nature).	Descriptions of attachments added for PPRP Letters 1 and 2 and USGS Letter 1
S I-3. *Incorrect Date in Correspondence Contents* p. I-2, TI Team Letter 1: Error in labeling the subject of the letter (change "dated August 12, 2008" to "dated August 15, 2008")	Errors corrected (including a typo in the letter heading – 2010 date corrected to 2008)
APPENDIX J — MAGNITUDE RECURRENCE MAPS	
General Comments	No revision necessary.

Appendix J presents the recurrence maps developed for all of the alternative configurations of the distributed seismicity zones. A brief description of the organization of the maps within the Appendix is provided on the title page. Consistent with the care taken in the writing of Section 5.3.2 (*Smoothing Approach*), this appendix is well organized and explained—beginning with the text on the title page that provides helpful guidance to the reader.	
Comments for Clarity and Completeness • Page J-1: Consider adding additional reference to specific figures in Sections 6.4 and 7.5; suggested wording: "Mean maps and magnitude-recurrence for each source zone are shown in Sections 6.4 (Figures 6.4-1 through 6.4-16) and 7.5 (Figures 7.5.2-1 through 7.5.2-42)." • Check: Were rates indeed calculated for **M** > 5 or for **M** ≥ 5? If perchance they were calculated for the latter, then labels on the figures should be changed or an explanation can be added on the title page of the appendix. • In figure caption for Figure J-1, need closing ["] for "no separation . . ." OR simply delete the ["], which doesn't appear in the captions for the following figures. • On Figures J-17 through J-48, the header information incorrectly indicates "MES" vs. "MESE" (the correct acronym, according to the list of Acronyms) written in the figure captions. • On Figures J-49 through J-112, the acronym "RCG" is used for Rough Creek graben vs. "RC" in the list of Acronyms. • Page J-87: Realization 7 for the seismotectonic zone, wide interpretation, Rough Creek Graben in Mid-Continent, full magnitude weights is missing.	Revisions made, as appropriate.
APPENDIX K — SCR DATABASES USED TO DEVELOP MMAX PRIOR DISTRIBUTIONS	
General Comments This appendix provides the database used to develop the Mmax prior distributions. The work done to update and refine data for the global Stable Continental Regions has great value and importance. However, there is no explanatory text provided beyond the Notes and the two tables. To help future users, as well as to enhance transparency, this Appendix could be improved by including additional information and a short description of the content being included in the appendix itself, or to a reference back to the relevant report text. It could also be noted whether or not the database is available in digital form elsewhere.	Short description of process added. Data will be included on project web site.
Specific Comments for Clarity and Completeness **K-1.** *Information that should be considered for Appendix K* Appendix K would benefit from including additional information for the reader to better appreciate where the domains and super domains are, and to better integrate with the text. The TI Team should considering adding the following: • Maps showing domains and superdomains (useful files for the boundaries of these domains should also be included in the Project Database, with a pointer to those files) • Figures displaying the Mmax-obs statistics for each of the superdomains • Summary table of statistical analysis completed on the various superdomain classifications	The digital data will be on project web site along with scanned images of the large plates from Johnston et al. (1994)
K-2. *Clarity of Documentation* For clarity of documentation, attention should be paid to the following: 8. Designation of time in an earthquake catalog should be explicit. Are the times/dates in	Greater explanation added for entries to the tables.

UTC? Local time? A mix? This is non-trivial if one tries to find the events in another catalog. 9. How should the reader interpret the variable presentation of significant figures in Table K-1 for latitude, longitude, **M**, and sig**M**? 10. “Extensive stress” is an unorthodox descriptor for “extensional stress”. (Google the two terms to see how most readers would interpret the first term.) 11. What are the units of “Area” in Table K-2? 12. Neither “Mx_obs” or “N > 4.5” is explicitly explained in Table K-2. 13. Check: Is N > 4.5 indeed the number of earthquakes greater than **M** 4.5? Or perchance is it **M** ≥ 4.5? 14. For the table to be self-contained, an explanation should be given for non-integer values of N > 4.5. 15. The wording used to explain SDNT and SDNC in Table K-2 will trip up most readers. Just add a few words to make it plain English. The acronyms certainly aren’t intuitive, but given that they are what they are, suggestion: SDNT Indicates which Superdomain the domain is assigned to when TYPE is included in the classification SDNC Indicates which Superdomain the domain is assigned to when TYPE is not included in the classification	

Technical Integration (TI) Team and

Project Manager (PM) Response to PPRP Letters

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September 16, 2008

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Subject: Response to *Central and Eastern United States Seismic Source Characterization for Nuclear Facilities*: Participatory Peer Review Report on Workshop No. 1, dated August 15, 2008.

Dear Carl and Walter,

Thank you for your letter summarizing the Participatory Peer Review Panel's review of Workshop No. 1 for the CEUS SSC project. The letter reflects a clear understanding of the purposes of the workshop in the context of the SSHAC Level 3 process. In the spirit of a participatory peer review process, we welcome timely, insightful, and constructive reviews and suggestions that will assist the Project Manager and TI team in steering the project toward a successful conclusion. One mechanism for that interaction is this correspondence between the PPRP and the project management.

To provide the PPRP with insights into our intentions relative to the specific recommendations made in the letter, we provide below a response to the recommendations that have been underlined in your letter to draw attention to their priority. We also value the perspectives provided in other parts of the letter and these will be given serious consideration during the course of the project activities leading up to and including Workshop No. 2.

1. Basic goals of workshop

While the resource experts did a high-quality job of describing data sets, the uncertainty in the data sets was not generally described. Uncertainty involving both quality and quantity of data—including non-uniqueness of interpretation—is fundamentally important for assessing a SSC model, both for evaluating alternatives and for considering the longevity of the results of the study. Future improvements in the quantity and quality of the data being used in the analysis may have an important effect on uncertainty and thus the stability of seismic hazard assessment. Evaluation and understanding of the present uncertainty in the data sets should be a key element of the assessment. <u>In order to fully address this important need, we recommend that the TI Team continue to interact with the data resource experts to evaluate the uncertainty in their data.</u> In this connection, we emphasize the importance of obtaining germane reference lists from the resource experts.

The TI team has established contact with a number of resource experts regarding their datasets, including the subset of experts who made presentations at the first workshop. We agree that a key consideration in the use of the various datasets is an evaluation of the quality of the data and the associated uncertainties. We will continue to interact with resource experts to evaluate the uncertainty in the various data that are compiled for the project.

2. How will data sets be used?
The schedule for the project specifies that a preliminary SSC model be completed over the period December 2008 to August 2009. However, the data sets, including the earthquake catalog, that will be used to evaluate and assess sources are not scheduled to be completed until June 2009. We recommend prioritizing this work element to ensure that the critical data sets are completed early so that the assessment is not left until the final two months of the assessment effort.

Although the schedule calls for carrying out the data compilation effort throughout the entire SSC model development period, most of the data compilation effort has already been completed. Work is proceeding on the seismicity catalog effort and priority will be given to completing it in a timeframe that makes it readily available during the SSC model development period.

Interpretations of these data that are in the public domain are spread throughout the geosciences literature. In view of the potential significance of the information from the seismic reflection profiles, not only for identifying seismic source zones and their properties but also for evaluating competing tectonic models, we recommend that interpretations of relevant seismic reflection profiles over the CEUS that are in the public domain be compiled for use in the project.

A variety of geophysical datasets are being compiled and considered in the SSC model development process. Most of the datasets reside within the literature. Seismic reflection data are one of the datasets that are being compiled and the TI team will make every effort to identify and consider the data that are available. The team is open to suggestions for datasets that might be identified by members of the PPRP and this input would be appreciated.

3. Identifying key SSC issues and alternative viewpoints
The PPRP recognizes the difficulty of identifying the SSC issues and relevant alternative interpretations that will be central to achieving the goals of Workshop #2 (WS-2). We recommend that the TI Team initiate identification and evaluation of these issues and interpretations as early as possible—to allow time for their full consideration prior to WS-2 and to ensure completeness vis-à-vis the diversity of views within the informed technical community. To this end, the PPRP has identified some key issues that should be considered when preparing for WS-2; these are listed below.

The goal of the TI team, as evaluators responsible for capturing the range of views held by the larger informed technical community, will use a variety of methods to identify alternative technical viewpoints, including reviews of the literature, conversations with researchers, professional conferences and proceedings (e.g., the upcoming USGS Maximum Magnitude workshop), and discussions at the workshops. The purpose of Workshop #2 is to consider alternative interpretations of important technical issues. The TI team agrees that the early identification of issues and proponents to speak to those issues is important and every effort will be made to do so. It is also recognized that not all proponents of alternative viewpoints will be able to attend the workshop, but this will not prevent the TI team from communication with the individuals or from evaluating their points of view.

Because of the key importance of WS-2, we recommend that the Project Team actively engage the PPRP in reviewing and commenting on the planning of WS-2 and in the development of the workshop agenda.

We welcome the assistance and perspectives that members of the PPRP can provide in the planning of WS -2.

5. Six test sites for hazard calculations

Insofar as the planned test sites (a) have not yet been selected and (b) apparently will play an important role later in the SSC process, the criteria for site selection will be of great interest to the PPRP beyond the example given in the Project Plan. We note that in the discussion of the test site selection in the Project Plan (see p. 4-4) the provision is made that the sites should be "as generic as possible." We recommend that the sites should be representative of the range of seismogenesis over the region of applicability of the CEUS SSC model.

We agree that the sites should be representative of the range of seismotectonic conditions that any site in the CEUS might entail. The notion of choosing "generic" sites was merely meant to imply that we are not planning to choose any particular named nuclear facility site. The TI Team and Project Manager will also provide the PPRP the criteria and timetable for identifying the demonstration sites. The TI Team and Project Manager will provide to the PPRP the preliminary demonstration sites for review and comment prior to their finalization for use in sensitivity analyses performed during Task 4.

Thanks again for the excellent reviews, and we trust that this will set a positive tone for carrying out this important project. If you have any questions regarding this letter, please feel free to contact us.

Sincerely,

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March 20, 2009

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Subject: Response to *Central and Eastern United States Seismic Source Characterization for Nuclear Facilities: Participatory Peer Review Report on Workshop No. 2* dated March 10, 2009.

Dear Carl and Walter,

Thank you for your letter summarizing the Participatory Peer Review Panel's review of Workshop No. 2 for the CEUS SSC project. The letter reflects a clear understanding of the purposes of the workshop in the context of the SSHAC Level 3 process. In the spirit of a participatory peer review process, we welcome timely, insightful, and constructive reviews and suggestions that will assist the Project Manager and TI team in steering the project toward a successful conclusion. One mechanism for that interaction is this correspondence between the PPRP and the project management.

To provide the PPRP with insights into our intentions relative to the specific recommendations made in the letter, we provide below a response to the recommendations that have been underlined in your letter to draw attention to their priority. We also value the perspectives provided in other parts of the letter and these will be given serious consideration during the course of the project activities leading up to and including Workshop No. 3.

1. Need for a Tectonic Framework*: The range and complexity of alternative hypotheses and interpretations presented at WS-2 <u>reinforce our previous recommendations concerning the need, first, to evaluate an overall tectonic framework for the study region and, second, to properly incorporate this evaluation into the CEUS seismic source model assessment</u>. We consider a transparent evaluation of uncertainty to be a necessary element of the tectonic framework evaluation. The tectonic framework should have a universal role in the seismic source model assessment. This would establish the approach and scale for the seismic source model assessment, and it would provide a transparent, consistent assessment (weighting) of the complex alternative interpretations and hypotheses that constitute the current state of knowledge of the technical community.*

We agree with the PPRP's recommendation that a Tectonic Framework be developed for the CEUS SSC project and this topic has been the subject of considerable focus by the TI team and staff over the past several months. To avoid narrowing the concept to include only a consideration of tectonic features, the project has used the term "Conceptual SSC Framework" to describe the process that is being used to identify and characterize seismic sources for the project. Over the course of three working meetings, the TI team and staff have reviewed the criteria that will be used to identify seismic sources, the process that will be used to identify and evaluate the data, the manner in which the criteria will be applied, and the means of documenting the evaluations in tables and text. These processes are being summarized in a document that will become a chapter in the project report. The concepts will be discussed at the PPRP meeting in May.

We observed that some proponent interpretations regarding seismic sources and the origin of the seismicity in the CEUS pointed to the significance of evaluating the geological and seismological characteristics of the entire lithosphere—including the upper brittle crust, the ductile lower crust, and the upper mantle. Geological and geophysical evidence indicates that these various zones of the lithosphere are laterally heterogeneous, which could have profound impact on the seismicity of the brittle upper crust. <u>*As a result, we recommend that the TI Team should include the attributes of the entire lithosphere in their evaluation of the tectonic framework and their seismic source model assessment.*</u>

As witnessed by the identification of resource experts with expertise in lithospheric modeling at WS2, the TI team and staff are aware of the potential importance of this type of data. Inasmuch as researchers have made assessments of the potential implications of their modeling of deeper mantle processes to seismicity within the seismogenic crust, the TI team and staff will make every effort to include this information in the considerations for identifying seismic sources.

2. Approach to Seismic Source Assessment and Scale:

a) "Granularity" of Seismic Source Model (i.e., the scale of uniform scrutiny): During the workshop, geological structures ranging in scale from very local to continental-scale were described and discussed. <u>*We recommend that the TI Team provide early assurance, through assessment criteria that are explained and justified, that a systematic approach and procedure are being used for defining and assessing seismic sources in terms of scale.*</u> *These assessment criteria will facilitate subsequent use of the model for a site-specific PSHA at any site in the study region. The assessment criteria should be at a level of detail that appropriately incorporates the state of knowledge of the sources and the current understanding of their inherent complexity. Using the criteria, one should be able to distinguish specific sources that have significant, identifiable, and relatively consistent seismic hazard potential. This systematic approach should be applied consistently across the study region.*

It is agreed that the "granularity" of the seismic source model and characterization effort is important and needs to be defined on a consistent basis for the entire study region. The Conceptual SSC Framework being used on the project begins with identifying the criteria that call for identifying a unique seismic source: variations in maximum magnitude, variations in recurrence rate, variations in future earthquake characteristics (e.g., depth, style of faulting), and significant variations in tectonic feature characteristics. It is acknowledged that the product of the CEUS SSC project is a *regional* seismic source model that can be applied at any location within the CEUS. As such, it includes variations in seismic source criteria that would lead to hazard-significant variations across the study region. It is also recognized that the CEUS SSC product will not include the detail that would be required for a site-specific application, say for inclusion in a PSHA conducted for power plant licensing. Per regulatory guidance (e.g., Regulatory Guide 1.208), those site-specific applications would need to consider possible refinements that might be needed to the CEUS SSC seismic source model in light of local geologic or seismologic investigations. It may be that a more refined model is possible at a few locations (e.g. New Madrid, Charleston) and we propose to use this refinement rather sacrificing the detail for the sake of a common level of "granularity."

b) Approach to Smoothing: We observed that there was little discussion or consideration of uncertainty involved in smoothing recorded seismicity versus deductive seismic source assessment, and there was no evaluation of alternative smoothing parameters. We consider this to be an important part of the assessment for the CEUS seismic source model and <u>we recommend greater attention to the issue of smoothing and corresponding documentation.</u>

The focus of the workshop was on alternative interpretations of various datasets and conceptual models. The notion of smoothing has a conceptual basis as well (i.e., degree of spatial stationarity in rates), which was addressed by those talks related to stationarity (e.g., Kafka talk on statistical analysis of past and future patterns of seismicity; multiple talks related to possible spatial migration of seismicity in New Madrid area). The audience at the workshop was not familiar with the mechanics of smoothing, and the mechanics of smoothing (e.g., kernel types, smoothing distances, etc.) were not discussed at the workshop. These details are recognized by the TI to be important and are the focus of attention by the TI team. We anticipate that alternative approaches will be used and captured in the SSC model.

3. Integrated Evaluation of Paleoliquefaction and Interpretations of Paleo-Fault Displacements:

a) Uncertainties in age dating: Multiple proponent experts discussed their interpretations of evidence for recent fault movement or the dating of geologic surfaces related to the formation of paleoliquefaction features. The proponents did not sufficiently describe the uncertainties in the age dating within their respective studies, and as such, the overall quality and reliability of this information is in question. The TI Team should strive to better understand the overall quality of these studies and develop a cohesive understanding of how the results can and cannot be used to establish recurrence information for various seismic sources. <u>We recommend that the TI Team perform an integrated analysis of the body of paleoseismic investigation results in the vicinity of the New Madrid Seismic Zone using appropriate statistical methods.</u> The study should incorporate uncertainty in the interpretations, to the extent that the uncertainty is described in or can be reasonably interpreted from the study results, in order to better correlate event times and rates of activity.

It is agreed that the ongoing studies of paleoseismicity in the New Madrid region are important and uncertain. The presenters at the workshop were encouraged to discuss uncertainties in the ages, locations, and sizes of paleo-earthquakes; some experts were more adept than others at describing their uncertainties. One of the responsibilities of the TI team and staff is to develop seismic source models that consider the present level of knowledge and uncertainties in the larger technical community. It is recognized that the seismic source models will provide a snapshot in time in this regard and that new data and information will continue to be developed in the future. Our focus, then, will be to incorporate the center, body, and range of views in the technical community on the recurrence models and rates in the New Madrid region. Given the present level of knowledge and uncertainties, it is likely that the "appropriate statistical methods" will be quite simple and will not entail unwarranted sophistication.

b) Size of paleoearthquakes: Paleoliquefaction is widely accepted to be a useful basis for assessing a seismic source model for the CEUS region; it is likely to gain even more importance in the future. The new approaches presented at WS-2 for assessing uncertainty in the observed data and interpretations and for using the interpretations for estimating the size of causal earthquakes have great promise and should be pursued in the future. At present, the uncertainties resulting from both the current and the newly presented method are poorly constrained. We recommend that particular care be taken in estimating magnitude and in assigning corresponding uncertainties. We further recommend that the lack of evidence of paleoliquefaction not be used to determine maximum magnitude.

We agree that the methods for assessing the magnitudes of paleo-earthquakes are still under development and that limited data have been developed that allow more quantitative methods to be applied consistently throughout the CEUS. For example, the geotechnical characterization that would lead to more confident magnitude estimates, as discussed by Drs. Green and Olsen, is only available in a limited number of cases at the present time. Hence, the magnitude estimates for paleo-events reported in the literature will be reviewed with care. We plan to factor appropriate uncertainty estimates of the size of paleo-earthquakes into the assessment of maximum magnitudes. We agree that the lack of evidence of paleoliquefaction needs to be interpreted with considerable caution, and there are no plans to use that evidence to place limits on maximum magnitudes.

c) Time-dependent models: Given the importance of paleoliquefaction studies for evaluating the New Madrid and Charleston seismic zones, the TI Team should make a fundamental decision whether the incorporation and use of time-dependent recurrence models should be pursued. While this topic came up during the workshop, there was no discussion focused on what weight should be given to time-dependent recurrence models. It was not clear how the TI Team would assess the views of the technical community on this issue.

The notion of time-dependent earthquake behavior in the New Madrid and Charleston seismic zones has been proposed by the technical community[1] and, therefore, must be seriously considered for inclusion by the TI team and staff. In addition, it has been used in several COLA applications. A variety of approaches exist for incorporating time-dependent behavior into a classical PSHA (i.e., one that is based on Poissonian temporal behavior), should we decide to do so. It is assumed that the CEUS SSC product will provide input to a PSHA that could be used to assess hazard for nuclear facilities having a design life of approximately 50 years. It would be in

[1] Recent examples include:
James S. Hebden, J. S. and Stein, S., 2009, *Time-dependent seismic hazard maps for the New Madrid seismic zone and Charleston, South Carolina, areas*: Seismological Research Letters, 80(1):12-20
Li, Q., Liu, M., and Stein, S., 2009, *Spatiotemporal Complexity of Continental Intraplate Seismicity: Insights from Geodynamic Modeling and Implications for Seismic Hazard Estimation*: Bulletin of the Seismological Society of America; v. 99; no. 1; p. 52-60
Calais, E. and Stein, S., 2009, *Time-Variable Deformation in the New Madrid Seismic Zone*
Science, March 13, 2009; 323(5920): 1442 - 1442.

this context that time-dependent recurrence models would be incorporated, should the TI team and staff judge this to be an important mechanism for capturing the views of the larger technical community.

4. Documentation of how alternative views are used*: At WS-2 a wide range of proponent views within the scientific community were presented about a number of important seismic source related issues. It is clear that, when assessed in detail, most CEUS locations are complex, with heterogeneities playing an important role in creating the data observed in the field. <u>The TI Team needs to document how alternative views are accounted for in the assessment of the seismic source model to be presented in May 2009.</u>*

We agree that any given seismic source or region of interest within the CEUS will potentially have a number of datasets that pertain to the spatial and temporal aspects of the source characteristics. The TI team and staff are fully aware of the responsibility to document in the project report all of the data and information sources that were used in the assessment. Doing so will allow future readers to understand how the views of the larger technical community were considered in the evaluation process.

***5. The hypothesis of late aftershocks:** During the workshop, a proponent, using chiefly qualitative evidence, offered the view that much of the contemporary seismicity observed in the CEUS represents late aftershock activity of prior moderate to large earthquakes. <u>If this view is used by the TI Team as a working hypothesis, it should first be critically examined</u>. Standard seismological and statistical tools exist for verifying whether observed contemporary seismicity can plausibly be related to prior earthquakes, consistent with aftershock decay models such as the modified Omori model or Ogata's epidemic-type aftershock sequence (ETAS) model. Modern aftershock sequences in the CEUS, for example, can provide Omori parameters that can be used to test the hypothesis of long-lived aftershock sequences in the region.*

The term "aftershock" was used in a variety of ways at the workshop, including some ways that would imply very long-lived sequences of earthquakes that occur decades to centuries following the "main shock." The TI team and staff agree that this issue must be viewed with caution and with care. Likewise, the treatment of the seismicity catalog for purposes of earthquake recurrence analysis (i.e., de-clustering) will also require that we consider the issue.

***6. Temporal Clustering**: One uncertainty that was briefly discussed is whether the New Madrid seismic source zone is coming out of a cluster in terms of short repeat times for larger earthquakes. Some proponents cited GPS data that indicate little if any measurable strain in the New Madrid seismic zone region over the past 20 years, and one proponent presented geologic evidence that could be interpreted to indicate a history of clustering with very long geologic time intervals between clusters. <u>The available data and overall lack of understanding of the mechanisms that may drive a clustering model for the New Madrid seismic source zone warrant caution about the supposition that a clustered sequence of higher recurrence behavior is ending</u>.*

As noted by several of the resource experts at the workshop, the notion of temporal clustering of earthquake behavior has been postulated based on geologic and seismic evidence at a number of localities within stable continental regions. It is true that the present state of knowledge does not provide insights into the physical mechanisms for this phenomenon, although attempts have been made (e.g., migrating strain localization, evolution of zones of weakness). The lack of understanding of the causative mechanism for temporal clustering adds uncertainty. Nevertheless, temporally-clustered behavior continues to be reported and must be considered in our evaluations. Likewise, some members of the larger technical community favor a temporal model in which the 1811-1812 earthquakes marked the end of a temporal cluster and the absence of evidence for contemporary strain accumulation is cited as evidence for the model. We agree that this model warrants caution in considering the manner in which it will be evaluated for incorporation into the CEUS SSC model.

7. ***SSHAC process issues****: Under SSHAC guidelines, the makeup of the TI team has implications for ownership issues relating to the seismic source model and subsequent hazard results. As evident during the workshop, there are blurred boundaries between the TI Team specified in the CEUS SSC organization chart and the TI Staff. The working "TI Team" appears to consider itself a larger group than listed in the Project Plan. The makeup of the "TI Team" in terms of individuals who will be responsible for ownership of the SSC inputs should be clarified.*

We also note that in the SSHAC framework there conventionally is a distinction between the TI (or TI Team) and the hazard analyst. In the CEUS SSC project this distinction is blurred with Robin McGuire having a dual role as a member of the TI Team and as one of the key analysts responsible for computing hazard at seven demonstration sites. This is not a conflicting role and indeed adds strength to the project. We suggest, however, that this circumstance be explained in the final project report.

During the course of discussions about the project activities, the term TI Team was used to indicate the working team that is evaluating the data and developing the seismic source model. This terminology is not consistent with the organization chart in the Project Plan. More accurately, the evaluations and development of the seismic source model is being conducted by the TI Team and the TI Staff. On the second point, the circumstance will be explained in the final project report.

Thanks again for the insightful review comments, and we are convinced that they will assist us in developing a better product. If you have any questions regarding this letter, please feel free to contact us.

Sincerely,

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September 25, 2009

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Subject: Response to *Central and Eastern United States Seismic Source Characterization for Nuclear Facilities: Participatory Peer Review Report on Workshop No. 3.*, dated September 18, 2009.

Dear Carl and Walter,

Thank you for your letter summarizing the Participatory Peer Review Panel's review of Workshop No. 3 for the CEUS SSC project. The letter reflects a clear understanding of the purposes of the workshop in the context of the SSHAC Level 3 process. In the spirit of a participatory peer review process, we welcome timely, insightful, and constructive reviews and suggestions that will assist the TI team in achieving a successful conclusion. One mechanism for that interaction is this correspondence between the PPRP and the project management.

We appreciate the kind words given in the General Observations regarding the management and TI team preparations for and success of the workshop. It is heartening to know that the PPRP recognizes the considerable efforts made over the months leading up to the workshop to ensure its success. Further, the comments demonstrate that the PPRP understands the preliminary nature of the SSC sensitivity model and how WS-3 provides a starting point for the development of the SSC model.

To provide the PPRP with insights into our intentions relative to the specific recommendations made in the letter, we provide below a response to the recommendations that have been underlined in your letter to draw attention to their priority. We also value the perspectives provided in other parts of the letter and these will be given serious consideration during the course of the project activities leading up to and including the development of the project report.

1. *The Principal SSHAC Goal for a PSHA:* We appreciate Dr. Coppersmith's informative presentation of the background and context of the principal SSHAC goal for a PSHA: ***"to represent the center, the body, and the range of technical interpretations that the larger technical community would have if they were to conduct the study."*** His description of the historical context of the treatment of uncertainties in seismic regulation practice illustrates the critical importance to safety decision making of proper treatment of uncertainty, which formed the basis for the SSHAC's evolution of this important goal as well as the process that the SSHAC defined for achieving it. The SSHAC assessment process defines roles for participants as well as process activities that when properly implemented provide reasonable assurance that the goal for a PSHA established by the SSHAC is achieved. Based on Dr. Coppersmith's presentation and the follow-on discussions during the workshop, we concur that the assessment process activities being implemented for the CEUS SSC Project satisfy

the SSHAC guidance. We recommend that this important presentation be developed in the form of a white paper suitable for inclusion as a section in the project final report and that the white paper be distributed among the project participants, including the PPRP and sponsor technical representatives, for early review.

Dr. Coppersmith's presentation was developed in response to the PPRP's previous suggestion that the conceptual framework for the SSC evaluation process be documented. As such, the TI team plans to include the discussion in the project report. The PPRP will have ample opportunity for review of the draft project report.

2. *USGS Open-File Report on Maximum Magnitude:* Although briefly mentioned during the workshop, it was not clear to us how the soon-to-be issued USGS Open-File Report on estimation of maximum magnitude for seismic sources in the CEUS will be considered by the TI Team. We recommend that the report be considered as part of the information base for assessment of the CEUS SSC model.

Several members of the TI team were in attendance at the workshop and the report has been available in draft form—along with a transcript of the meeting—for the use of the TI team. The recommendation to include the report as part of the information base is accepted.

3. *CEUS Earthquake Catalog:* The development and attendant analyses of the updated CEUS Earthquake Catalog are important contributions of the CEUS SSC Project that could potentially have high value for use in future PSHAs. The work summarized by Dr. Youngs on the catalog reflects a tremendous amount of work and represents a significant advancement in this important hazard data base. In order to be assured of the catalog's continuing high value, arrangements should be made to continually maintain this consensus catalog, and the analyses should be periodically updated as warranted by the addition of new data. Because multiple agencies and organizations will use the SSC Model, we recommend that the Project suggest a plan for keeping the CEUS Earthquake Catalog current into the future as a companion product for use of the SSC Model.

We agree that the CEUS Earthquake Catalog will be a significant product developed as part of the CEUS SSC project. It is envisioned that the project report will include a section devoted to recommendations for the future implementation of the products of the study. This discussion will include recommendations regarding plans for keeping the catalog current into the future.

4. *Comments on Smoothing*:
   - We consider the alternative procedures for smoothing seismicity that were presented and discussed during the workshop to be valuable tools for the TI Team to use to express uncertainty in its tectonic-based assessments of the spatial variation of seismicity. Accordingly, we recommend that the use of these tools (i.e., the choice of smoothing method, the use of anisotropic kernels, priors on parameters, and so on) be justified in terms of the Team's evaluations of tectonic processes governing earthquake occurrence.

It is agreed that the justifications for the choice of smoothing tools should be made in terms of tectonic and other technical arguments. For example, if an adaptive kernel is used that varies the smoothing distance as a function of data density, the technical basis for the use of such a kernel will be documented in terms of the expected future spatial distribution of seismicity.

6. *Data Summary Table and Data Evaluation Table:* The **Data Summary Table** appears to be a highly valuable means of documenting the current range of the larger technical community's technical interpretations. We believe that the **Data Evaluation Table** also is an important part of the documentation of the CEUS SSC assessment that can serve the important need for transparent documentation of the TI Team's evaluations supporting its assessments of the center and body of uncertainty in the larger technical community's technical interpretations. The **Data Evaluation Table** also is potentially useful as a record of lessons learned and as such will be valuable in considering the need for and planning future investigations of the CEUS. This includes not only the utility of the various data most important in the SSC assessment, but also the nature and quality of data which imposed limitations on their use in identification and characterization of the seismic source zones. A summary of the various documents, their contents, and relationships would likely prove helpful and increase clarity for future implementation of the SSC Model. <u>We recommend that the Project and TI Teams give careful consideration to these important potential uses of the **Data Evaluation Table** as the assessment goes forward.</u>

It is agreed that the data evaluation and data summary tables provide a valuable means of documenting the use and considerations of data made by the TI team. In the project report, the tables will supplement the detailed discussions of the technical bases for the SSC model (i.e., documentation of the bases for the branches and weights on the final logic trees). The TI team will give due consideration to the potential uses for the tables given in the PPRP comment.

7. *Sensitivity studies:* We consider the sensitivity studies to be highly valuable for providing insights and gaining understanding of the sensitivity of PSHA at a specific site to various elements of the SSC model. Additional sensitivity studies at a range of distances from the sources of frequent large earthquakes could add value for future use of the SSC model. However, <u>we recommend that the sensitivity studies not be used to justify devoting a reduced effort to assessing any fundamental element of the SSC model.</u> (See also Comment 11.)

See response to Comment 11.

8. *Lack of Consideration of Focal Depths:* There was a lack of discussion of earthquake focal depths in the workshop presentation on the updated CEUS seismicity catalog. This omission should be rectified. <u>Because focal depth is a potentially important contributor to our knowledge of seismic hazards, useful in characterizing and defining the limits of seismic source zones, and helpful in assessing potential ground motion, we recommend that greater consideration be made of this parameter in the CEUS SSC.</u>

We agree that seismic sources are three-dimensional and the vertical dimension is to a large extent constrained by the depth of earthquake hypocenters. The accuracy of focal depths varies considerably throughout the study region. The project report will include a discussion of earthquake focal depths and their use in characterizing seismic sources for the CEUS SSC project.

9. *Plan for use of gravity and magnetic data.* Gravity and magnetic anomaly data and a variety of maps processed from these data are important in mapping largely hidden geological structures of the CEUS that may be useful in identifying seismic source zones and their geographic boundaries. We note that the contract for preparing the gravity anomaly data and associated maps has been let to the University of Oklahoma, but the contract has not been executed for preparing and processing the magnetic anomaly data. Furthermore, the Expanded Schedule for the CEUS project (7/14/09) set the completion date for both of these contracts as October 30, 2009, which we learned at WS-3 has now been delayed until December 31, 2009. Despite the lack of the products from these contracts, the work of the TI team including the identification and delimiting of source zones must continue. As a result, <u>we recommend that after December 31, 2009, once the new data sets and maps are available, a thorough review be conducted of decisions on identification and bounding of source zones that were reached prior to the availability of the gravity and magnetic anomaly data and related maps.</u> This review may lead to modification of previous decisions.

The TI team will plan to carry out such a review once the gravity and magnetic data are available.

10. *Preliminary Seismic Source Zones:* The seismic source zones used for the sensitivity evaluations and discussions during WS-3 are still tentative, but a cursory review of these zones raises several concerns:
    - Where the evidence for the identified seismic source zones and their geographic limits are not described in referenced publications, <u>we recommend that a comprehensive description be provided for the basis underlying the assessments of the source zones and their boundaries.</u>

    Descriptions of the bases for all seismic sources will be provided in the project report.

    - It is unclear why certain regions were selected as “zones of elevated seismicity.” What is their role? Why was the Clarendon-Linden region identified but not southeastern New York, the Niagara Peninsula, and other CEUS regions of above normal seismicity in the historical record? <u>We recommend that definitive criteria be cited for the selection of elevated seismicity zones.</u>

    Zones of elevated seismicity were identified as a means of organizing the data summary tables. That is, the historical literature refers to several seismicity zones (e.g., Central Virginia, eastern Tennessee, Charlevoix) and we use this terminology to assist the reader of the data summary tables in recognizing the geographic distribution used in the literature. In most cases, zones of elevated seismicity—without a clear RLME source—are handled in the SSC model by the use of spatial smoothing. A complete discussion of the manner in which observed seismicity is used in the SSC model will be included in the project report.

- Earlier at Workshop No. 2, a scheduled presentation by Nano Seeber on seismicity and faulting in Ohio, Pennsylvania, New York State, and New York City was canceled and no similar presentation on this topic was made. Has anything been done to fill this void in the consideration and treatment of alternative interpretations? For example, a 2008 paper by Sykes and others[4] suggests an alternative view of seismicity in the New York City area that has not been cited in the Data Summary Table. We recommend that the list of alternative interpretations be updated to include those pertaining to the region that was to be discussed by Dr. Seeber at WS-2.

We appreciate the PPRP providing recommended literature and databases that the TI team should include in its considerations; hence, we welcome the suggestions for inclusion of the cited paper. Despite Dr. Seeber's cancelation of his participation at WS-2 due to illness, the TI team is aware of his models and will ensure that his publications are included in the associated data tables. In addition, representatives from the TI team will be attending the upcoming Eastern Section of the Seismological Society of America and the associated field trip led by Dr. Seeber.

- There may be an inconsistency in the way that "extended zones" are used in the identification of seismic source zones. The area of the extended zone with normal faulting associated with the Iapetan Rift Margin is moved hundreds of kilometers west into the stable craton from the mapped rift margin. However, the limits of the seismic source zone associated with Iapetan (Cambrian) rifting in the midcontinent, including the New Madrid Rift Zone and its extensions, appear to be limited to mapped grabens without consideration of a bordering extended zone. Of particular note is the lack of an extended zone associated with the Grayville graben in southern Indiana. The "wide" interpretation of the seismic source zones is a step in the correct direction, but without further documentation on the factors defining the boundaries of this interpretation, it is difficult to determine if the broader extended zone is being captured in this interpretation. We recommend that the TI Team consider the possibility of an "extended zone" marginal to midcontinent seismic source zones.

The TI team will reexamine the technical bases for defining the extended/non-extended boundary, relative to its potential influence on establishing a *prior* distribution on Mmax consistent with the way that extended/non-extended SCR crust has been subdivided elsewhere. Further, the technical bases for the alternative locations of the boundary will be documented in the project report as a means of expressing the epistemic uncertainty.

11. *Pruning the Logic Tree and Need for Complete, Clear Documentation*. The use of an initial sensitivity model to inform evaluations to support the final model assessments is a sound and efficient approach. However, care must be taken to fully and clearly document the results of the sensitivity study, particularly as it impacts development of the final model and particularly in cases where alternative branches are removed. In a SSHAC level-3 study, the degree of credibility that the technical community grants the final model may be based heavily on the clarity and completeness of documentation and the ability of the technical community to understand the basis of assessments made by the TI team. In addition, robust

documentation can more easily allow for the incorporation of new data and site-specific information into the model. In fact, specific guidance on how new or site-specific data should be evaluated could prove very valuable to the practitioner.

The final model must represent the range of legitimate interpretations of the informed technical community in a scientifically defensible way. While some pruning of the tree based on the sensitivity study is desirable, we recommend that the sensitivity study not be used to trim branches that represented significant concepts or alternate hypotheses, even if the inclusion of alternate branches does not impact hazard. Some computational efficiencies could possibly be gained for the future hazard analyst if the study provides specific guidance as to the distance from the more significant sources at which the source no longer impacts hazard, and can be trimmed from the model.

The TI team is aware of the need to show that all potentially significant hypotheses have been considered in the course of the evaluations. We are also aware that some hypotheses—although subject to debate within the technical community—may have relatively little significance to hazard at the annual frequencies of interest. Likewise, certain technical issues will have a profound effect on hazard (e.g., those related to rate) and should be given priority in the development of the preliminary SSC model. In this spirit, the feedback gained from the analyses conducted for WS-3 and the follow-on analyses that were identified during the workshop will serve as a means to prioritize the subsequent efforts by the TI team as we move forward. This certainly does not mean that "significant concepts or hypotheses" will be "trimmed from the tree." However, first priority will be given to the concepts and hypotheses that matter most to hazard. Whether or not the concepts and hypotheses are actually included in the logic trees, evidence that they have been fully considered and evaluated will be included in the project documentation. In addition, consideration will be given to including specific guidance for site-specific application of the SSC model relative to the distances and sources that may need to be included. This guidance would be part of the site-specific implementation guidance anticipated for inclusion in the project report.

13. *Sanity Check for Seismic Sources Defined by Paleoliquefaction:* We recommend that the TI Team make a sanity check for those seismic sources defined by paleoliquefaction—that is, whether the source boundaries make sense, given the assumed magnitude versus area (or length) using relationships between magnitude and the maximum distance to liquefaction. For example, the magnitude-versus-area relationship for the CEUS results in an assumed rupture length of ~21 km for M = 6.7. For the currently defined Charleston source options, can ruptures at the far ends of the source (e.g., the southeastern or northwestern corners of the large zone shown on Figure 15 in the HID) explain the observed paleoliquefaction at the opposite end of the source? The TI Team may need to factor in how they are modeling the recurrence of the source relative to the paleoliquefaction—but they need to make sure that the sources for the paleoliquefaction regions do not become too large when considering how rupture length is being modeled relative to paleoliquefaction.

The TI team will plan to conduct such sanity checks during the development of the preliminary SSC model.

15. *Need for Uniform Rigor in Assessing Rate-Information Inputs.* Examination of the SSC Sensitivity Model shows an apparent unevenness in rigor applied to assessing rate-information inputs in terms of significant figures and assessed distributions. This stands in contrast to the systematic rigor applied, say, to recurrence modeling. Because of the fundamental importance of rate information to hazard, we recommend careful uniform attention to the assessment of rate inputs. Such assessments should meet the basic expectations of a normative expert in a PSHA if one were overseeing the assessments.

The TI team agrees with the comment and will provide uniform attention to the assessment of rate inputs across the entire SSC model.

16. *PPRP Observers in Remaining Working Meetings*. Under the CEUS SSC Project Expanded Schedule (dated July 14, 2009), the next face-to-face meeting of the PPRP with the TI Team will be in March 2010. Because this will be at a relatively late stage of shaping a near-final (albeit still "preliminary") SSC model, we recommend that the Project Manager facilitate participation of at least two PPRP members as observers in the TI Team's Working Meeting #6 (October 20–21, 2009) and Working Meeting #7 (January 12–13, 2010).

We agree with the comment and encourage participation by members of the PPRP at the upcoming working meetings.

Thanks again for your insightful review comments, and we are convinced that they will assist us in developing a better product. If you have any questions regarding this letter, please feel free to contact us.

Sincerely,

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April 19, 2010

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Subject: *Central and Eastern United States Seismic Source Characterization for Nuclear Facilities:* Feedback on CEUS SSC Preliminary Model dated April 7, 2010.

Dear Carl and Walter,

Thank you for your letter summarizing the Participatory Peer Review Panel's review of the Preliminary SSC Model for the CEUS SSC project. The letter reflects the Panel's continuing review of both the technical and process aspects of the project. In the spirit of a participatory peer review process, we welcome timely, insightful, and constructive reviews and suggestions that will assist the TI team in achieving a successful conclusion.

To provide the PPRP with insights into our intentions relative to the specific recommendations made in the letter, we provide below a response to the recommendations that have been underlined in your letter to draw attention to their priority. We also value the perspectives provided in other parts of the letter, and these will be given serious consideration during the course of the project activities leading up to and including the development of the project report.

> **"General Observations**
> We commend the Project Manager and TI Team leader for their continuing effective leadership of the Project. This leadership continues to stimulate and maintain productive interactions among TI Team members and between the Project Team and the Panel. Actions required to complete the Project identified in "Path Forward" discussed at the end of the meeting appear to be well formed and achievable. The Panel noted, however, that the actions do not include a feedback interaction following completion of the Panel's review of the Draft Project Report to be delivered on September 1, 2010. We recommend that a process for resolving the Panel's comments and recommendations aimed at completing the Final Project Report be identified and scheduled."

We agree that a process for resolving the Panel's comments and recommendations on the Draft Project Report should be identified and scheduled. The process will be developed in consultation with the PPRP.

> **"Specific Comments and Recommendations**
> 2. *Differences Between Seismic Source Zones:* The TI Team stated that the conceptual approach used to define distributed seismic sources, specifically those defined on a seismotectonic basis, focused on four key factors: (1) earthquake recurrence rates; (2) maximum magnitude; (3) expected earthquake characteristics; and (4) tectonics. The

Data Evaluation Tables provide information on some of these factors indicating some differences between seismic source zones. However, because the TI Team had not completed development of the final earthquake catalog, implementation of the approach to defining maximum magnitude and spatial smoothing of earthquake recurrence rates for each of the distributed seismic sources had not been finalized. As a result it is difficult for the PPRP to have high confidence that the preliminary seismic source characterization model captures the center, body, and range of the ITC. While some significant differences between distributed seismic sources may be anticipated (e.g., Mmax differences between Non-Extended crust relative to differences between the Illinois Basin Extended Basement (IBEB) and Mid-continent Crust seismic sources), it is not intuitive that such differences will fully support the seismotectonic zones that subdivide the Mesozoic Extended crust, and as a result the conceptual approach used to define distributed seismic sources. The PPRP had expected that the Hazard Input Document would have included information to justify the approach being used. The PPRP recommends that the TI Team provide this information for PPRP review concurrent with providing hazard input to the project's hazard analyst.

We recommend the following with respect to maximum magnitude: (1) The TI Team should describe how paleoliquefaction evidence was used to define seismic source likelihood functions. (2) The TI Team should provide specific likelihood functions and posterior distributions for each of the Hybrid and Seismotectonic source zones, for each of the prior assumption cases considered.

With respect to the application of the smoothed seismicity approach, we recommend that the PPRP be provided with sufficient activity rate maps for each hybrid and seismotectonic source zone (such as for M = 5) to appreciate the significance of recurrence rate differences between seismic sources."

The TI Team will provide the HID for the Final SSC Model to the PPRP at the time that it is provided to the hazard analyst for calculations. The HID will include the Mmax distributions for all sources as well as the earthquake recurrence rates that are derived from spatial smoothing. For each seismic source, the largest observed event that defines the likelihood function will be identified, including those derived from paleoseismic data and historical seismicity data. An appropriate display of earthquake recurrence rate spatial variation will also be provided.

"3. *Organization of the Logic Trees*: We note that there are significant changes in the organization of the logic trees of the current CEUS SSC from previous PSHAs of the region. The Panel is generally supportive of these changes, but we recommend that the documentation of the design of the logic trees include a clear and detailed explanation of the reasoning involved in making the changes from previous studies. For example, the magnitude of the largest observed events (both historical and inferred from paleoliquefaction) is a major factor in isolating source zones for detailed characterization (the RLMEs), while regions of moderate to intense earthquake activity without moment magnitudes that exceed mid-5 values such as eastern Tennessee, northeastern Ohio, the

Humboldt fault zone (Nemaha Ridge), and the Ramapo fault that have been included in earlier studies are not called out as specific seismic zones.

Furthermore, we have the sense that some lines of evidence used by the ITC in identifying and characterizing the seismic source zones of the CEUS have not received the attention in the current study that they have been given by some members of the ITC and in former PSHAs of the region. For example, contrary to the present study, some investigators place considerable emphasis on recent strain (GPS) measurements and others give considerable weight to tectonic features of the CEUS that have been mapped directly or indirectly in the identification and characterization of seismic source zones. The project would be well served by documented justification of the reasoning supporting minimization of these elements by the TI team in their decisions—and we recommend that the Draft Technical Report include such documentation."

We agree that the project documentation must provide a detailed discussion of the criteria that were used to identify seismic sources and a justification for all logic tree branches and weights. To the extent that it helps the explanation, this discussion will be made in the context of previous seismic source characterizations for PSHA and the evolution of the technical community. Elements of emerging issues within the technical community that have not yet seen routine incorporation into SSC for PSHA, such as the use of geodetic strain data, will be discussed in the project report if they were evaluated for potential use by the TI Team in the SSC Model. It is important to note that the "informed technical community" that is being represented in the SSC Model is the hypothetical community of seismic source characterizers for purposes of PSHA, who are assumed to have been through the same interactive process that the TI Team has been through. As such, there is often a difference between the issues being considered by the larger research community and those that find their way into the SSC Model for a PSHA.

"4. *Clarity of terms in the Master Logic Tree*: In labeling and discussing branches of the Master Logic Tree, clarity can be improved. The TI Team may want to consider another term for "hybrid" at the very front end of the tree. The term is a vestige from labeling a former three-branch node (now collapsed to two), and many readers would expect a hybrid branch to be a combination of two other branches. Referring to "zoneless" seismicity sources is confusing insofar as these sources lie within demarcated areas of differently affected Mesozoic crust. In general, we recommend that the TI Team examine jargon that has evolved in their internal discussions and evaluate whether terms used in their working discussions now help or hinder clear communication to others. Labeling of Iapetan Extended/Non-extended as a different case from Mesozoic Extended/Non-extended may be confusing to those unfamiliar with the arcane term "Iapetan." Labeling of "Inter-event Times" as a Recurrence Method for the RLME logic tree branches is confusing because the method used in fact involves the use of both inter-event and event-interval paleoearthquake data. In source geometry branches for RLME sources (e.g., Figures 15 and 17 in the HID), "extended trace" should be used instead of just "extended" to avoid confusion with crustal extension."

The terminology used in the Master Logic Tree will be re-examined and revised to assist the reader.

> "5. *Assigning Weights to the Logic Trees*: As mentioned during the Briefing Meeting, we recommend that TI Team describe the overall approach to assigning weights to the logic trees, and that this written description be included in the Draft Technical Report. In some cases these weights represent an explicit statistical assumption or distribution while in other cases these weights are the TI's evaluated judgment of the informed technical community views. In these cases it would be useful to have an understanding of how the TI assigned weights from a generic perspective."

A description of the overall approach to assigning weights to the logic tree will be provided in the Draft Project Report.

> "6. *Spatial Smoothing*: Conceptually, the PPRP endorses the direction the TI team is taking with respect to spatial smoothing approach and implementation. However, thus far there has been no written documentation provided to us that: (1) describes the method in detail as it is being applied in this project, (2) describes the bases for choices of parameters of the model, or (3) justifies reliance entirely on the penalized likelihood method. We recommend that the eventual documentation not only describe the adopted technique in detail but also document any perceived advantages of this technique relative to simpler kernel techniques. Some discussion of "floor" values in regions of very low rates should also be included. It would benefit our review to receive this section for review as soon as is practicable."

A discussion of the spatial smoothing approach and its technical basis are planned for inclusion in the Draft Project Report. The discussion will include a comparison to kernel smoothing approaches as well as the issue of a "floor" on recurrence rates in regions lacking seismicity. Every effort will be made to provide the written discussion in advance of the delivery of the Draft Project Report.

> "7. *ALM Area Characterization*: The TI Team presented its independent evaluation of published field data, including original field copies of trench logs and field photographs of features that Randy Cox had described in WS #2 and interpreted as liquefaction features. "Project-specific *Criteria for Identifying Earthquake-Induced Liquefaction Features Used in Development of Paleoearthquake Chronologies*" were used to perform the evaluation. Discussions during the TI Team's presentation identified that these criteria are current state of practice for determining whether observed features are earthquake-induced liquefaction features or properly explained as depositional or due to another geologic process. First, given that the criteria are identified as representing the state of practice of the informed technical community, the "project-specific" qualification is confusing and misleading. We recommend that these criteria be clarified or removed.
>
> Second, the Team's evaluation appears to reasonably support their conclusion that the features do not satisfy the informed community's criteria for reasonably assessing that the features are earthquake-induced. However, this evaluation appears inconsistent with the

highly qualified ALM area model assessment conclusion: "the paleoliquefaction data from the ALM region are immature and highly uncertain and, at the present time, do not provide strong evidence for a source of RLME in the ALM area." This highly qualified conclusion clearly conveys a level of uncertainty that would support giving some assessed weight to an interpretation that the ALM should be modeled as a RLME. Perhaps what is meant is that the information in the current dataset, when assessed using the criteria for determining whether features are indeed liquefaction features consistent with current state of practice, does not support the interpretation that these are paleoliquefaction features. We strongly support the TI Team's decision, as stated during the discussion, to revisit and clarify this assessment—and we recommend that the TI Team do so.

To support this last point, it would be helpful if the discussion of the criteria include not only what the specific criteria are but the scientific and technical basis of each criterion. This would support not only this assessment, but would provide a valuable tool for projects in the future when datasets are not clear, or even as new information becomes available in the ALM area."

The criteria used to evaluate the paleoliquefaction in the CEUS, including the ALM area, will be clearly stated and defended technically in the Draft Project Report. Also, the terminology used in the evaluation of paleoliquefaction in the ALM area will be revised to more accurately reflect the assessment made.

"8. *Data Summary and Evaluation Tables*: The Panel finds the Data Summary and Data Evaluation tables to be highly important in supporting and annotating the decisions regarding identification and characterization of the seismic source zones of the CEUS. Every effort should be made to include in these tables documentation for the current, complete center, body, and range of the ITC by seeking feedback from appropriate current investigators prior to finalizing the tables. A full description is warranted of the procedures used in selecting material for the Data Summary table. Additionally, both tables are essential in reviewing the basis for, and the assessments regarding, seismic source zones—but there remains the need for a full narrative that will allow the user of the CEUS SSC Model to completely understand the data evaluations that support the assessments made by the TI Team. We recommend that the Draft Technical Report include such a full narrative for the Data Summary and Data Evaluation tables."

The Draft Project Report will include a discussion of the purpose and content of the Data Summary and Data Evaluation tables. The tables are intended to support the discussions of the characterization of the seismic sources, which will also be included in the Draft Project Report.

"10. *"Other" Reviews of the CEUS SSC Model*: At the Briefing Meeting, the Project Manager showed tracking milestones including "Review of Draft [Technical] Report by PPRP, USGS, and Sponsor Reviewers—August 2, 2010 to September 1, 2010." It seems appropriate to call attention to the following statement in Implementation of the SSHAC

Guidelines for Level 3 and 4 PSHAs—Experience Gained from Actual Applications (USGS Open-File Report 2009-1093, p. 35:

> The PPRP is the only legitimate review panel recognized by the SSHAC Guidelines; there is only one PPRP for a SSHAC Level 3 or 4 study, and its sole and unique obligation is to provide on-going commentary to TI/TFI as the project develops. All other "review panels" should be considered as observers, unless the project leadership agrees in advance to a different role/format for them.

The Panel recognizes the prerogative of the Project Sponsors to request comments on the Draft Technical Report from other parties of its choosing for its own purposes. <u>However, we recommend—and believe it is essential—that any comments on the CEUS SSC Model provided to the TI Team that result from a TI Team request be made available to the PPRP for its awareness and consideration."</u>

We agree that within the context of a SSHAC process, the PPRP is the only group with standing to review the technical and process aspects of the project. As noted, the Sponsors, as observers, may carry out their own reviews of the Draft Project Report and provide comments to the TI Team for consideration.

"11. *Comments on Draft Report Outline:* We recognize that the Draft Report Outline dated March 9, 2010, is preliminary (in its present form, the outline is a mix of topical phrases and explanations of what specific subsections will contain). As such, a detailed review is premature, and we only offer some general comments (not exhaustive). <u>We recommend that the PPRP have another opportunity to review the Draft Report Outline after the TI Team finalizes it.</u> This could avoid some late-stage criticisms of the content of the Draft Technical Report during our August review."

We appreciate the comments made on the preliminary Draft Report Outline and, as requested, the final draft outline will be sent to the PPRP for their review.

"Closing Comment
The Panel is aware that, at the request of the Project, the USGS is preparing to deliver to the TI team independent feedback on the Project Earthquake Catalog and on the draft HID focusing on completeness of datasets, models, and tools being used in the CEUS SSC assessment. Based on telephone discussions between the PPRP and the Project Team on April 5, 2010, we understand that the TI Team will evaluate the USGS comments and will consider them in its final assessment and in its development of the final HID for the Project. We further understand that the TI Team's evaluation of the USGS comments will be finalized as part of its final working meeting scheduled to be held on April 12-13, 2010, in which one or more PPRP members will participate as observers."

As noted, the USGS was asked to provide their comments on two review products, and they responded in letters dated April 8, 2010 and April 9, 2010, which was provided to the PPRP on April 9, 2010. We have responded to the USGS letter in a letter dated April 9, 2010, which was

provided to the PPRP on April 9, 2010. Working Meeting #8 on April 12-13, 2010 provided the opportunity to ensure that all comments are addressed.

Thanks again for your insightful review comments, and we are convinced that they will assist us in developing a better product. If you have any questions regarding this letter, please feel free to contact us.

Sincerely,

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APPENDIX J

Magnitude-Recurrence Maps for All Realizations and All Source-Zone Configurations

J

APPENDIX MAGNITUDE-RECURRENCE MAPS FOR ALL REALIZATIONS AND ALL SOURCE-ZONE CONFIGURATIONS

The figures in this appendix show the eight alternative realizations of the recurrence maps, as well as maps of the uncertainty in recurrence parameters, for all alternative source zone configurations in the master logic tree and for the three alternative magnitude weights (Cases A, B, and E). Figures J-1 through J-81 show the maps for the three alternative configurations of the Mmax source zones. Figures J-82 through J-189 show the maps for the four alternative configurations of the seismotectonic source zones. The methodology used to generate these maps is documented in Section 5.3.2. Mean maps and magnitude-recurrence comparisons for each source zone are shown in Chapter 6 on Figures 6.4.1-1 through 6.4.1-9 and Figures 6.4.2-1 through 6.4.2-15, respectively; and in Chapter 7 on Figures 7.5.1-1 through 7.5.1-12 and Figures 7.5.2-1 through 7.5.2-51, respectively.

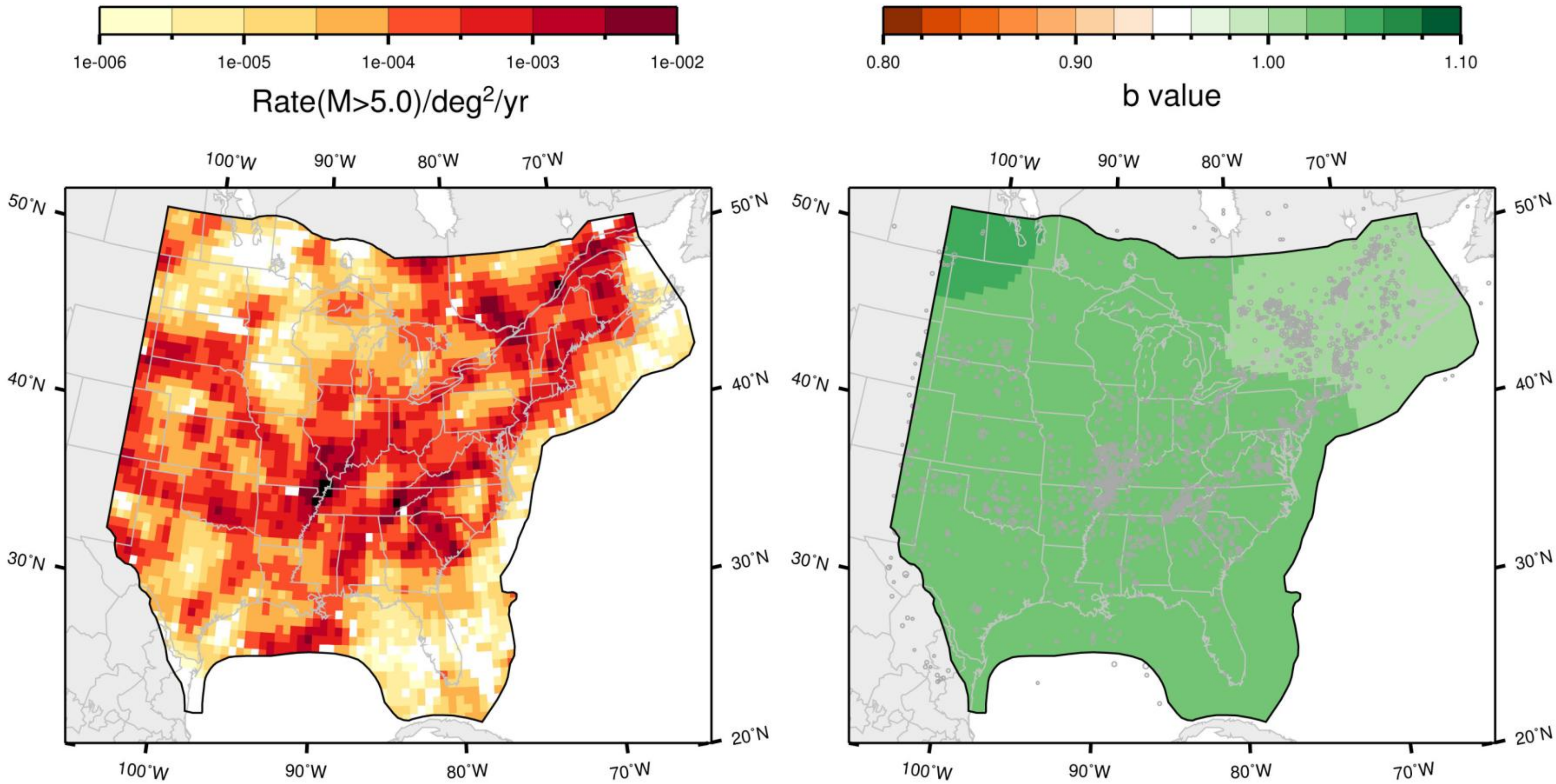


Figure J-1
Map of the rate and *b*-value for the study region under the Mmax zonation, with no separation of Mesozoic extended and non-extended; Case A magnitude weights: Realization 1

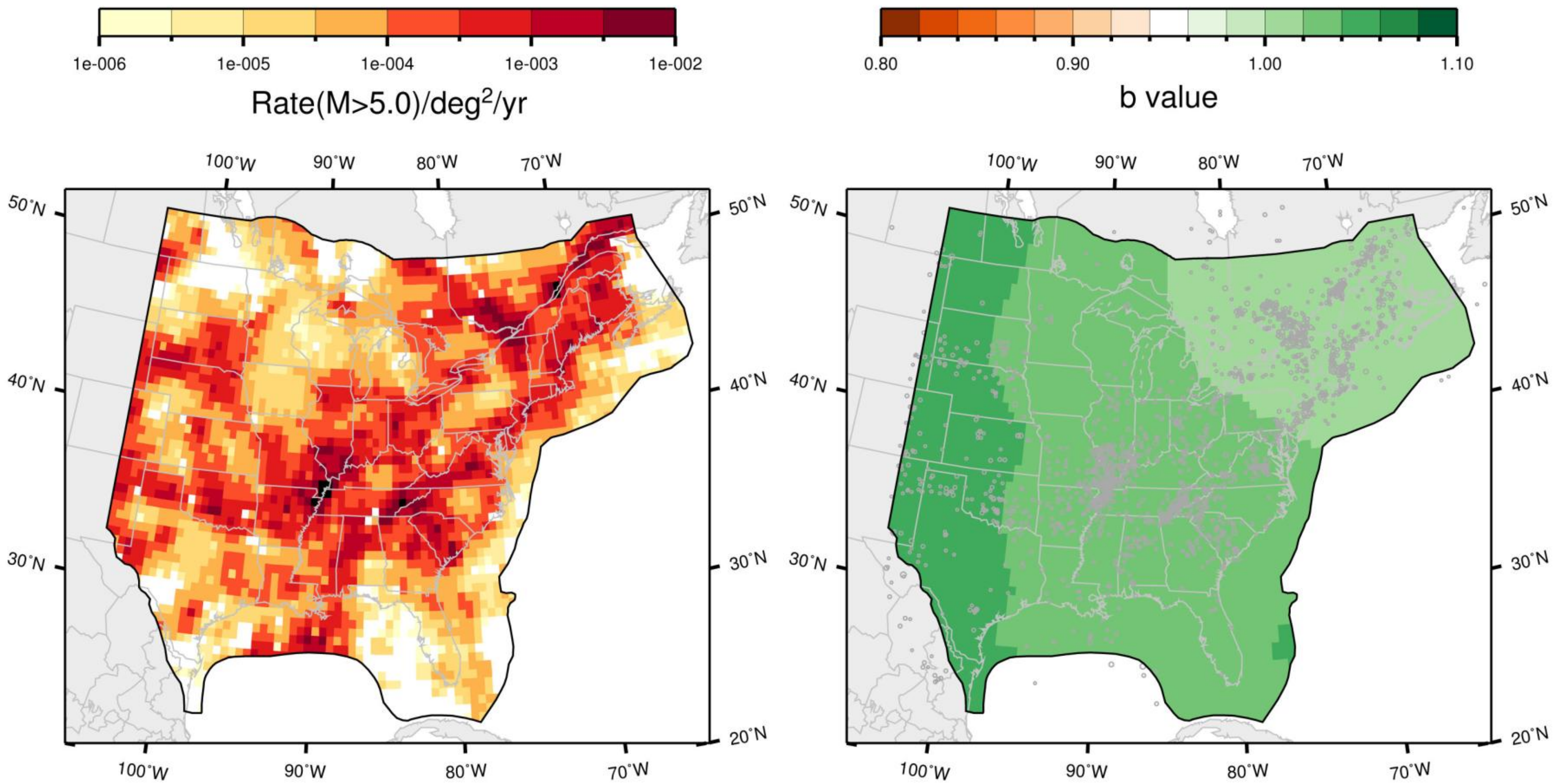


Figure J-2
Map of the rate and *b*-value for the study region under the Mmax zonation, with no separation of Mesozoic extended and non-extended; Case A magnitude weights: Realization 2

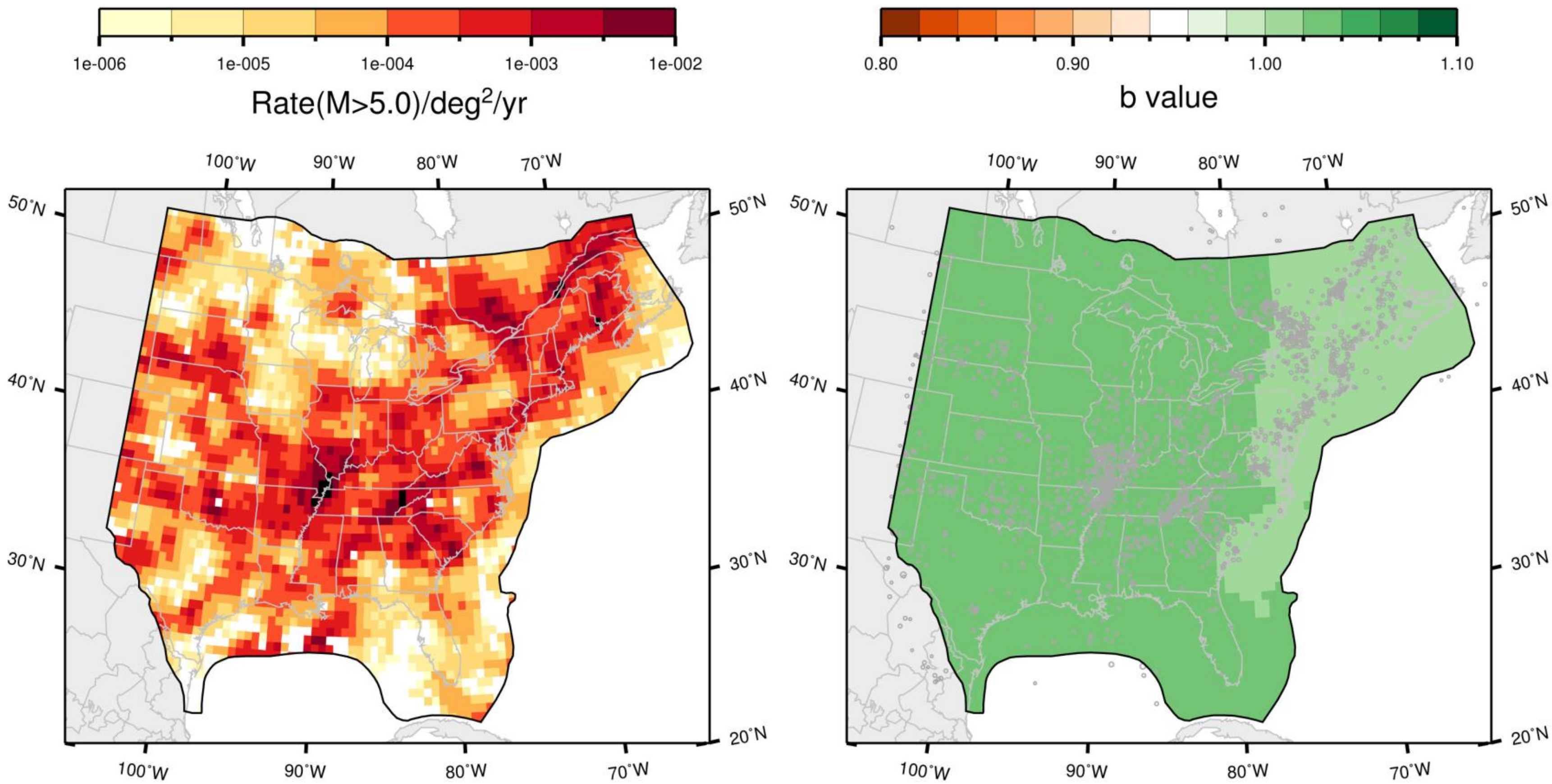


Figure J-3
Map of the rate and *b*-value for the study region under the Mmax zonation, with no separation of Mesozoic extended and non-extended; Case A magnitude weights: Realization 3

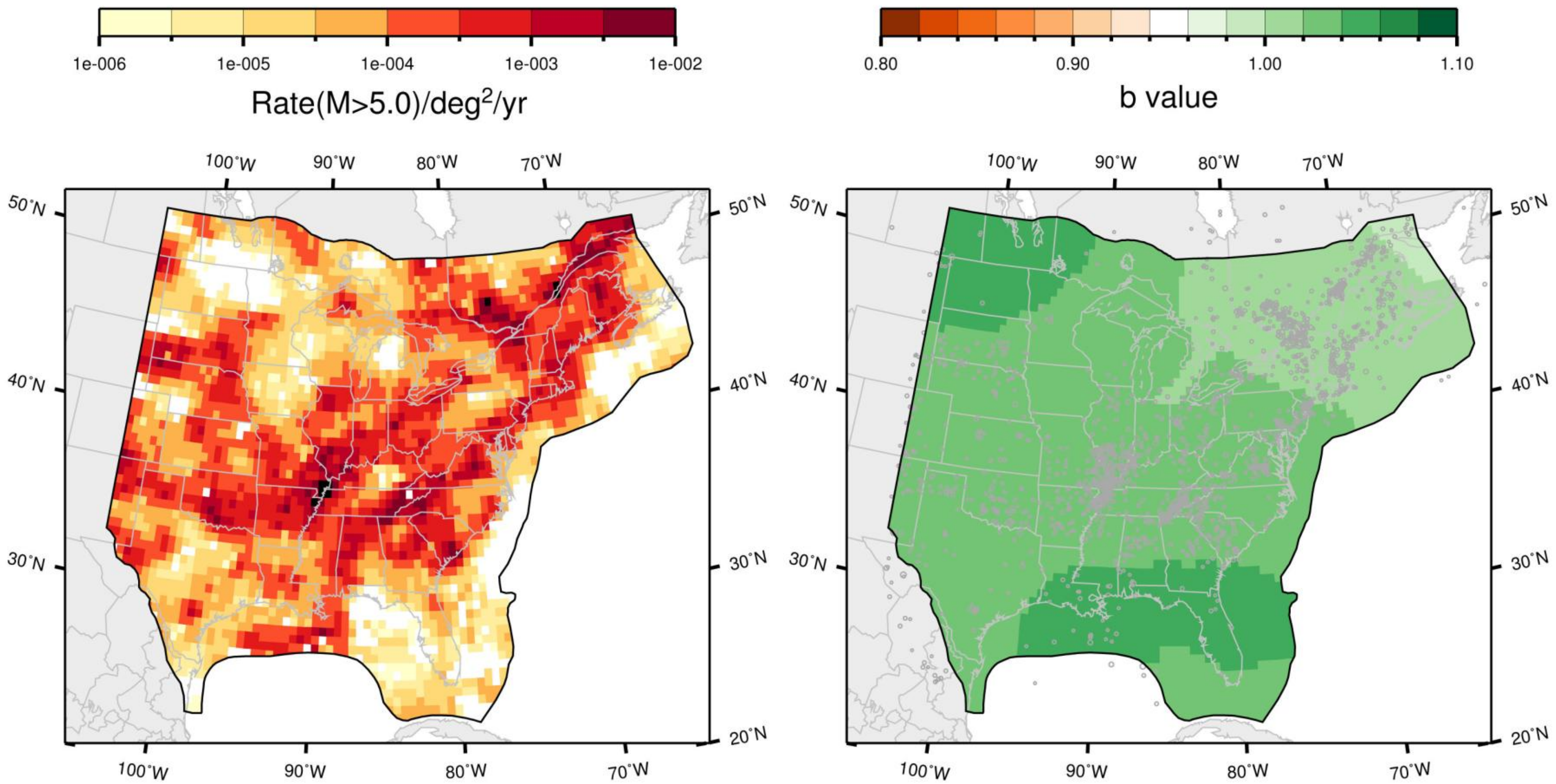


Figure J-4
Map of the rate and *b*-value for the study region under the Mmax zonation, with no separation of Mesozoic extended and non-extended; Case A magnitude weights: Realization 4

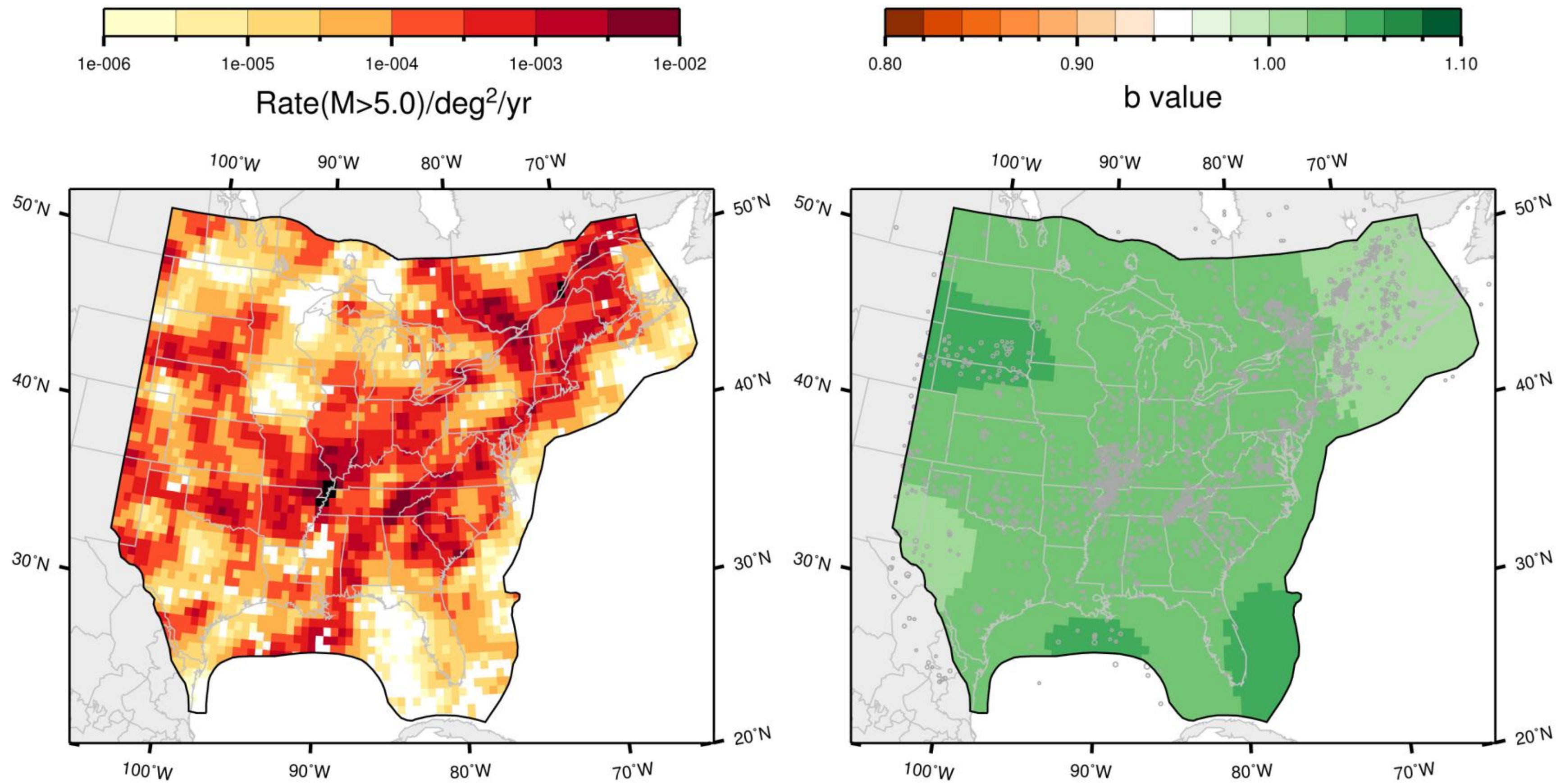


Figure J-5
Map of the rate and *b*-value for the study region under the Mmax zonation, with no separation of Mesozoic extended and non-extended; Case A magnitude weights: Realization 5

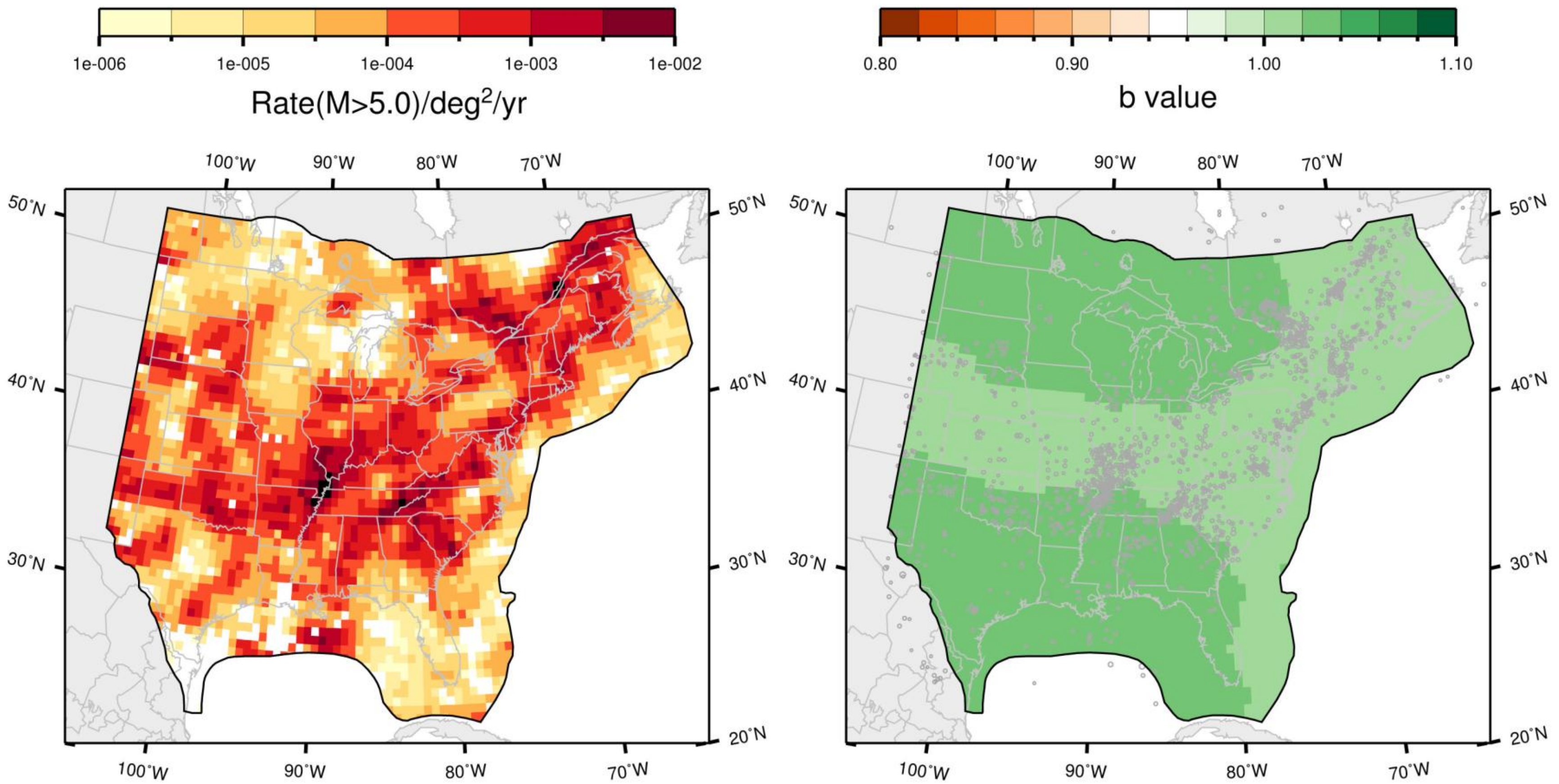


Figure J-6
Map of the rate and *b*-value for the study region under the Mmax zonation, with no separation of Mesozoic extended and non-extended; Case A magnitude weights: Realization 6

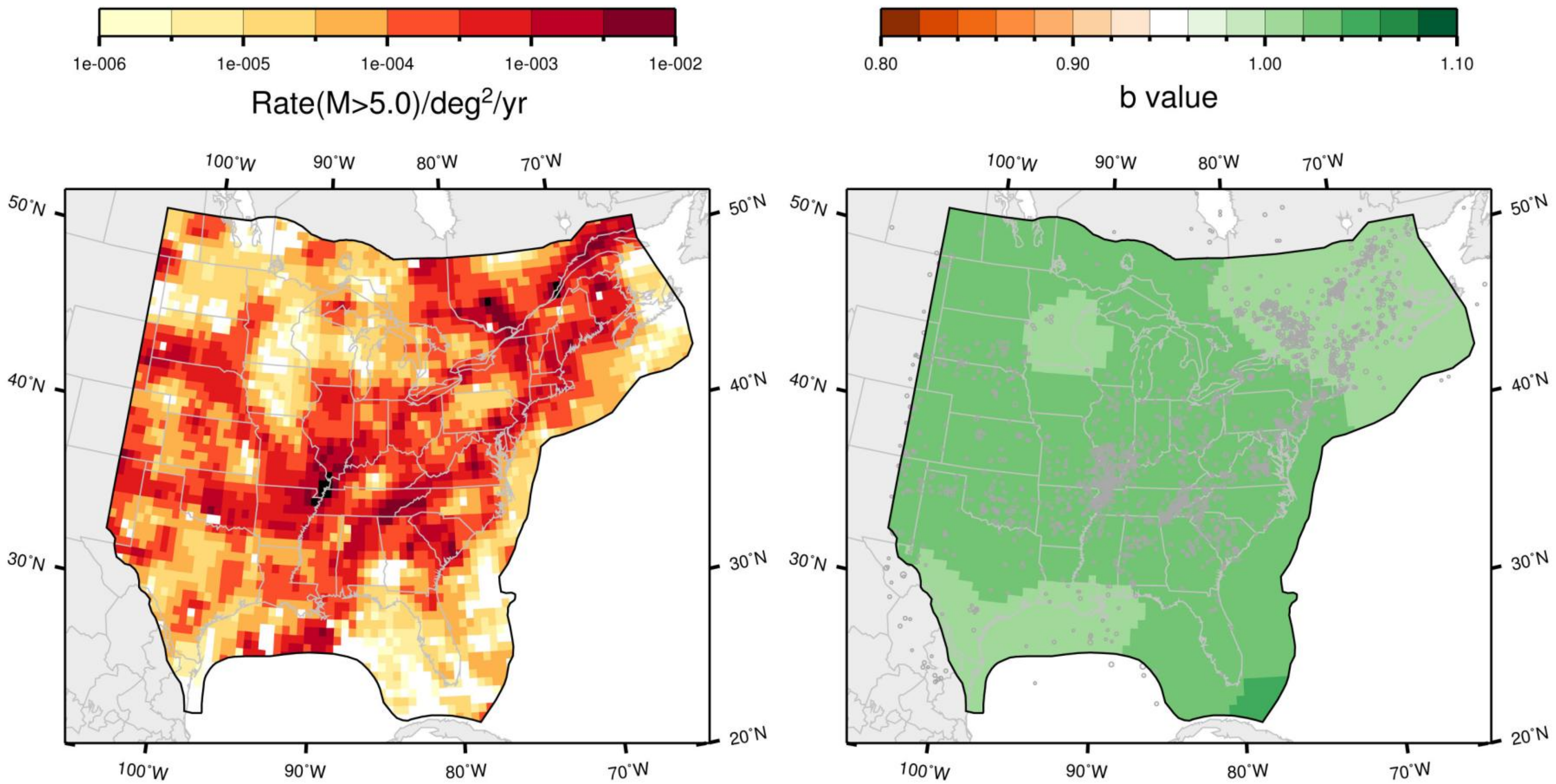


Figure J-7
Map of the rate and *b*-value for the study region under the Mmax zonation, with no separation of Mesozoic extended and non-extended; Case A magnitude weights: Realization 7

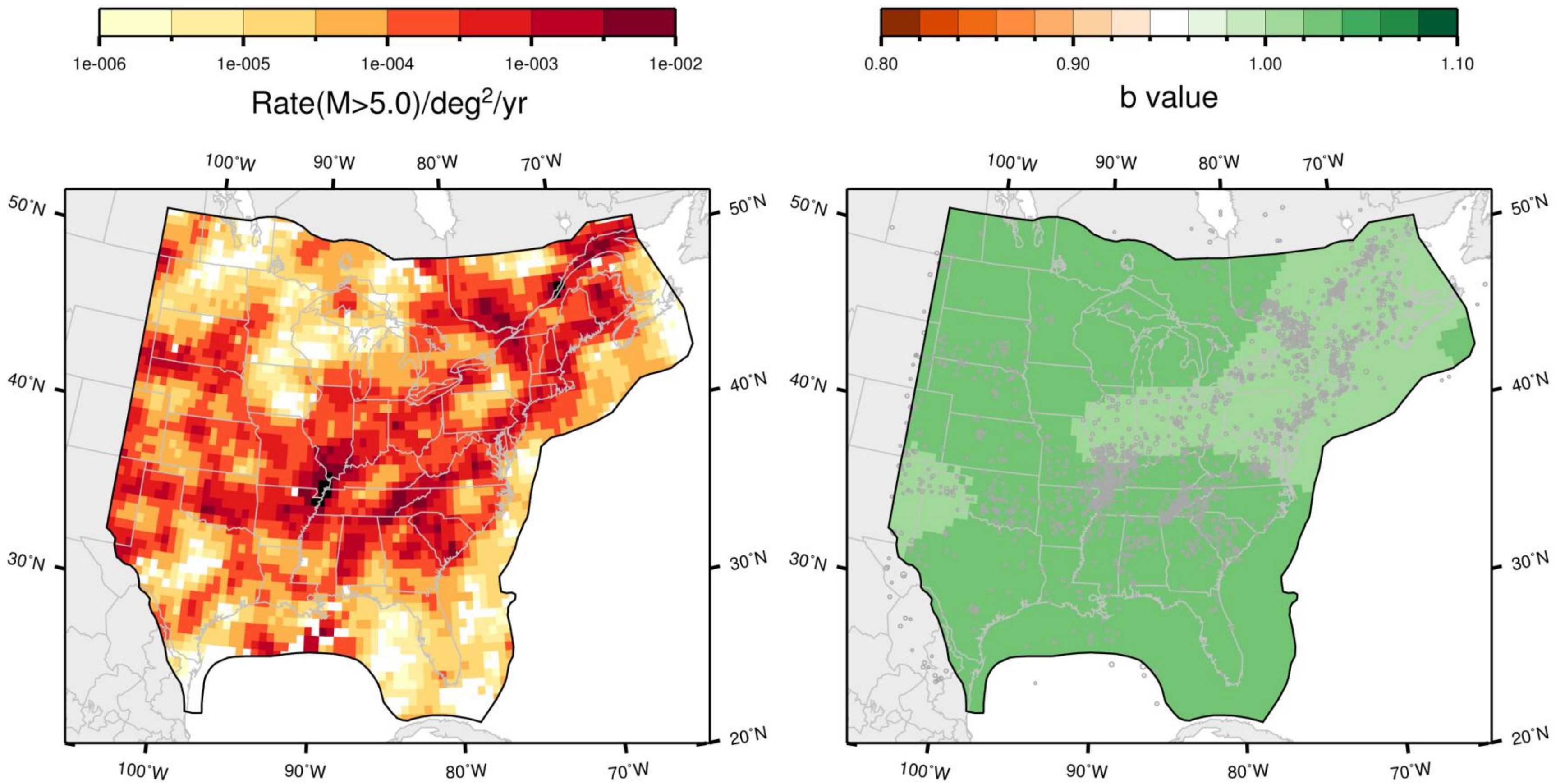


Figure J-8
Map of the rate and *b*-value for the study region under the Mmax zonation, with no separation of Mesozoic extended and non-extended; Case A magnitude weights: Realization 8

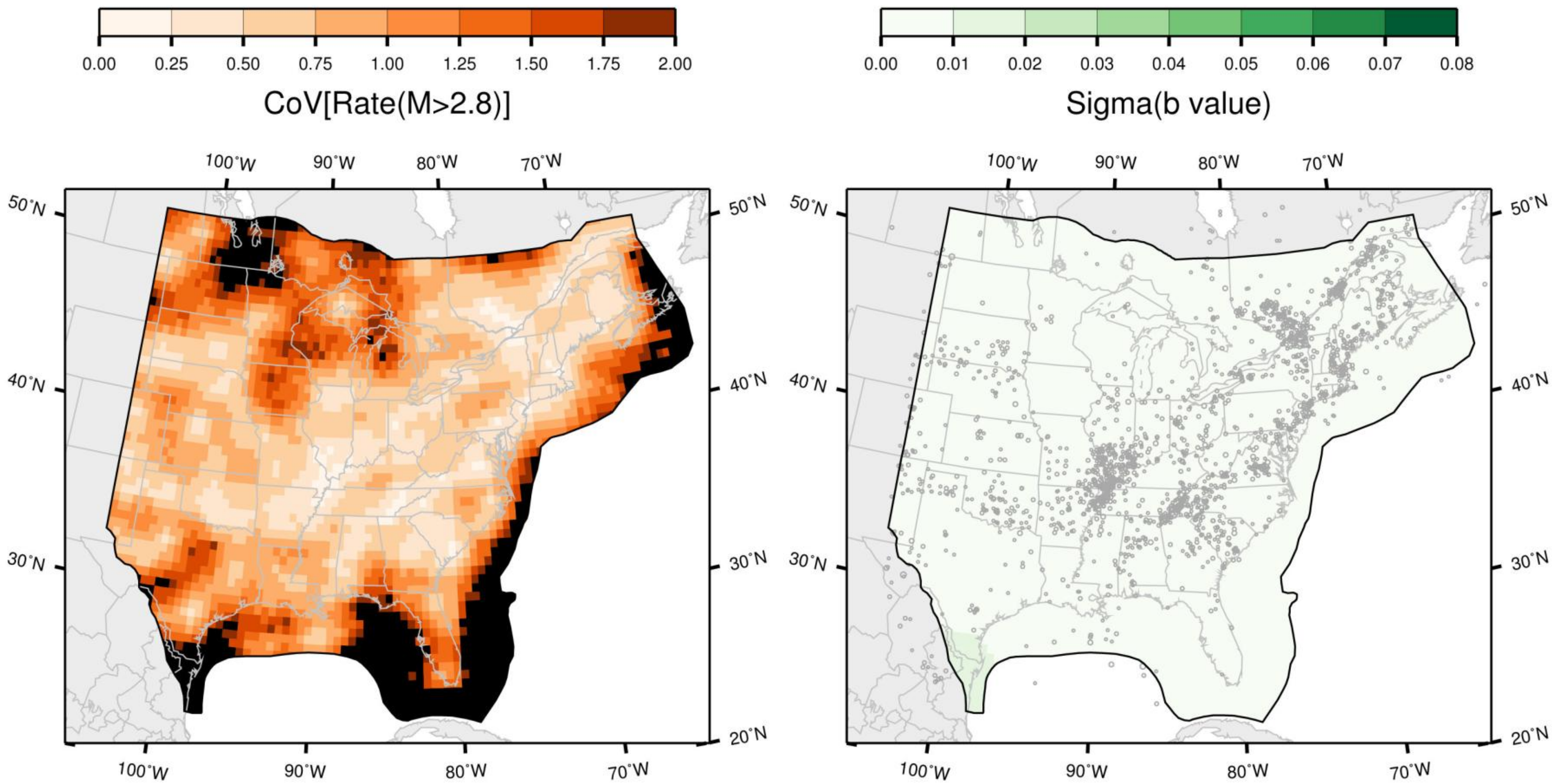


Figure J-9
Map of the coefficient of variation of the rate and the standard deviation of the *b*-value for the study region under the Mmax zonation, with no separation of Mesozoic extended and non-extended; Case A magnitude weights

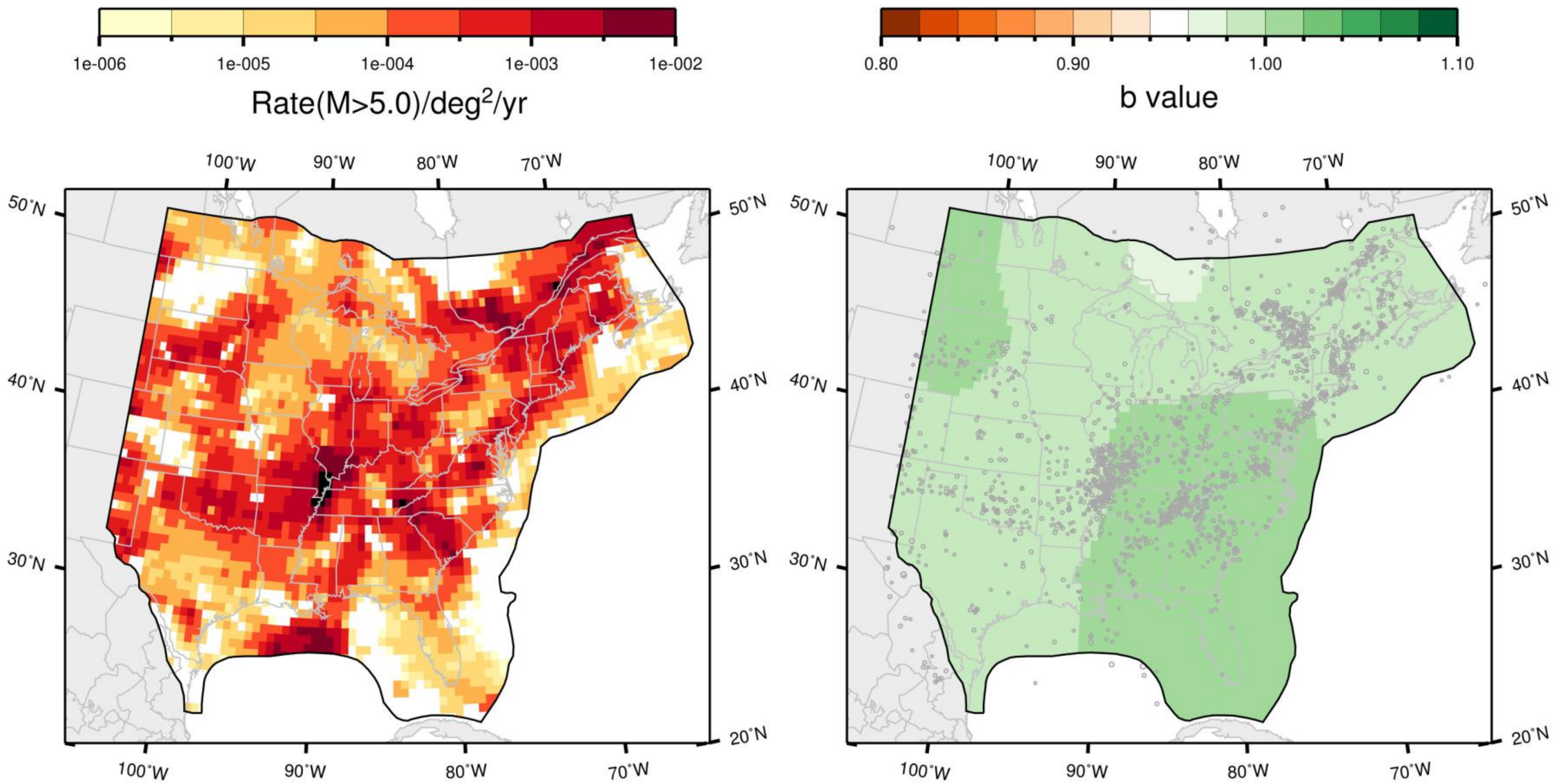


Figure J-10
Map of the rate and *b*-value for the study region under the Mmax zonation, with no separation of Mesozoic extended and non-extended; Case B magnitude weights: Realization 1

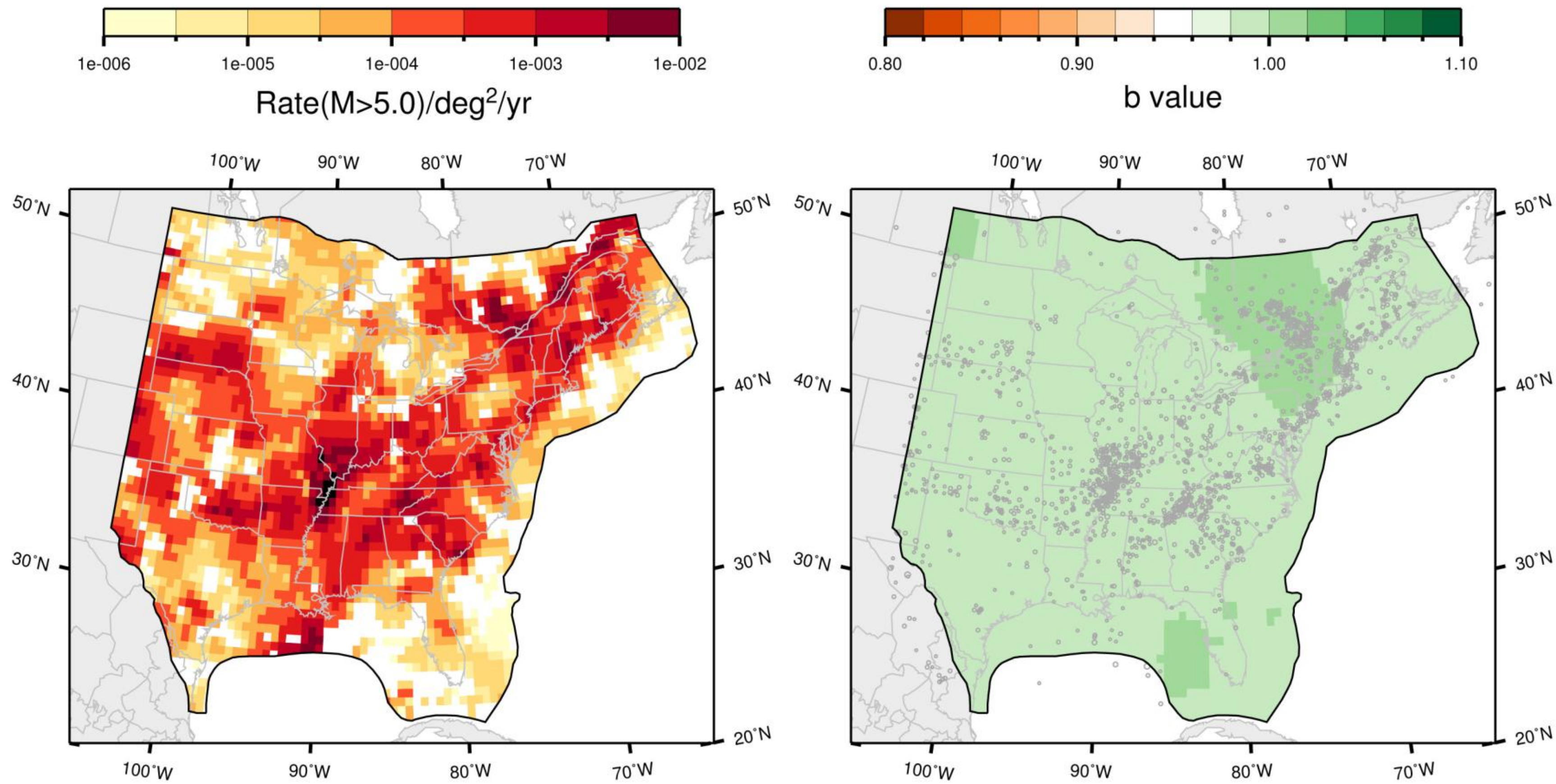


Figure J-11
Map of the rate and *b*-value for the study region under the Mmax zonation, with no separation of Mesozoic extended and non-extended; Case B magnitude weights: Realization 2

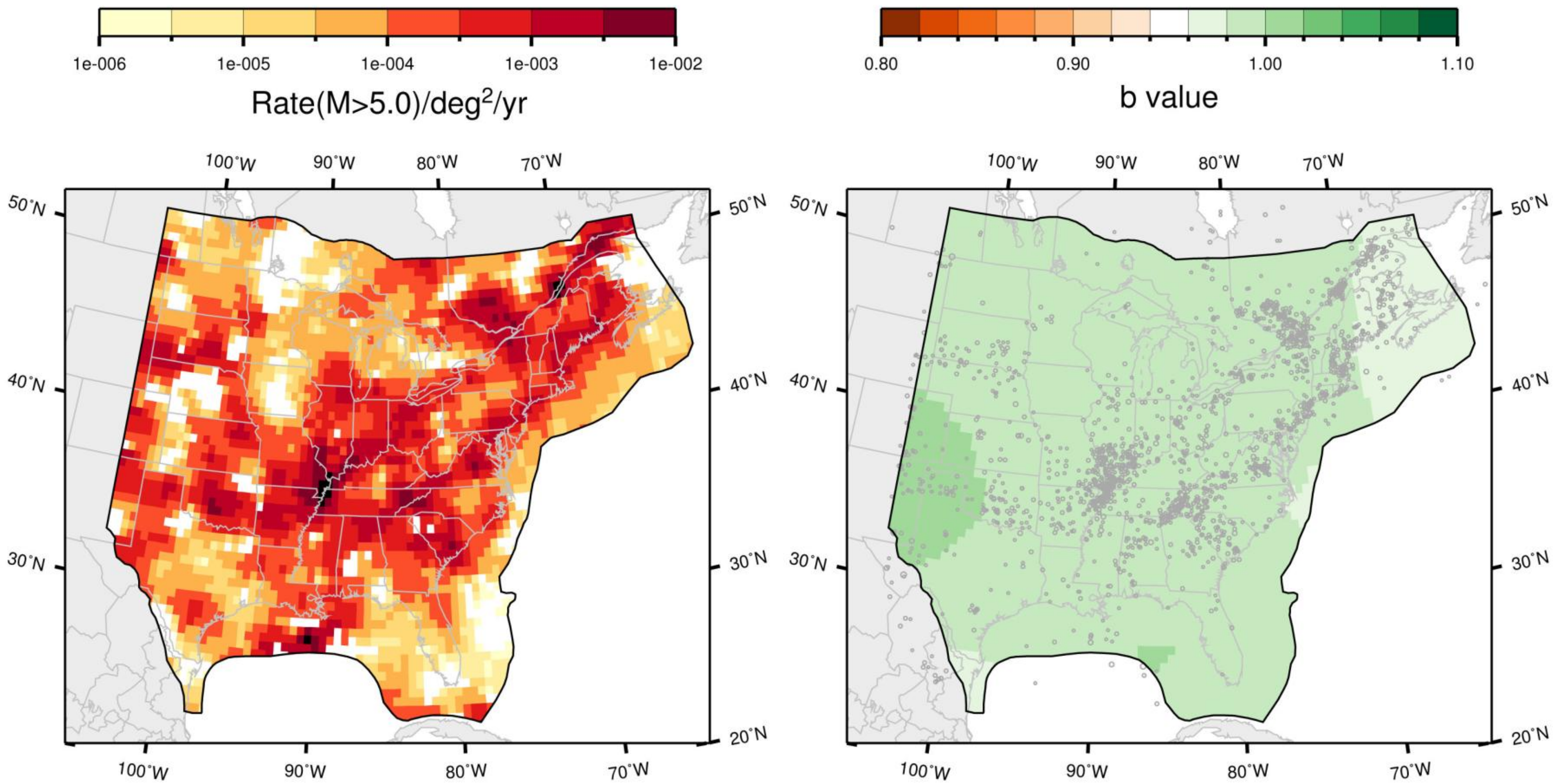


Figure J-12
Map of the rate and *b*-value for the study region under the Mmax zonation, with no separation of Mesozoic extended and non-extended; Case B magnitude weights: Realization 3

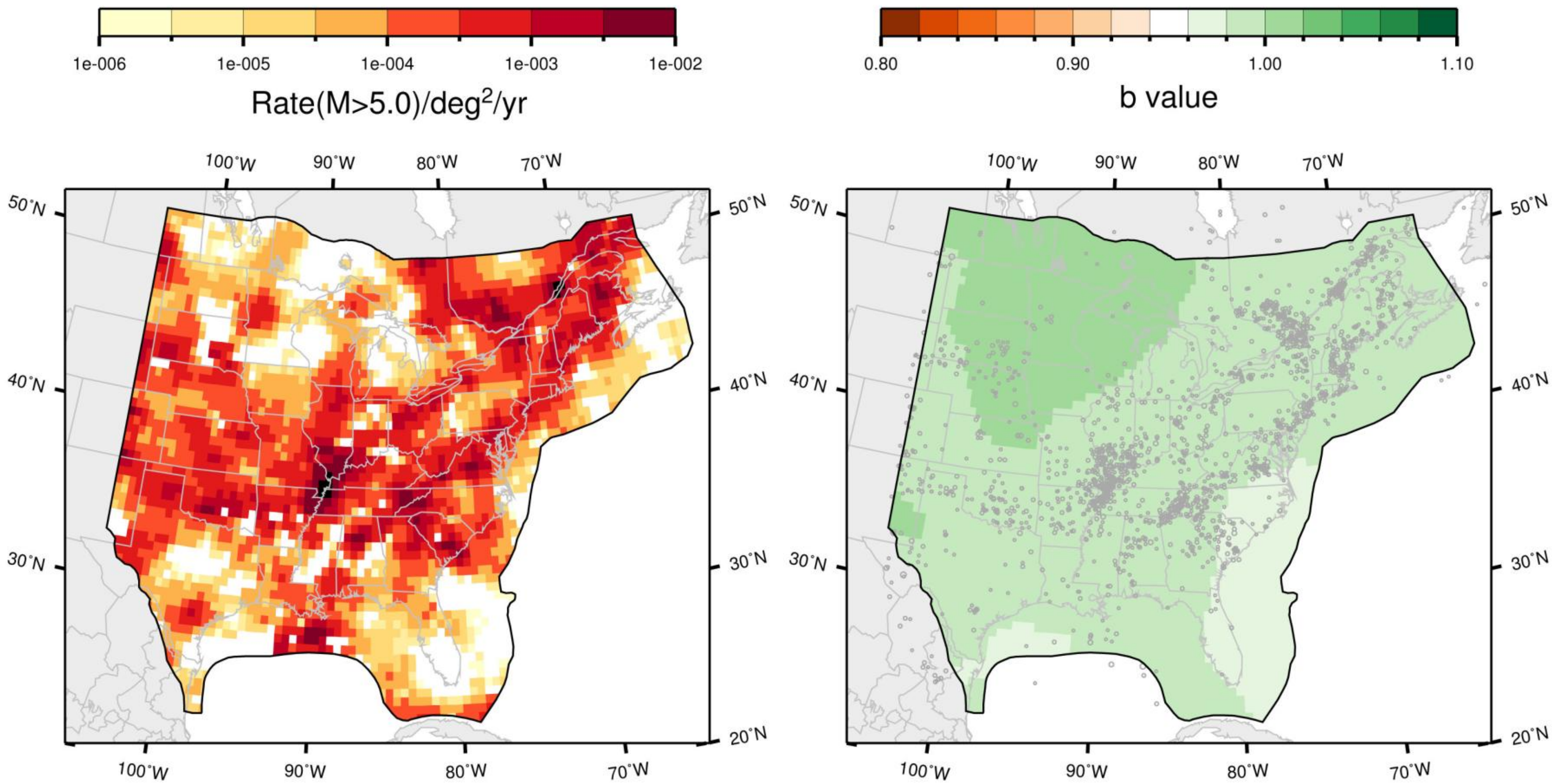


Figure J-13
Map of the rate and *b*-value for the study region under the Mmax zonation, with no separation of Mesozoic extended and non-extended; Case B magnitude weights: Realization 4

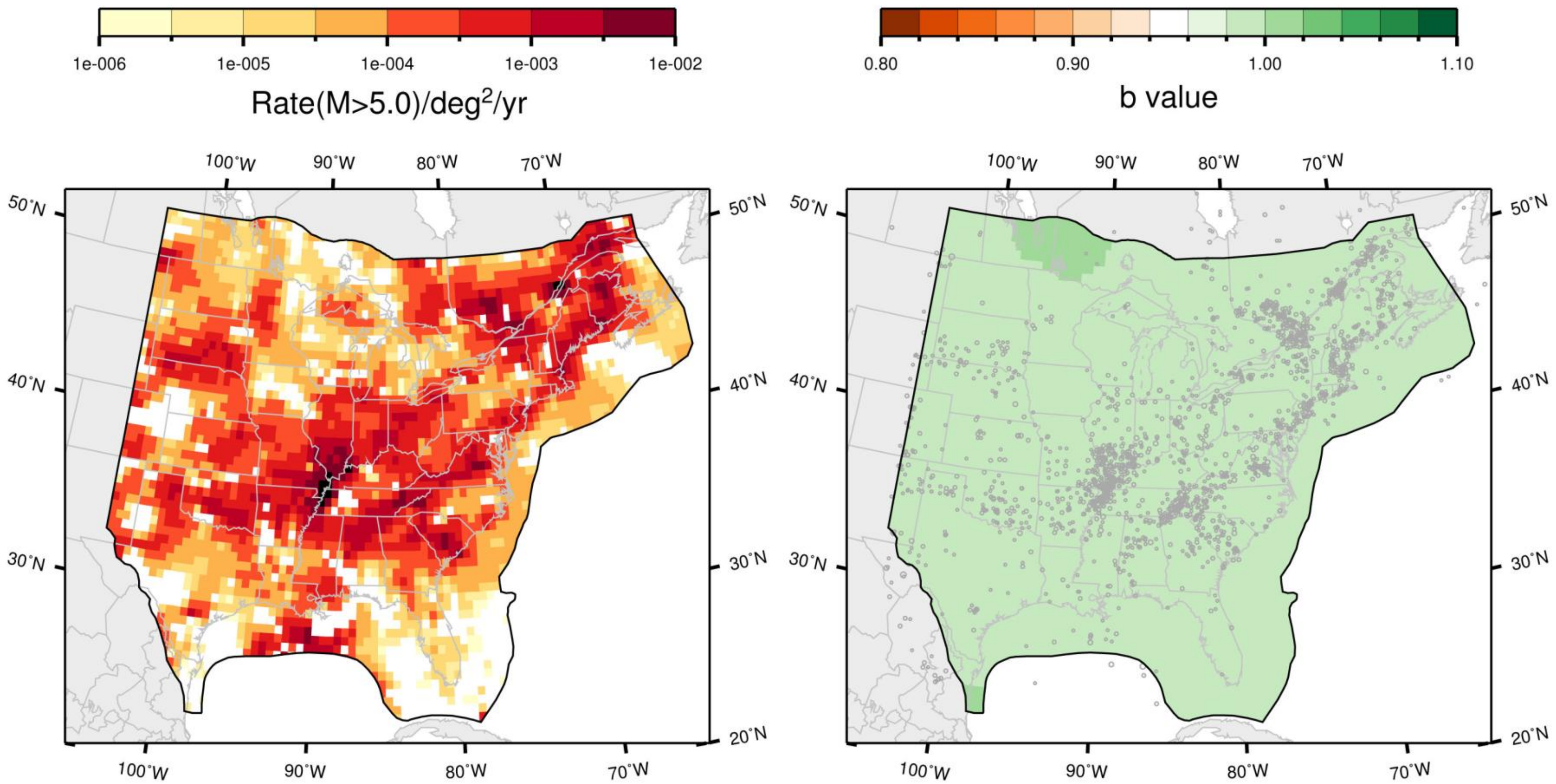


Figure J-14
Map of the rate and *b*-value for the study region under the Mmax zonation, with no separation of Mesozoic extended and non-extended; Case B magnitude weights: Realization 5

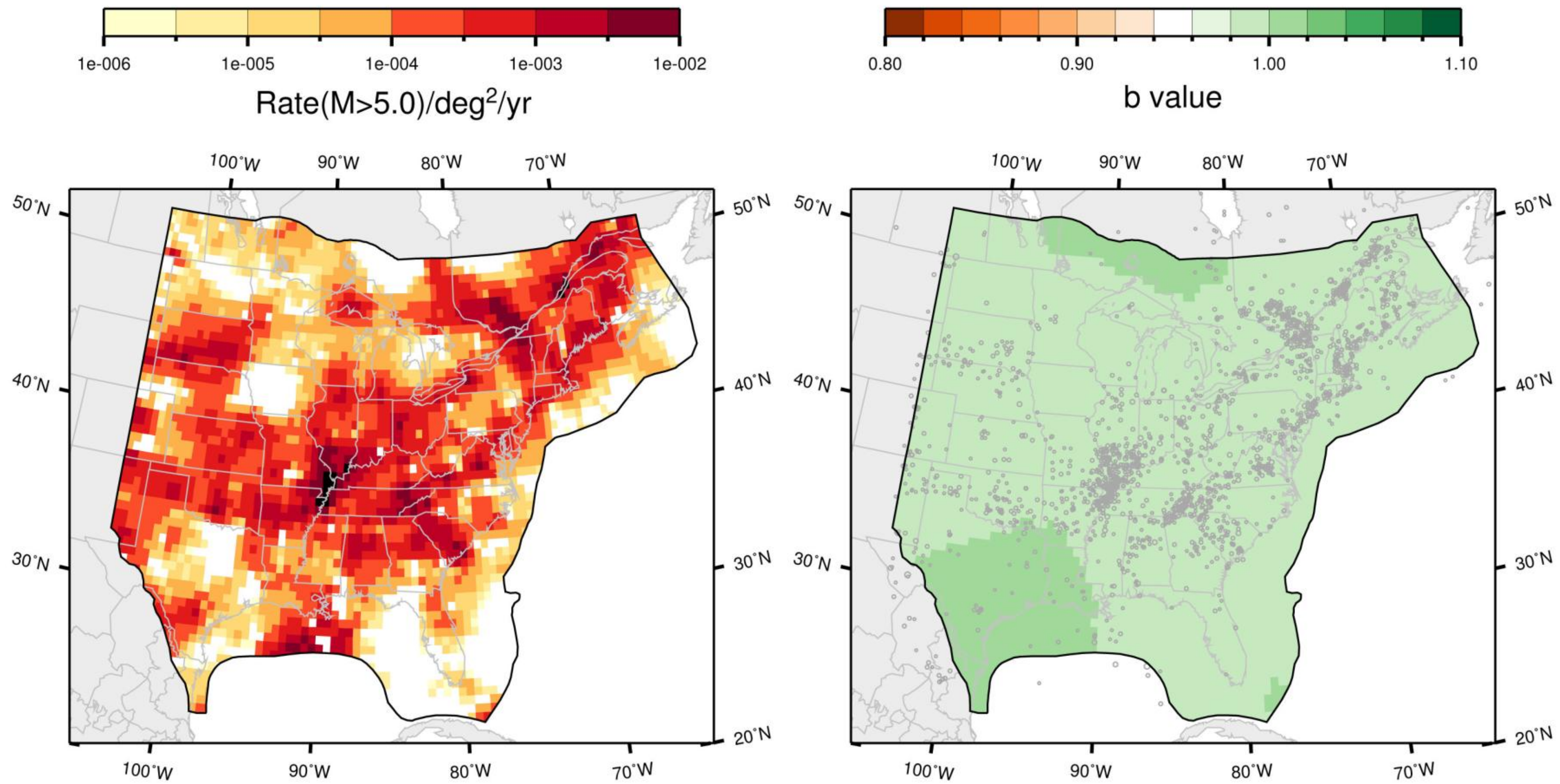


Figure J-15
Map of the rate and *b*-value for the study region under the Mmax zonation, with no separation of Mesozoic extended and non-extended; Case B magnitude weights: Realization 6

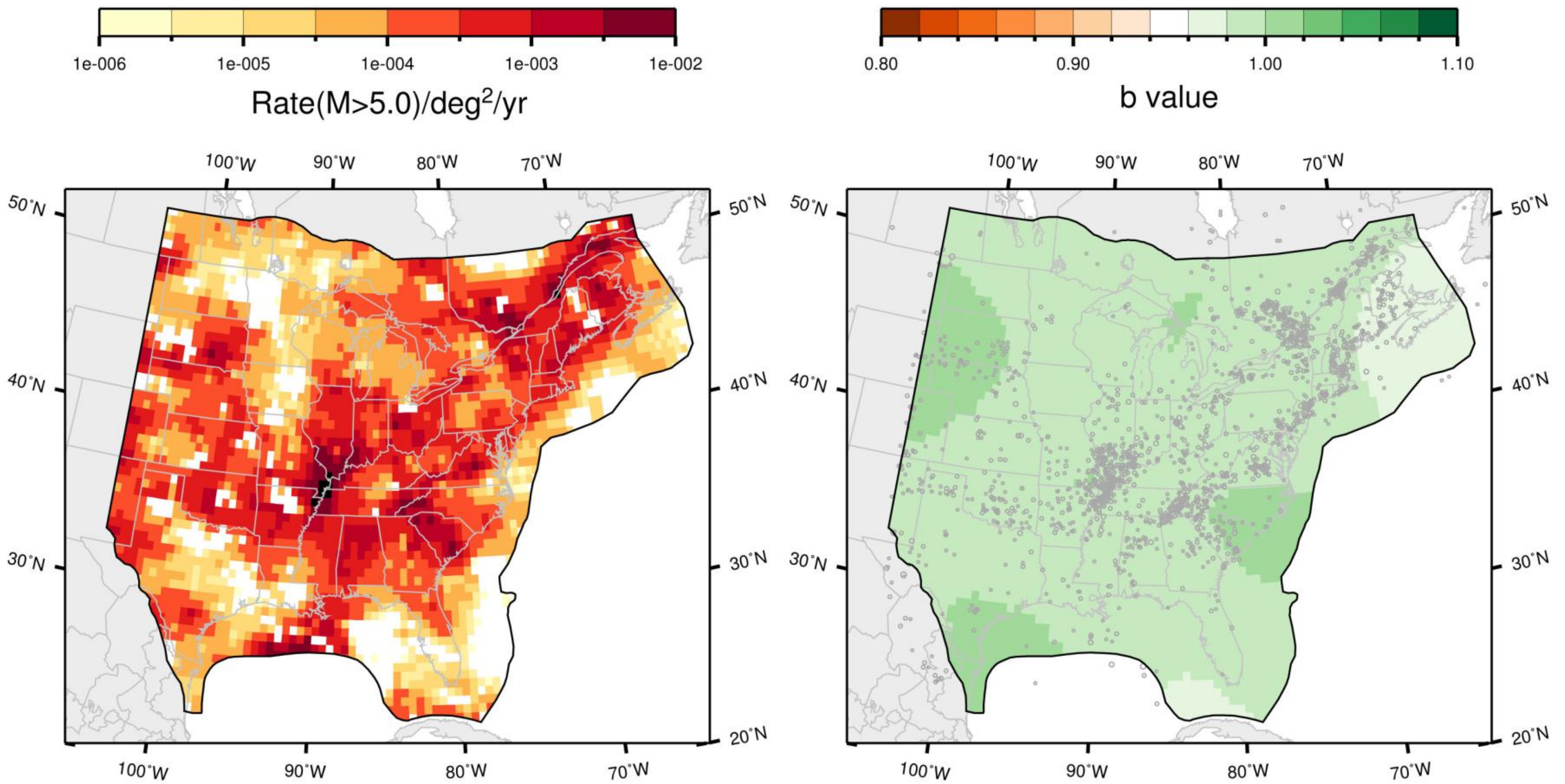


Figure J-16
Map of the rate and *b*-value for the study region under the Mmax zonation, with no separation of Mesozoic extended and non-extended; Case B magnitude weights: Realization 7

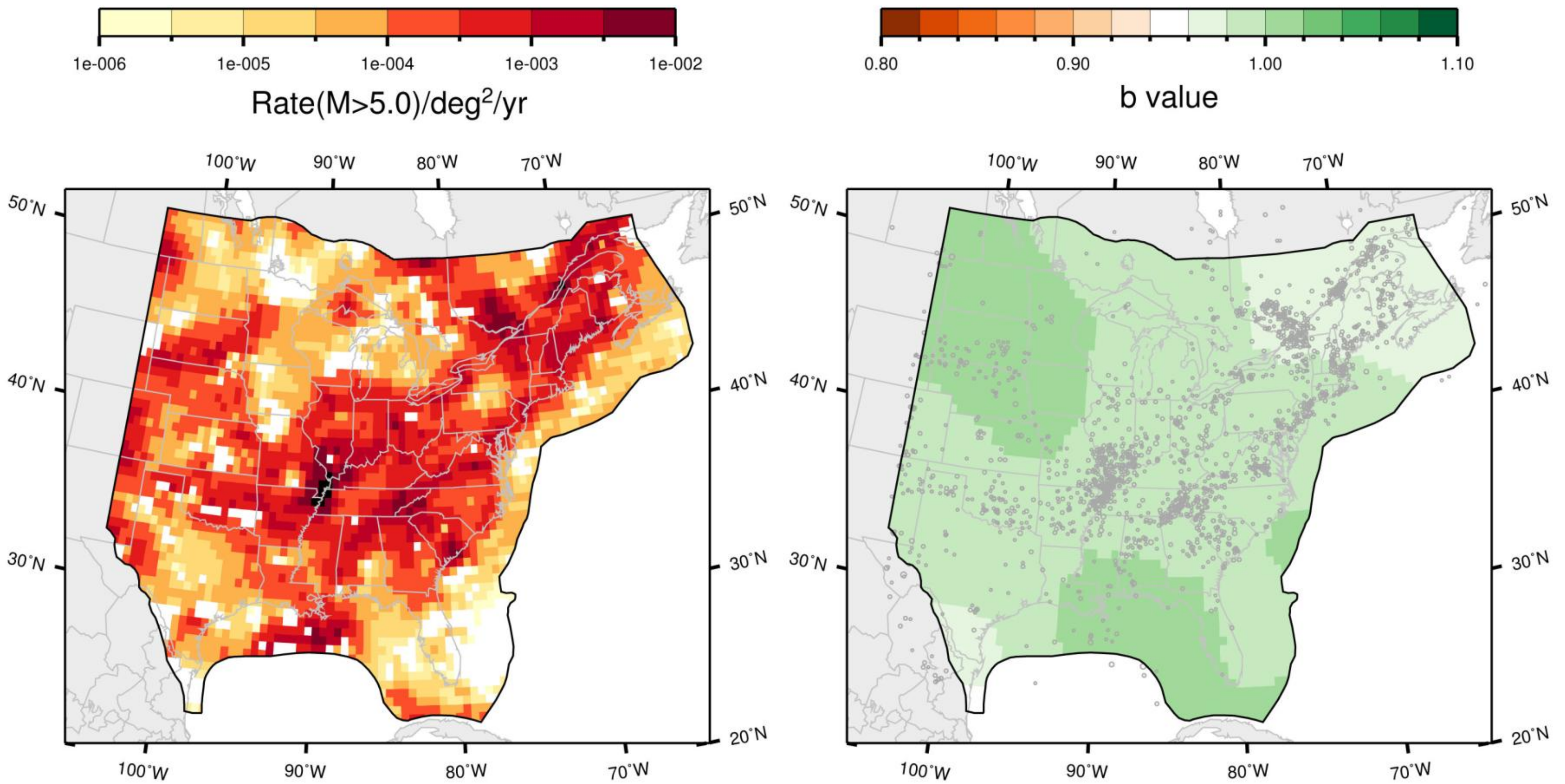


Figure J-17
Map of the rate and *b*-value for the study region under the Mmax zonation, with no separation of Mesozoic extended and non-extended; Case B magnitude weights: Realization 8

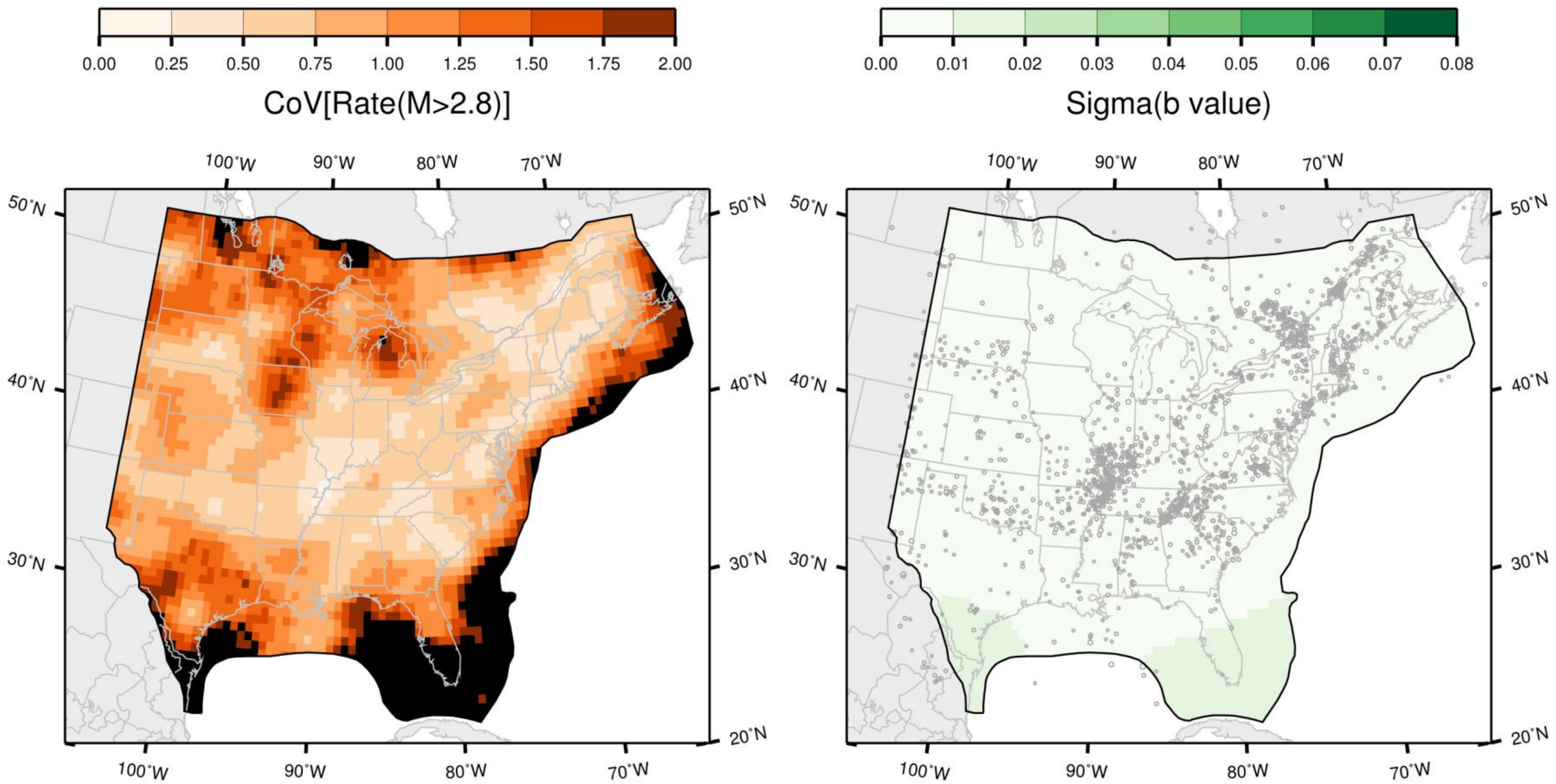


Figure J-18
Map of the coefficient of variation of the rate and the standard deviation of the *b*-value for the study region under the Mmax zonation, with no separation of Mesozoic extended and non-extended; Case B magnitude weights

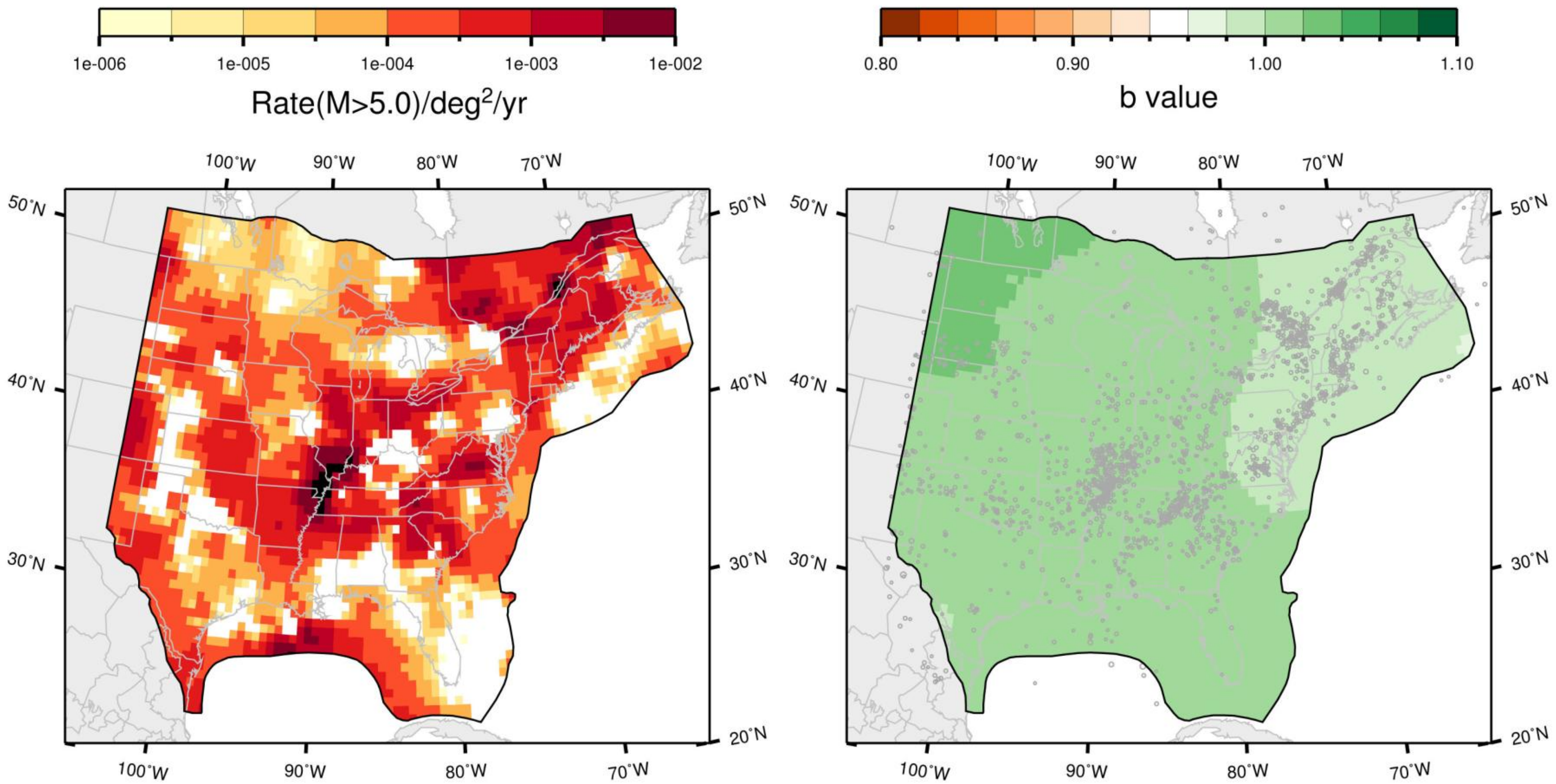


Figure J-19
Map of the rate and *b*-value for the study region under the Mmax zonation, with no separation of Mesozoic extended and non-extended; Case E magnitude weights: Realization 1

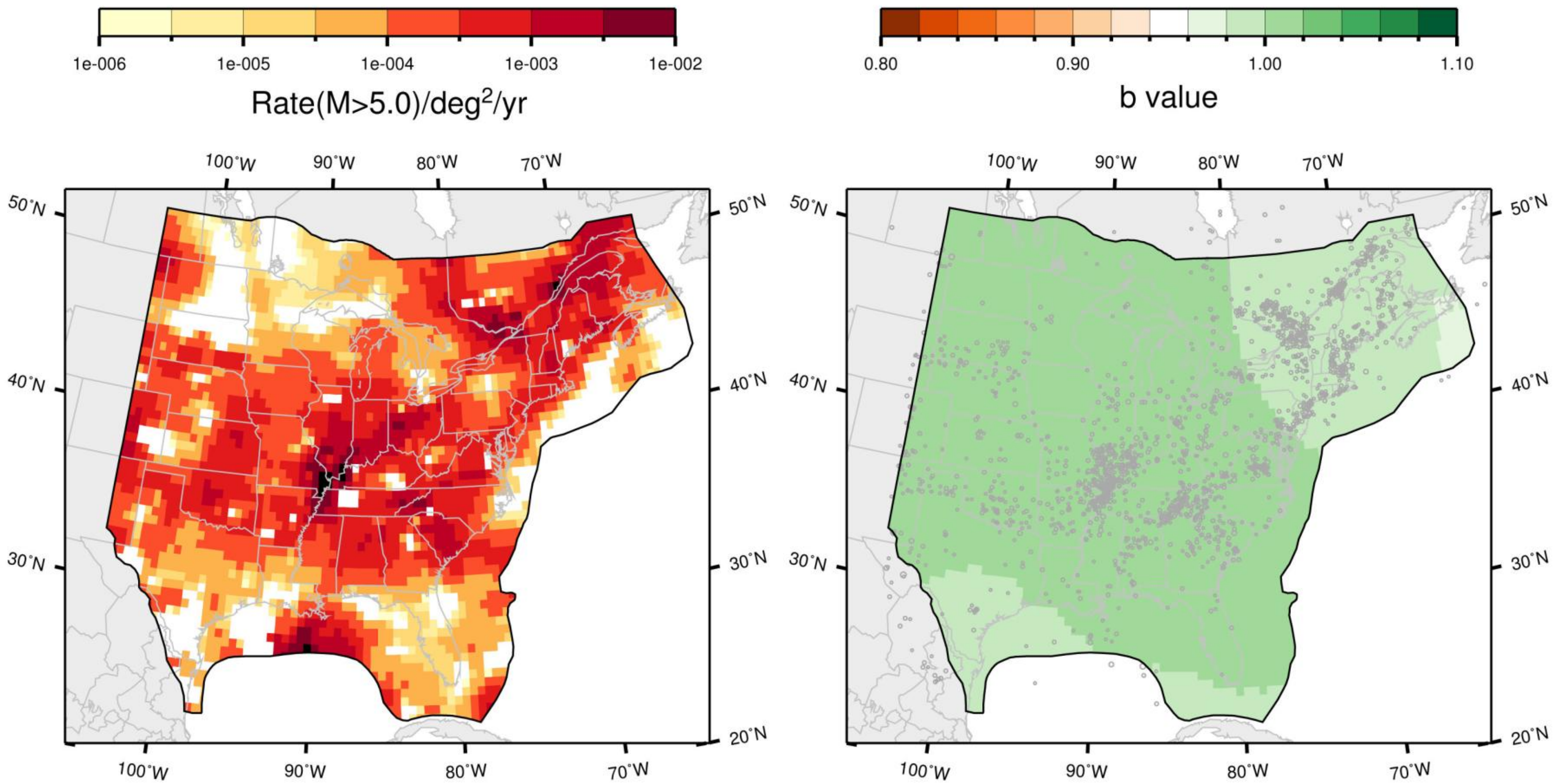


Figure J-20
Map of the rate and *b*-value for the study region under the Mmax zonation, with no separation of Mesozoic extended and non-extended; Case E magnitude weights: Realization 2

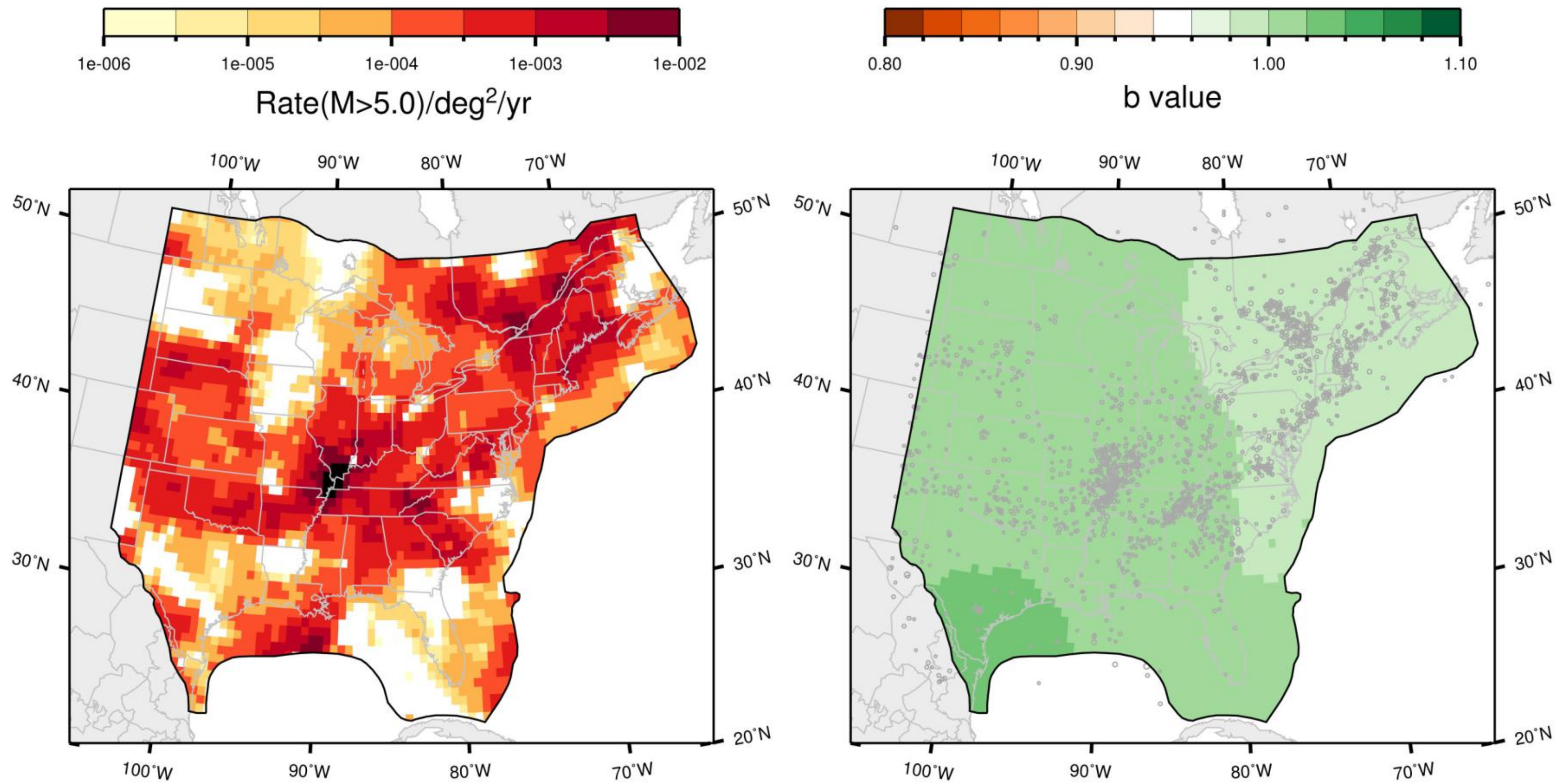


Figure J-21
Map of the rate and *b*-value for the study region under the Mmax zonation, with no separation of Mesozoic extended and non-extended; Case E magnitude weights: Realization 3

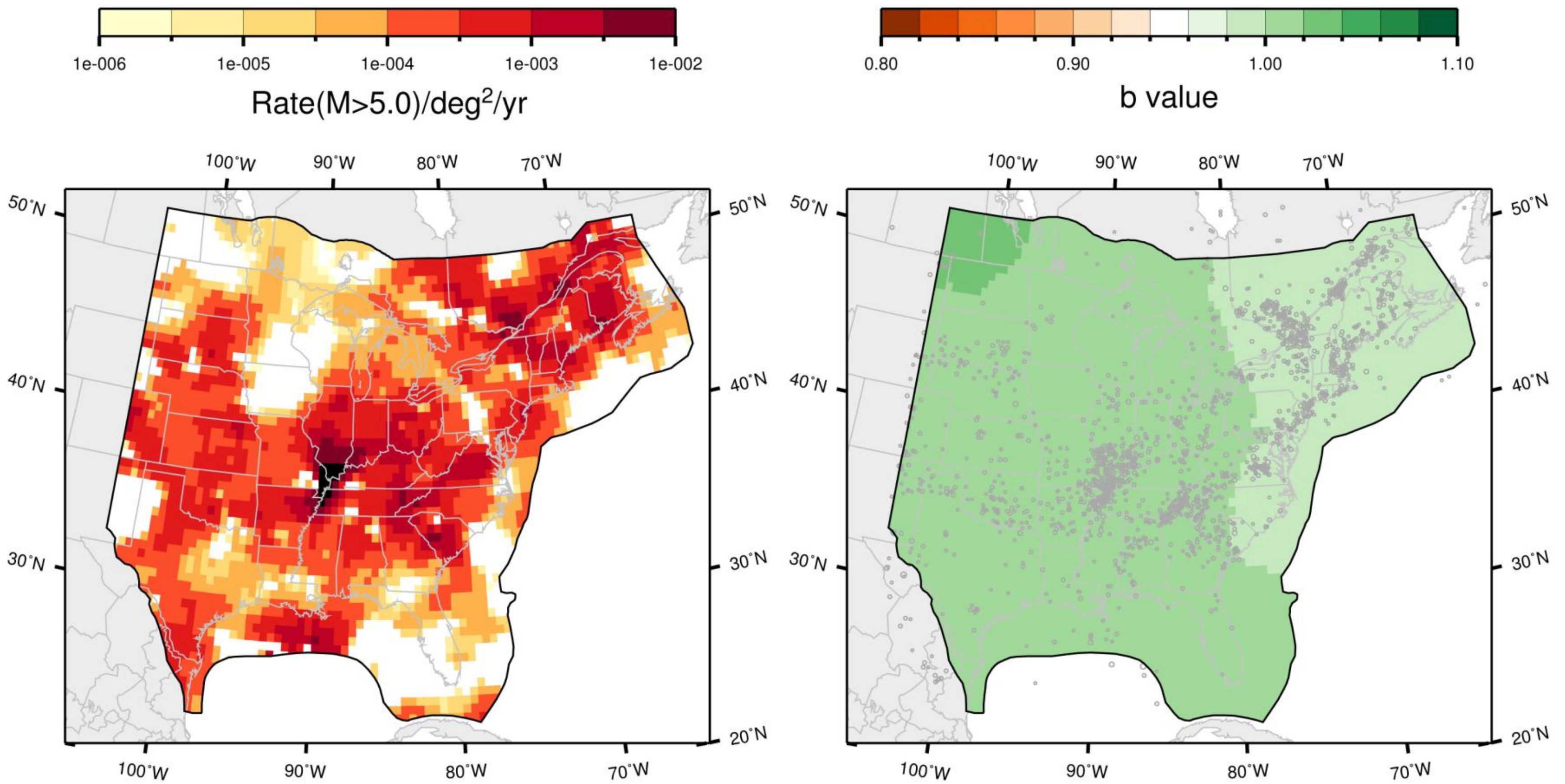


Figure J-22
Map of the rate and *b*-value for the study region under the Mmax zonation, with no separation of Mesozoic extended and non-extended; Case E magnitude weights: Realization 4

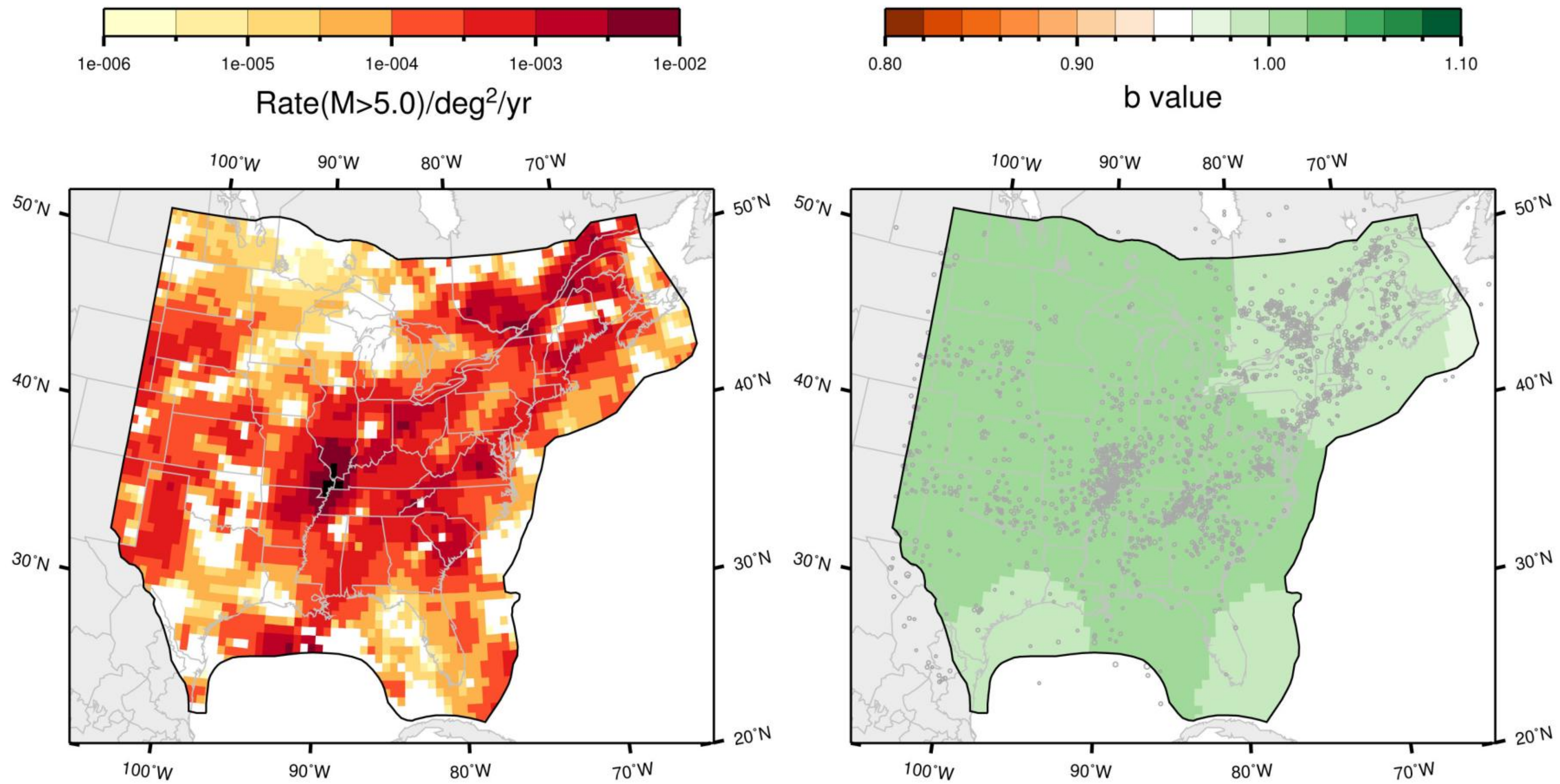


Figure J-23
Map of the rate and *b*-value for the study region under the Mmax zonation, with no separation of Mesozoic extended and non-extended; Case E magnitude weights: Realization 5

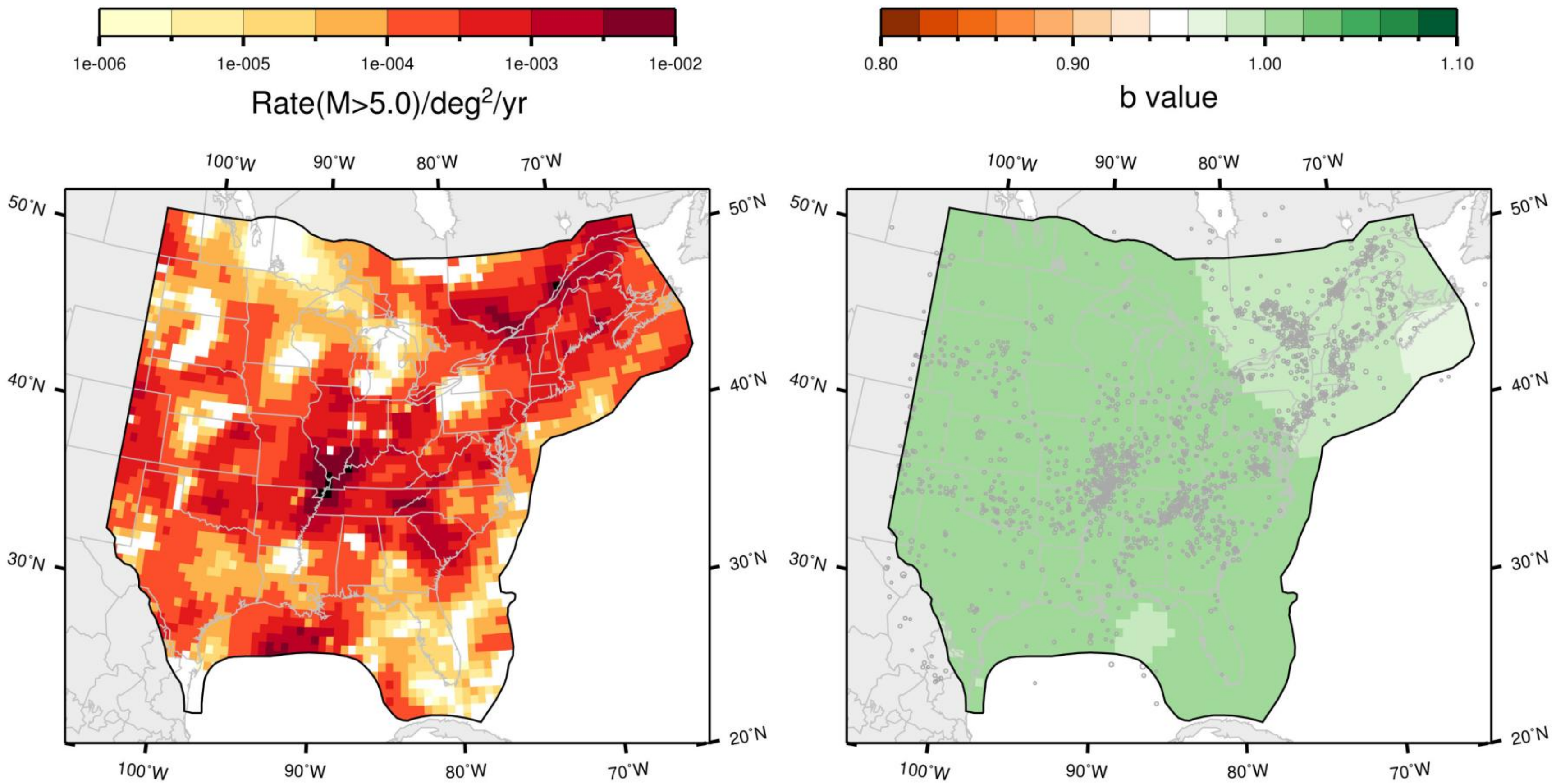


Figure J-24
Map of the rate and *b*-value for the study region under the Mmax zonation, with no separation of Mesozoic extended and non-extended; Case E magnitude weights: Realization 6

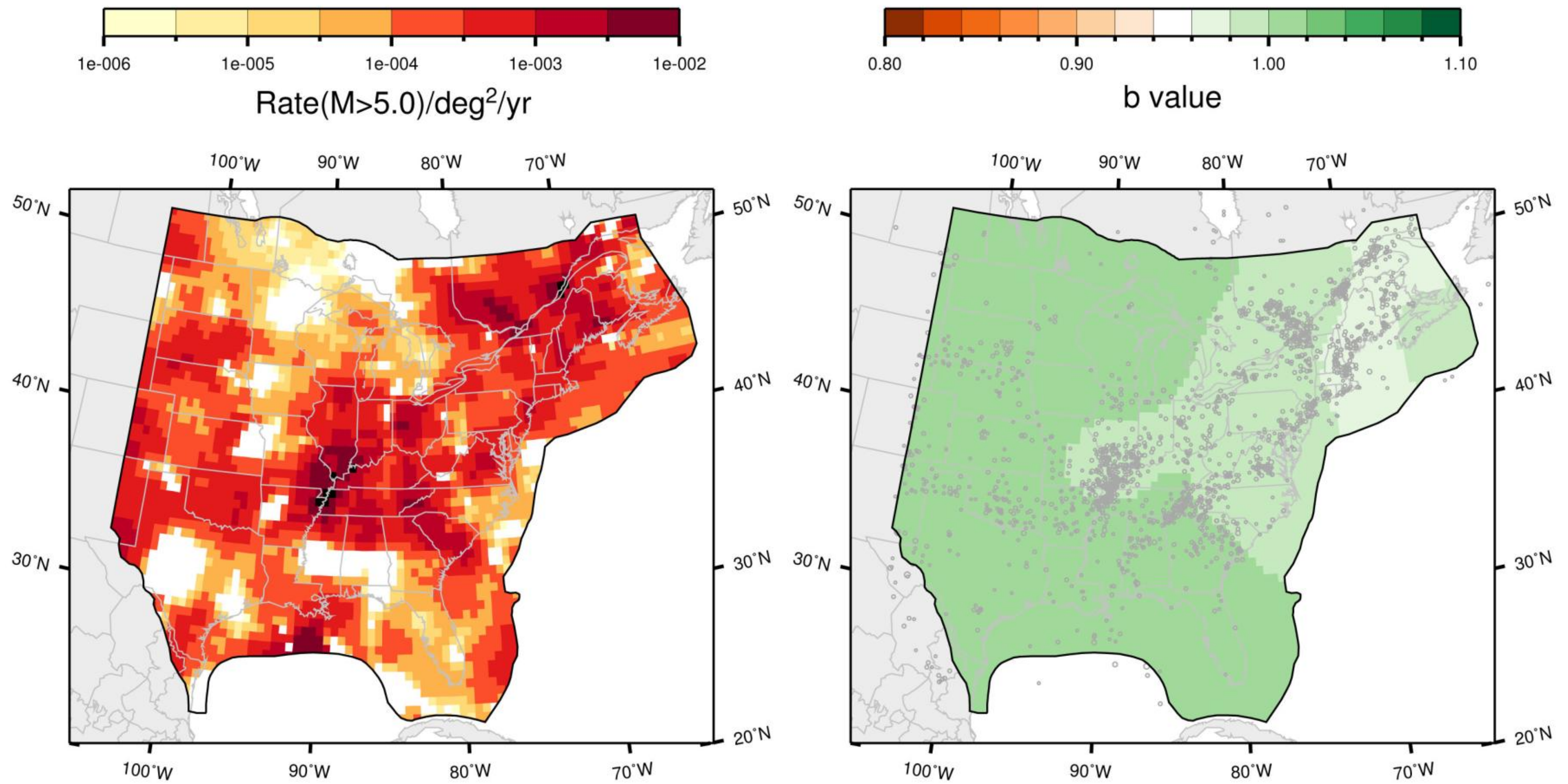


Figure J-25
Map of the rate and *b*-value for the study region under the Mmax zonation, with no separation of Mesozoic extended and non-extended; Case E magnitude weights: Realization 7

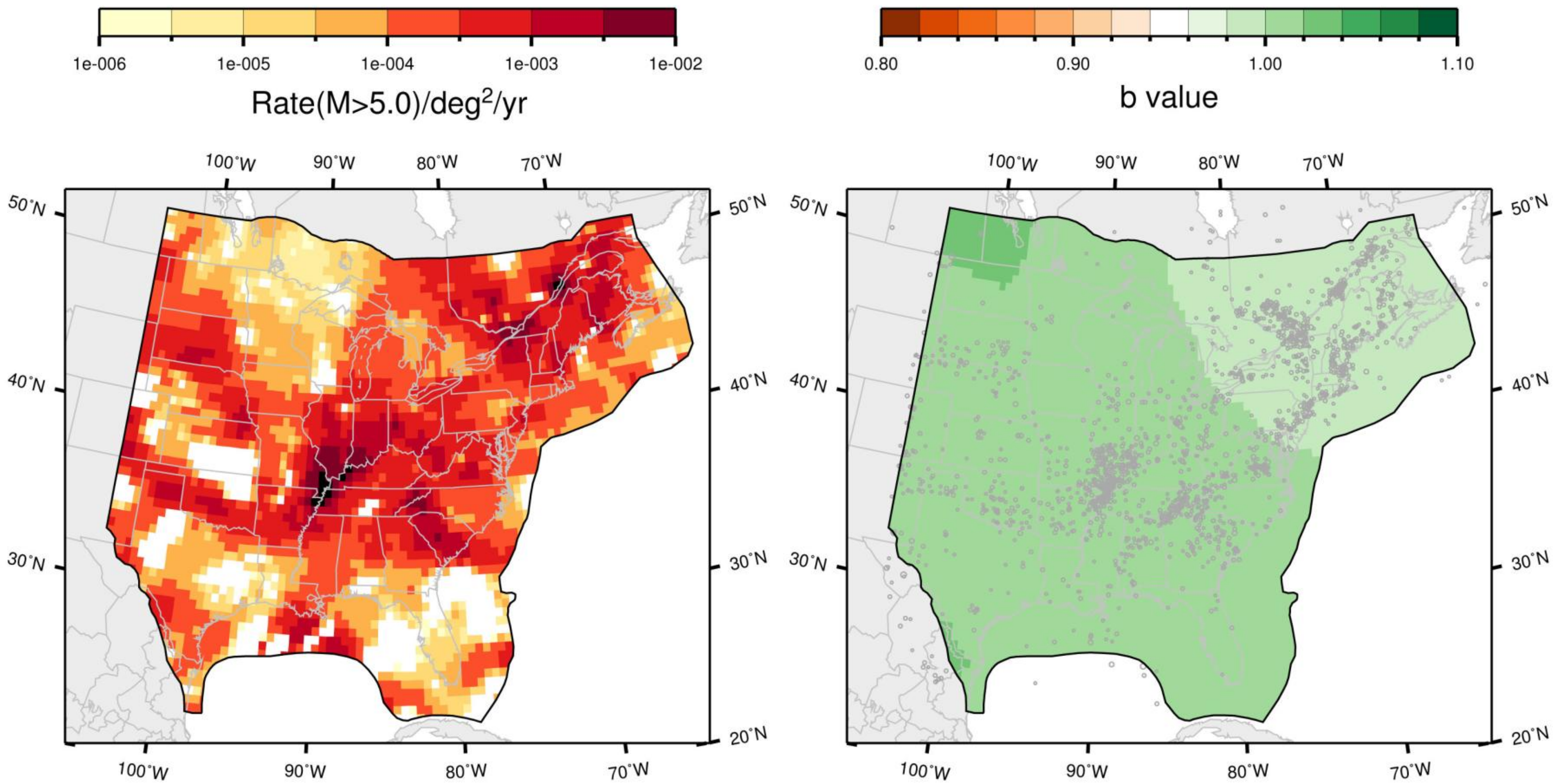


Figure J-26
Map of the rate and *b*-value for the study region under the Mmax zonation, with no separation of Mesozoic extended and non-extended; Case E magnitude weights: Realization 8

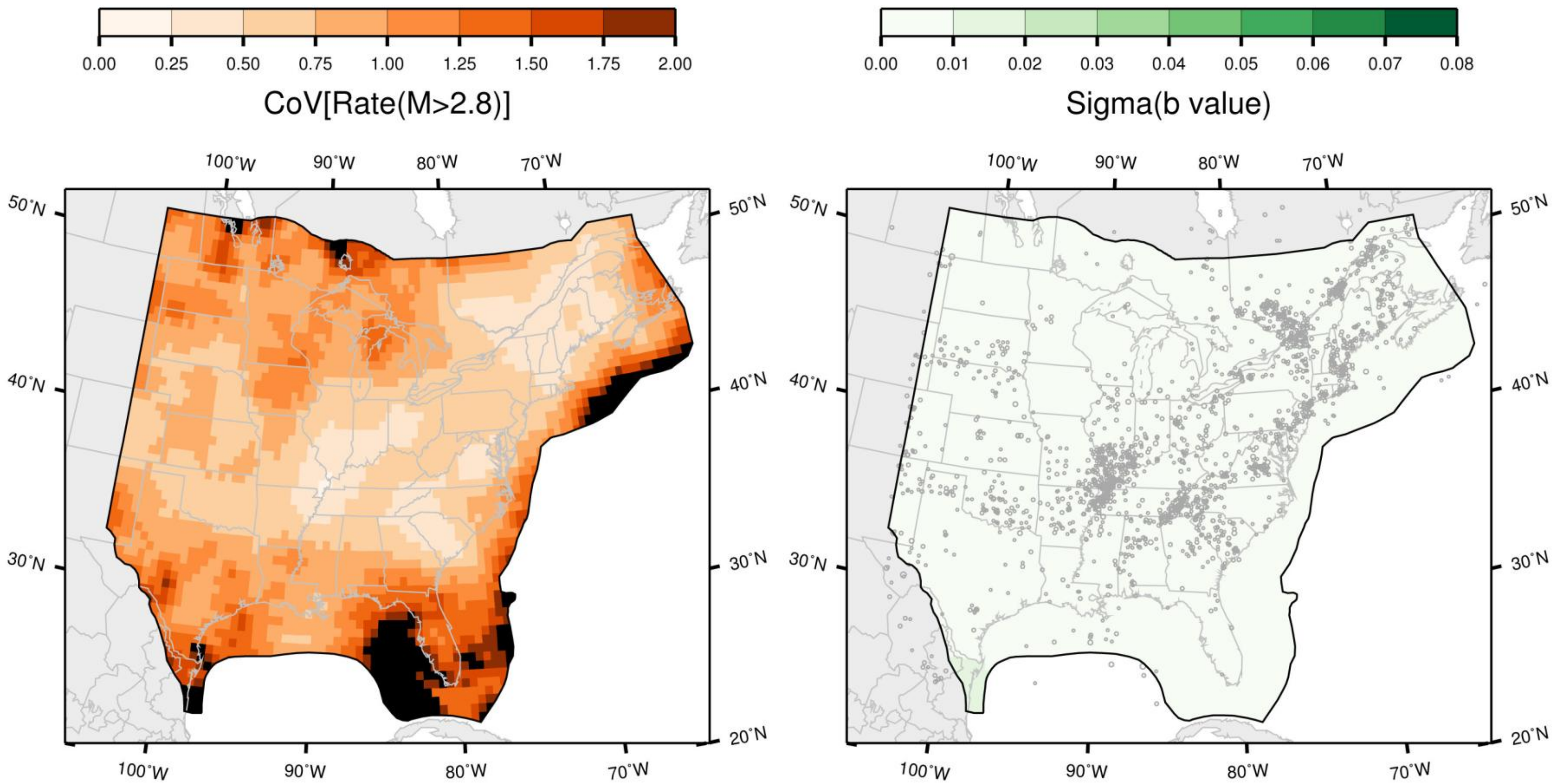


Figure J-27
Map of the coefficient of variation of the rate and the standard deviation of the *b*-value for the study region under the Mmax zonation, with no separation of Mesozoic extended and non-extended; Case E magnitude weights

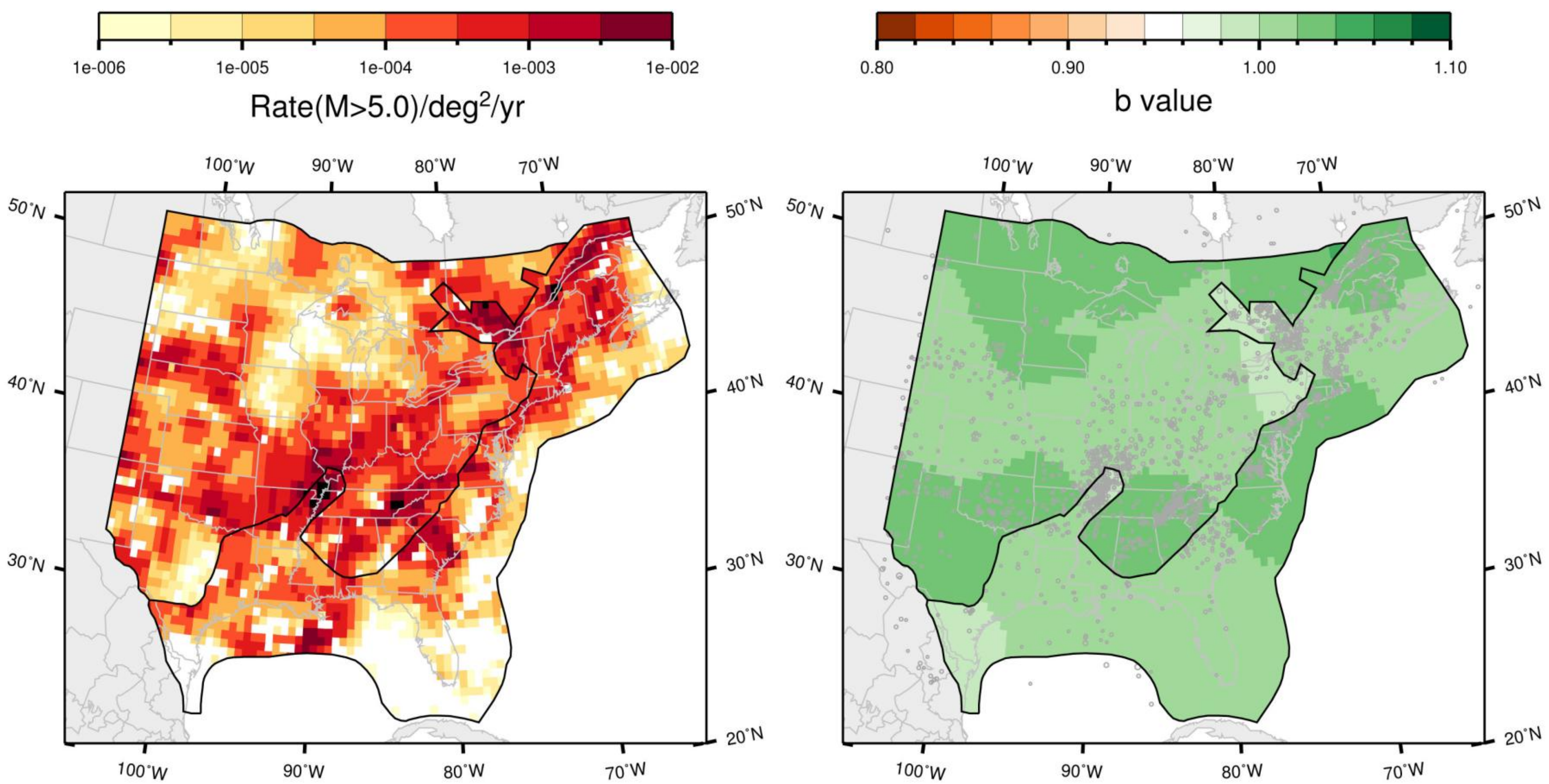


Figure J-28
Map of the rate and *b*-value for the study region under the Mmax zonation, with separation of Mesozoic extended and non-extended; Case A magnitude weights: Realization 1

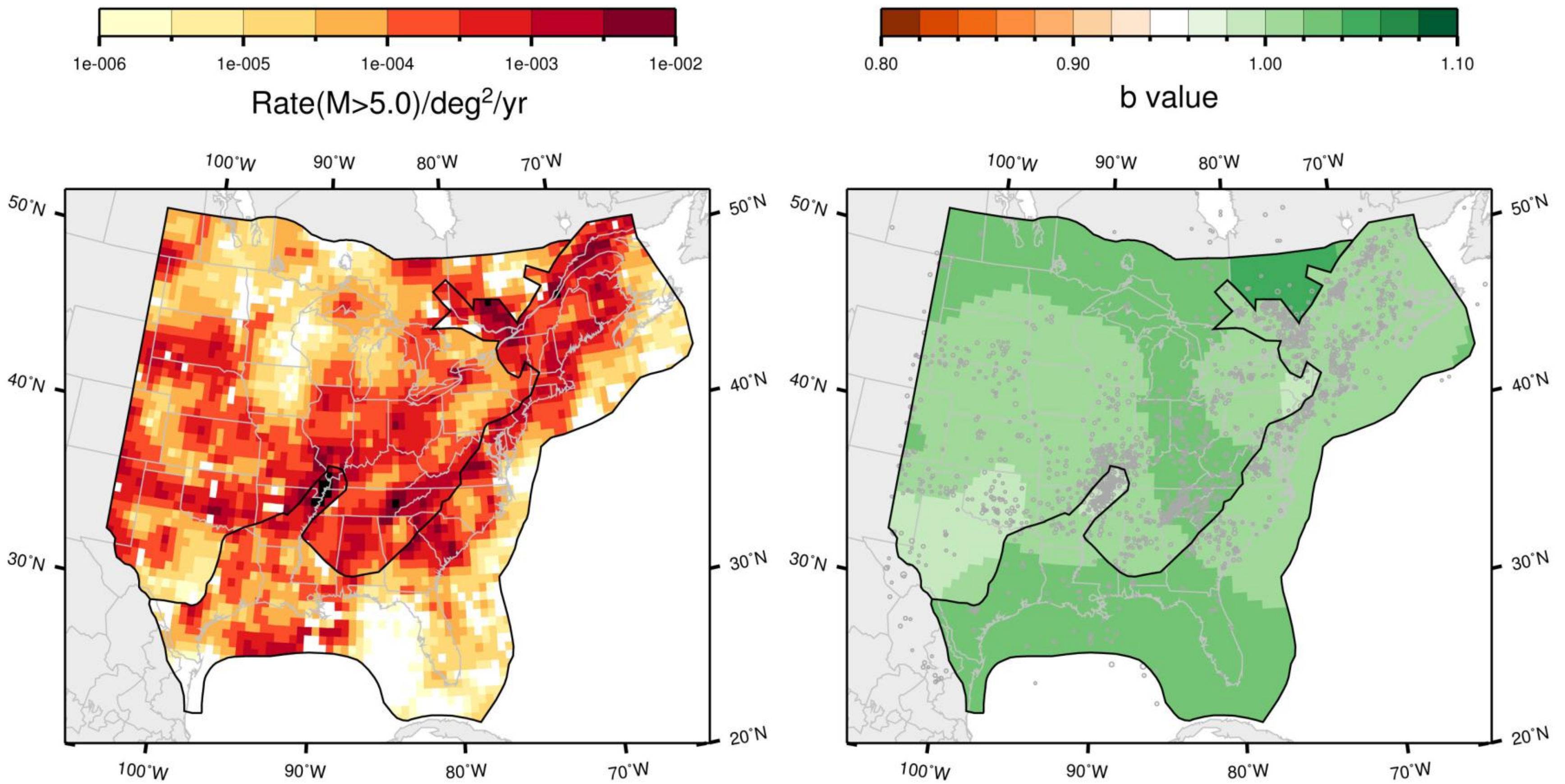


Figure J-29
Map of the rate and *b*-value for the study region under the Mmax zonation, with separation of Mesozoic extended and non-extended; Case A magnitude weights: Realization 2

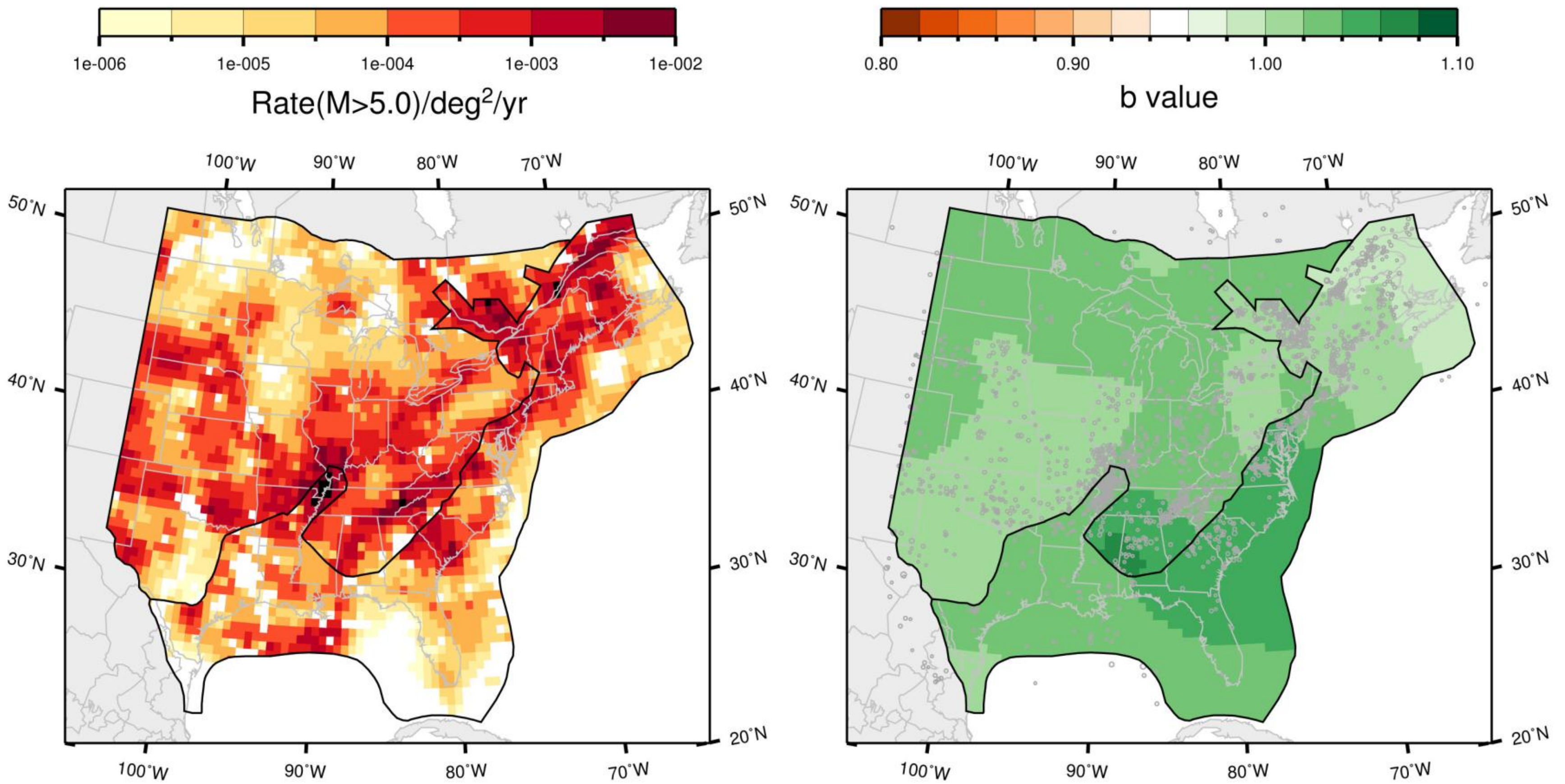


Figure J-30
Map of the rate and *b*-value for the study region under the Mmax zonation, with separation of Mesozoic extended and non-extended; Case A magnitude weights: Realization 3

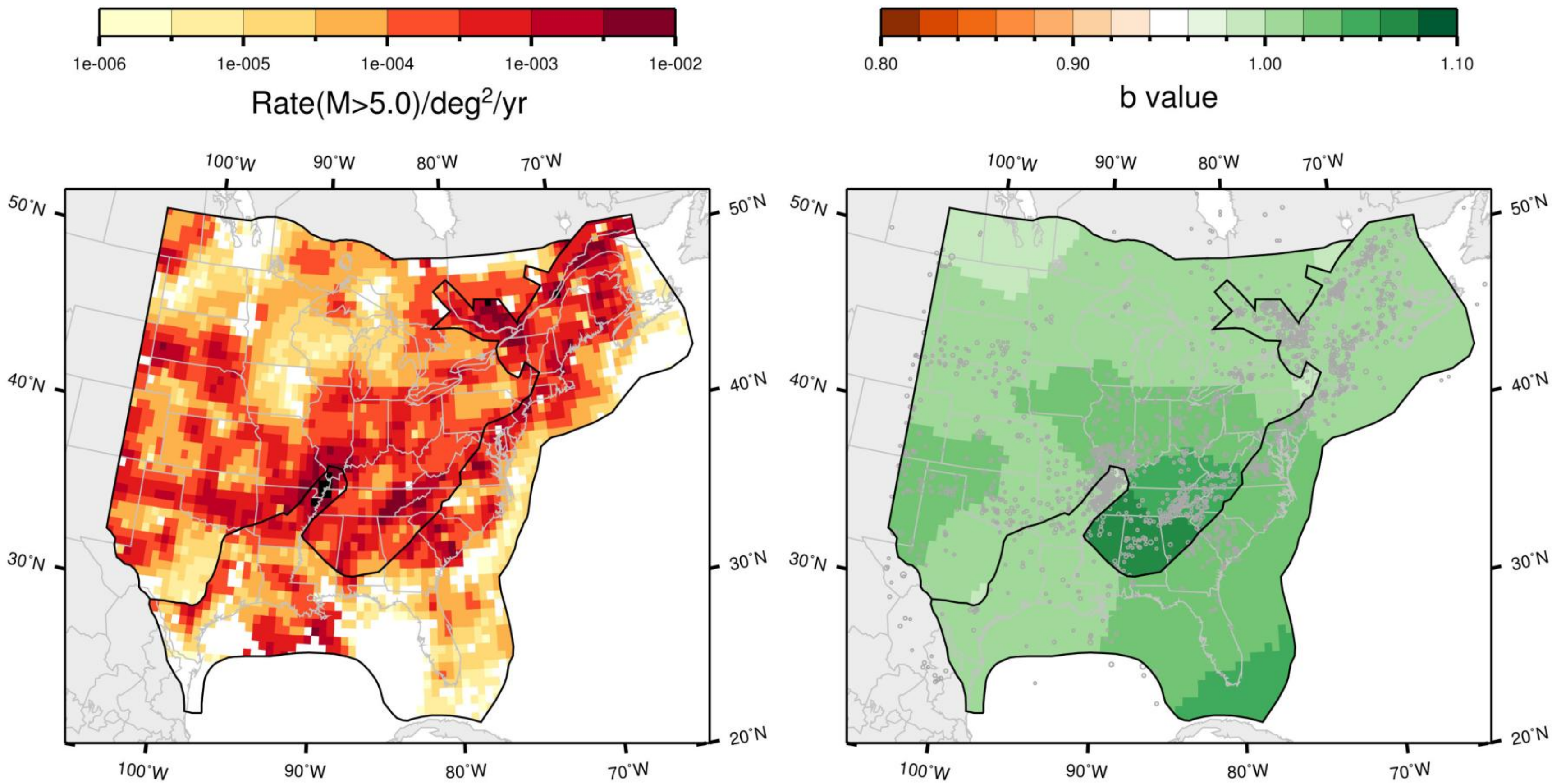


Figure J-31
Map of the rate and *b*-value for the study region under the Mmax zonation, with separation of Mesozoic extended and non-extended; Case A magnitude weights: Realization 4

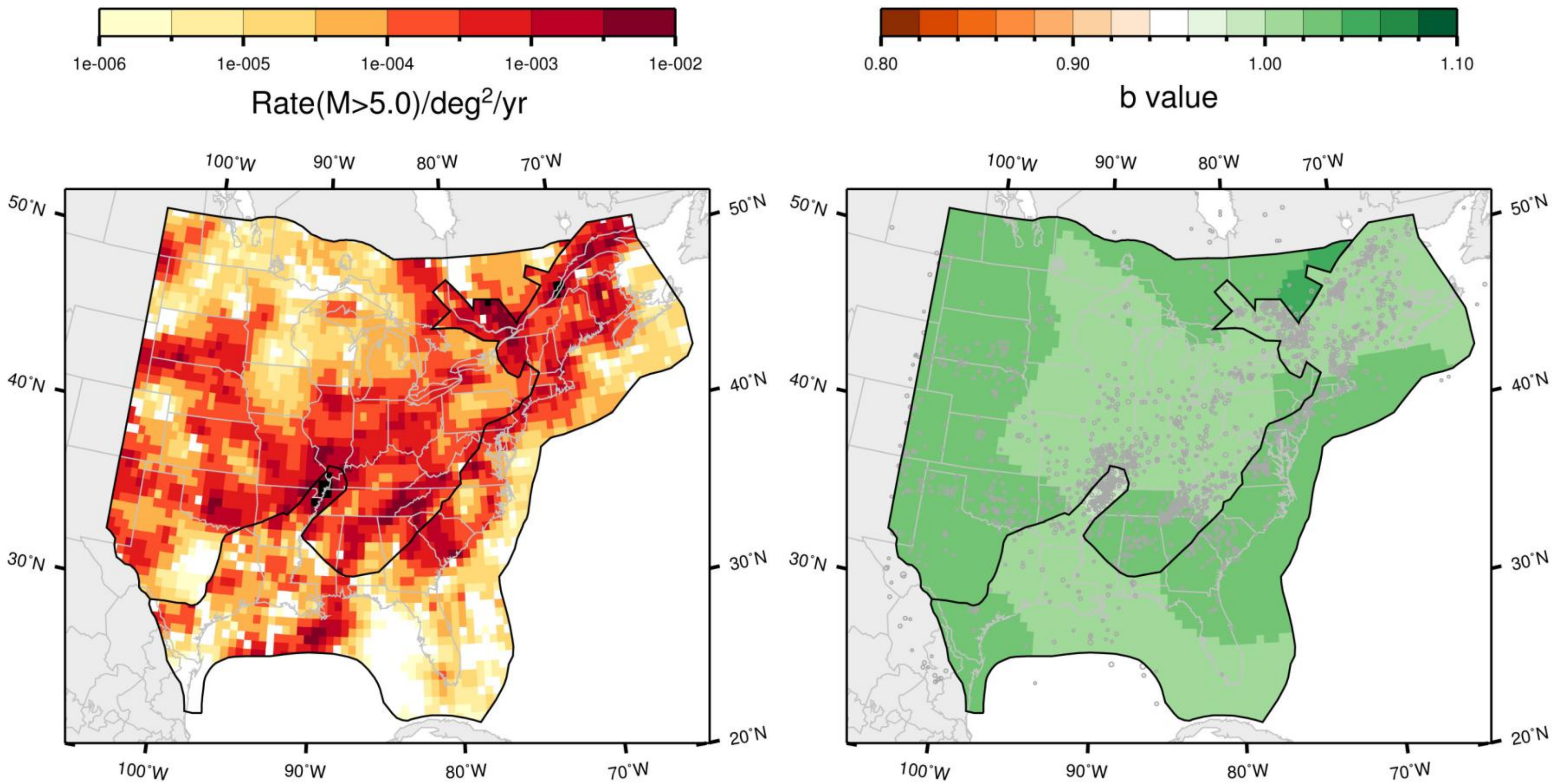


Figure J-32
Map of the rate and *b*-value for the study region under the Mmax zonation, with separation of Mesozoic extended and non-extended; Case A magnitude weights: Realization 5

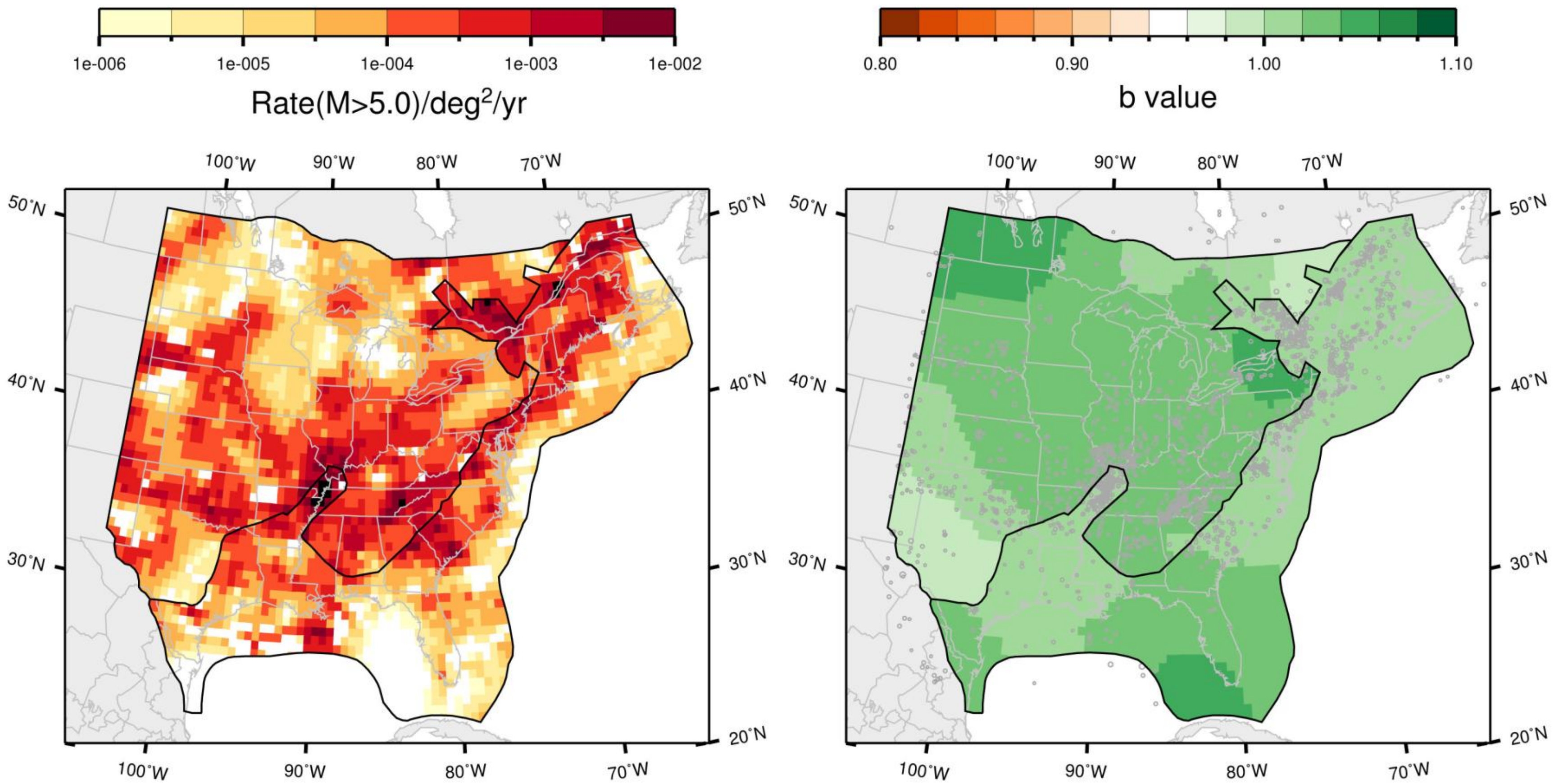


Figure J-33
Map of the rate and *b*-value for the study region under the Mmax zonation, with separation of Mesozoic extended and non-extended; Case A magnitude weights: Realization 6

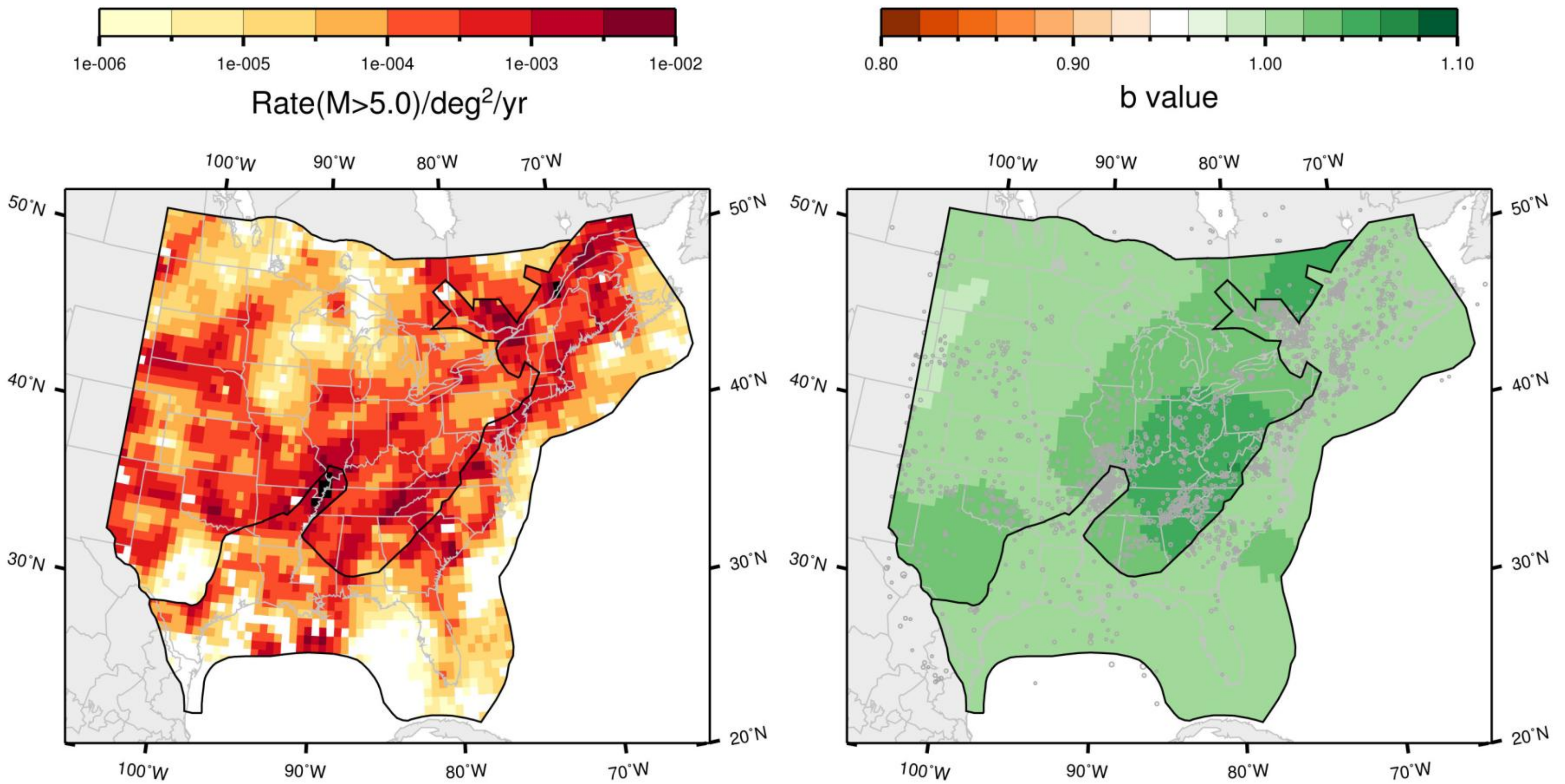


Figure J-34
Map of the rate and *b*-value for the study region under the Mmax zonation, with separation of Mesozoic extended and non-extended; Case A magnitude weights: Realization 7

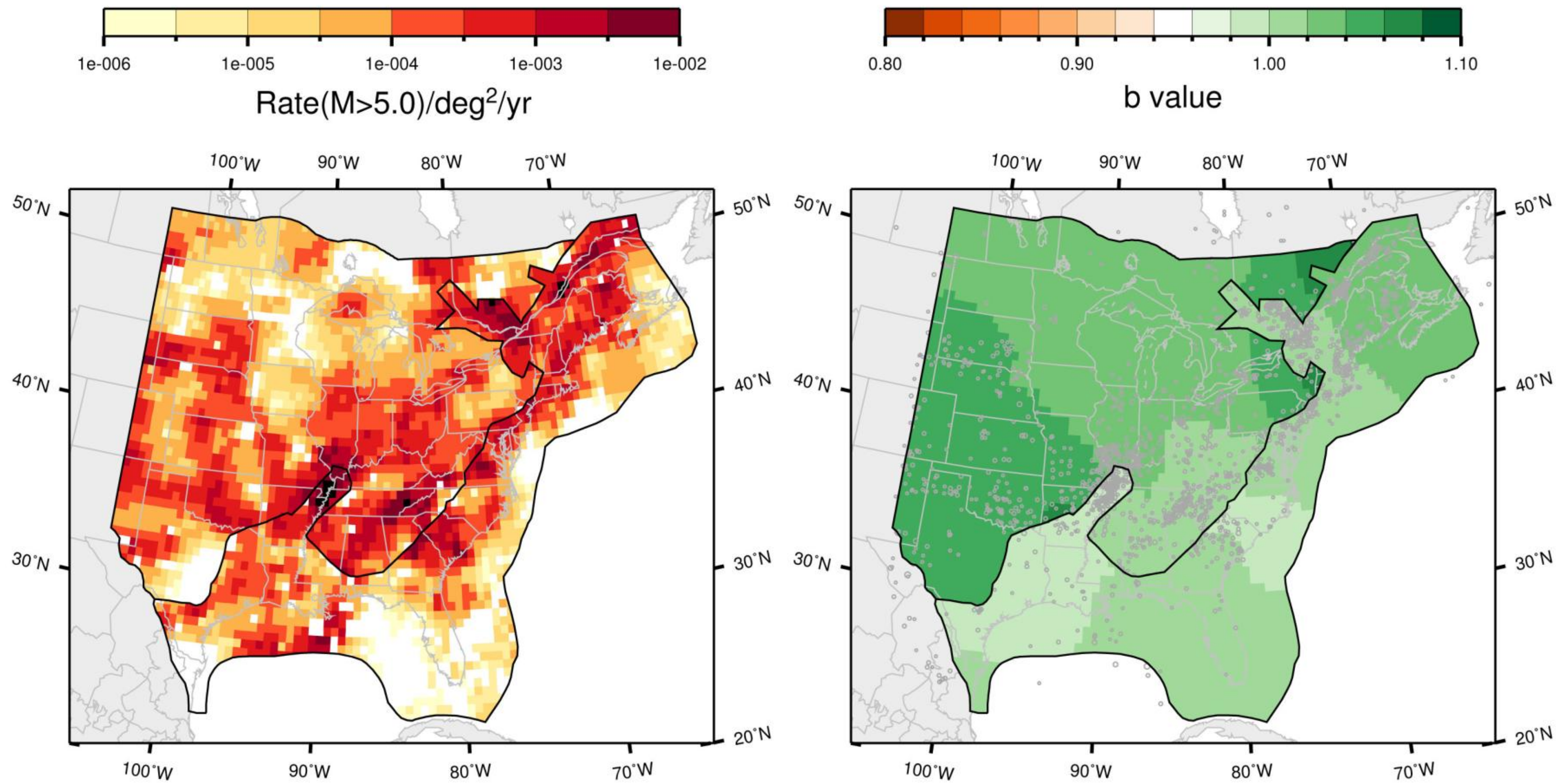


Figure J-35
Map of the rate and *b*-value for the study region under the Mmax zonation, with separation of Mesozoic extended and non-extended; Case A magnitude weights: Realization 8

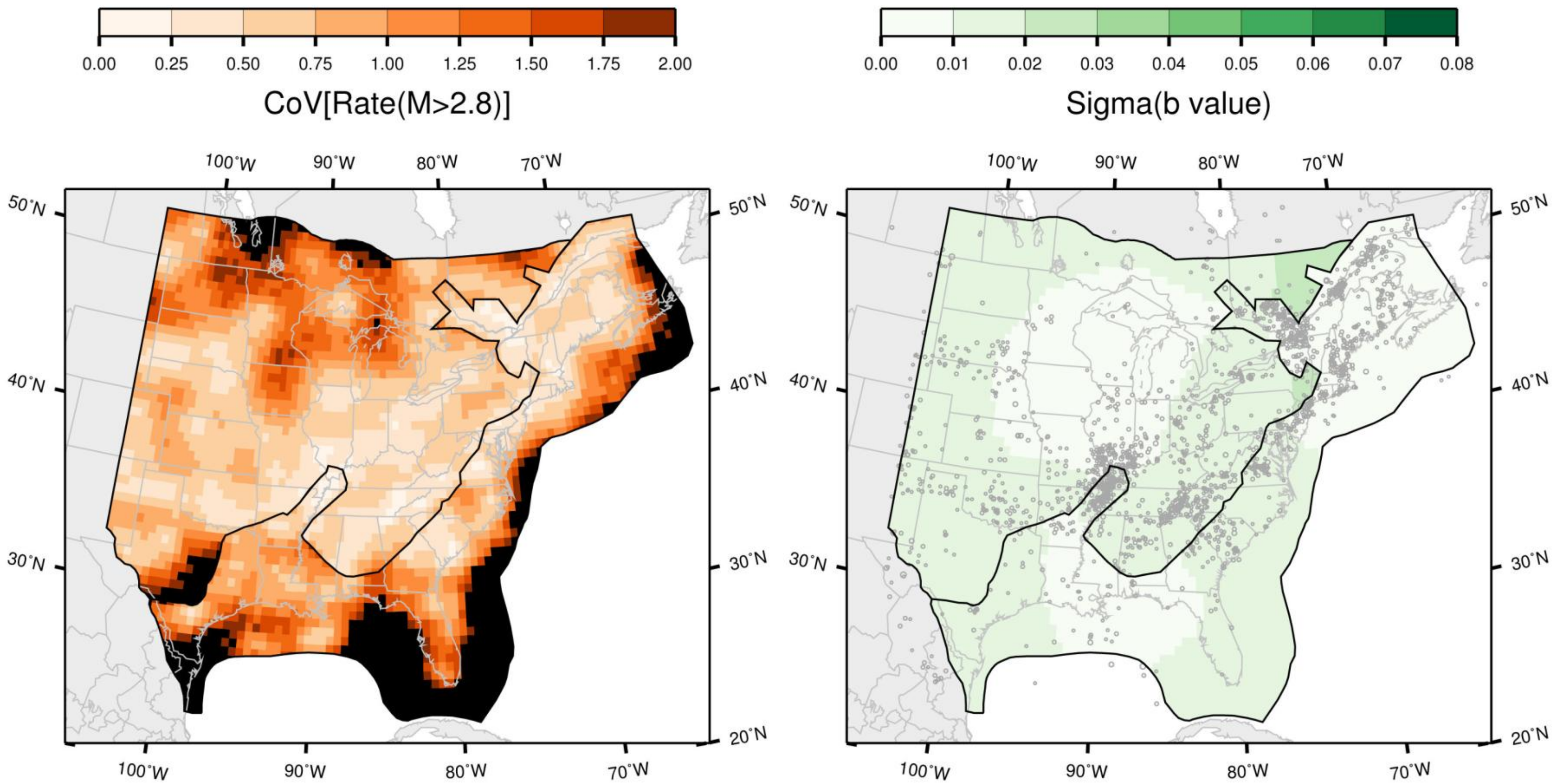


Figure J-36
Map of the coefficient of variation of the rate and the standard deviation of the *b*-value for the study region under the Mmax zonation, with separation of Mesozoic extended and non-extended; Case A magnitude weights

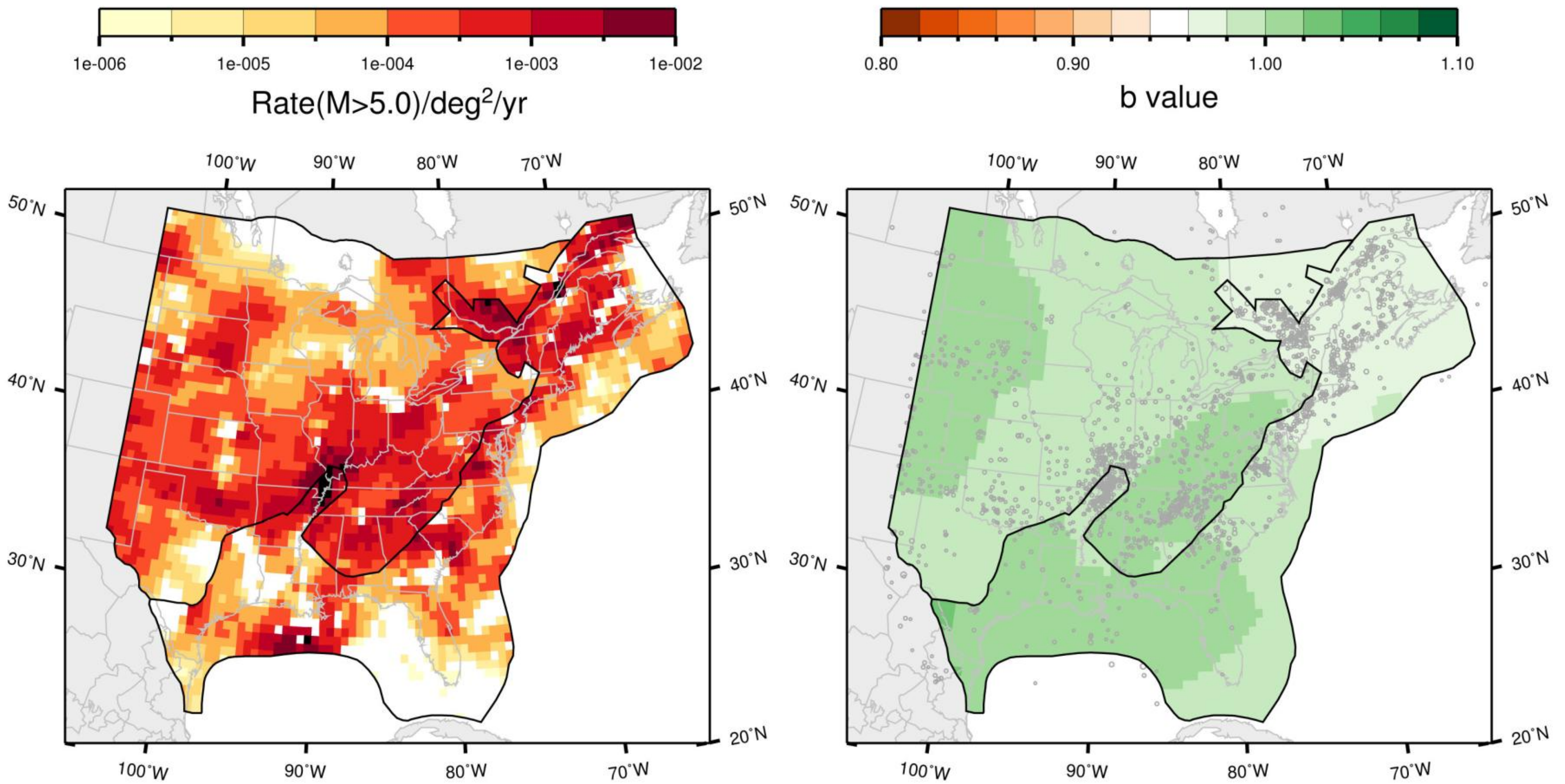


Figure J-37
Map of the rate and *b*-value for the study region under the Mmax zonation, with separation of Mesozoic extended and non-extended; Case B magnitude weights: Realization 1

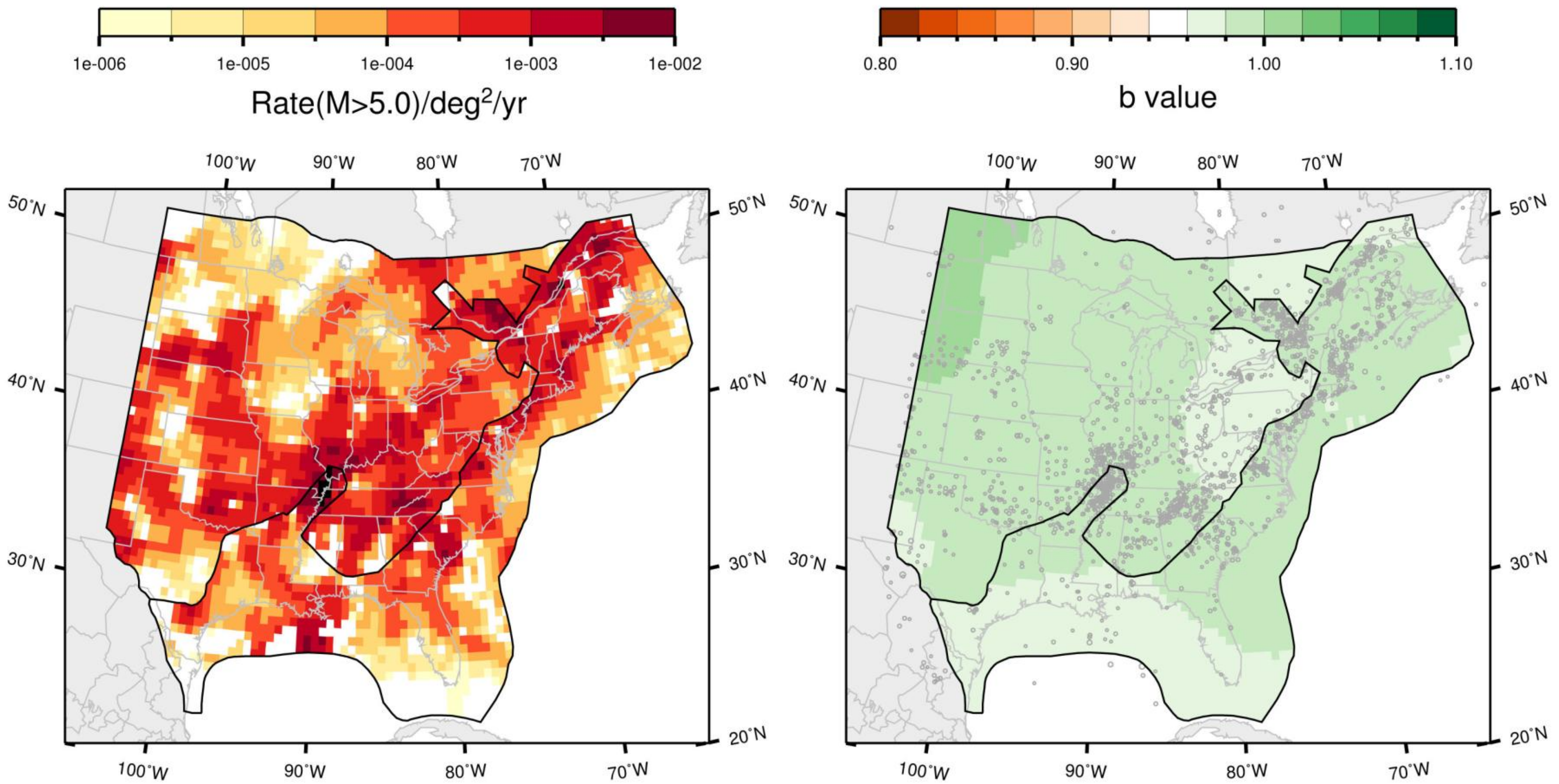


Figure J-38
Map of the rate and *b*-value for the study region under the Mmax zonation, with separation of Mesozoic extended and non-extended; Case B magnitude weights: Realization 2

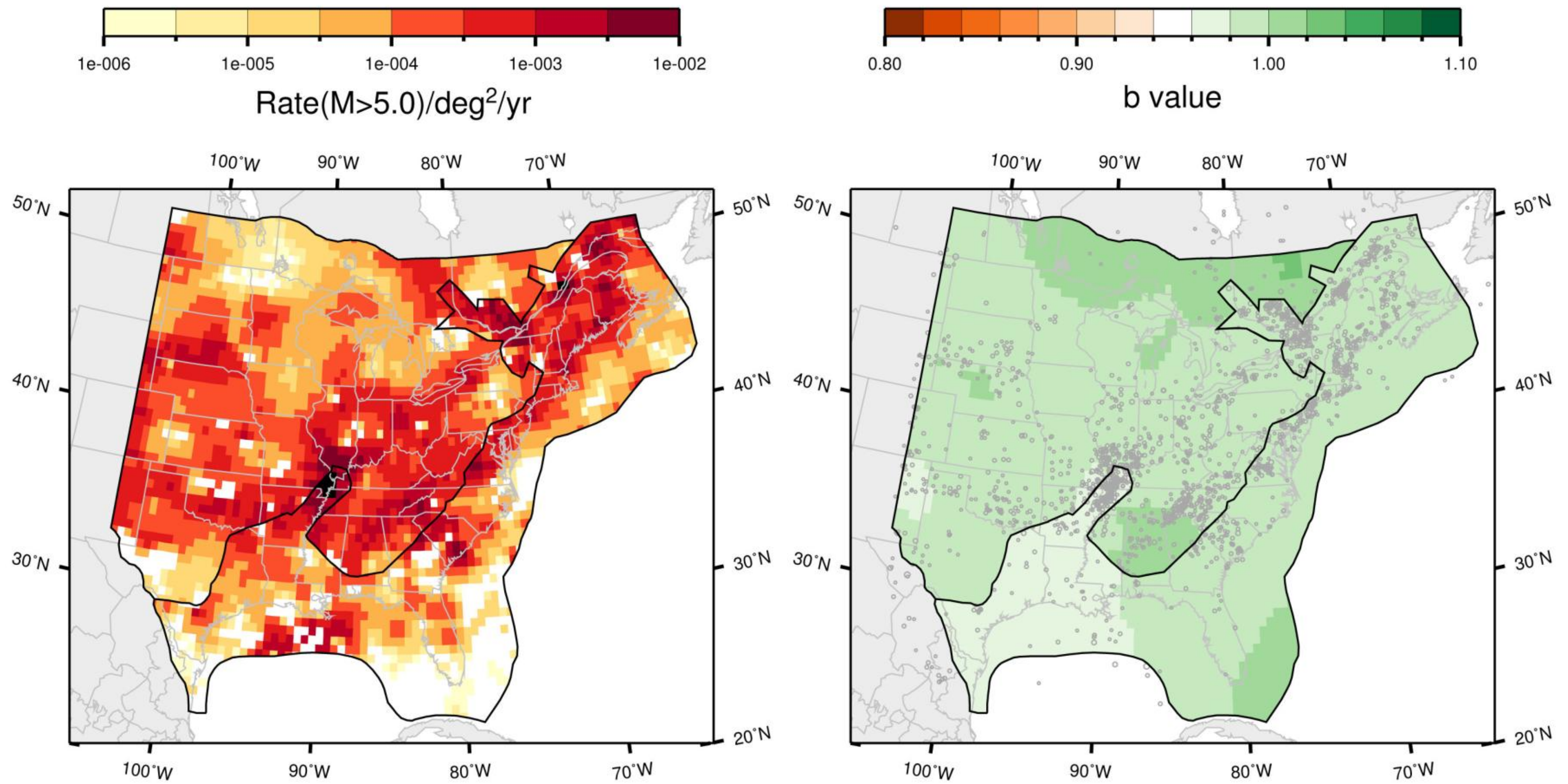


Figure J-39
Map of the rate and *b*-value for the study region under the Mmax zonation, with separation of Mesozoic extended and non-extended; Case B magnitude weights: Realization 3

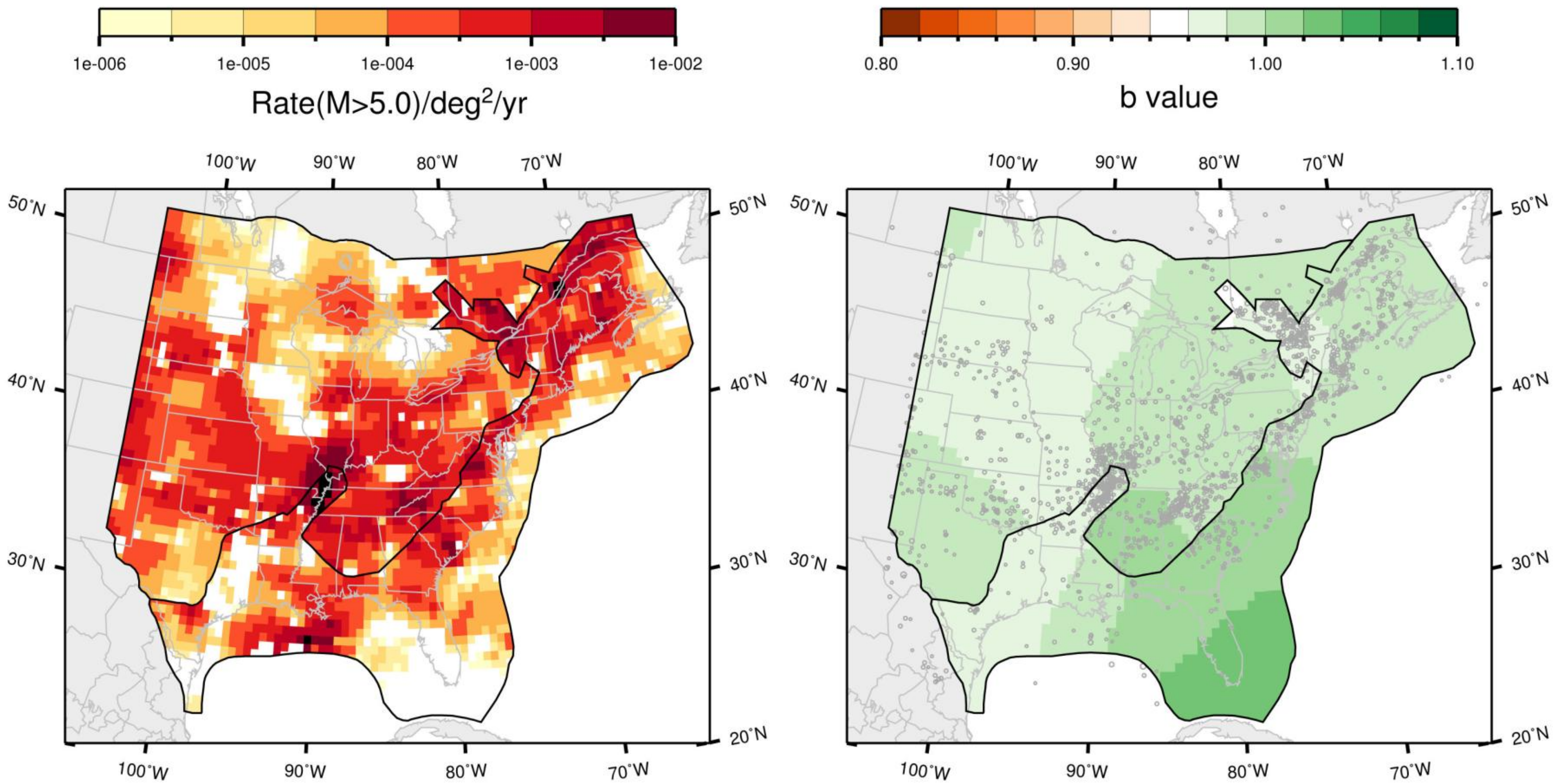


Figure J-40
Map of the rate and *b*-value for the study region under the Mmax zonation, with separation of Mesozoic extended and non-extended; Case B magnitude weights: Realization 4

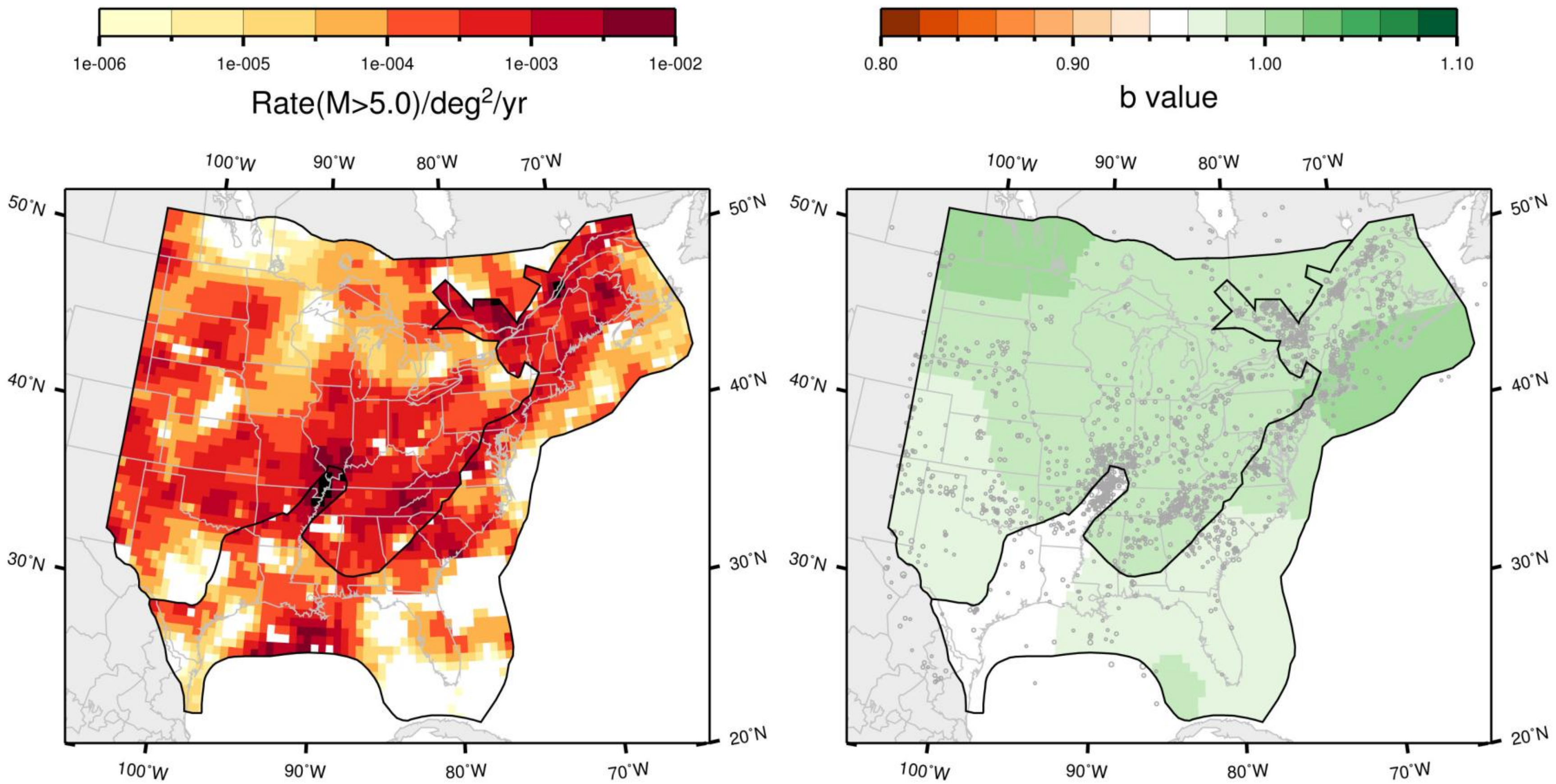


Figure J-41
Map of the rate and *b*-value for the study region under the Mmax zonation, with separation of Mesozoic extended and non-extended; Case B magnitude weights: Realization 5

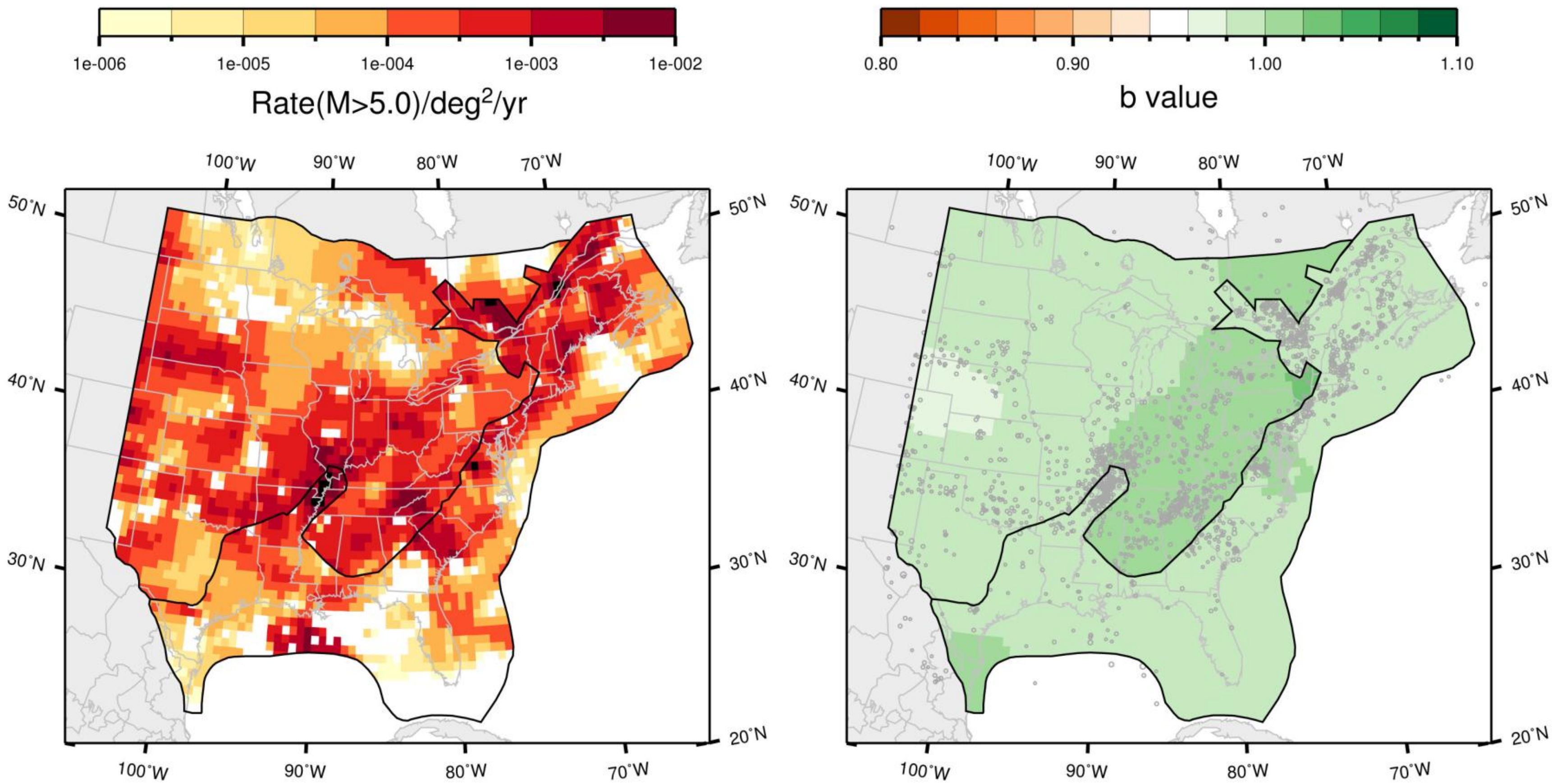


Figure J-42
Map of the rate and *b*-value for the study region under the Mmax zonation, with separation of Mesozoic extended and non-extended; Case B magnitude weights: Realization 6

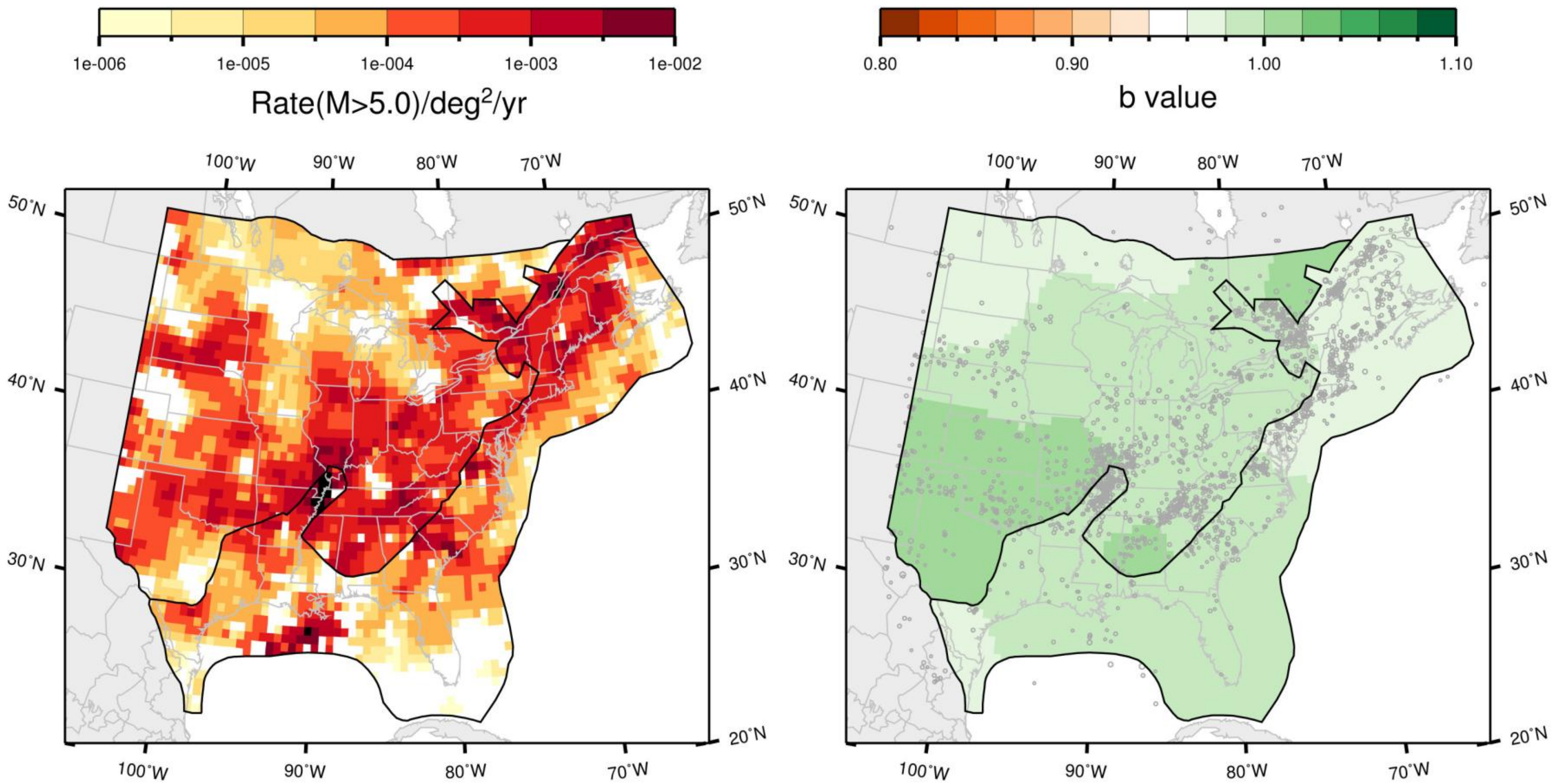


Figure J-43
Map of the rate and *b*-value for the study region under the Mmax zonation, with separation of Mesozoic extended and non-extended; Case B magnitude weights: Realization 7

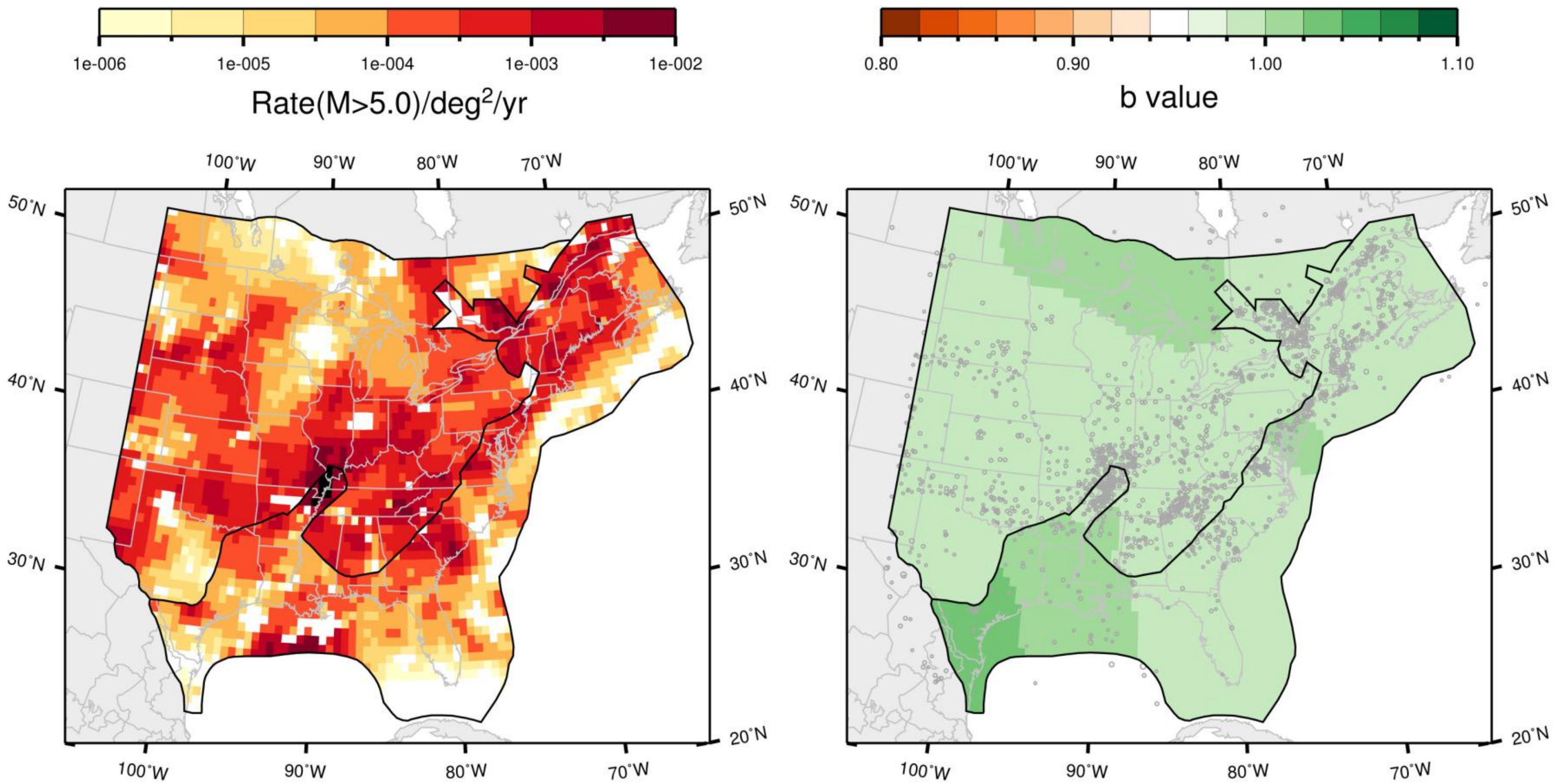


Figure J-44
Map of the rate and *b*-value for the study region under the Mmax zonation, with separation of Mesozoic extended and non-extended; Case B magnitude weights: Realization 8

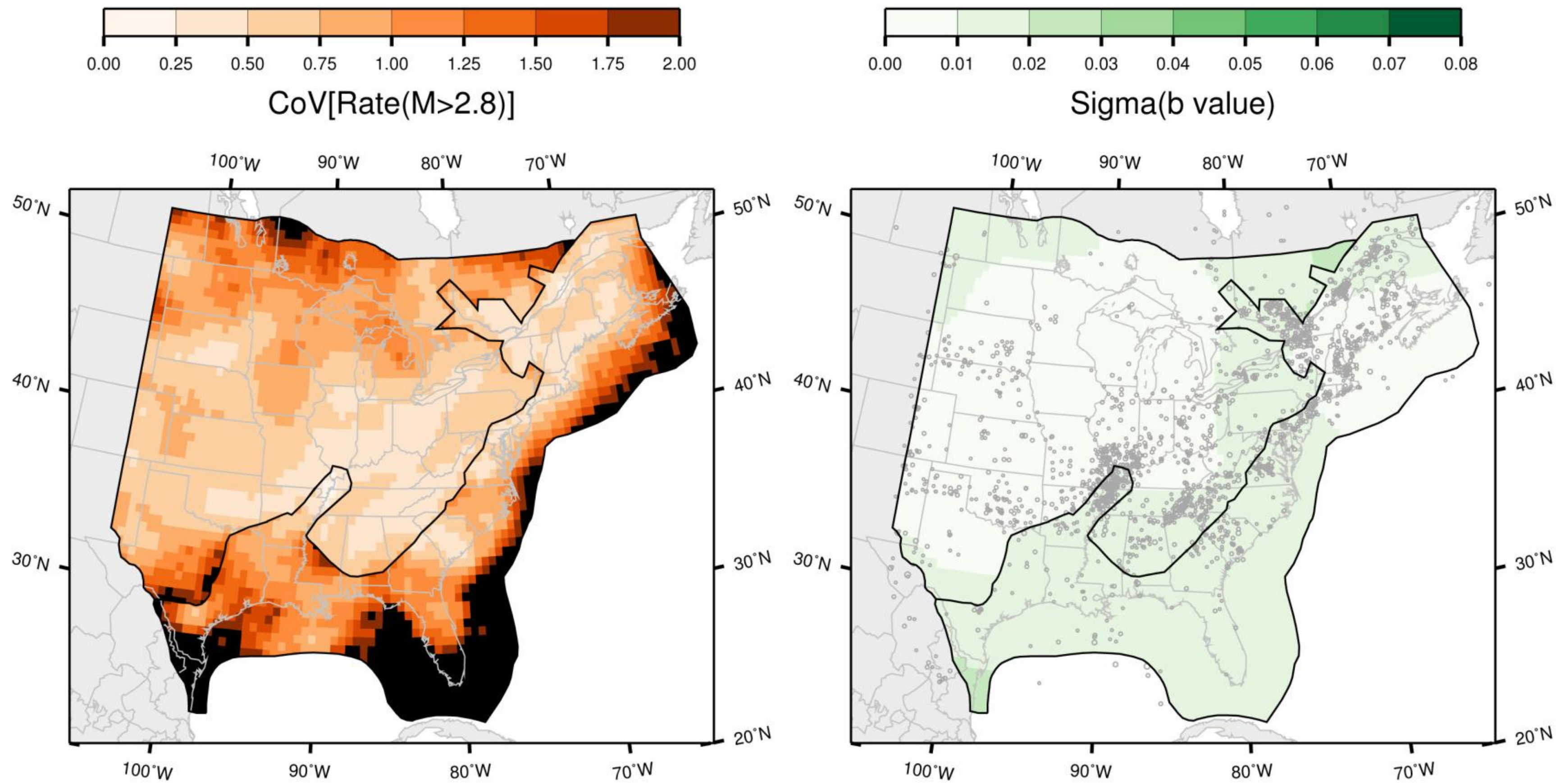


Figure J-45
Map of the coefficient of variation of the rate and the standard deviation of the *b*-value for the study region under the Mmax zonation, with separation of Mesozoic extended and non-extended; Case B magnitude weights

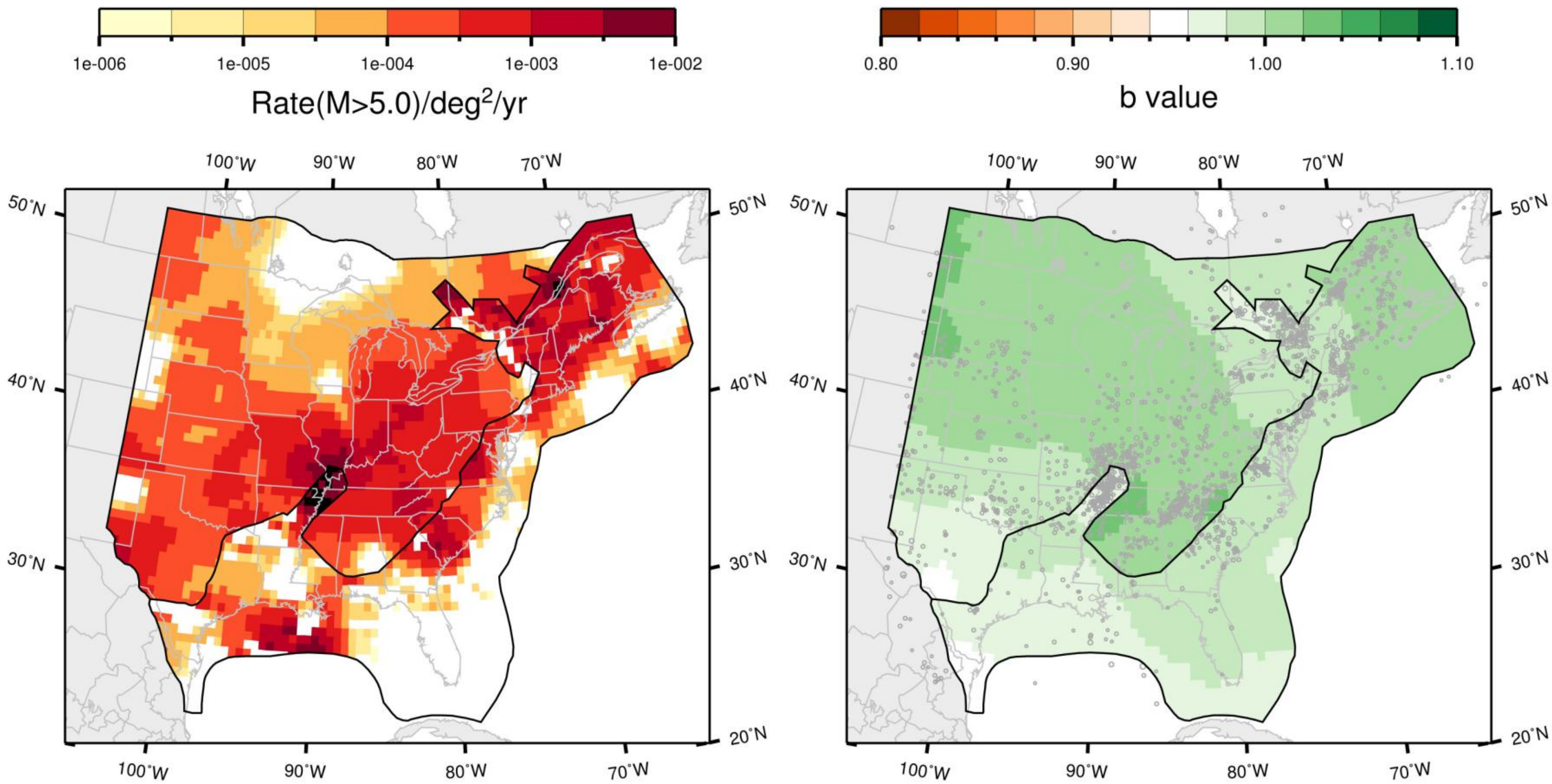


Figure J-46
Map of the rate and *b*-value for the study region under the Mmax zonation, with separation of Mesozoic extended and non-extended; Case E magnitude weights: Realization 1

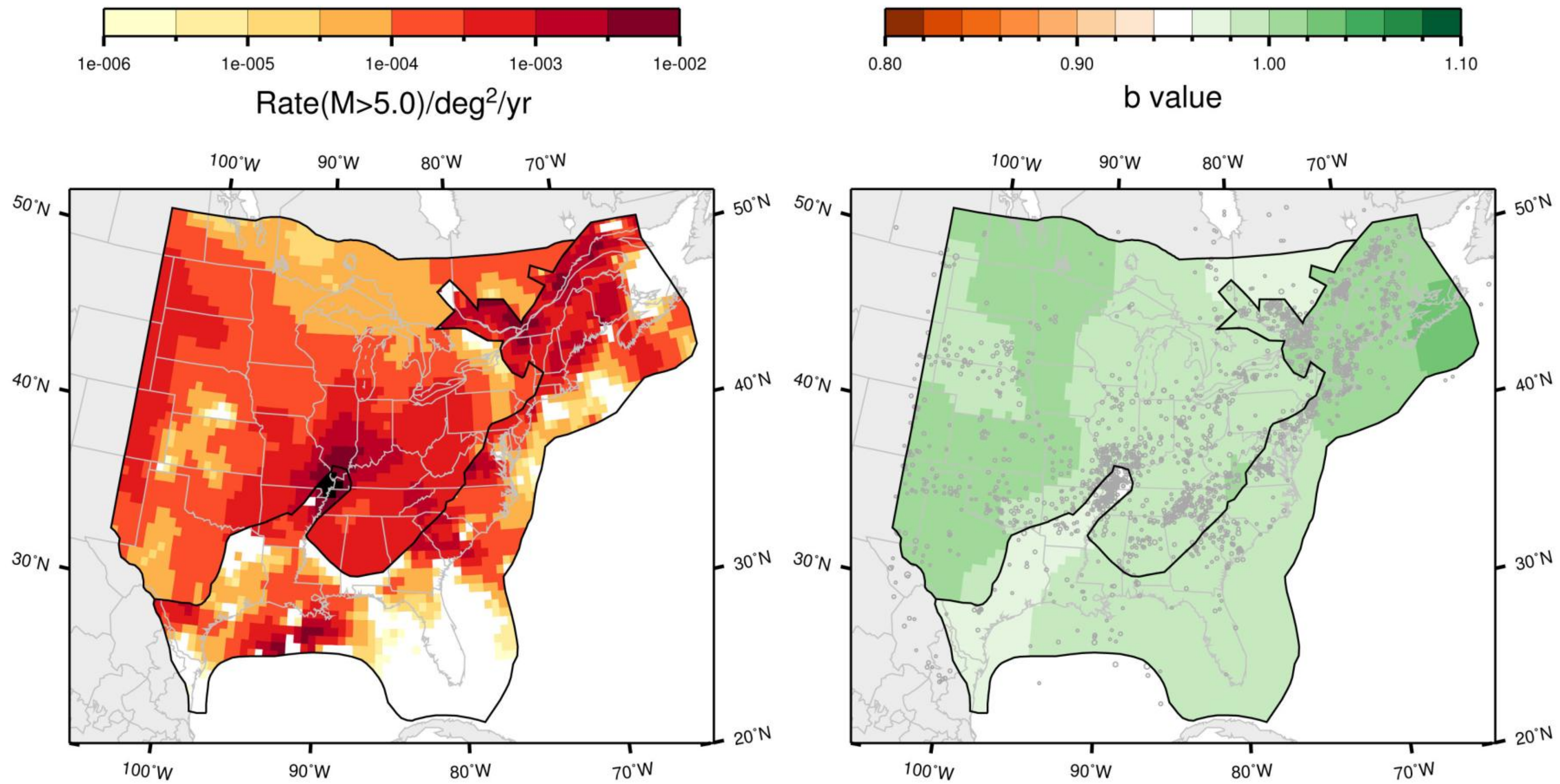


Figure J-47
Map of the rate and *b*-value for the study region under the Mmax zonation, with separation of Mesozoic extended and non-extended; Case E magnitude weights: Realization 2

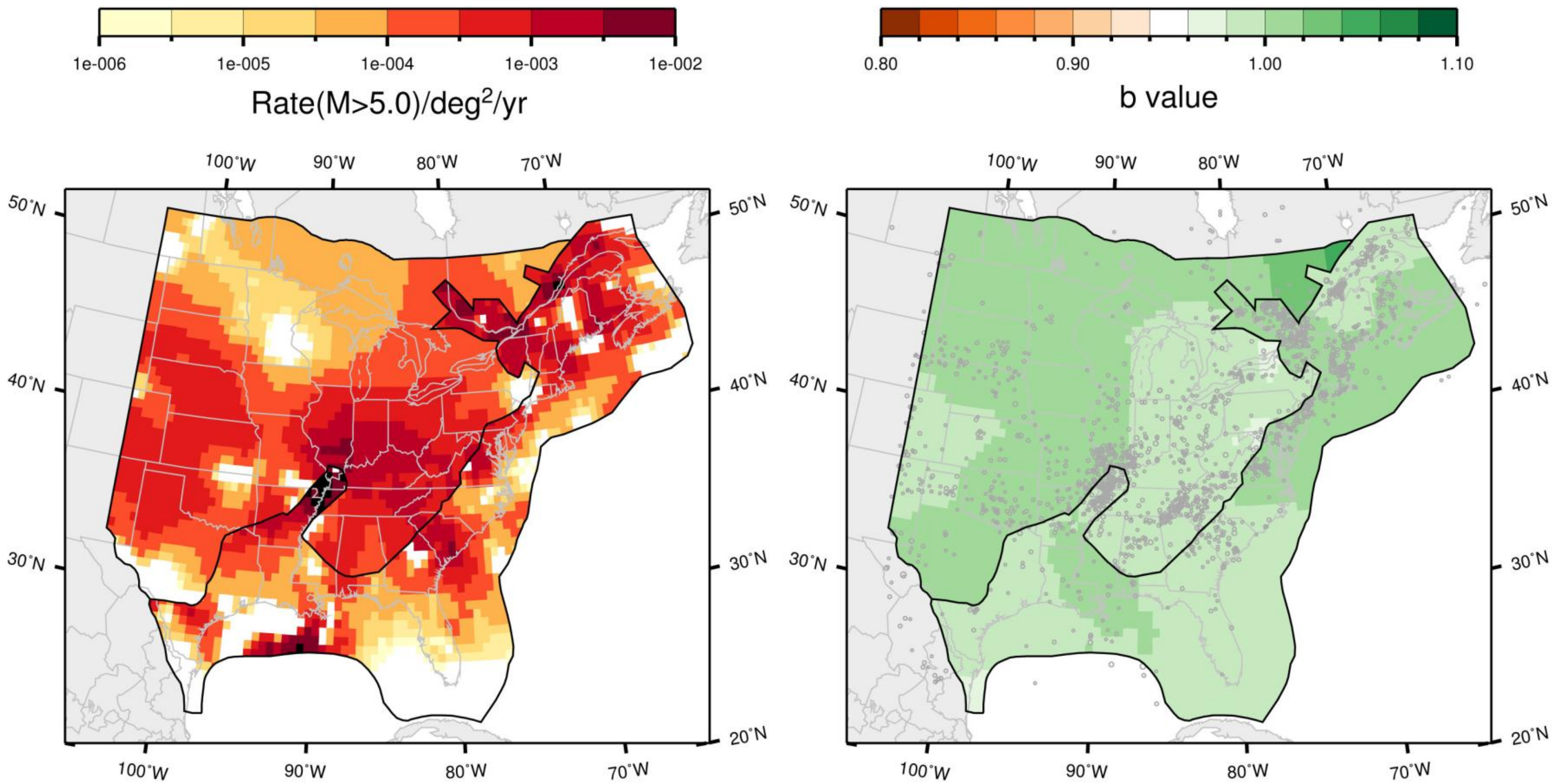


Figure J-48
Map of the rate and *b*-value for the study region under the Mmax zonation, with separation of Mesozoic extended and non-extended; Case E magnitude weights: Realization 3

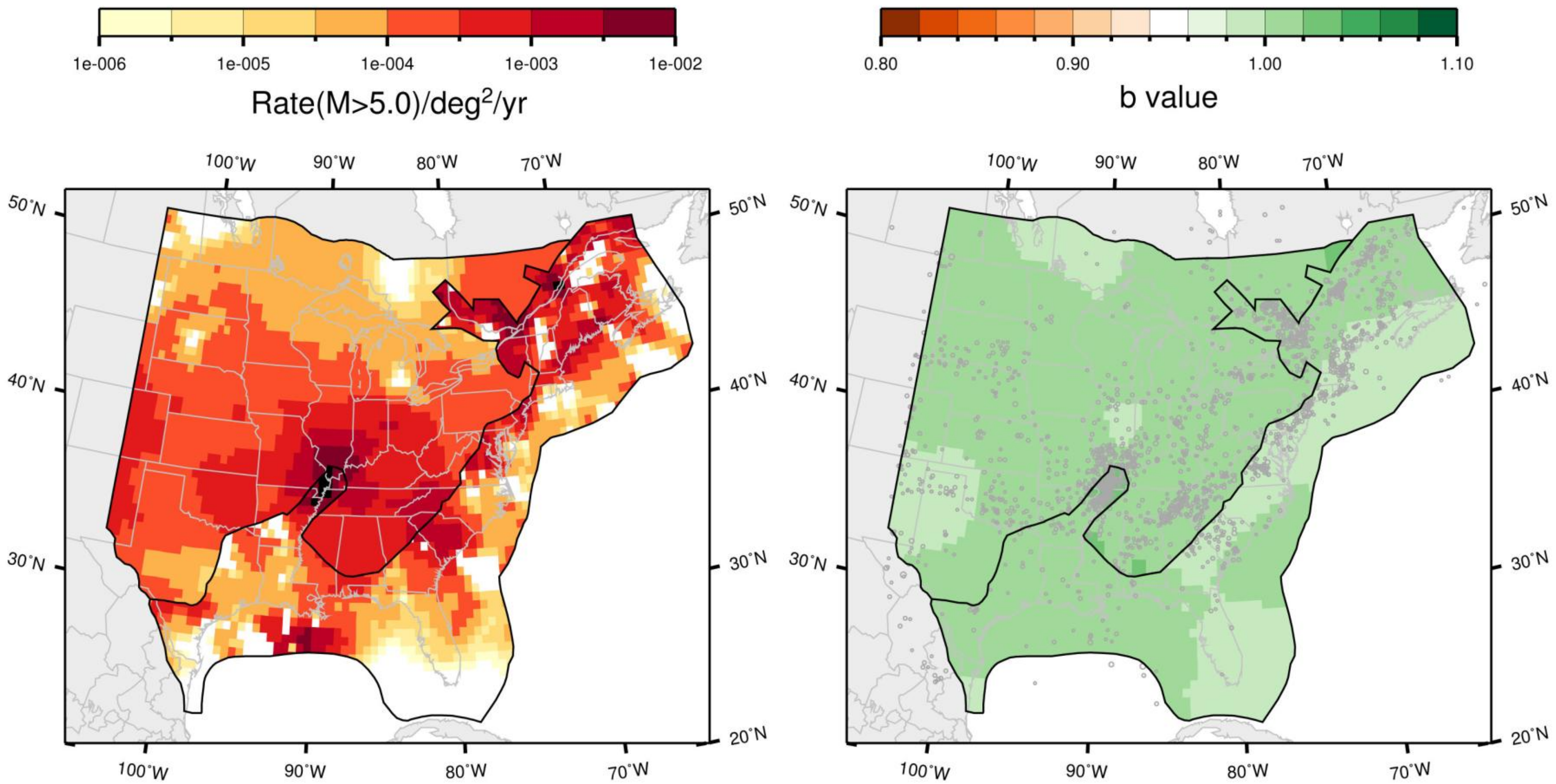


Figure J-49
Map of the rate and *b*-value for the study region under the Mmax zonation, with separation of Mesozoic extended and non-extended; Case E magnitude weights: Realization 4

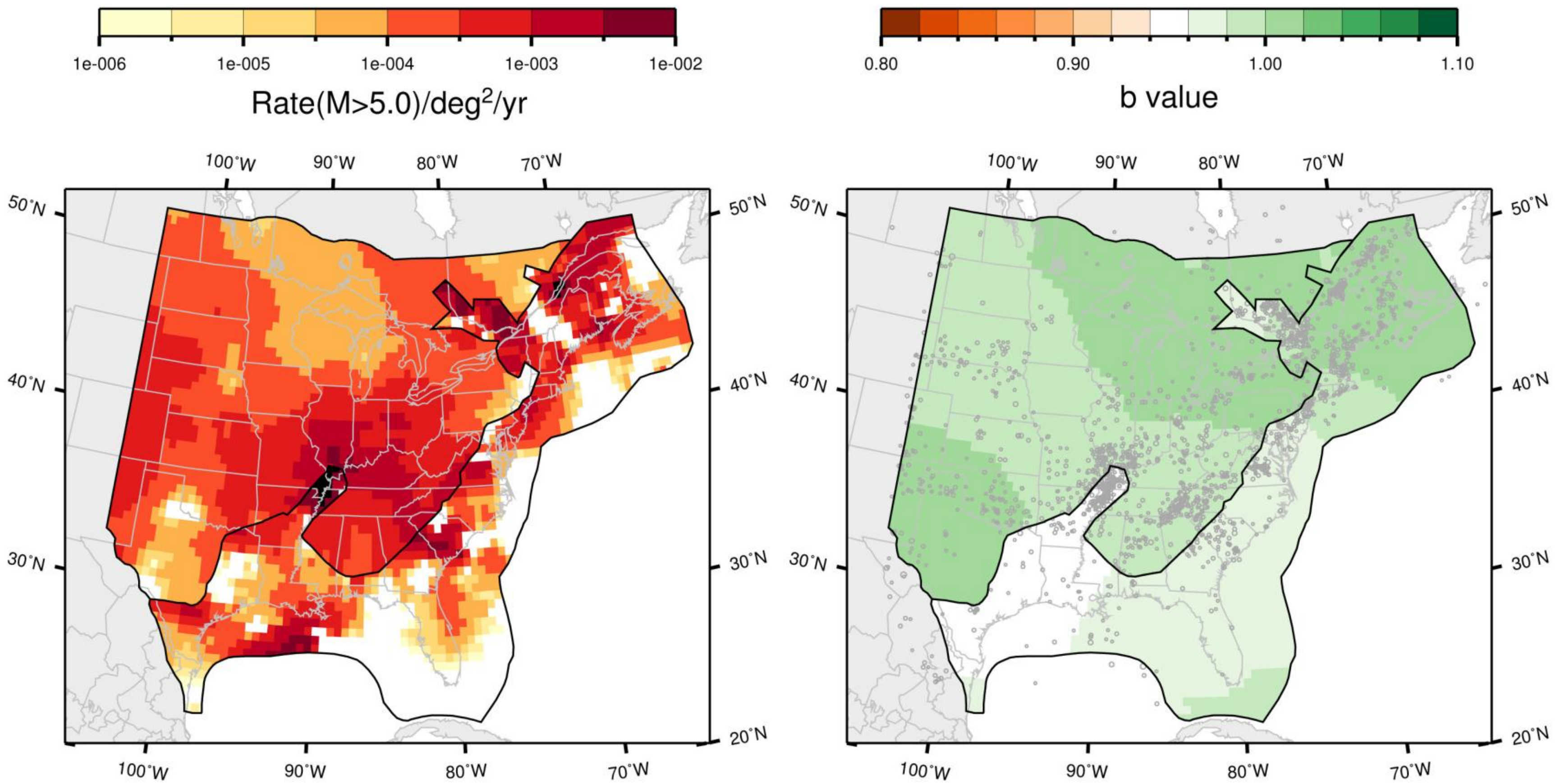


Figure J-50
Map of the rate and *b*-value for the study region under the Mmax zonation, with separation of Mesozoic extended and non-extended; Case E magnitude weights: Realization 5

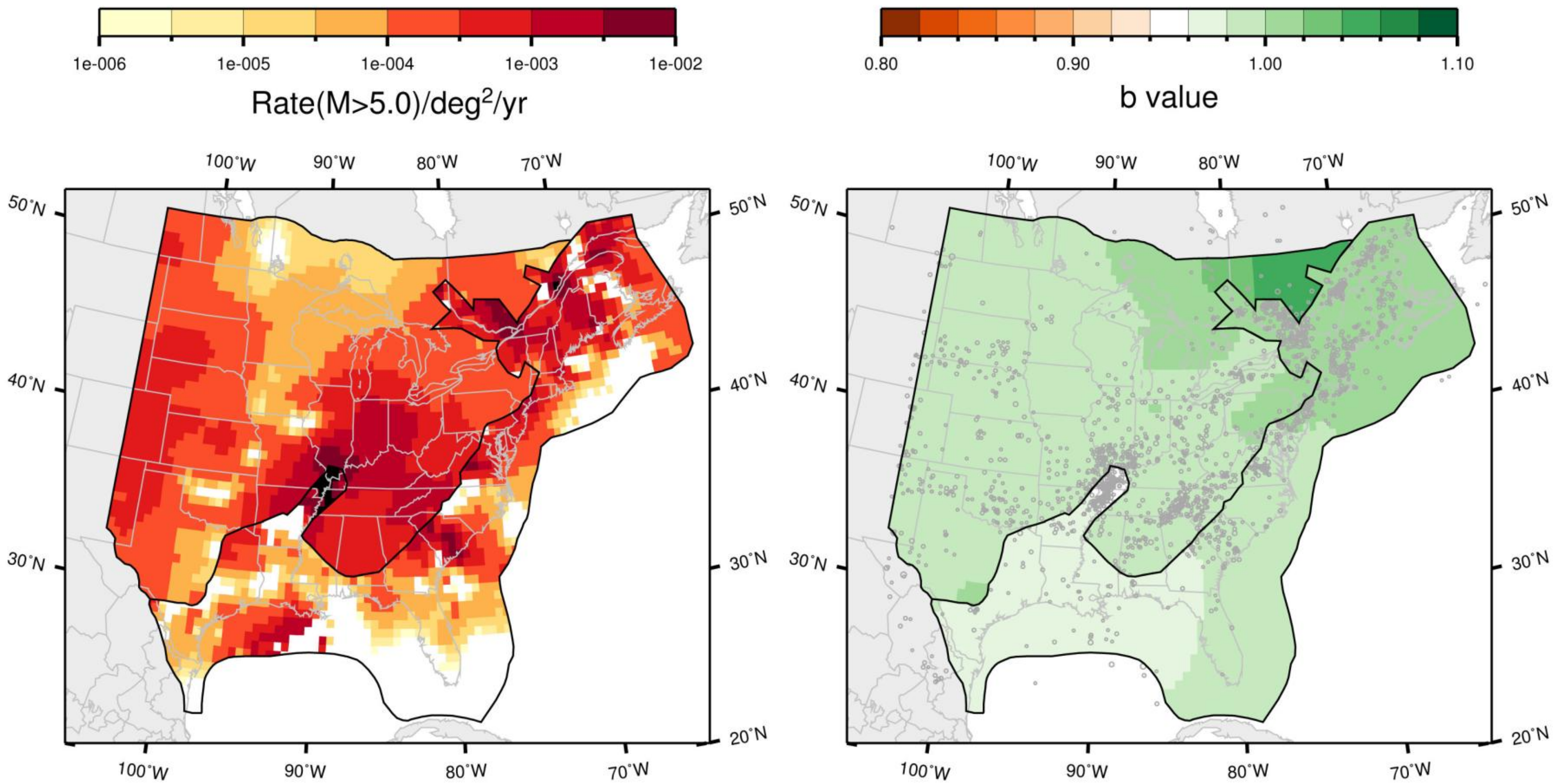


Figure J-51
Map of the rate and *b*-value for the study region under the Mmax zonation, with separation of Mesozoic extended and non-extended; Case E magnitude weights: Realization 6

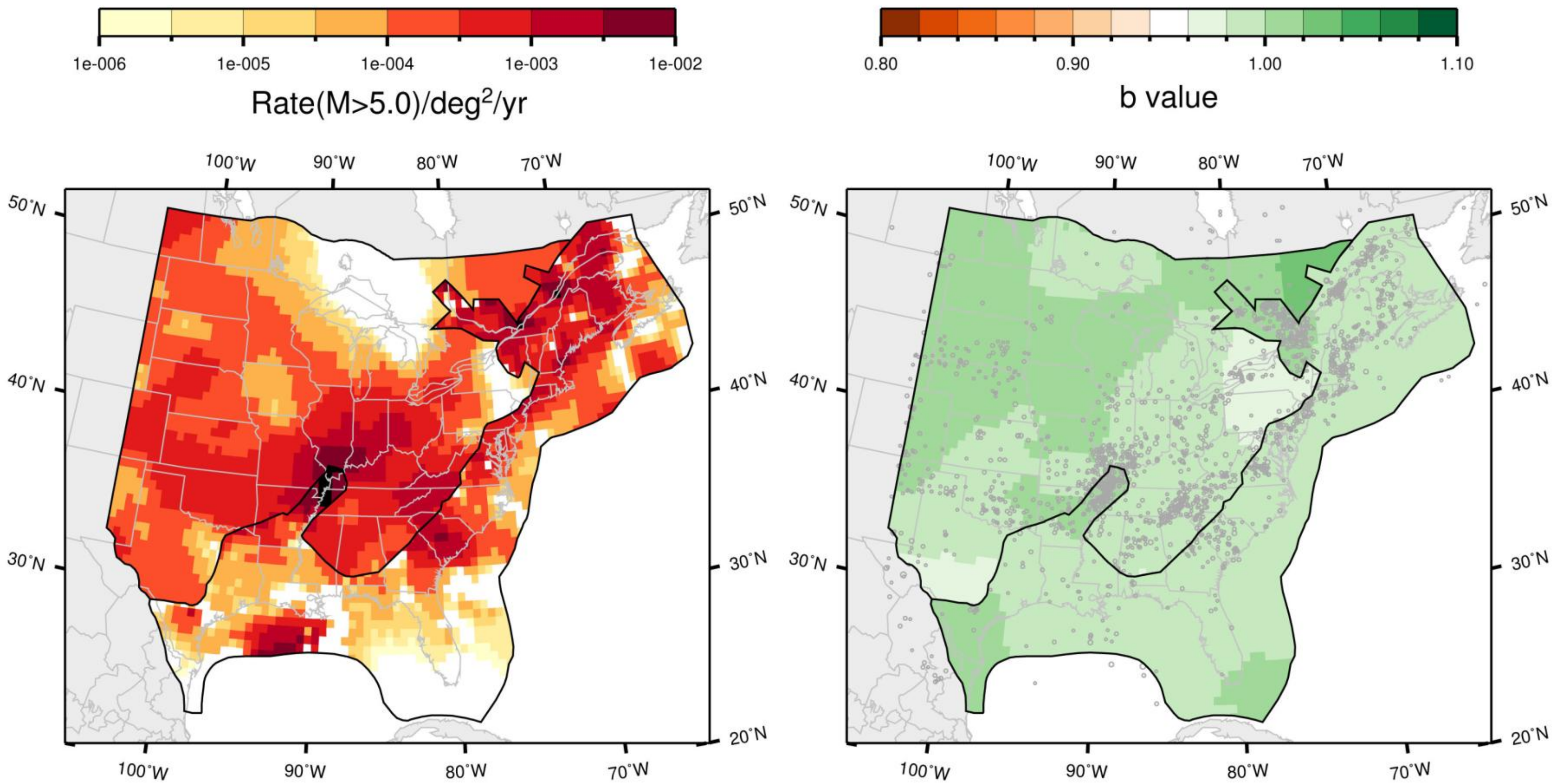


Figure J-52
Map of the rate and *b*-value for the study region under the Mmax zonation, with separation of Mesozoic extended and non-extended; Case E magnitude weights: Realization 7

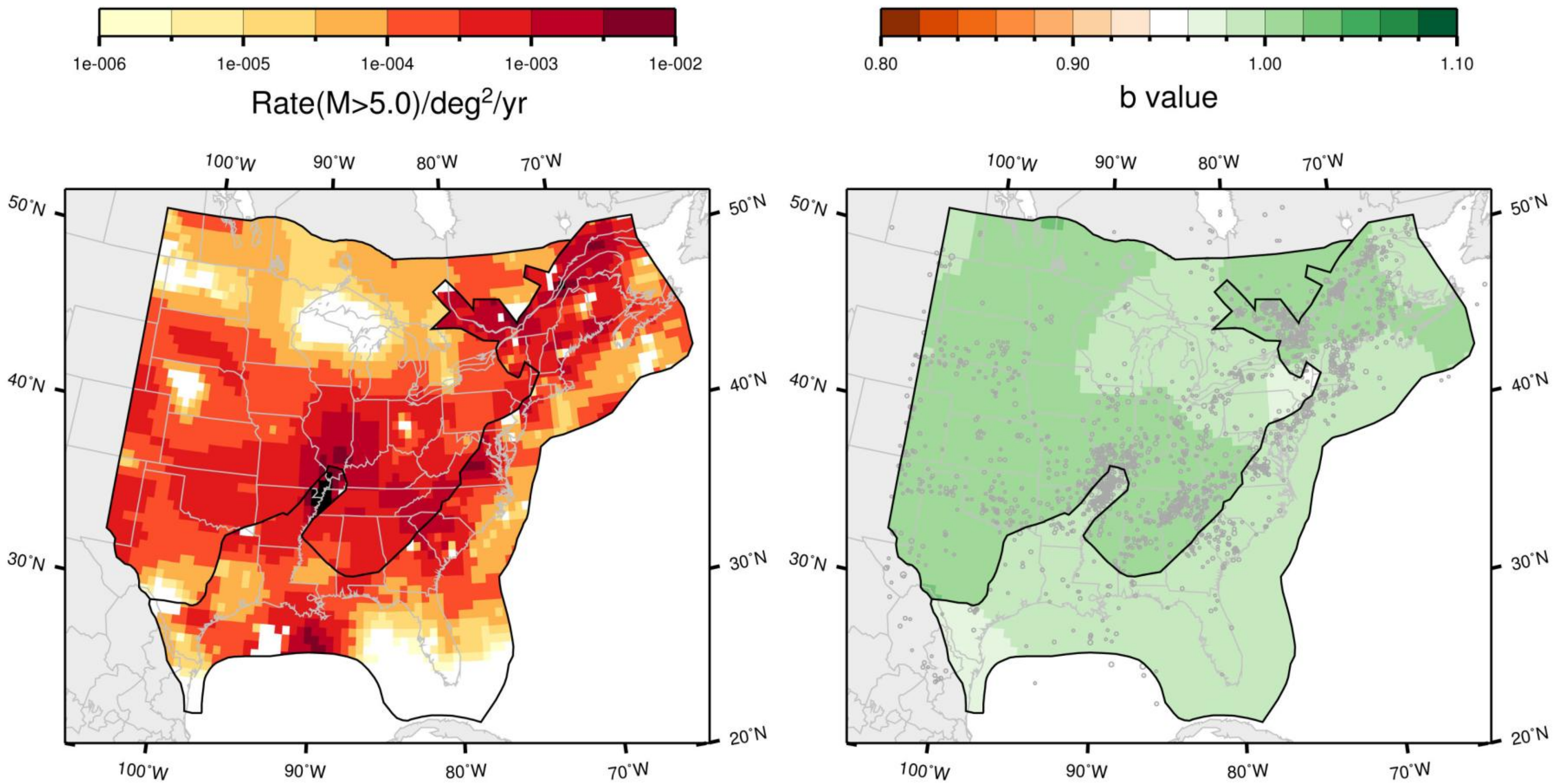


Figure J-53
Map of the rate and *b*-value for the study region under the Mmax zonation, with separation of Mesozoic extended and non-extended; Case E magnitude weights: Realization 8

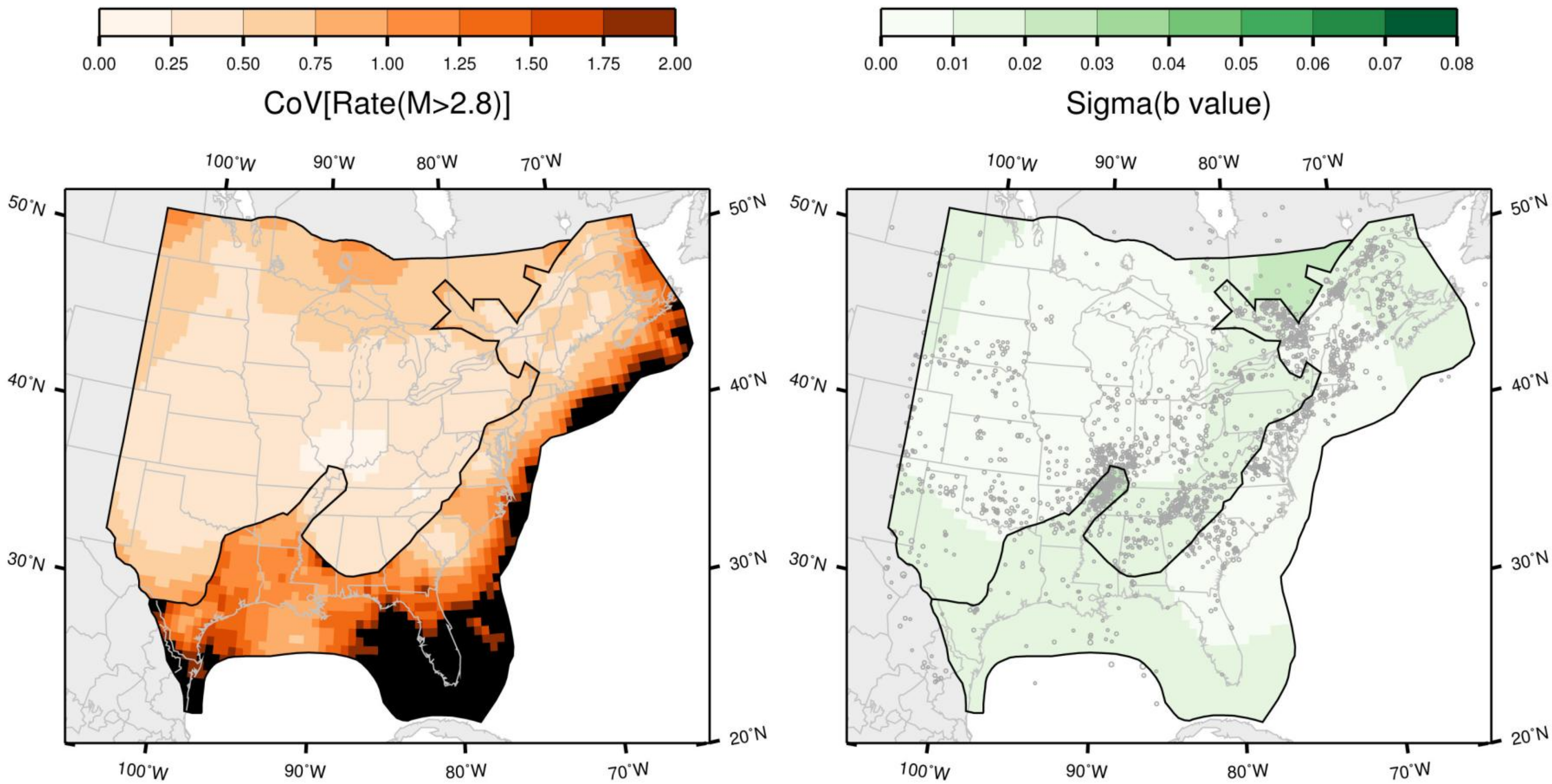


Figure J-54
Map of the coefficient of variation of the rate and the standard deviation of the *b*-value for the study region under the Mmax zonation, with separation of Mesozoic extended and non-extended; Case E magnitude weights

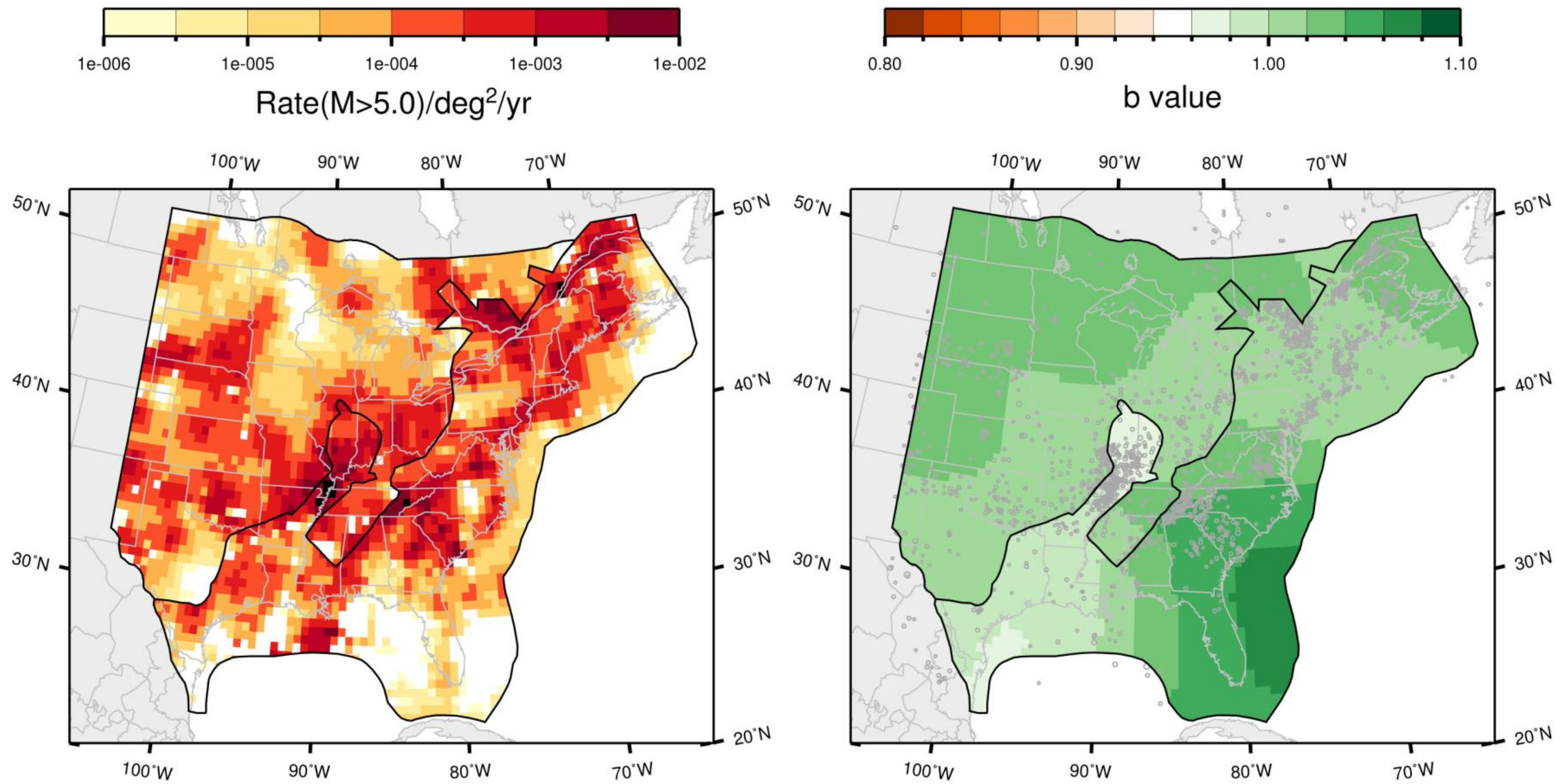


Figure J-55
Map of the rate and *b*-value for the study region under the Mmax zonation, with separation of Mesozoic extended and non-extended; Case A magnitude weights: Realization 1

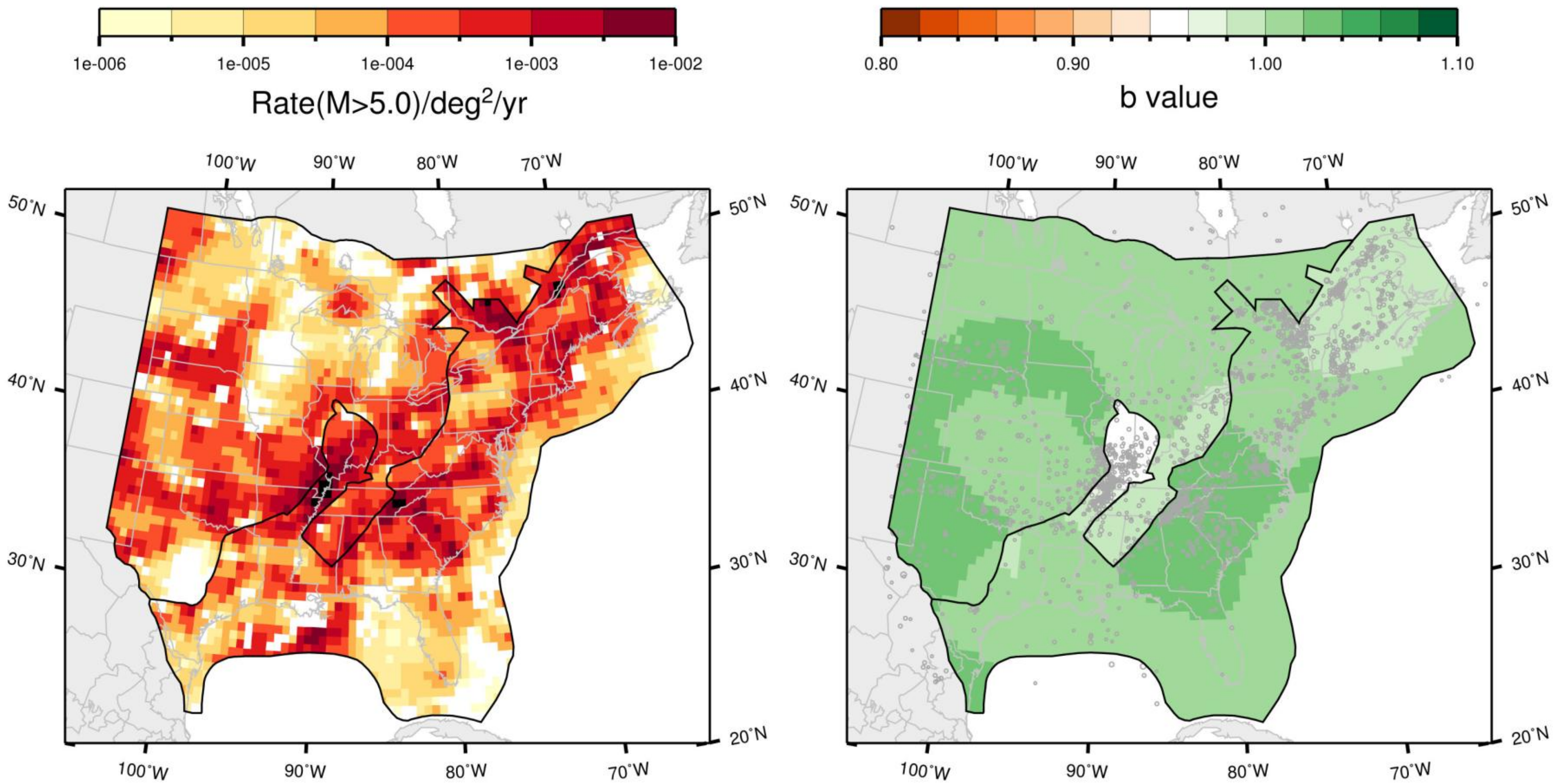


Figure J-56
Map of the rate and *b*-value for the study region under the Mmax zonation, with separation of Mesozoic extended and non-extended; Case A magnitude weights: Realization 2

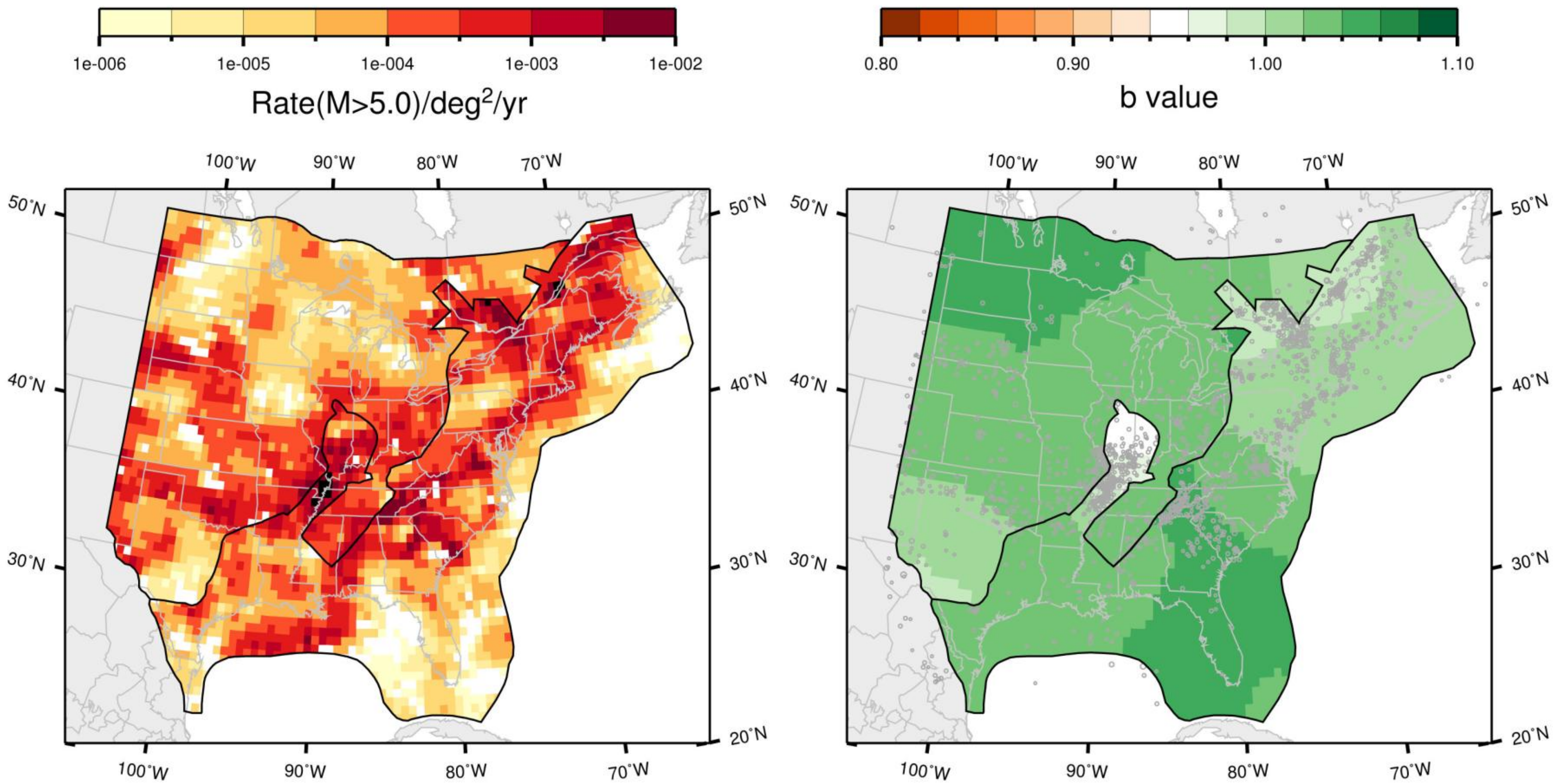


Figure J-57
Map of the rate and *b*-value for the study region under the Mmax zonation, with separation of Mesozoic extended and non-extended; Case A magnitude weights: Realization 3

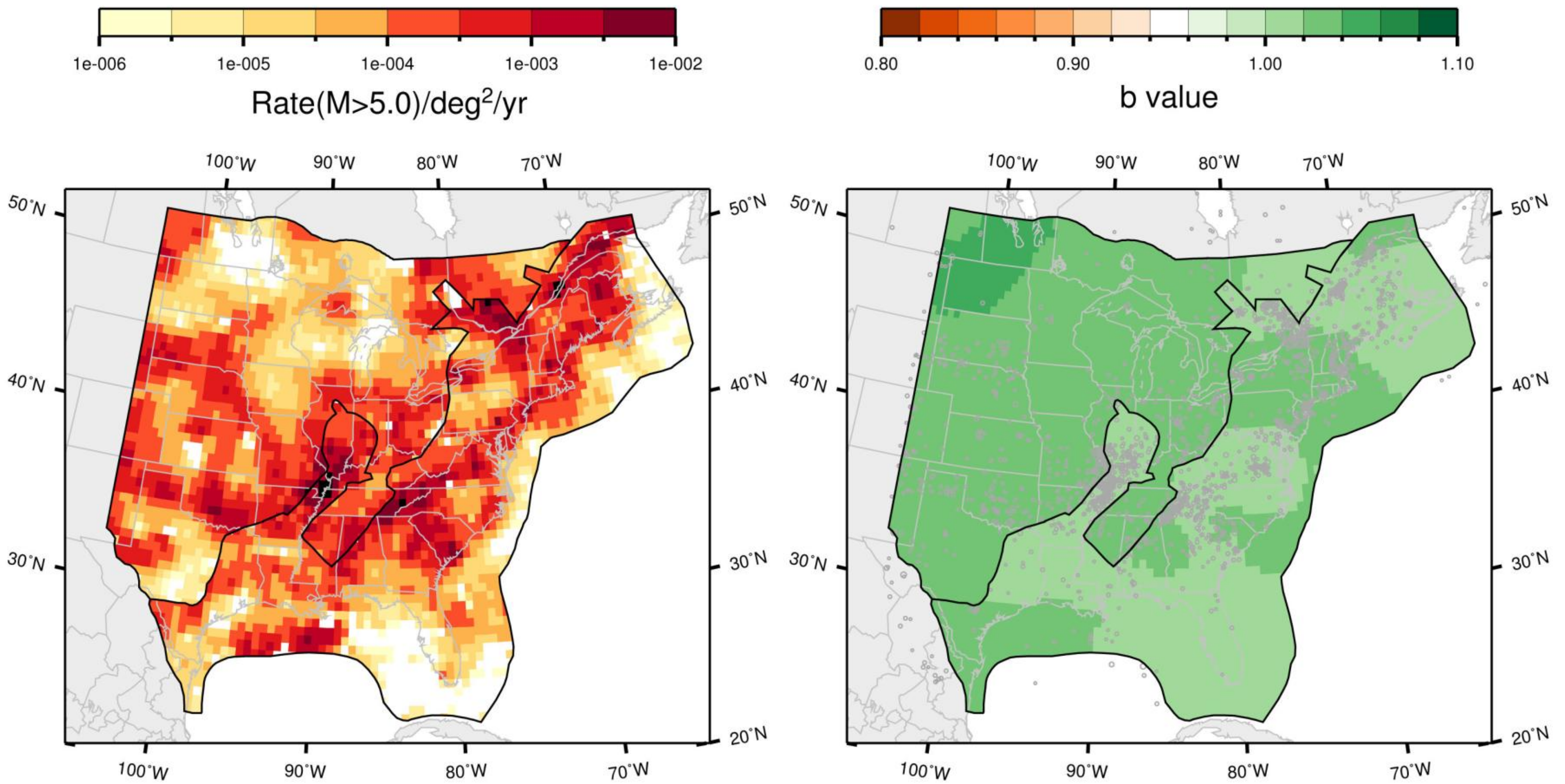


Figure J-58
Map of the rate and *b*-value for the study region under the Mmax zonation, with separation of Mesozoic extended and non-extended; Case A magnitude weights: Realization 4

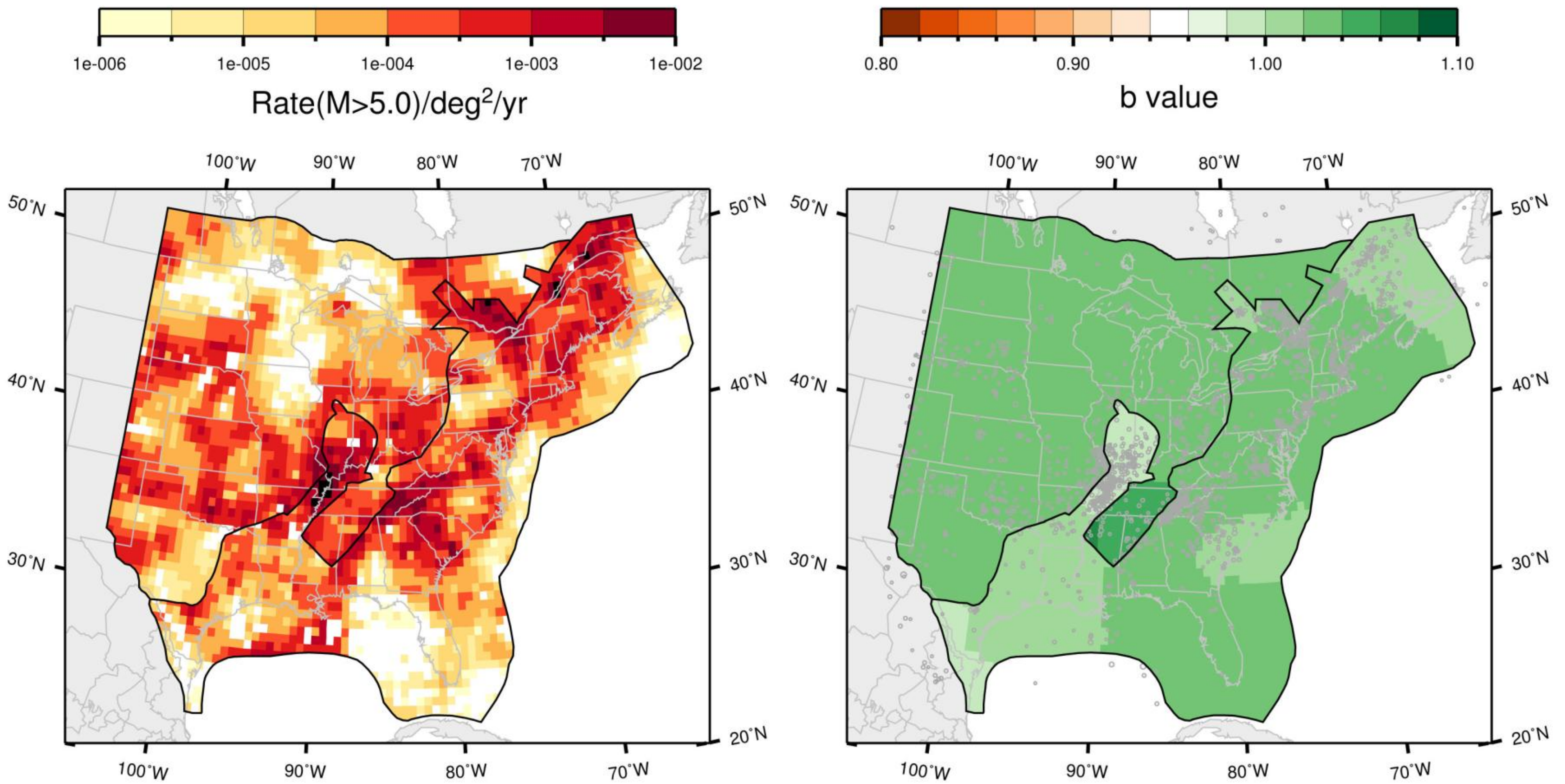


Figure J-59
Map of the rate and *b*-value for the study region under the Mmax zonation, with separation of Mesozoic extended and non-extended; Case A magnitude weights: Realization 5

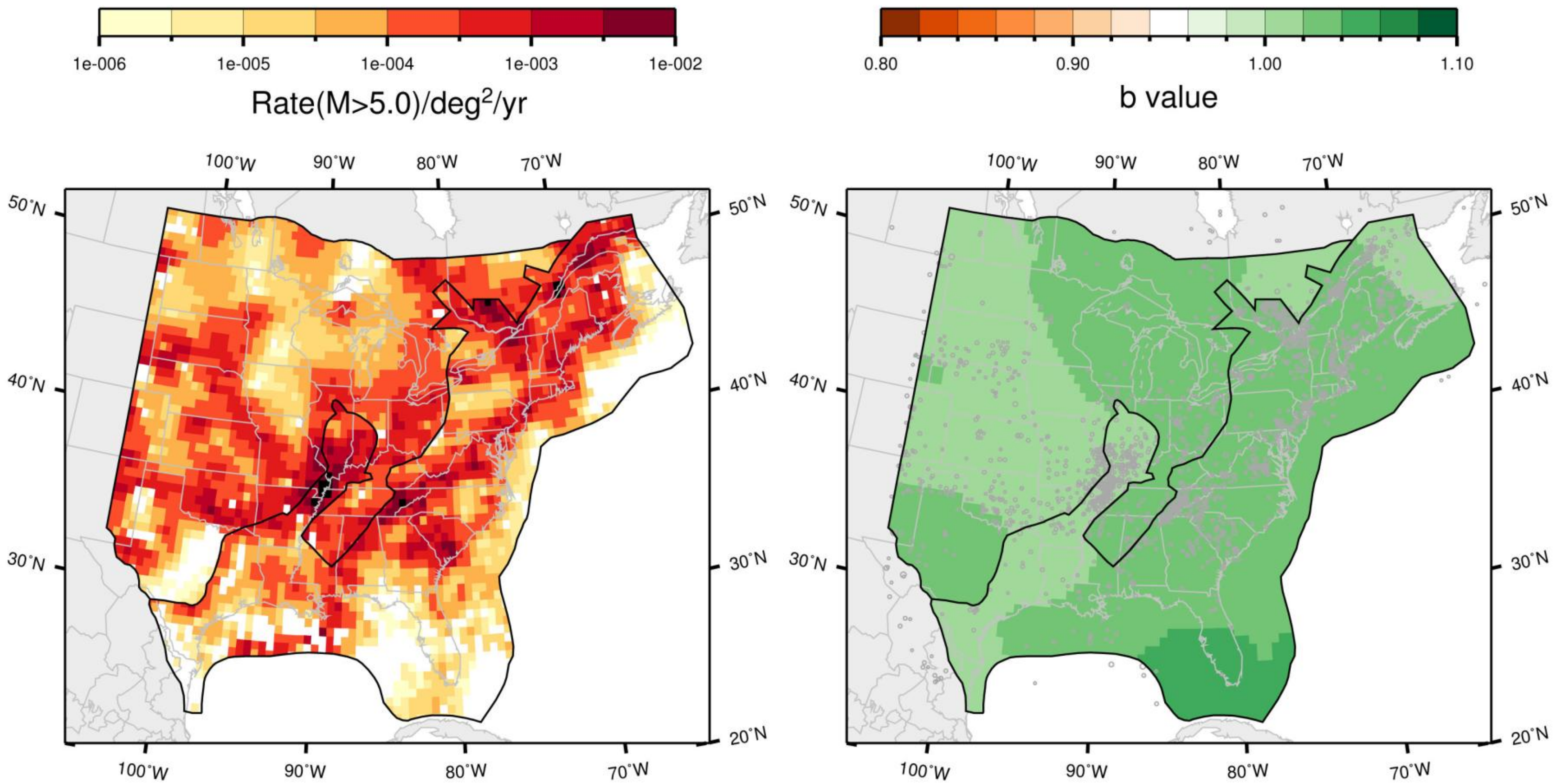


Figure J-60
Map of the rate and *b*-value for the study region under the Mmax zonation, with separation of Mesozoic extended and non-extended; Case A magnitude weights: Realization 6

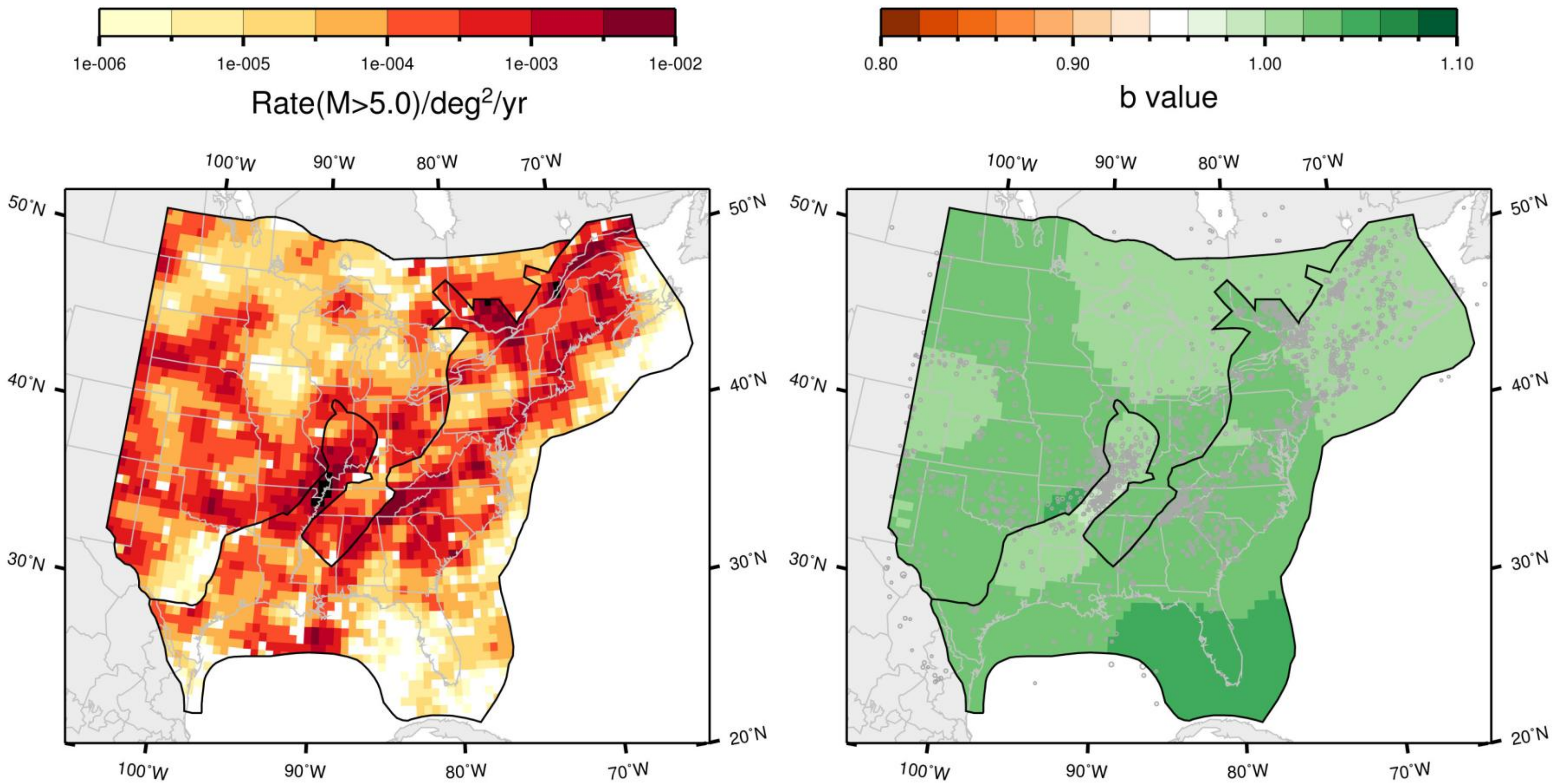


Figure J-61
Map of the rate and *b*-value for the study region under the Mmax zonation, with separation of Mesozoic extended and non-extended; Case A magnitude weights: Realization 7

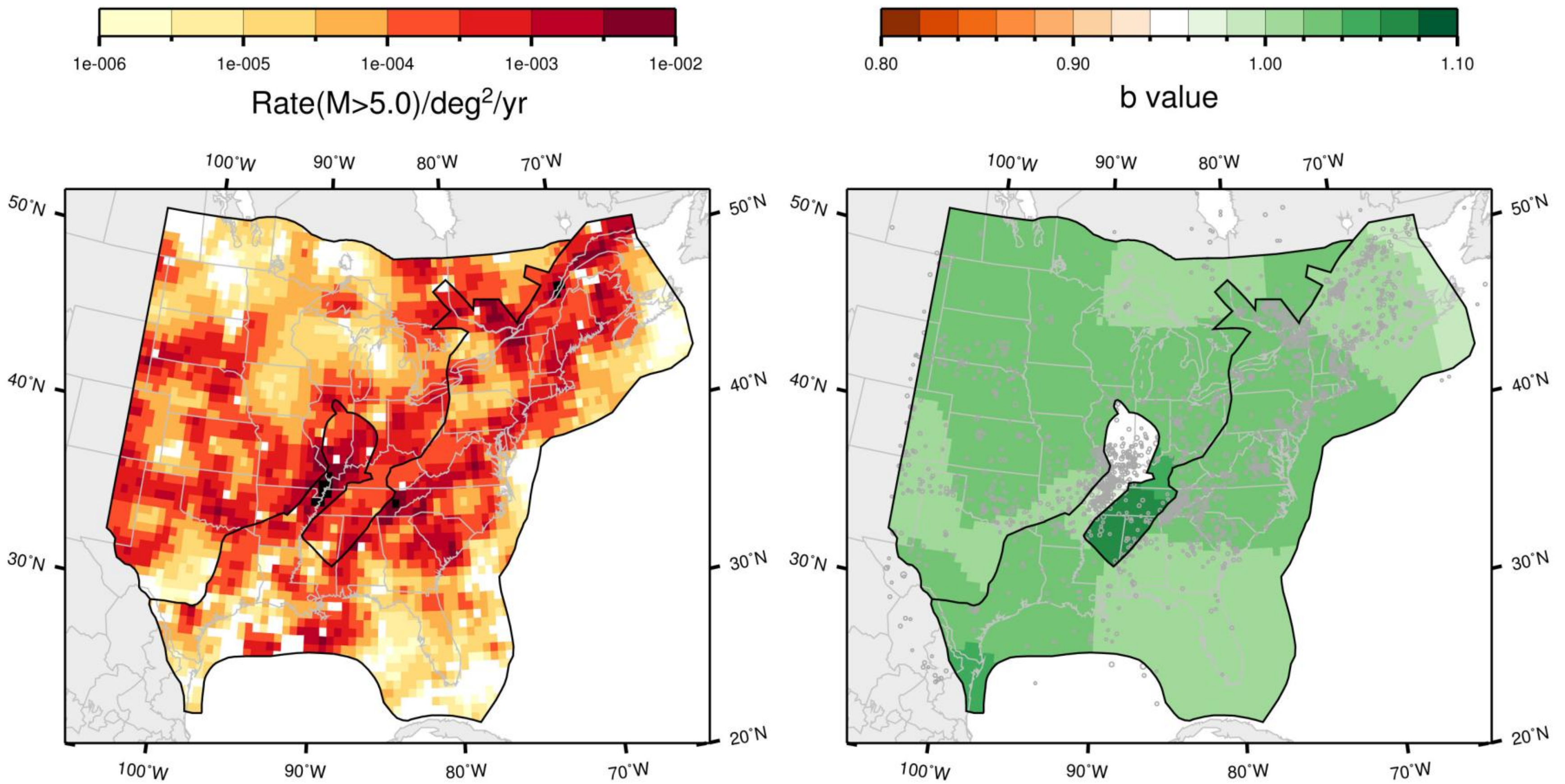


Figure J-62
Map of the rate and *b*-value for the study region under the Mmax zonation, with separation of Mesozoic extended and non-extended; Case A magnitude weights: Realization 8

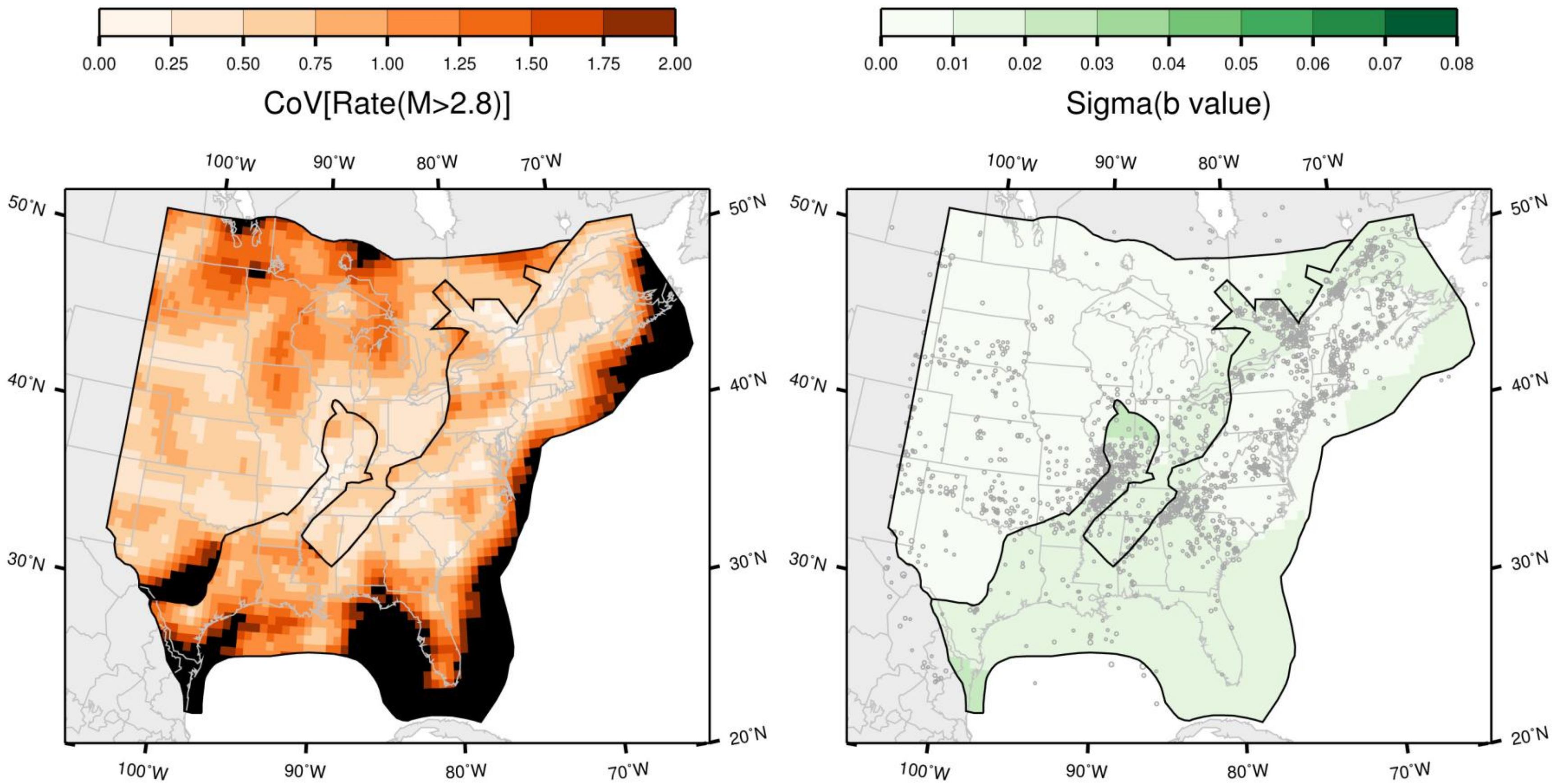


Figure J-63
Map of the coefficient of variation of the rate and the standard deviation of the *b*-value for the study region under the Mmax zonation, with separation of Mesozoic extended and non-extended; Case A magnitude weights

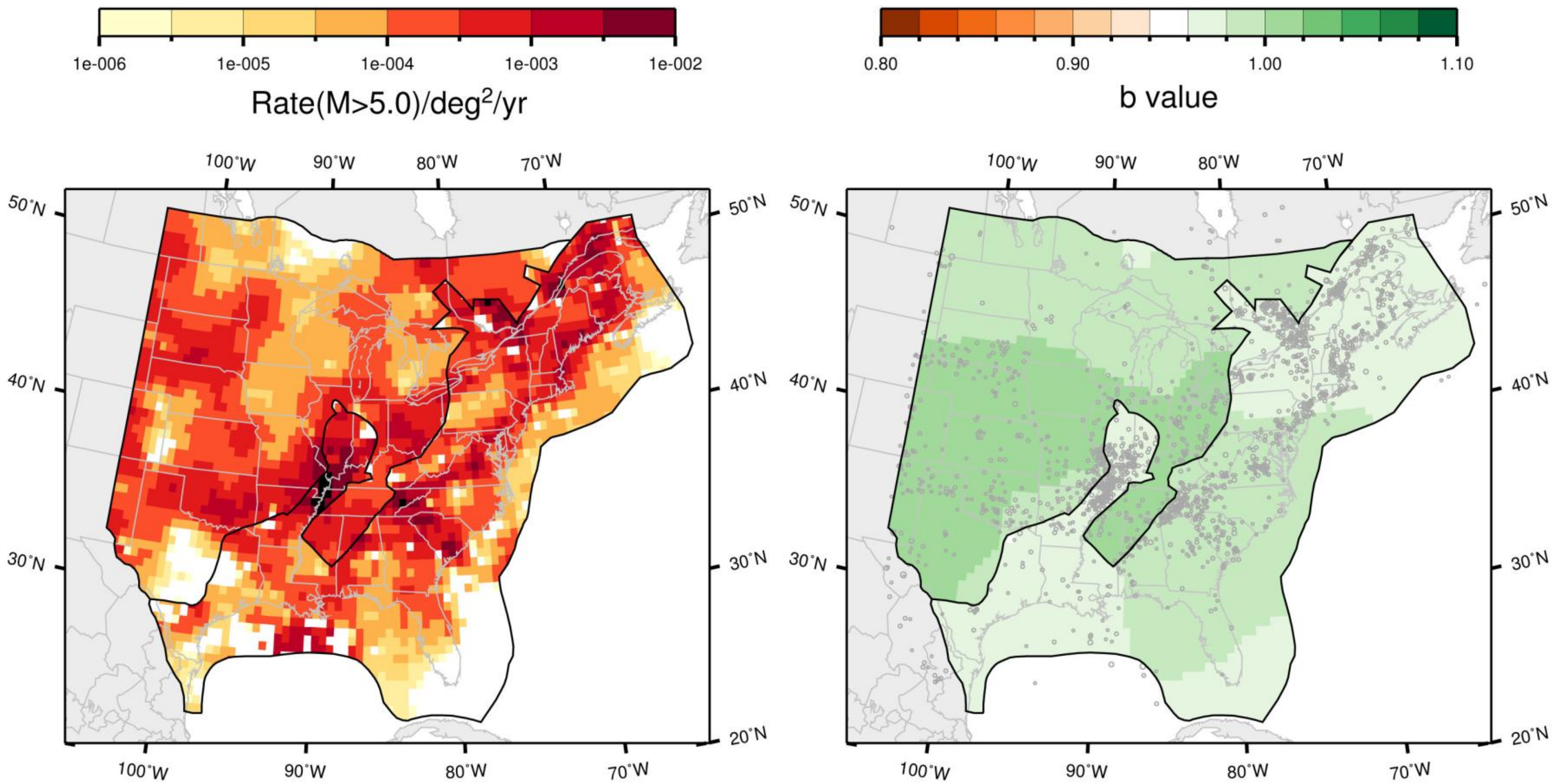


Figure J-64
Map of the rate and *b*-value for the study region under the Mmax zonation, with separation of Mesozoic extended and non-extended; Case B magnitude weights: Realization 1

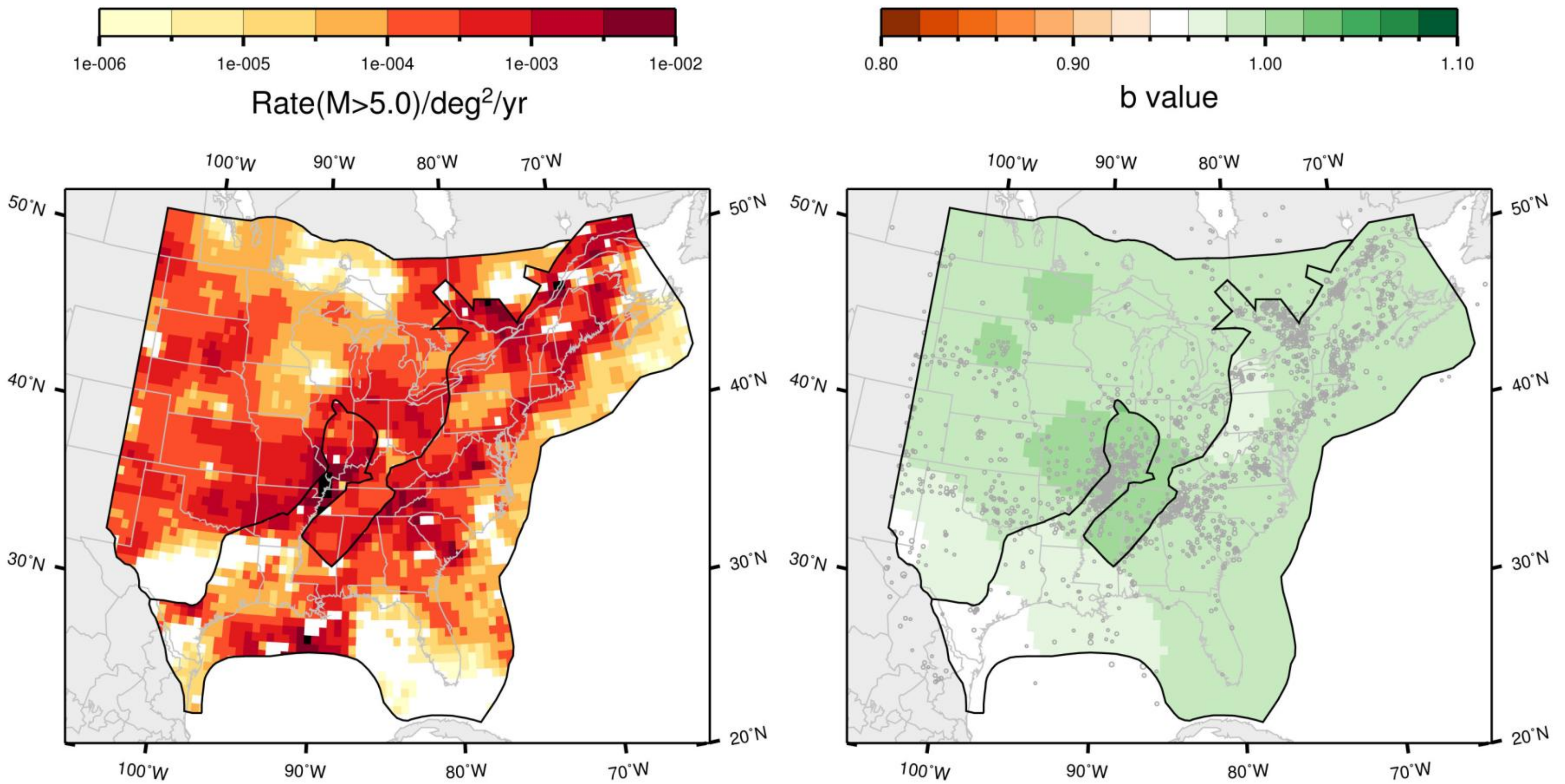


Figure J-65
Map of the rate and *b*-value for the study region under the Mmax zonation, with separation of Mesozoic extended and non-extended; Case B magnitude weights: Realization 2

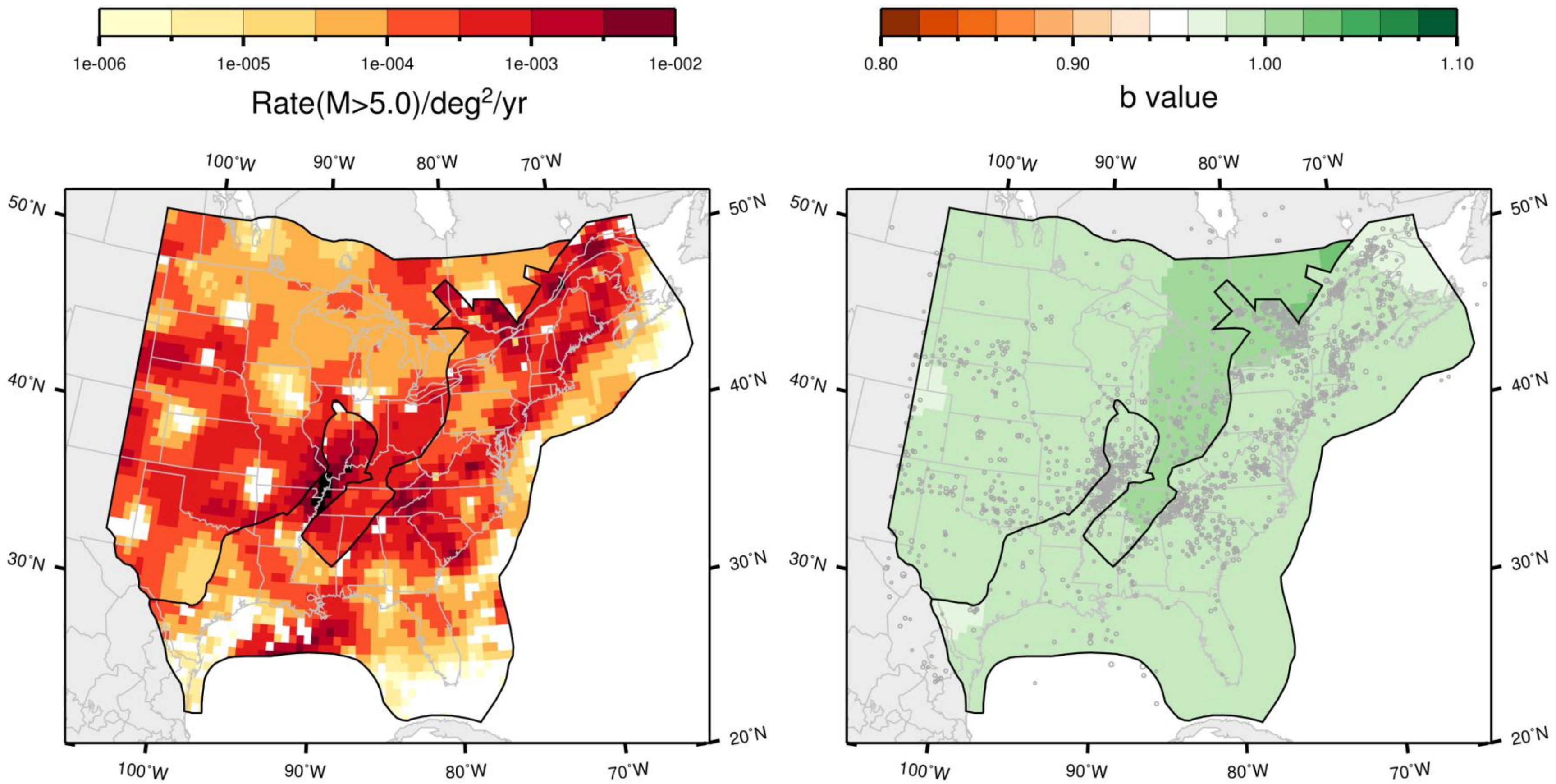


Figure J-66
Map of the rate and *b*-value for the study region under the Mmax zonation, with separation of Mesozoic extended and non-extended; Case B magnitude weights: Realization 3

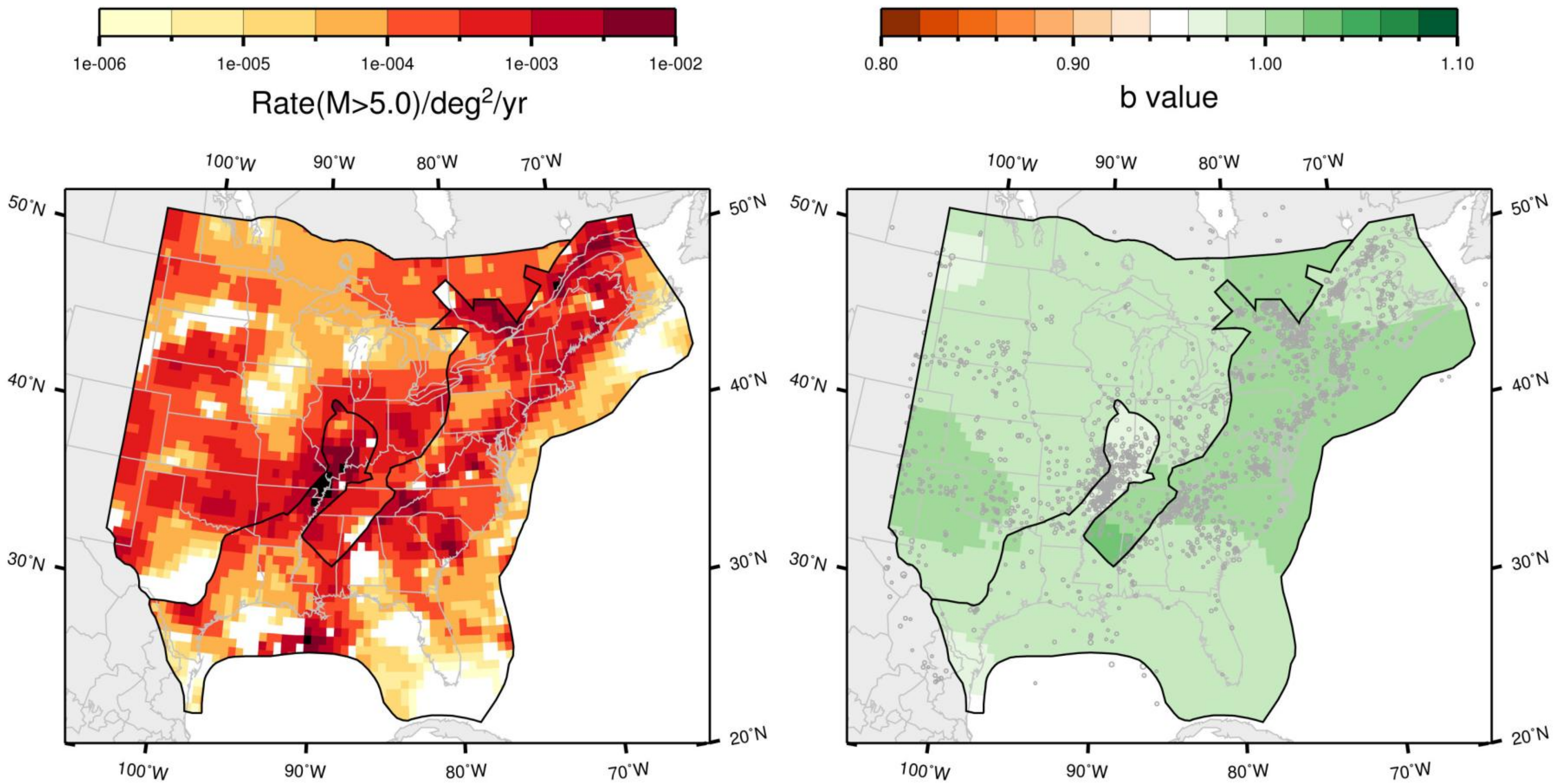


Figure J-67
Map of the rate and *b*-value for the study region under the Mmax zonation, with separation of Mesozoic extended and non-extended; Case B magnitude weights: Realization 4

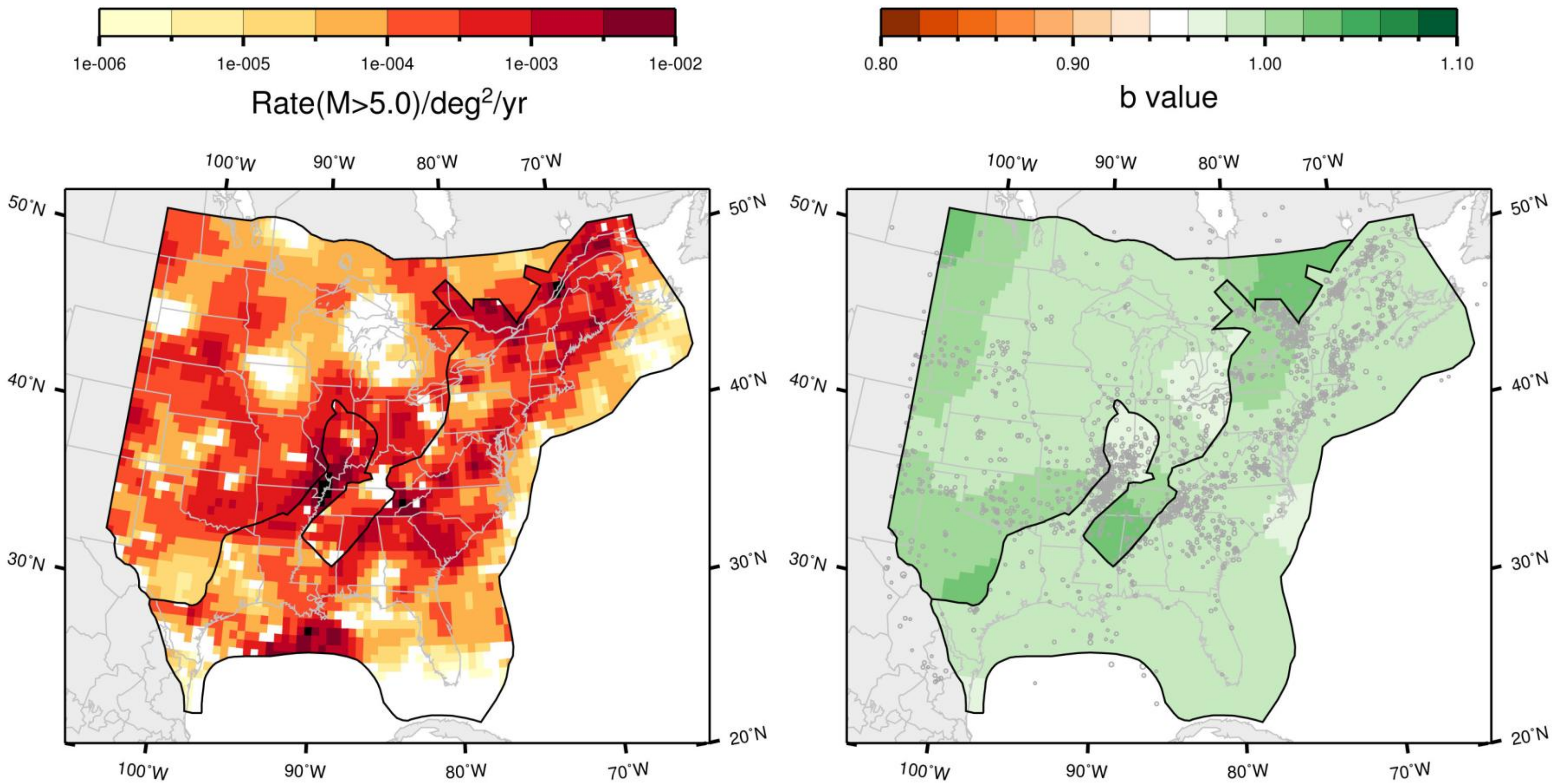


Figure J-68
Map of the rate and *b*-value for the study region under the Mmax zonation, with separation of Mesozoic extended and non-extended; Case B magnitude weights: Realization 5

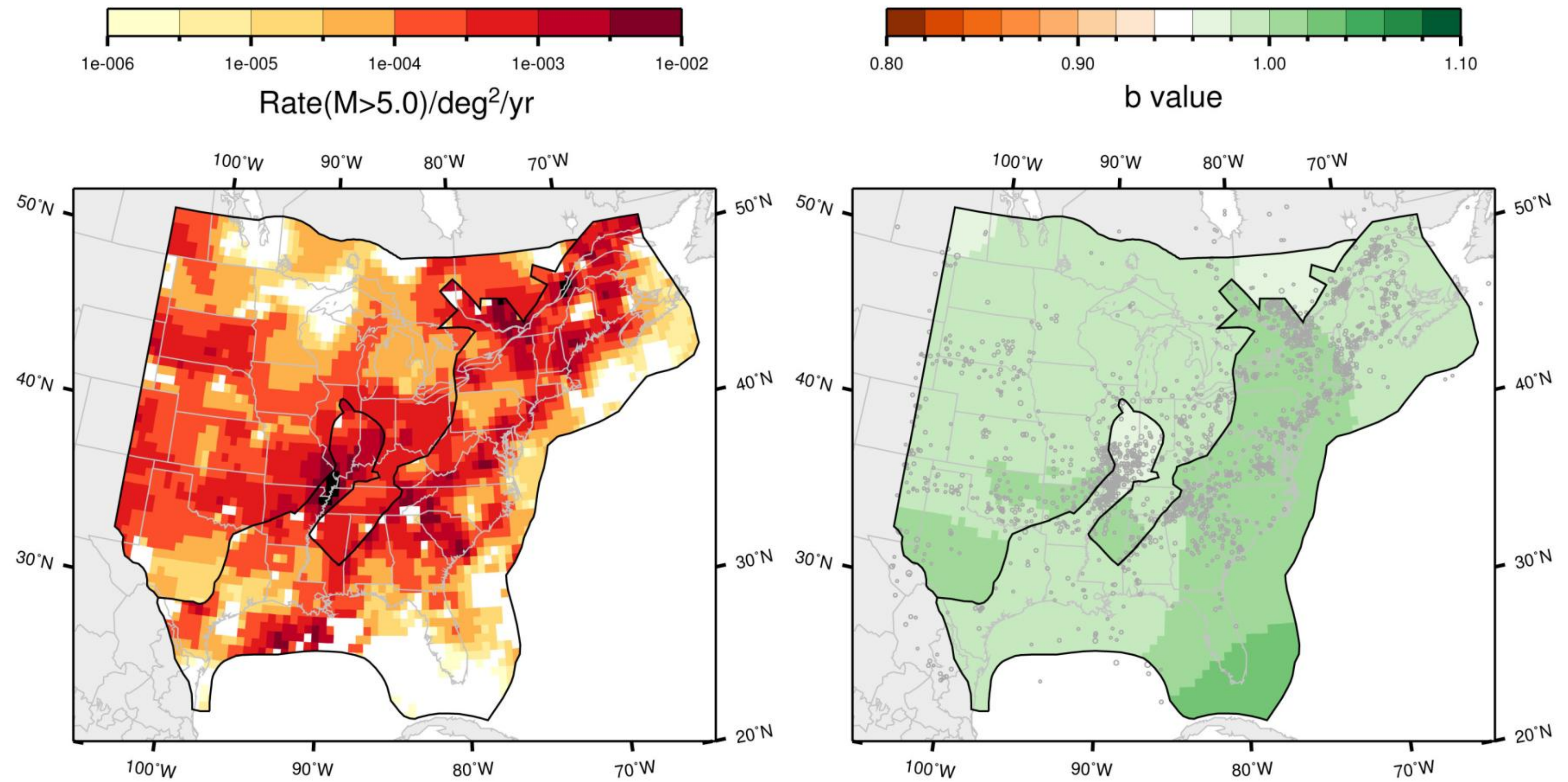


Figure J-69
Map of the rate and *b*-value for the study region under the Mmax zonation, with separation of Mesozoic extended and non-extended; Case B magnitude weights: Realization 6

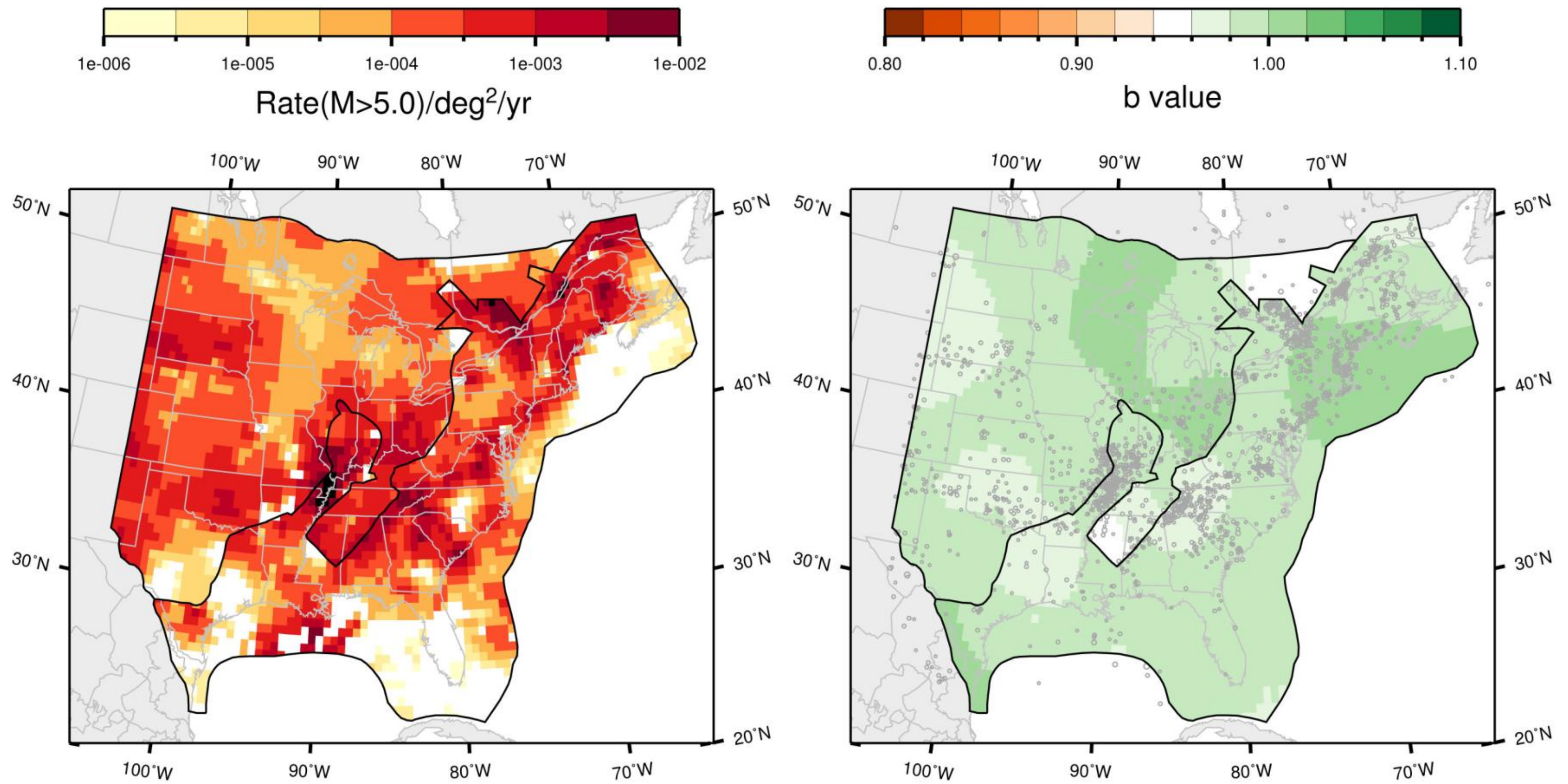


Figure J-70
Map of the rate and *b*-value for the study region under the Mmax zonation, with separation of Mesozoic extended and non-extended; Case B magnitude weights: Realization 7

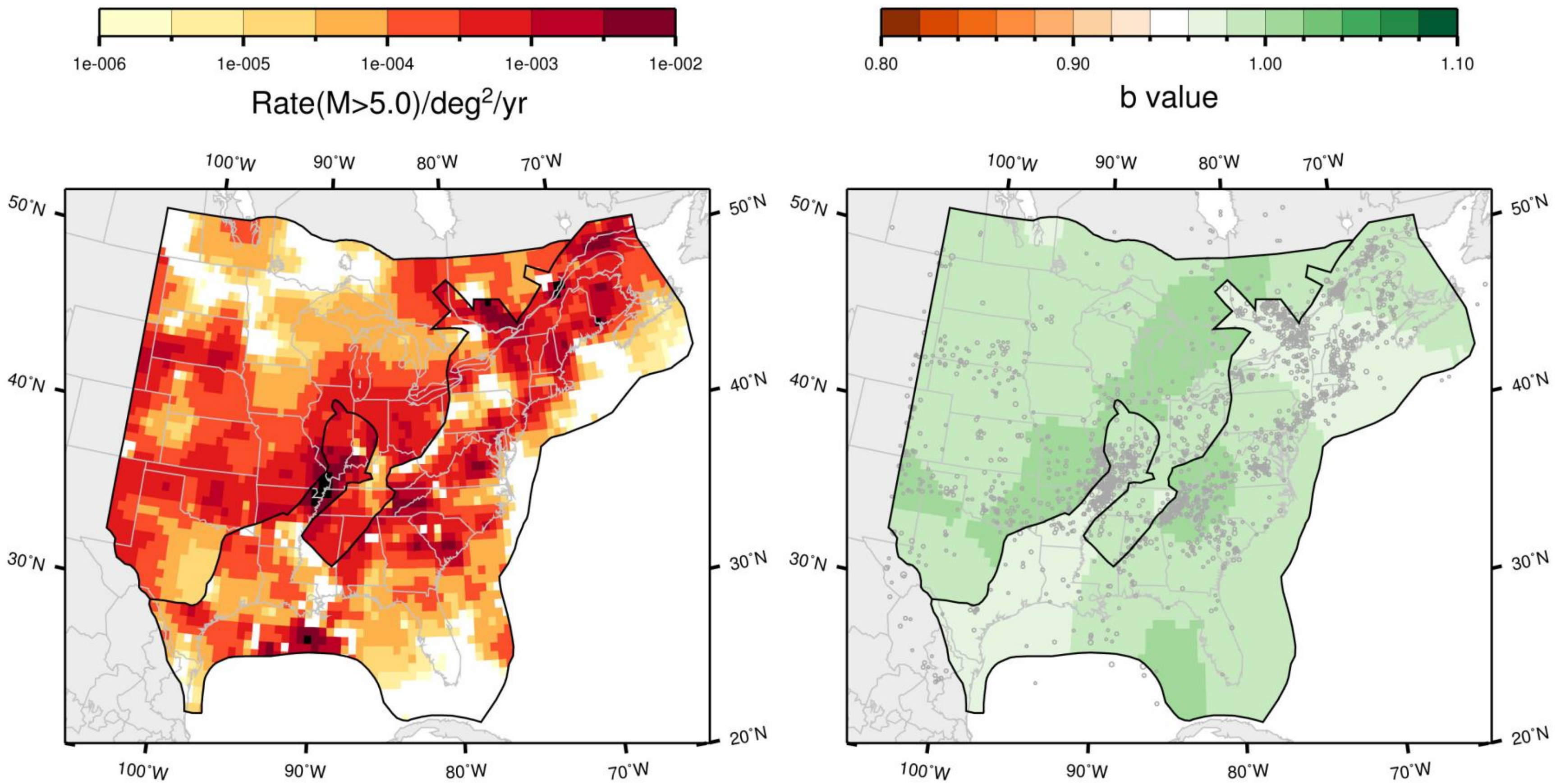


Figure J-71
Map of the rate and *b*-value for the study region under the Mmax zonation, with separation of Mesozoic extended and non-extended; Case B magnitude weights: Realization 8

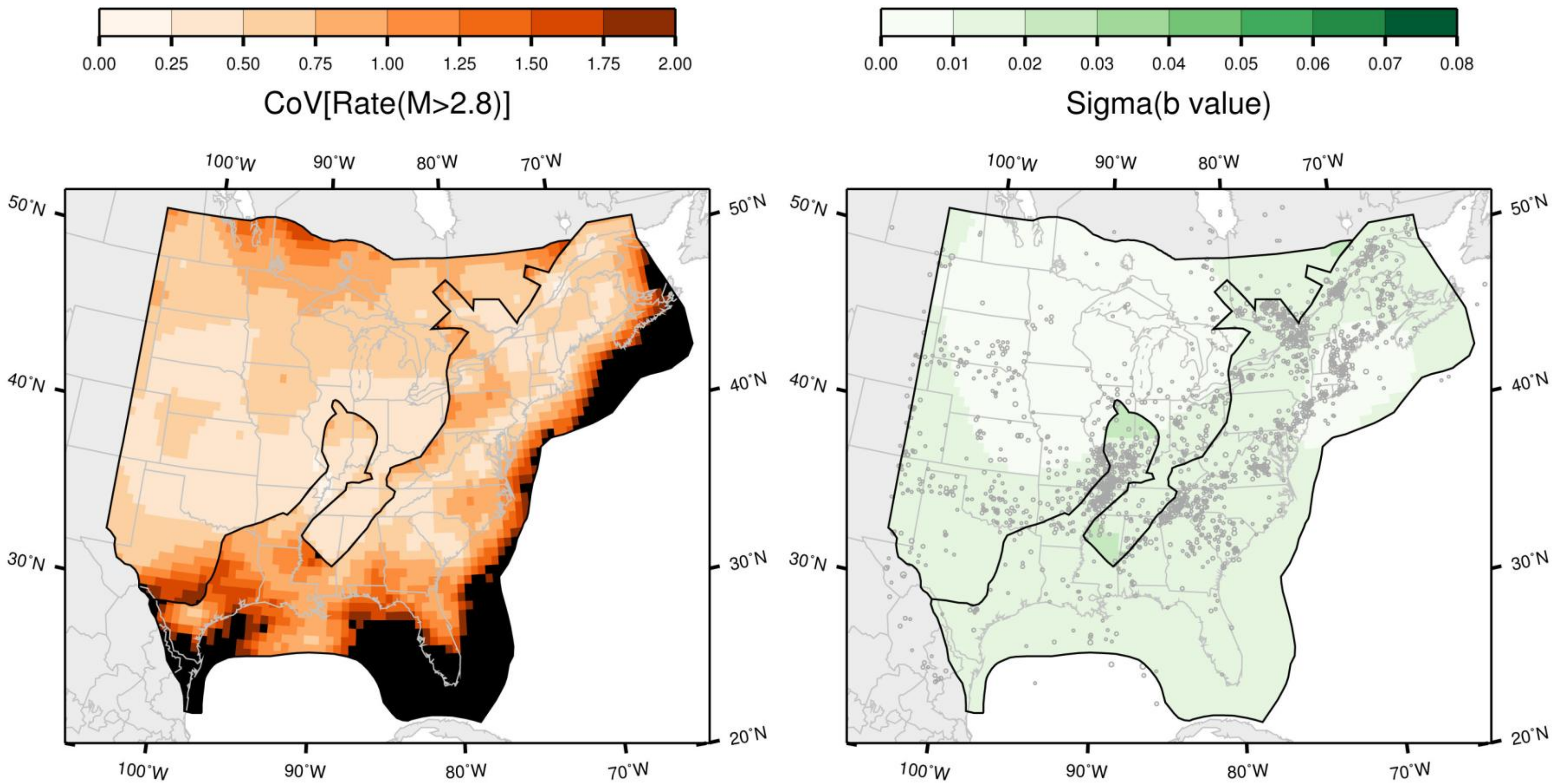


Figure J-72
Map of the coefficient of variation of the rate and the standard deviation of the *b*-value for the study region under the Mmax zonation, with separation of Mesozoic extended and non-extended; Case B magnitude weights

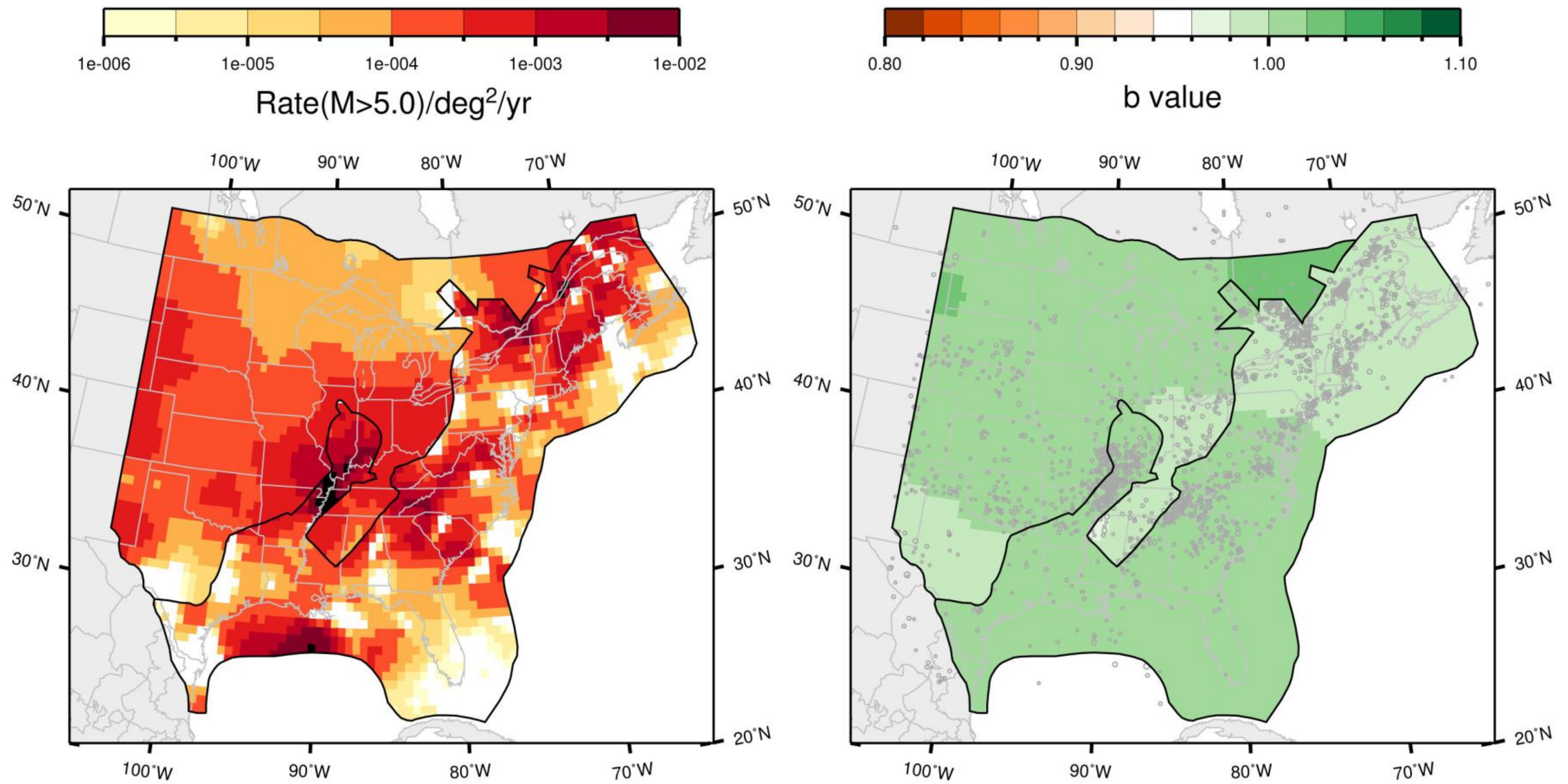


Figure J-73
Map of the rate and *b*-value for the study region under the Mmax zonation, with separation of Mesozoic extended and non-extended; Case E magnitude weights: Realization 1

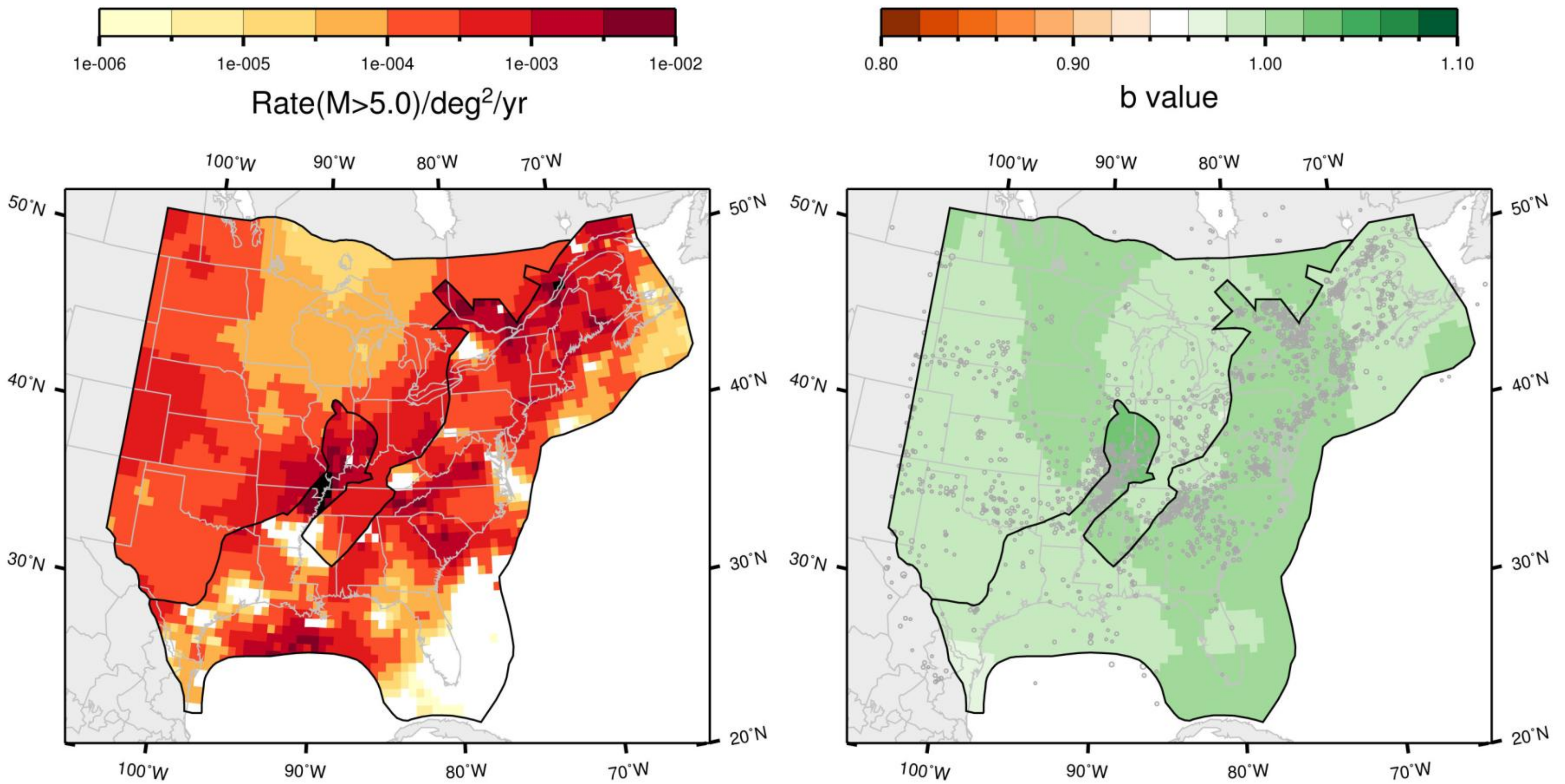


Figure J-74
Map of the rate and *b*-value for the study region under the Mmax zonation, with separation of Mesozoic extended and non-extended; Case E magnitude weights: Realization 2

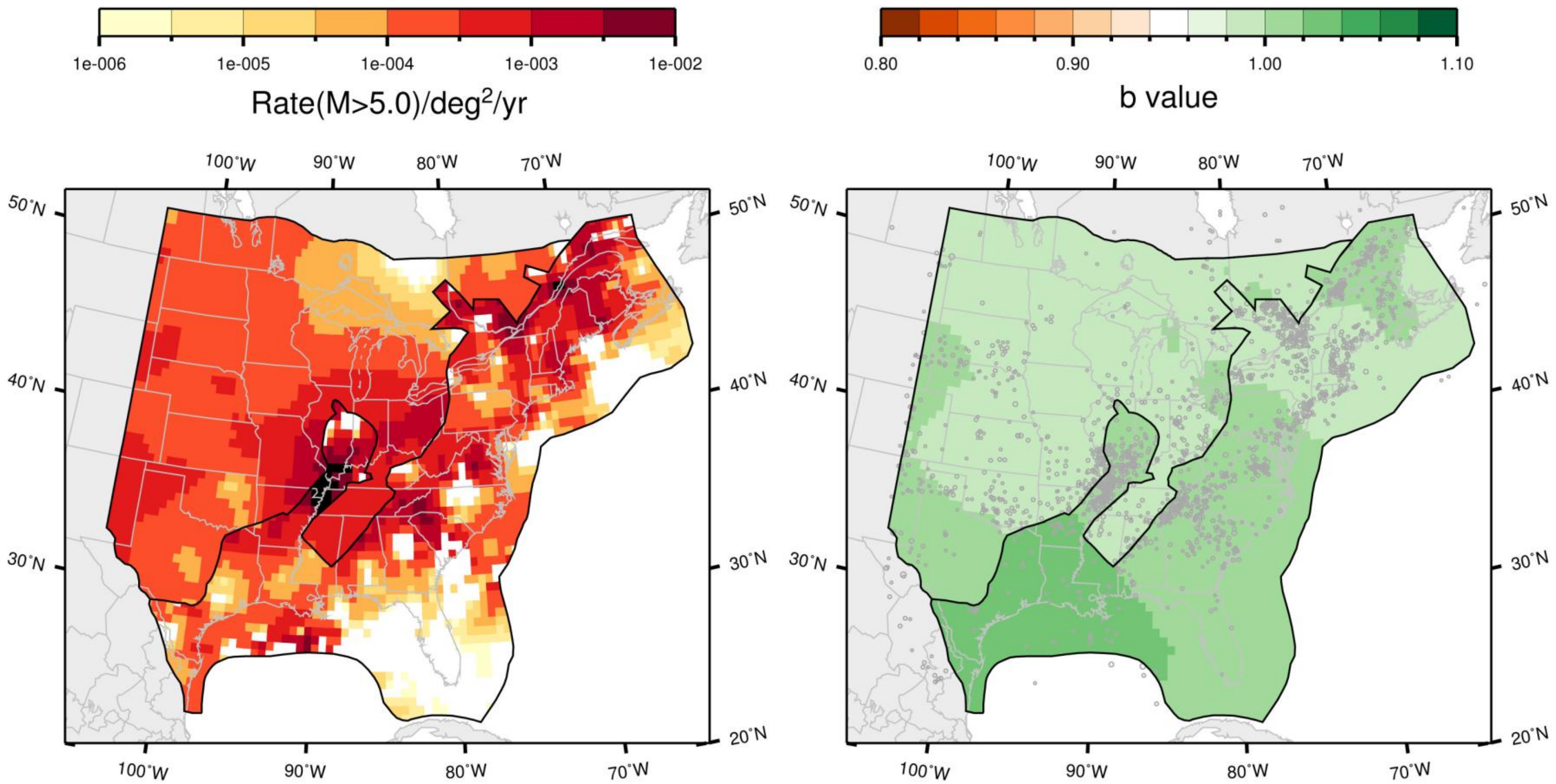


Figure J-75
Map of the rate and *b*-value for the study region under the Mmax zonation, with separation of Mesozoic extended and non-extended; Case E magnitude weights: Realization 3

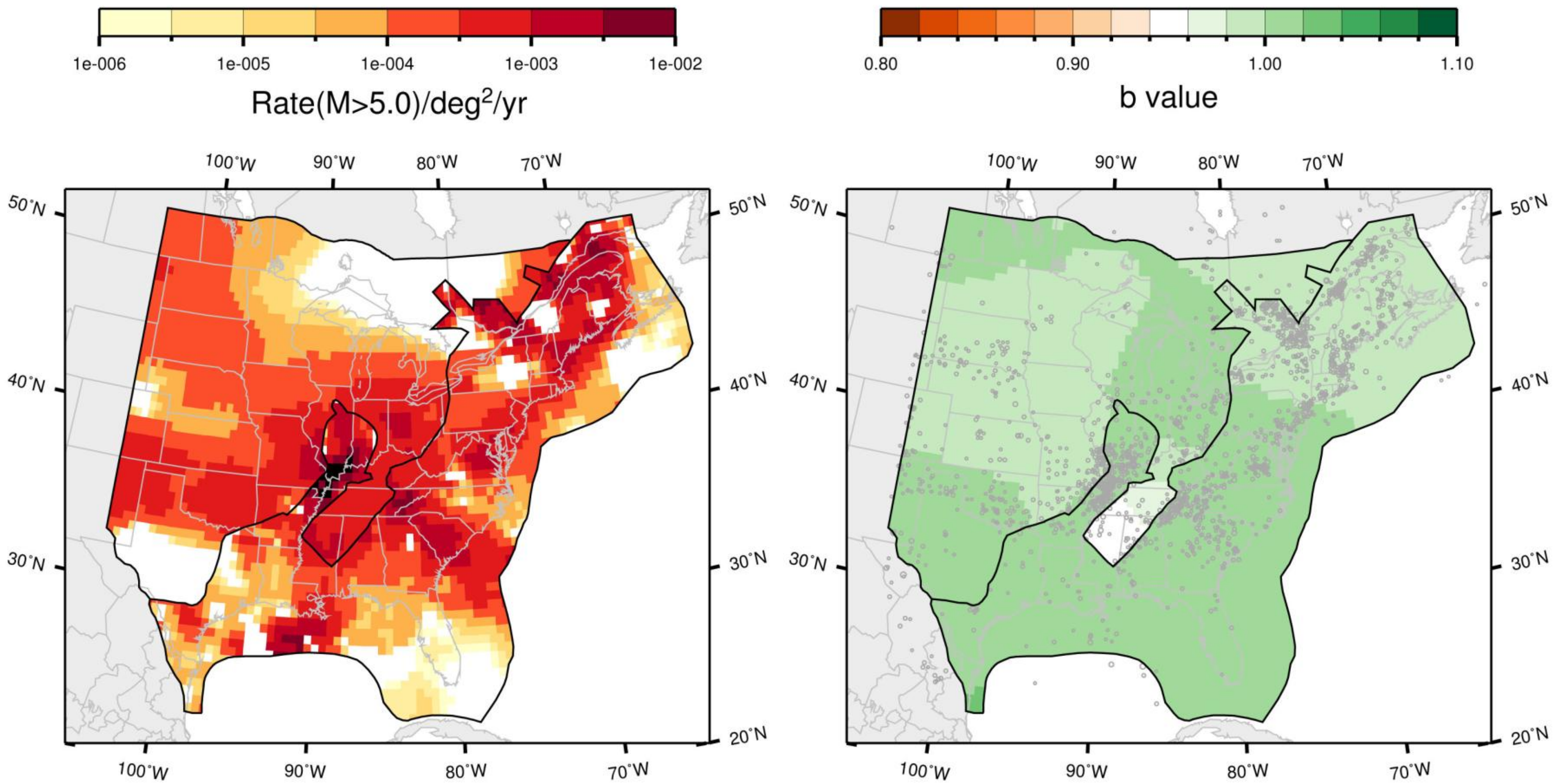


Figure J-76
Map of the rate and *b*-value for the study region under the Mmax zonation, with separation of Mesozoic extended and non-extended; Case E magnitude weights: Realization 4

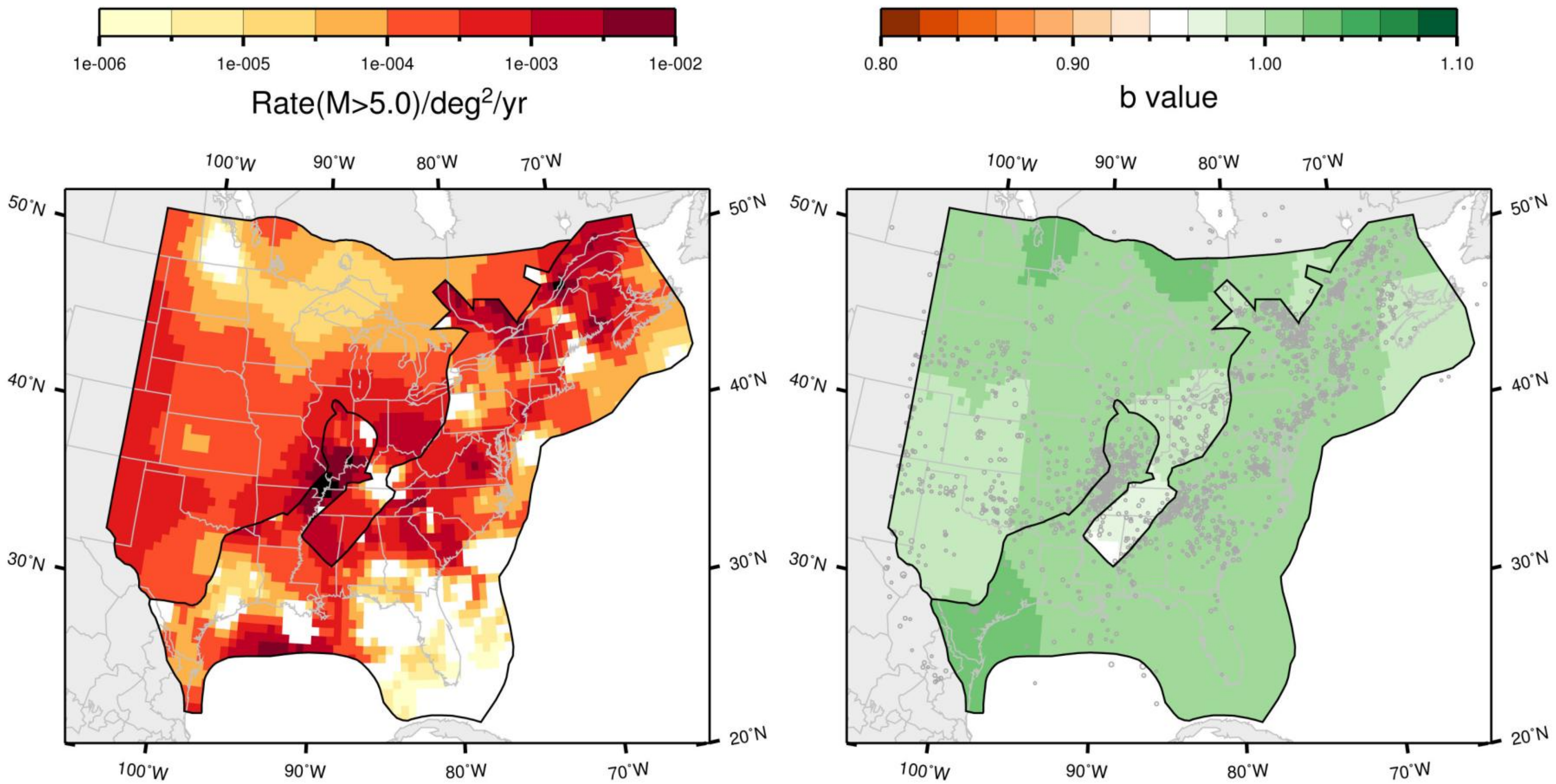


Figure J-77
Map of the rate and *b*-value for the study region under the Mmax zonation, with separation of Mesozoic extended and non-extended; Case E magnitude weights: Realization 5

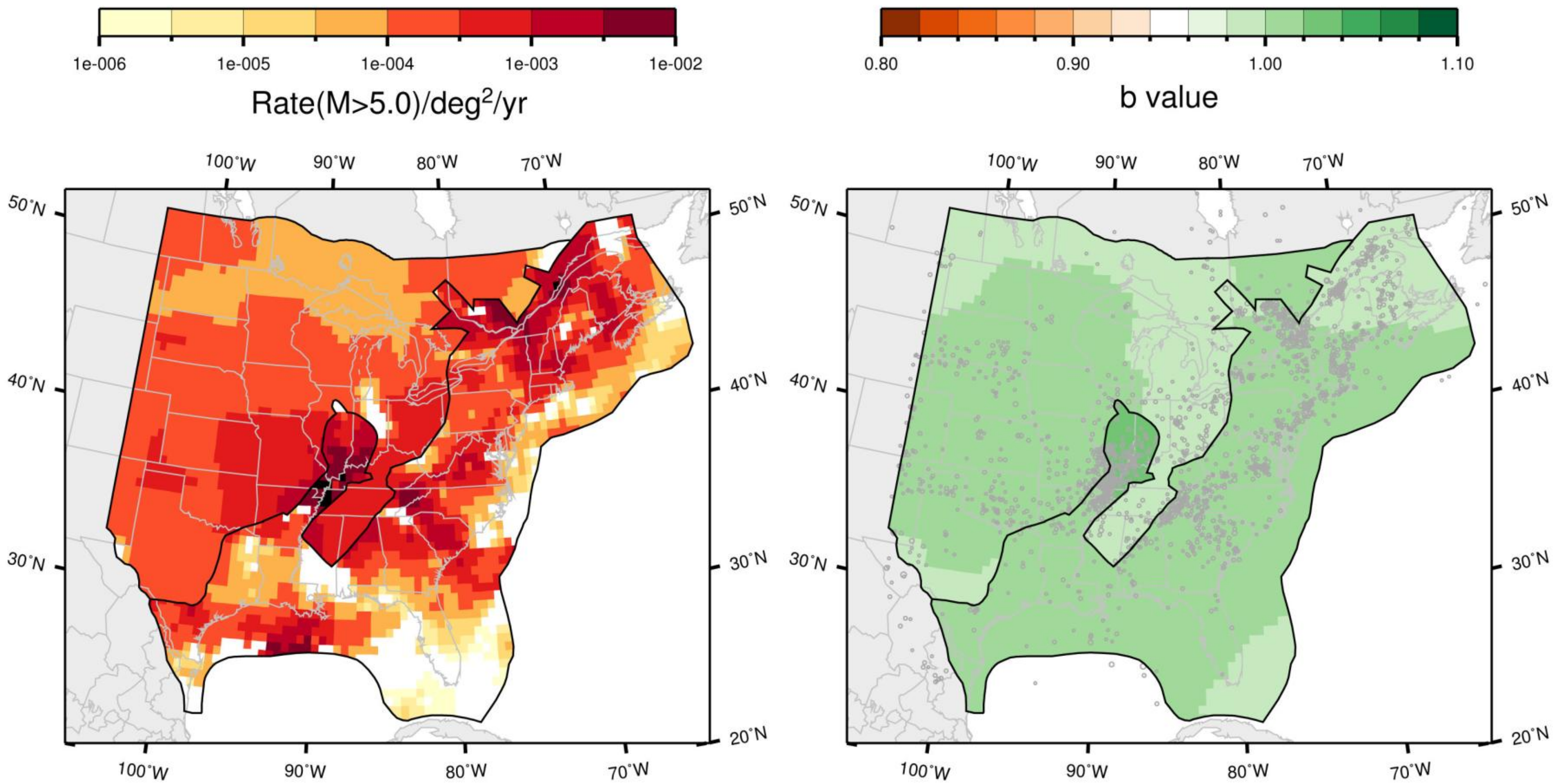


Figure J-78
Map of the rate and *b*-value for the study region under the Mmax zonation, with separation of Mesozoic extended and non-extended; Case E magnitude weights: Realization 6

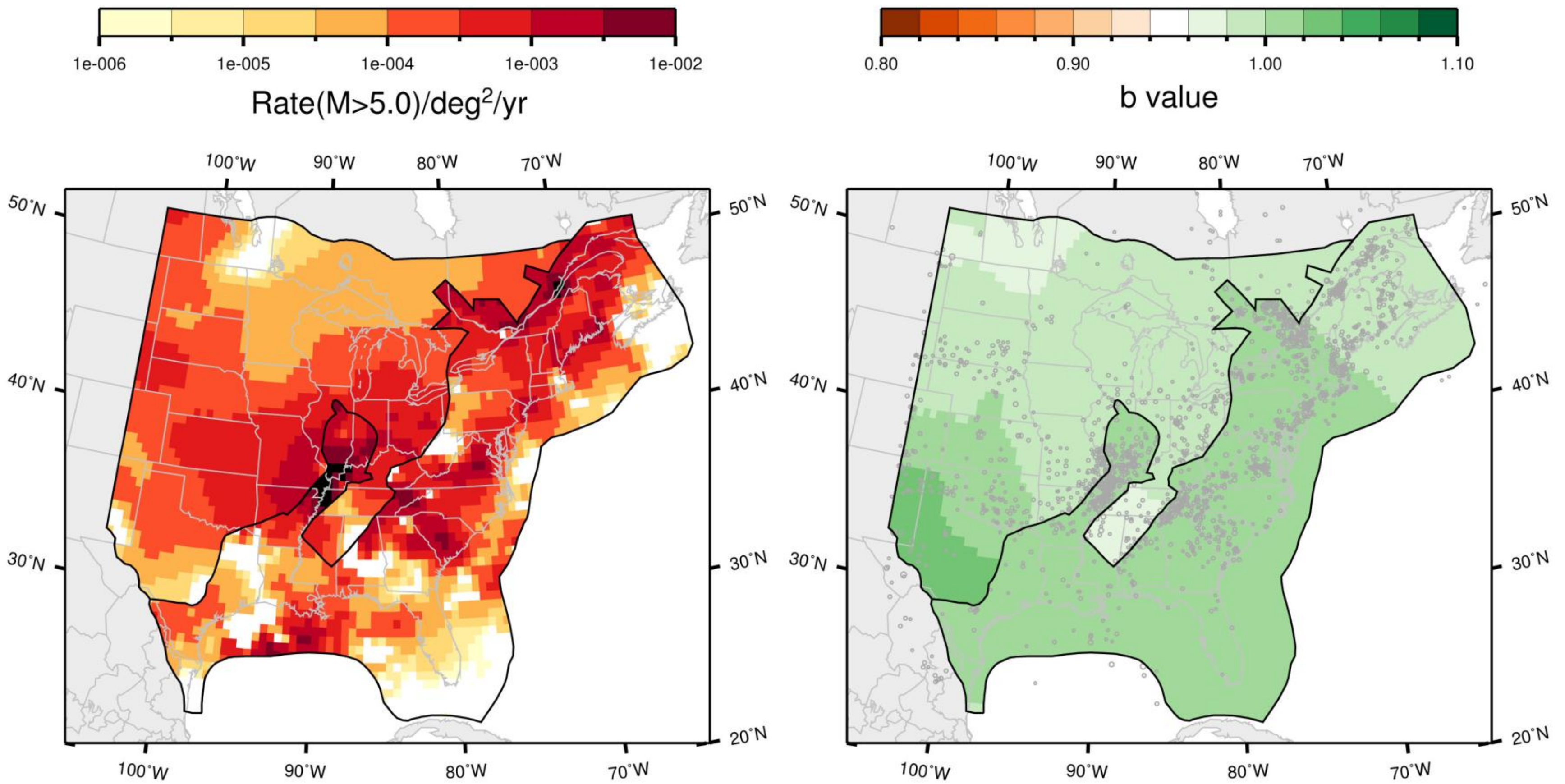


Figure J-79
Map of the rate and *b*-value for the study region under the Mmax zonation, with separation of Mesozoic extended and non-extended; Case E magnitude weights: Realization 7

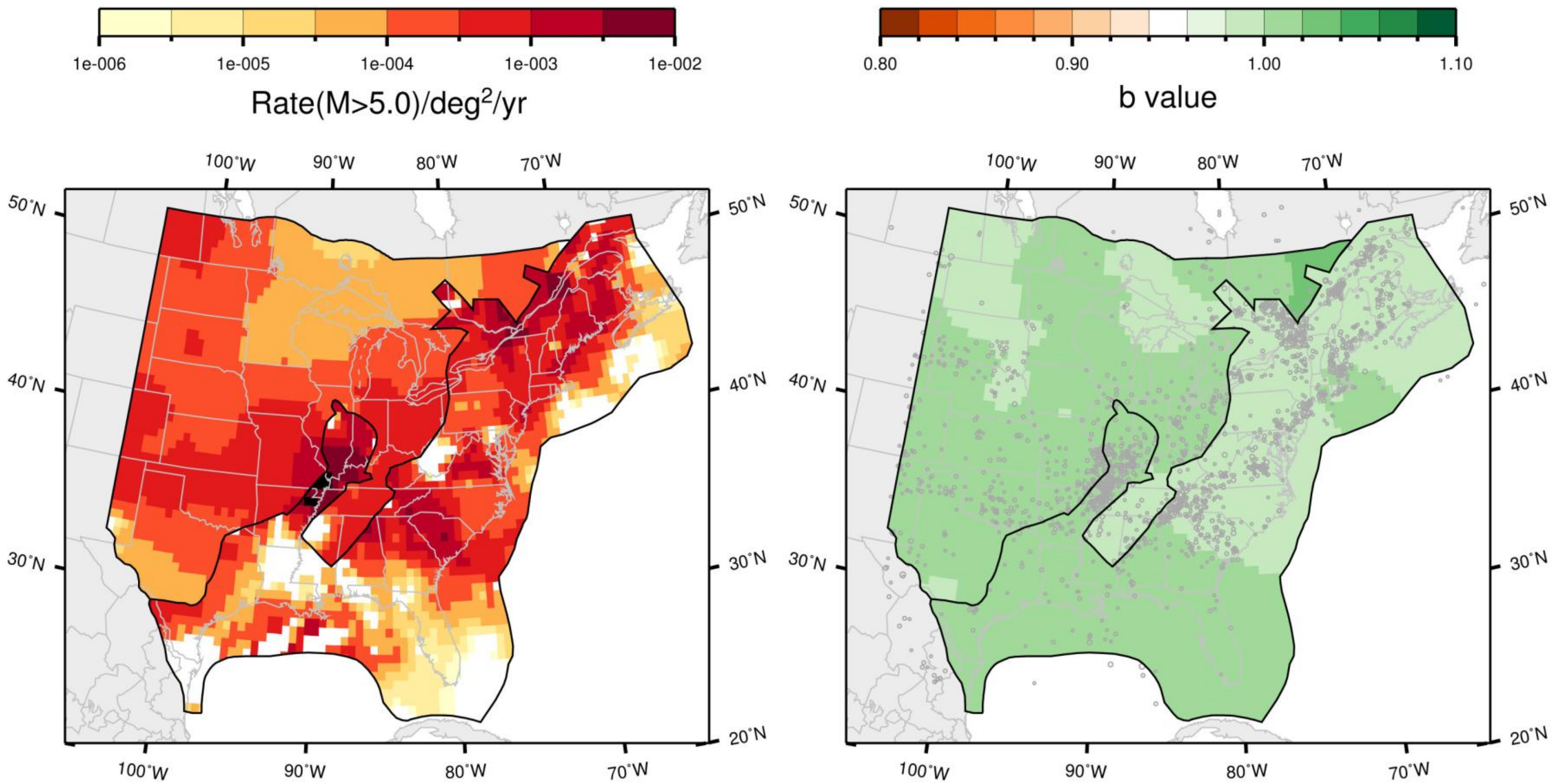


Figure J-80
Map of the rate and *b*-value for the study region under the Mmax zonation, with separation of Mesozoic extended and non-extended; Case E magnitude weights: Realization 8

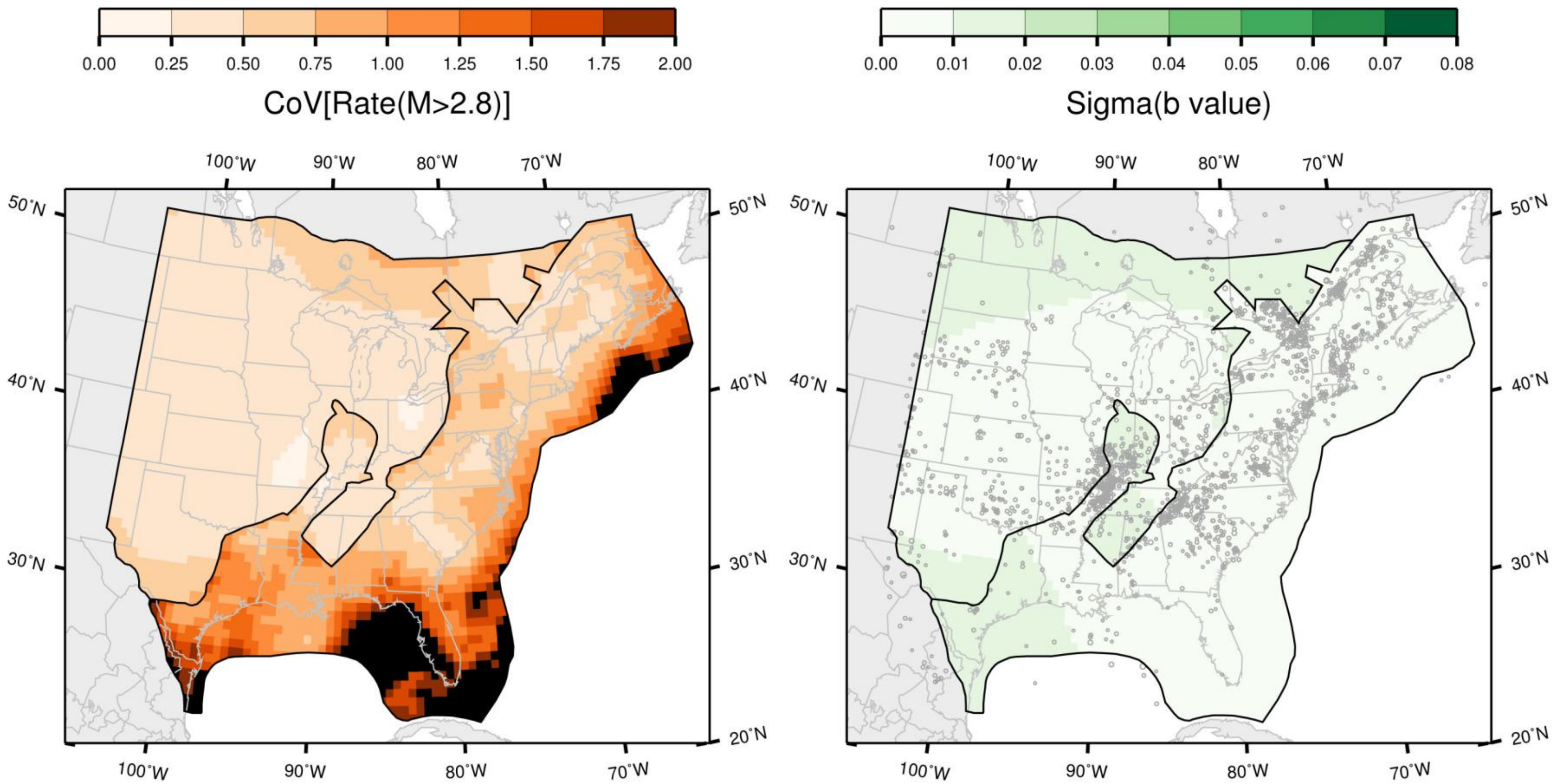


Figure J-81
Map of the coefficient of variation of the rate and the standard deviation of the *b*-value for the study region under the Mmax zonation, with separation of Mesozoic extended and non-extended; Case E magnitude weights

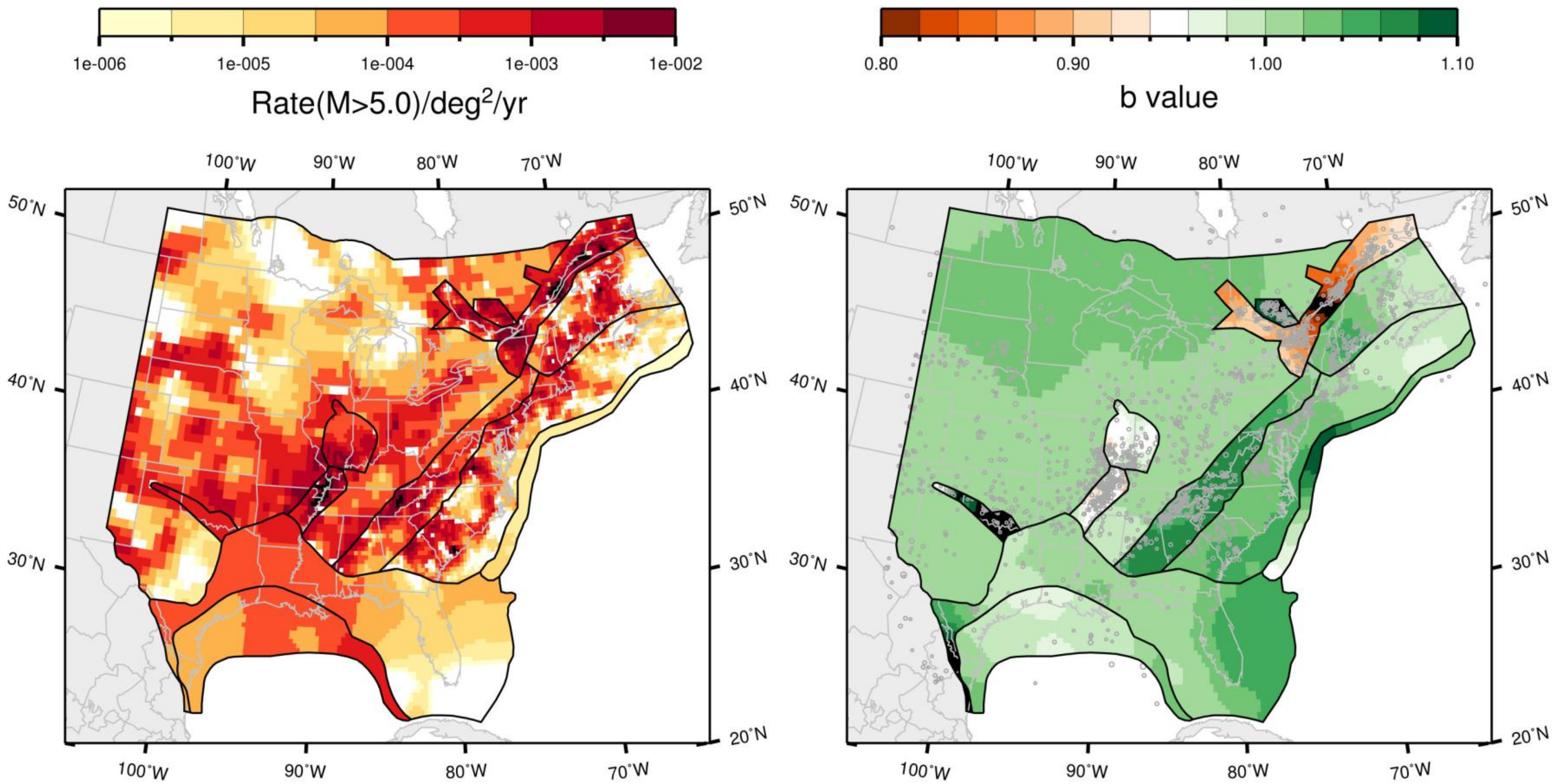


Figure J-82
Map of the rate and *b*-value for the study region under the seismotectonic zonation, with narrow interpretation of PEZ; Case A magnitude weights: Realization 1

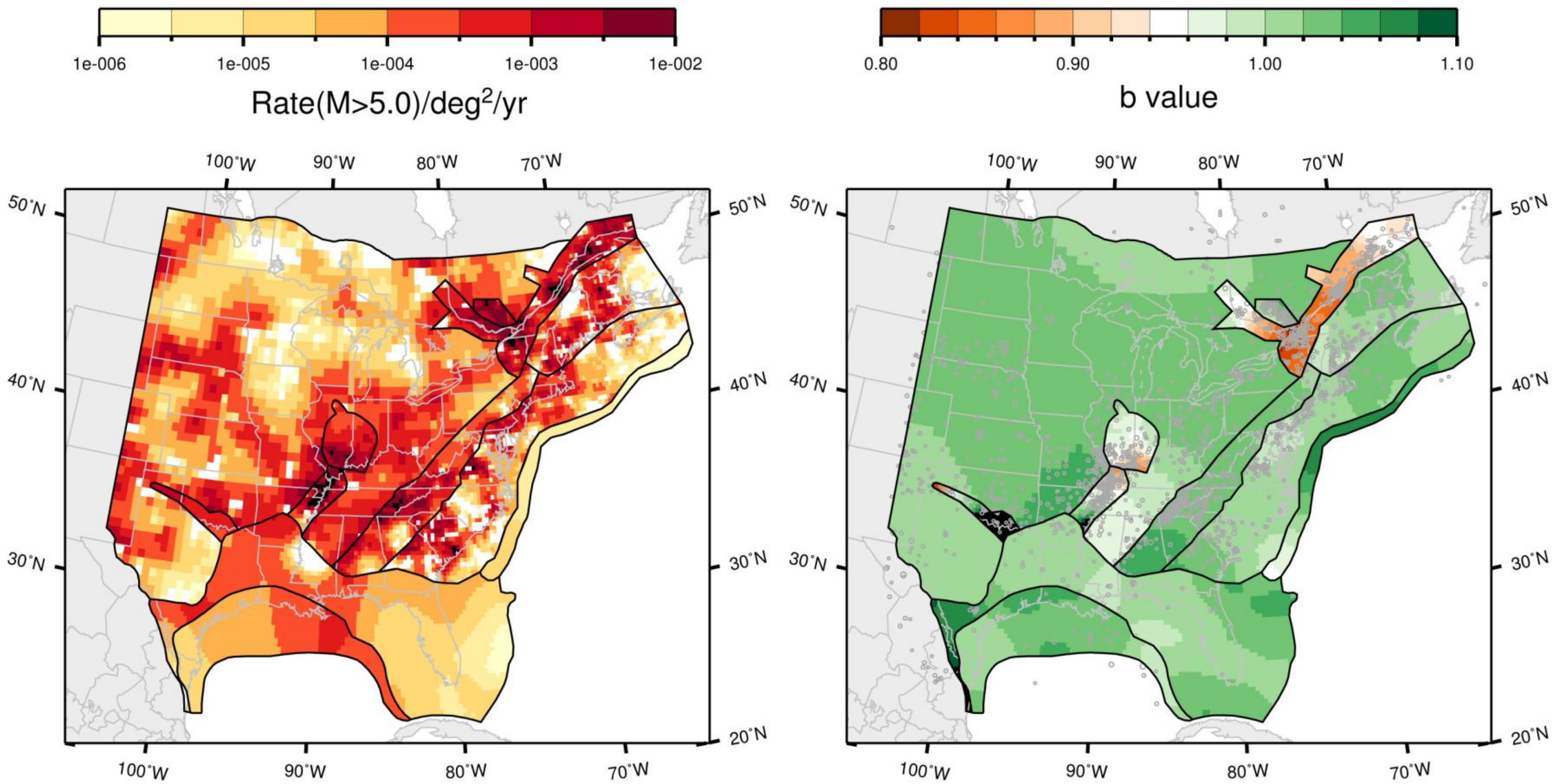


Figure J-83
Map of the rate and *b*-value for the study region under the seismotectonic zonation, with narrow interpretation of PEZ; Case A magnitude weights: Realization 2

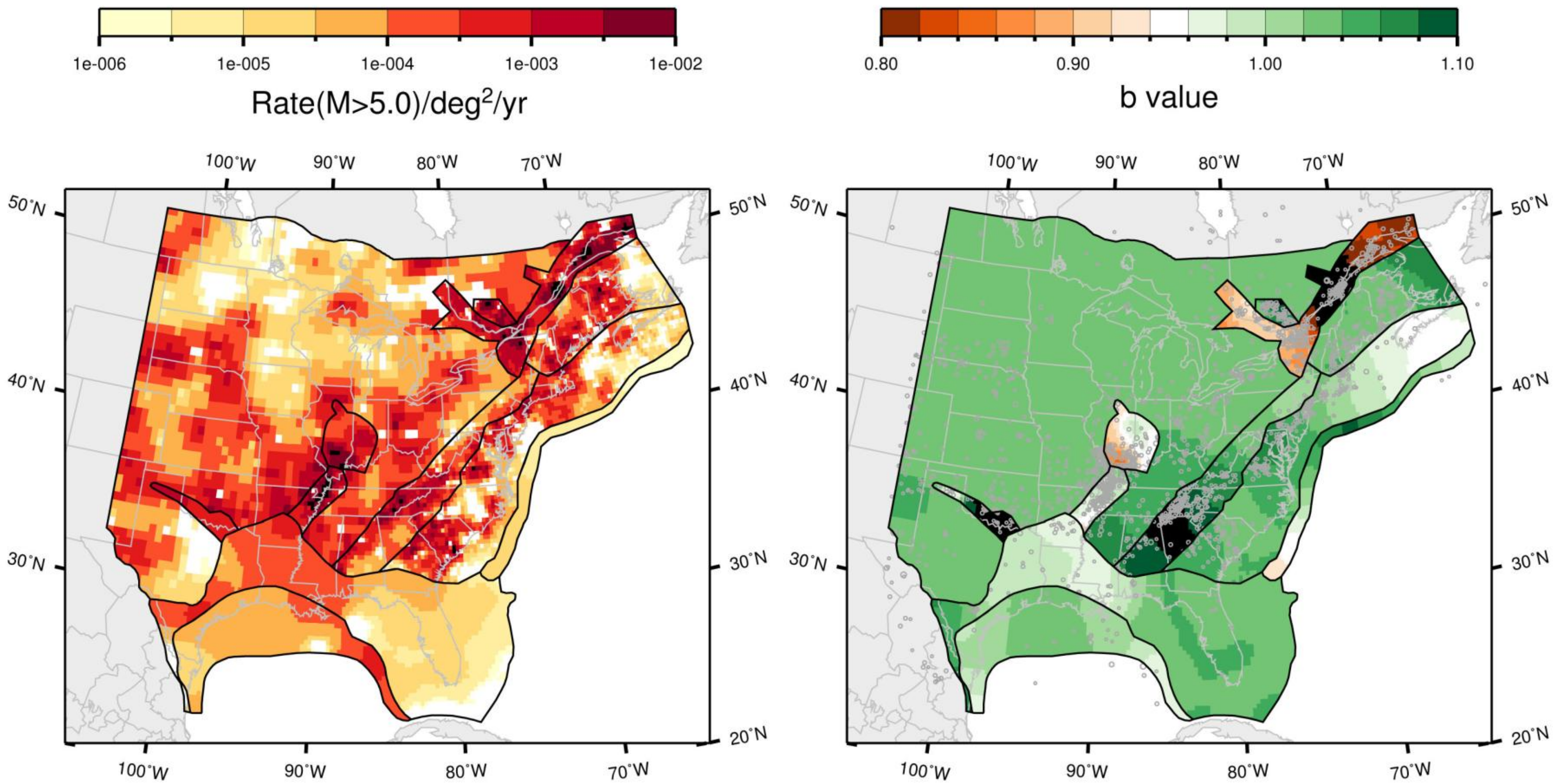


Figure J-84
Map of the rate and *b*-value for the study region under the seismotectonic zonation, with narrow interpretation of PEZ; Case A magnitude weights: Realization 3

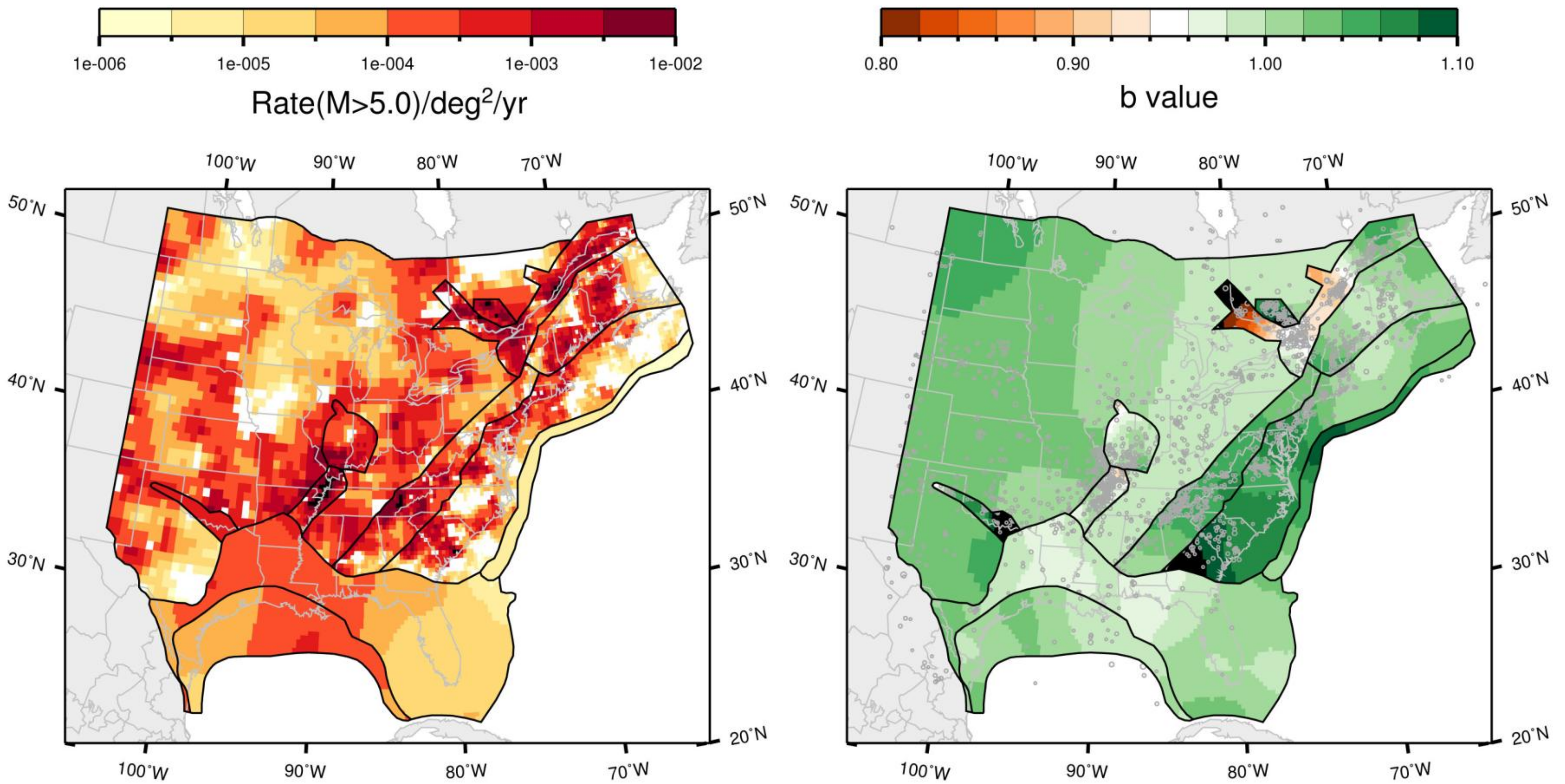


Figure J-85
Map of the rate and *b*-value for the study region under the seismotectonic zonation, with narrow interpretation of PEZ; Case A magnitude weights: Realization 4

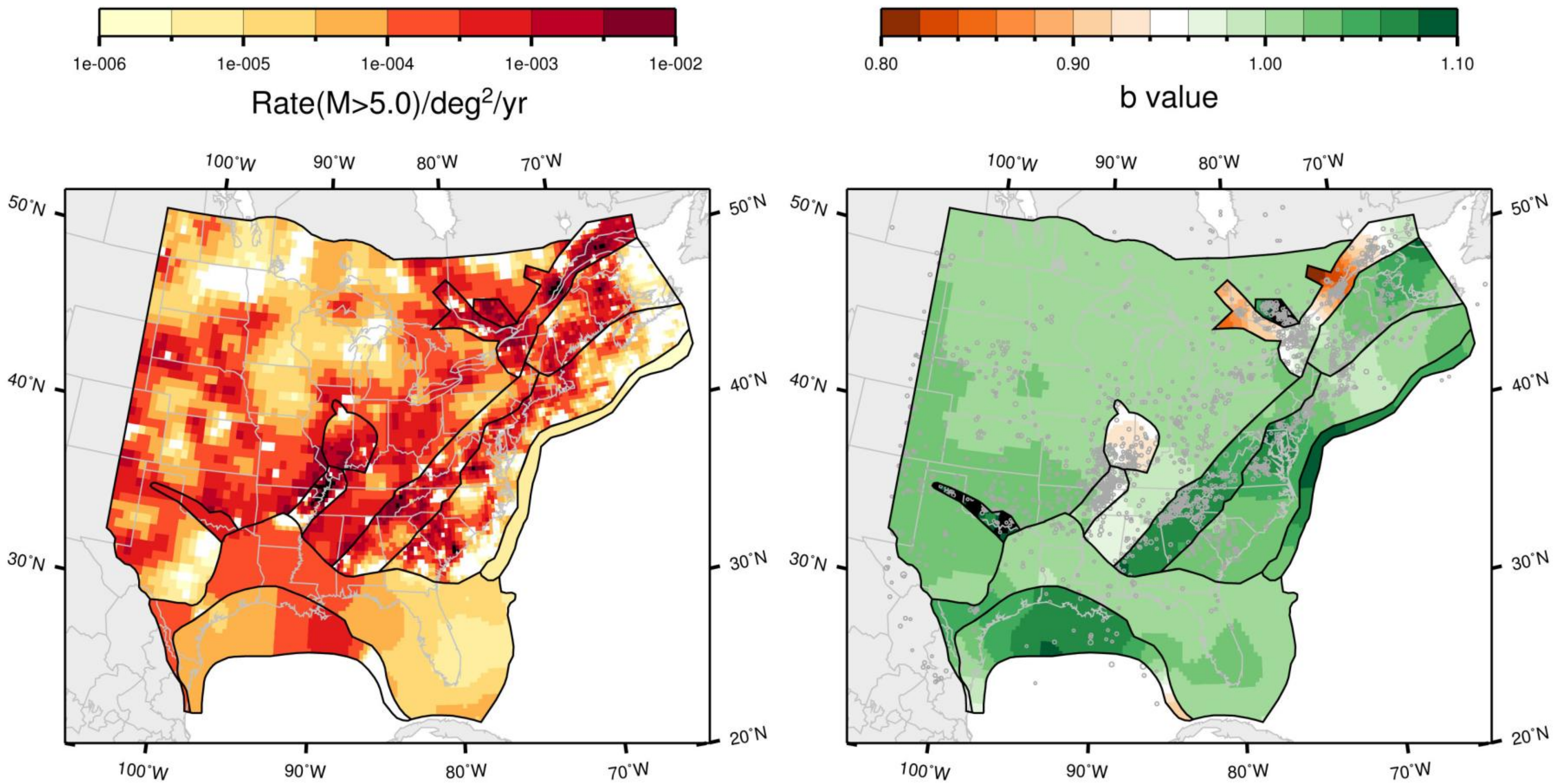


Figure J-86
Map of the rate and *b*-value for the study region under the seismotectonic zonation, with narrow interpretation of PEZ; Case A magnitude weights: Realization 5

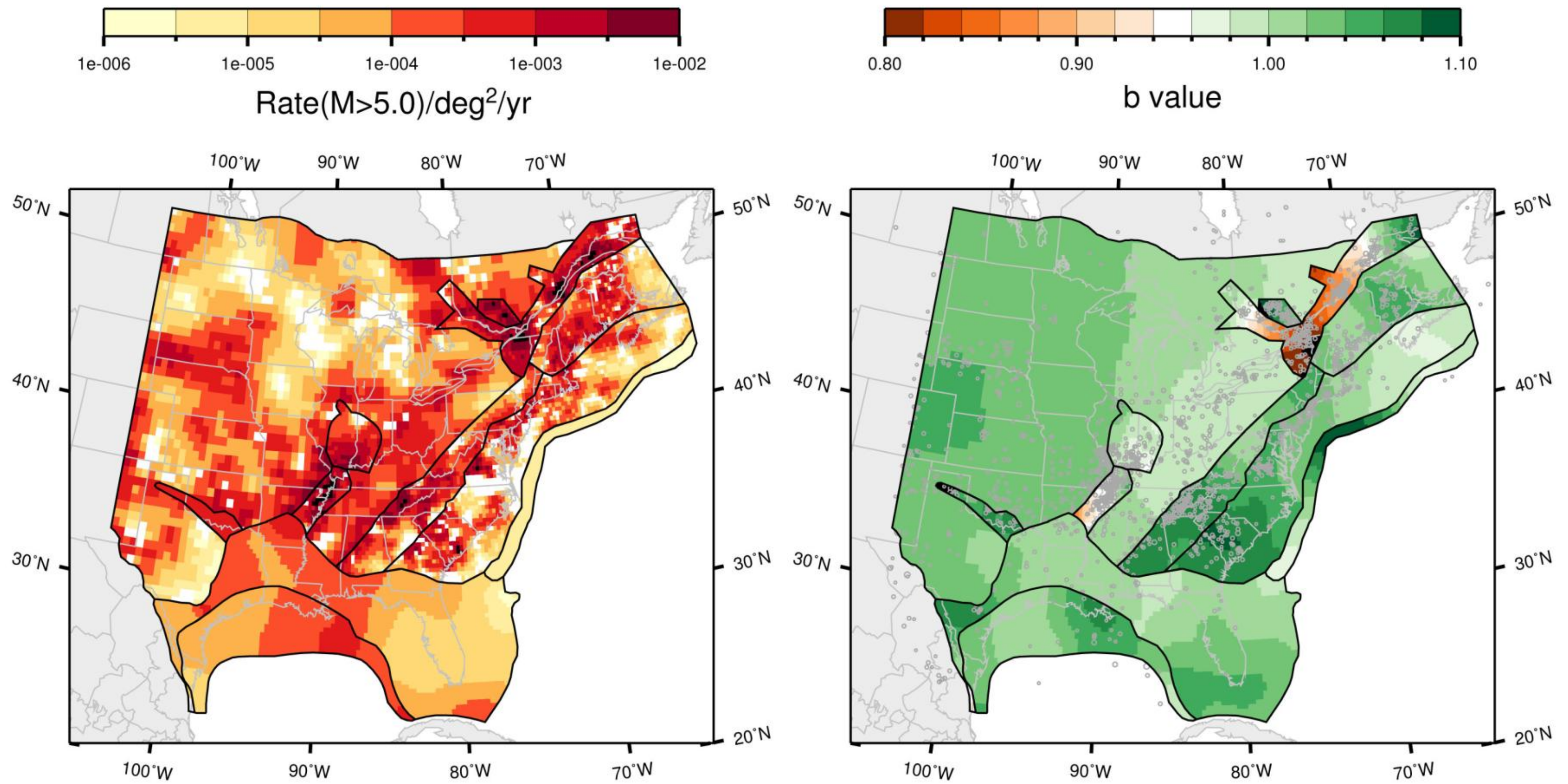


Figure J-87
Map of the rate and *b*-value for the study region under the seismotectonic zonation, with narrow interpretation of PEZ; Case A magnitude weights: Realization 6

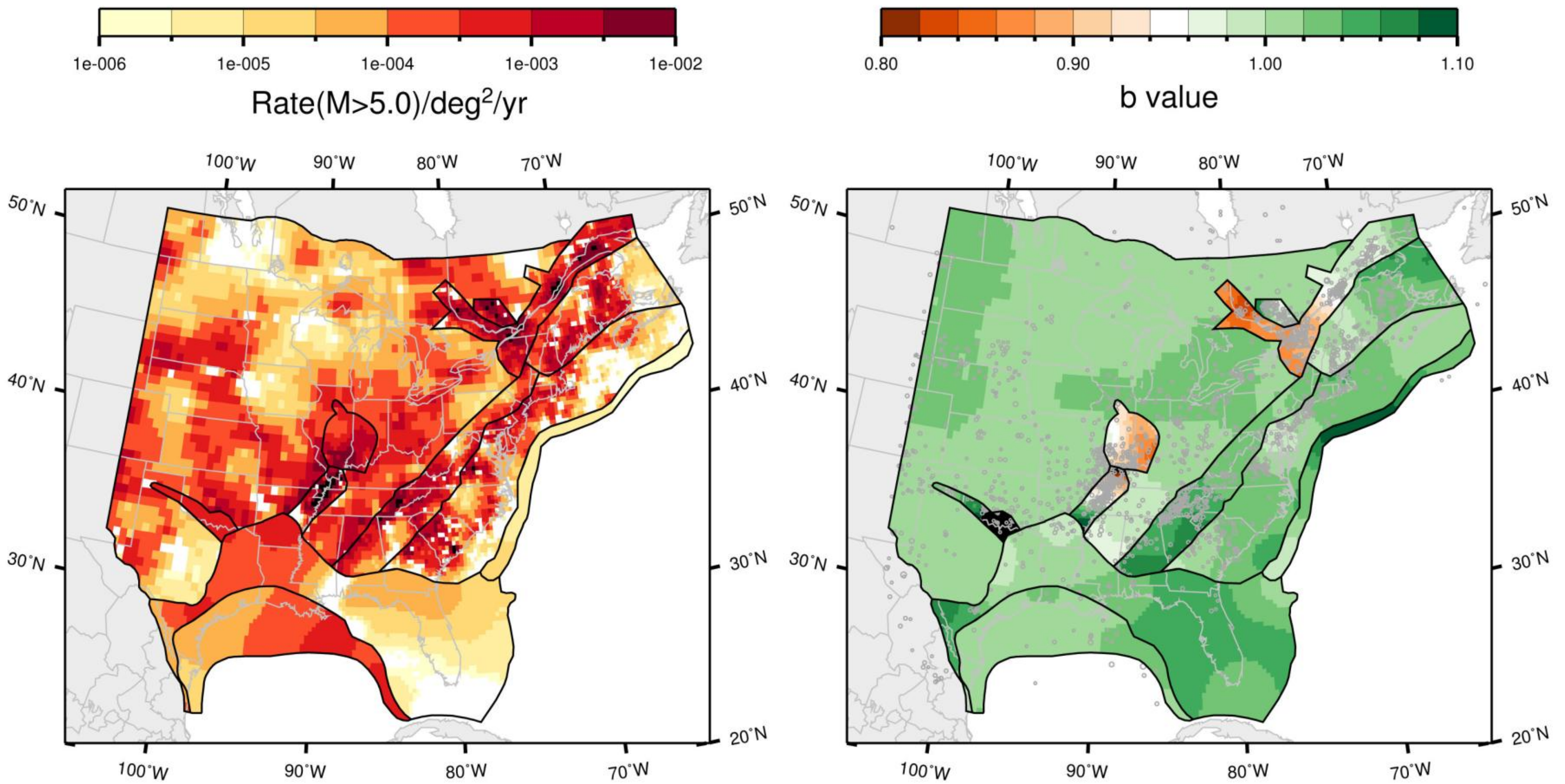


Figure J-88
Map of the rate and *b*-value for the study region under the seismotectonic zonation, with narrow interpretation of PEZ; Case A magnitude weights: Realization 7

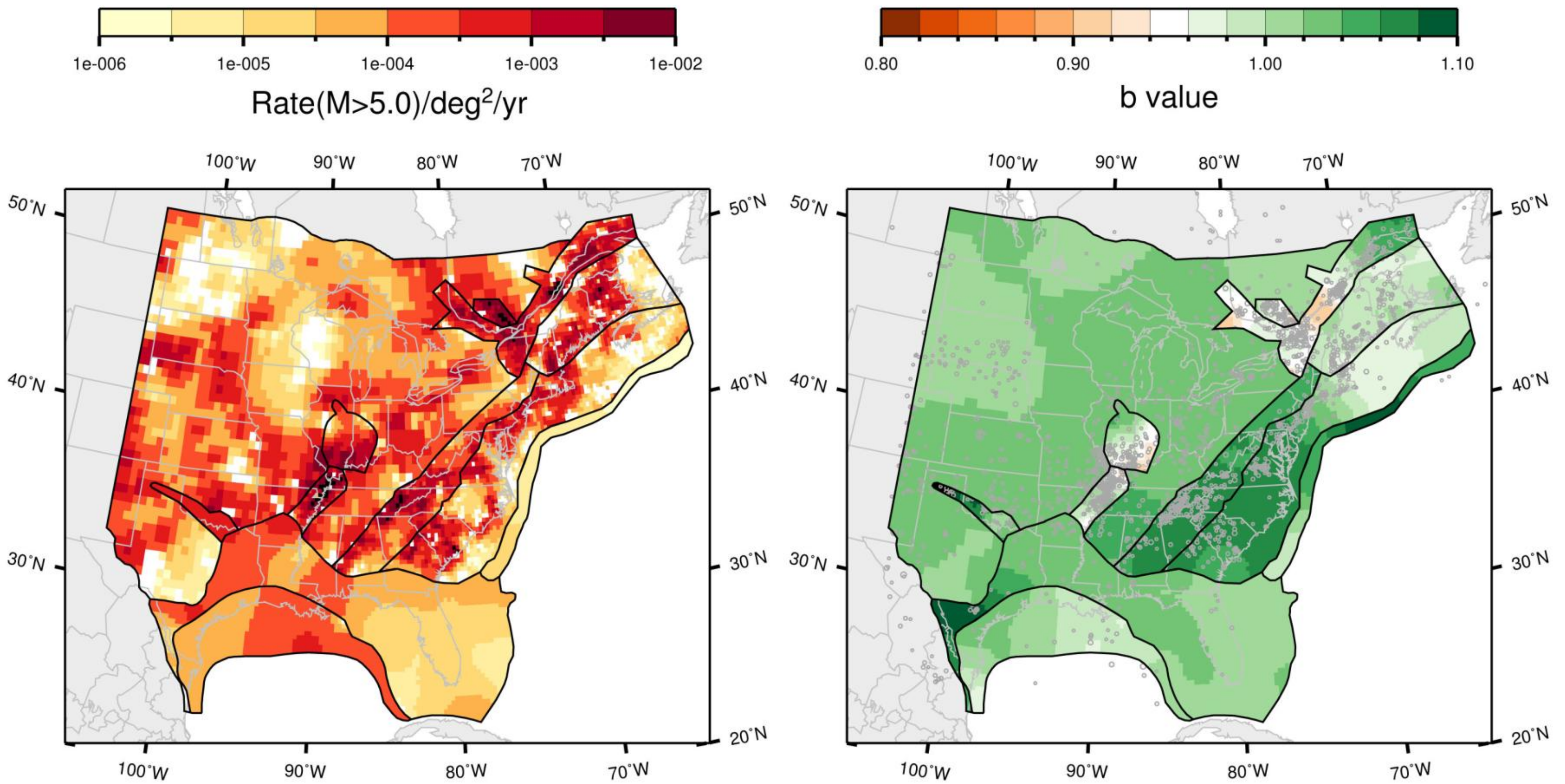


Figure J-89
Map of the rate and *b*-value for the study region under the seismotectonic zonation, with narrow interpretation of PEZ; Case A magnitude weights: Realization 8

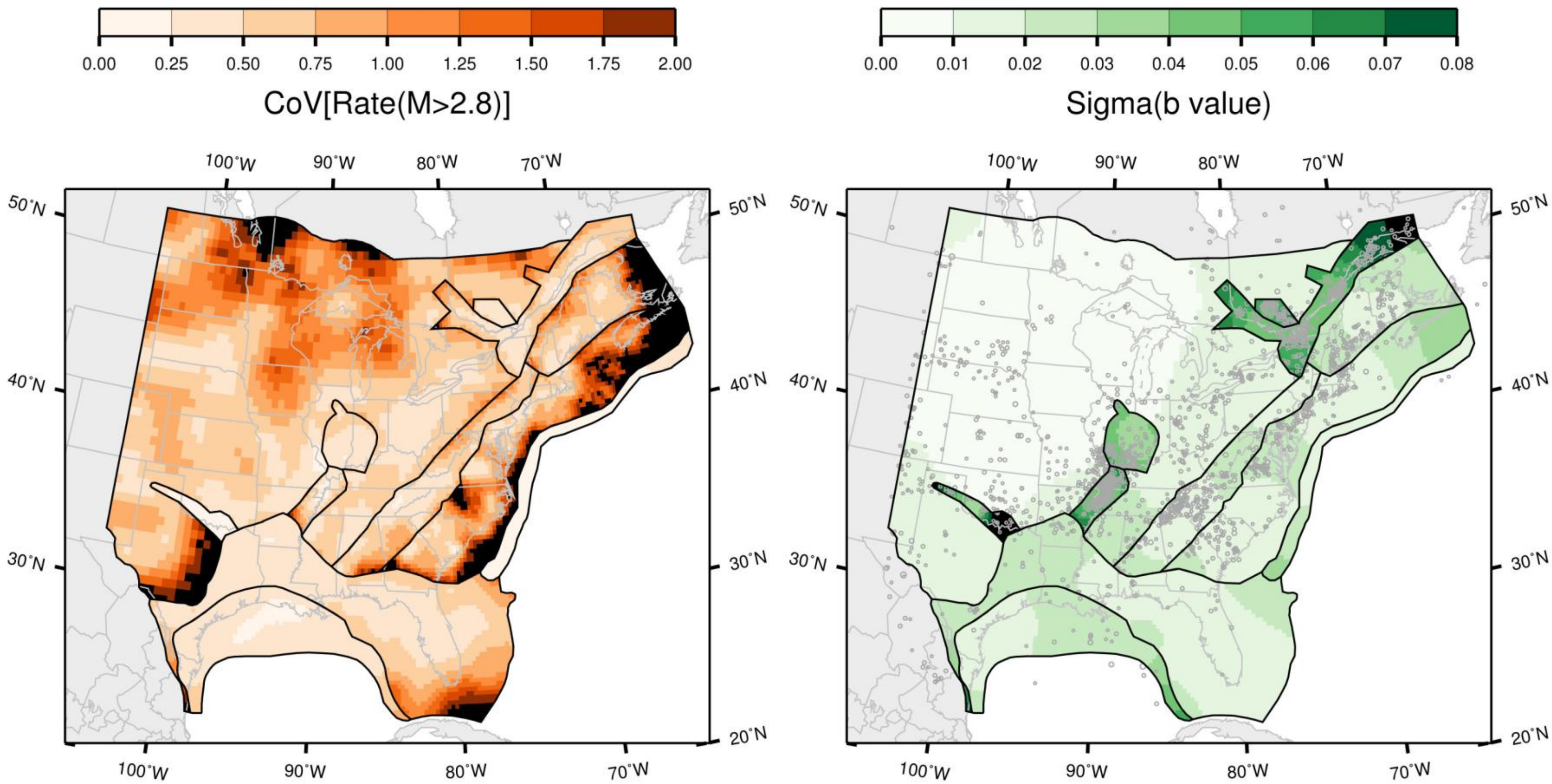


Figure J-90
Map of the coefficient of variation of the rate and the standard deviation of the *b*-value for the study region under the seismotectonic zonation, with narrow interpretation of PEZ; Case A magnitude weights

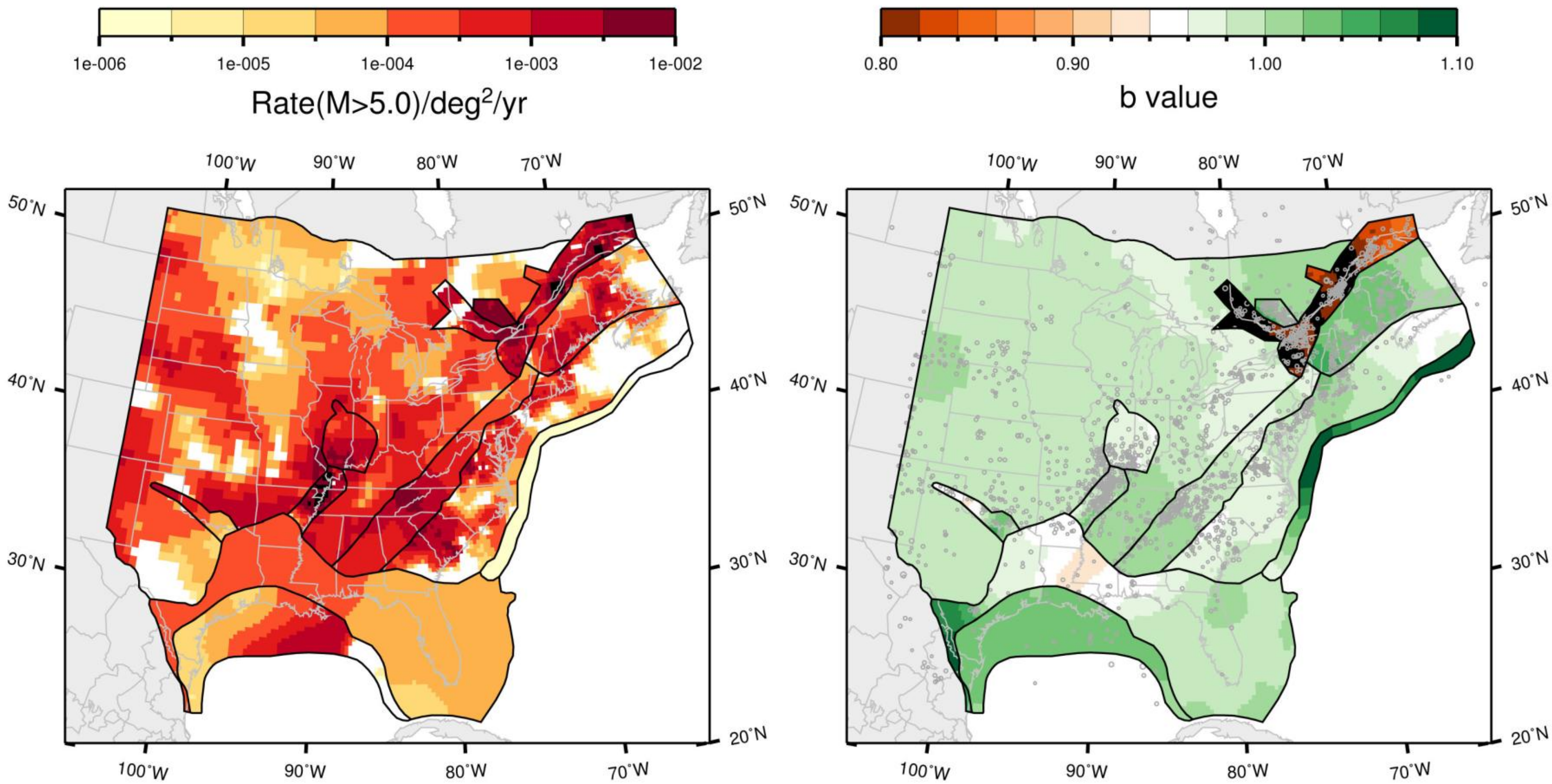


Figure J-91
Map of the rate and *b*-value for the study region under the seismotectonic zonation, with narrow interpretation of PEZ; Case B magnitude weights: Realization 1

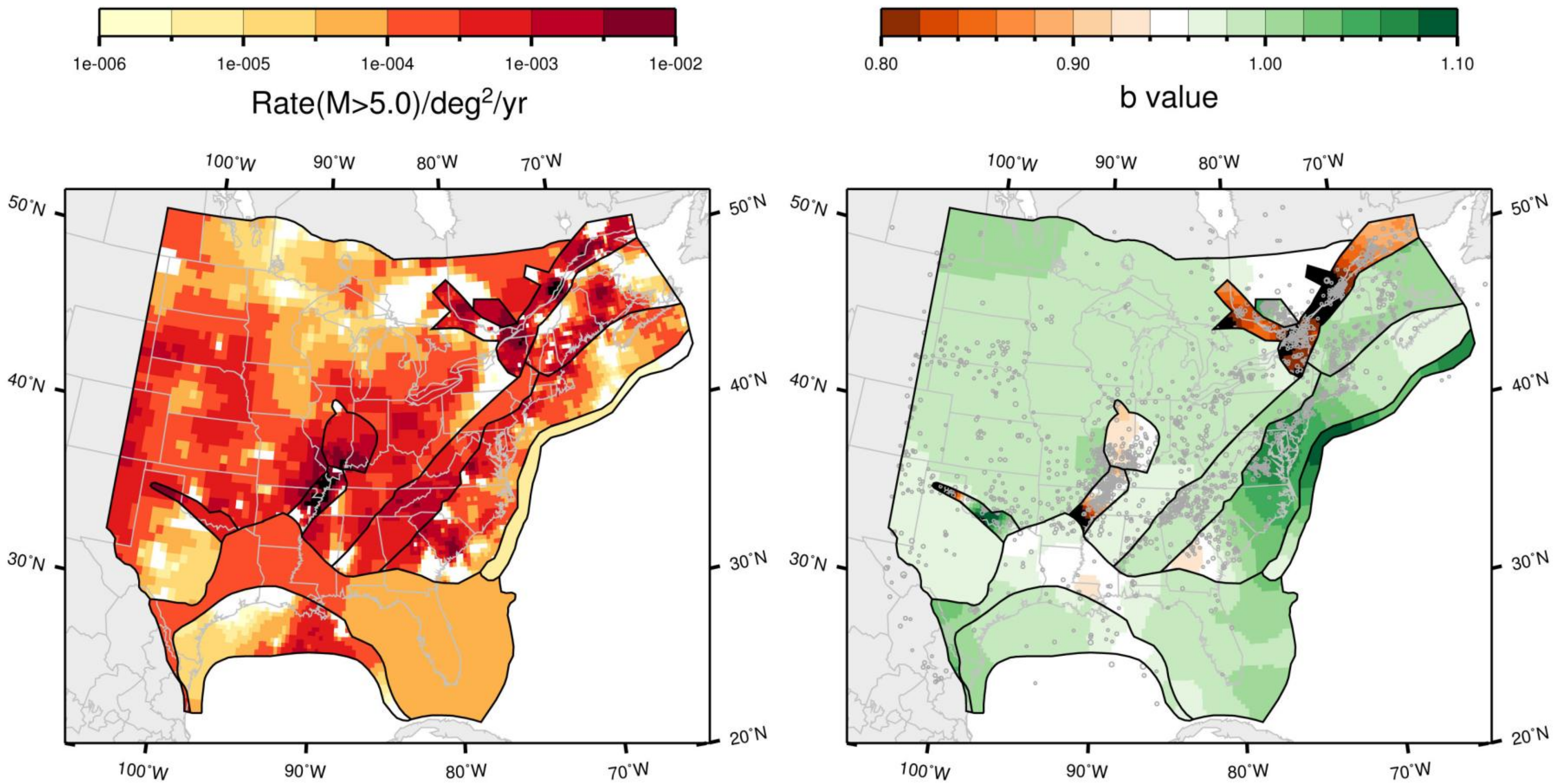


Figure J-92
Map of the rate and *b*-value for the study region under the seismotectonic zonation, with narrow interpretation of PEZ; Case B magnitude weights: Realization 2

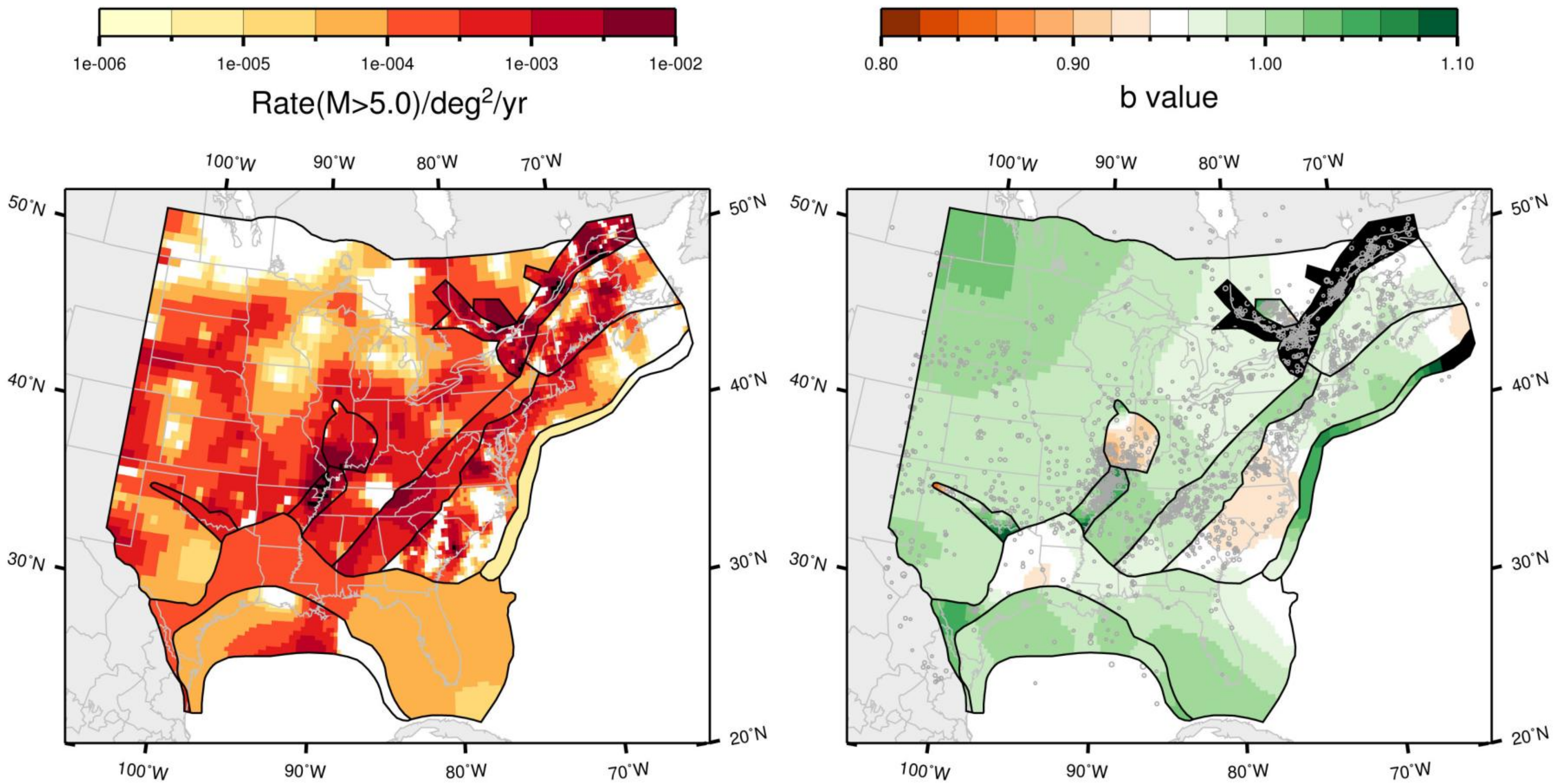


Figure J-93
Map of the rate and *b*-value for the study region under the seismotectonic zonation, with narrow interpretation of PEZ; Case B magnitude weights: Realization 3

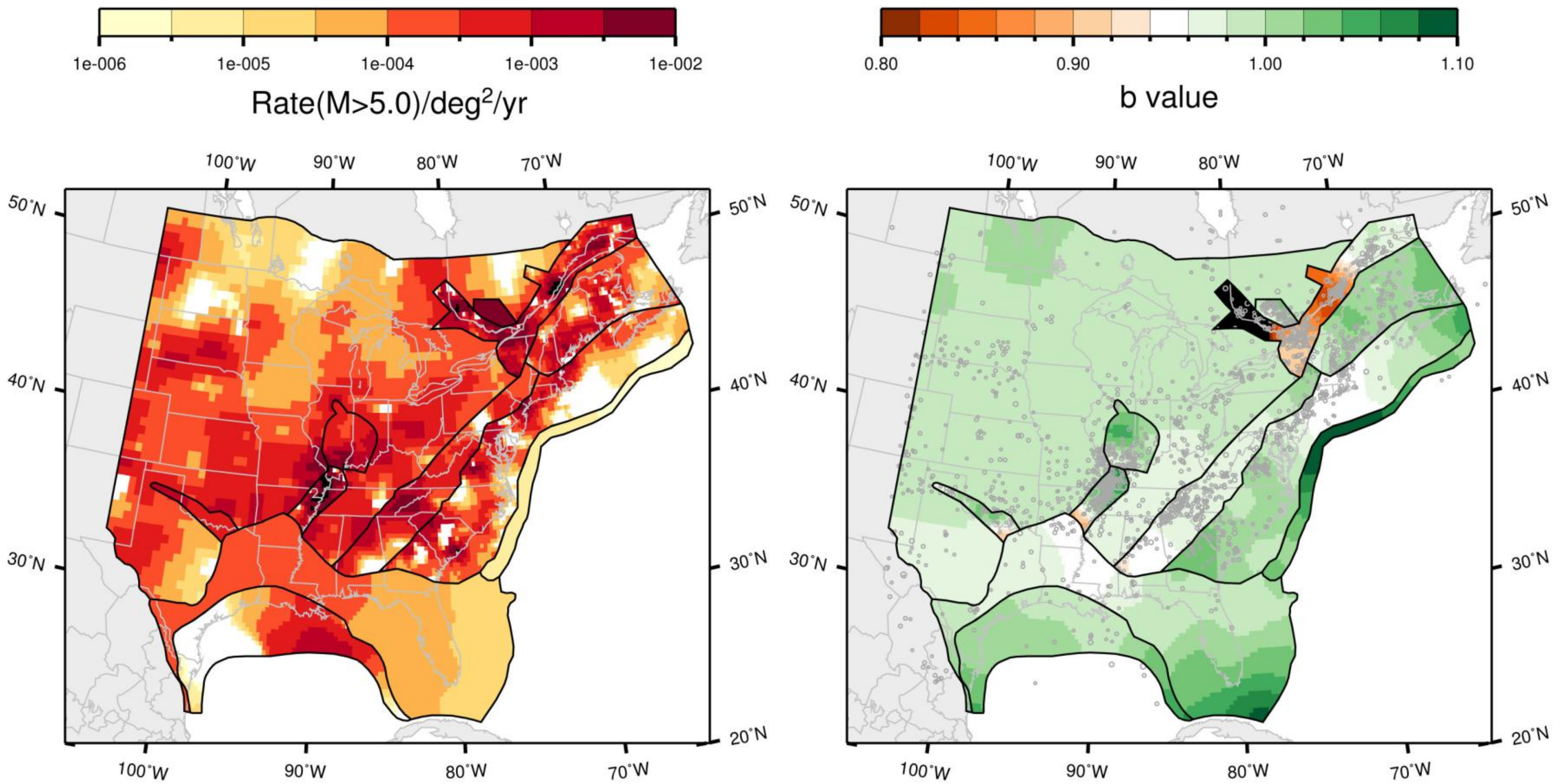
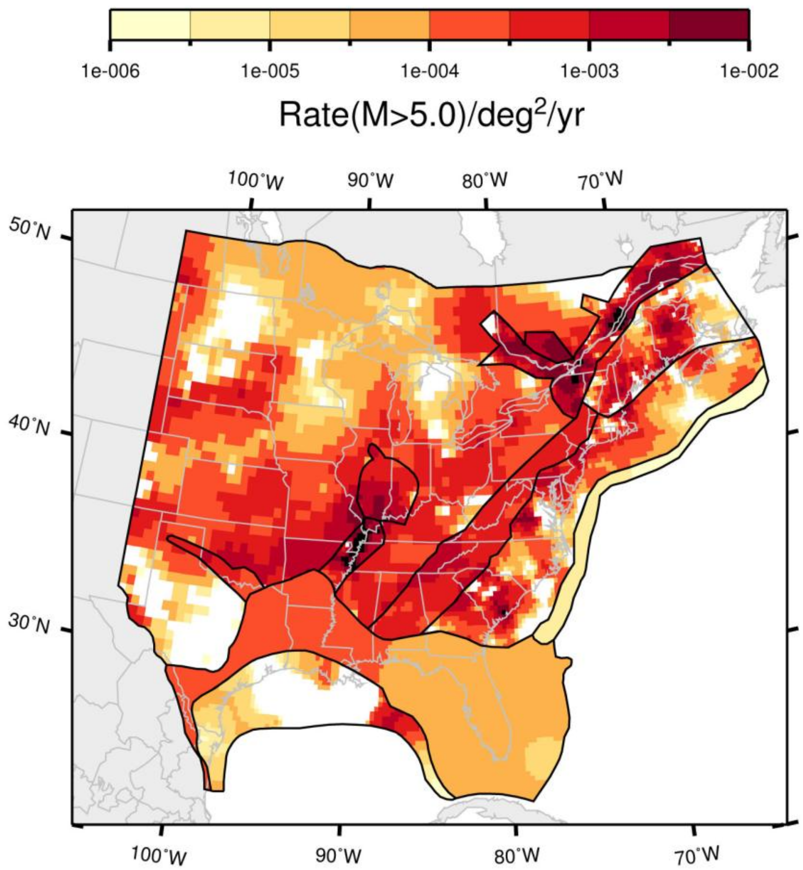


Figure J-94
Map of the rate and *b*-value for the study region under the seismotectonic zonation, with narrow interpretation of PEZ; Case B magnitude weights: Realization 4



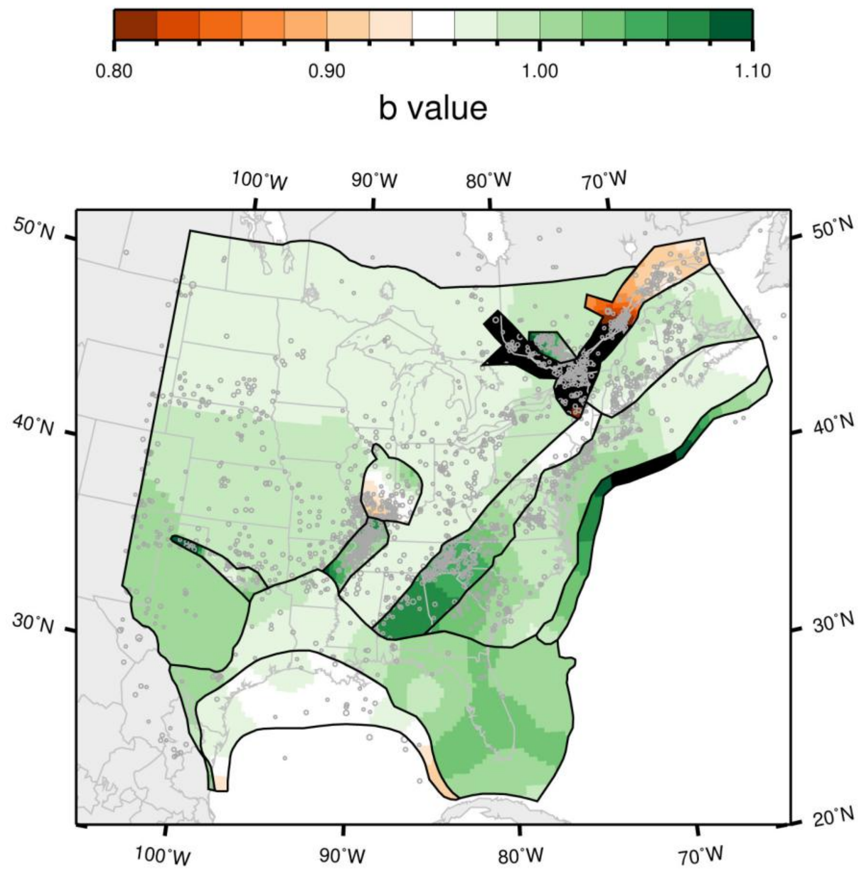


Figure J-95
Map of the rate and *b*-value for the study region under the seismotectonic zonation, with narrow interpretation of PEZ; Case B magnitude weights: Realization 5

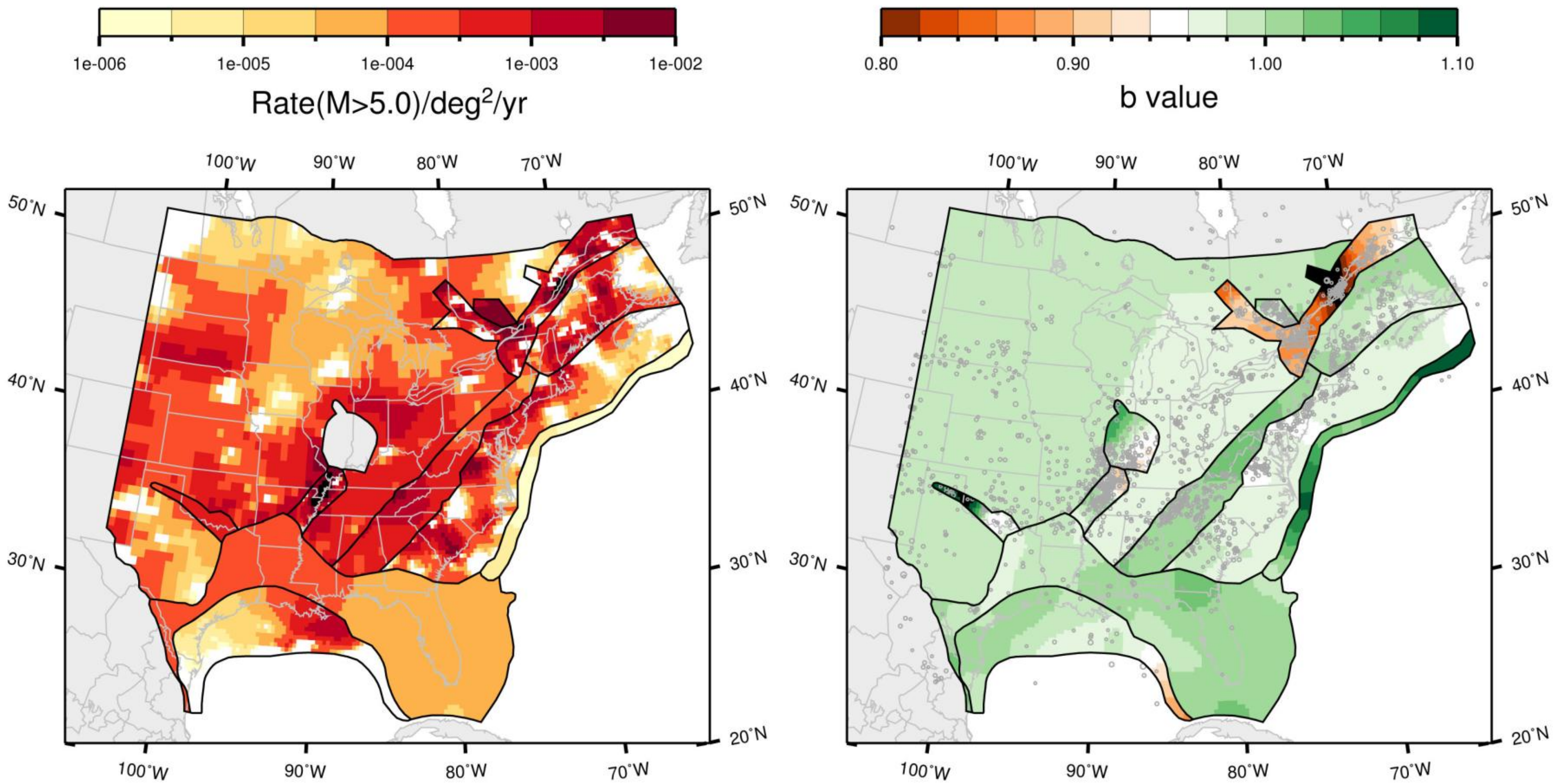


Figure J-96
Map of the rate and *b*-value for the study region under the seismotectonic zonation, with narrow interpretation of PEZ; Case B magnitude weights: Realization 6

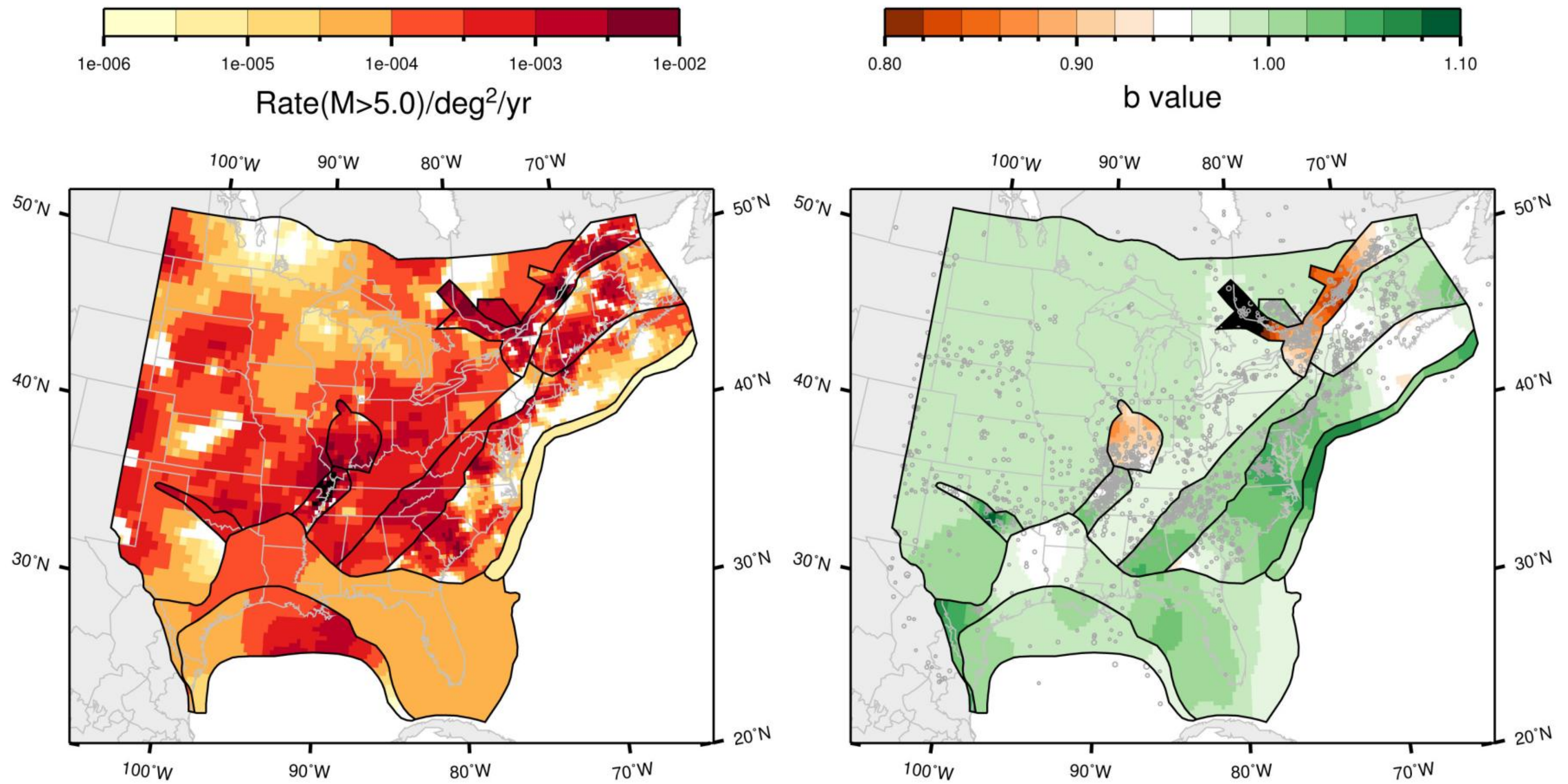


Figure J-97
Map of the rate and *b*-value for the study region under the seismotectonic zonation, with narrow interpretation of PEZ; Case B magnitude weights: Realization 7

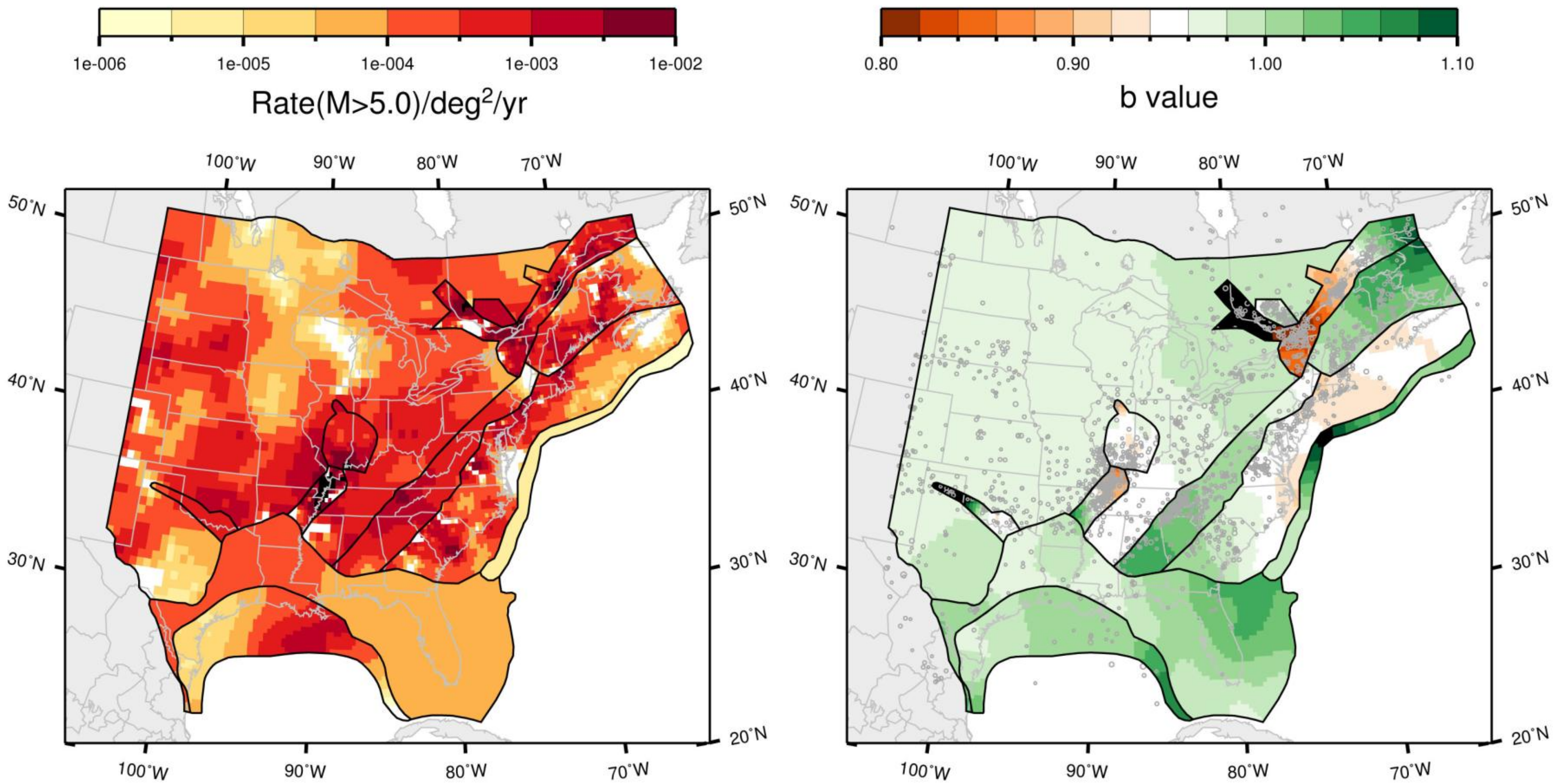


Figure J-98
Map of the rate and *b*-value for the study region under the seismotectonic zonation, with narrow interpretation of PEZ; Case B magnitude weights: Realization 8

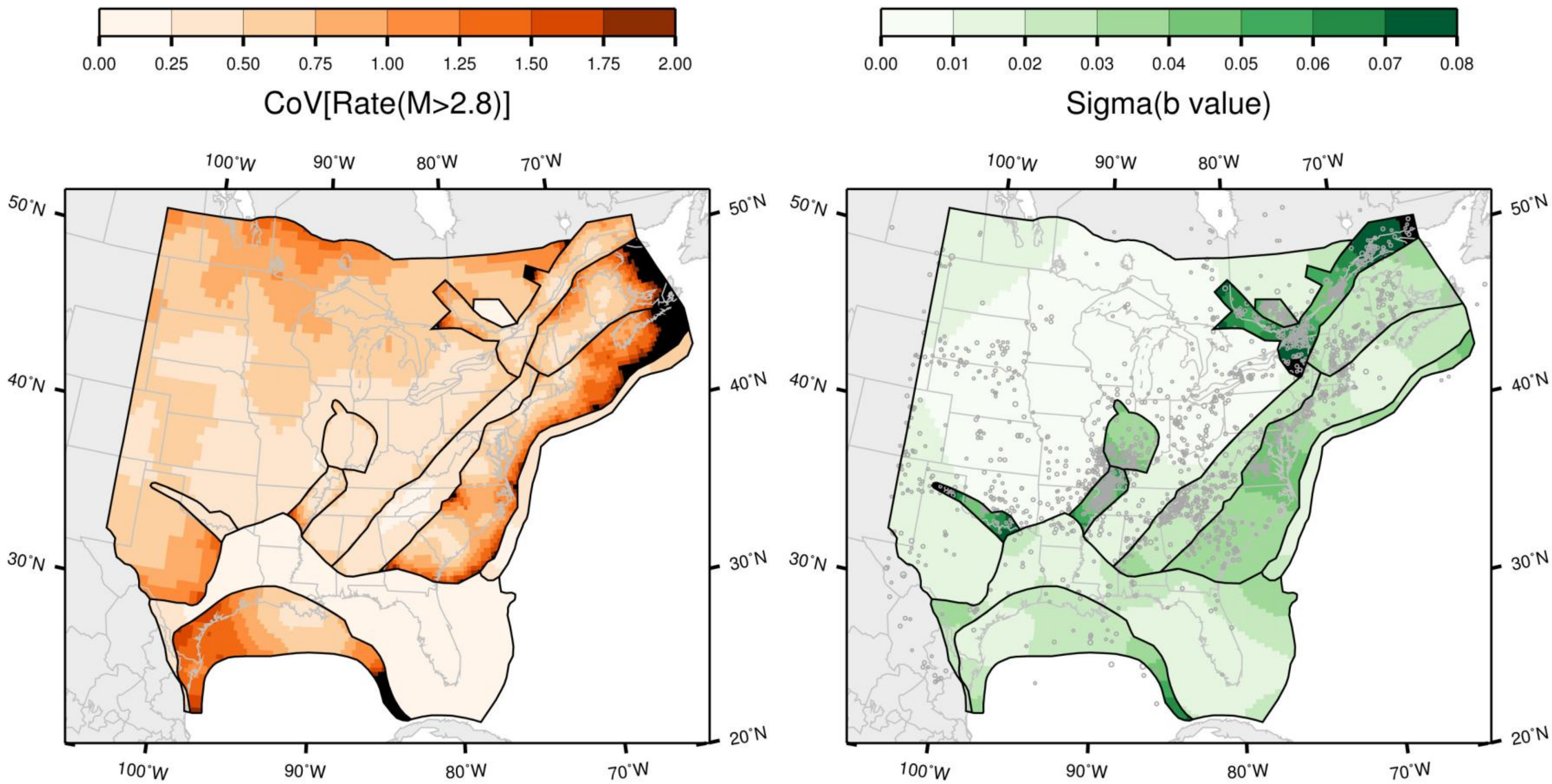


Figure J-99
Map of the coefficient of variation of the rate and the standard deviation of the *b*-value for the study region under the seismotectonic zonation, with narrow interpretation of PEZ; Case B magnitude weights

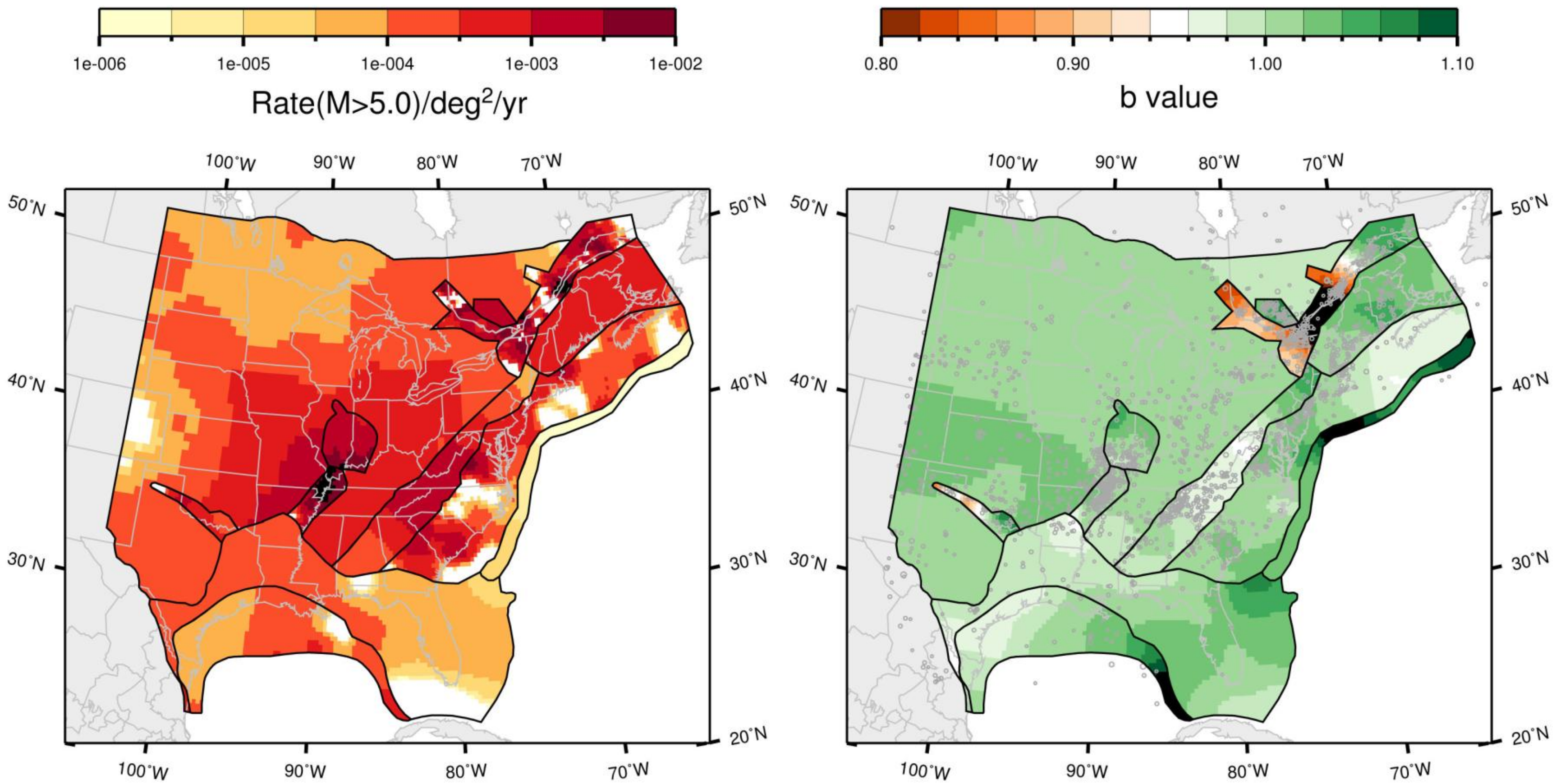


Figure J-100
Map of the rate and *b*-value for the study region under the seismotectonic zonation, with narrow interpretation of PEZ; Case E magnitude weights: Realization 1

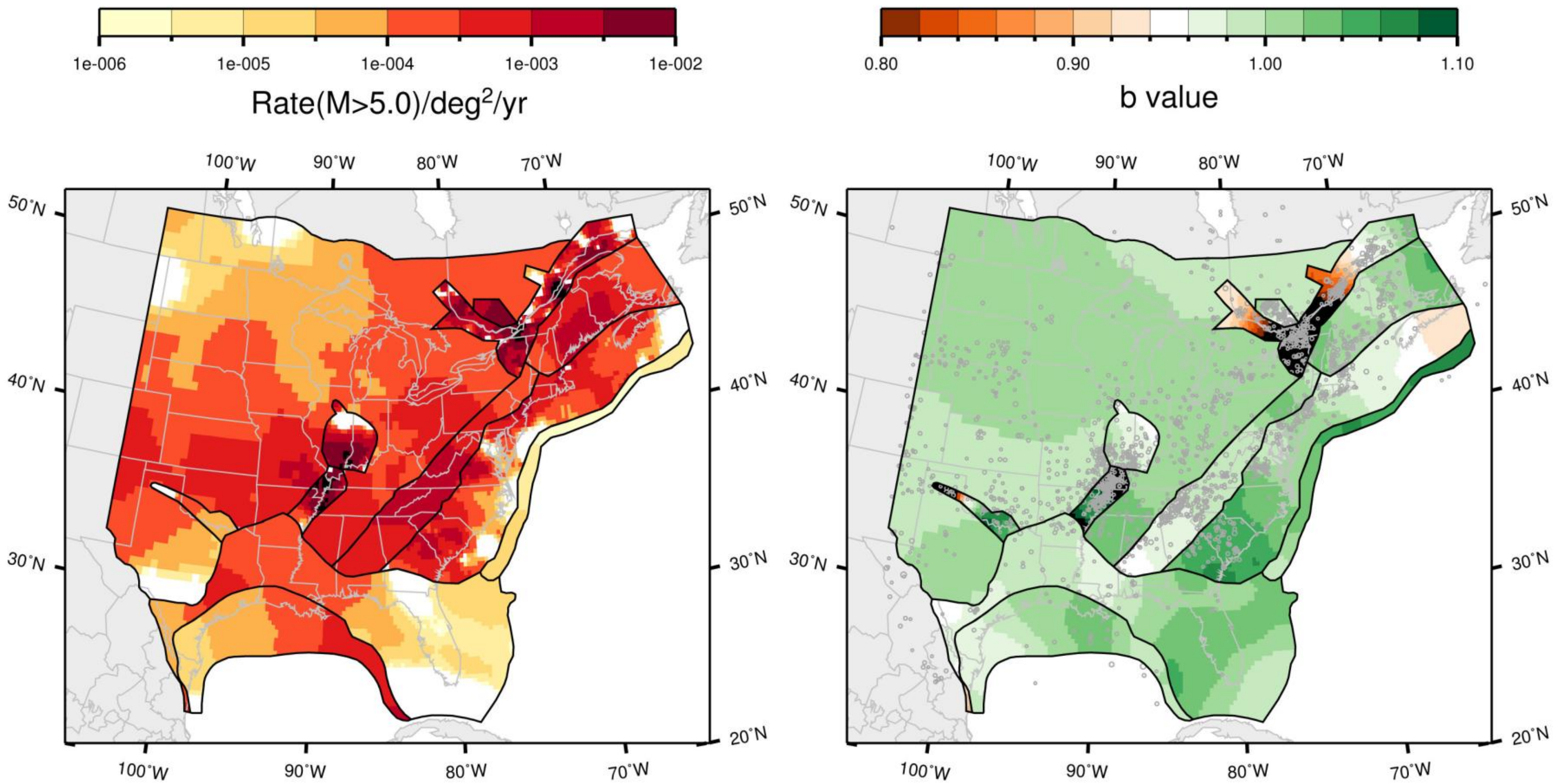


Figure J-101
Map of the rate and *b*-value for the study region under the seismotectonic zonation, with narrow interpretation of PEZ; Case E magnitude weights: Realization 2

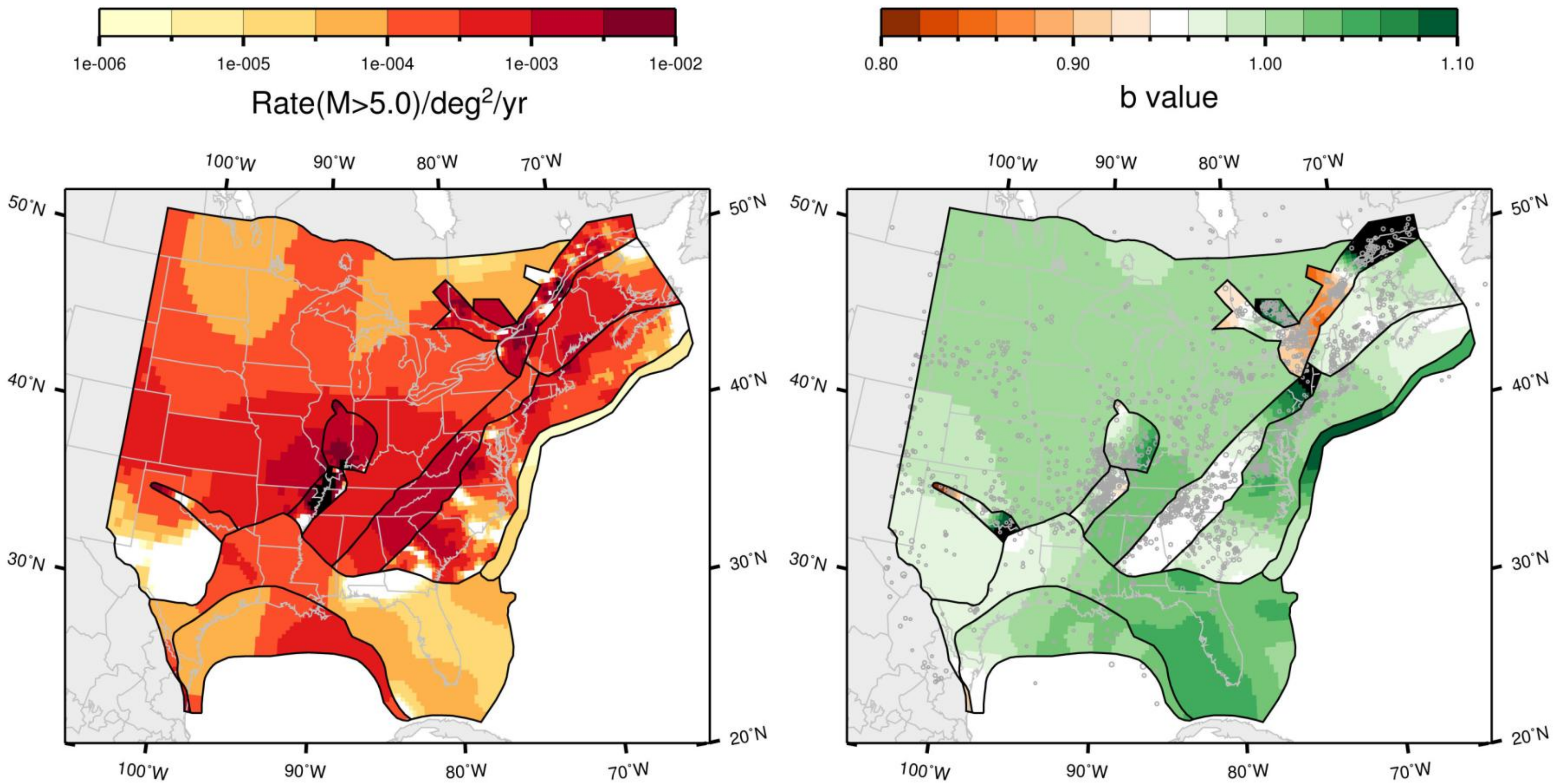


Figure J-102
Map of the rate and *b*-value for the study region under the seismotectonic zonation, with narrow interpretation of PEZ; Case E magnitude weights: Realization 3

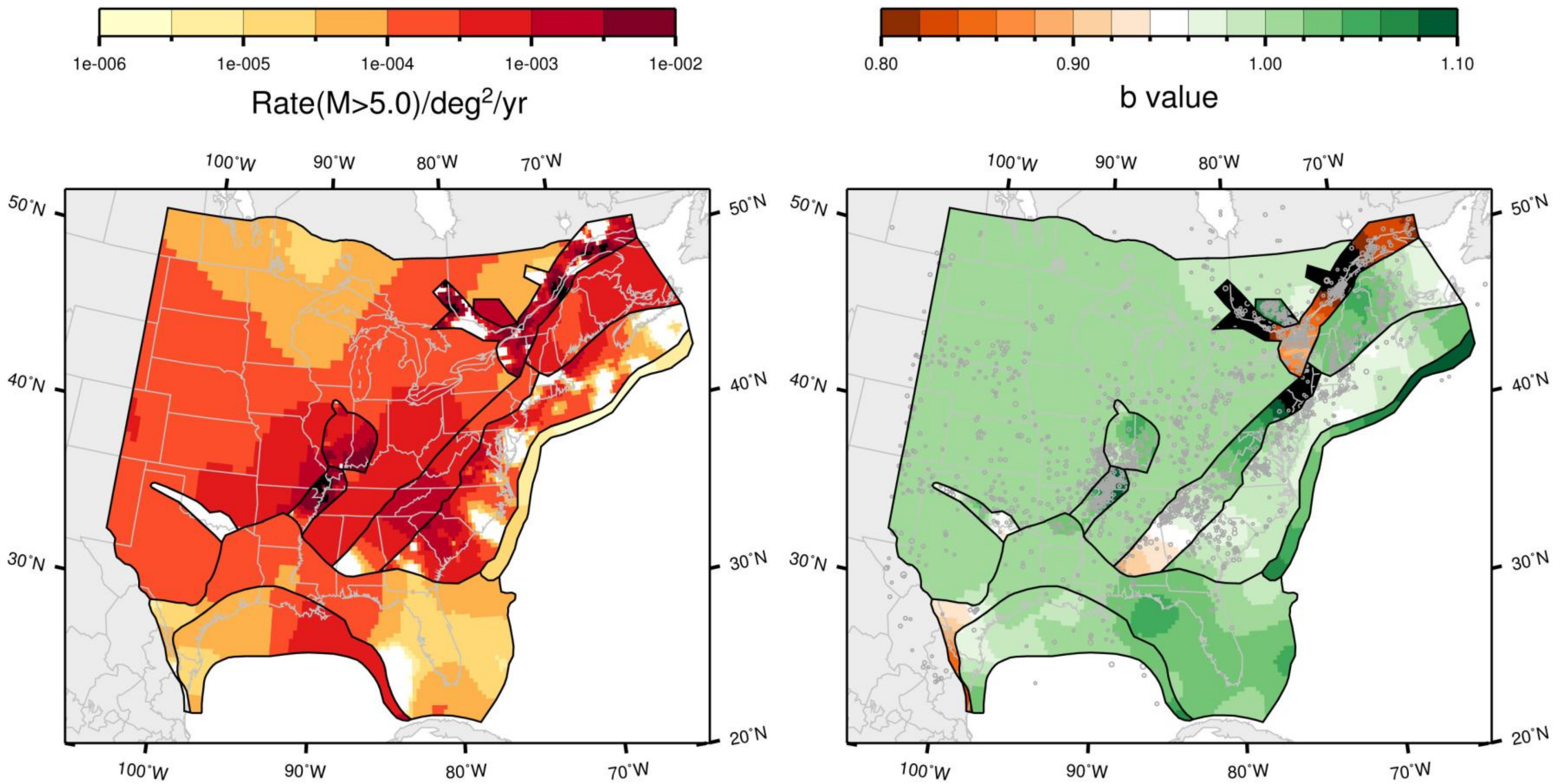


Figure J-103
Map of the rate and *b*-value for the study region under the seismotectonic zonation, with narrow interpretation of PEZ; Case E magnitude weights: Realization 4

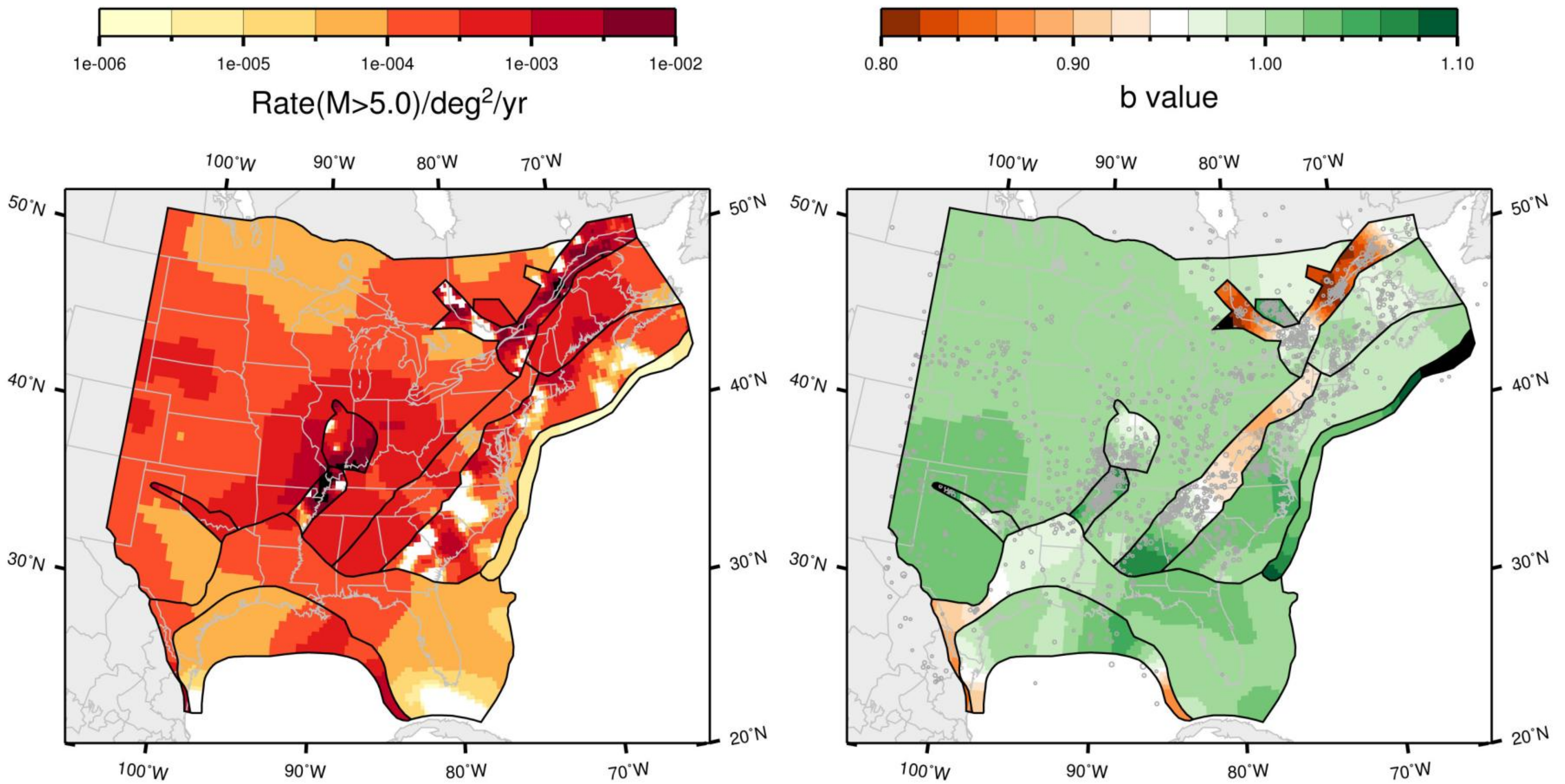


Figure J-104
Map of the rate and *b*-value for the study region under the seismotectonic zonation, with narrow interpretation of PEZ; Case E magnitude weights: Realization 5

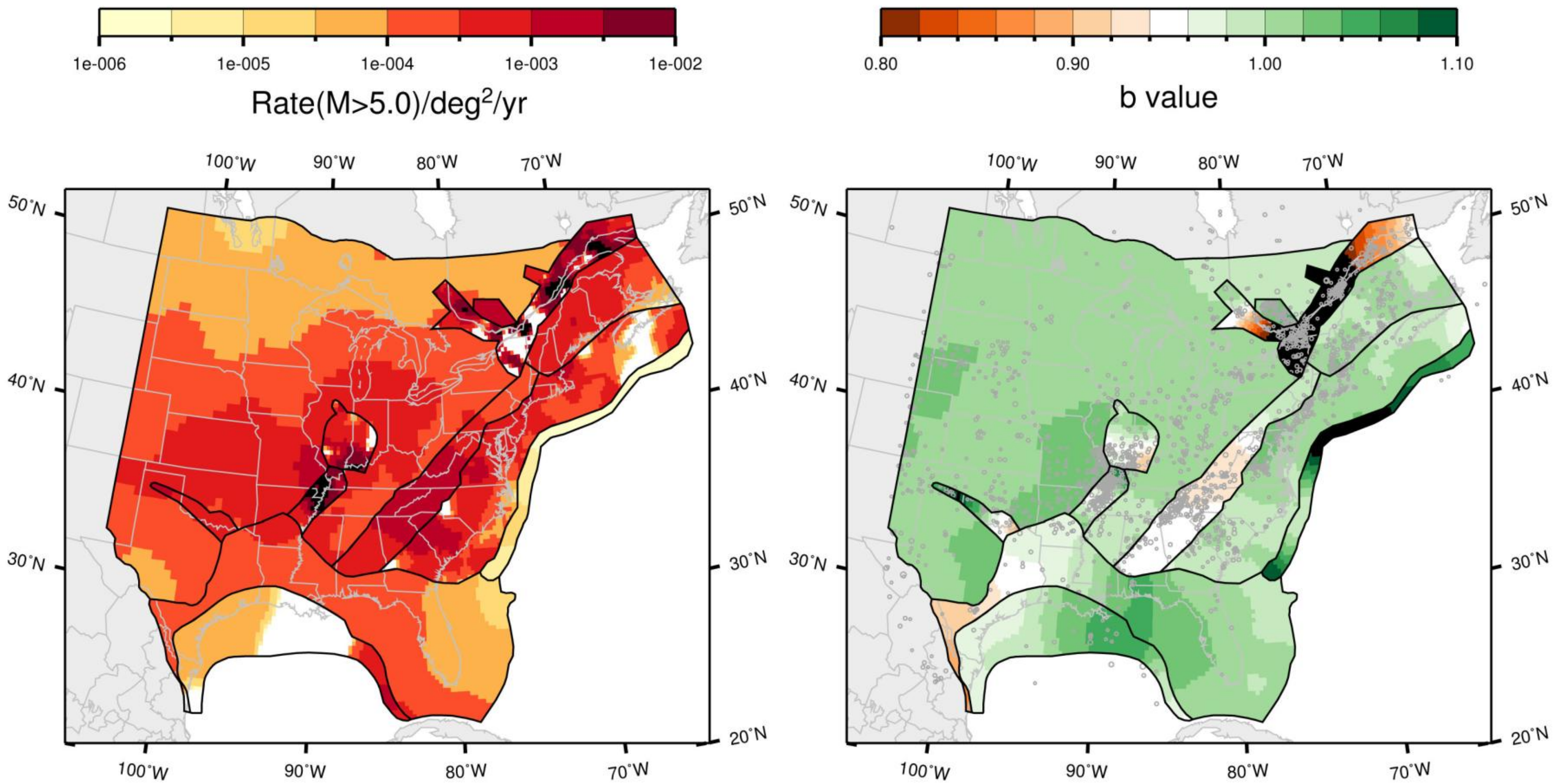


Figure J-105
Map of the rate and *b*-value for the study region under the seismotectonic zonation, with narrow interpretation of PEZ; Case E magnitude weights: Realization 6

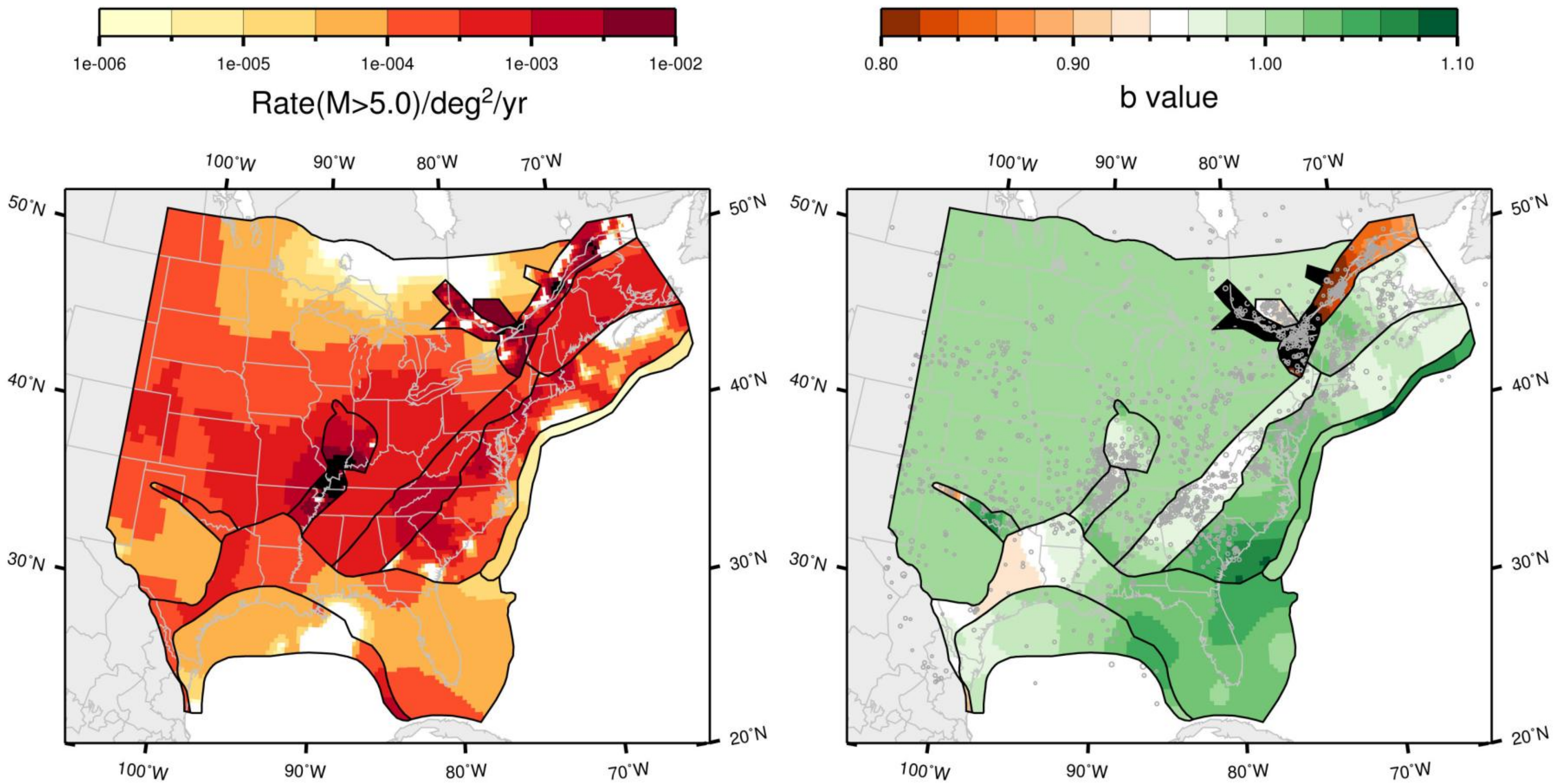


Figure J-106
Map of the rate and *b*-value for the study region under the seismotectonic zonation, with narrow interpretation of PEZ; Case E magnitude weights: Realization 7

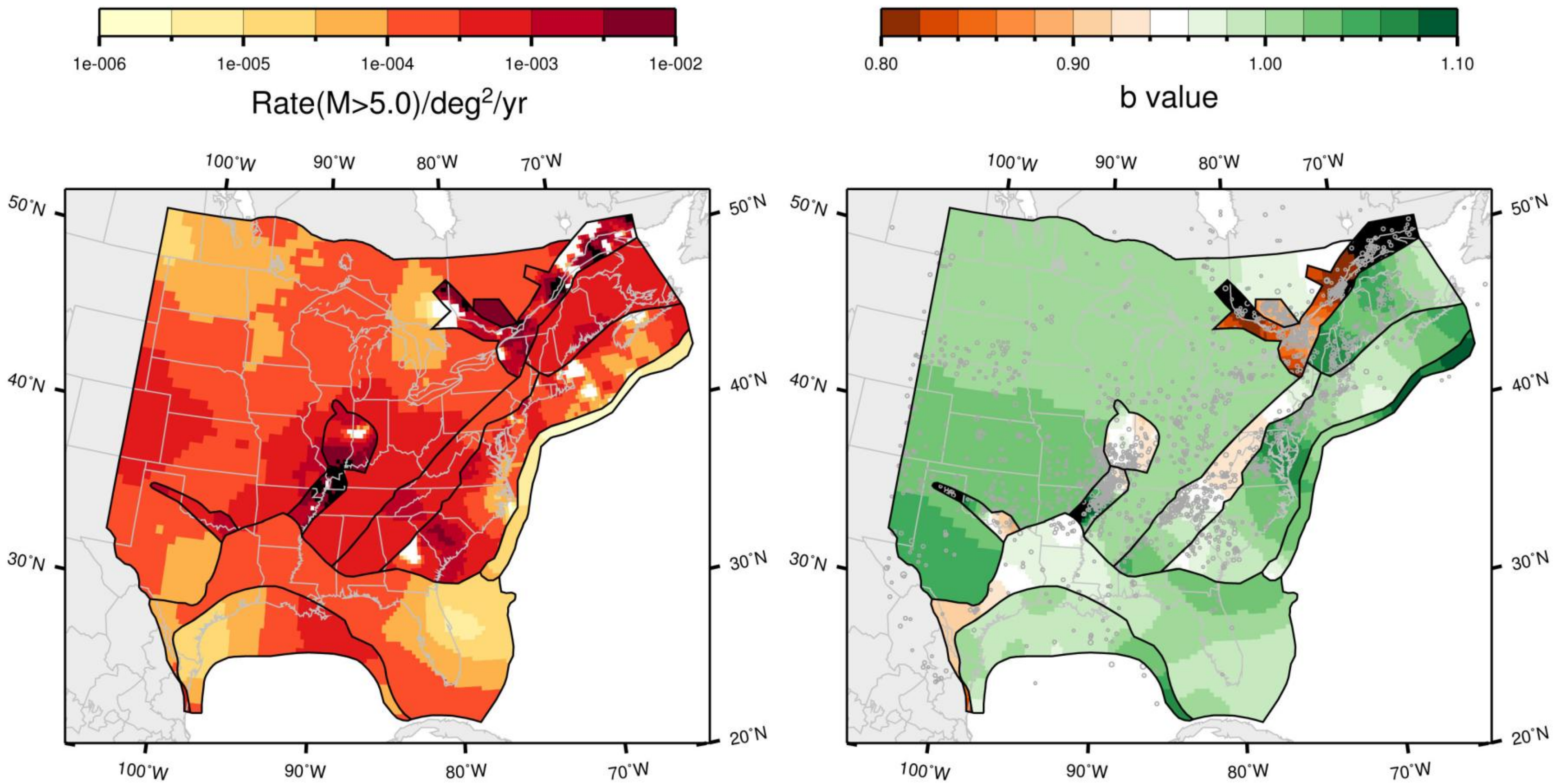


Figure J-107
Map of the rate and *b*-value for the study region under the seismotectonic zonation, with narrow interpretation of PEZ; Case E magnitude weights: Realization 8

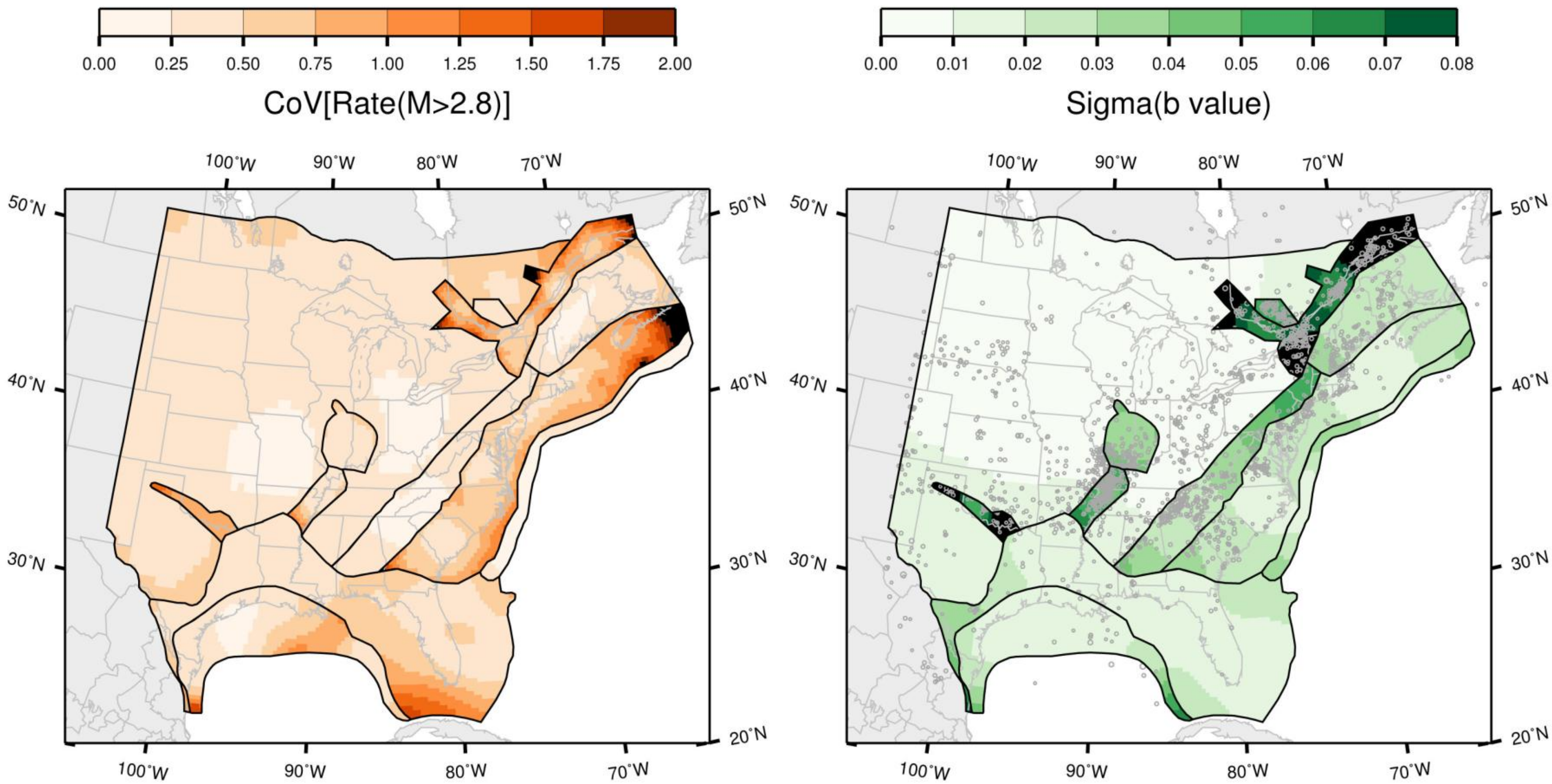


Figure J-108
Map of the coefficient of variation of the rate and the standard deviation of the *b*-value for the study region under the seismotectonic zonation, with narrow interpretation of PEZ; Case E magnitude weights

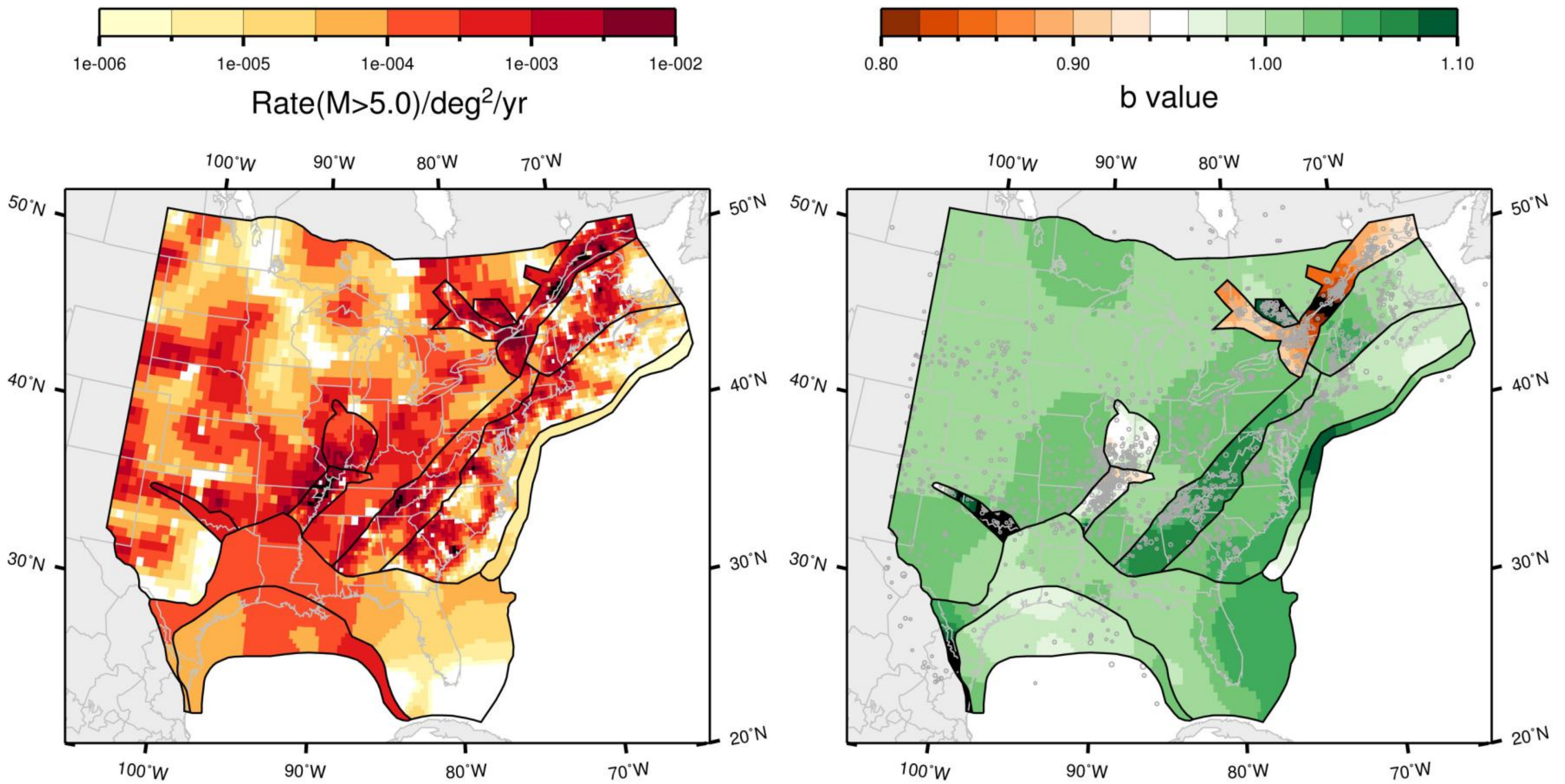


Figure J-109
Map of the rate and *b*-value for the study region under the seismotectonic zonation, with narrow interpretation of PEZ; Case A magnitude weights: Realization 1

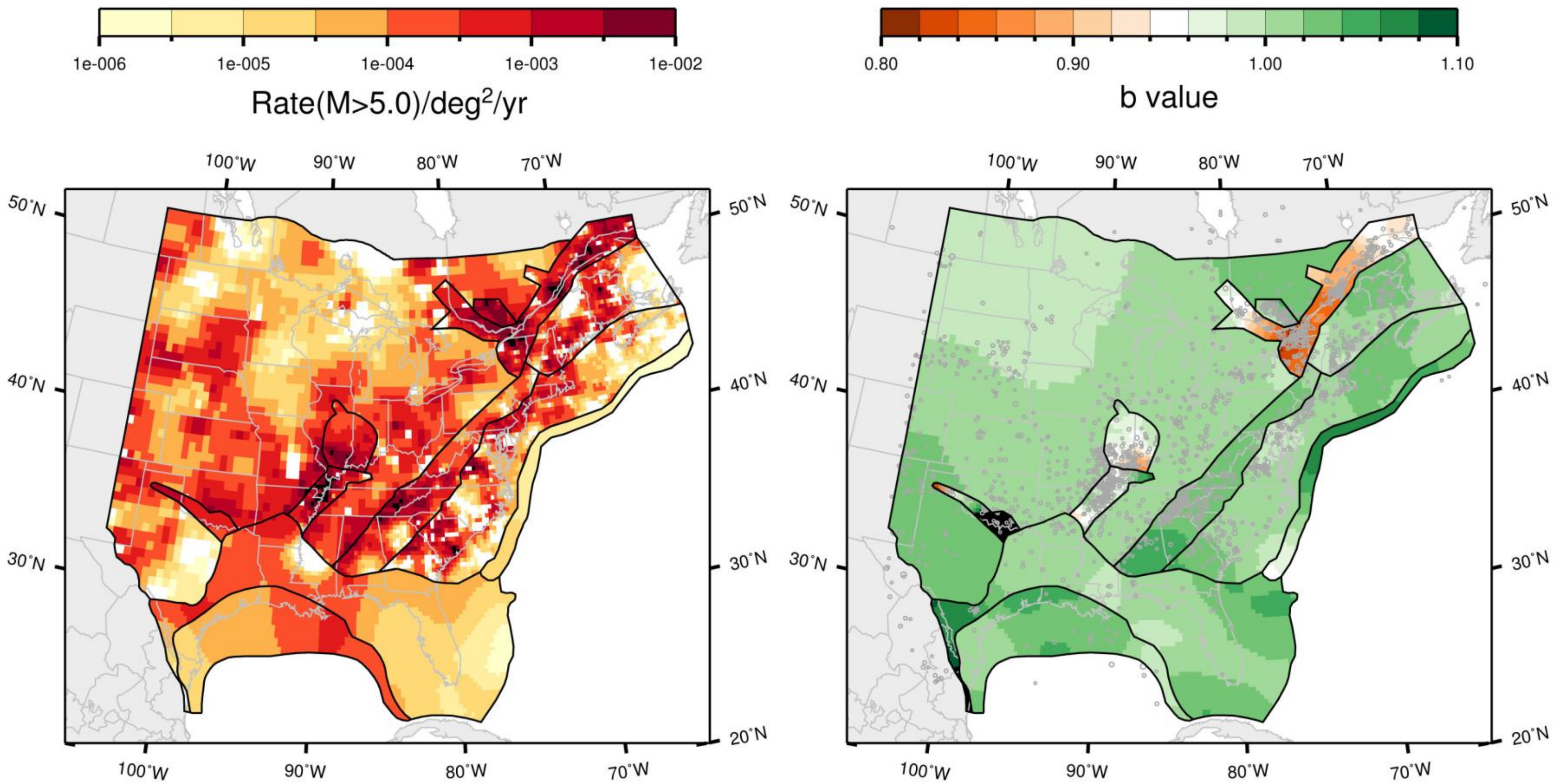


Figure J-110
Map of the rate and *b*-value for the study region under the seismotectonic zonation, with narrow interpretation of PEZ; Case A magnitude weights: Realization 2

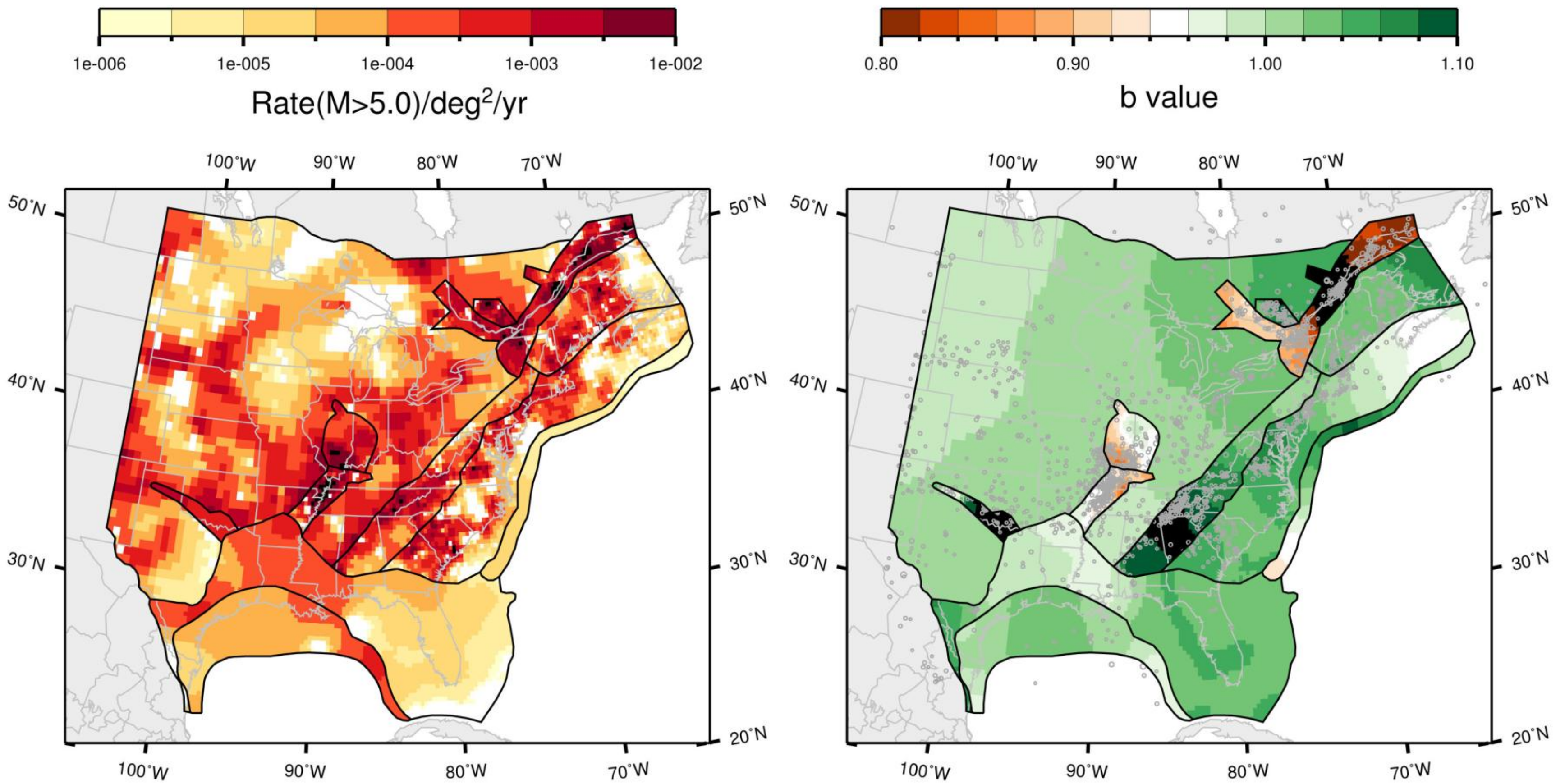


Figure J-111
Map of the rate and *b*-value for the study region under the seismotectonic zonation, with narrow interpretation of PEZ; Case A magnitude weights: Realization 3

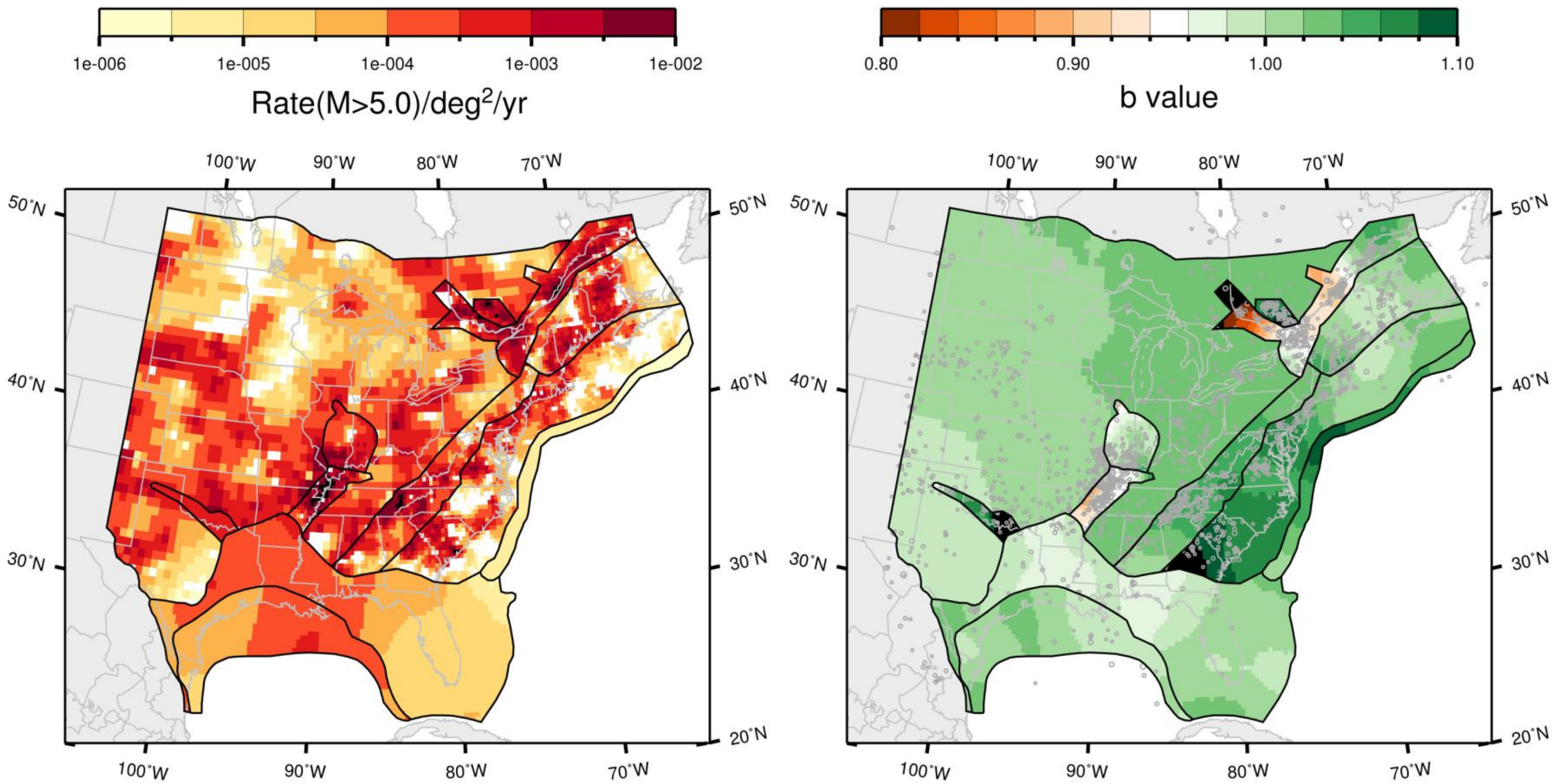


Figure J-112
Map of the rate and *b*-value for the study region under the seismotectonic zonation, with narrow interpretation of PEZ; Case A magnitude weights: Realization 4

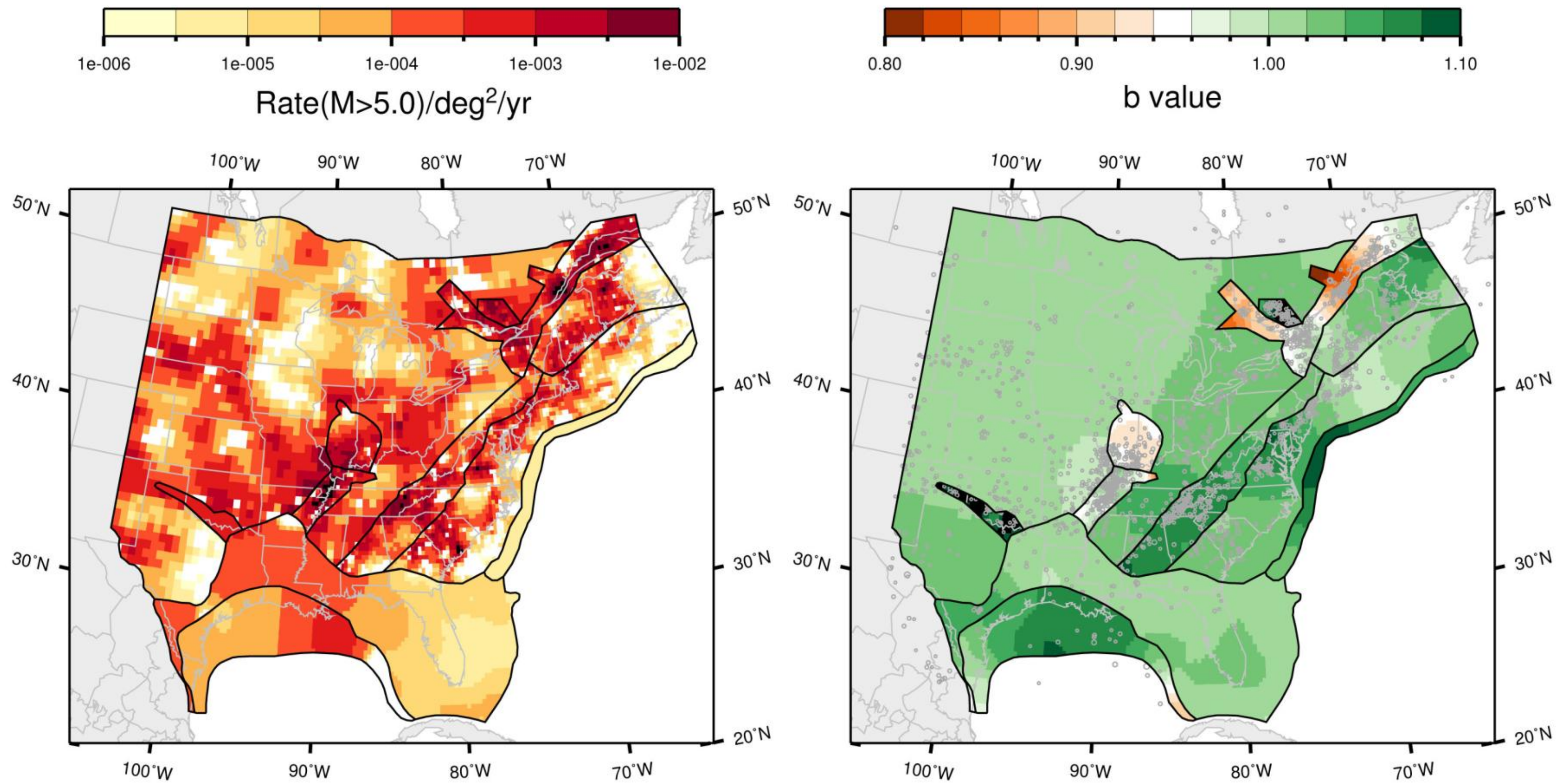


Figure J-113
Map of the rate and *b*-value for the study region under the seismotectonic zonation, with narrow interpretation of PEZ; Case A magnitude weights: Realization 5

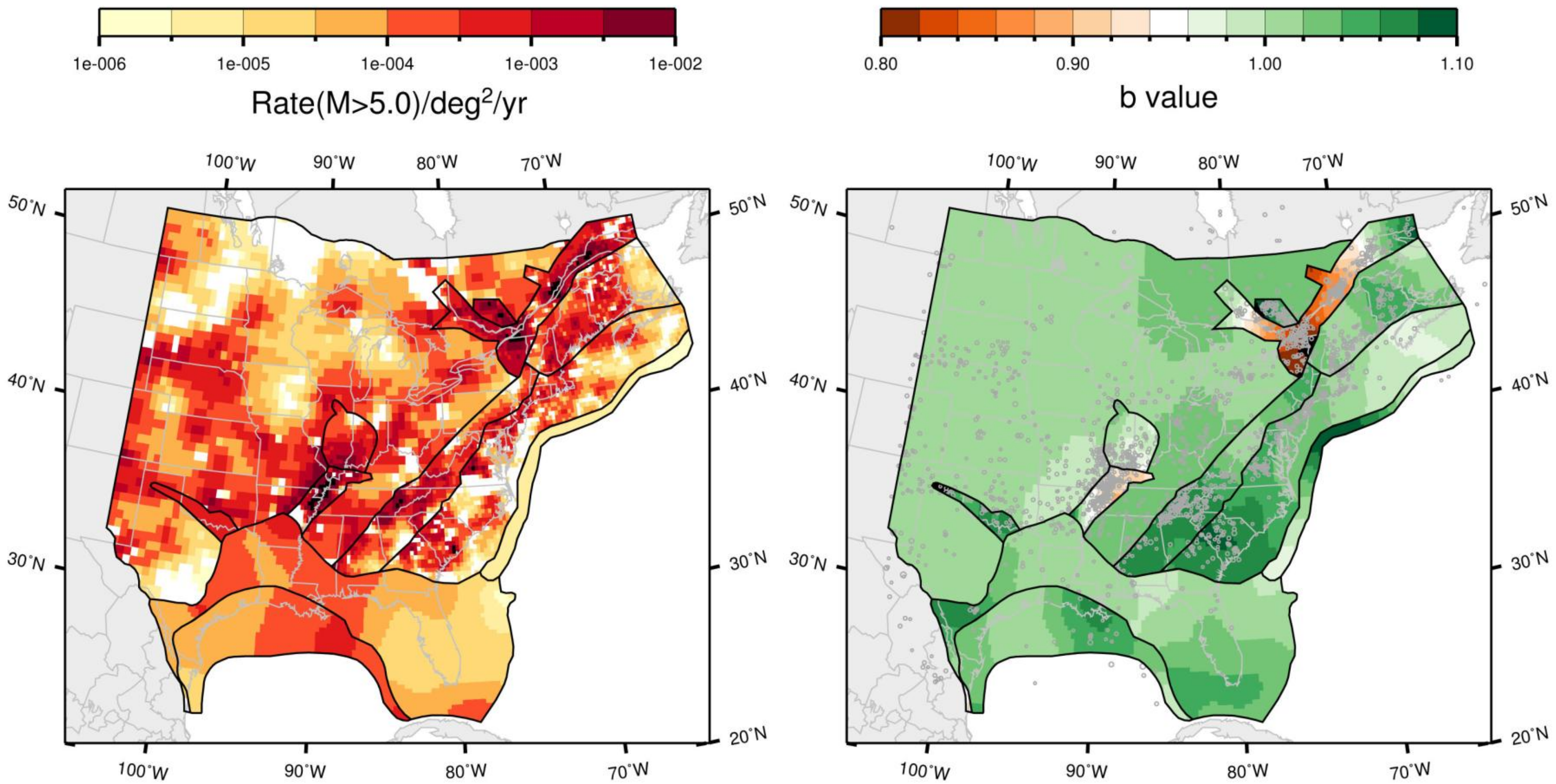


Figure J-114
Map of the rate and *b*-value for the study region under the seismotectonic zonation, with narrow interpretation of PEZ; Case A magnitude weights: Realization 6

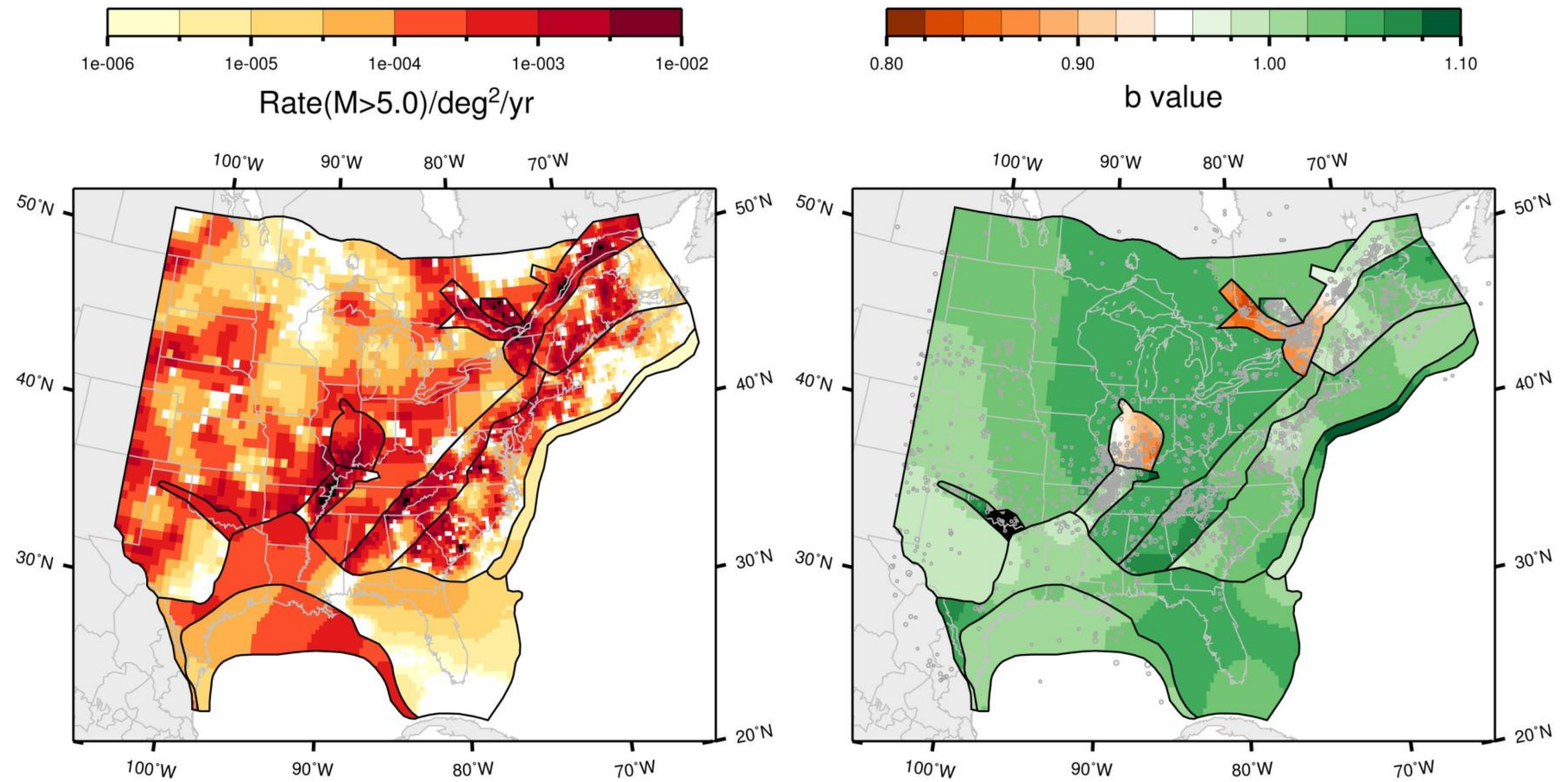


Figure J-115
Map of the rate and *b*-value for the study region under the seismotectonic zonation, with narrow interpretation of PEZ; Case A magnitude weights: Realization 7

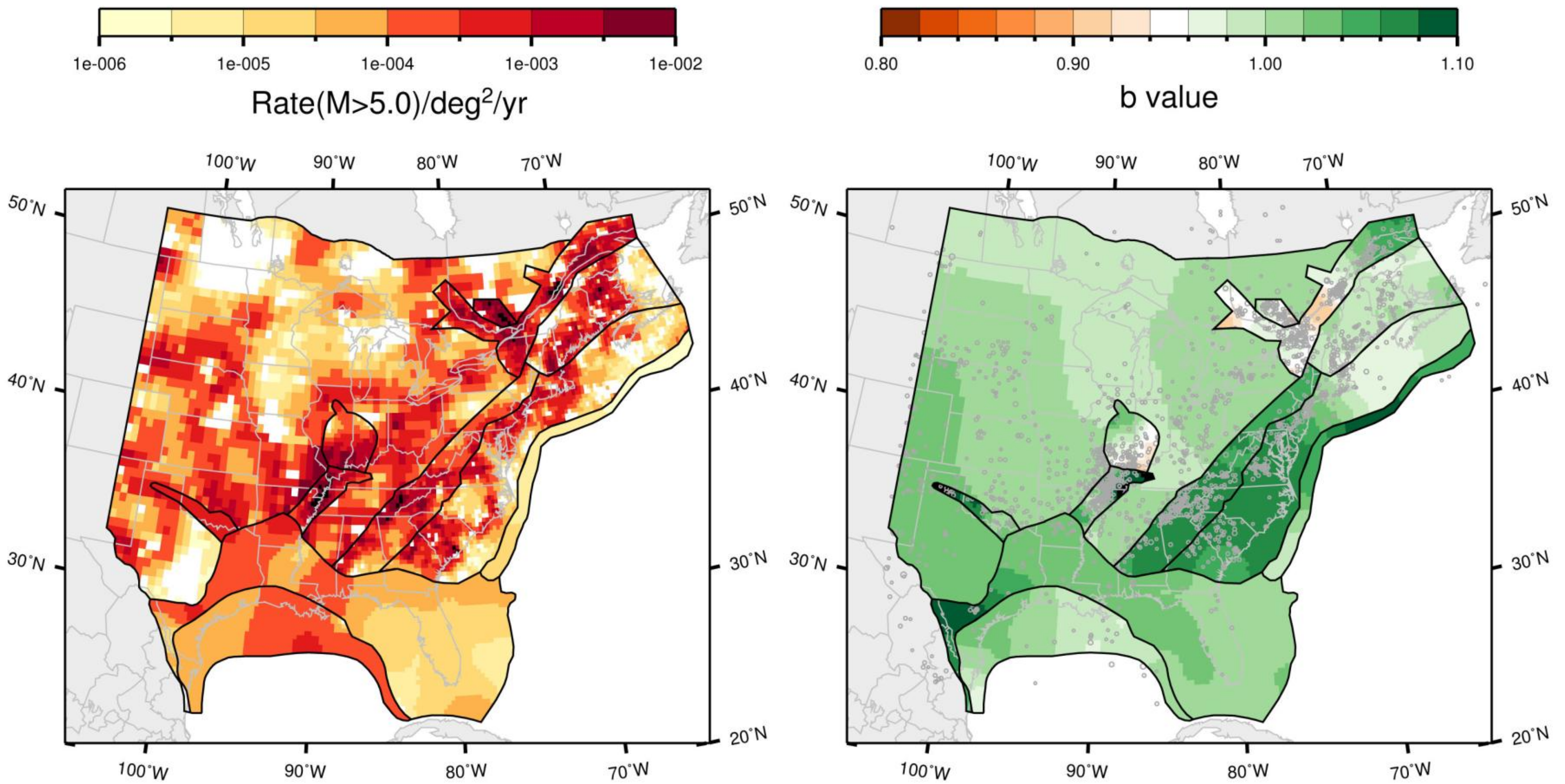


Figure J-116
Map of the rate and *b*-value for the study region under the seismotectonic zonation, with narrow interpretation of PEZ; Case A magnitude weights: Realization 8

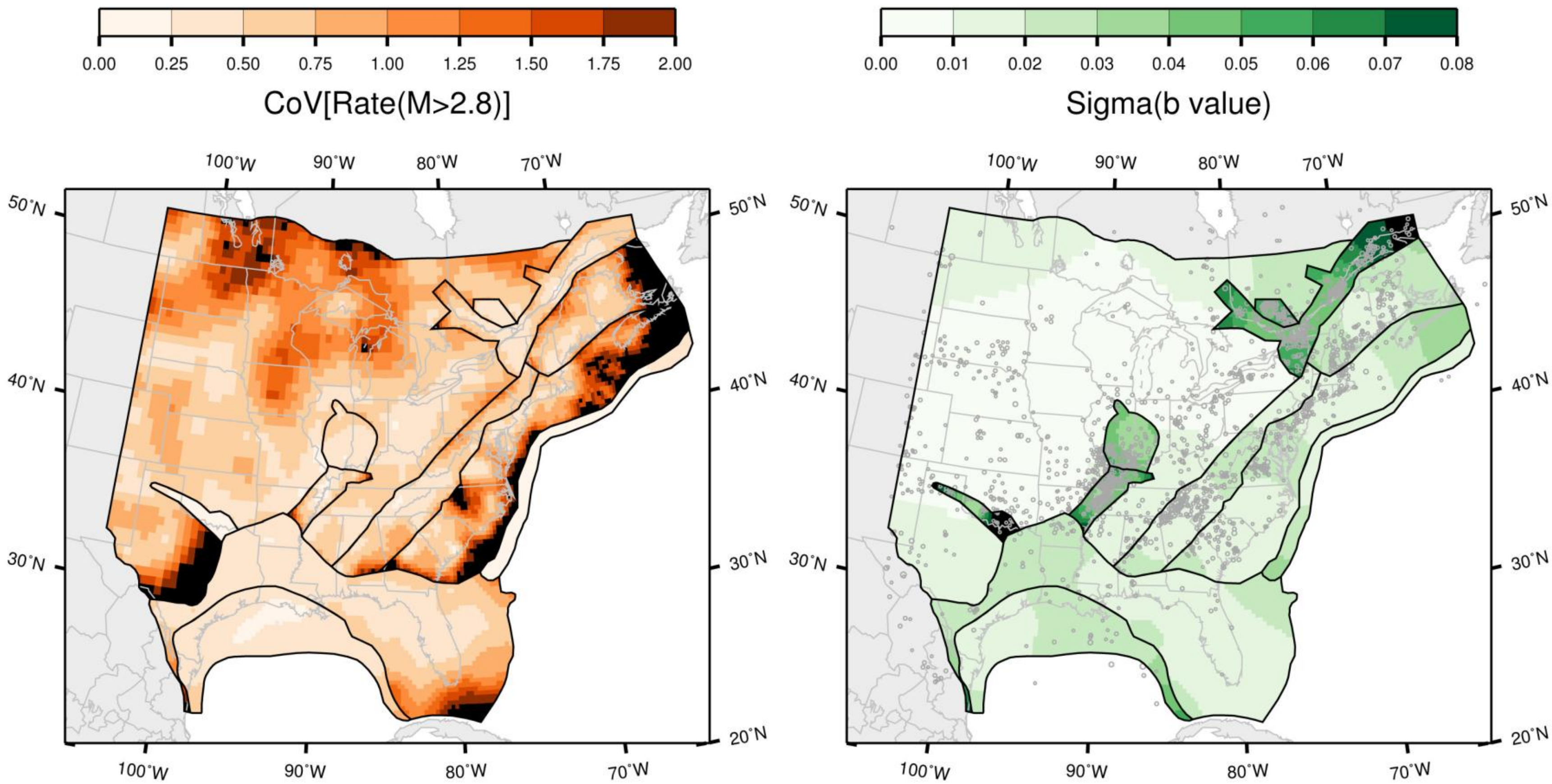


Figure J-117
Map of the coefficient of variation of the rate and the standard deviation of the *b*-value for the study region under the seismotectonic zonation, with narrow interpretation of PEZ; Case A magnitude weights

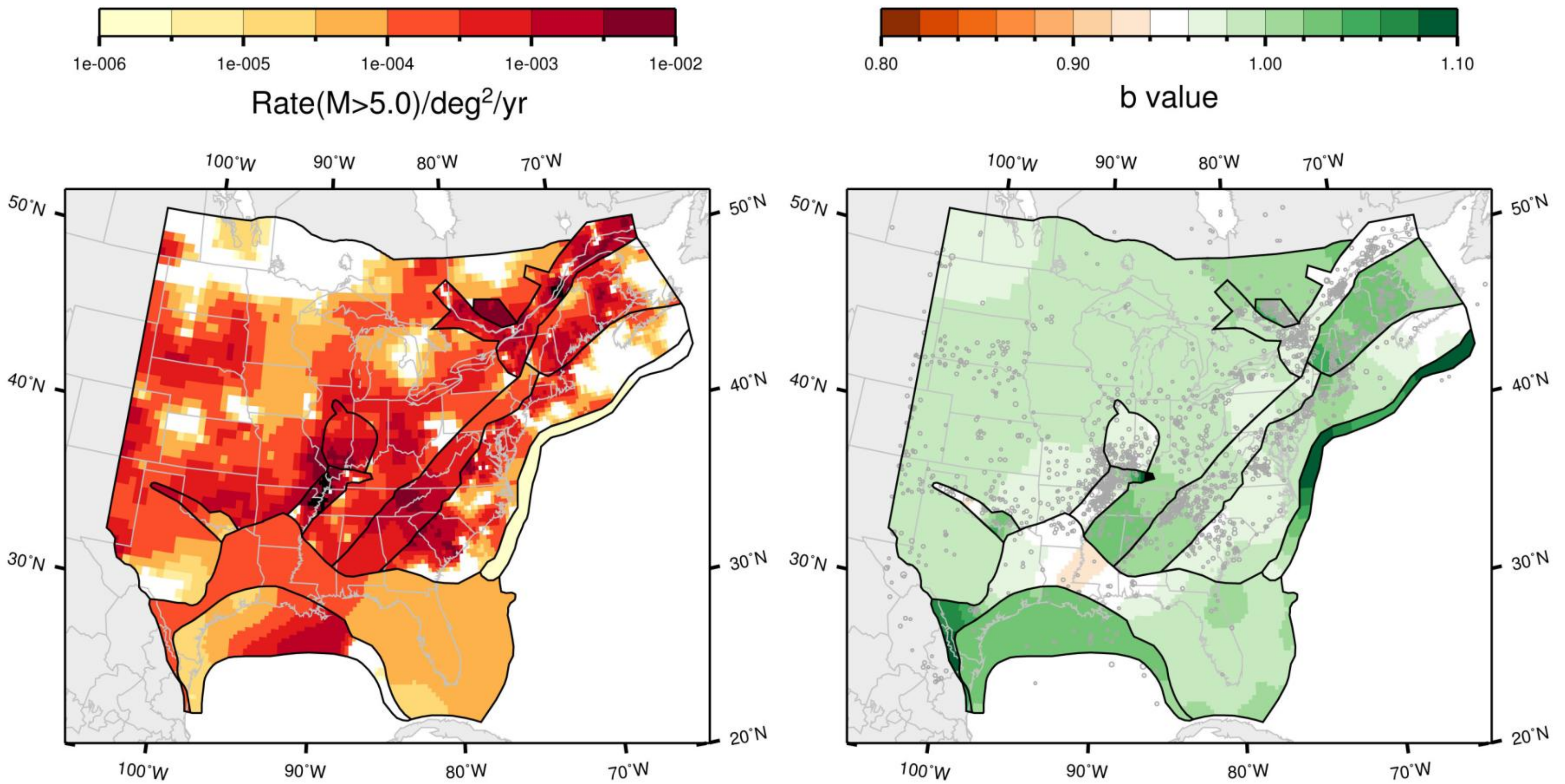


Figure J-118
Map of the rate and *b*-value for the study region under the seismotectonic zonation, with narrow interpretation of PEZ; Case B magnitude weights: Realization 1

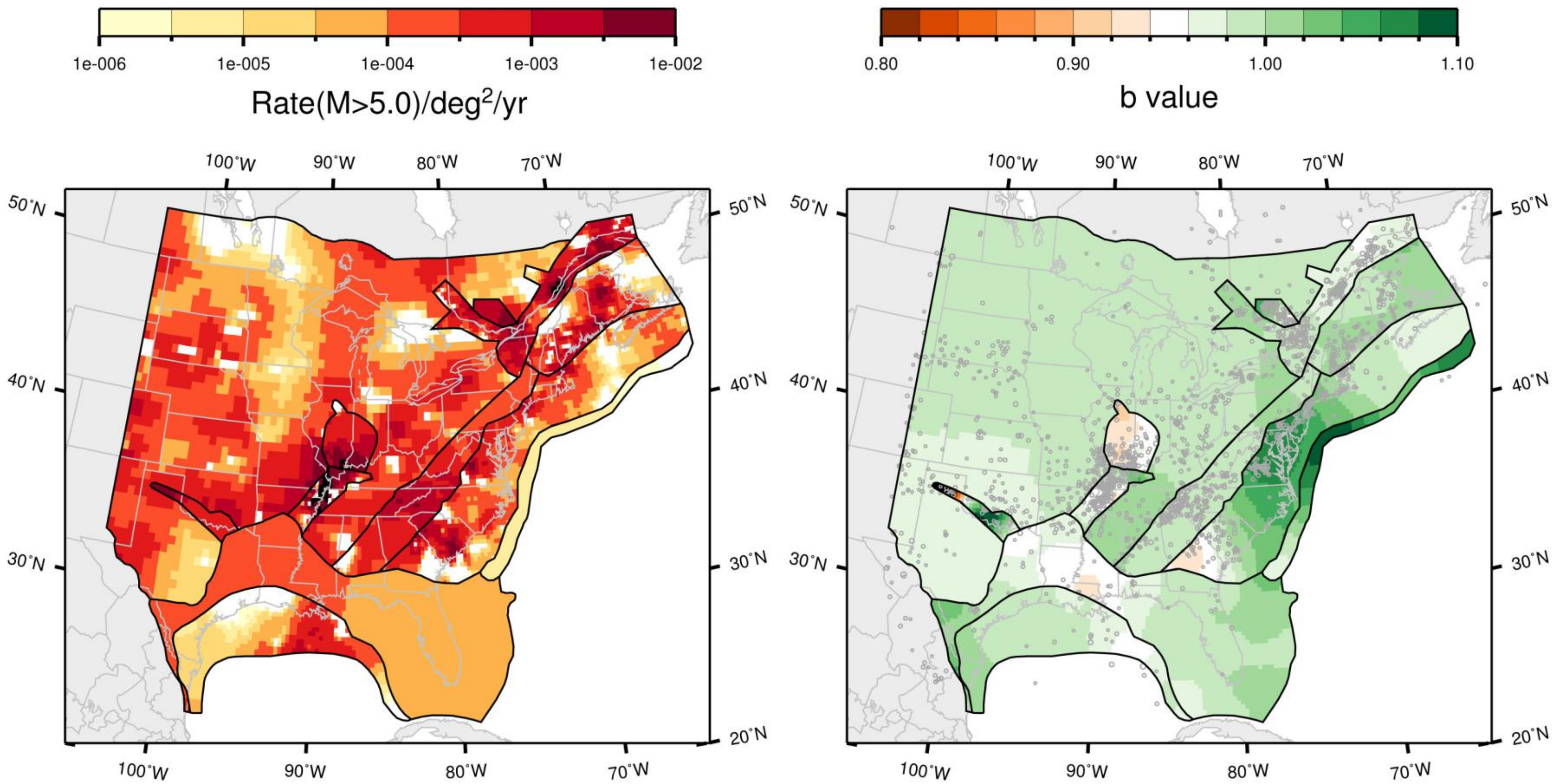


Figure J-119
Map of the rate and *b*-value for the study region under the seismotectonic zonation, with narrow interpretation of PEZ; Case B magnitude weights: Realization 2

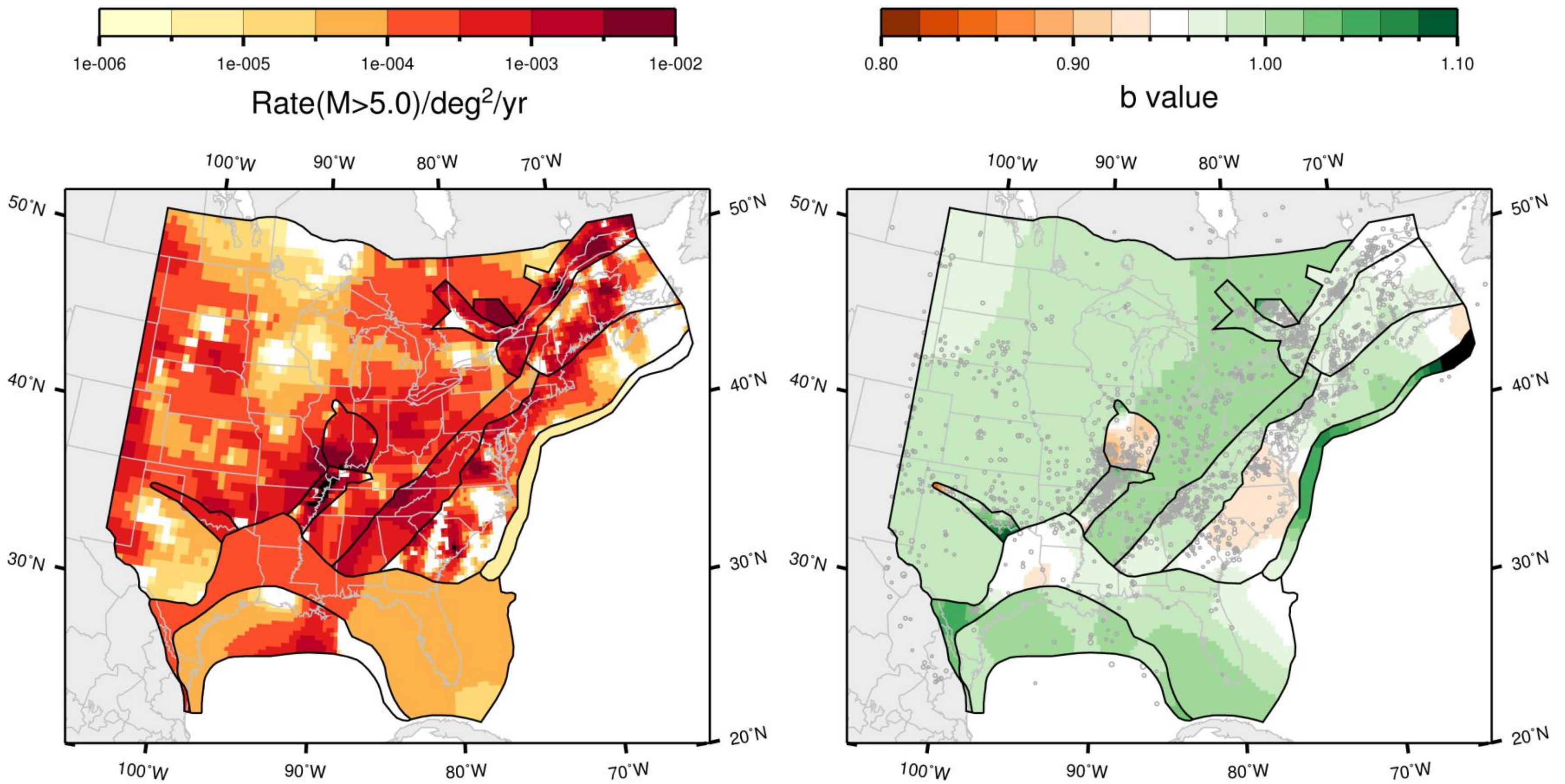


Figure J-120
Map of the rate and *b*-value for the study region under the seismotectonic zonation, with narrow interpretation of PEZ; Case B magnitude weights: Realization 3

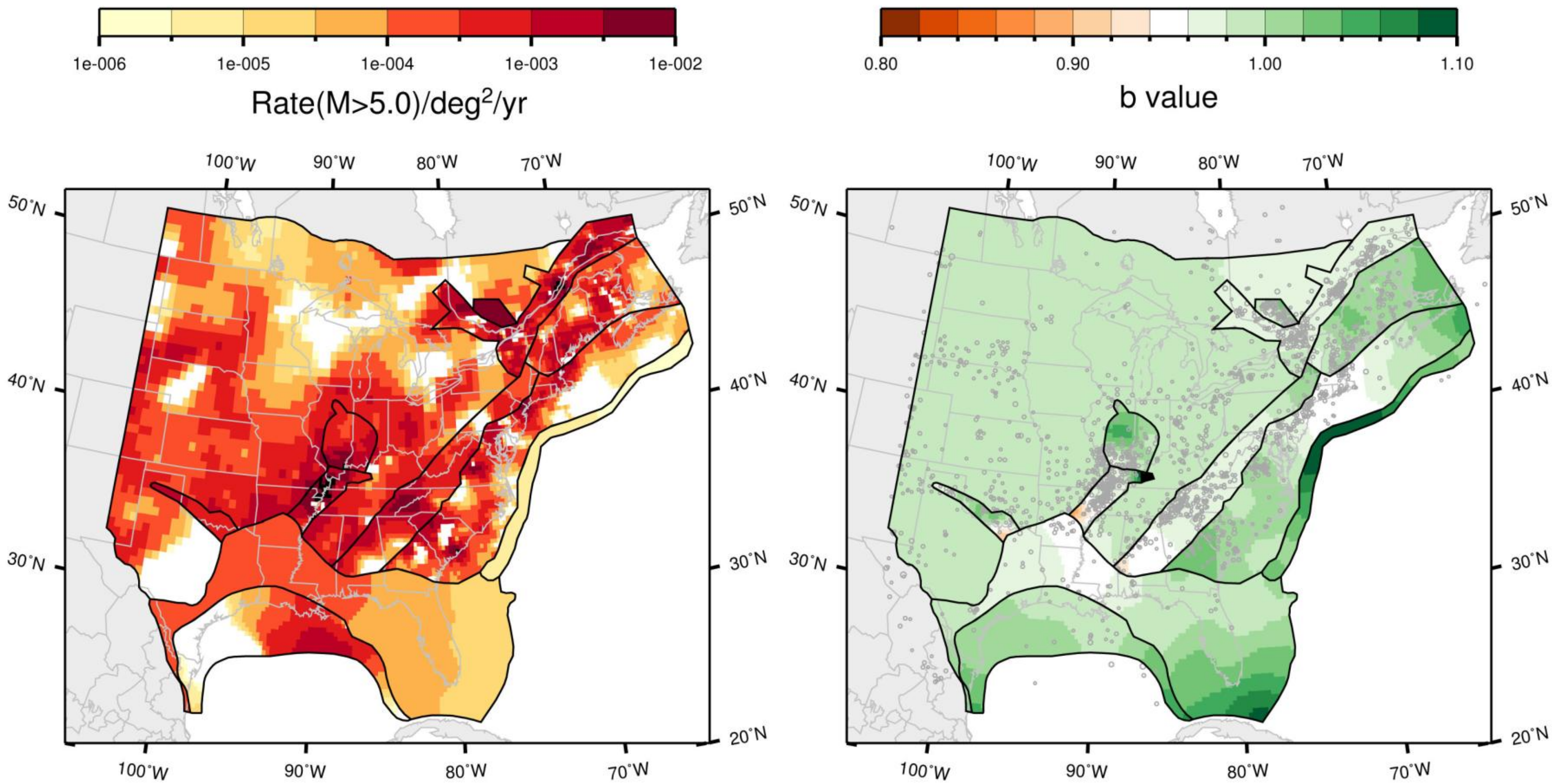
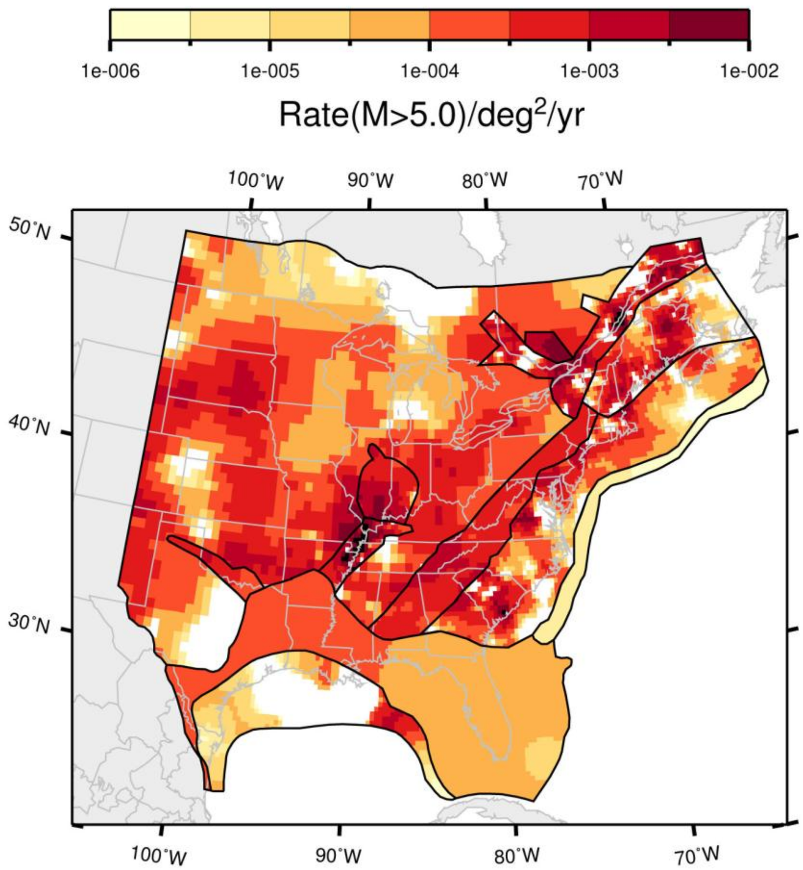


Figure J-121
Map of the rate and *b*-value for the study region under the seismotectonic zonation, with narrow interpretation of PEZ; Case B magnitude weights: Realization 4



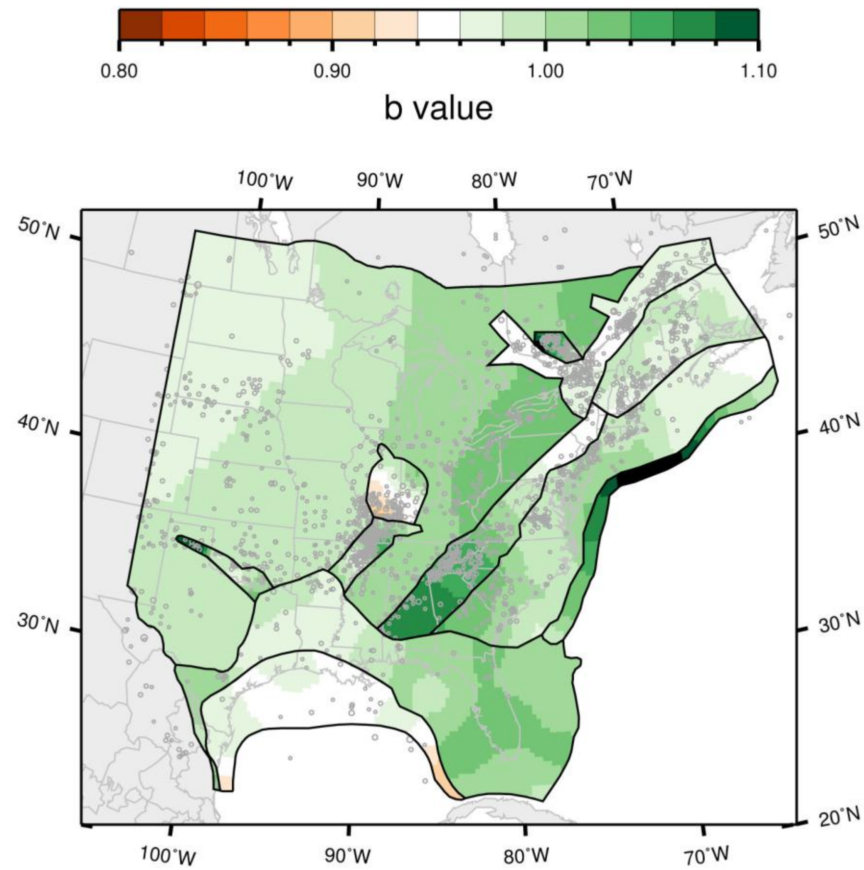


Figure J-122
Map of the rate and *b*-value for the study region under the seismotectonic zonation, with narrow interpretation of PEZ; Case B magnitude weights: Realization 5

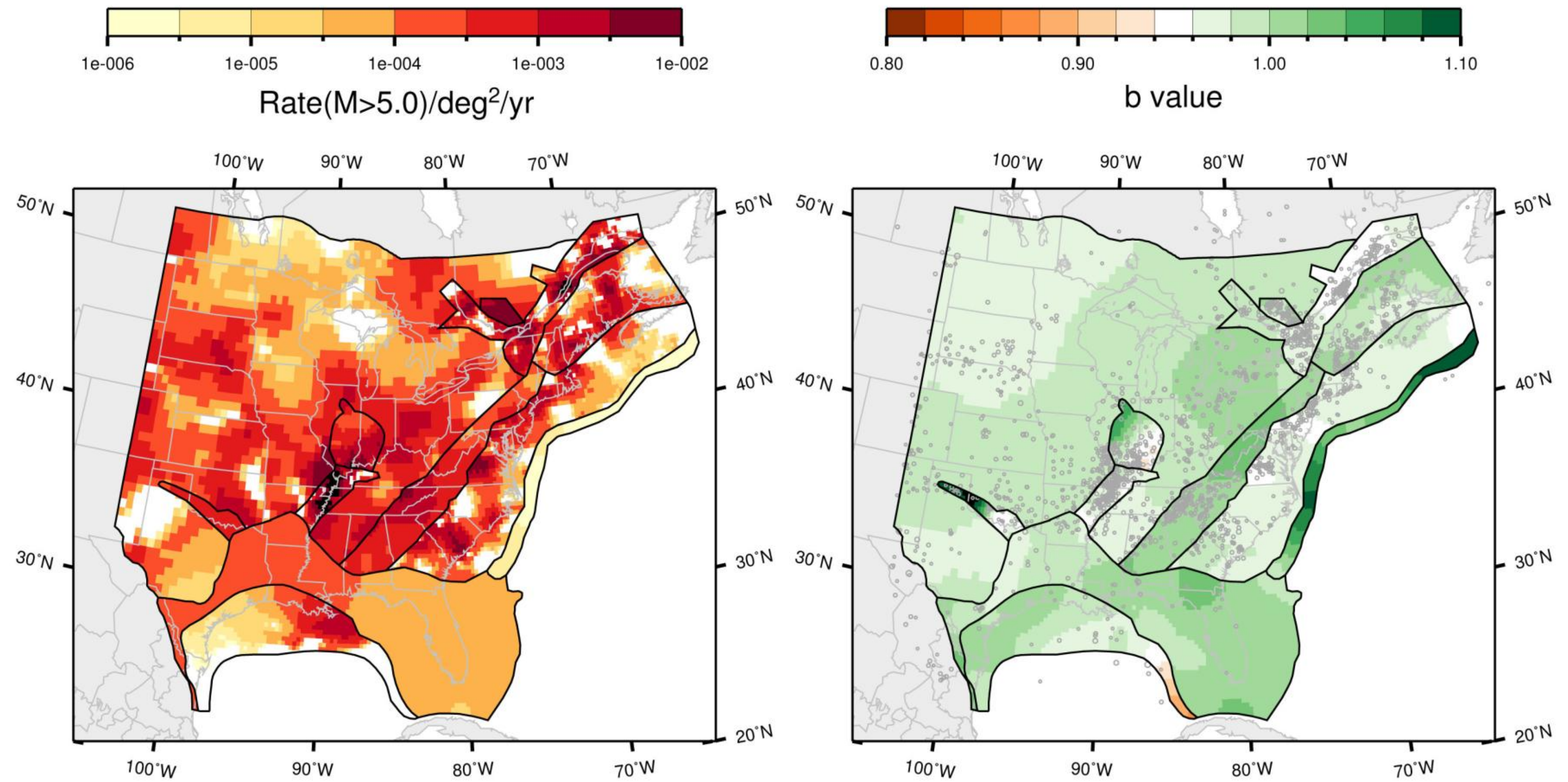


Figure J-123
Map of the rate and *b*-value for the study region under the seismotectonic zonation, with narrow interpretation of PEZ; Case B magnitude weights: Realization 6

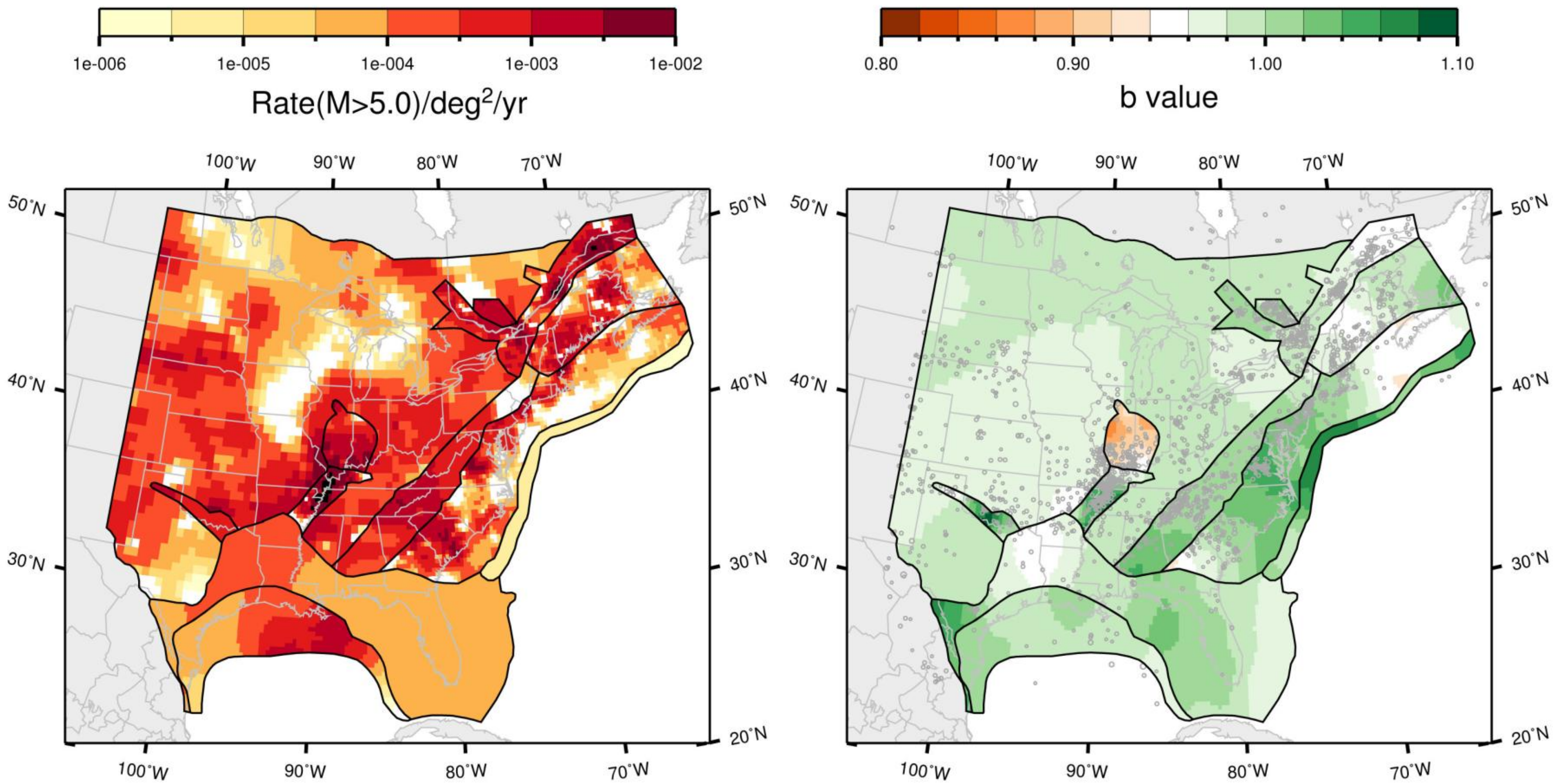


Figure J-124
Map of the rate and *b*-value for the study region under the seismotectonic zonation, with narrow interpretation of PEZ; Case B magnitude weights: Realization 7

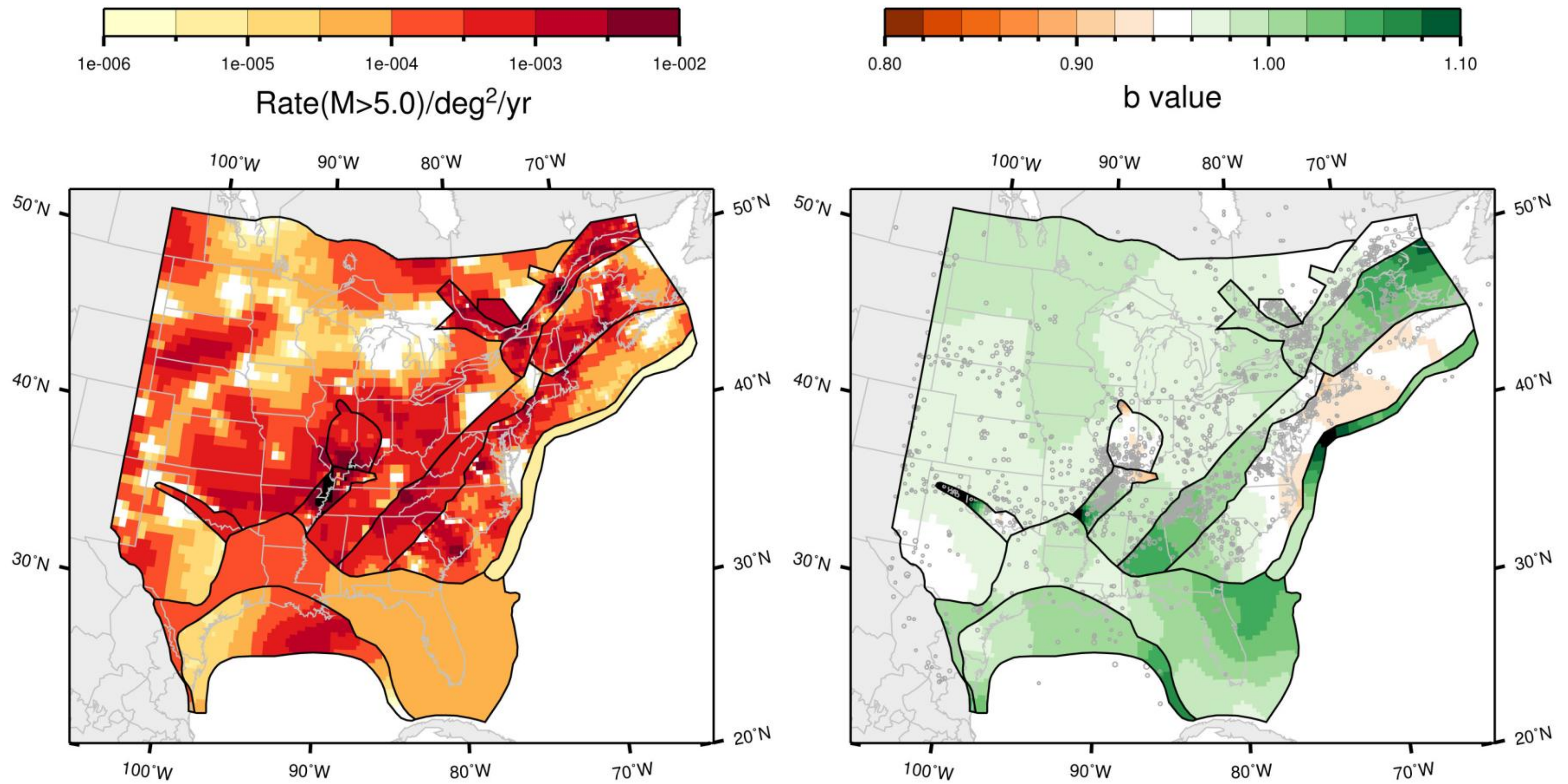


Figure J-125
Map of the rate and *b*-value for the study region under the seismotectonic zonation, with narrow interpretation of PEZ; Case B magnitude weights: Realization 8

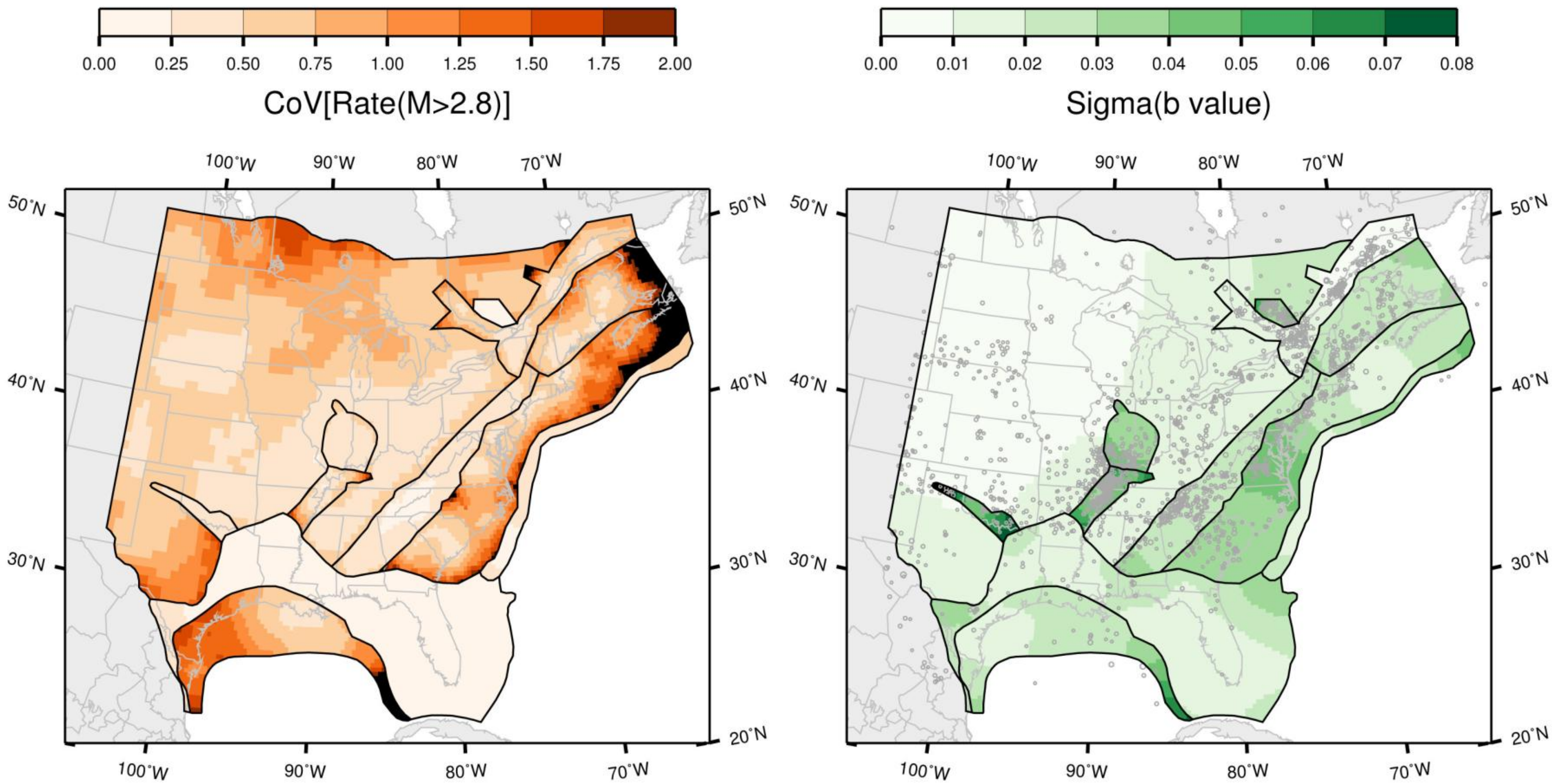


Figure J-126
Map of the coefficient of variation of the rate and the standard deviation of the *b*-value for the study region under the seismotectonic zonation, with narrow interpretation of PEZ; Case B magnitude weights

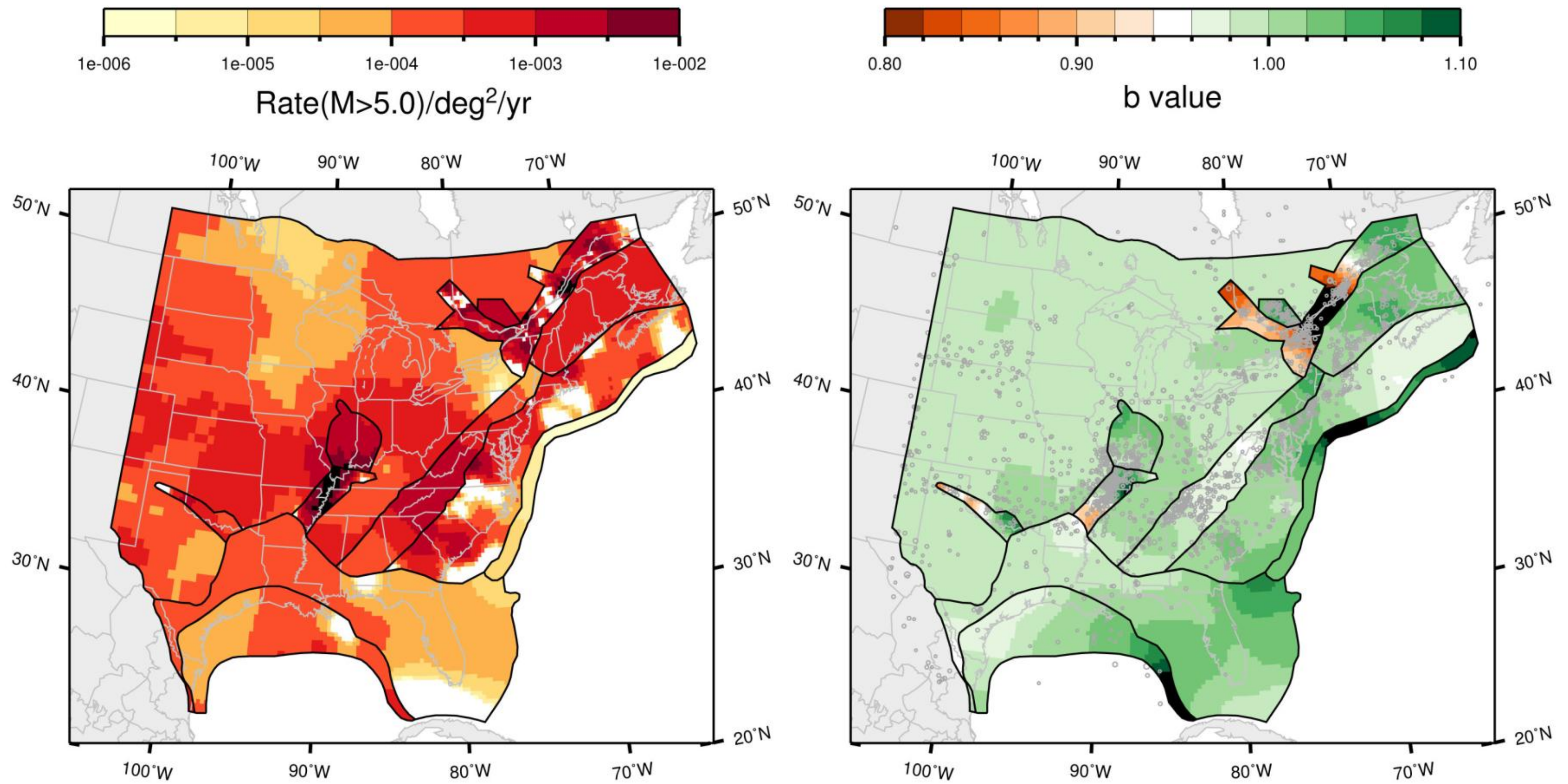


Figure J-127
Map of the rate and *b*-value for the study region under the seismotectonic zonation, with narrow interpretation of PEZ; Case E magnitude weights: Realization 1

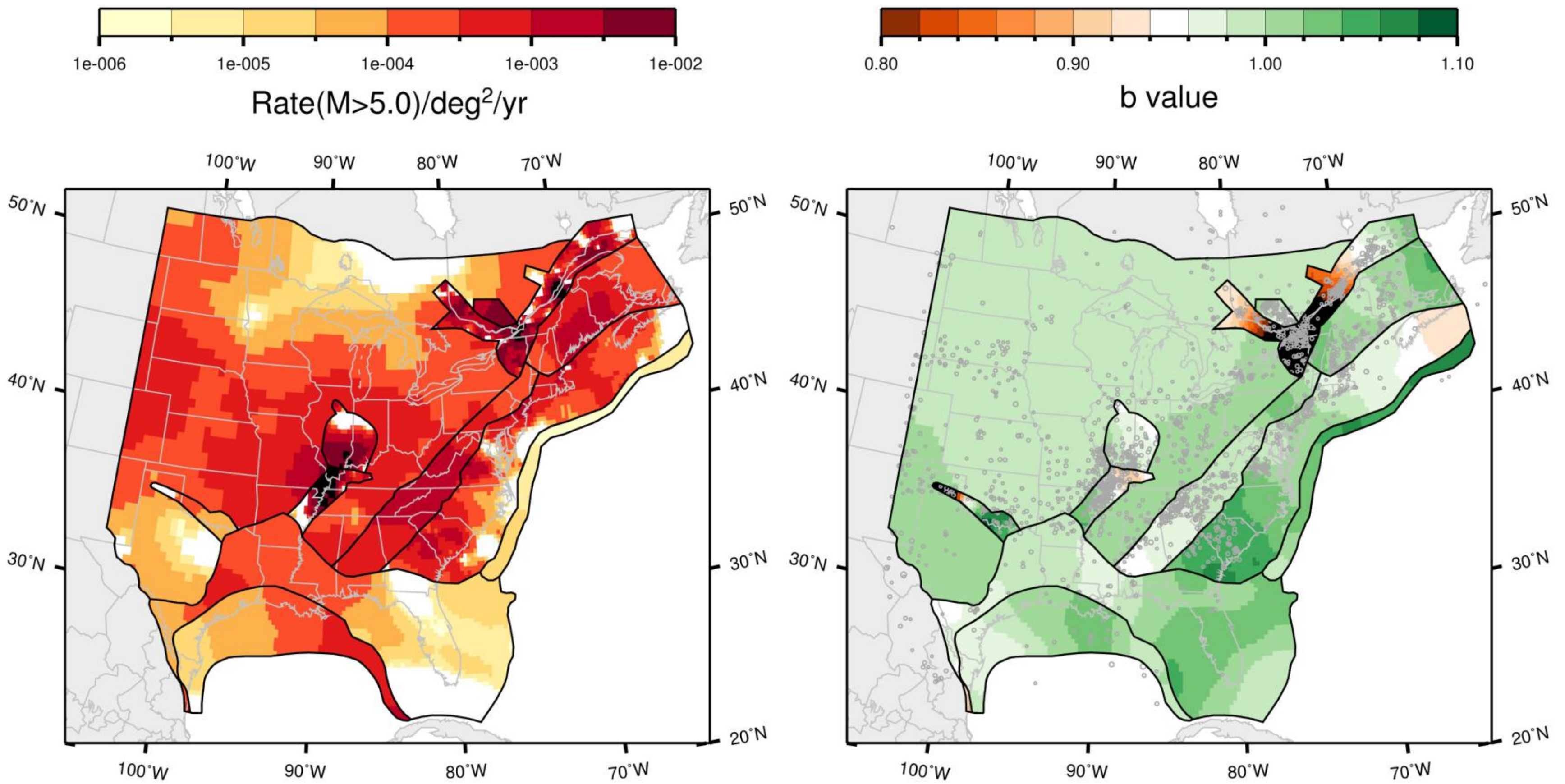


Figure J-128
Map of the rate and *b*-value for the study region under the seismotectonic zonation, with narrow interpretation of PEZ; Case E magnitude weights: Realization 2

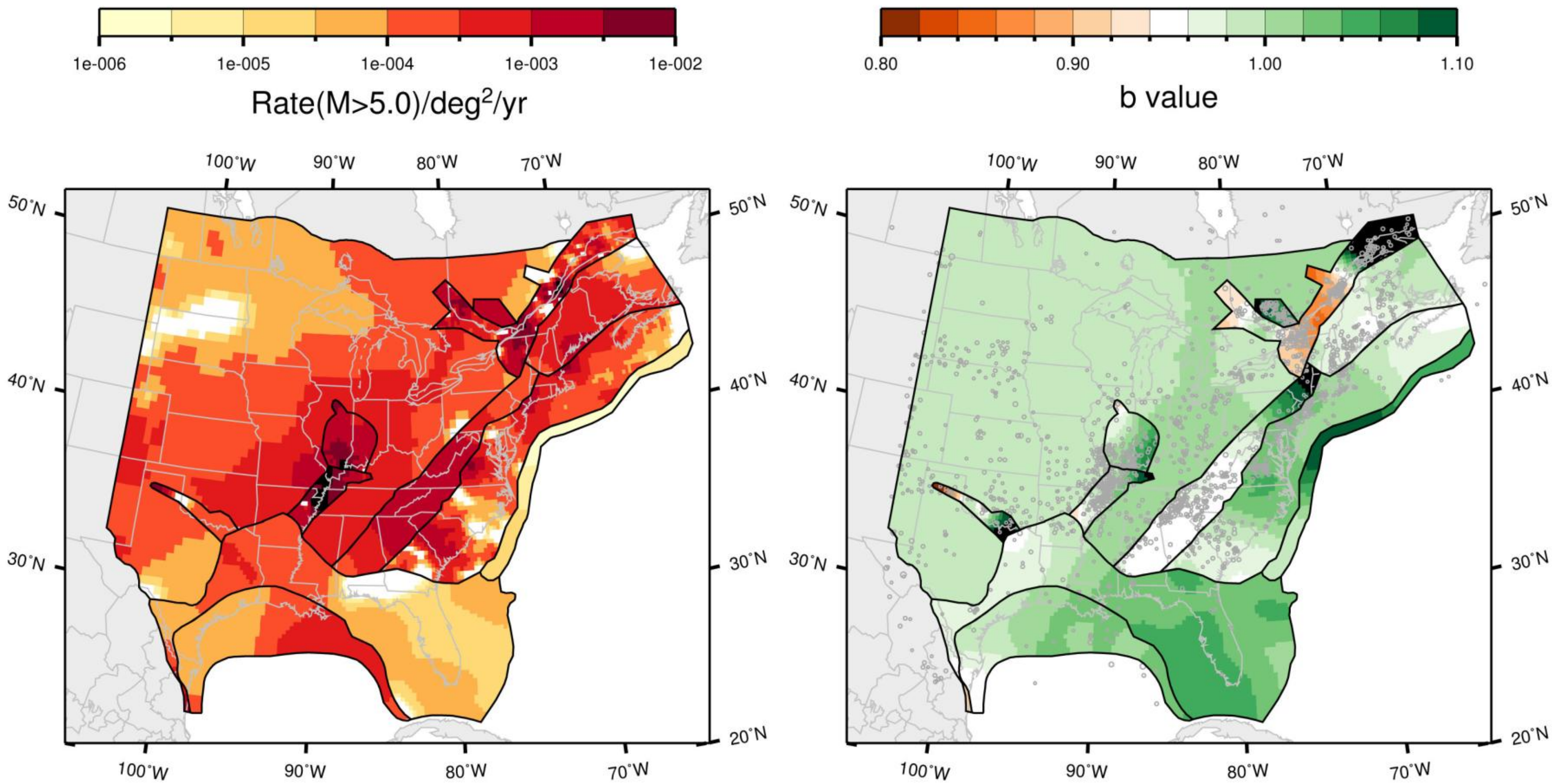


Figure J-129
Map of the rate and *b*-value for the study region under the seismotectonic zonation, with narrow interpretation of PEZ; Case E magnitude weights: Realization 3

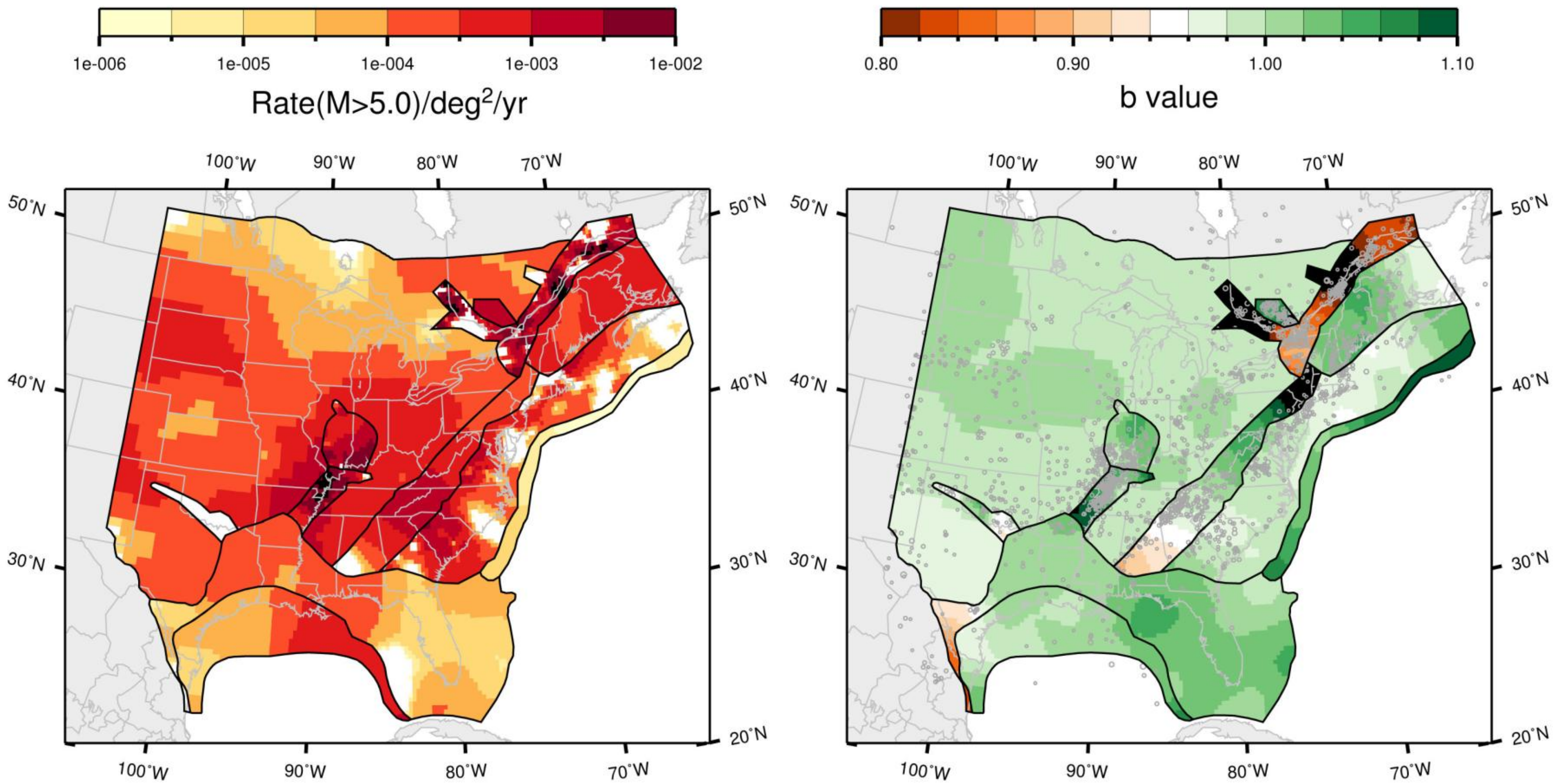


Figure J-130
Map of the rate and *b*-value for the study region under the seismotectonic zonation, with narrow interpretation of PEZ; Case E magnitude weights: Realization 4

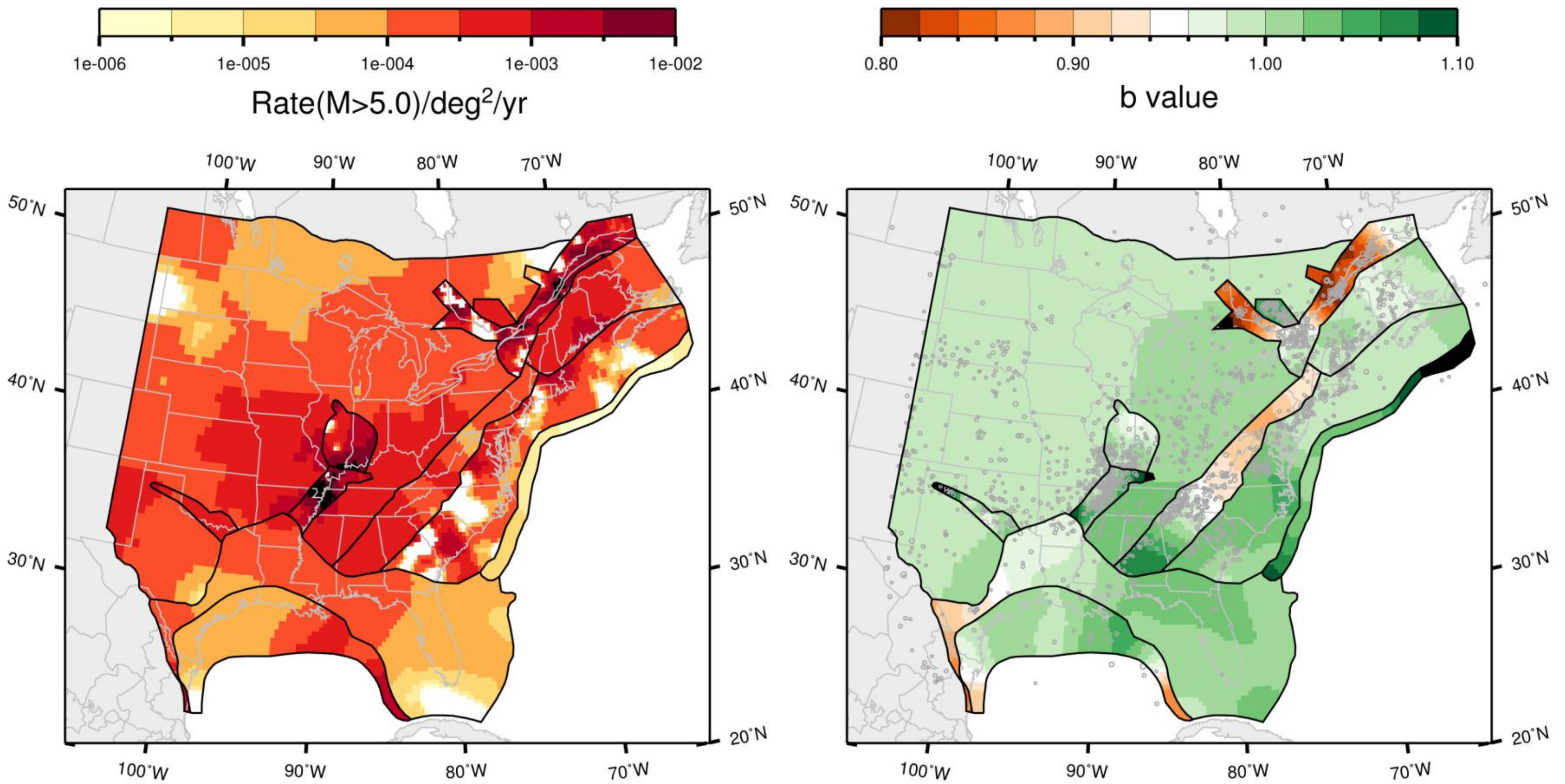


Figure J-131
Map of the rate and *b*-value for the study region under the seismotectonic zonation, with narrow interpretation of PEZ; Case E magnitude weights: Realization 5

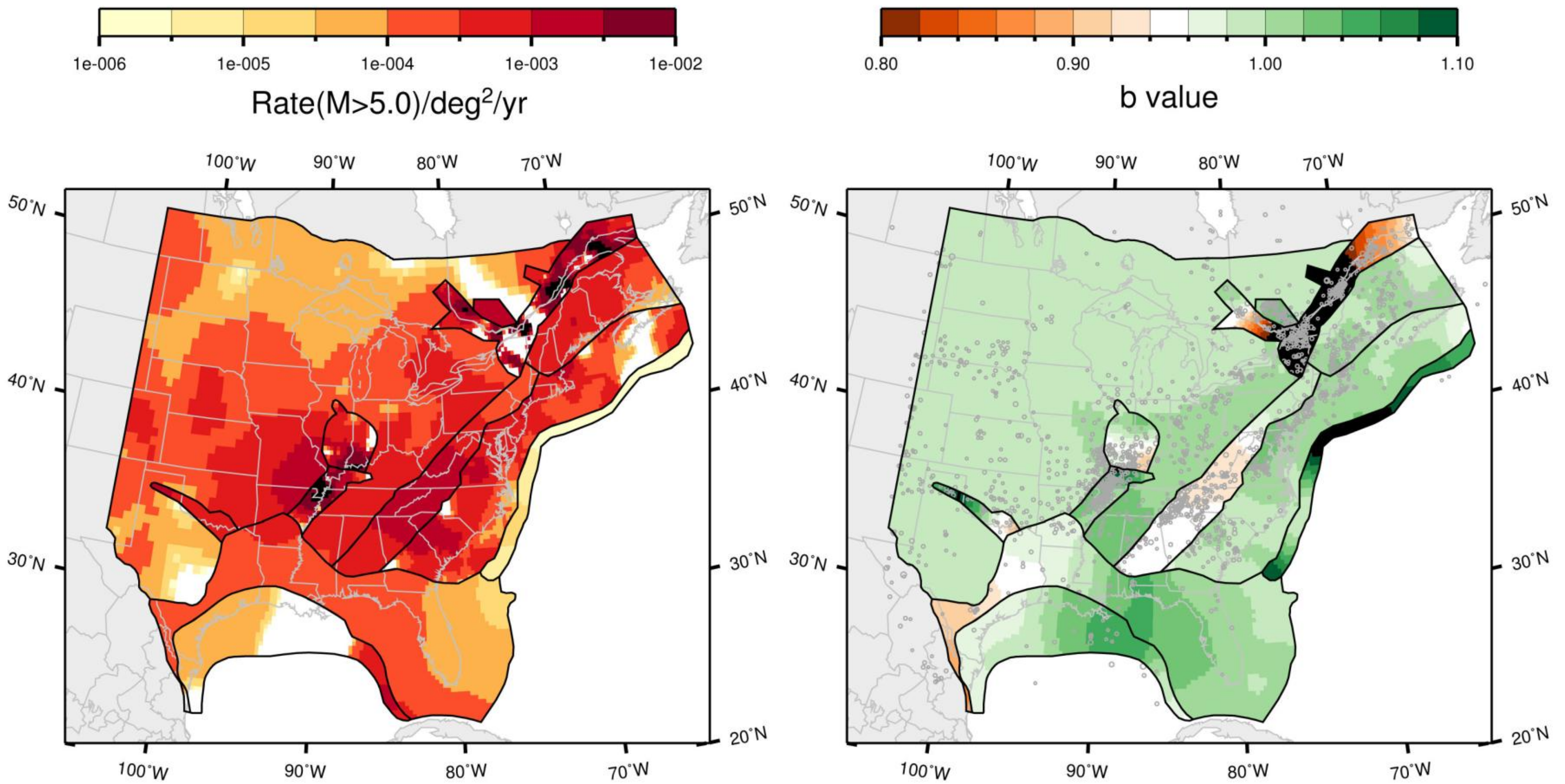


Figure J-132
Map of the rate and *b*-value for the study region under the seismotectonic zonation, with narrow interpretation of PEZ; Case E magnitude weights: Realization 6

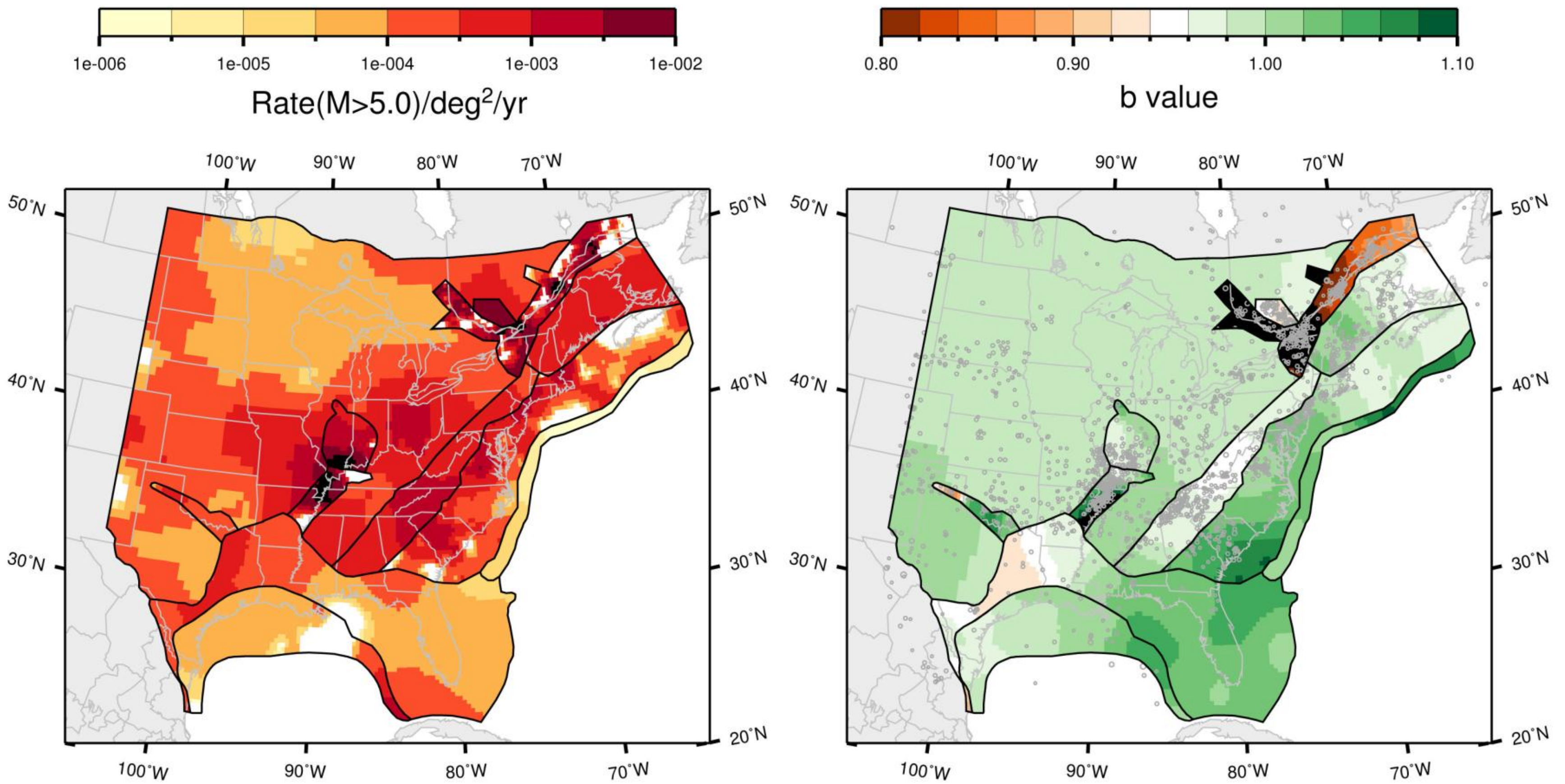


Figure J-133
Map of the rate and *b*-value for the study region under the seismotectonic zonation, with narrow interpretation of PEZ; Case E magnitude weights: Realization 7

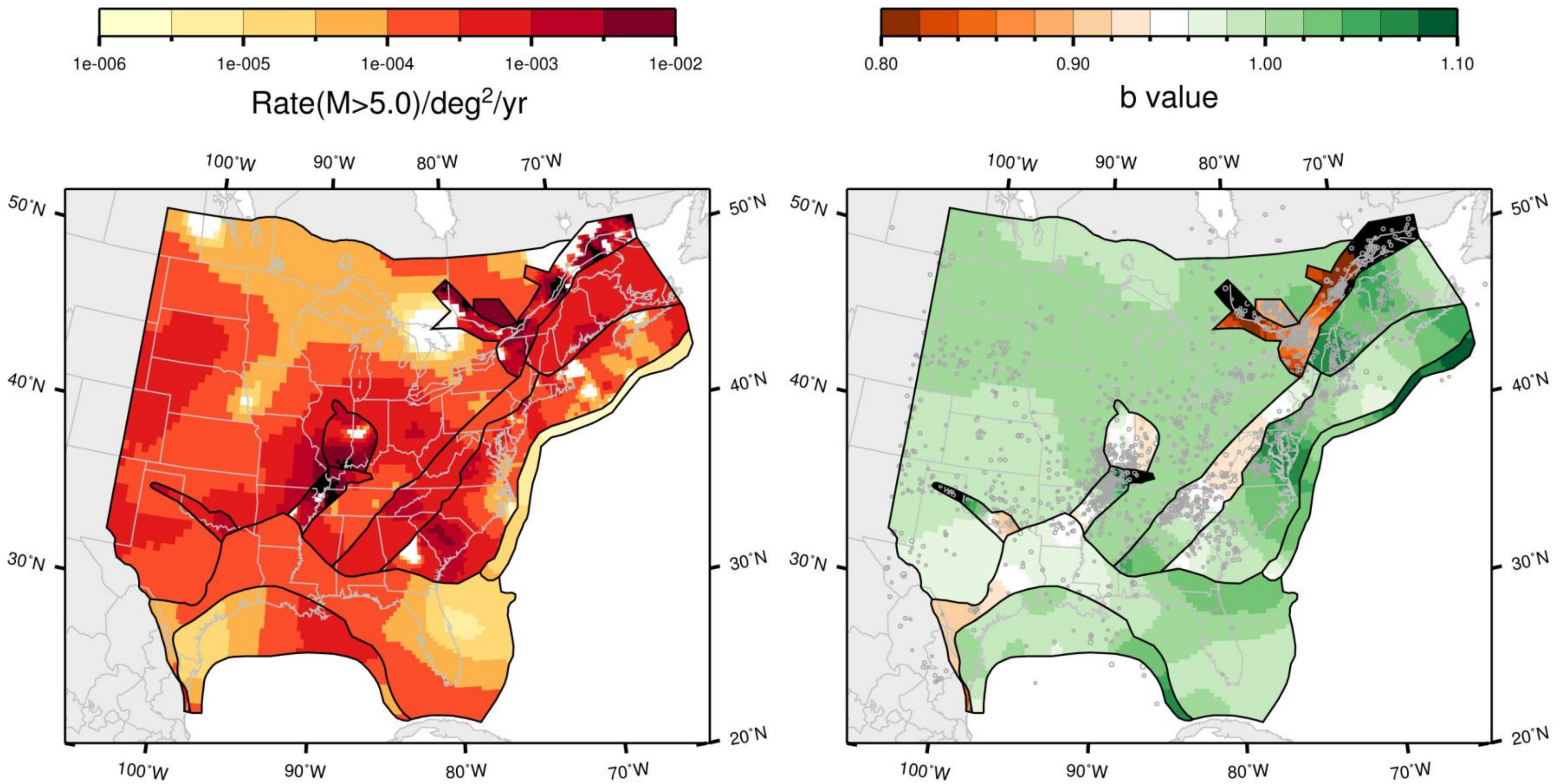


Figure J-134
Map of the rate and *b*-value for the study region under the seismotectonic zonation, with narrow interpretation of PEZ; Case E magnitude weights: Realization 8

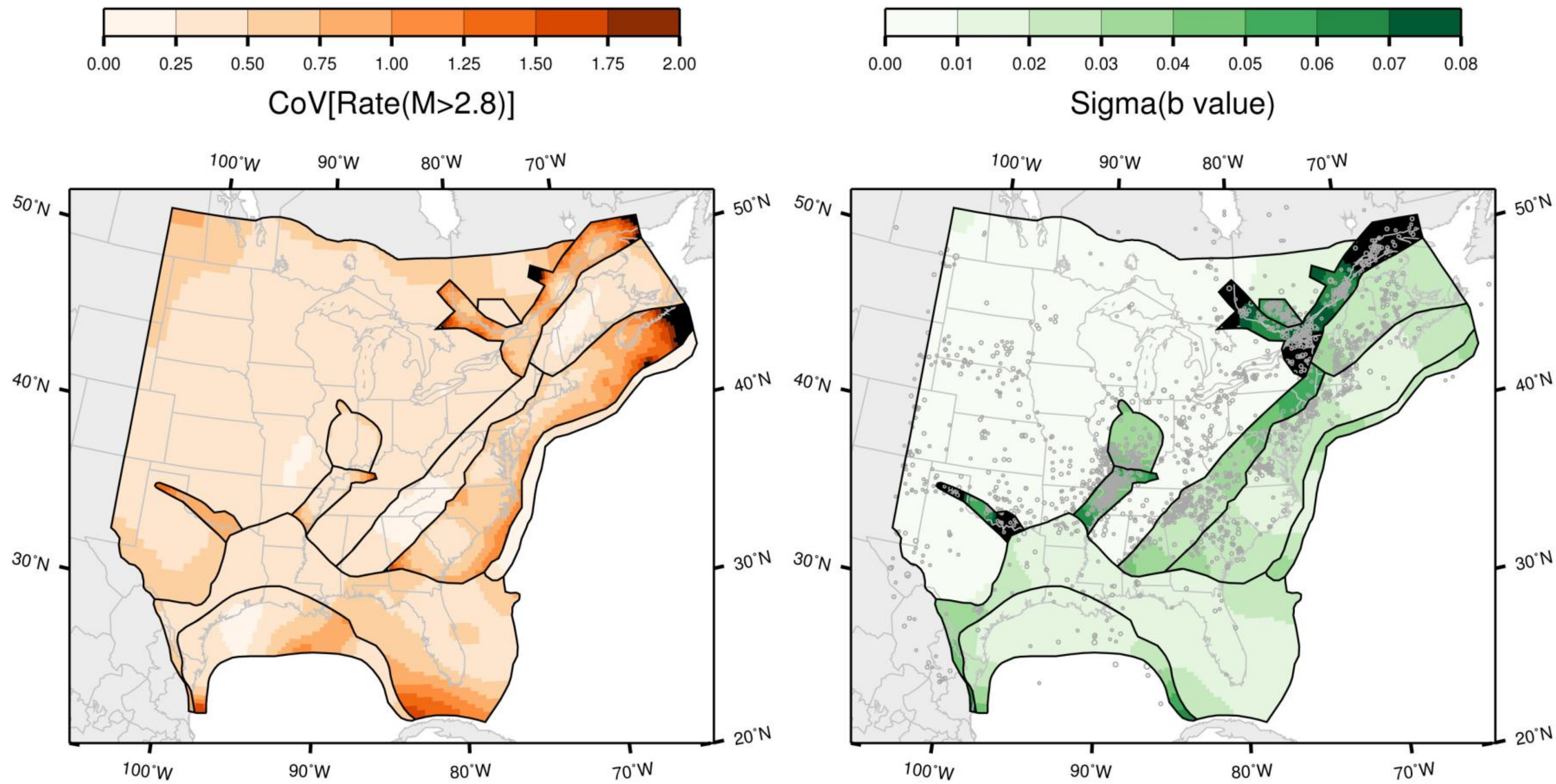


Figure J-135
Map of the coefficient of variation of the rate and the standard deviation of the *b*-value for the study region under the seismotectonic zonation, with narrow interpretation of PEZ; Case E magnitude weights

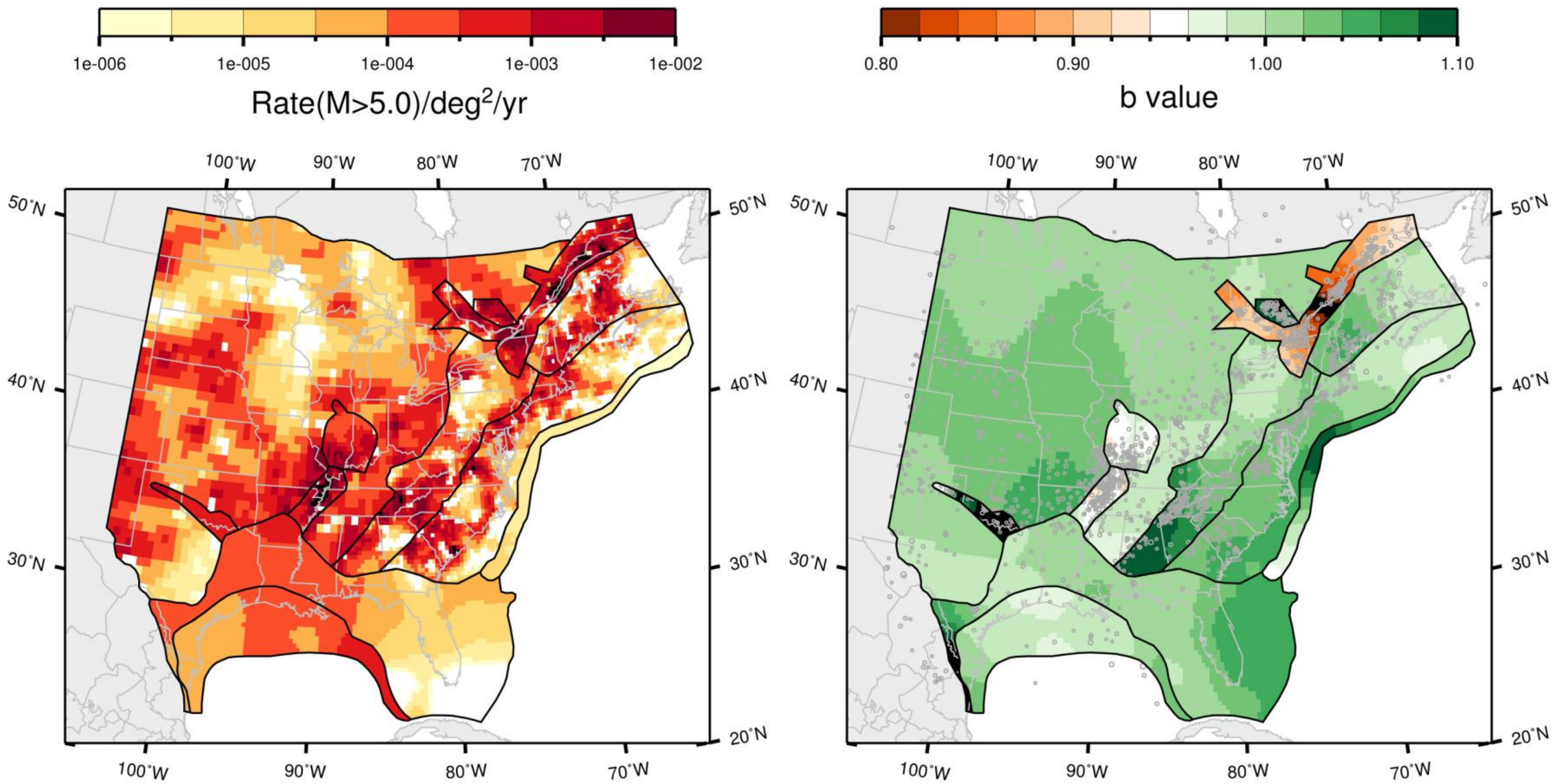


Figure J-136
Map of the rate and *b*-value for the study region under the seismotectonic zonation, with wide interpretation of PEZ; Case A magnitude weights: Realization 1

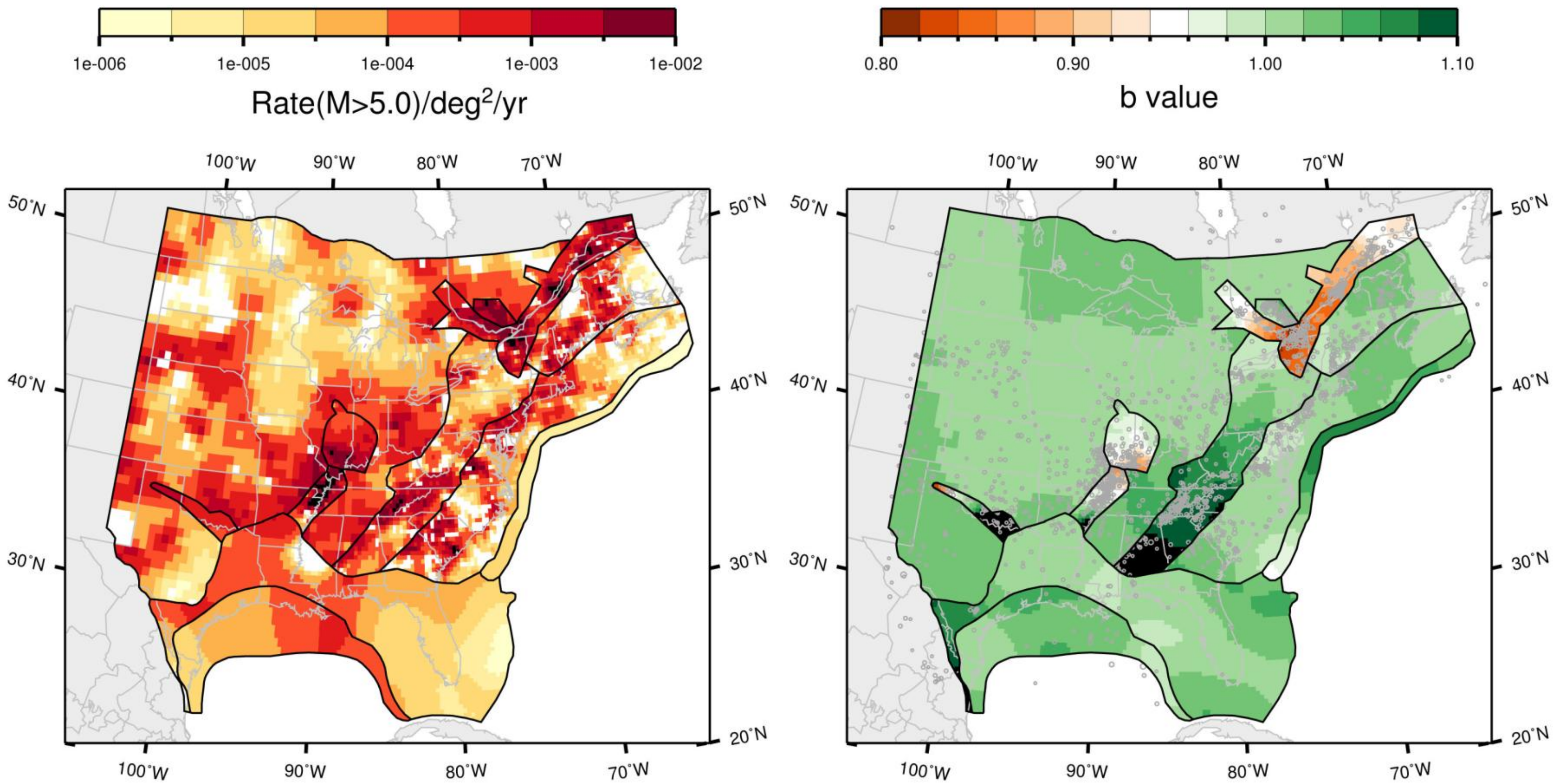


Figure J-137
Map of the rate and *b*-value for the study region under the seismotectonic zonation, with wide interpretation of PEZ; Case A magnitude weights: Realization 2

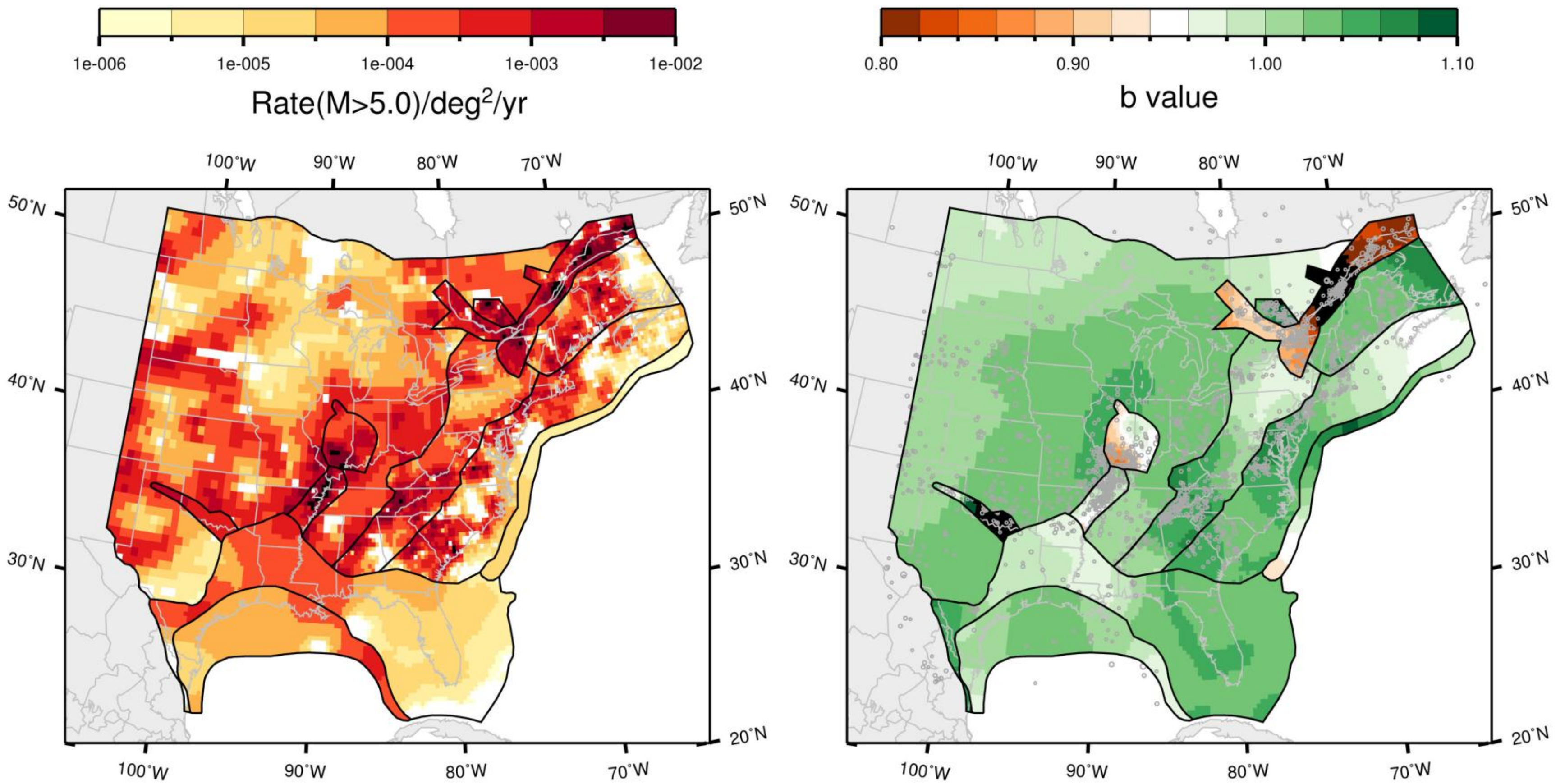


Figure J-138
Map of the rate and *b*-value for the study region under the seismotectonic zonation, with wide interpretation of PEZ; Case A magnitude weights: Realization 3

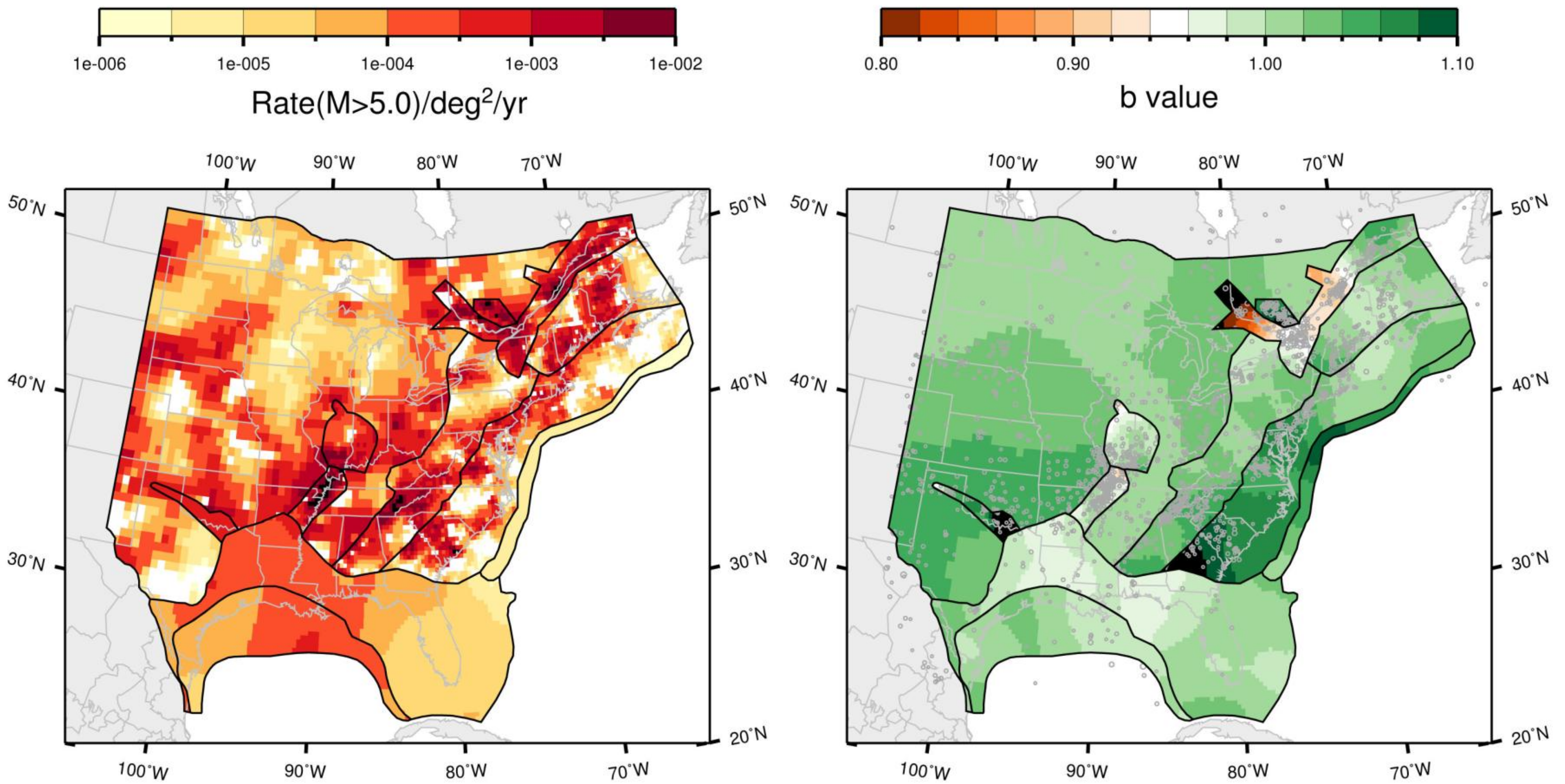


Figure J-139
Map of the rate and *b*-value for the study region under the seismotectonic zonation, with wide interpretation of PEZ; Case A magnitude weights: Realization 4

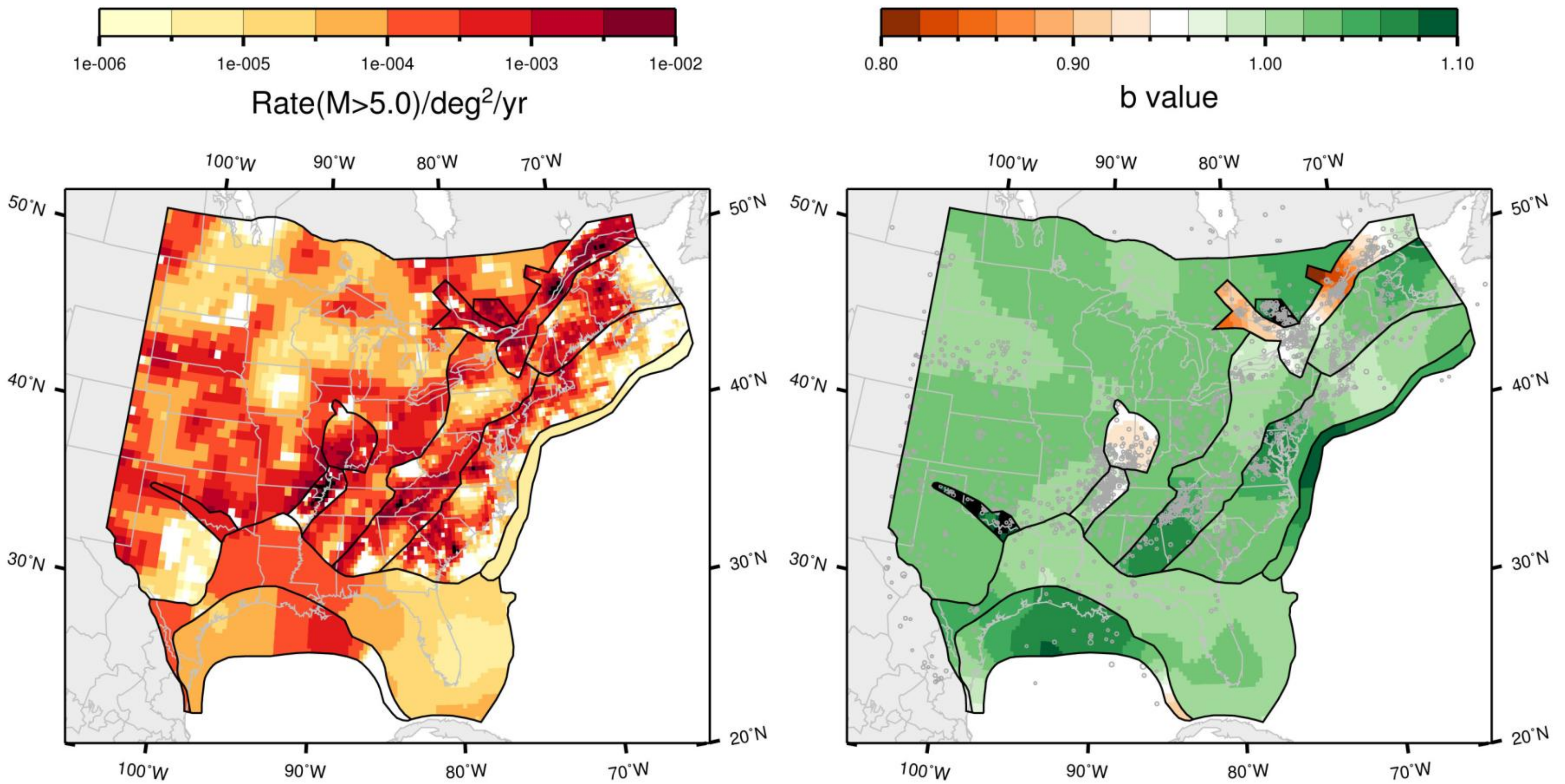


Figure J-140
Map of the rate and *b*-value for the study region under the seismotectonic zonation, with wide interpretation of PEZ; Case A magnitude weights: Realization 5

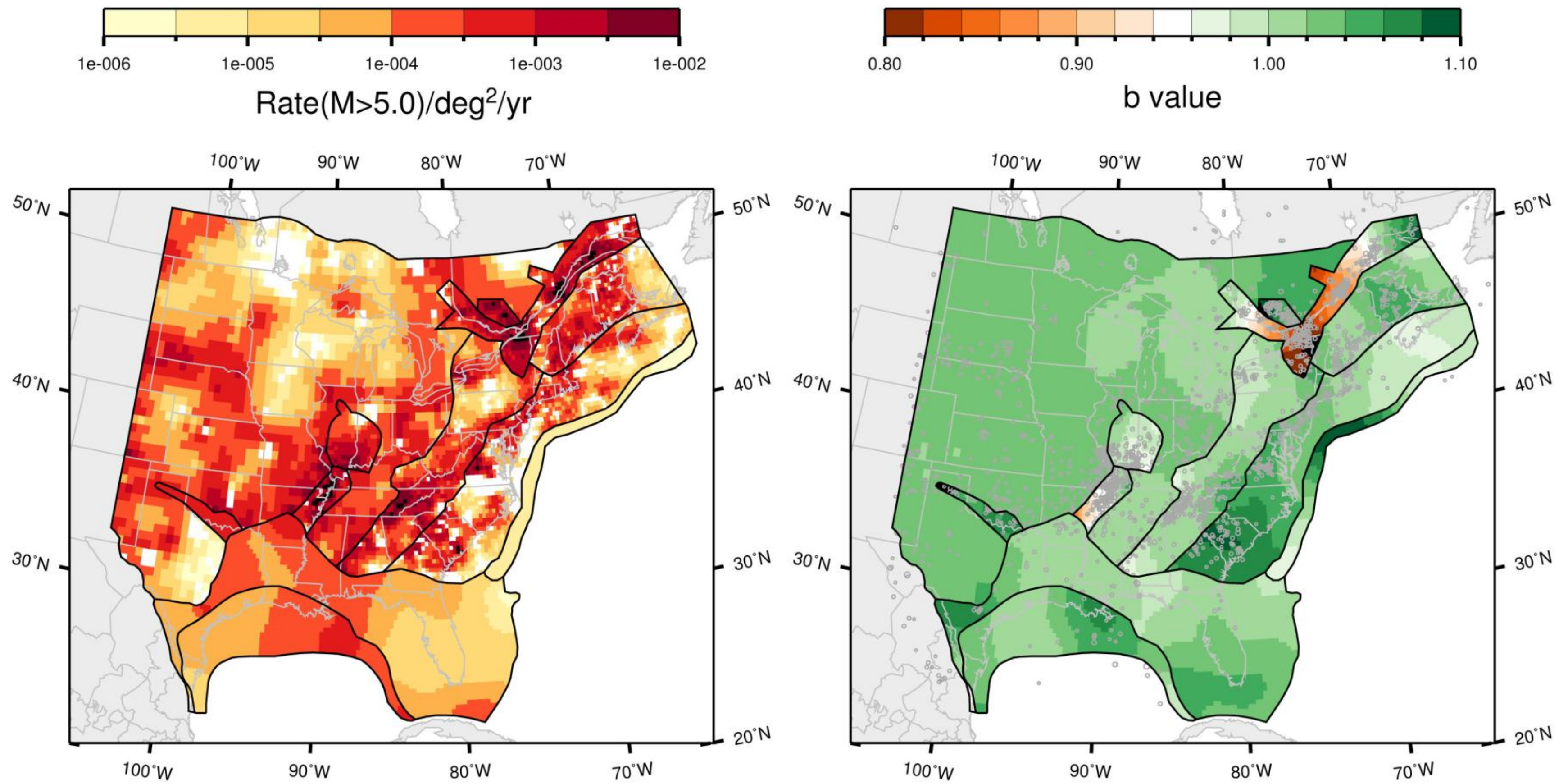


Figure J-141
Map of the rate and *b*-value for the study region under the seismotectonic zonation, with wide interpretation of PEZ; Case A magnitude weights: Realization 6

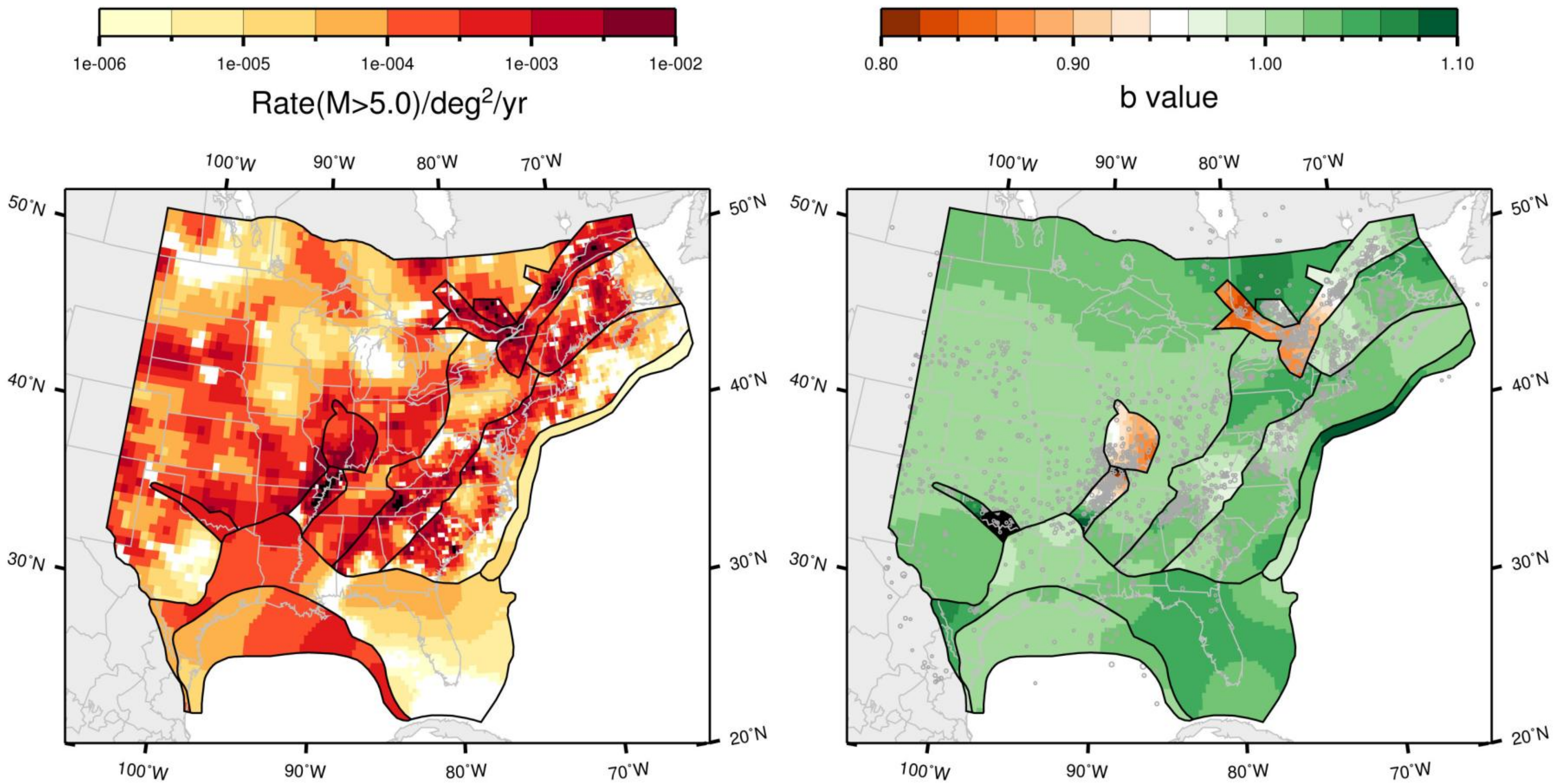


Figure J-142
Map of the rate and *b*-value for the study region under the seismotectonic zonation, with wide interpretation of PEZ; Case A magnitude weights: Realization 7

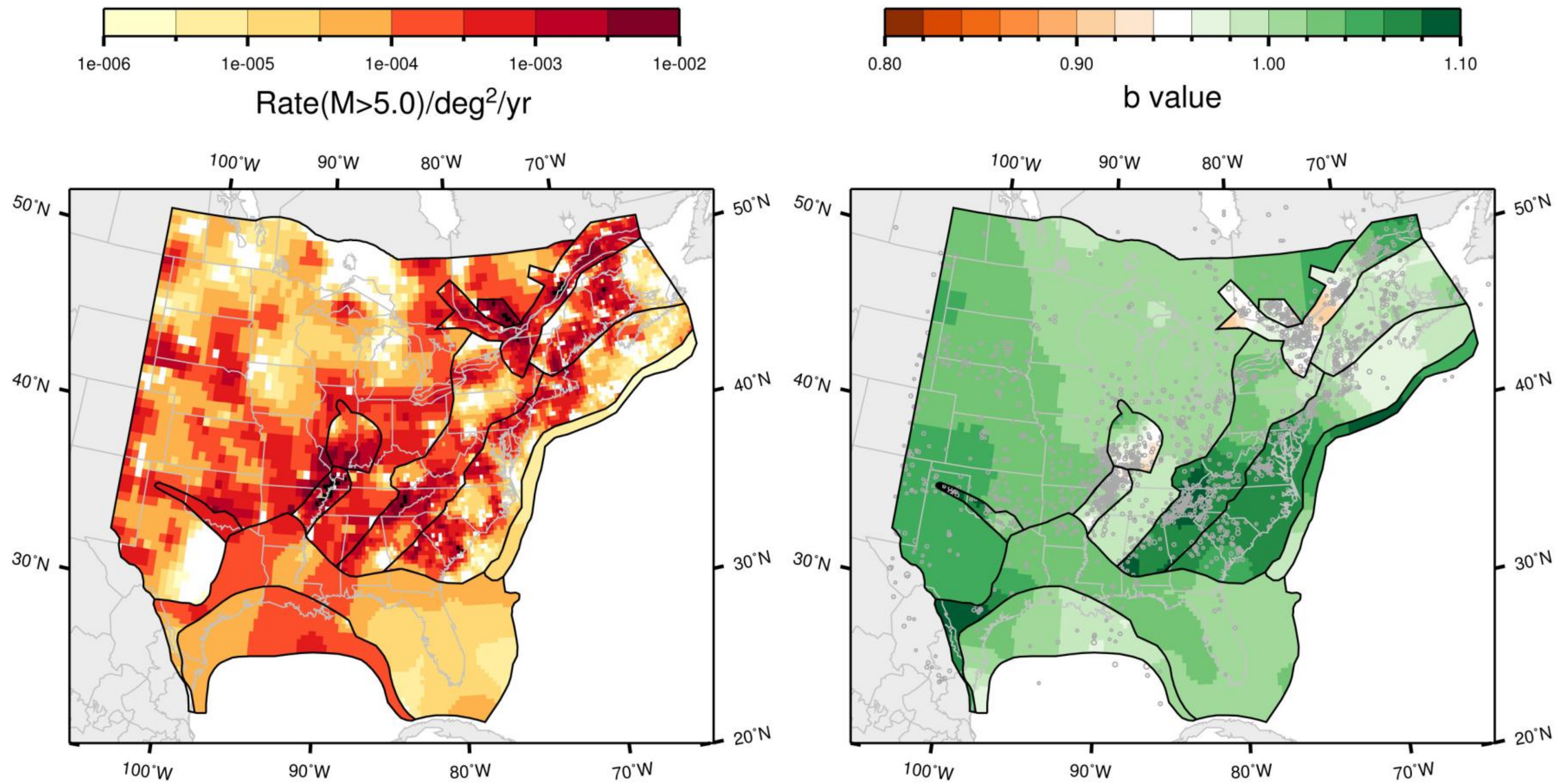


Figure J-143
Map of the rate and *b*-value for the study region under the seismotectonic zonation, with wide interpretation of PEZ; Case A magnitude weights: Realization 8

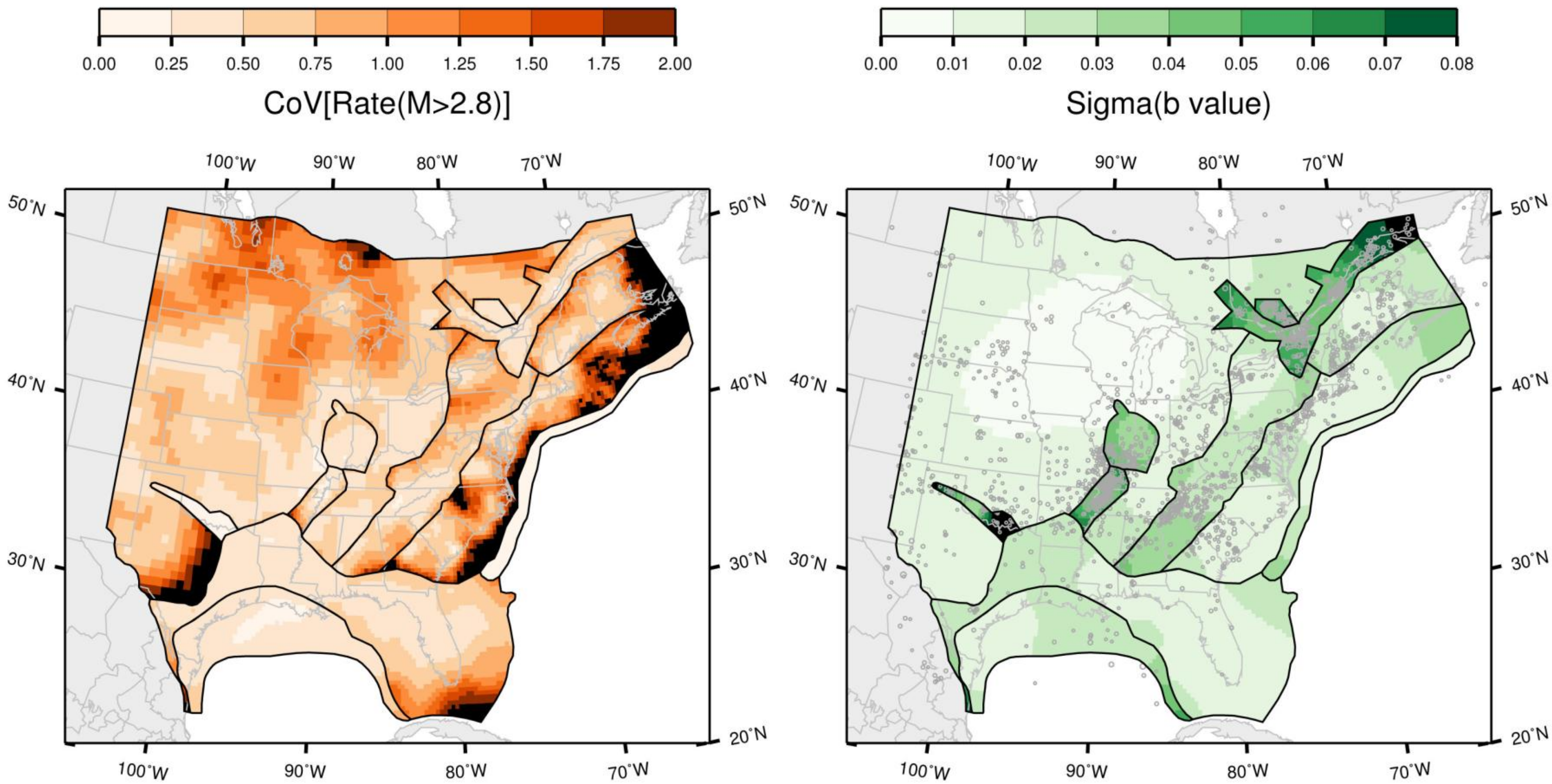


Figure J-144
Map of the coefficient of variation of the rate and the standard deviation of the *b*-value for the study region under the seismotectonic zonation, with wide interpretation of PEZ; Case A magnitude weights

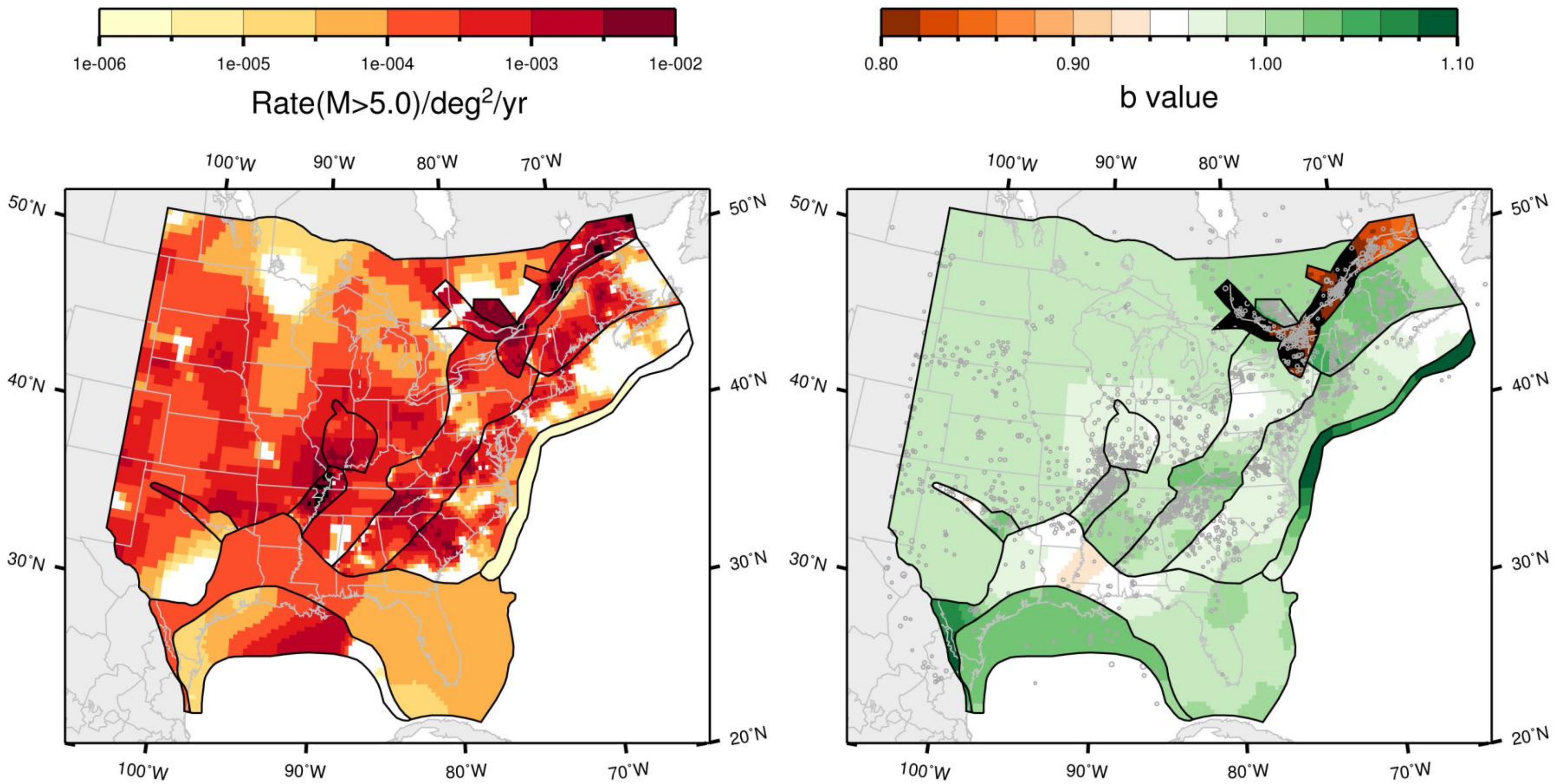


Figure J-145
Map of the rate and *b*-value for the study region under the seismotectonic zonation, with wide interpretation of PEZ; Case B magnitude weights: Realization 1

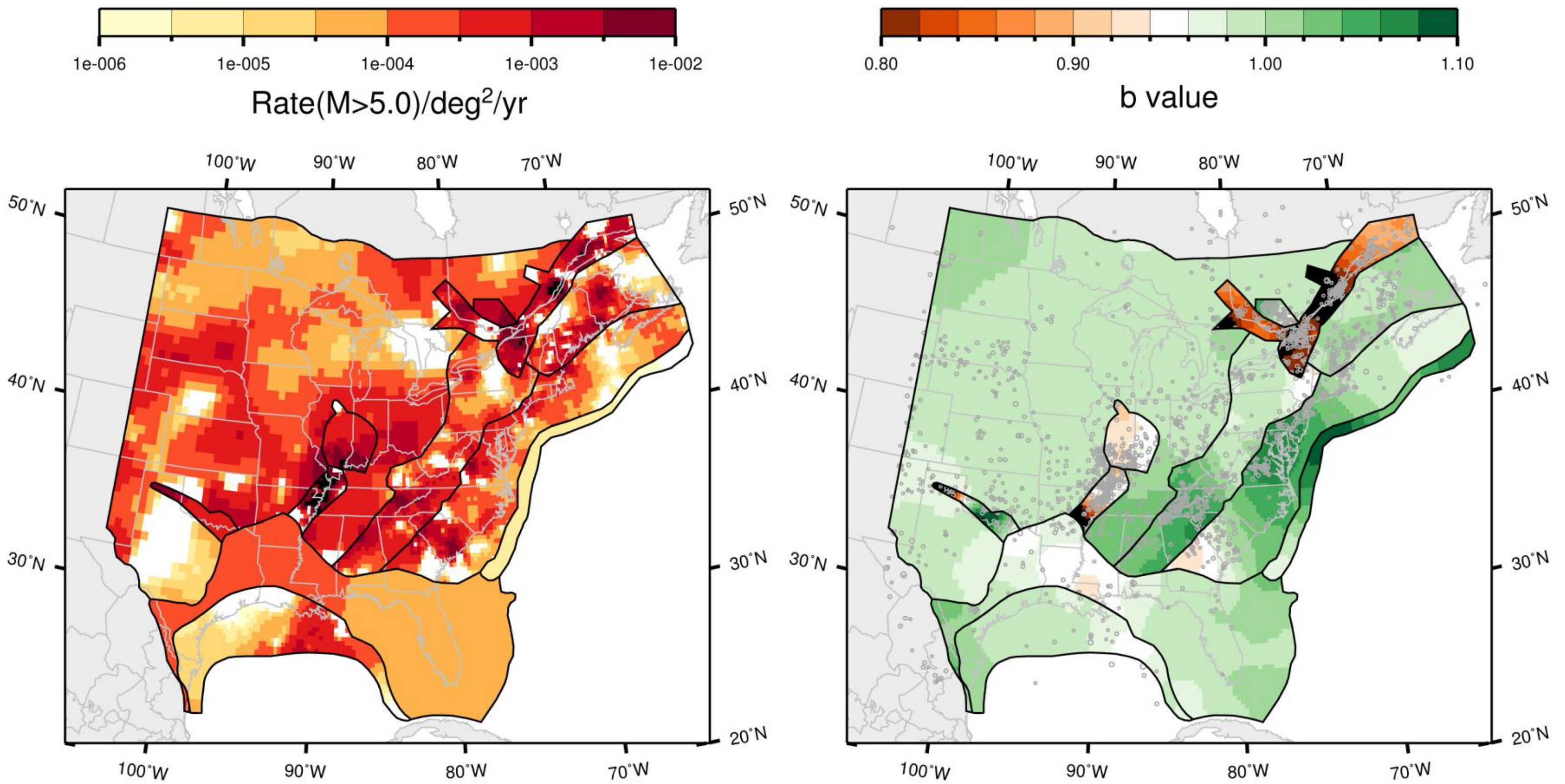


Figure J-146
Map of the rate and *b*-value for the study region under the seismotectonic zonation, with wide interpretation of PEZ; Case B magnitude weights: Realization 2

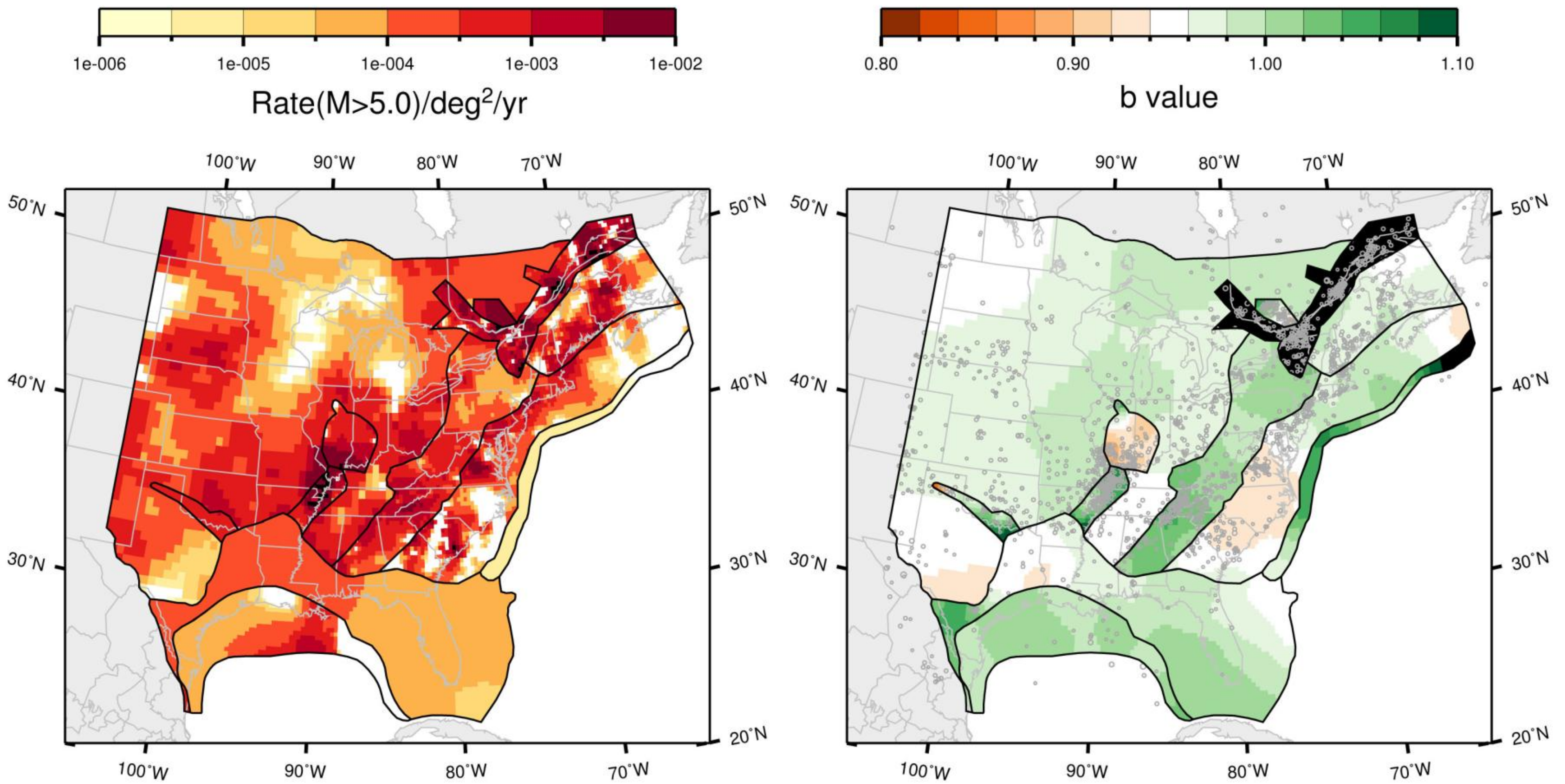


Figure J-147
Map of the rate and *b*-value for the study region under the seismotectonic zonation, with wide interpretation of PEZ; Case B magnitude weights: Realization 3

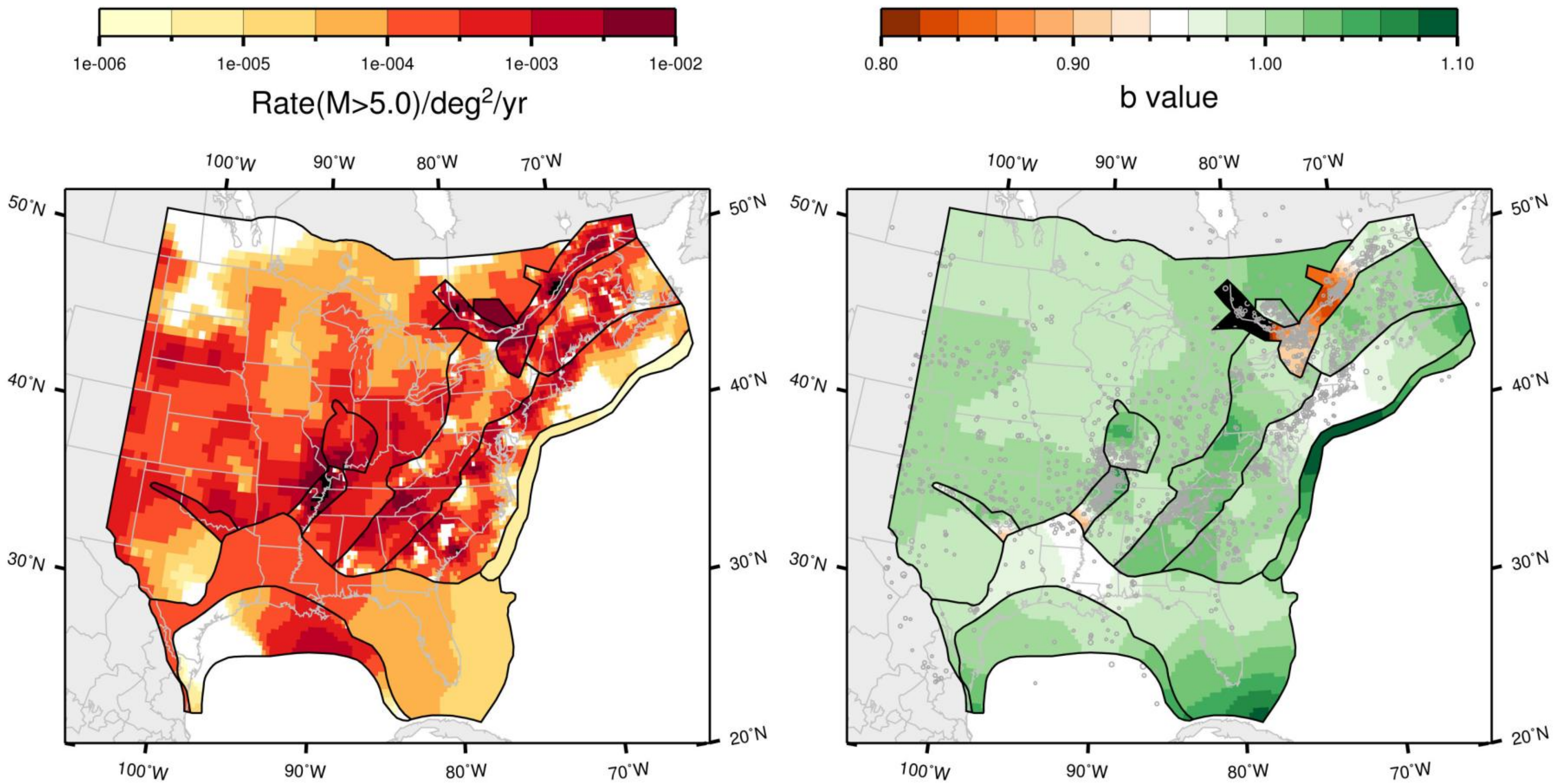


Figure J-148
Map of the rate and *b*-value for the study region under the seismotectonic zonation, with wide interpretation of PEZ; Case B magnitude weights: Realization 4

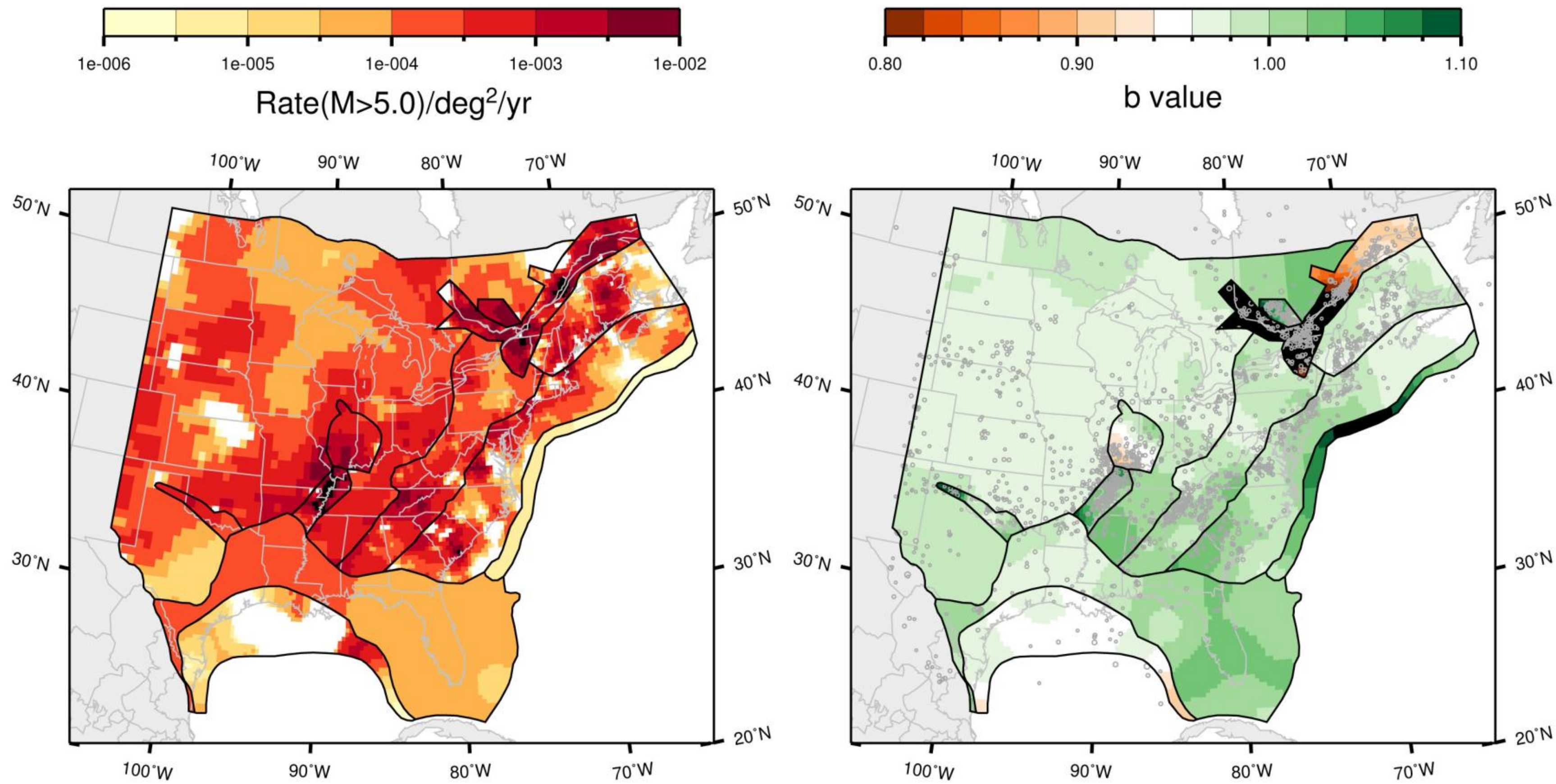


Figure J-149
Map of the rate and *b*-value for the study region under the seismotectonic zonation, with wide interpretation of PEZ; Case B magnitude weights: Realization 5

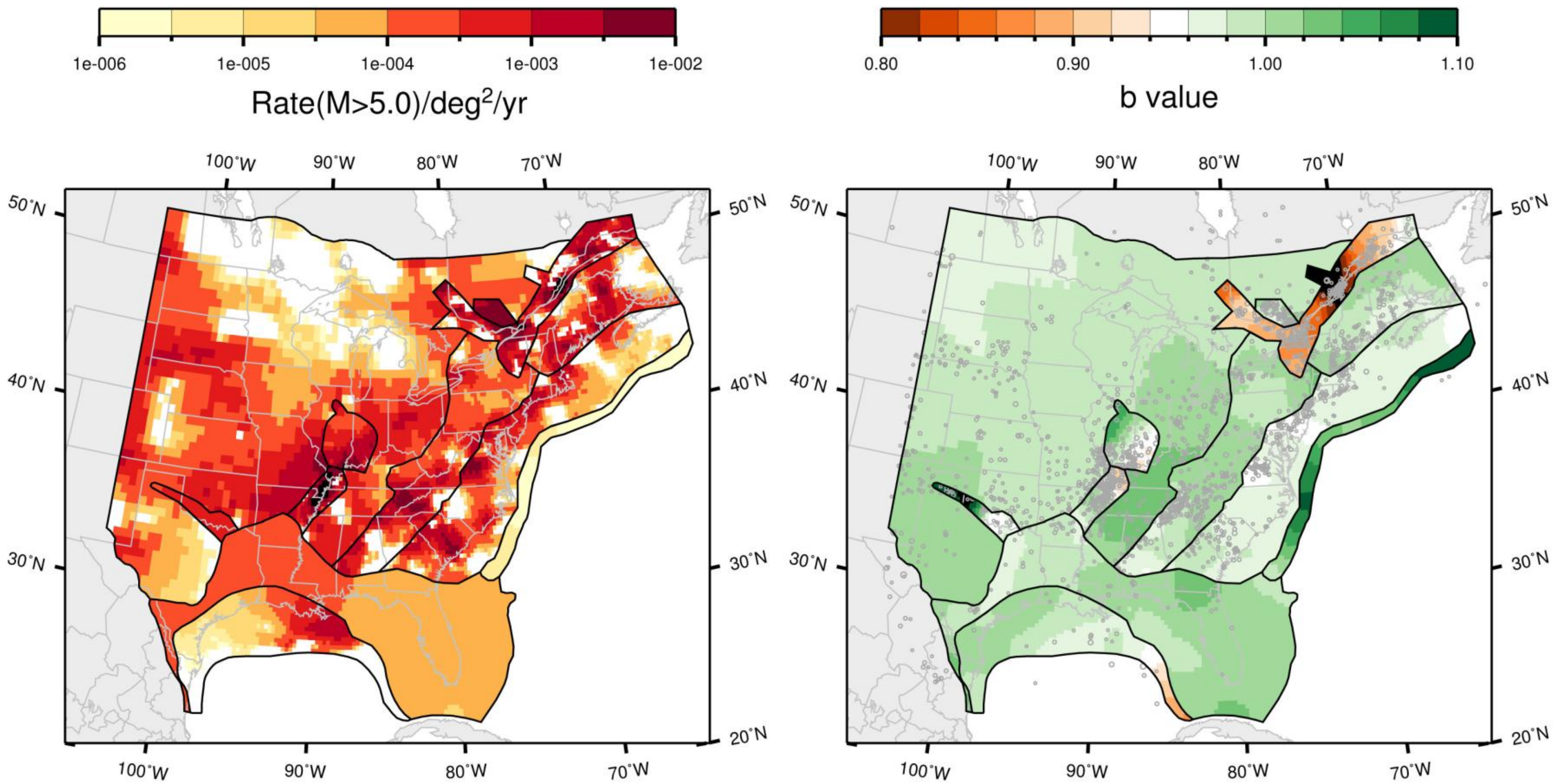
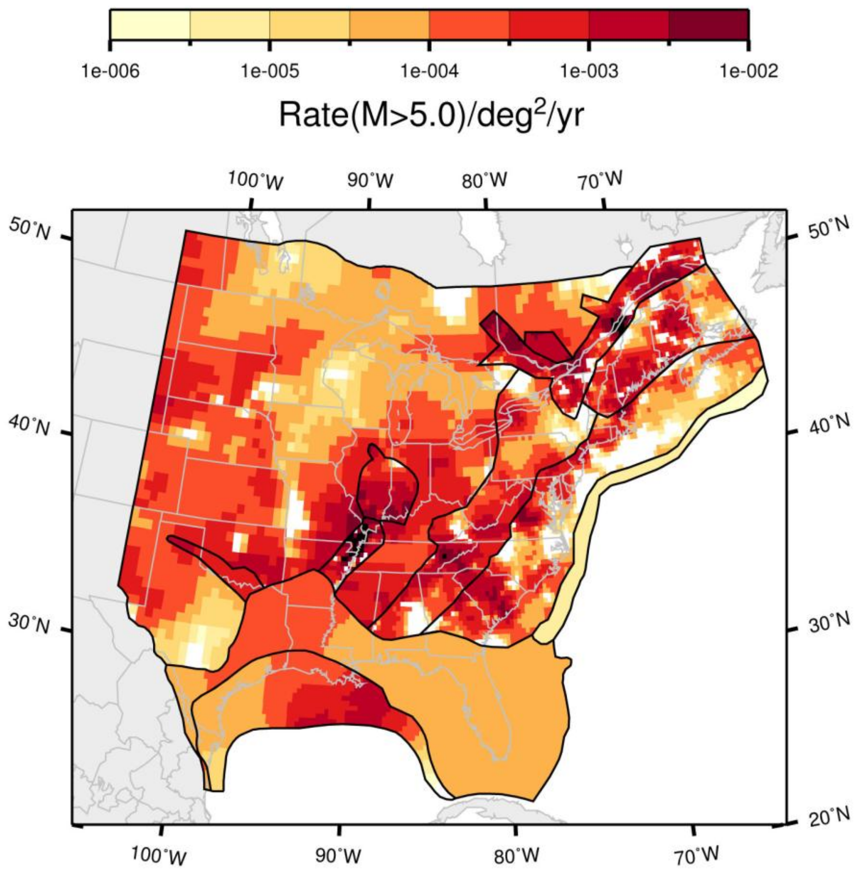


Figure J-150
Map of the rate and *b*-value for the study region under the seismotectonic zonation, with wide interpretation of PEZ; Case B magnitude weights: Realization 6



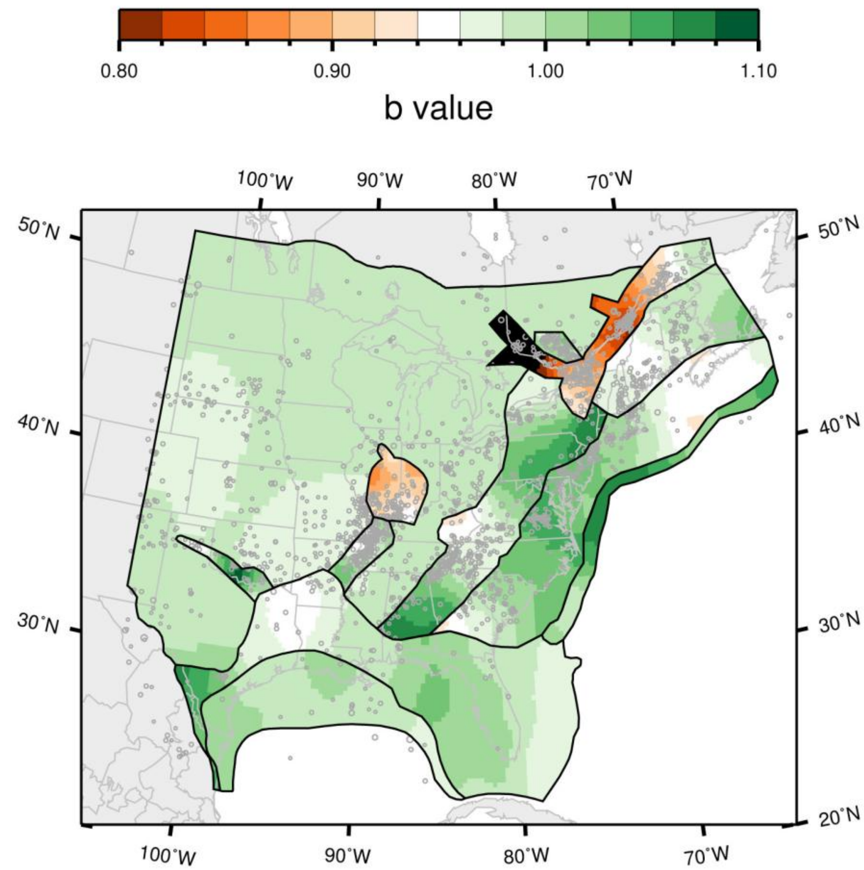


Figure J-151
Map of the rate and *b*-value for the study region under the seismotectonic zonation, with wide interpretation of PEZ; Case B magnitude weights: Realization 7

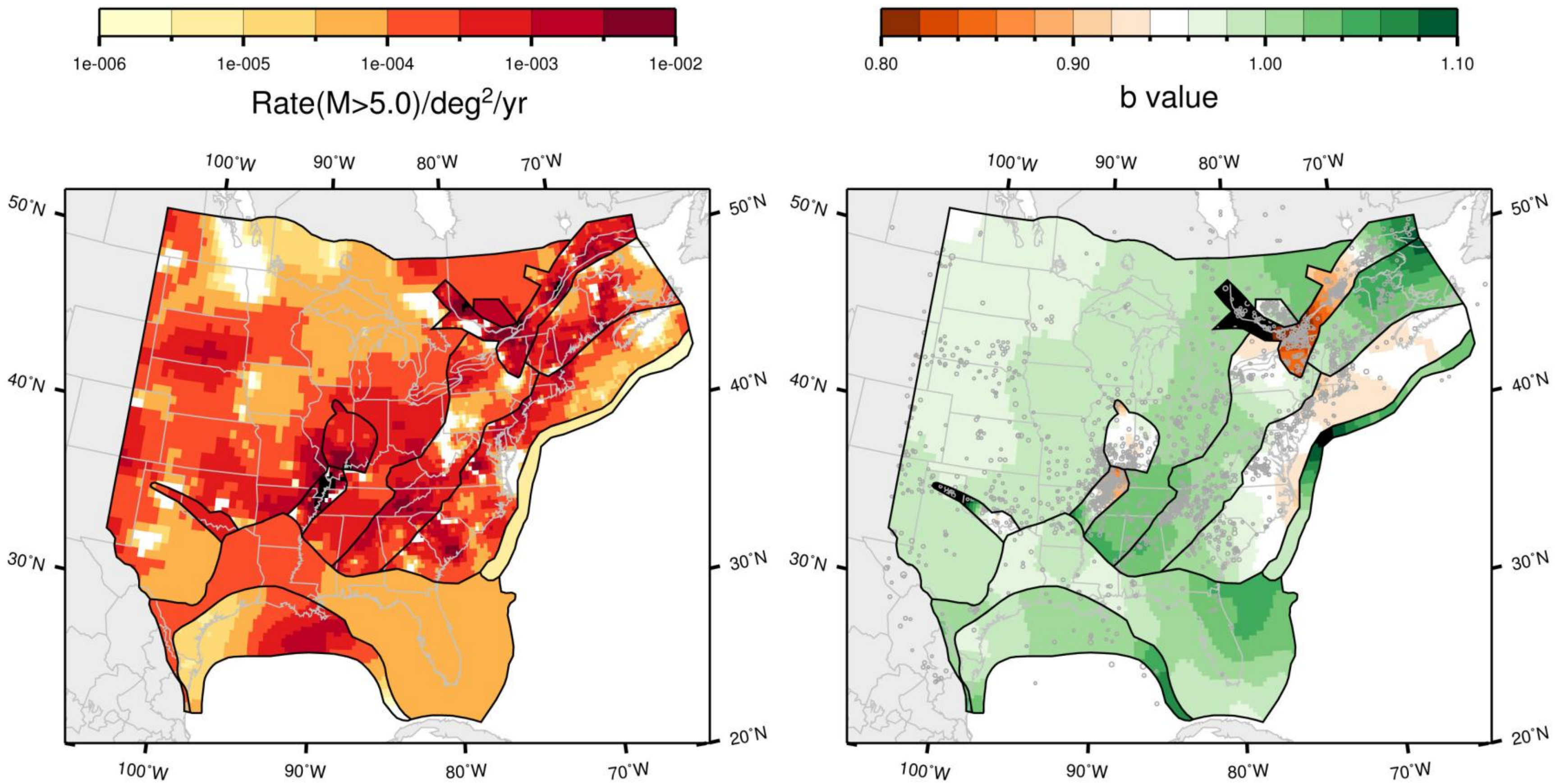


Figure J-152
Map of the rate and *b*-value for the study region under the seismotectonic zonation, with wide interpretation of PEZ; Case B magnitude weights: Realization 8

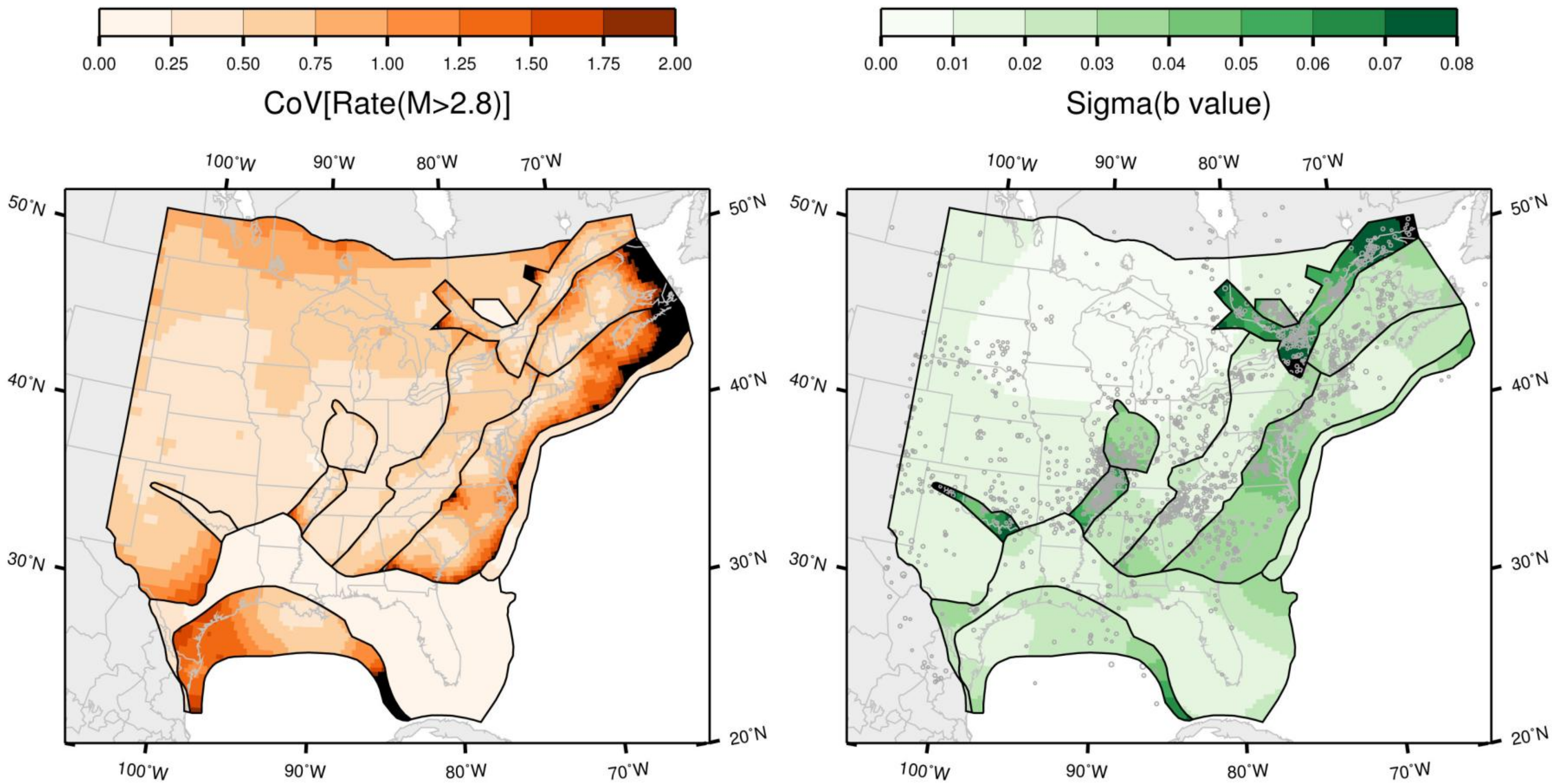


Figure J-153
Map of the coefficient of variation of the rate and the standard deviation of the *b*-value for the study region under the seismotectonic zonation, with wide interpretation of PEZ; Case B magnitude weights

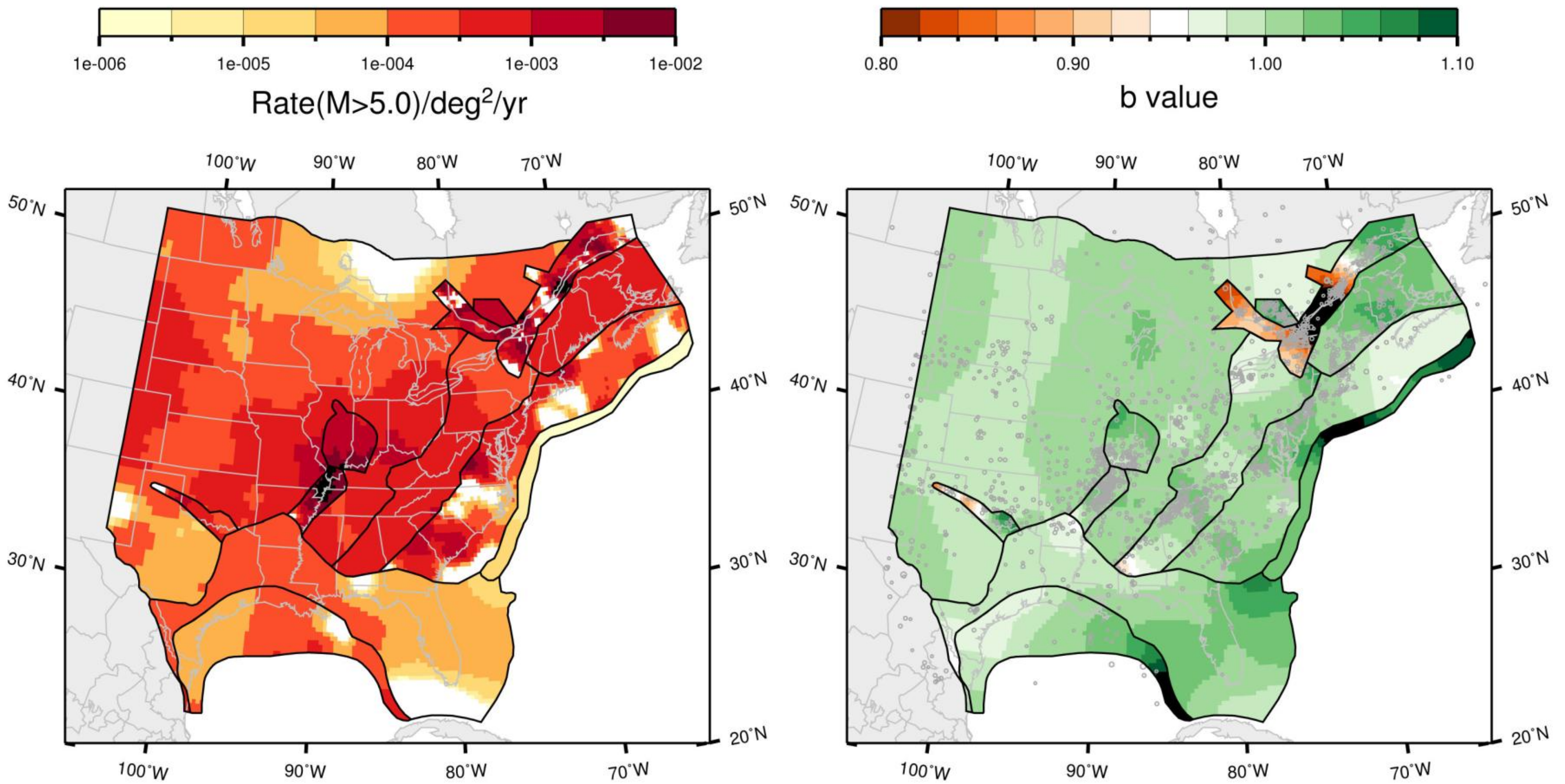
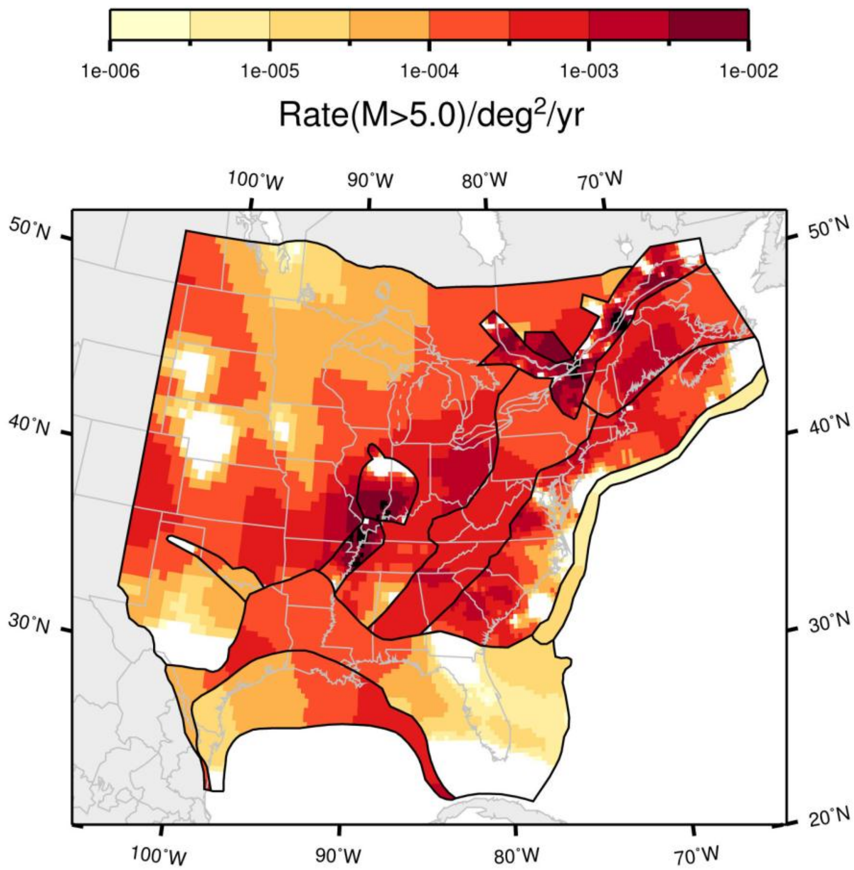


Figure J-154
Map of the rate and *b*-value for the study region under the seismotectonic zonation, with wide interpretation of PEZ; Case E magnitude weights: Realization 1



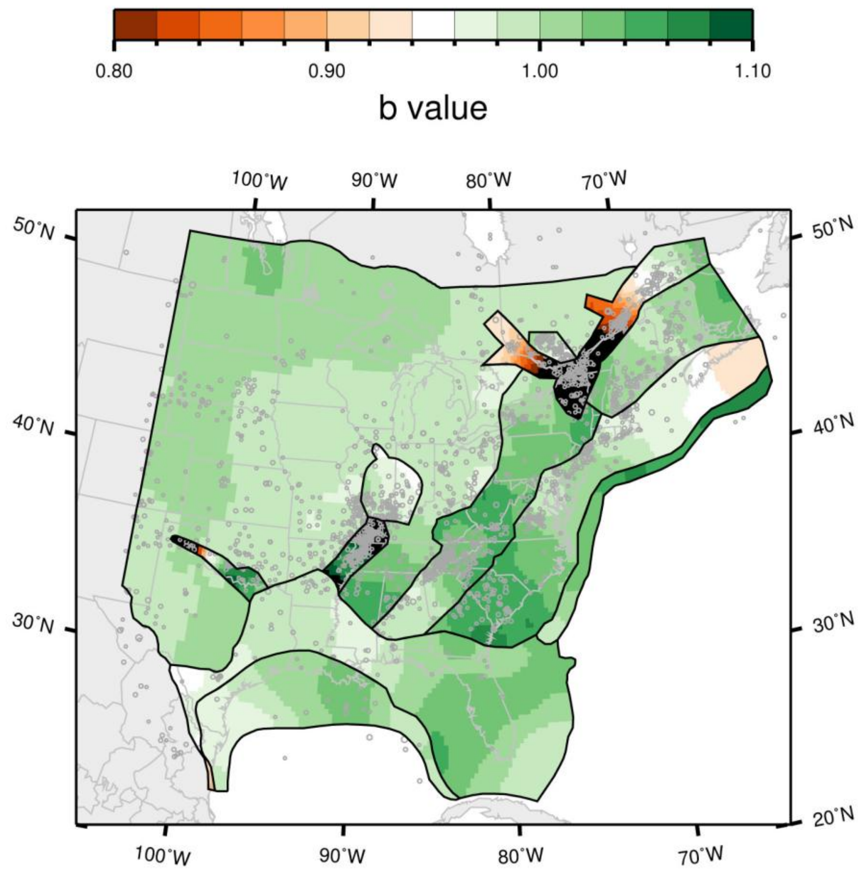


Figure J-155
Map of the rate and *b*-value for the study region under the seismotectonic zonation, with wide interpretation of PEZ; Case E magnitude weights: Realization 2

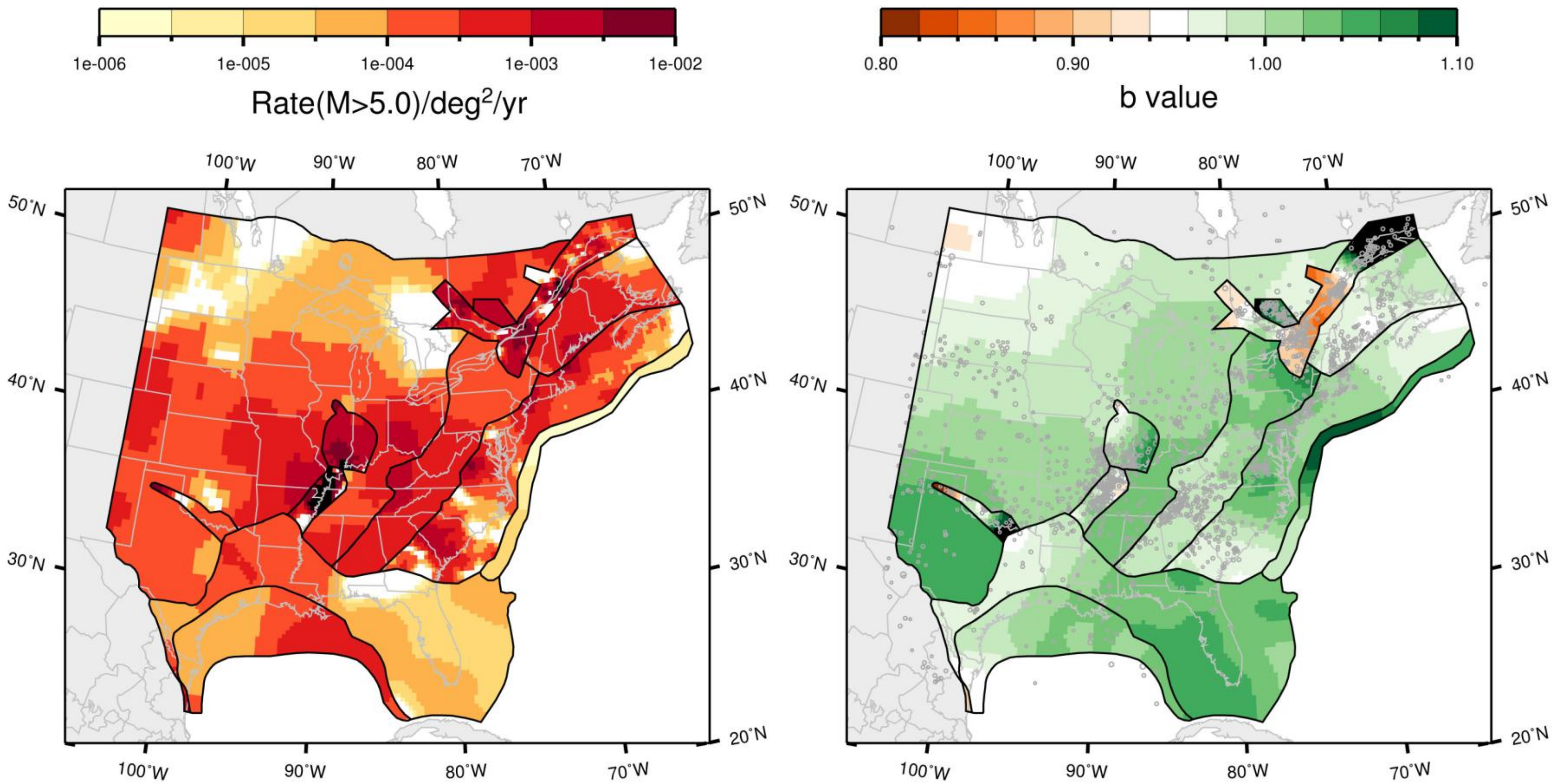


Figure J-156
Map of the rate and *b*-value for the study region under the seismotectonic zonation, with wide interpretation of PEZ; Case E magnitude weights: Realization 3

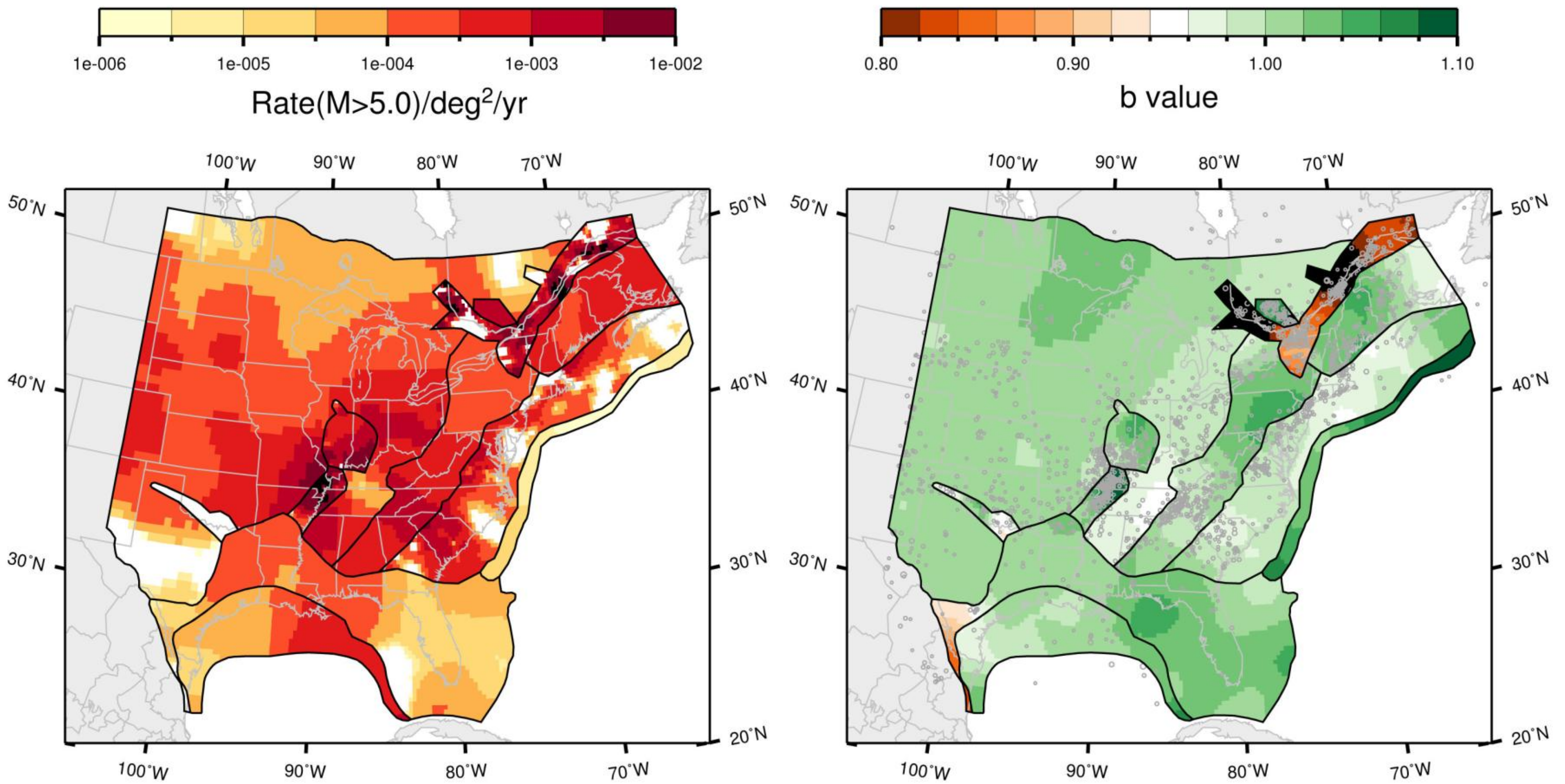


Figure J-157
Map of the rate and *b*-value for the study region under the seismotectonic zonation, with wide interpretation of PEZ; Case E magnitude weights: Realization 4

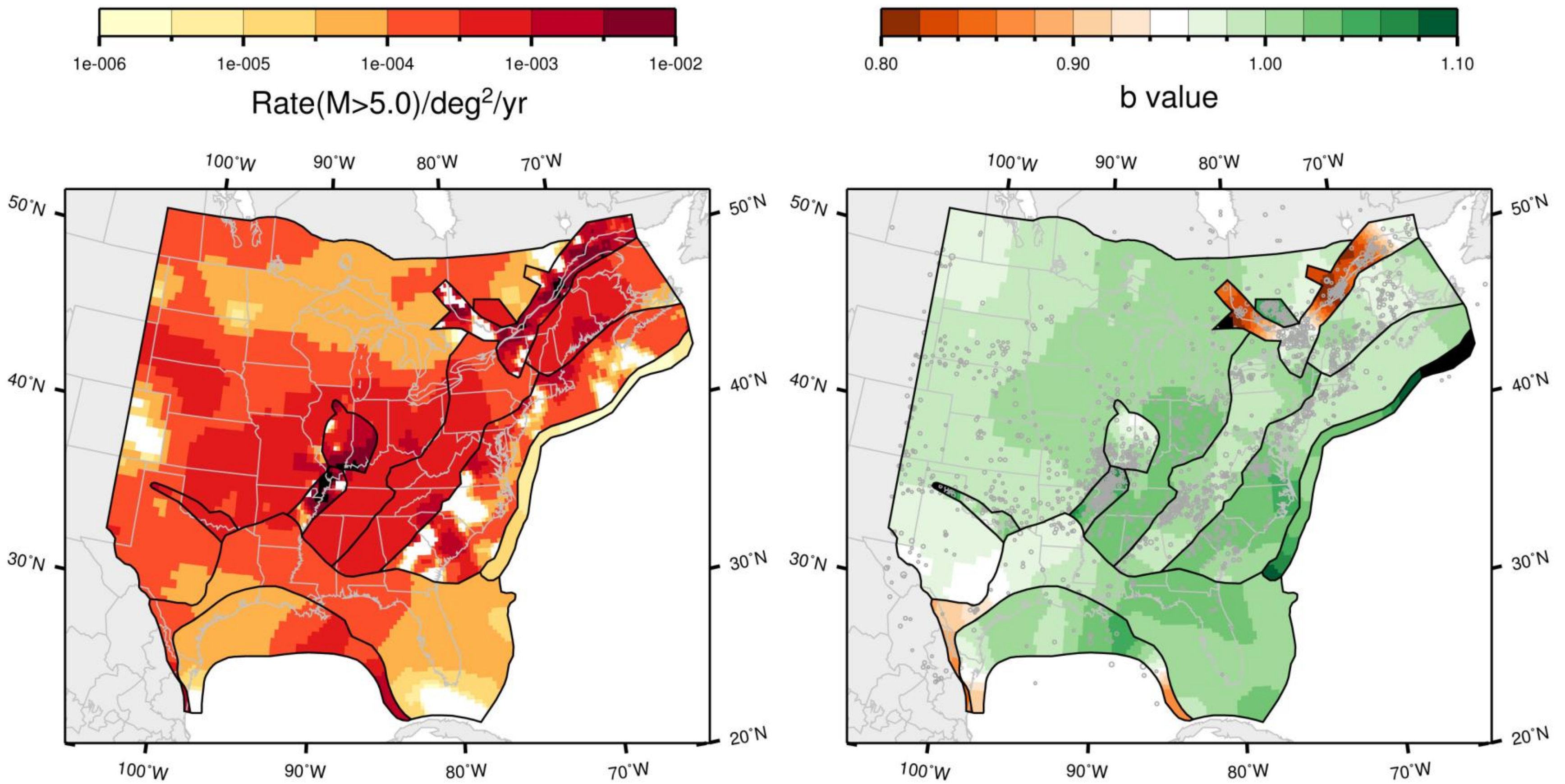


Figure J-158
Map of the rate and *b*-value for the study region under the seismotectonic zonation, with wide interpretation of PEZ; Case E magnitude weights: Realization 5

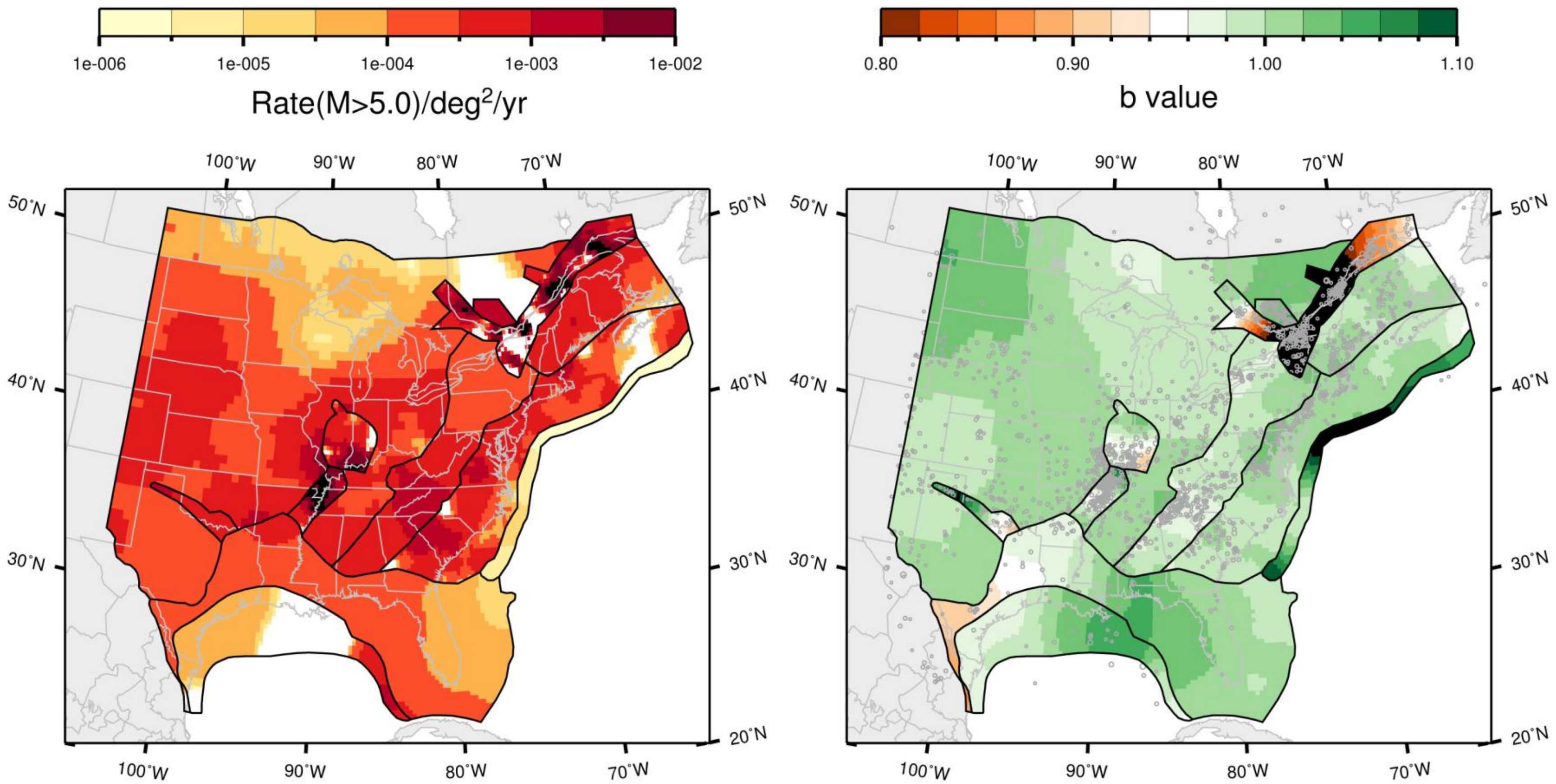


Figure J-159
Map of the rate and *b*-value for the study region under the seismotectonic zonation, with wide interpretation of PEZ; Case E magnitude weights: Realization 6

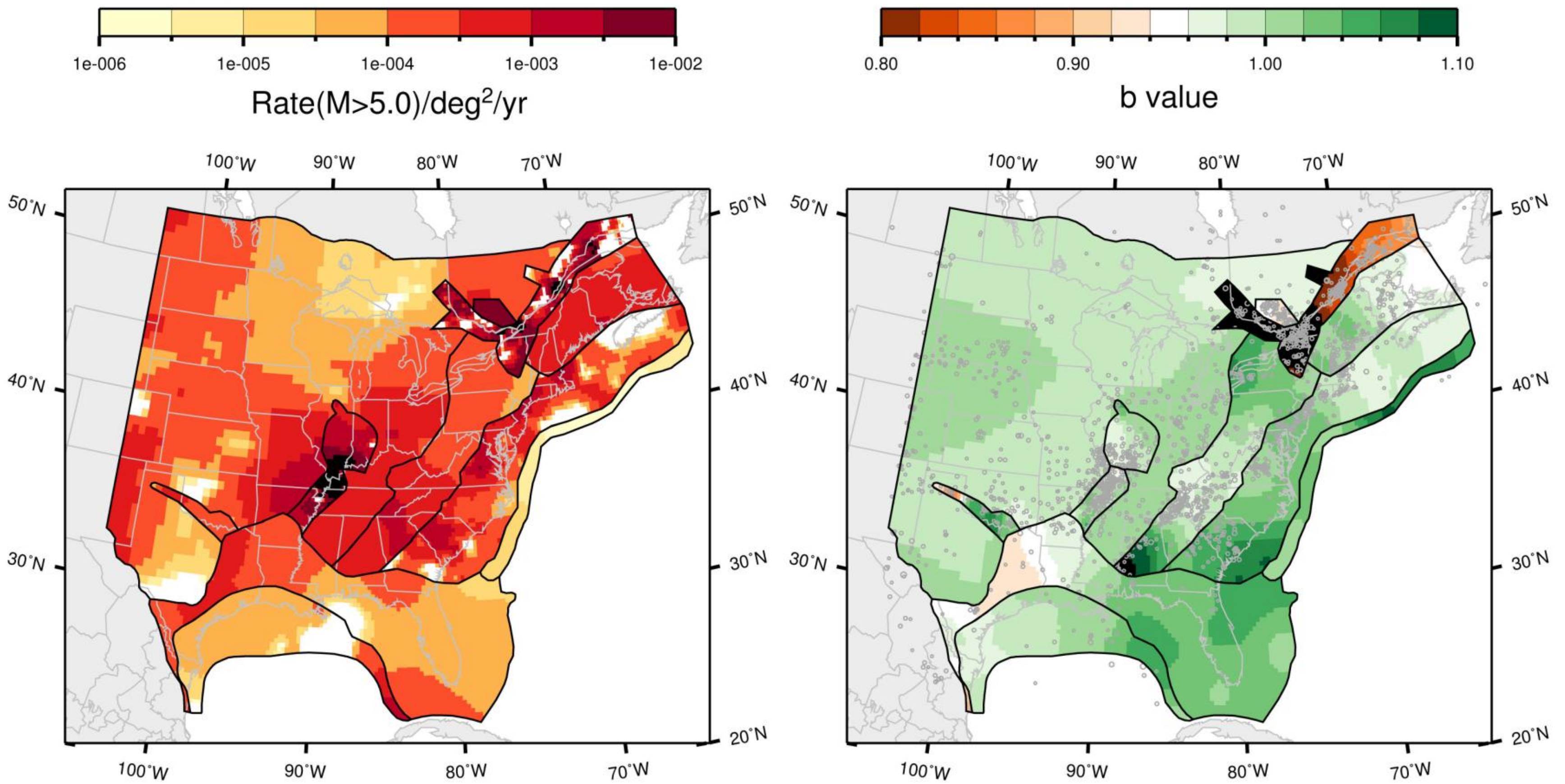


Figure J-160
Map of the rate and *b*-value for the study region under the seismotectonic zonation, with wide interpretation of PEZ; Case E magnitude weights: Realization 7

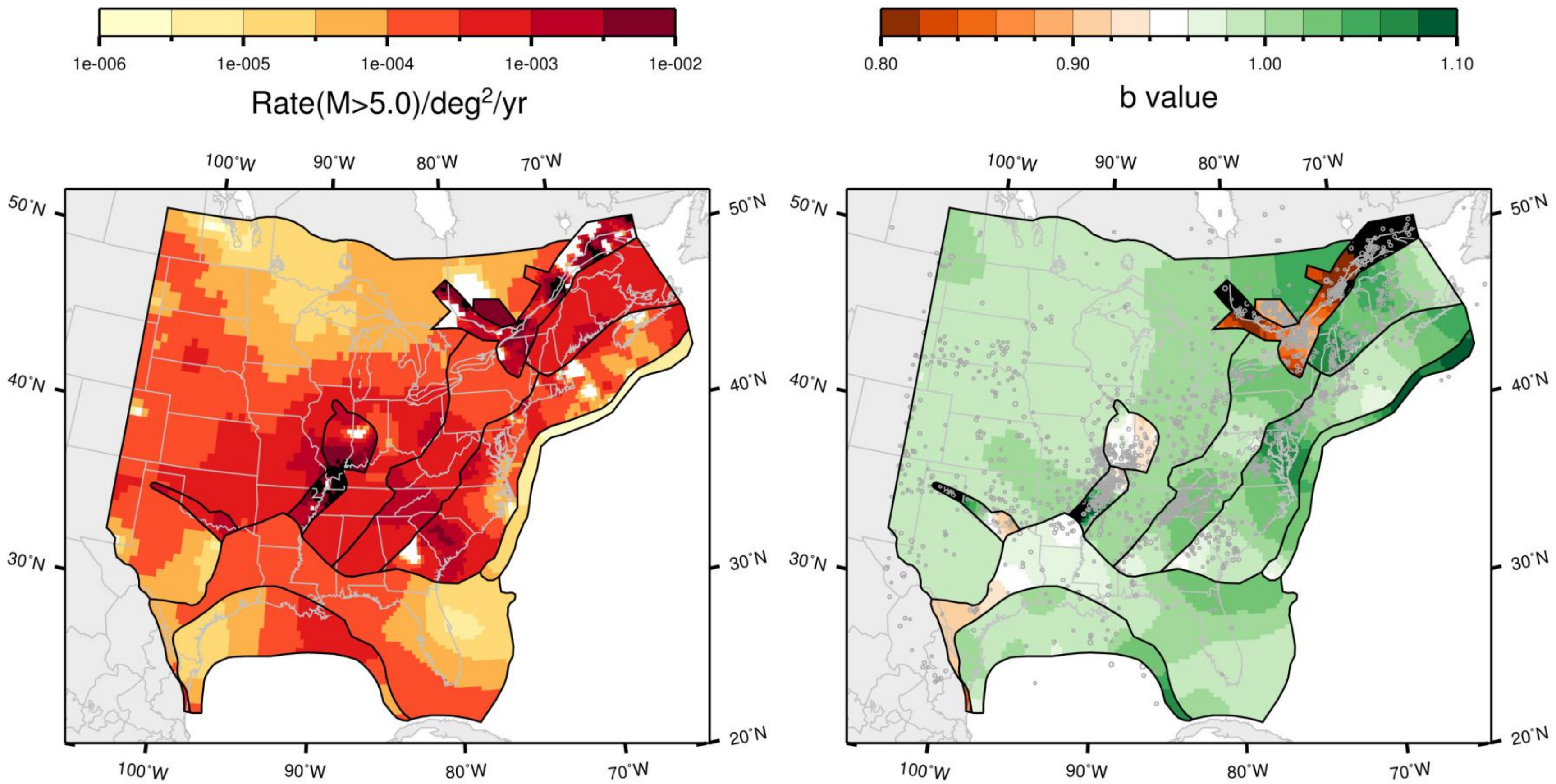


Figure J-161
Map of the rate and *b*-value for the study region under the seismotectonic zonation, with wide interpretation of PEZ; Case E magnitude weights: Realization 8

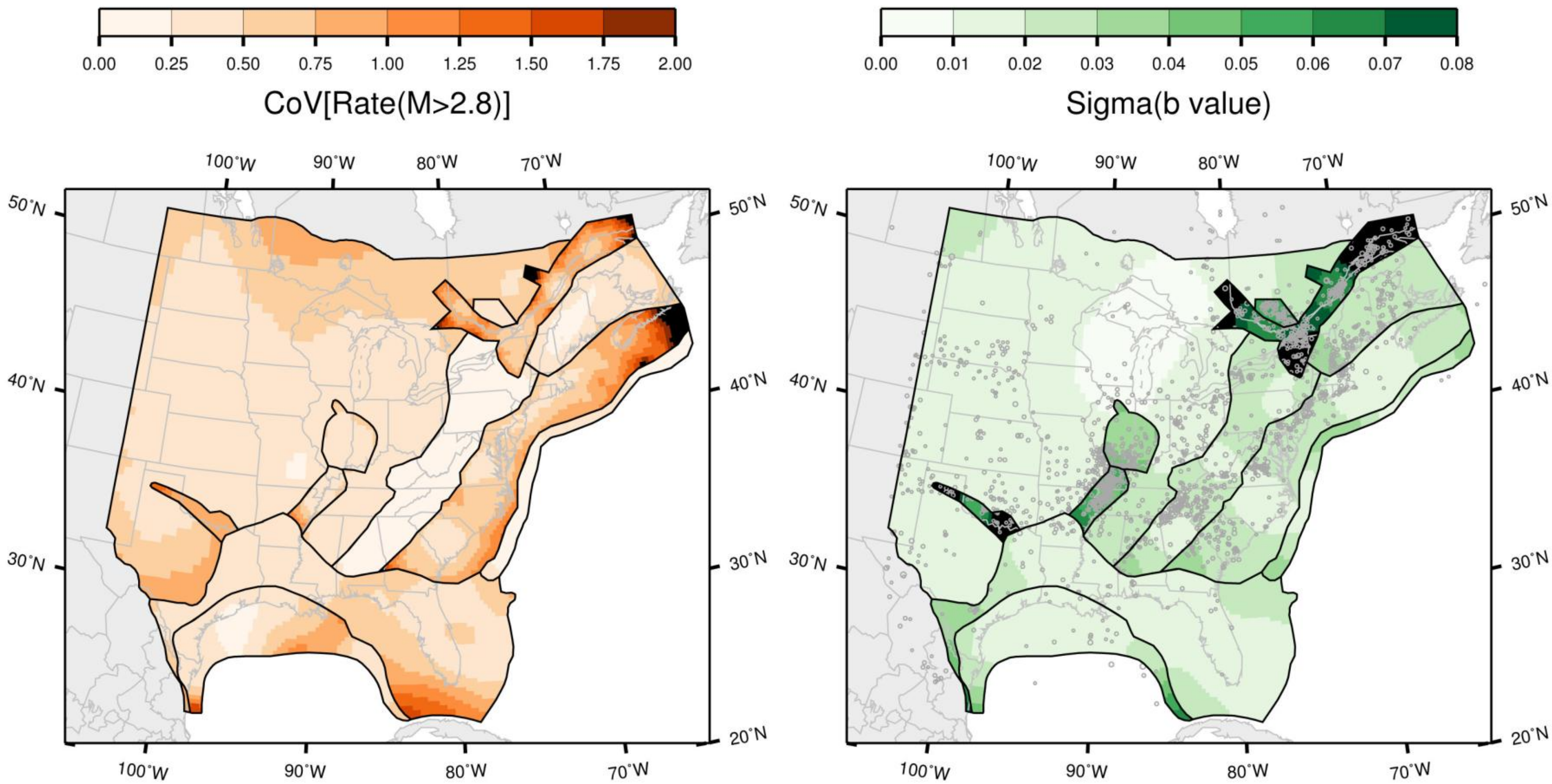


Figure J-162
Map of the coefficient of variation of the rate and the standard deviation of the *b*-value for the study region under the seismotectonic zonation, with wide interpretation of PEZ; Case E magnitude weights

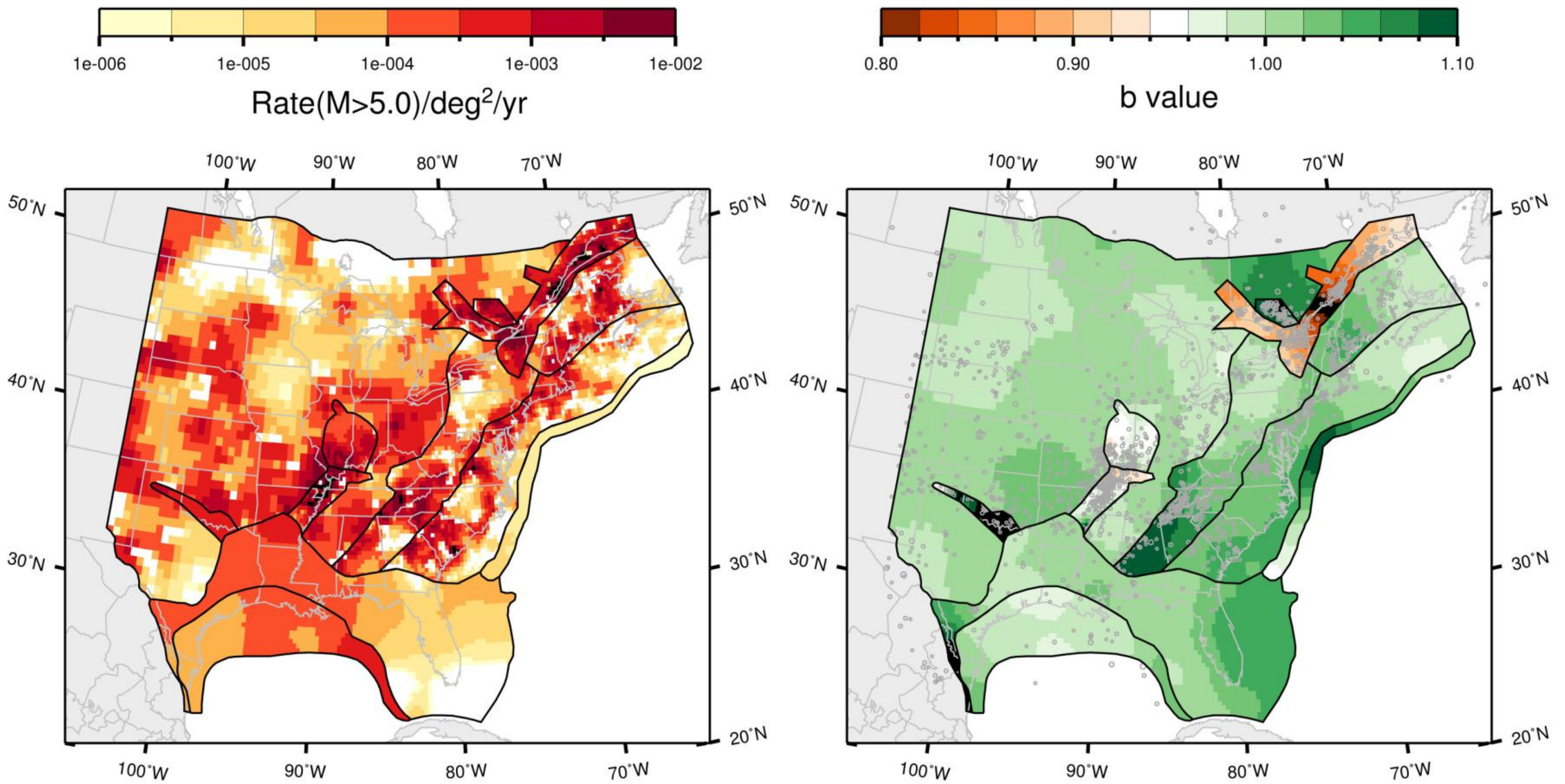
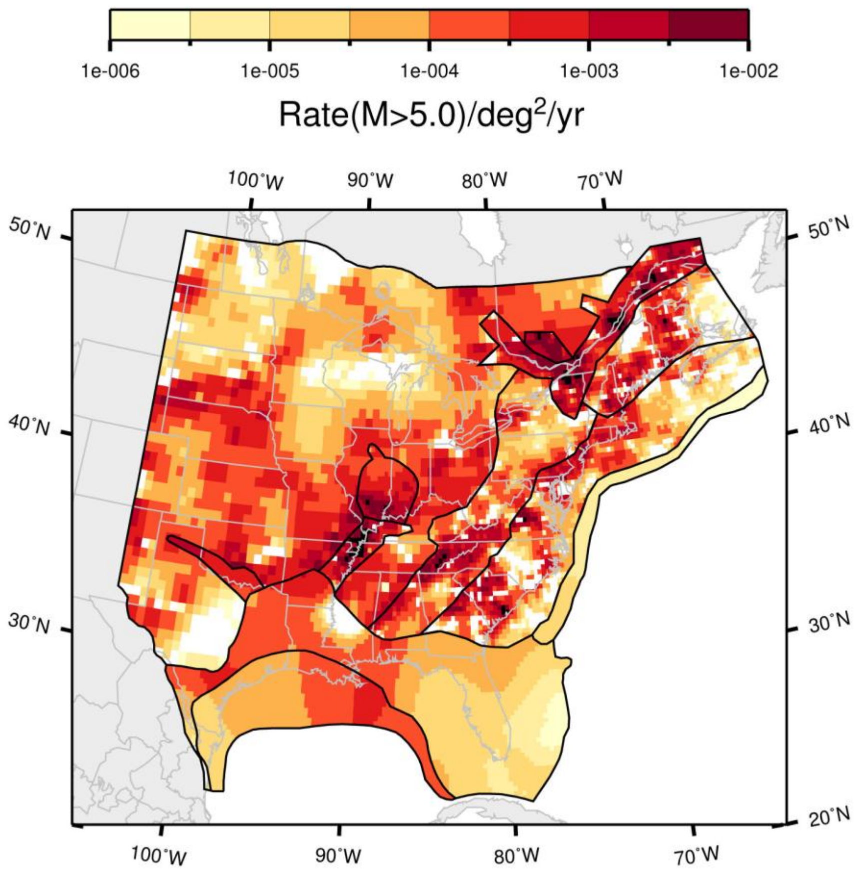


Figure J-163
Map of the rate and *b*-value for the study region under the seismotectonic zonation, with wide interpretation of PEZ; Case A magnitude weights: Realization 1



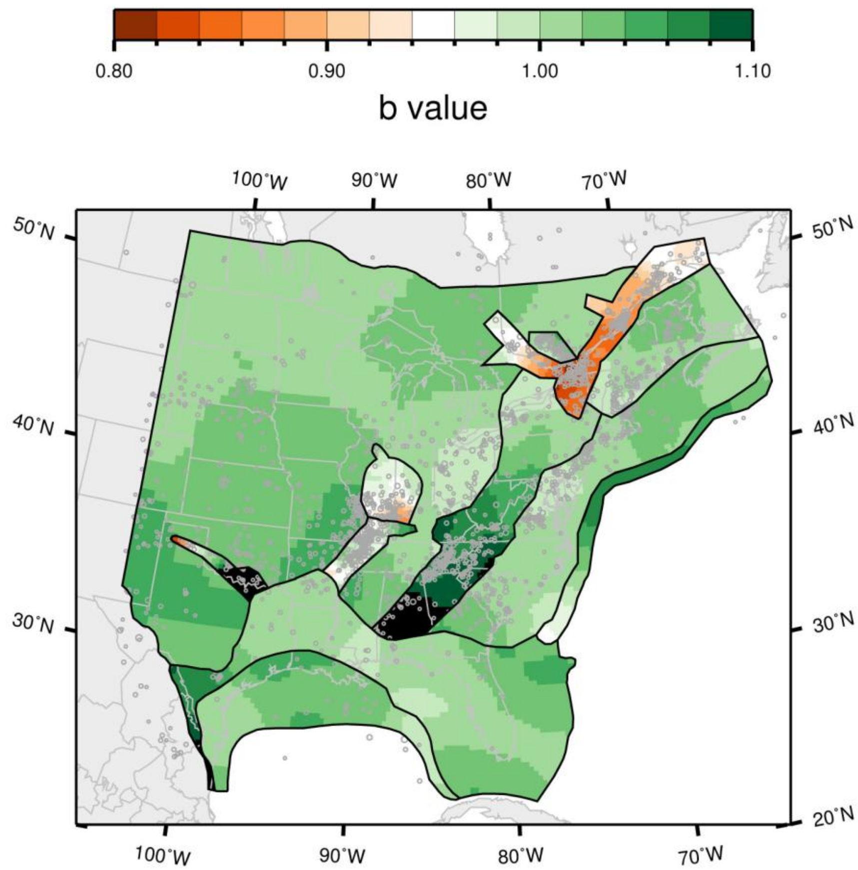


Figure J-164
Map of the rate and *b*-value for the study region under the seismotectonic zonation, with wide interpretation of PEZ; Case A magnitude weights: Realization 2

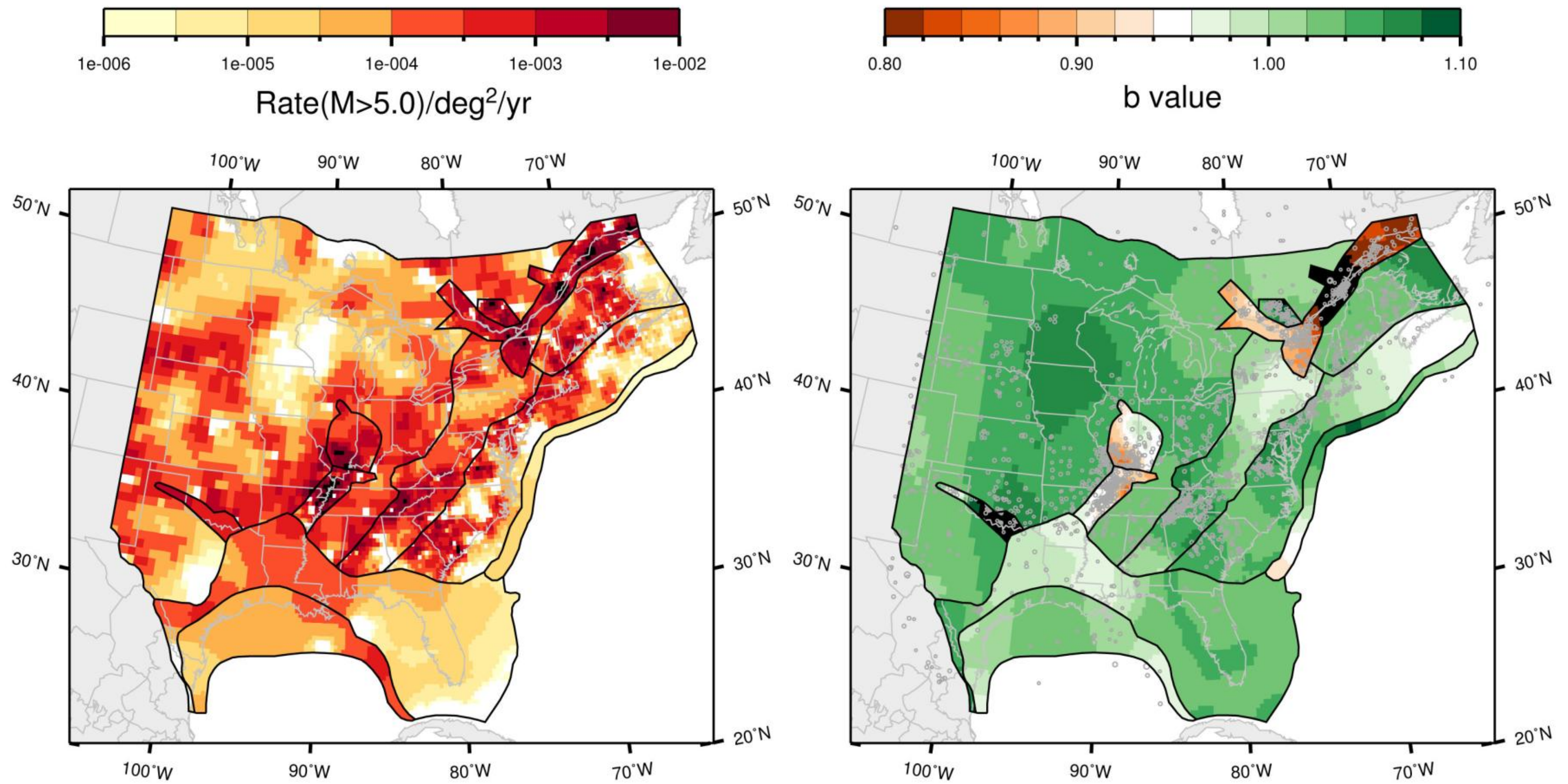


Figure J-165
Map of the rate and *b*-value for the study region under the seismotectonic zonation, with wide interpretation of PEZ; Case A magnitude weights: Realization 3

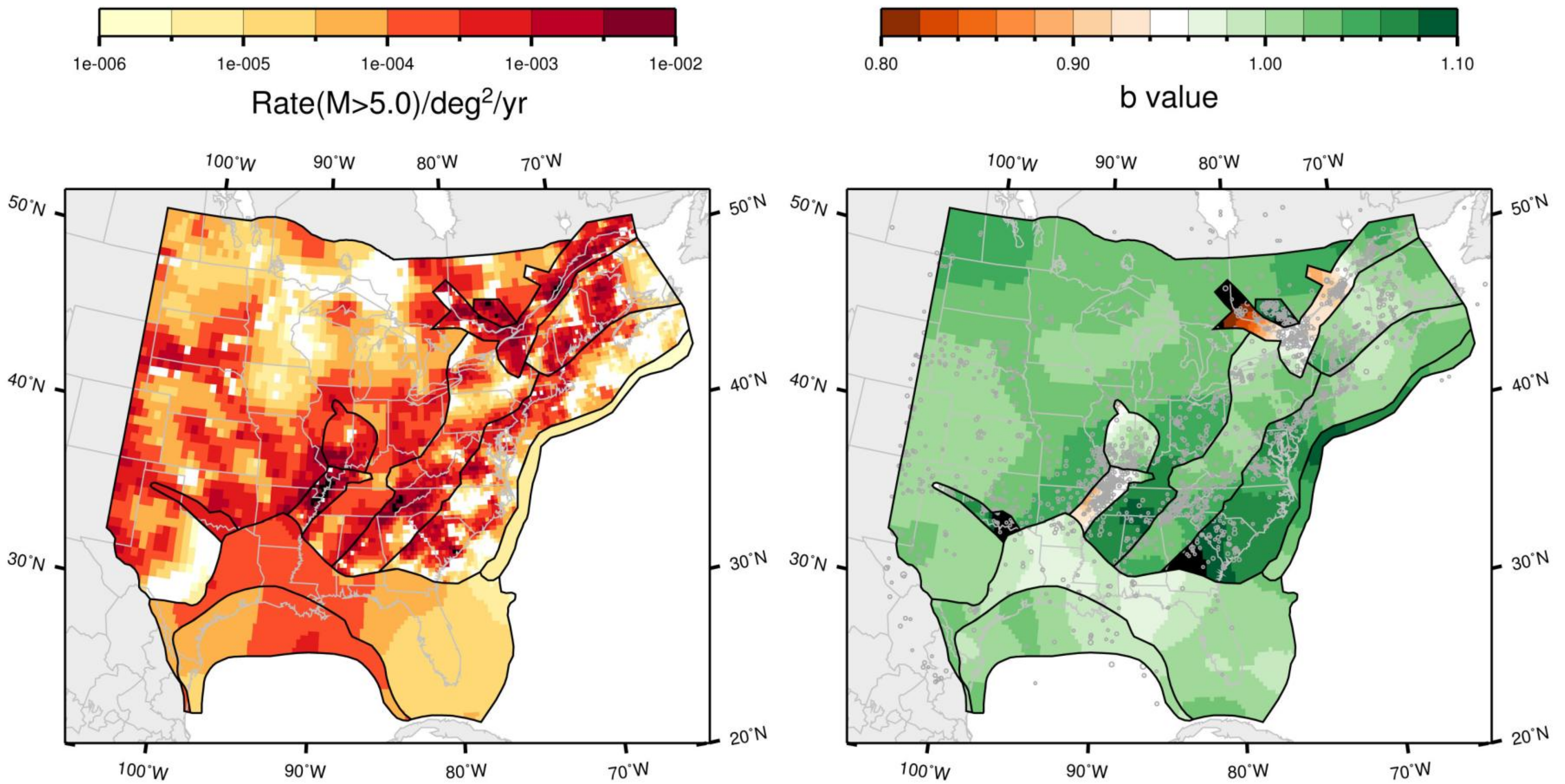


Figure J-166
Map of the rate and *b*-value for the study region under the seismotectonic zonation, with wide interpretation of PEZ; Case A magnitude weights: Realization 4

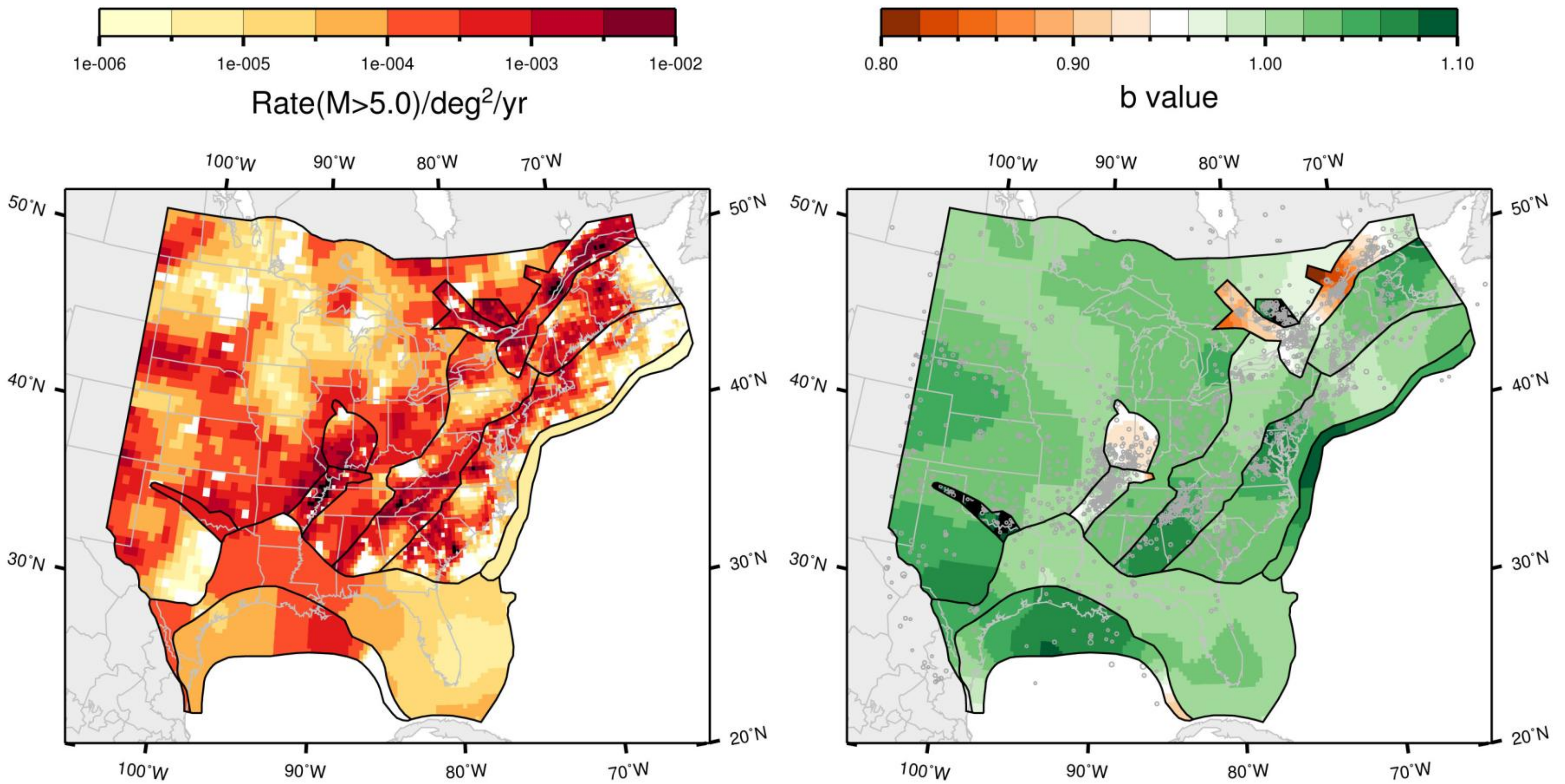


Figure J-167
Map of the rate and *b*-value for the study region under the seismotectonic zonation, with wide interpretation of PEZ; Case A magnitude weights: Realization 5

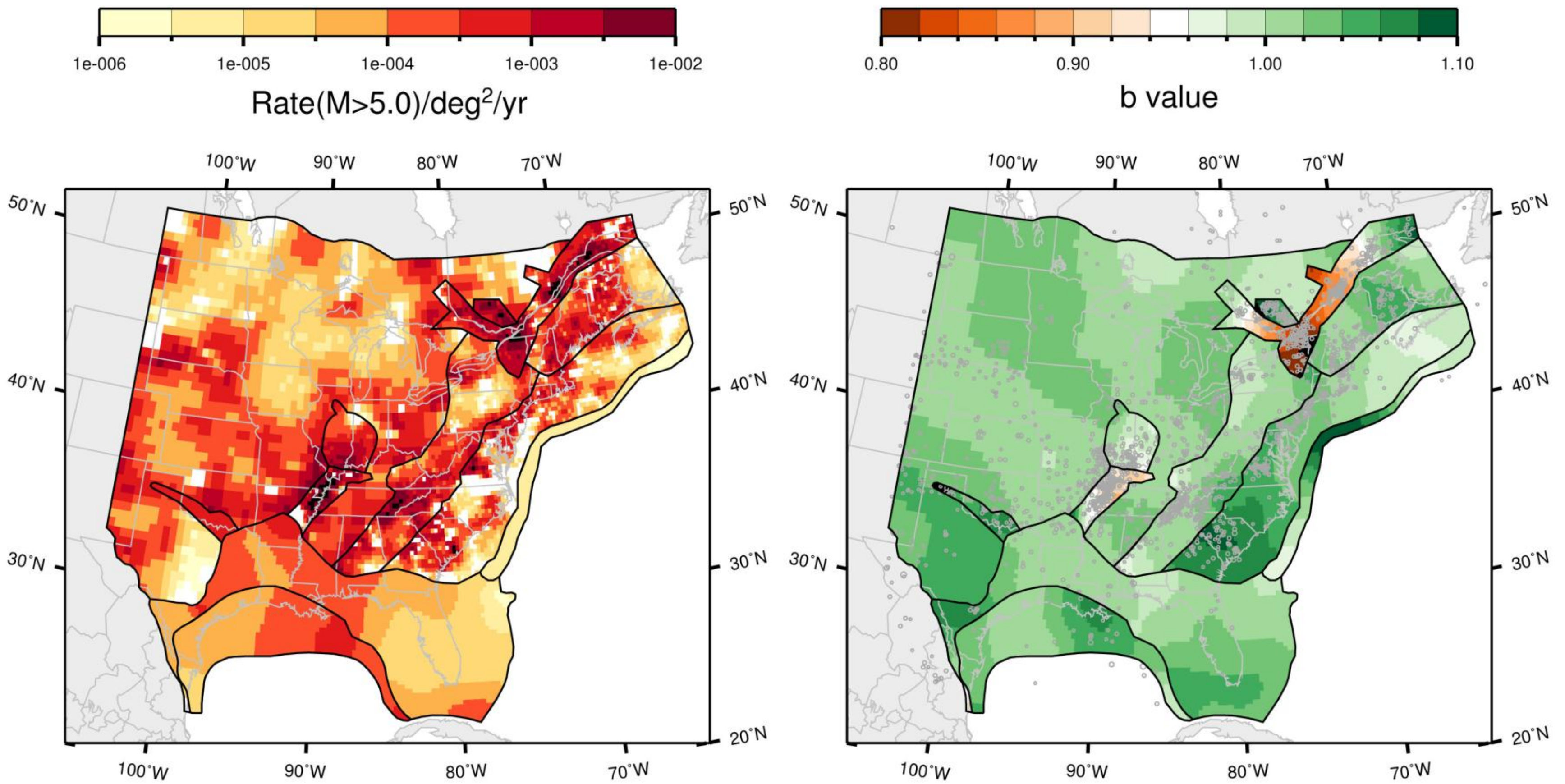


Figure J-168
Map of the rate and *b*-value for the study region under the seismotectonic zonation, with wide interpretation of PEZ; Case A magnitude weights: Realization 6

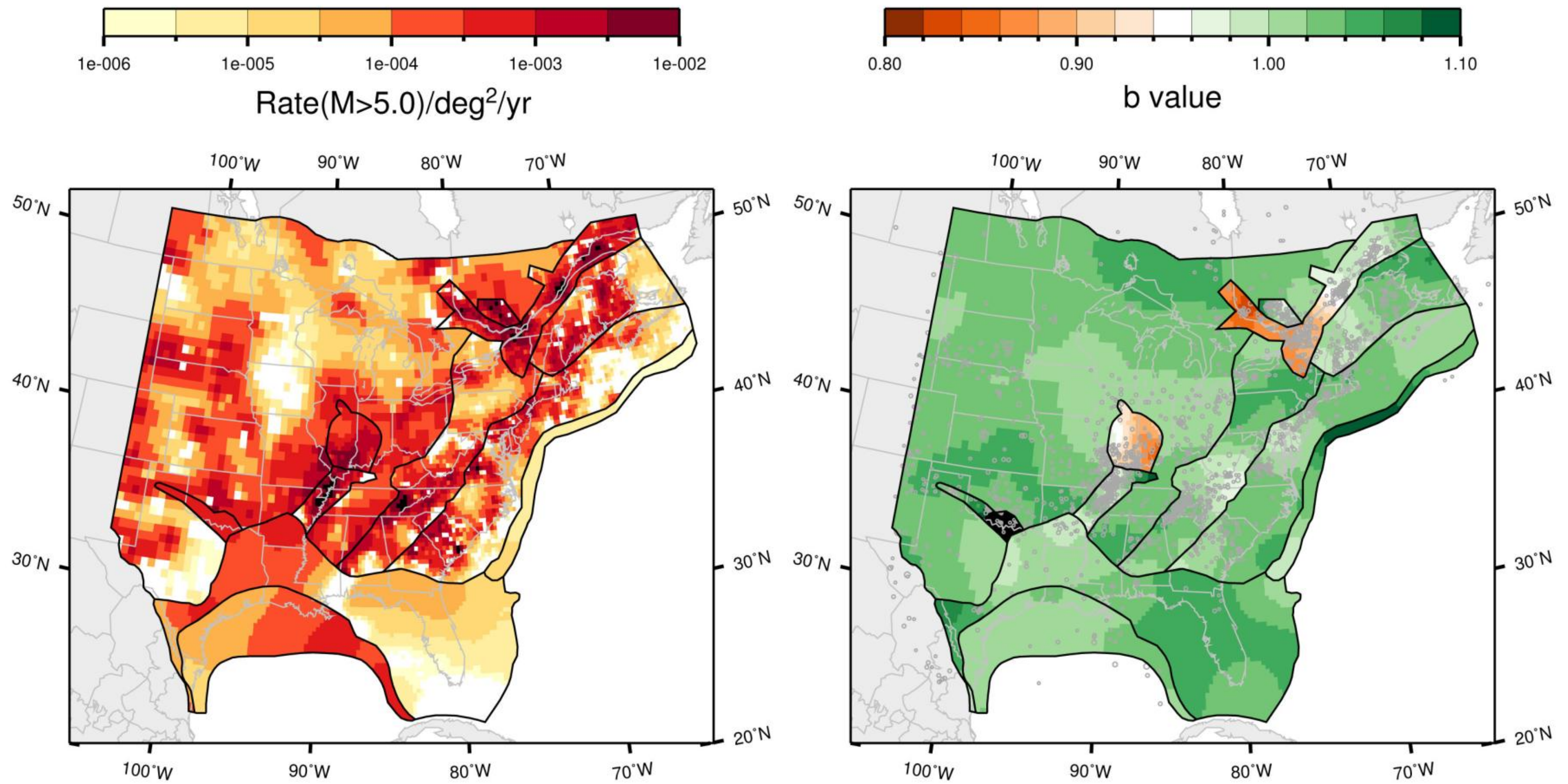


Figure J-169
Map of the rate and *b*-value for the study region under the seismotectonic zonation, with wide interpretation of PEZ; Case A magnitude weights: Realization 7

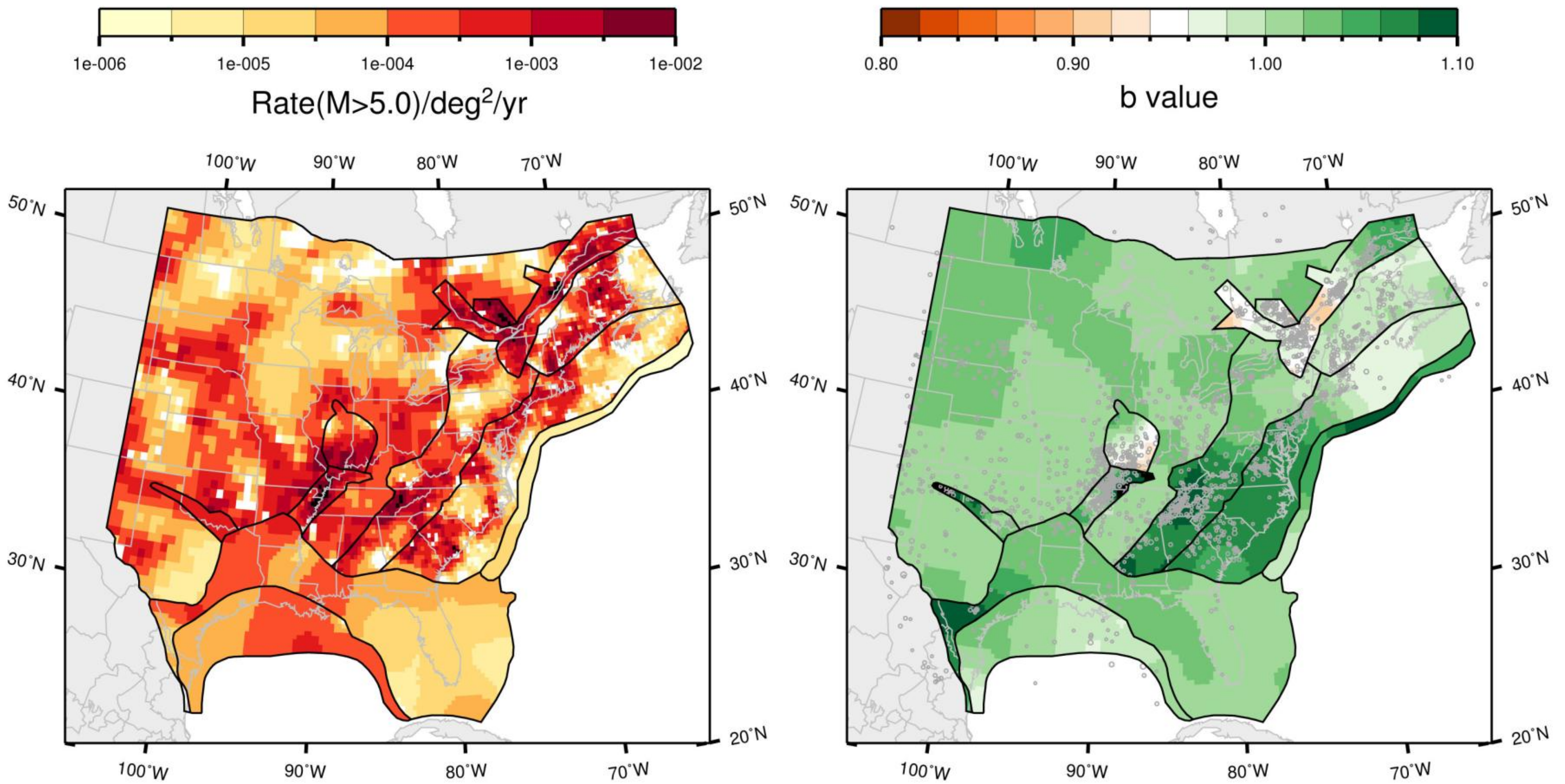


Figure J-170
Map of the rate and *b*-value for the study region under the seismotectonic zonation, with wide interpretation of PEZ; Case A magnitude weights: Realization 8

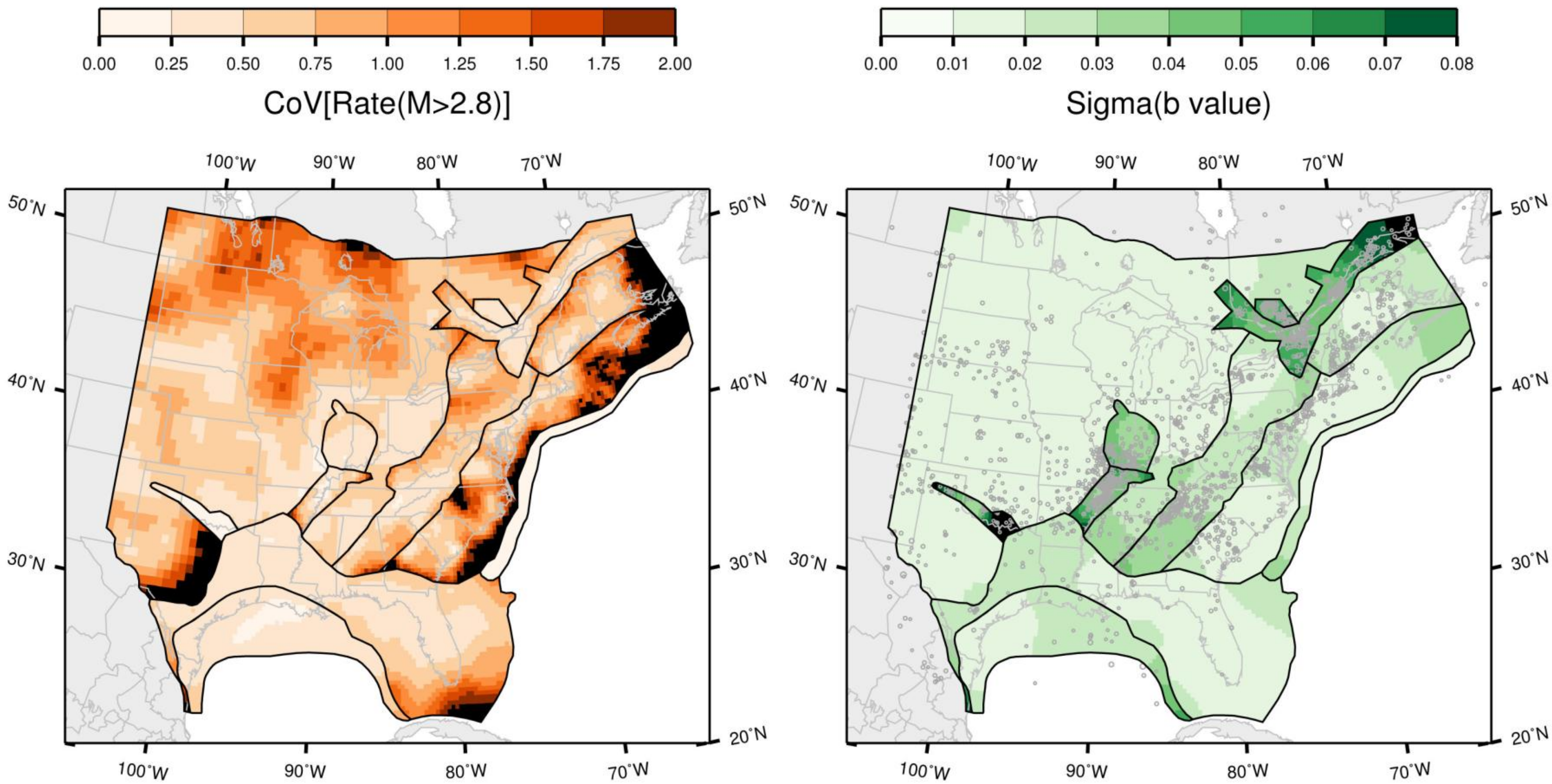


Figure J-171
Map of the coefficient of variation of the rate and the standard deviation of the *b*-value for the study region under the seismotectonic zonation, with wide interpretation of PEZ; Case A magnitude weights

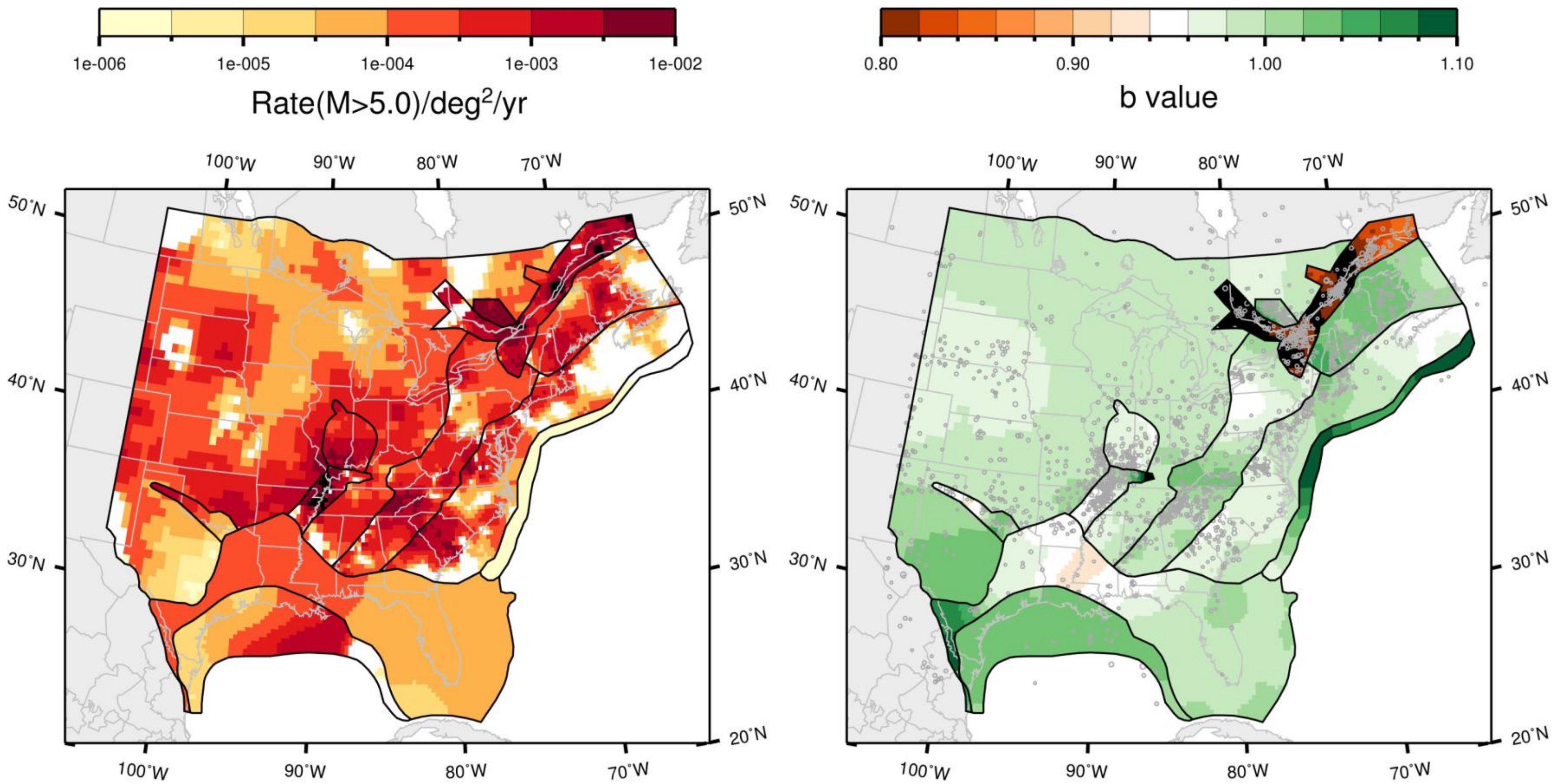


Figure J-172
Map of the rate and *b*-value for the study region under the seismotectonic zonation, with wide interpretation of PEZ; Case B magnitude weights: Realization 1

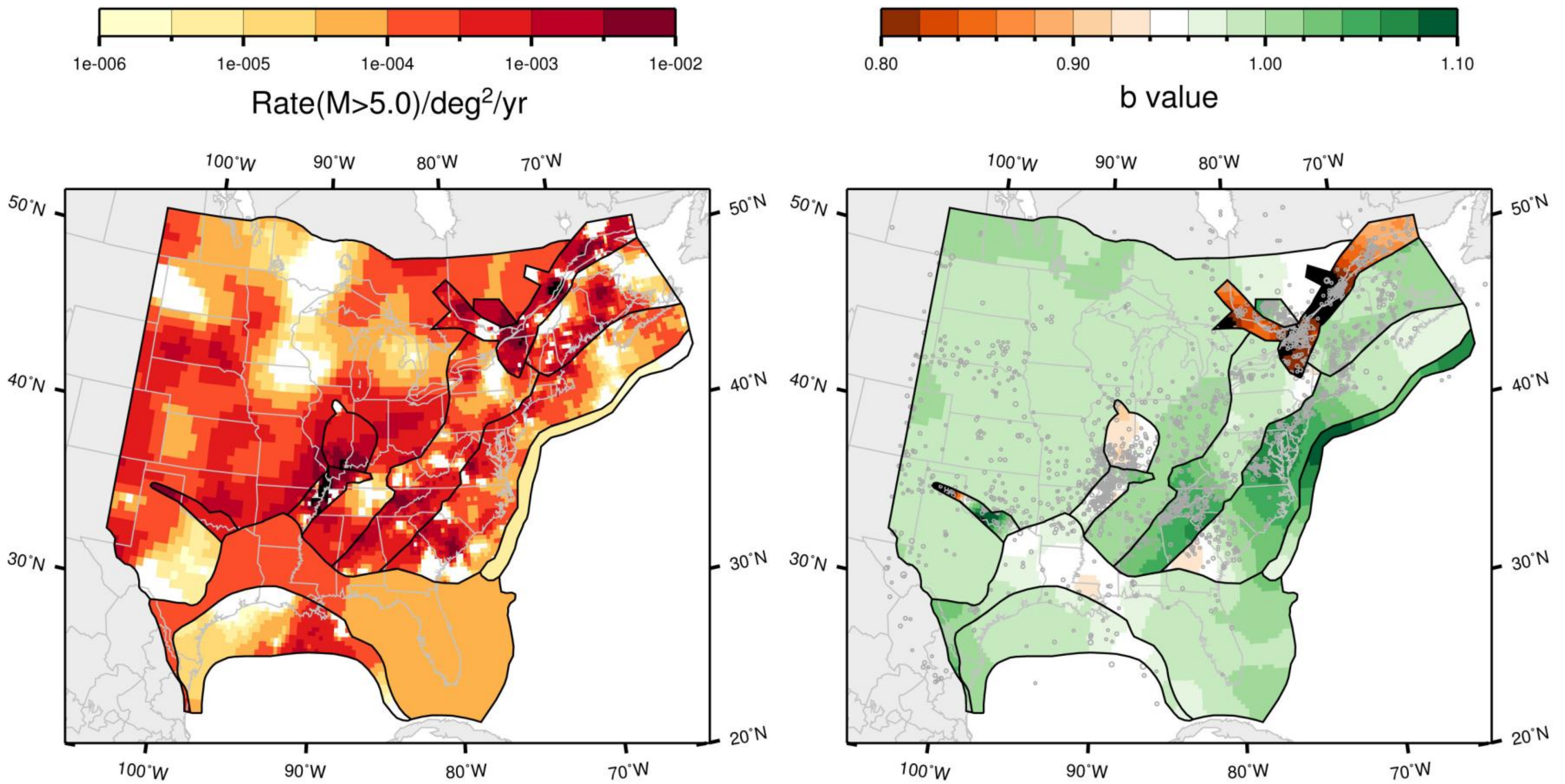


Figure J-173
Map of the rate and *b*-value for the study region under the seismotectonic zonation, with wide interpretation of PEZ; Case B magnitude weights: Realization 2

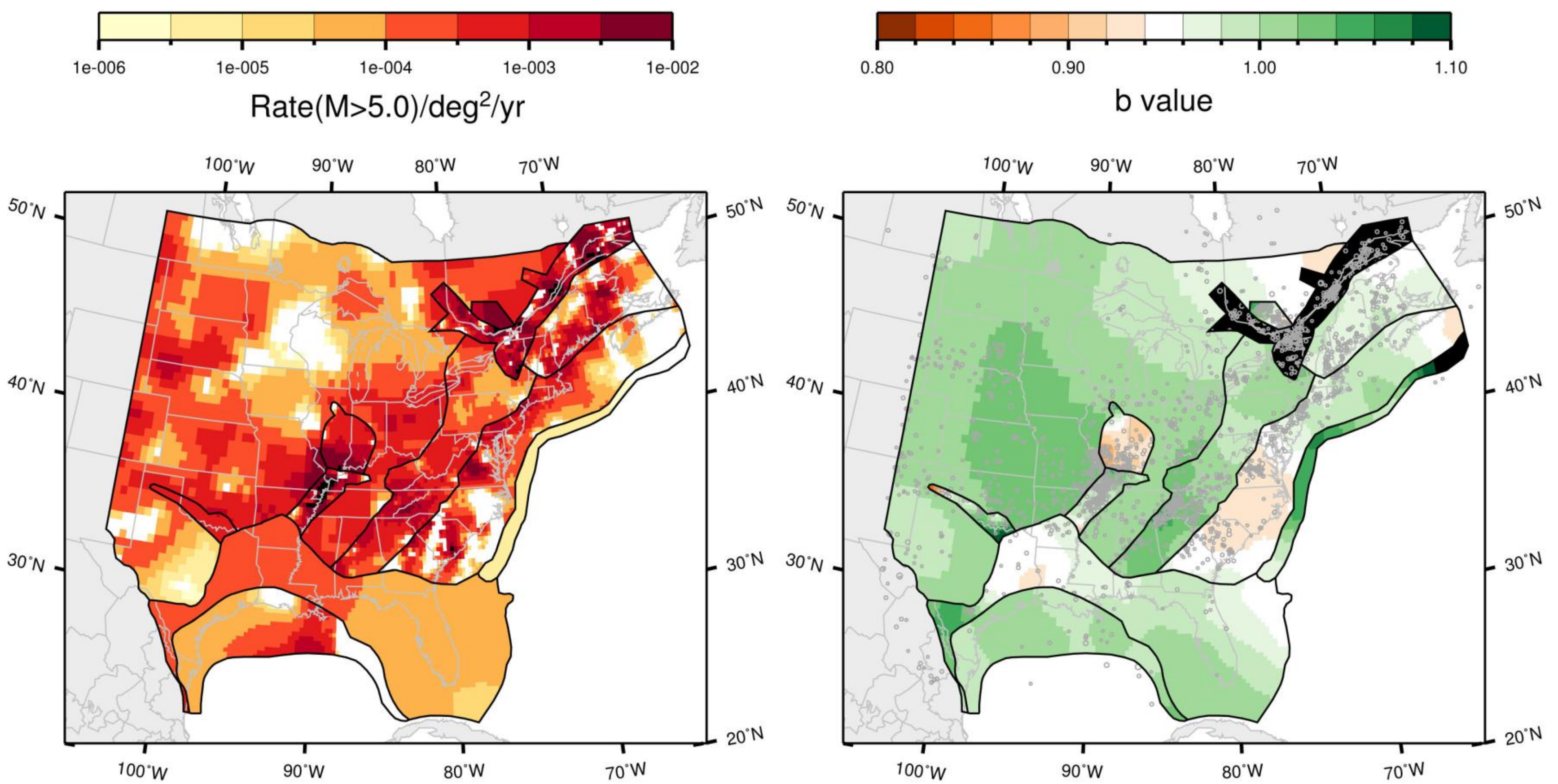


Figure J-174
Map of the rate and *b*-value for the study region under the seismotectonic zonation, with wide interpretation of PEZ; Case B magnitude weights: Realization 3

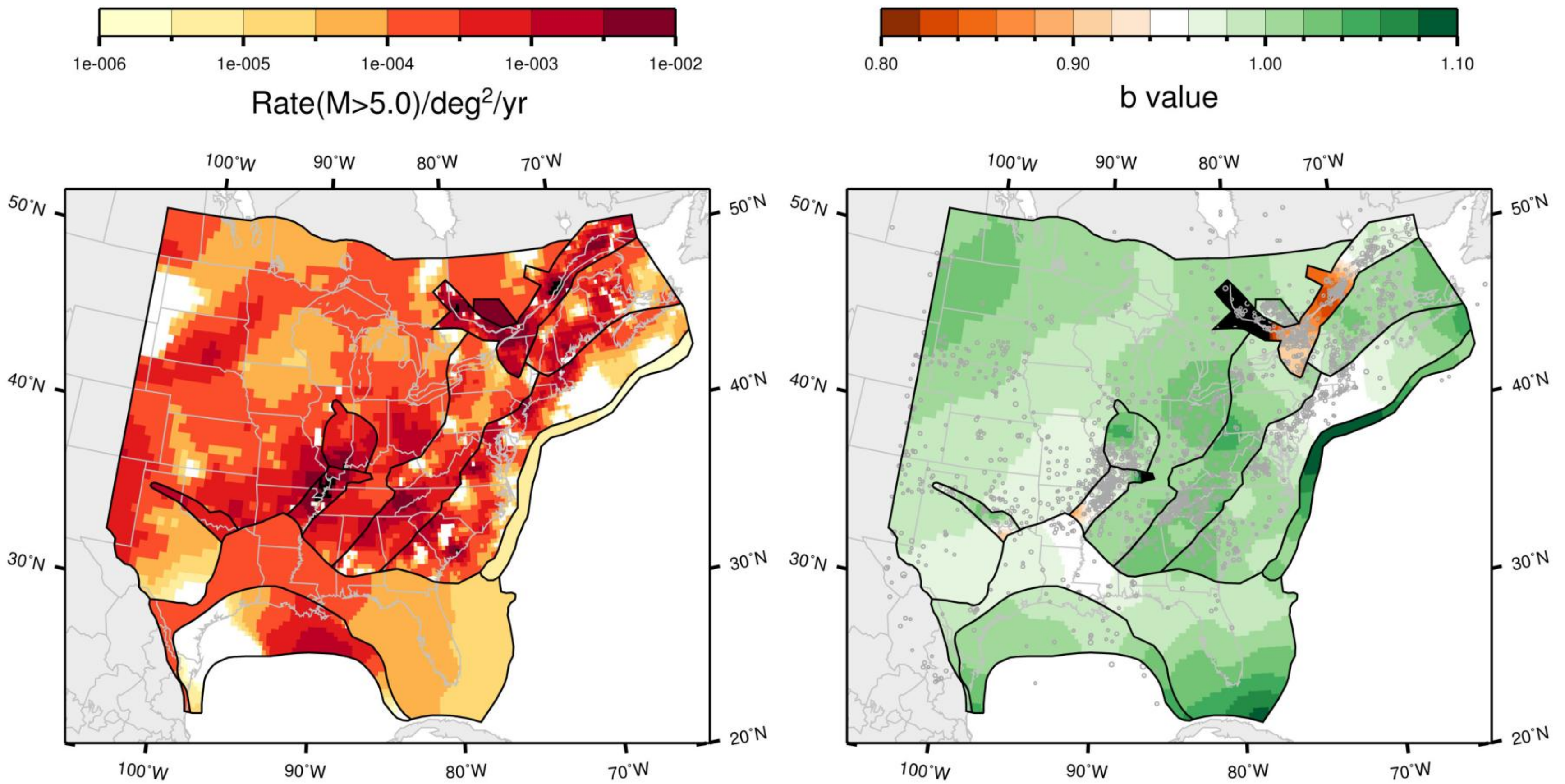


Figure J-175
Map of the rate and *b*-value for the study region under the seismotectonic zonation, with wide interpretation of PEZ; Case B magnitude weights: Realization 4

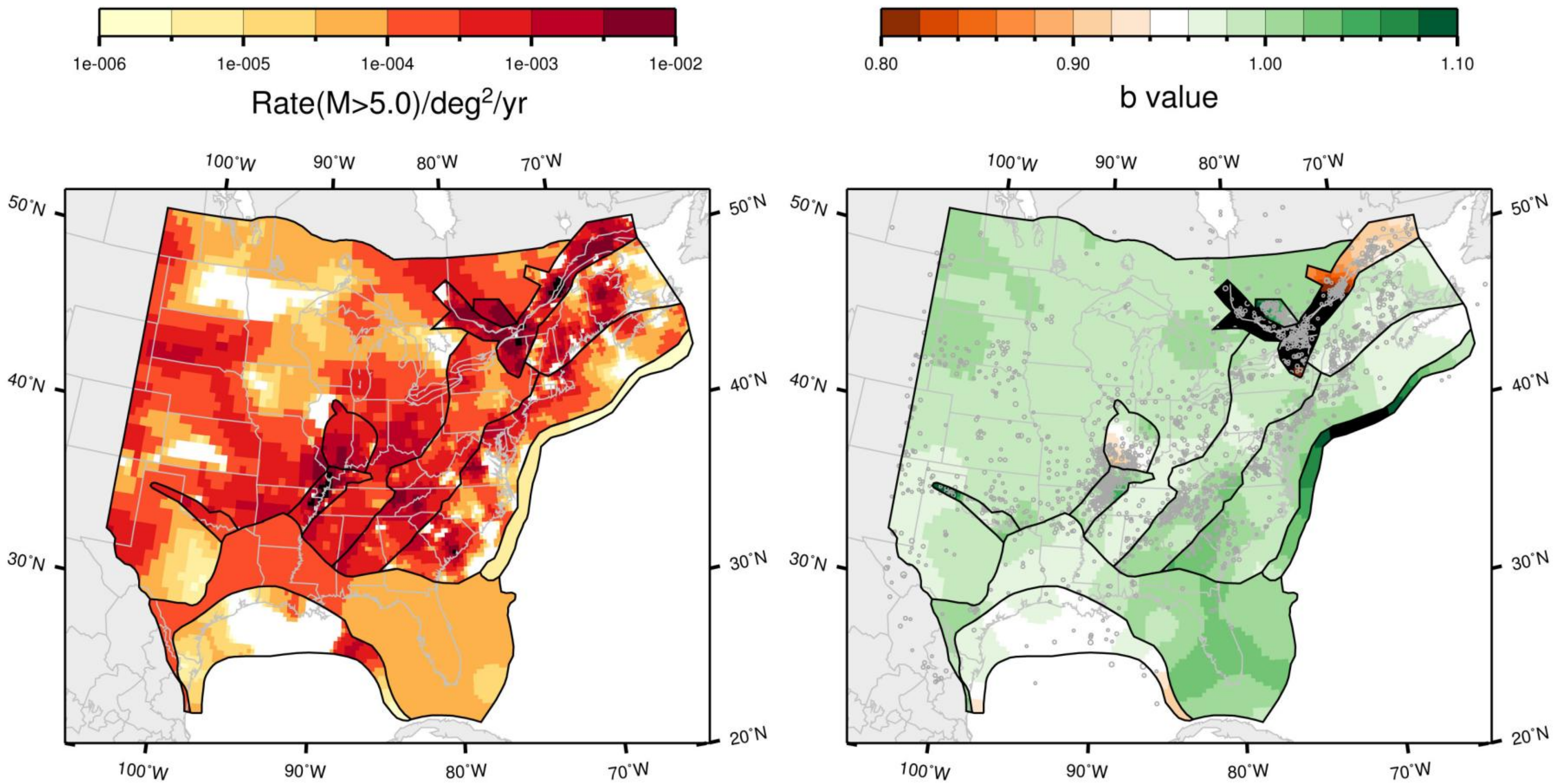


Figure J-176
Map of the rate and *b*-value for the study region under the seismotectonic zonation, with wide interpretation of PEZ; Case B magnitude weights: Realization 5

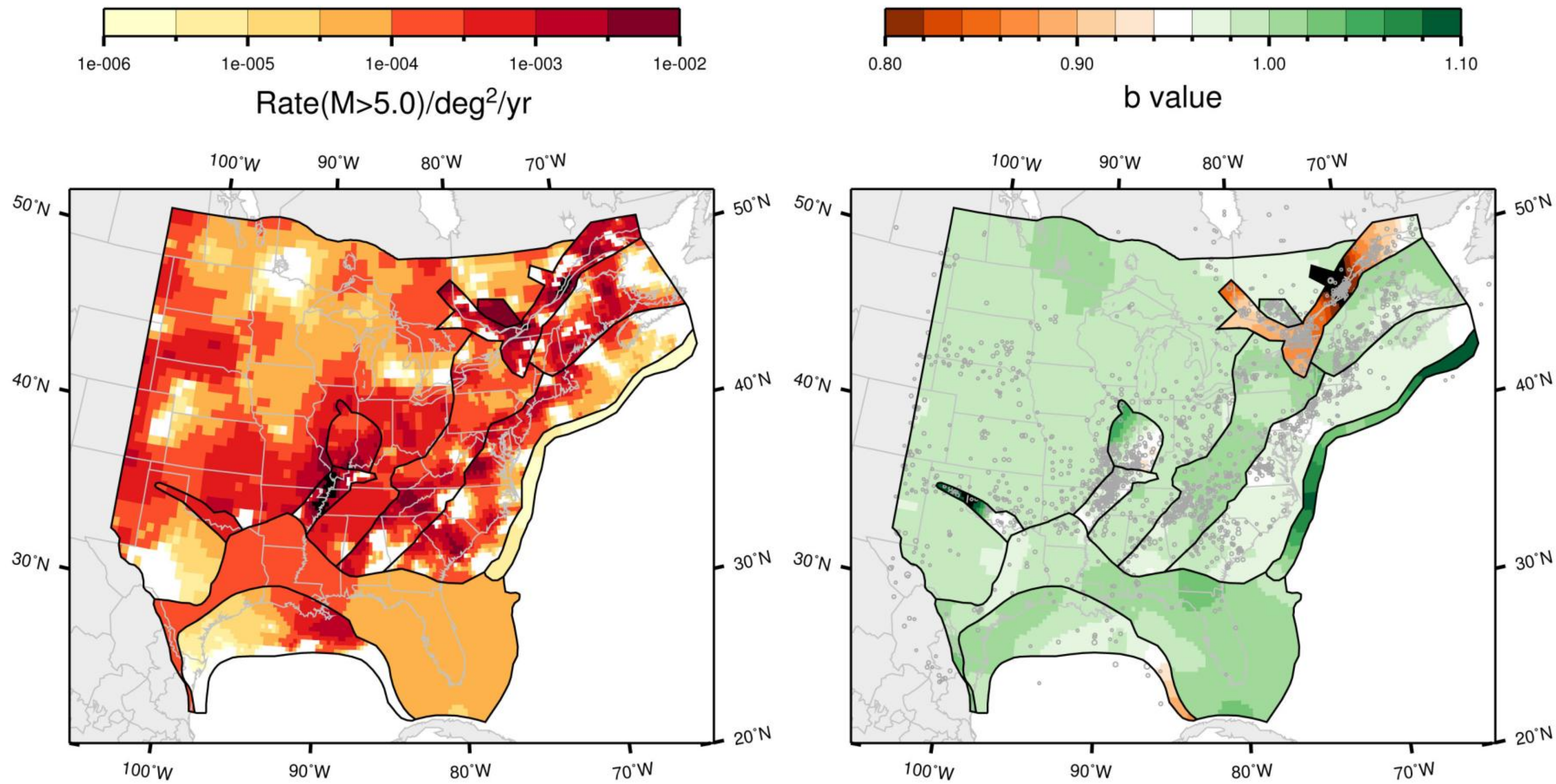


Figure J-177
Map of the rate and *b*-value for the study region under the seismotectonic zonation, with wide interpretation of PEZ; Case B magnitude weights: Realization 6

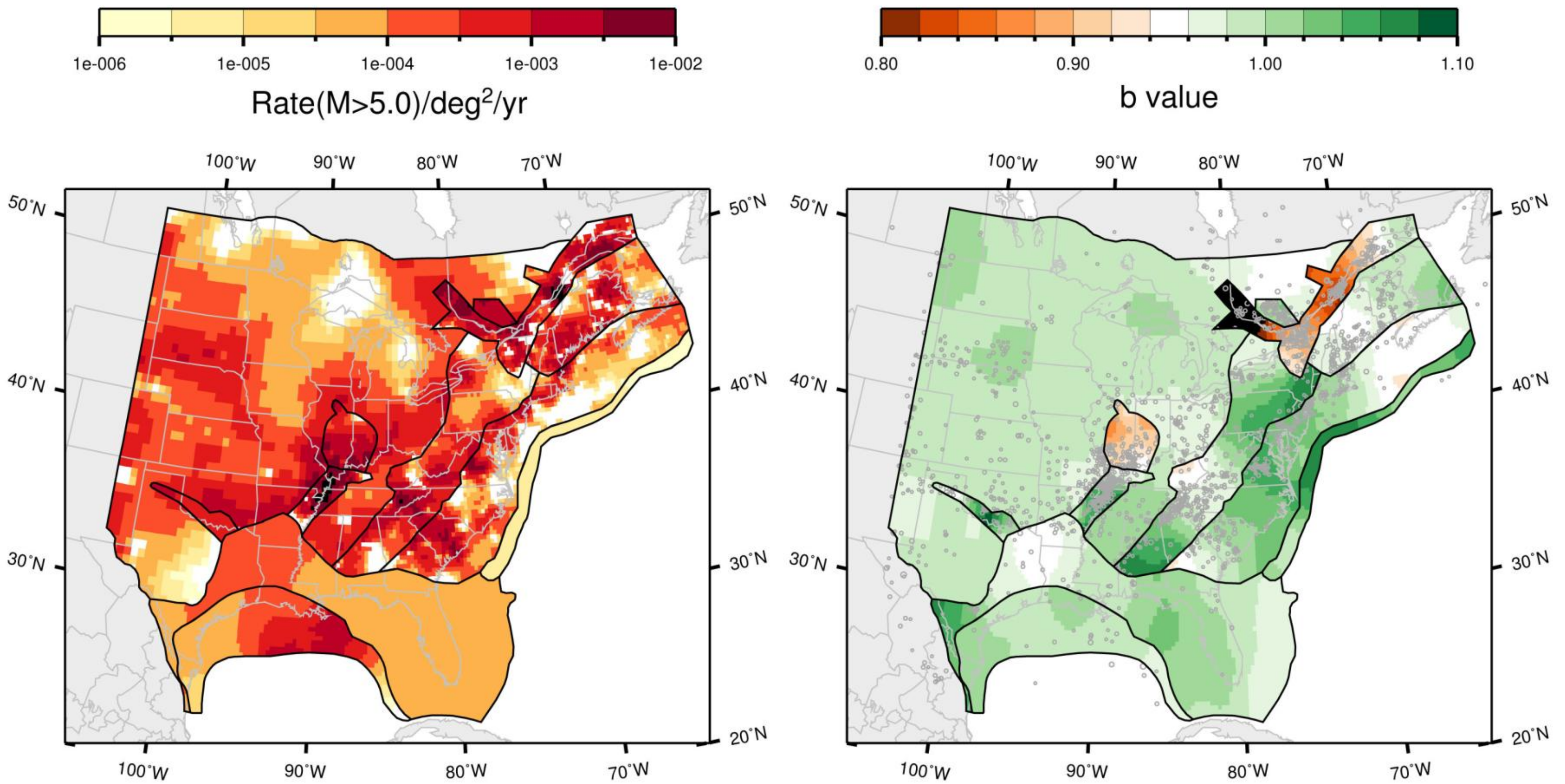


Figure J-178
Map of the rate and *b*-value for the study region under the seismotectonic zonation, with wide interpretation of PEZ; Case B magnitude weights: Realization 7

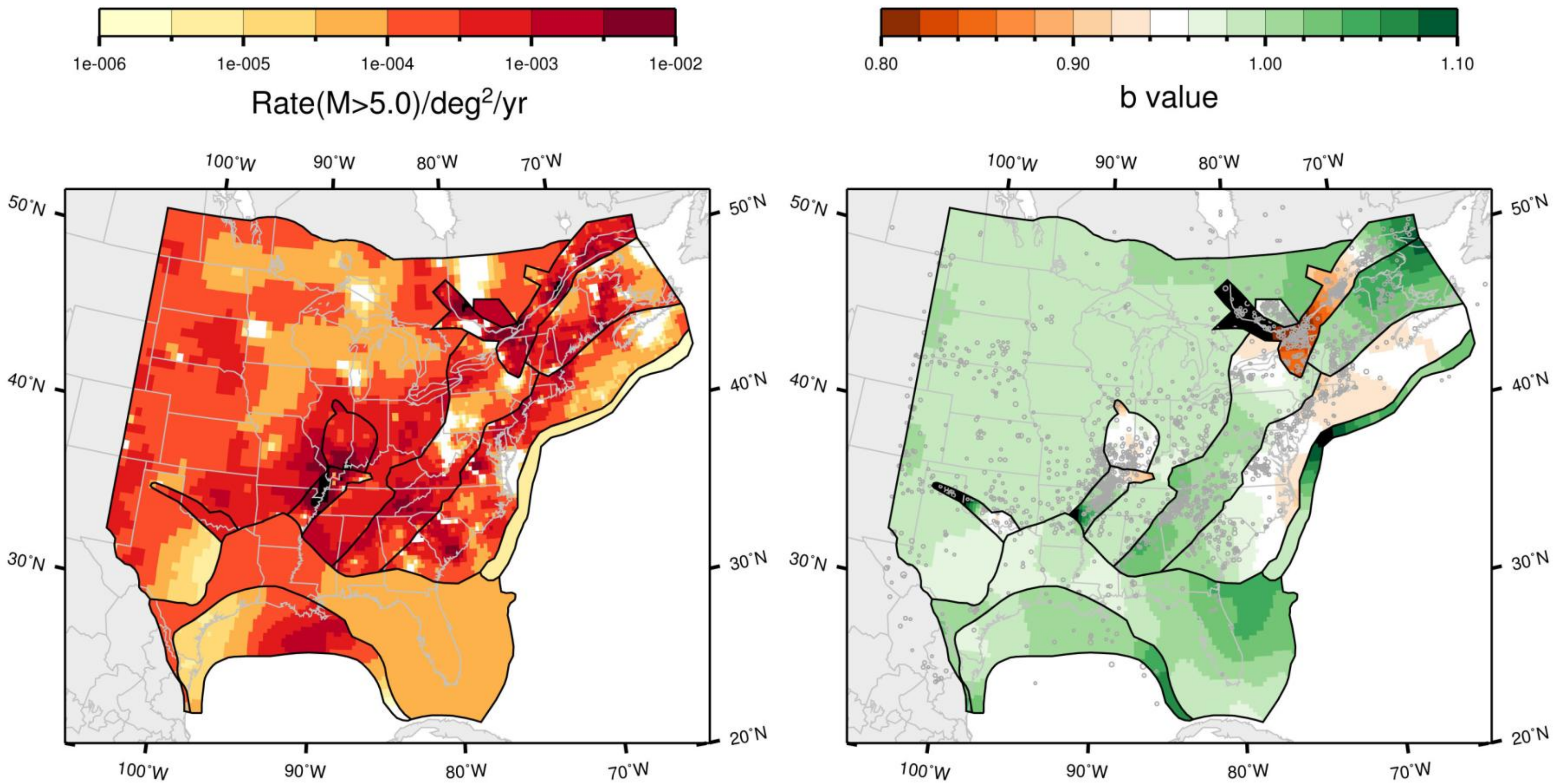


Figure J-179
Map of the rate and *b*-value for the study region under the seismotectonic zonation, with wide interpretation of PEZ; Case B magnitude weights: Realization 8

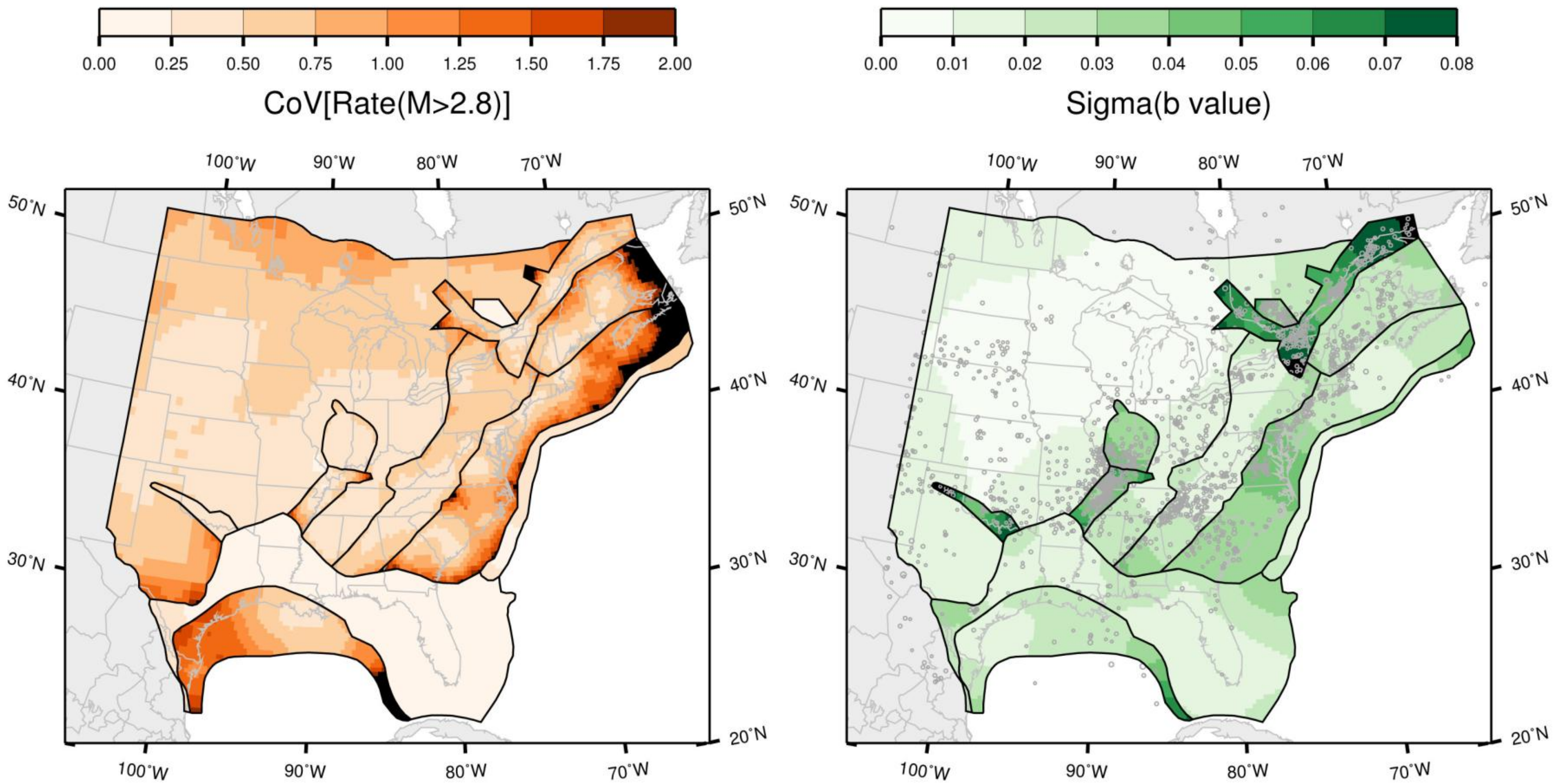


Figure J-180
Map of the coefficient of variation of the rate and the standard deviation of the *b*-value for the study region under the seismotectonic zonation, with wide interpretation of PEZ; Case B magnitude weights

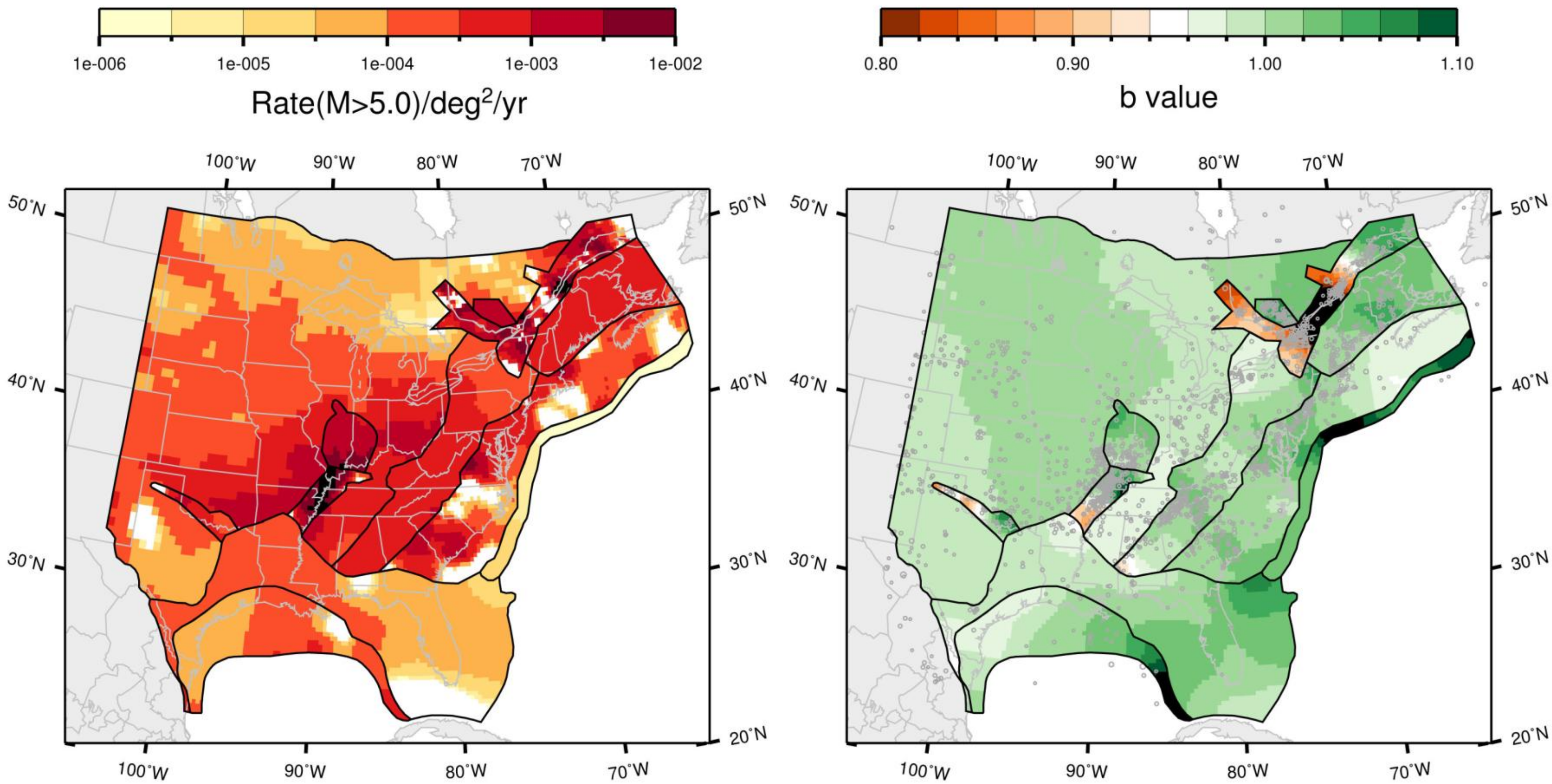


Figure J-181
Map of the rate and *b*-value for the study region under the seismotectonic zonation, with wide interpretation of PEZ; Case E magnitude weights: Realization 1

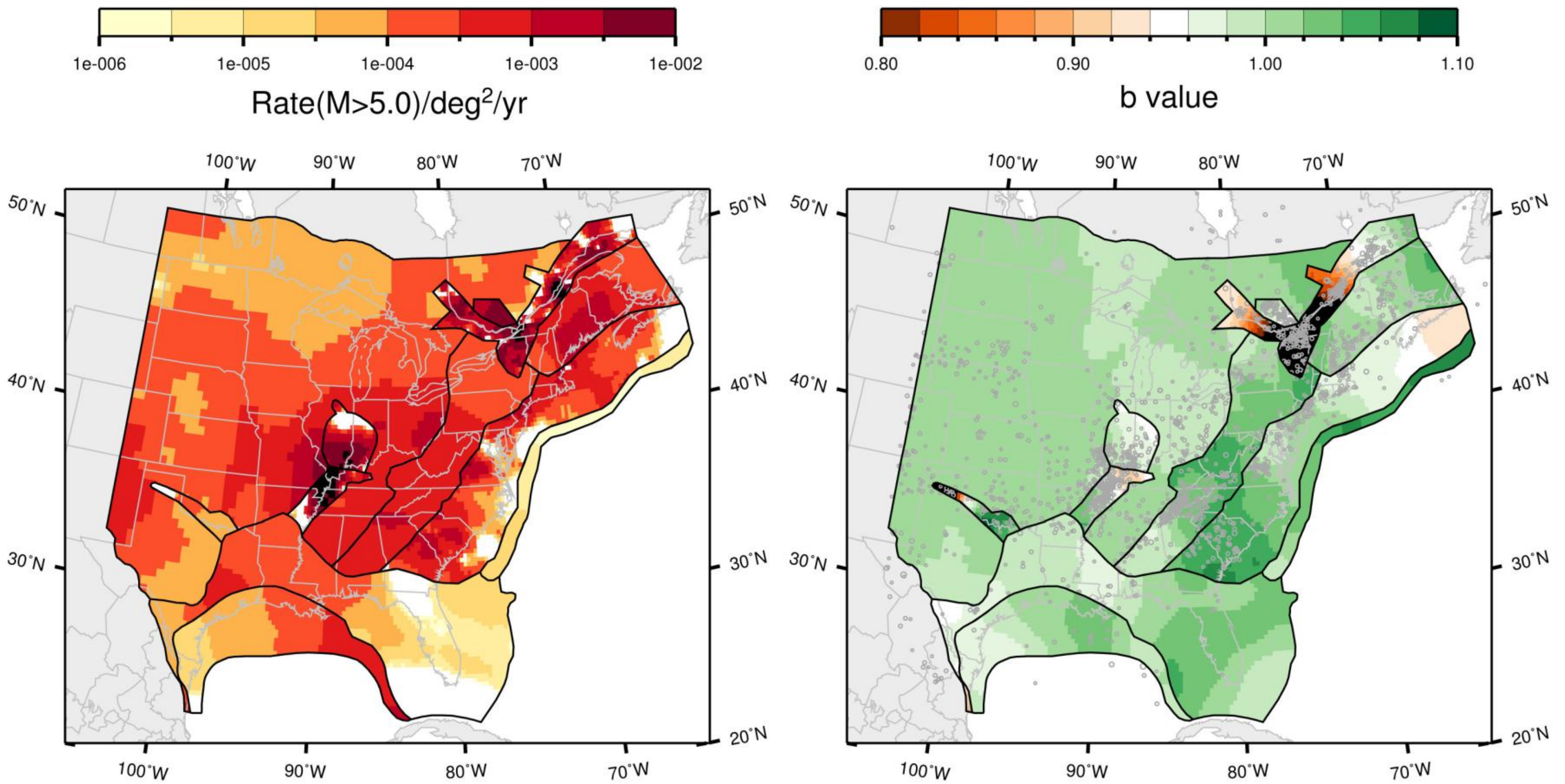


Figure J-182
Map of the rate and *b*-value for the study region under the seismotectonic zonation, with wide interpretation of PEZ; Case E magnitude weights: Realization 2

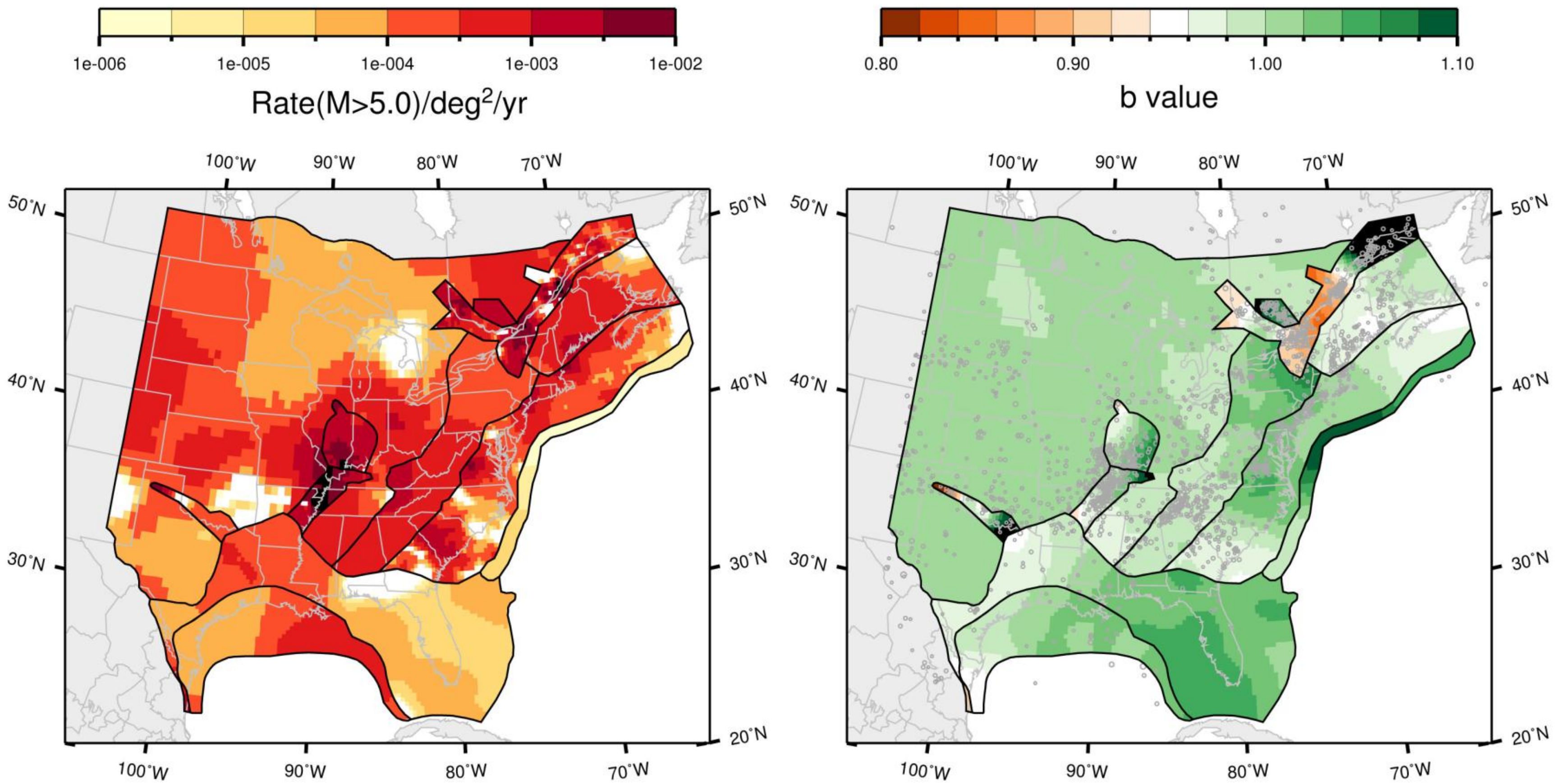


Figure J-183
Map of the rate and *b*-value for the study region under the seismotectonic zonation, with wide interpretation of PEZ; Case E magnitude weights: Realization 3

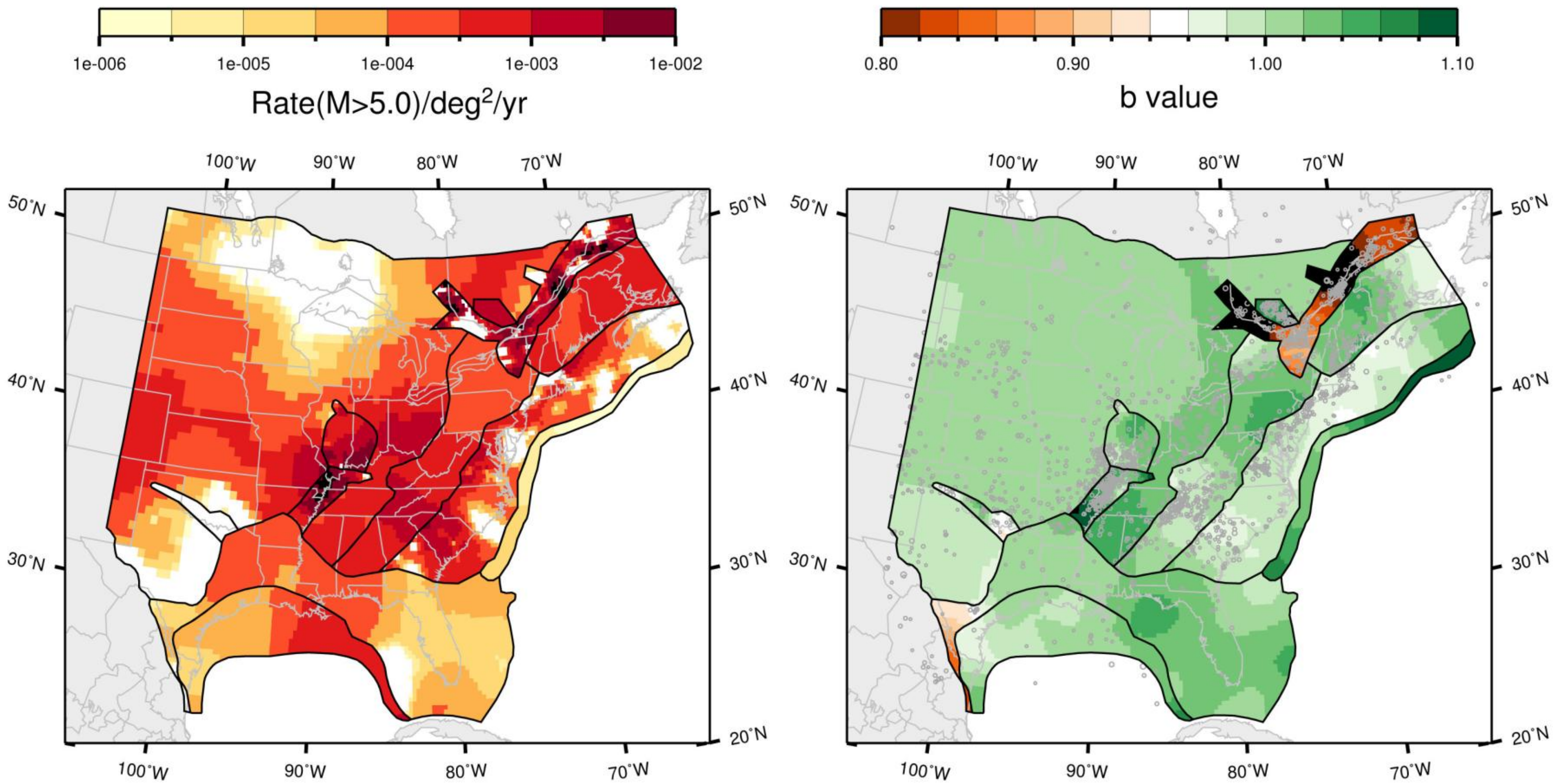


Figure J-184
Map of the rate and *b*-value for the study region under the seismotectonic zonation, with wide interpretation of PEZ; Case E magnitude weights: Realization 4

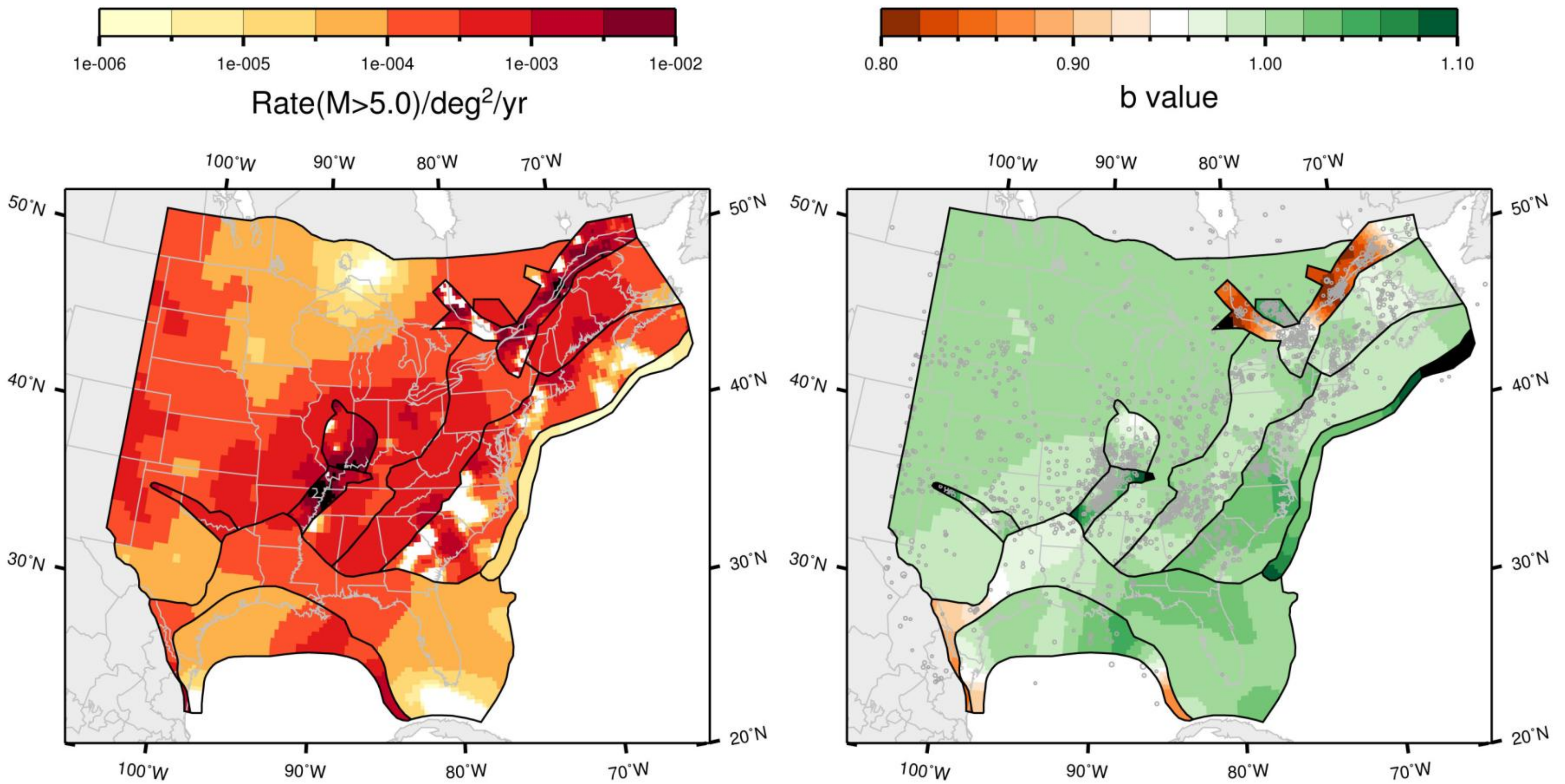


Figure J-185
Map of the rate and *b*-value for the study region under the seismotectonic zonation, with wide interpretation of PEZ; Case E magnitude weights: Realization 5

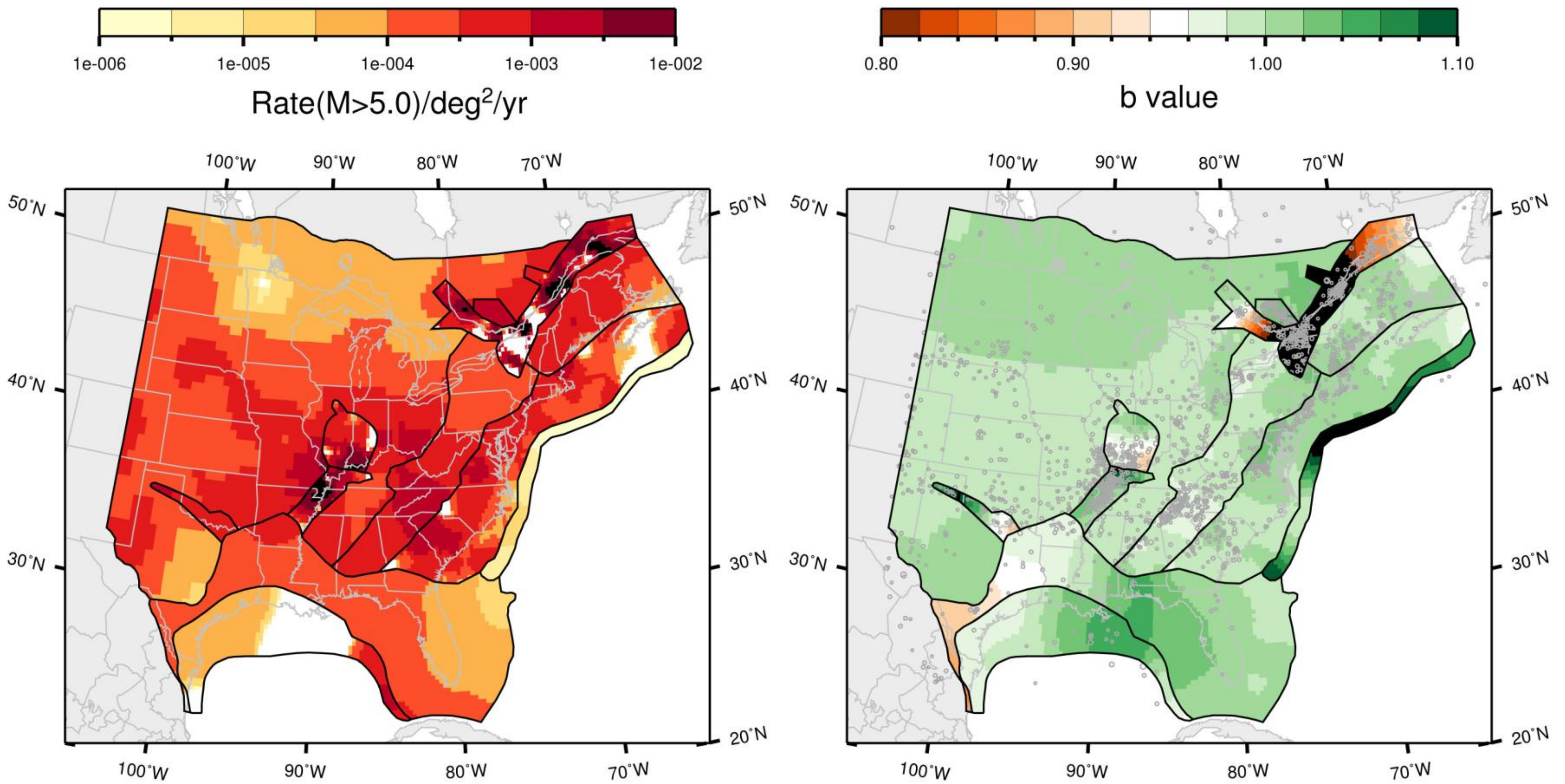


Figure J-186
Map of the rate and *b*-value for the study region under the seismotectonic zonation, with wide interpretation of PEZ; Case E magnitude weights: Realization 6

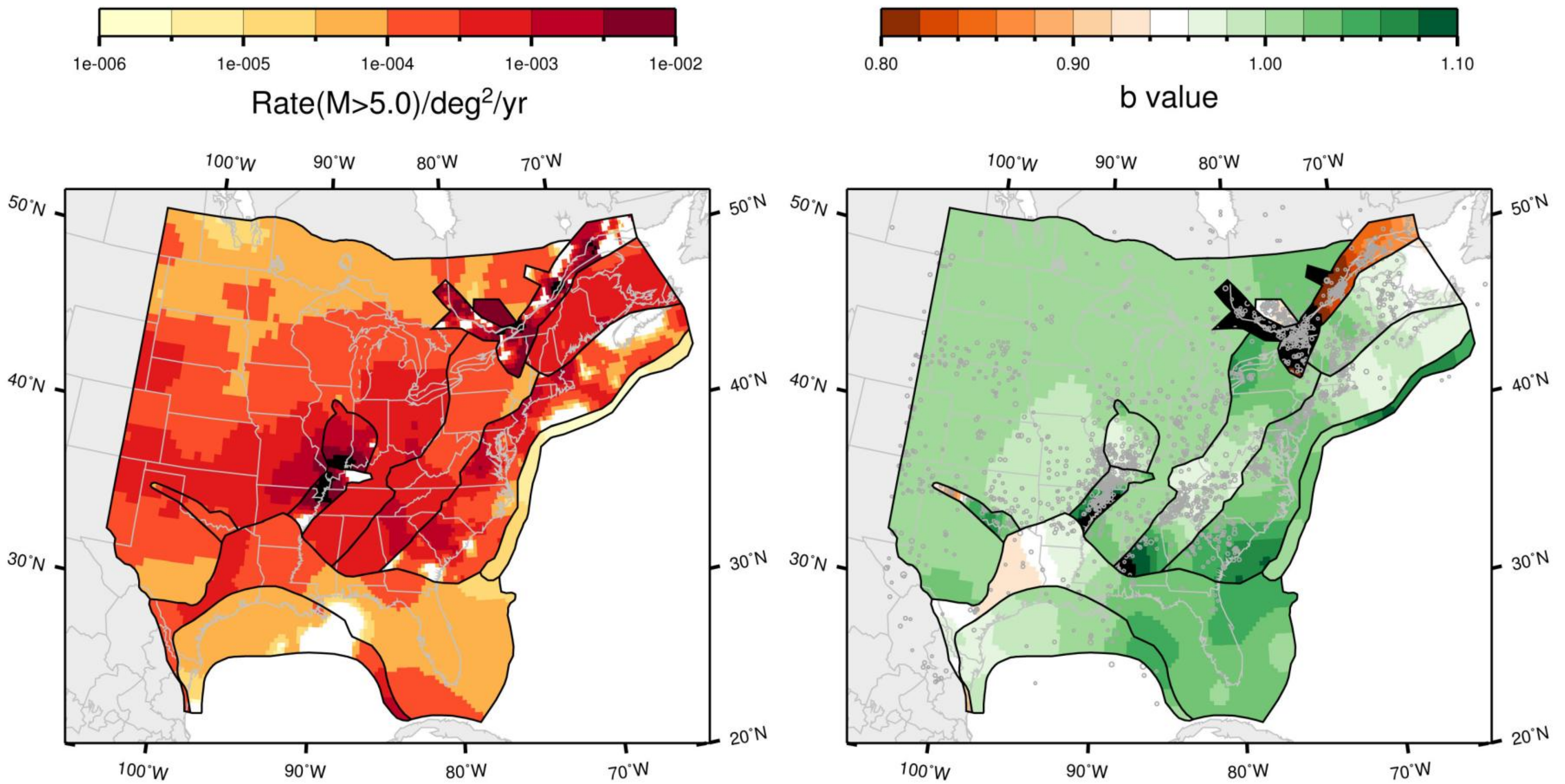


Figure J-187
Map of the rate and *b*-value for the study region under the seismotectonic zonation, with wide interpretation of PEZ; Case E magnitude weights: Realization 7

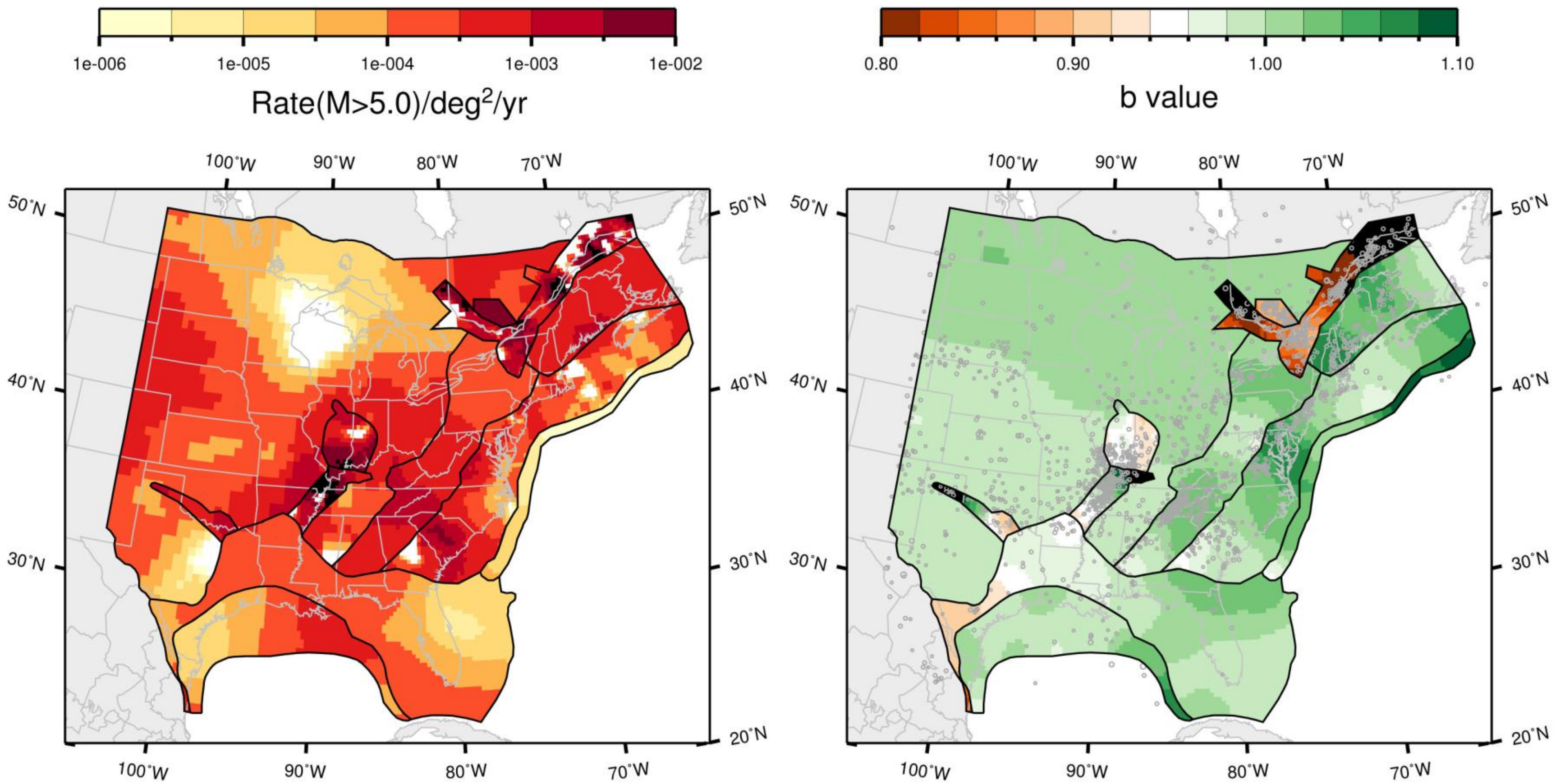


Figure J-188
Map of the rate and *b*-value for the study region under the seismotectonic zonation, with wide interpretation of PEZ; Case E magnitude weights: Realization 8

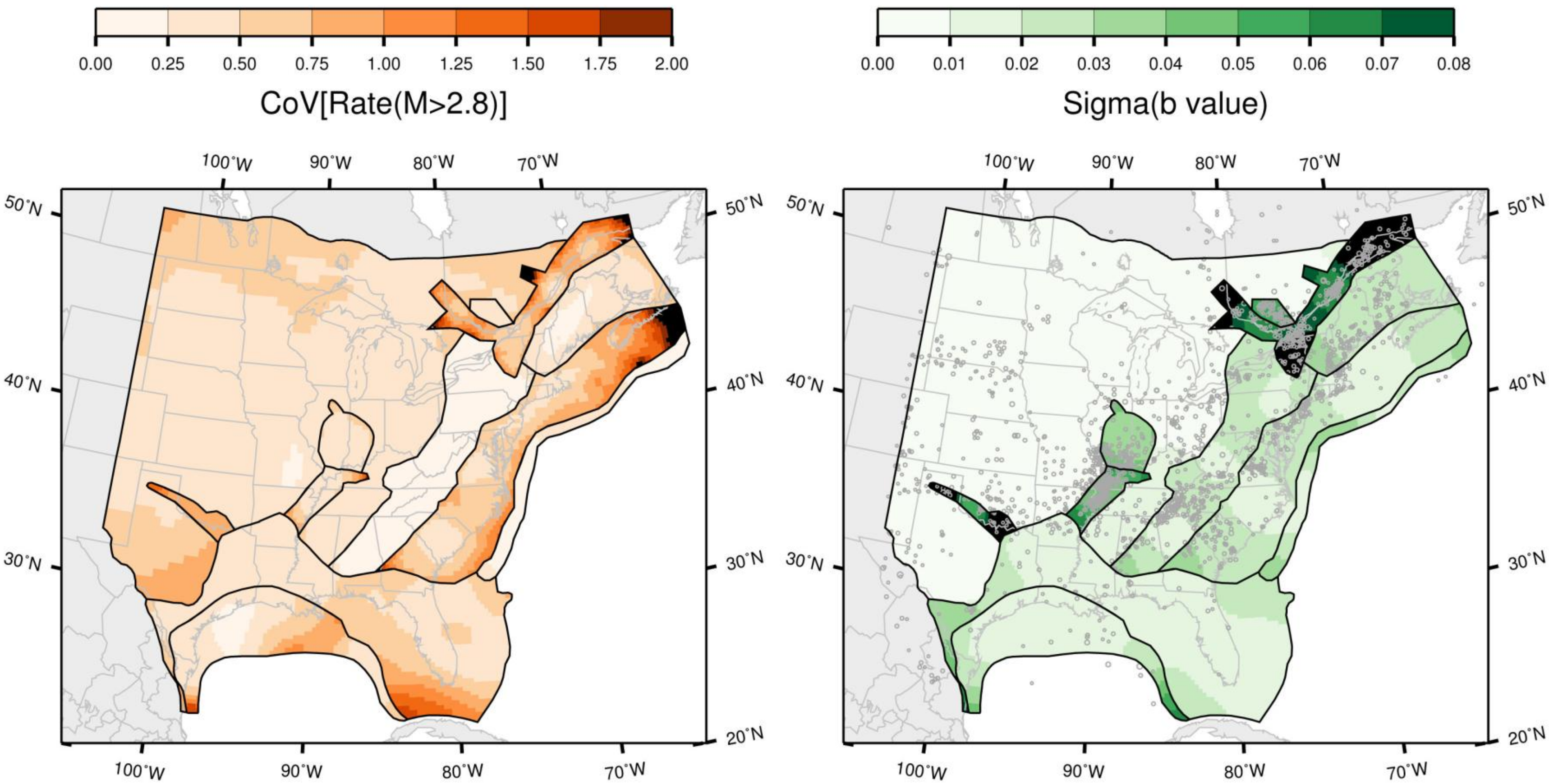


Figure J-189
Map of the coefficient of variation of the rate and the standard deviation of the *b*-value for the study region under the seismotectonic zonation, with wide interpretation of PEZ; Case E magnitude weights

APPENDIX K

SCR Database Used To Develop MMAX Prior Distributions

K

APPENDIX SCR DATABASE USED TO DEVELOP MMAX PRIOR DISTRIBUTIONS

This appendix contains the Stable Continental Regions (SCR) database utilized in the CEUS SSC Project to develop prior distributions for Mmax. The database consists of two components: the catalog of SCR earthquakes and the catalog of SCR crustal domains. The use of these data to develop the Mmax prior distributions is described in Section 5.2.1.1. The databases are based primarily on the work presented in Johnston et al. (1994) updated as described below for the CEUS SSC Project.

K.1 SCR Earthquake Catalog

Johnston et al. (1994) developed a catalog of SCR earthquakes. An important part of that catalog was the development of moment magnitude, **M**, estimates for all of the SCR earthquakes contained in the catalog. For the most part, the assessment of moment magnitude was based on correlations with other size measures. These included correlations with other magnitude scales for instrumentally recorded earthquakes and correlations with shaking intensity measures for pre-instrumental earthquakes.

Schulte and Mooney (2005) extended the SCR earthquake catalog of Johnston et al. (1994) to include earthquakes in the time period 1991 through 2003 as well as additional earthquakes identified from the literature that occurred in the time period covered by Johnston et al. (1994). The Schulte and Mooney (2005) update of the Johnston et al. (1994) SCR earthquake catalog was used as the basis for the SCR earthquake catalog used in the CEUS SSC Project. The SCR catalog was extended to cover the time period ending 12/31/2008 utilizing moment magnitudes from the Harvard Central Moment Tensor (CMT) catalog for earthquakes that occurred in the SCR regions described in Section K.2. Table K-1 lists the resulting updated SCR earthquake catalog developed for the CEUS SSC Project. The dates, times, and locations were taken directly from the catalog sources Johnston et al. (1994), Schulte and Mooney (2005), and Harvard CMT.

The magnitudes utilized in the CEUS SSC catalog of SCR earthquakes are values of E[**M**], the expected value of moment magnitude given the uncertainty in its estimate. The value of E[**M**] also incorporates the effect of the general exponential distribution of earthquake magnitudes. Section 3.3.1 discusses the estimation of E[**M**] from observations and the relationships presented in that section are utilized to produce values of E[**M**] for the SCR earthquakes. The two general cases are when **M** is based on direct observations of moment magnitude computed from wave form inversions (e.g. Harvard CMT value) and when **M** is estimated from other size measures. For the case when **M** is obtained directly from observations of moment magnitude, its value is designated $\hat{\mathbf{M}}$ to indicate that it is observed with some level of uncertainty. As described in

Section 3.3.1, in this case E[**M**] is obtained by the relationship given in Equation 3.3-5 utilizing the uncertainty in the measurement of **M** defined by $\sigma[\mathbf{M}|\hat{\mathbf{M}}]$. For those earthquakes in Table K-1 whose moment magnitudes were directly estimated, the values of E[**M**] were computed from the reported values of $\hat{\mathbf{M}}$ utilizing Equation 3.3-5 and the reported values of $\sigma[\mathbf{M}|\hat{\mathbf{M}}]$. The adjustments to E[**M**] were made using a *b*-value of 0.95, an average value found for earthquakes in the SCR domains. The second case is when **M** is estimated from other size measures. As discussed in Section 3.3.1, estimation of **M** from regression relationships with other size measures directly produces values of E[**M**]. In this case, the reported values of **M** are used directly as E[**M**]. However, an adjustment to the value of the standard error of the estimate of **M** is needed to account for the inflation of the standard error obtained from regression due to the uncertainty in the values of $\hat{\mathbf{M}}$ used in the regressions (see Equation 3.3-8 and related text).

The magnitudes and magnitude uncertainties listed in Schulte and Mooney (2005) were updated as follows. Johnston (1996a, 1996b) provides updates to the magnitude conversion relationships presented in Johnston et al. (1994) as well as updated moment magnitude and magnitude uncertainty estimates for many of the SCR earthquakes. These updated magnitudes were used in updating the SCR earthquake catalog for the CEUS SSC Project. Reported values of standard error given by the relationships in Johnston (1996a, 1996b) were reduced using the average value of $\sigma[\mathbf{M}|\hat{\mathbf{M}}]$ equal to 0.16 reported in Johnston (1996b). The magnitude and uncertainty estimates for those SCR earthquakes that are in the CEUS SSC Project catalog were taken directly from Appendix B.

Updates to the magnitude and uncertainty values reported in Schulte and Mooney (2005) and Johnston et al. (1994) were made for earthquake magnitudes based on maximum intensity, I_0. These earthquake magnitudes were designated type X in Johnston et al. (1994, Appendix C). The Johnston et al. (1994) type X magnitudes were converted back into I_0 using the relationship given in Johnston et al. (1994) and then new estimates of E[**M**] and standard error were obtained using Johnston (1996b). The following table summarizes the adjustments.

Update of Johnston et al. (1994) Type X

EPRI (1994) **M**	I_0	Johnston (1996b) E[**M**]	Johnston (1996b) σ_P	$\sigma[\mathbf{M}\|I_0]$
4.20	V	4.22	0.522	0.50
	V-VI	4.46	0.522	0.50
4.39	VI	4.72	0.522	0.50
4.62	VI-VII	4.98	0.522	0.50
4.85	VII	5.25	0.522	0.50
5.16	VII-VIII	5.53	0.522	0.50
5.46, 5.47	VIII	5.81	0.524	0.50
5.85, 5.86	VIII-IX	6.11	0.527	0.50
6.24	IX	6.41	0.534	0.51
6.67	IX-X	6.72	0.545	0.52
6.94	X	7.04	0.563	0.54

Johnston et al. (1994) designated type Z as earthquakes of type X with additional uncertainty in the estimates of I_0. Following Johnston (1996b, Equation 18) the uncertainty in these earthquakes was set at the nominal standard error for type X, 0.5, times the square root of 2, or a nominal value of 0.7.

Johnston et al. (1994) reports magnitude estimates based on the number of stations reporting the earthquake. These are designated magnitude type D1 in Johnston et al. (1994, Appendix C). Figure K-1 compares the relationships between number of reporting stations, N_R, normalized by the maximum number of stations available, N_M and moment magnitude developed by Johnston et al. (1994) with the updated relationship presented in Johnston (1996b). Significant differences in the estimated values of moment magnitude are indicated on the figure. Therefore, the type D1 magnitudes reported in Johnston et al. (1994) were updated using the relationship presented in Johnston (1996b). The values of N_R/N_M were estimated from the moment magnitudes listed in Johnston et al. (1994) and then used to compute E[**M**] using the relationship in Johnston (1996b). The value of standard error was reduced from 0.48 reported in Johnston (1996b) to a value of 0.45 representing the uncertainty in the true moment magnitude using Equation 3.3-8 and the average value of $\sigma[\mathbf{M}|\hat{\mathbf{M}}]$ equal to 0.16 reported in Johnston (1996b).

Many of the moment magnitudes reported in Johnston et al. (1994) were based on correlations between **M** and various isoseismal areas. Figure K-2 compares these relationships with the updated relationships presented in Johnston (1996b). For the most part, the updated relationships are similar to those published in Johnston et al. (1994) and no update to the magnitude estimates of this type was considered necessary.

K.2 SCR Crustal Domains

Johnston et al. (1994) divided the SCR portions of the earth into 255 domains based on differences in their geology and tectonic history. These domains were used in the CEUS SSC Project without modification to their boundaries. Table K-2 lists the 255 domains. Scanned images of the plates from Johnston et al. (1994) that outline the domains as well as digital listings of the domain boundaries are contained on the CEUS SSC Project web site.

Table K-2 lists the attributes assigned to the domains used in the development of the prior distributions for Mmax. The AGE attribute has two entries. The first is the age assigned in Johnston et al. (1994). The second is the age of most recent extension (MRE Age) which was found to provide a better means of discriminating between domains in assessing Mmax priors (see Section 5.2.1.1).

The maximum observed magnitude in each domain is based on the SCR earthquake catalog listed in Table K-1. The number of earthquakes of magnitude equal to or larger than **M** 4.5 includes the adjustment for the effect of magnitude completeness defined by Equation 5.2.1-3.

As described in Section 5.2.1.1, the domains were grouped into superdomains using the attributes listed in Table K-2. The last two columns of Table K-2 indicate the superdomain number each domain was assigned to. The designation SDNT indicates the superdomain number for the case when the superdomains are separated into two groups by the attribute TYPE. In this case the extension attribute and the MRE Age attribute are used to group the domains into extended superdomains, indicated by the characters SE in the superdomain number, and non-extended superdomains, indicated by the characters SN in the superdomain number. The designation SDNC indicates the superdomain number for the case when the superdomains are not separated into two groups by the attribute TYPE.

Table K-1
SCR Earthquake Catalog

Notes:

Year, Month, Day	Earthquake Date
Hour, Minute, Second	Earthquake Time. The time is based on values reported in the primary sources and is assumed to be UTC time. However, these times were not verified as UTC and may contain a mixture time zone values.
Latitude, Longitude	Earthquake Location. The precision of the location values were taken directly from the catalog source.
E[**M**]	Expected value of Moment Magnitude
sig**M**	Standard deviation of moment magnitude estimate
DN	SCR Domain Number (see Table K-2)

Table K-1
SCR Earthquake Catalog

Year	Month	Day	Hour	Minute	Second	Latitude	Longitude	E[M]	sigma M	DN
495	3	31	0	0	0	37.5	121.5	5.22	0.44	133
827	0	0	0	0	0	51.1	12.8	5.25	0.50	192
973	9	0	0	0	0	32.2	46.3	5.53	0.50	81
999	10	0	0	0	0	31.8	119.9	5.25	0.50	132
1058	12	8	0	0	0	34.3	44.7	5.62	0.47	81
1062	2	8	0	0	0	49	12	5.81	0.50	192
1067	11	0	0	0	0	23.6	116.5	6.12	0.32	125
1068	3	18	0	0	0	28.7	36.75	6.9	0.47	81
1088	5	12	0	0	0	51.1	13.1	5.25	0.50	192
1112	0	0	0	0	0	48.417	8.833	5.81	0.50	195
1128	0	0	0	0	0	47.483	7.567	5.81	0.50	195
1130	2	27	0	0	0	33.6	45.7	6.09	0.47	81
1185	4	15	0	0	0	53.22	-0.5	5.53	0.50	187
1194	3	0	0	0	0	32	44.3	4.67	0.44	81
1247	2	20	0	0	0	52	-6	5.28	0.32	197
1275	9	11	0	0	0	51	-2.5	5.49	0.44	196
1279	9	2	0	0	0	49	8	5.81	0.50	195
1344	0	0	0	0	0	38.9	-8.85	5.96	0.50	199
1346	0	0	0	0	0	50.8	12.2	5.39	0.50	192
1366	5	24	0	0	0	50.8	12.2	5.25	0.50	192
1382	5	21	0	0	0	51.5	2.5	5.41	0.44	187
1407	11	0	0	0	0	31.2	112.6	5.25	0.50	130
1430	0	0	0	0	0	32.2	46.4	5.48	0.47	81
1445	2	14	0	0	0	50	6.3	5.81	0.50	196
1445	12	12	0	0	0	24.5	117.6	5.65	0.44	125
1457	0	0	0	0	0	31.9	46.9	5.7	0.47	81
1477	8	6	0	0	0	45.8	3	5.51	0.32	195
1490	3	1	0	0	0	45.85	3.1	5.85	0.32	195
1523	8	14	0	0	0	29.9	121.7	5.25	0.50	125
1528	3	12	0	0	0	39.7	-8.9	5.25	0.50	199
1531	1	26	0	0	0	38.95	-9	7.04	0.54	199
1548	9	13	0	0	0	38	121	6.1	0.32	133
1553	8	17	0	0	0	51.583	13	5.39	0.50	192
1556	1	0	0	0	0	29.4	113.1	5.15	0.32	130
1558	6	0	0	0	0	23.4	111.5	4.81	0.32	129
1568	0	0	0	0	0	41.5	-72.5	5.25	0.50	218
1574	0	0	0	0	0	27.6	119.1	5.25	0.50	125
1574	0	0	0	0	0	41.5	-72.5	5.25	0.50	218
1574	8	19	0	0	0	26.1	119.3	5.83	0.32	125
1575	2	26	0	0	0	53	-1.5	4.9	0.44	187
1580	4	6	0	0	0	50.9	1.7	6.67	0.32	187
1584	0	0	0	0	0	41.5	-72.5	5.25	0.50	218
1585	3	6	0	0	0	31.2	117.7	5.28	0.32	130
1592	0	0	0	0	0	41.5	-72.6	5.25	0.50	222
1600	9	29	0	0	0	23.5	117	6.84	0.32	125

Year	Month	Day	Hour	Minute	Second	Latitude	Longitude	E[M]	sigma M	DN
1604	12	29	0	0	0	25	119.5	7.65	0.32	127
1605	7	13	0	0	0	19.9	110.5	7.47	0.32	126
1611	9	9	0	0	0	21.5	111.3	5.25	0.50	129
1615	0	0	0	0	0	5.1	-1.3	5.81	0.50	100
1618	2	18	0	0	0	16.7	-3.2	5.37	0.44	99
1618	5	26	0	0	0	18.9	72.9	6.41	0.51	106
1624	2	10	0	0	0	32.4	119.5	5.73	0.32	132
1624	9	1	0	0	0	31.2	121.4	4.65	0.32	132
1624	10	0	0	0	0	33.2	107.5	5.25	0.50	131
1626	5	14	0	0	0	66	35.5	5.27	0.44	173
1631	8	14	0	0	0	29.3	111.7	6.38	0.32	130
1635	10	26	0	0	0	33.2	107.5	5.25	0.50	131
1636	0	0	0	0	0	33.1	107	5.25	0.50	131
1636	12	18	0	0	0	5.1	-2.2	6.19	0.32	100
1638	6	11	0	0	0	42.5	-69	5.81	0.50	218
1641	11	26	0	0	0	23.6	116.5	5.47	0.44	125
1651	2	15	0	0	0	26.2	116.6	5.16	0.32	125
1655	3	29	0	0	0	48.5	9.067	5.25	0.50	195
1657	2	15	0	0	0	47.1	0.6	5.53	0.50	196
1661	2	10	0	0	0	45.5	-73	5.25	0.50	227
1663	2	5	0	0	0	47.6	-70.1	6.72	0.52	227
1668	7	25	0	0	0	34.3	118.5	7.87	0.32	132
1679	12	16	0	0	0	31.4	119.5	4.98	0.50	132
1682	5	12	0	0	0	47.9	6.5	6.55	0.32	195
1690	10	7	0	0	0	53	-3	4.77	0.44	185
1692	9	18	0	0	0	50.7	4.333	5.08	0.32	187
1710	4	16	0	0	0	27.8	111.3	5.25	0.50	129
1711	10	6	0	0	0	47.06	0.03	5.93	0.32	196
1720	7	15	0	0	0	28.53	77.2	6.11	0.50	113
1727	7	19	0	0	0	51.5	-3.5	5.09	0.32	196
1727	11	10	0	0	0	42.8	-70.8	4.77	0.32	218
1728	8	3	0	0	0	48.3	7.8	5.55	0.32	195
1732	9	16	0	0	0	45.5	-73.6	6.25	0.32	227
1736	4	30	0	0	0	56.18	-3.77	4.98	0.50	186
1737	12	19	0	0	0	40.8	-74	5.25	0.50	218
1743	6	29	0	0	0	30.7	118.4	4.76	0.32	130
1751	12	19	0	0	0	41	-7	5.53	0.50	200
1752	3	27	0	0	0	40.65	-8.55	5.53	0.50	199
1755	11	18	0	0	0	42.7	-70.3	6.1	0.26	218
1755	12	26	0	0	0	50.8	6.333	5.5	0.32	195
1759	12	22	0	0	0	57.7	11.1	5.1	0.32	177
1764	6	4	0	0	0	24	88	5.81	0.50	118
1764	8	17	0	0	0	17.9	73.7	4.65	0.44	106
1769	11	14	0	0	0	57.46	-4.22	4.69	0.44	185
1772	2	18	0	0	0	68.7	33.3	4.66	0.44	171
1772	6	0	0	0	0	44.37	4.82	5.35	0.32	195
1775	9	8	0	0	0	51.6	-4	5.01	0.32	196

Year	Month	Day	Hour	Minute	Second	Latitude	Longitude	E[M]	sigma M	DN
1775	12	30	0	0	0	49.17	-0.4	5.28	0.32	196
1780	0	0	0	0	0	58.5	121	5.08	0.44	147
1782	4	30	0	0	0	26.2	111.7	4.91	0.32	129
1785	1	2	0	0	0	42.3	-71.1	5.25	0.50	218
1786	8	11	0	0	0	54.53	-3.68	4.98	0.50	185
1788	0	0	0	0	0	7.6	1.7	5.74	0.44	92
1791	4	8	0	0	0	24.5	117.7	5.25	0.50	125
1791	12	6	0	0	0	47.4	-70.5	5.5	0.48	226
1795	5	20	0	0	0	9.3	-13.4	4.78	0.32	105
1798	5	23	0	0	0	57.9	56.8	4.76	0.44	166
1799	1	25	0	0	0	46.95	-2	5.91	0.32	196
1803	9	1	0	0	0	27.5	77.7	6.65	0.44	113
1804	5	5	0	0	0	53.3	104	5.41	0.44	149
1806	1	11	0	0	0	25.3	115.7	5.71	0.44	125
1808	8	8	0	0	0	-5.7	-37.7	4.58	0.32	56
1809	12	4	0	0	0	-34	18.4	5.53	0.50	59
1811	6	2	0	0	0	-34	18.4	5.25	0.50	59
1812	2	7	0	0	0	36.5	-89.6	7.8	0.17	228
1816	8	13	0	0	0	57.45	-4.17	4.71	0.32	185
1816	9	9	0	0	0	45.5	-73.6	5.25	0.50	227
1817	3	18	0	0	0	42.25	-2.1	5.24	0.32	201
1817	5	22	0	0	0	44.72	-67.5	4.69	0.32	222
1818	1	0	0	0	0	12.1	-12.4	5.85	0.32	100
1819	6	16	0	0	0	23.6	69.6	7.79	0.32	114
1819	8	31	0	0	0	66.7	15.5	6.38	0.32	179
1819	9	14	0	0	0	26.5	107.2	5.25	0.32	130
1820	0	0	0	0	0	-4.5	11.6	6.35	0.44	74
1822	4	3	0	0	0	24	89	5.25	0.50	118
1823	2	9	0	0	0	7	80	5.25	0.50	107
1824	0	0	0	0	0	-8	-39	5.81	0.50	56
1827	5	0	0	0	0	57.9	108.8	6.4	0.44	149
1827	9	24	0	0	0	31.57	74.35	6.11	0.50	113
1828	7	8	0	0	0	22.6	88.4	5.25	0.50	118
1828	8	22	0	0	0	13	75	5.25	0.50	106
1829	12	1	0	0	0	53.8	82.4	4.95	0.44	156
1831	5	8	0	0	0	47.3	-70.5	5.25	0.50	227
1833	10	4	0	0	0	27	85	6.41	0.51	112
1833	10	18	0	0	0	27	84	5.81	0.50	112
1834	9	3	0	0	0	61	6	5.15	0.32	179
1838	6	9	0	0	0	38.5	-89	5.12	0.48	230
1841	4	3	0	0	0	56.9	8	4.64	0.32	190
1842	5	21	0	0	0	25	87	5.25	0.50	111
1843	1	5	0	0	0	35.5	-90.5	6	0.17	228
1843	3	31	0	0	0	15.2	76.9	5.29	0.32	106
1845	6	19	0	0	0	23.78	68.83	5.53	0.50	114
1845	8	6	0	0	0	22.7	88.4	5.25	0.50	118
1846	0	0	0	0	0	31.6	106	5.22	0.44	131

Year	Month	Day	Hour	Minute	Second	Latitude	Longitude	E[M]	sigma M	DN
1846	5	27	0	0	0	23	80	5.25	0.50	111
1846	7	29	0	0	0	50.2	7.7	4.55	0.32	195
1848	4	26	0	0	0	24.4	72.7	5.48	0.44	113
1850	1	18	0	0	0	58.5	121	5.55	0.44	147
1852	4	29	0	0	0	36.7	-82	5.21	0.26	224
1852	11	9	0	0	0	53.23	-4.12	4.99	0.32	185
1853	4	1	0	0	0	49.27	-1.82	4.72	0.32	196
1854	11	24	0	0	0	29.1	107.1	5.25	0.50	131
1855	2	8	0	0	0	46	-64.5	4.9	0.32	221
1855	12	11	0	0	0	39.1	121.6	5.25	0.50	133
1856	6	10	0	0	0	29.7	108.8	4.79	0.32	130
1856	12	25	0	0	0	21.15	72.9	5.12	0.50	115
1857	10	8	0	0	0	38.7	-89.2	5.13	0.32	230
1858	11	11	0	0	0	38.2	-9	7.09	0.32	199
1859	11	21	0	0	0	-40.7	145.2	4.73	0.32	26
1860	0	0	0	0	0	45.97	-94.82	4.98	0.50	236
1860	10	17	0	0	0	47.5	-70.1	6.08	0.48	227
1861	2	16	0	0	0	22.6	88.4	5.25	0.50	118
1861	7	13	0	0	0	45.4	-75.4	4.71	0.48	227
1861	7	19	0	0	0	39.1	121.7	5.81	0.50	133
1861	8	31	0	0	0	36.2	-81.2	5.63	0.26	223
1862	7	10	0	0	0	7	0.4	6.75	0.32	92
1863	10	6	0	0	0	51.97	-2.88	4.89	0.32	187
1863	11	18	0	0	0	21.8	75.3	5.53	0.50	120
1864	4	29	0	0	0	22.3	72.8	4.98	0.50	115
1864	12	7	0	0	0	33.3	45.9	5.91	0.47	81
1865	5	7	0	0	0	59.5	4.8	4.92	0.32	179
1865	8	17	0	0	0	36	-89.5	5.21	0.32	228
1866	3	9	0	0	0	63.3	6.7	5.75	0.32	183
1866	5	23	0	0	0	25	87	5.67	0.50	111
1866	9	14	0	0	0	46.8	1.2	4.98	0.32	196
1867	4	24	0	0	0	39.17	-96.3	5.08	0.15	235
1867	12	18	0	0	0	44.7	-75.2	4.4	0.15	226
1868	6	18	0	0	0	-32.8	151.6	4.64	0.32	27
1868	9	30	0	0	0	24	85	5.25	0.50	111
1869	10	22	0	0	0	45	-67.5	5.47	0.32	222
1870	10	20	0	0	0	47.4	-70.5	6.55	0.48	226
1872	3	6	0	0	0	50.86	12.28	4.9	0.32	192
1872	4	14	0	0	0	5.5	-0.4	5.06	0.44	92
1873	7	19	0	0	0	44.48	4.72	5.2	0.32	195
1873	12	15	0	0	0	-26.8	127.2	6.04	0.70	9
1875	6	18	0	0	0	40.2	-84	4.6	0.32	235
1875	8	17	0	0	0	50.3	24.2	4.86	0.44	167
1875	12	12	0	0	0	31.57	74.35	5.53	0.50	113
1875	12	23	0	0	0	37.8	-78	4.77	0.32	218
1877	11	4	0	0	0	44.5	-74	4.71	0.32	226
1877	11	15	0	0	0	41	-97	5.05	0.32	255

Year	Month	Day	Hour	Minute	Second	Latitude	Longitude	E[M]	sigma M	DN
1878	1	28	0	0	0	49.8	-0.3	4.78	0.32	196
1878	8	26	0	0	0	50.9	6.4	4.94	0.32	195
1879	2	11	0	0	0	6.5	-3.3	5.56	0.32	100
1880	2	3	0	0	0	-43	146.4	4.62	0.32	26
1880	11	28	0	0	0	56.4	-7.3	4.88	0.32	184
1882	1	0	0	0	0	8.6	81.2	5.81	0.50	107
1882	3	15	0	0	0	54.7	83.2	5.24	0.44	156
1882	10	22	0	0	0	35.9	-95.1	5.58	0.32	231
1883	8	0	0	0	0	30	9.5	4.93	0.44	89
1883	8	28	0	0	0	-25.5	151.7	5.12	0.32	28
1884	4	22	0	0	0	51.83	0.92	4.8	0.32	187
1884	7	13	0	0	0	-40.5	148.5	5.66	0.32	26
1884	8	10	0	0	0	40.6	-74	4.79	0.32	218
1885	1	5	0	0	0	-26.5	116.3	6.5	0.70	7
1885	5	12	0	0	0	-39.9	148.9	5.96	0.32	26
1885	7	2	0	0	0	-39	146	4.92	0.44	26
1885	7	14	0	0	0	24	90	5.25	0.50	118
1886	9	1	0	0	0	32.9	-80	6.9	0.17	218
1886	10	25	0	0	0	61.6	5.9	5.01	0.32	179
1886	11	29	0	0	0	-34.75	148.8	4.79	0.32	27
1888	8	23	0	0	0	50	134	5.53	0.50	139
1889	0	0	0	0	0	6.8	-6.7	5.09	0.44	100
1889	5	30	0	0	0	49.5	-0.5	4.77	0.32	196
1891	9	27	0	0	0	38.25	-88.5	5.52	0.32	230
1892	1	26	0	0	0	-40.4	149.5	6.35	0.32	26
1892	5	15	0	0	0	60.6	4.4	5.4	0.32	194
1892	8	18	0	0	0	51.6	-5.2	4.77	0.32	196
1893	11	2	0	0	0	51.6	-4.6	4.58	0.32	196
1893	11	27	0	0	0	45.5	-73.3	5.12	0.48	227
1894	7	23	0	0	0	68.5	13	5.84	0.32	183
1895	2	5	0	0	0	63.5	5	5.47	0.32	183
1895	8	8	0	0	0	57	133	6.19	0.44	147
1895	8	30	0	0	0	23.5	116.3	5.67	0.50	125
1895	10	31	0	0	0	37	-89.4	6	0.17	230
1896	9	2	0	0	0	50.3	2.88	4.87	0.32	196
1896	12	17	0	0	0	52.02	-2.69	4.75	0.32	187
1897	3	23	0	0	0	45.5	-73.6	4.59	0.48	227
1897	5	10	0	0	0	-37.33	139.75	6.16	0.32	23
1897	5	31	0	0	0	37.3	-80.7	5.91	0.32	224
1897	6	22	0	0	0	19.4	84.9	5.12	0.50	108
1897	8	25	0	0	0	62.5	55	4.86	0.44	168
1900	2	8	0	0	0	10.75	76.75	5.66	0.32	106
1901	1	10	0	0	0	50.5	16.1	4.67	0.32	192
1902	4	10	0	0	0	64.3	27.6	4.81	0.44	173
1902	9	19	0	0	0	-35	137.4	5.38	0.32	19
1902	11	4	0	0	0	38.9	-5.6	5.43	0.44	200
1903	1	14	0	0	0	24	70	5.53	0.50	114

Year	Month	Day	Hour	Minute	Second	Latitude	Longitude	E[M]	sigma M	DN
1903	4	6	0	0	0	-38.43	142.53	4.5	0.37	23
1903	6	4	0	0	0	0	26	6.3	0.37	78
1903	6	19	0	0	0	53.05	-4.38	4.58	0.32	185
1903	7	14	0	0	0	-38.43	142.53	4.58	0.32	23
1903	8	9	0	0	0	38.3	-9	6	0.32	199
1903	11	4	0	0	0	36.9	-89.3	4.97	0.32	228
1904	2	13	0	0	0	56.4	73	5.26	0.44	158
1904	3	21	0	0	0	45	-67.2	5.73	0.32	222
1904	4	9	0	0	0	-37	147.1	4.5	0.44	27
1904	10	23	0	0	0	59	10.5	5.87	0.37	177
1905	7	18	0	0	0	-10.2	-40.4	4.67	0.32	47
1905	8	22	0	0	0	36.8	-89.6	4.95	0.32	228
1906	1	8	0	0	0	39.2	-96.5	4.91	0.32	235
1906	3	27	0	0	0	24.5	118.5	6.04	0.37	125
1906	6	27	0	0	0	52.64	-4	4.87	0.32	185
1906	11	19	0	0	0	-19.1	111.8	7.2	0.19	2
1906	11	20	0	0	0	6.5	0.3	5.09	0.32	92
1907	1	14	0	0	0	65.5	11	5.32	0.37	183
1908	0	0	0	0	0	7.7	-7.8	5.8	0.32	100
1908	4	2	0	0	0	3	25.5	6.3	0.37	73
1909	4	23	0	0	0	38.95	-8.82	6.4	0.37	199
1909	5	16	0	0	0	50	-104	5.72	0.32	237
1909	5	26	0	0	0	41.75	-88.3	5.15	0.48	230
1909	8	5	0	0	0	-22.2	29	5.01	0.32	66
1909	9	27	0	0	0	39.5	-87.4	4.73	0.32	230
1910	1	8	0	0	0	35	122	6.5	0.19	132
1910	5	30	0	0	0	10	27	5.8	0.37	84
1910	10	21	0	0	0	-30.5	24.7	5.26	0.32	63
1910	12	4	0	0	0	-10	140	6.8	0.25	13
1911	3	26	0	0	0	3.1	11	5.79	0.37	73
1911	8	6	0	0	0	53.5	127.1	4.92	0.44	136
1911	11	16	0	0	0	48.22	9.05	6.17	0.25	192
1912	2	20	0	0	0	-29.45	25.06	6.04	0.25	63
1912	4	13	0	0	0	78.9	108	5.12	0.37	170
1912	6	12	0	0	0	32.9	-80	4.5	0.48	218
1912	11	6	0	0	0	42.9	-2.7	5.25	0.50	198
1913	1	1	0	0	0	34.7	-81.7	4.54	0.32	218
1913	4	3	0	0	0	32.2	119.5	5.22	0.37	132
1913	7	19	0	0	0	64	8	5.15	0.37	183
1913	8	4	0	0	0	61.3	5.2	4.95	0.37	179
1913	10	9	0	0	0	3.8	12.3	4.9	0.32	84
1913	10	27	0	0	0	41.67	-8.72	4.7	0.32	199
1913	12	18	0	0	0	-20	147	5.12	0.37	27
1914	2	10	0	0	0	46	-75	5.1	0.48	226
1914	4	13	0	0	0	53.8	81.5	5.06	0.37	156
1914	5	18	0	0	0	31.35	15.25	5.35	0.37	90
1914	5	24	0	0	0	-10	15	6.15	0.25	72

Year	Month	Day	Hour	Minute	Second	Latitude	Longitude	E[M]	sigma M	DN
1914	6	7	0	0	0	73	119	5.37	0.37	146
1914	8	17	0	0	0	57	59.4	5.24	0.44	159
1914	9	25	0	0	0	39	-8.82	4.91	0.32	199
1915	6	2	0	0	0	48.9	11.4	4.68	0.32	192
1915	10	10	0	0	0	48.8	11.6	4.84	0.32	192
1916	2	21	0	0	0	35.5	-82.5	5.13	0.32	223
1916	10	18	0	0	0	33.5	-86.2	4.98	0.32	224
1916	12	3	0	0	0	43.7	-7.5	5.25	0.50	198
1917	1	21	0	0	0	-3	10	5.63	0.37	76
1917	4	9	0	0	0	38.1	-90.2	4.86	0.32	229
1917	4	17	0	0	0	18	84	4.66	0.45	117
1917	7	30	0	0	0	28	104	6.5	0.25	131
1918	2	13	0	0	0	23.54	117.243	7.42	0.19	125
1918	6	6	0	0	0	-23.5	152.5	5.8	0.25	32
1919	4	21	0	0	0	22	72	5.25	0.50	113
1919	6	1	0	0	0	27.074	123.315	7.5	0.25	127
1919	6	1	0	0	0	-18	-56	4.75	0.44	49
1919	10	31	0	0	0	-27	31.5	6.5	0.47	64
1919	10	31	0	0	0	24	116.5	5.33	0.45	125
1920	2	8	0	0	0	-35	111	6.15	0.25	6
1920	5	29	0	0	0	25.1	120.5	5.13	0.47	127
1920	11	26	0	0	0	42.4	-8.6	4.97	0.37	199
1921	5	30	0	0	0	-35	145	4.95	0.37	27
1921	9	16	0	0	0	3.8	16.3	4.84	0.32	84
1921	12	1	0	0	0	33.7	122	6.4	0.37	132
1922	1	19	0	0	0	-7	143	7.29	0.37	16
1922	1	27	0	0	0	-22.17	-47.04	4.78	0.32	49
1922	4	7	0	0	0	23.5	119	5.71	0.37	127
1922	4	10	0	0	0	-39.14	144.85	5.11	0.37	26
1922	4	13	0	0	0	60	-110	5.11	0.37	239
1922	5	20	0	0	0	24.7	116.5	4.79	0.44	125
1922	7	26	0	0	0	70	-70	5.12	0.37	248
1922	8	14	0	0	0	52.069	130.539	6.72	0.52	139
1923	10	15	0	0	0	48.5	122.5	4.98	0.50	135
1923	12	8	0	0	0	32	127.5	5.71	0.37	127
1924	3	1	0	0	0	-41.6	145	4.52	0.32	26
1924	5	27	0	0	0	62	135.5	5.34	0.37	147
1924	7	25	0	0	0	72.5	16	5.09	0.37	183
1924	9	30	0	0	0	47.6	-69.7	4.69	0.16	222
1924	10	17	0	0	0	60	-118	5.08	0.37	241
1925	2	1	0	0	0	49.16	-5.22	5.04	0.32	197
1925	2	7	0	0	0	48	105	5.3	0.37	136
1925	2	18	0	0	0	69	145	4.97	0.37	141
1925	3	1	0	0	0	47.76	-69.84	6.18	0.29	227
1925	4	27	0	0	0	38.3	-87.6	4.87	0.32	229
1925	7	30	0	0	0	35.4	-101.3	5.24	0.32	231
1925	9	24	0	0	0	25.51	55.38	5.88	0.37	81

Year	Month	Day	Hour	Minute	Second	Latitude	Longitude	E[M]	sigma M	DN
1925	11	6	0	0	0	26.5	81.5	4.52	0.45	112
1925	12	18	0	0	0	-33	151.6	4.56	0.32	27
1926	2	28	0	0	0	38.58	-7.9	5.28	0.32	200
1926	3	10	0	0	0	66.5	-130	4.55	0.45	241
1926	6	13	0	0	0	20	116.5	4.78	0.45	127
1926	6	29	0	0	0	27	121	5.06	0.44	127
1926	7	30	0	0	0	49.22	-1.82	4.98	0.32	196
1926	8	18	0	0	0	65.8	28.5	4.76	0.44	173
1926	9	19	0	0	0	57.3	67	5.3	0.44	158
1926	9	29	0	0	0	48	122.7	4.98	0.50	135
1926	12	14	0	0	0	-12	121	6.26	0.25	1
1926	12	31	0	0	0	25	77.5	4.47	0.45	112
1927	1	24	0	0	0	59.9	1.8	5.57	0.32	188
1927	2	3	0	0	0	33.5	121	6.6	0.25	132
1927	5	7	0	0	0	35.7	-90.6	4.84	0.32	228
1927	6	2	0	0	0	23.5	81	6.4	0.25	119
1928	4	5	0	0	0	9.8	-13.3	4.51	0.32	105
1929	2	8	0	0	0	24.9	119.9	4.47	0.45	127
1929	4	11	0	0	0	25	77.5	5.39	0.50	112
1929	7	26	0	0	0	-2.5	24.5	5.5	0.37	73
1929	8	12	0	0	0	42.91	-78.402	4.72	0.20	226
1929	8	16	0	0	0	-16.99	120.66	6.26	0.25	1
1929	10	24	0	0	0	22	118	6.57	0.25	127
1929	11	18	0	0	0	44.691	-56.006	6.97	0.31	218
1929	12	28	0	0	0	-39.69	149.45	5.42	0.37	26
1930	1	3	0	0	0	32.2	119.4	5.04	0.44	132
1930	1	9	0	0	0	47.62	-2.88	5.1	0.37	196
1930	4	3	0	0	0	32.5	43.7	5.2	0.37	81
1930	6	25	0	0	0	25	77.5	4.45	0.45	112
1930	7	5	0	0	0	37.6	-4.6	5.21	0.37	200
1930	9	23	0	0	0	27.5	106	5.15	0.37	130
1931	1	8	0	0	0	47.63	-70.17	4.89	0.37	226
1931	4	20	0	0	0	43.4	-73.7	4.58	0.32	224
1931	5	1	0	0	0	3	27	5.21	0.37	73
1931	6	7	0	0	0	54.1	1.5	5.7	0.32	194
1931	6	29	0	0	0	48.5	123.5	4.98	0.37	135
1931	7	1	0	0	0	30	109	4.44	0.45	130
1931	9	17	0	0	0	50.1	127	5	0.44	138
1931	9	20	0	0	0	40.4	-84.21	4.58	0.48	235
1931	9	21	0	0	0	19.421	113.158	6.73	0.25	127
1931	12	17	0	0	0	34.1	-89.9	4.71	0.32	225
1932	6	21	0	0	0	16.7	111.8	5.31	0.37	127
1932	8	14	0	0	0	62.8	154.6	4.97	0.37	140
1932	8	22	0	0	0	36.1	121.6	6.26	0.25	132
1932	11	20	0	0	0	51.71	5.61	4.97	0.37	195
1932	12	31	0	0	0	-28.5	32.75	6.61	0.25	63
1933	2	8	0	0	0	48.8	8.2	4.71	0.37	195

Year	Month	Day	Hour	Minute	Second	Latitude	Longitude	E[M]	sigma M	DN
1933	7	14	0	0	0	42.9	56.5	5.33	0.37	160
1933	12	2	0	0	0	-51.5	-44	6.49	0.25	35
1934	5	12	0	0	0	44.43	4.82	4.75	0.32	195
1934	5	21	0	0	0	25	118.2	5.47	0.37	125
1934	11	12	0	0	0	38	-8.5	5.15	0.37	199
1934	11	18	0	0	0	-34.8	149.2	4.99	0.32	27
1935	3	1	0	0	0	40.35	-96.15	4.5	0.32	235
1935	3	21	0	0	0	24.2	89.5	6.08	0.25	118
1935	4	12	0	0	0	-25.5	151.67	5.14	0.37	28
1935	4	18	0	0	0	70.5	-73	5.38	0.37	248
1935	4	19	0	0	0	31.243	15.3	6.62	0.31	90
1935	6	27	0	0	0	48.1	9.5	5.44	0.32	192
1935	7	17	0	0	0	66.05	8.1	5.26	0.37	183
1935	7	20	0	0	0	21	72.4	4.98	0.50	115
1935	11	1	0	0	0	46.885	-79.004	6.06	0.20	226
1935	12	30	0	0	0	48.6	8.2	4.91	0.37	195
1936	1	12	0	0	0	-27	31	4.82	0.32	64
1936	1	16	0	0	0	-29.8	25.3	5.3	0.32	63
1936	4	1	0	0	0	22.5	109.4	6.24	0.32	129
1936	4	26	0	0	0	28.733	103.497	6.72	0.52	131
1936	6	13	0	0	0	32.75	22.5	5.79	0.37	90
1936	6	20	0	0	0	42.4	-9.8	5.56	0.37	199
1937	1	24	0	0	0	56	130	4.76	0.58	147
1937	3	9	0	0	0	40.47	-84.28	5.11	0.32	235
1937	10	28	0	0	0	-26.1	136.5	5.35	0.37	12
1937	12	20	0	0	0	-25.4	136.5	5.55	0.37	12
1938	1	26	0	0	0	33.12	45.87	5.63	0.37	81
1938	3	11	0	0	0	61.7	4.2	4.75	0.37	183
1938	3	14	0	0	0	21.68	75.2	6.26	0.25	106
1938	3	24	0	0	0	-35.5	146	4.97	0.37	27
1938	4	17	0	0	0	-25.5	137.2	5.84	0.25	5
1938	6	11	0	0	0	50.78	3.58	5.28	0.37	187
1938	7	23	0	0	0	22.4	71.8	4.93	0.37	113
1938	9	10	0	0	0	7.7	79.2	5.56	0.37	117
1938	10	16	0	0	0	43.25	-3.62	5.3	0.25	198
1939	1	20	0	0	0	31.03	15.84	5.7	0.37	90
1939	1	23	0	0	0	31.69	16.06	5.95	0.37	90
1939	2	2	0	0	0	31.8	16.8	5.21	0.37	90
1939	3	26	0	0	0	-32	138	5.79	0.37	21
1939	6	22	0	0	0	5.18	-0.13	6.35	0.24	91
1939	6	28	0	0	0	-29	-49	6.08	0.32	46
1939	8	18	0	0	0	6.2	-0.3	5.25	0.37	100
1939	10	19	0	0	0	48.016	-69.734	5.02	0.36	227
1940	1	19	0	0	0	42.7	121.3	5.89	0.37	137
1940	2	27	0	0	0	8.3	-60.8	5.78	0.25	52
1940	5	24	0	0	0	51.467	11.792	4.85	0.37	192
1940	5	29	0	0	0	67	-135	6.21	0.25	241

Year	Month	Day	Hour	Minute	Second	Latitude	Longitude	E[M]	sigma M	DN
1940	6	23	0	0	0	74.7	-14	5.7	0.37	254
1940	10	31	0	0	0	22.5	70.4	5.71	0.37	113
1940	11	10	0	0	0	-24	30.2	5.16	0.32	65
1940	12	24	0	0	0	43.908	-71.283	5.13	0.47	222
1941	3	4	0	0	0	30.75	15.75	5.17	0.37	90
1941	4	29	0	0	0	-26.791	116.197	6.78	0.25	7
1941	5	4	0	0	0	-26.3	136.9	5.9	0.37	12
1941	5	5	0	0	0	46.5	126.9	6.22	0.25	137
1941	6	27	0	0	0	-25.95	137.34	6.49	0.25	12
1941	9	21	0	0	0	25.1	115.6	5.02	0.32	125
1942	2	14	0	0	0	-29.5	136	4.97	0.37	19
1942	7	8	0	0	0	43.5	121.9	5.71	0.37	137
1943	5	28	0	0	0	48.2	9	5.2	0.37	192
1943	7	16	0	0	0	33	21.5	5.28	0.37	90
1943	11	7	0	0	0	21.6	119.3	4.72	0.45	127
1944	4	9	0	0	0	49.92	-67.43	4.44	0.13	226
1944	6	23	0	0	0	49.42	-67.75	4.79	0.37	226
1944	7	17	0	0	0	35.91	42.55	6.21	0.58	81
1944	9	5	0	0	0	44.958	-74.723	5.71	0.19	226
1944	12	19	0	0	0	39.7	124.3	6.73	0.25	133
1945	9	12	0	0	0	2.5	15.6	5.92	0.27	84
1945	11	8	0	0	0	83	-15	6.16	0.25	251
1946	4	19	0	0	0	-33.5	114.5	4.5	0.70	6
1946	9	14	0	0	0	-40.2	149	5.56	0.37	26
1948	1	21	0	0	0	-31.11	-57.27	4.87	0.32	42
1948	5	23	0	0	0	37.2	121.8	5.71	0.37	133
1948	8	6	0	0	0	-37.36	139.68	5.24	0.37	23
1948	9	26	0	0	0	80.7	99.6	4.97	0.37	170
1949	1	14	0	0	0	33.2	121	5.39	0.37	132
1949	3	10	0	0	0	-34.74	149.2	5.04	0.37	27
1949	5	2	0	0	0	-30.9	116.4	4.6	0.37	7
1949	9	17	0	0	0	3.83	-51.84	5.11	0.32	52
1950	4	14	0	0	0	48	-75.7	4.59	0.37	226
1950	9	30	0	0	0	-30.5	18	4.36	0.45	60
1950	10	28	0	0	0	52.3	79.3	4.56	0.37	157
1951	1	1	0	0	0	47.7	109.9	5.69	0.37	136
1951	3	10	0	0	0	38.18	-3.82	5.47	0.32	200
1951	3	14	0	0	0	50.633	6.717	5.49	0.37	195
1951	4	8	0	0	0	18.5	70.8	4.69	0.45	116
1951	4	19	0	0	0	-19.2	28.8	4.41	0.45	67
1951	4	22	0	0	0	76	-73	5.32	0.37	248
1951	5	28	0	0	0	31.8	27	5.18	0.37	90
1951	6	27	0	0	0	45	-57	4.59	0.37	218
1951	9	17	0	0	0	-18.5	23	5.12	0.50	61
1952	1	28	0	0	0	-32.9	20.5	4.98	0.50	58
1952	3	19	0	0	0	39	125.5	6.2	0.37	133
1952	4	9	0	0	0	35.525	-97.85	5.29	0.12	231

Year	Month	Day	Hour	Minute	Second	Latitude	Longitude	E[M]	sigma M	DN
1952	4	20	0	0	0	-69.9	157.7	4.60	0.45	208
1952	5	10	0	0	0	-18	22.5	5.25	0.50	61
1952	6	9	0	0	0	-27.5	18.6	5.25	0.50	60
1952	6	24	0	0	0	-25.5	152.8	4.81	0.37	32
1952	9	7	0	0	0	-34.8	149.3	4.66	0.37	27
1952	10	11	0	0	0	-19.3	23.4	5.02	0.45	61
1952	10	14	0	0	0	48.02	-69.78	4.54	0.32	227
1953	2	22	0	0	0	50.917	10	5.09	0.37	192
1953	4	2	0	0	0	-18	27	5.53	0.50	67
1953	5	1	0	0	0	-29	17	5.53	0.50	61
1953	9	28	0	0	0	41.13	-1.58	5.09	0.37	201
1954	2	28	0	0	0	-34.93	138.69	5.09	0.32	21
1954	7	7	0	0	0	59.8	4.8	4.64	0.37	179
1954	8	18	0	0	0	-19.5	23.5	5.25	0.50	61
1954	8	28	0	0	0	45.17	-56.87	4.79	0.37	218
1954	9	19	0	0	0	-28.5	148.6	4.74	0.37	27
1954	10	16	0	0	0	44.83	-56.8	4.86	0.37	218
1954	11	26	0	0	0	-18	13	4.98	0.50	61
1955	1	31	0	0	0	-12.42	-57.3	6.12	0.37	52
1955	3	30	0	0	0	22.4	118.7	4.78	0.37	127
1955	5	26	0	0	0	25.5	105	4.56	0.37	130
1955	6	3	0	0	0	61.9	4.15	5.12	0.37	183
1955	8	23	0	0	0	31.31	71.38	5.56	0.37	113
1955	11	27	0	0	0	-18	25	5.25	0.50	61
1956	1	29	0	0	0	61.5	131.4	4.72	0.37	147
1956	4	9	0	0	0	49	130.5	4.88	0.37	139
1956	6	3	0	0	0	79.5	-118.5	5.77	0.37	250
1956	6	5	0	0	0	56.8	-58.9	4.67	0.37	247
1956	6	29	0	0	0	-5	22	5.02	0.37	73
1956	7	21	0	0	0	23.3	70	5.96	0.17	114
1956	10	10	0	0	0	28.2	77.7	6.05	0.37	113
1956	10	13	0	0	0	48.5	122	4.98	0.44	135
1957	1	4	0	0	0	7.42	-12.52	5.2	0.44	105
1957	2	11	0	0	0	52.86	-1.15	4.66	0.37	187
1957	4	13	0	0	0	-30.18	26.91	5.56	0.37	60
1957	4	16	0	0	0	-9.5	-67	4.92	0.44	51
1957	8	9	0	0	0	62.3	132	4.59	0.37	147
1957	8	25	0	0	0	22	80	4.9	0.37	111
1958	1	1	0	0	0	-42.2	146.1	4.79	0.37	26
1958	1	23	0	0	0	65.19	6.91	5.42	0.37	183
1958	3	2	0	0	0	67	144	4.69	0.37	141
1958	5	14	0	0	0	47.092	-76.818	4.17	0.16	226
1958	5	17	0	0	0	31.81	11.28	5.25	0.37	89
1958	7	8	0	0	0	50.833	10.117	5.15	0.37	192
1958	8	6	0	0	0	59.61	5.94	4.78	0.37	179
1958	9	25	0	0	0	22.5	109.5	4.7	0.32	129
1959	1	2	0	0	0	47.99	-3.99	5.35	0.37	196

Year	Month	Day	Hour	Minute	Second	Latitude	Longitude	E[M]	sigma M	DN
1959	1	30	0	0	0	61	-78.5	4.46	0.25	237
1959	3	10	0	0	0	-15.31	30.16	5.31	0.37	68
1959	4	14	0	0	0	-14.55	22.11	5.16	0.37	61
1959	5	18	0	0	0	-36.218	148.64	4.61	0.37	27
1959	5	21	0	0	0	-31.4	139	4.64	0.37	21
1959	8	12	0	0	0	-14.96	26.54	5.86	0.37	70
1959	10	12	0	0	0	15.68	80.07	5.15	0.37	117
1959	10	21	0	0	0	65	-87	4.84	0.37	239
1959	11	2	0	0	0	-33.36	135.98	4.64	0.37	19
1959	12	31	0	0	0	43.5	111	4.73	0.37	135
1960	5	12	0	0	0	-9	-72.5	4.92	0.47	51
1960	7	15	0	0	0	-14.15	21.85	4.91	0.37	72
1960	8	26	0	0	0	-11	123.9	5.4	0.37	1
1960	8	27	0	0	0	28.59	76.72	4.7	0.32	113
1960	9	6	0	0	0	64.7	-86.4	4.98	0.37	239
1960	10	19	0	0	0	-21	149.3	4.49	0.32	32
1960	11	5	0	0	0	24	108.5	4.87	0.32	129
1960	12	24	0	0	0	-38.88	143.59	4.79	0.37	23
1961	3	7	0	0	0	30.28	111.2	4.75	0.32	130
1961	5	16	0	0	0	-30.85	147.27	4.61	0.37	27
1961	5	21	0	0	0	-34.547	150.503	5.08	0.37	27
1961	6	12	0	0	0	21.6	106.02	5.53	0.32	130
1961	6	18	0	0	0	-20.1	119.3	4.88	0.37	9
1961	8	23	0	0	0	-18.5	119	4.79	0.37	2
1961	12	28	0	0	0	-28.12	141.57	4.5	0.37	27
1962	3	8	0	0	0	3.73	28.99	5.67	0.37	83
1962	3	18	0	0	0	23.72	114.67	6.00	0.14	125
1962	4	20	0	0	0	24.3	106	4.65	0.32	130
1962	12	15	0	0	0	67.36	13.9	4.73	0.37	179
1962	12	26	0	0	0	39.3	-10.6	5.33	0.32	199
1963	1	18	0	0	0	-32.25	117.17	4.64	0.32	7
1963	2	21	0	0	0	32.6	21	5.71	0.37	90
1963	3	3	0	0	0	36.7	-90	4.62	0.14	230
1963	3	8	0	0	0	76.6	-94.33	5.18	0.37	248
1963	3	14	0	0	0	-25.7	137.4	4.75	0.37	5
1963	4	9	0	0	0	22.5	85.8	4.8	0.70	109
1963	5	8	0	0	0	21.7	84.9	5.1	0.37	109
1963	6	21	0	0	0	47.91	130.61	5.62	0.37	139
1963	6	22	0	0	0	53.1	121.4	5.27	0.37	136
1963	7	13	0	0	0	24.77	70.26	5.61	0.37	113
1963	8	15	0	0	0	56	134.5	4.59	0.37	147
1963	9	4	0	0	0	71.234	-72.998	6.14	0.05	248
1963	9	6	0	0	0	36.47	130.76	5.80	0.05	127
1963	9	23	0	0	0	-16.58	28.46	5.65	0.17	67
1963	10	7	0	0	0	42.9	110.5	5.35	0.37	135
1963	12	14	0	0	0	-2.3	-61.01	5.21	0.20	53
1963	12	26	0	0	0	76.53	23.46	4.62	0.45	169

Year	Month	Day	Hour	Minute	Second	Latitude	Longitude	E[M]	sigma M	DN
1964	1	8	0	0	0	46.23	-77.53	3.74	0.12	226
1964	2	13	0	0	0	-18.06	-56.69	5.3	0.25	49
1964	3	23	0	0	0	-17.71	123.16	5.26	0.37	11
1964	3	28	0	0	0	42.997	-101.798	4.84	0.32	255
1964	4	15	0	0	0	21.6	88.07	5.25	0.25	118
1964	5	12	0	0	0	-11	126	4.83	0.25	1
1964	6	19	0	0	0	2.55	-59.3	4.56	0.25	52
1964	7	12	0	0	0	53.8	81.4	4.79	0.25	156
1964	7	14	0	0	0	57.03	7.2	4.71	0.25	189
1964	8	10	0	0	0	9.15	-62.02	5.35	0.25	52
1964	9	23	0	0	0	23.73	114.68	4.74	0.32	125
1965	1	25	0	0	0	-31.93	138.49	4.73	0.25	21
1965	2	15	0	0	0	53.65	81.53	5.2	0.25	156
1965	3	2	0	0	0	-30.52	138.22	5.2	0.25	21
1965	3	14	0	0	0	-31.95	138.57	4.93	0.37	21
1965	3	18	0	0	0	-40.29	149.59	4.5	0.37	26
1965	3	26	0	0	0	24.18	69.56	4.75	0.25	114
1965	5	18	0	0	0	-17.6	49.91	5.38	0.14	71
1965	5	19	0	0	0	-25	112.5	5.09	0.25	4
1965	6	3	0	0	0	-28.084	150.217	4.49	0.32	28
1965	8	15	0	0	0	2.71	-60.24	4.96	0.25	52
1965	8	28	0	0	0	-32.23	138.1	4.69	0.25	21
1965	9	10	0	0	0	-18.1	122.2	4.6	0.37	11
1965	9	14	0	0	0	-38.68	144.24	4.94	0.25	23
1965	10	13	0	0	0	71.1	-20	4.83	0.25	254
1965	10	21	0	0	0	37.5	-91	4.61	0.08	230
1966	1	1	0	0	0	42.8	-78.2	4.26	0.08	226
1966	3	22	0	0	0	64.75	-88	4.69	0.37	239
1966	3	26	0	0	0	-18.54	26.39	5.06	0.25	67
1966	4	5	0	0	0	-16.45	28.68	4.71	0.25	67
1966	5	3	0	0	0	-37.042	147.168	4.40	0.17	27
1966	5	27	0	0	0	24.46	68.69	4.96	0.25	113
1966	6	18	0	0	0	-29.52	29.37	4.92	0.25	60
1966	6	23	0	0	0	-14.17	22.03	4.96	0.25	61
1966	8	15	0	0	0	28.67	78.93	5.51	0.25	113
1966	9	26	0	0	0	22.3	117.9	4.88	0.25	127
1966	10	2	0	0	0	43.83	125.12	4.6	0.25	137
1966	10	9	0	0	0	12.63	30.75	5.64	0.37	82
1966	10	12	0	0	0	-11.94	121.77	5.58	0.25	1
1966	11	13	0	0	0	-23.97	111.67	5.1	0.25	4
1966	12	3	0	0	0	-8.8	135.5	4.55	0.25	13
1967	3	20	0	0	0	35.89	44.08	5.01	0.25	81
1967	3	27	0	0	0	15.6	80.1	5.2	0.25	117
1967	4	20	0	0	0	-16.64	28.26	5.14	0.37	67
1967	4	25	0	0	0	18.26	73.3	4.31	0.45	106
1967	6	4	0	0	0	33.6	-90.9	4.29	0.08	225
1967	6	13	0	0	0	42.9	-78.2	4.07	0.08	226

Year	Month	Day	Hour	Minute	Second	Latitude	Longitude	E[M]	sigma M	DN
1967	6	21	0	0	0	48.7	122	4.63	0.25	135
1967	8	9	0	0	0	39.9	-104.7	4.79	0.15	255
1967	8	21	0	0	0	57.06	4.92	4.67	0.25	194
1967	10	14	0	0	0	-3.32	38.19	5.16	0.14	79
1967	12	10	0	0	0	17.39	73.774	6.27	0.14	106
1967	12	30	0	0	0	20.4	118.2	4.92	0.25	127
1968	1	12	0	0	0	-33.7	25.2	5.01	0.25	59
1968	4	1	0	0	0	25.1	117.6	4.89	0.32	125
1968	5	15	0	0	0	-15.92	26.099	5.70	0.25	61
1968	6	13	0	0	0	23.2	105.2	4.5	0.70	130
1968	7	6	0	0	0	-6.351	133.831	5.64	0.25	16
1968	10	14	0	0	0	-31.522	116.978	6.57	0.08	7
1968	11	9	0	0	0	37.96	-88.46	5.32	0.06	230
1968	12	2	0	0	0	-14.104	23.779	5.47	0.27	61
1968	12	15	0	0	0	-13.47	26.6	4.83	0.25	61
1968	12	31	0	0	0	-31.04	149.26	4.67	0.37	27
1969	4	13	0	0	0	17.838	80.68	5.72	0.10	110
1969	6	17	0	0	0	-25.26	116.73	5.25	0.37	7
1969	6	20	0	0	0	-38.47	146.3	4.79	0.37	26
1969	7	25	0	0	0	21.611	111.803	5.71	0.17	129
1969	8	30	0	0	0	-26.77	26.8	4.9	0.25	63
1969	9	9	0	0	0	-2.602	24.744	5.1	0.25	73
1969	9	11	0	0	0	-33.41	21.8	4.89	0.37	58
1969	9	29	0	0	0	-33.191	19.335	6.38	0.10	58
1969	9	29	0	0	0	65.1	6.5	4.75	0.25	183
1969	10	24	0	0	0	24.76	72.54	5.01	0.25	113
1969	11	20	0	0	0	37.4	-81	4.5	0.14	224
1969	12	17	0	0	0	18.11	110.55	4.79	0.25	127
1970	1	22	0	0	0	48.328	9.094	4.52	0.25	192
1970	2	8	0	0	0	-27.4	125.073	4.33	0.45	3
1970	2	13	0	0	0	24.603	68.617	4.88	0.25	113
1970	3	8	0	0	0	55	-116.6	4.75	0.25	242
1970	3	10	0	0	0	-31.093	116.513	5.46	0.25	7
1970	3	23	0	0	0	21.7	73	5.37	0.10	115
1970	3	24	0	0	0	-22.053	126.666	6.03	0.08	9
1970	4	14	0	0	0	-33.17	19.47	5.69	0.20	58
1970	6	15	0	0	0	-25.97	28.18	4.55	0.37	63
1970	7	25	0	0	0	25.711	88.496	5.06	0.25	112
1970	8	22	0	0	0	-26.36	27.38	4.52	0.37	63
1970	8	29	0	0	0	51.1	135.1	5.3	0.25	139
1970	10	14	0	0	0	31.226	74.34	5.1	0.25	113
1970	10	31	0	0	0	-26.78	26.85	4.62	0.37	63
1970	11	19	0	0	0	-22.19	30.73	4.78	0.37	66
1970	12	2	0	0	0	68.5	-67.55	5.06	0.15	248
1971	2	22	0	0	0	-18.425	26.474	4.87	0.25	67
1971	7	6	0	0	0	-38.423	145.113	4.45	0.32	26
1971	7	26	0	0	0	-31.37	138.76	4.5	0.37	21

Year	Month	Day	Hour	Minute	Second	Latitude	Longitude	E[M]	sigma M	DN
1971	8	16	0	0	0	28.879	103.673	5.4	0.25	131
1971	10	2	0	0	0	64.4	-86.5	4.68	0.05	239
1971	11	26	0	0	0	79.438	-17.766	5.06	0.25	253
1971	12	7	0	0	0	55.082	-54.352	5.52	0.15	247
1972	1	15	0	0	0	57.5	121.1	4.63	0.25	147
1972	1	21	0	0	0	71.84	-74.96	4.56	0.15	248
1972	2	3	0	0	0	33.31	-80.58	4.31	0.15	218
1972	2	25	0	0	0	-34.22	147.47	4.5	0.37	27
1972	4	5	0	0	0	23	118.3	4.85	0.37	127
1972	4	14	0	0	0	40.1	122.5	4.45	0.25	133
1972	4	18	0	0	0	-31.58	138.62	4.87	0.32	21
1972	8	9	0	0	0	56.9	127.7	5.15	0.19	147
1972	8	28	0	0	0	-24.992	136.326	5.28	0.10	5
1972	9	2	0	0	0	31.39	16.09	5.53	0.19	90
1972	9	7	0	0	0	45.99	-1.5	5.01	0.25	196
1972	9	30	0	0	0	79.88	-107.72	4.49	0.25	250
1972	10	21	0	0	0	-24.88	115.55	4.71	0.37	3
1972	10	24	0	0	0	-21.8	-40.5	4.83	0.25	46
1972	12	18	0	0	0	-16.7	28.1	5.57	0.17	67
1972	12	27	0	0	0	76.759	-107.093	6.10	0.30	249
1973	3	9	0	0	0	-34.14	150.29	5.06	0.19	27
1973	3	11	0	0	0	-21.96	127.44	4.34	0.45	13
1973	6	15	0	0	0	45.3	-70.9	4.48	0.08	222
1973	12	15	0	0	0	74.2	147.1	4.86	0.25	144
1974	2	1	0	0	0	-17.882	26.05	4.65	0.37	61
1974	3	17	0	0	0	13.32	30.88	4.8	0.25	82
1974	4	3	0	0	0	38.6	-88.1	4.29	0.15	230
1974	4	22	0	0	0	31.6	119.1	5.31	0.10	132
1974	5	10	0	0	0	28.181	103.994	6.8	0.25	131
1974	8	1	0	0	0	-16.652	28.004	4.96	0.25	67
1974	9	4	0	0	0	33.103	13.411	5.68	0.10	90
1974	9	23	0	0	0	-0.296	12.758	5.98	0.05	73
1974	9	27	0	0	0	2.646	-71.355	5.9	0.19	52
1974	10	8	0	0	0	60.6	118.5	4.75	0.25	148
1974	10	15	0	0	0	-70.55	161.3	4.75	0.25	208
1974	11	17	0	0	0	-22	126.53	4.94	0.25	9
1974	12	24	0	0	0	-21.81	153.21	4.59	0.37	32
1975	3	6	0	0	0	-17.08	126.38	4.91	0.32	14
1975	3	8	0	0	0	79.82	-94.07	5.03	0.19	249
1975	4	15	0	0	0	9.42	-61.47	5.27	0.19	52
1975	6	23	0	0	0	50.592	9.859	4.57	0.32	195
1975	6	30	0	0	0	71.44	-71.19	4.75	0.25	248
1975	7	24	0	0	0	-21.09	120.47	4.49	0.37	10
1975	9	2	0	0	0	32.83	121.83	4.93	0.19	132
1975	10	3	0	0	0	-22.21	126.58	4.95	0.25	9
1975	10	6	0	0	0	44.71	-57.07	5.06	0.14	218
1976	1	18	0	0	0	77.816	18.466	5.98	0.19	181

Year	Month	Day	Hour	Minute	Second	Latitude	Longitude	E[M]	sigma M	DN
1976	1	22	0	0	0	8.8	-60.3	4.32	0.45	52
1976	2	19	0	0	0	66.41	-135.28	4.94	0.19	241
1976	3	12	0	0	0	-0.487	12.624	5.06	0.25	73
1976	3	25	0	0	0	35.59	-90.48	4.62	0.08	228
1976	5	15	0	0	0	4.461	19.348	5.43	0.14	84
1976	6	4	0	0	0	24.575	68.41	5.23	0.19	113
1976	6	23	0	0	0	21.415	88.79	5.06	0.25	118
1976	7	1	0	0	0	-29.559	25.112	5.74	0.10	63
1976	8	28	0	0	0	43.88	114.17	4.45	0.25	135
1976	10	6	0	0	0	35.296	124.297	5.32	0.19	132
1976	12	8	0	0	0	-27.91	26.71	5.1	0.25	63
1977	3	24	0	0	0	51.48	16.05	4.64	0.19	192
1977	4	6	0	0	0	61.605	2.466	4.67	0.25	188
1977	8	2	0	0	0	-0.1	-50	4.67	0.25	54
1977	10	19	0	0	0	23.229	107.594	5.06	0.19	130
1978	1	10	0	0	0	3.51	-73.64	4.88	0.25	51
1978	2	5	0	0	0	78.24	-107.33	5.08	0.14	249
1978	5	1	0	0	0	-23.64	115.59	4.76	0.32	3
1978	5	6	0	0	0	-19.55	126.56	4.89	0.37	11
1978	6	16	0	0	0	33.01	-100.72	4.49	0.10	231
1978	9	3	0	0	0	48.283	9.033	5.04	0.17	192
1978	11	28	0	0	0	-23.34	152.52	4.94	0.25	32
1978	12	9	0	0	0	23.951	26.353	5.11	0.19	82
1979	2	6	0	0	0	48.9	116.8	5.02	0.19	136
1979	2	12	0	0	0	-17.34	-63.63	4.92	0.25	51
1979	4	23	0	0	0	-16.616	120.163	6.12	0.08	1
1979	5	21	0	0	0	31.08	110.5	4.92	0.25	130
1979	6	2	0	0	0	-30.818	117.105	6.08	0.05	7
1979	6	27	0	0	0	70.03	-96.48	4.96	0.14	239
1979	7	9	0	0	0	31.45	119.25	5.44	0.08	132
1979	7	14	0	0	0	-18.42	122.82	5.03	0.14	9
1979	8	19	0	0	0	47.672	-69.901	4.72	0.12	227
1979	12	26	0	0	0	54.903	-2.683	4.5	0.25	185
1980	1	7	0	0	0	40.26	125.11	5.09	0.17	133
1980	2	10	0	0	0	48.9	122.02	5.04	0.17	135
1980	3	6	0	0	0	-6.17	-71.16	4.83	0.25	51
1980	7	27	0	0	0	38.18	-83.94	5.01	0.13	226
1980	9	2	0	0	0	17.179	73.707	5.49	0.19	106
1980	11	12	0	0	0	-8.04	-50.14	4.79	0.25	52
1980	11	20	0	0	0	-4.3	-38.4	5.19	0.08	56
1981	3	3	0	0	0	31.39	73.216	4.98	0.19	113
1981	4	25	0	0	0	48.93	121.952	5.02	0.19	135
1981	6	16	0	0	0	-38.913	144.262	4.81	0.37	23
1981	6	18	0	0	0	-10.328	135.476	4.94	0.25	13
1981	8	18	0	0	0	65.67	-90.5	4.6	0.25	239
1981	9	3	0	0	0	69.62	13.68	4.75	0.25	183
1981	11	18	0	0	0	-2.282	22.813	5.53	0.14	73

Year	Month	Day	Hour	Minute	Second	Latitude	Longitude	E[M]	sigma M	DN
1981	11	21	0	0	0	79.52	-108.11	4.7	0.19	249
1981	12	15	0	0	0	-65.74	133.6	4.75	0.25	213
1982	1	9	0	0	0	46.98	-66.66	5.47	0.05	222
1982	2	13	0	0	0	-22.096	126.643	4.74	0.25	9
1982	2	14	0	0	0	38.27	125.68	5.17	0.15	132
1982	2	28	0	0	0	37.04	129.6	4.83	0.25	127
1982	4	8	0	0	0	-24.8	-58.1	4.96	0.19	41
1982	4	13	0	0	0	-27.926	26.783	4.88	0.25	63
1982	5	1	0	0	0	31.583	71.41	5.31	0.19	113
1982	6	28	0	0	0	50.733	7.804	4.51	0.37	195
1982	7	29	0	0	0	60.118	2.151	4.79	0.25	188
1982	10	27	0	0	0	23.951	106.049	5.19	0.14	130
1982	11	3	0	0	0	-20.53	120.48	4.69	0.37	9
1982	11	4	0	0	0	-80.79	36.9	4.52	0.25	202
1982	11	21	0	0	0	-37.205	146.956	4.60	0.15	27
1983	1	26	0	0	0	-30.73	117.13	4.96	0.25	7
1983	2	8	0	0	0	-26.26	-59.89	4.88	0.25	41
1983	3	8	0	0	0	59.74	5.38	3.28	0.32	179
1983	8	5	0	0	0	-3.59	-62.17	5.39	0.19	52
1983	9	20	0	0	0	-68.87	122.1	4.45	0.25	202
1983	10	7	0	0	0	43.938	-74.258	4.84	0.05	226
1983	11	8	0	0	0	50.63	5.5	4.68	0.20	187
1983	12	22	0	0	0	11.863	-13.512	6.21	0.12	105
1983	12	25	0	0	0	-5.09	-73.42	5.1	0.19	51
1983	12	29	0	0	0	-30.79	138.4	4.62	0.37	21
1984	3	16	0	0	0	-14.95	123.38	4.64	0.25	14
1984	5	19	0	0	0	-67.43	113	4.91	0.17	202
1984	5	21	0	0	0	32.694	121.513	6.06	0.10	132
1984	7	19	0	0	0	52.958	-4.398	4.95	0.19	185
1984	8	31	0	0	0	-10.698	126.349	4.5	0.70	1
1984	9	8	0	0	0	44.24	-106.019	4.90	0.14	238
1984	10	26	0	0	0	-16.465	28.667	5.29	0.14	67
1984	11	29	0	0	0	-11.614	123.952	4.84	0.25	1
1985	3	13	0	0	0	-15.45	121.853	4.83	0.37	1
1985	4	12	0	0	0	-23.94	-60.55	5.09	0.14	41
1985	4	19	0	0	0	-10.552	124.403	5.05	0.25	1
1985	5	26	0	0	0	37.84	-4.69	4.96	0.19	200
1985	7	23	0	0	0	-19.14	126.77	4.64	0.25	13
1985	7	28	0	0	0	-32.51	122.22	5.13	0.19	8
1985	10	4	0	0	0	-18.304	48.433	5.53	0.14	71
1985	10	23	0	0	0	-11.109	125.159	5.77	0.10	1
1985	12	21	0	0	0	50.14	12.44	4.65	0.32	193
1986	1	2	0	0	0	-34.484	112.098	5.56	0.19	6
1986	1	31	0	0	0	41.65	-81.162	4.65	0.20	226
1986	2	5	0	0	0	62.68	5.05	4.69	0.10	183
1986	2	10	0	0	0	-27.944	26.735	4.88	0.25	63
1986	3	30	0	0	0	-26.31	132.741	5.76	0.05	9

Year	Month	Day	Hour	Minute	Second	Latitude	Longitude	E[M]	sigma M	DN
1986	4	20	0	0	0	57.4	-59.6	5.07	0.20	247
1986	7	18	0	0	0	-16.356	28.502	5.19	0.14	67
1986	8	1	0	0	0	73.031	56.726	4.68	0.19	156
1986	8	15	0	0	0	48.638	126.621	4.95	0.14	137
1986	10	5	0	0	0	-30.546	28.737	5.33	0.14	60
1986	10	22	0	0	0	22.42	118.79	5.01	0.19	127
1986	11	30	0	0	0	-5.5	-35.75	5.08	0.14	56
1987	1	9	0	0	0	-20.11	133.636	5.40	0.14	13
1987	1	26	0	0	0	6.373	12.453	4.89	0.14	85
1987	2	17	0	0	0	33.69	120.66	5.1	0.19	132
1987	3	5	0	0	0	52.48	132.64	5.04	0.19	136
1987	4	18	0	0	0	22.346	79.259	4.79	0.25	111
1987	6	10	0	0	0	38.713	-87.954	4.95	0.08	230
1987	8	2	0	0	0	24.924	115.608	4.99	0.10	125
1987	9	5	0	0	0	22.5	118.73	4.98	0.19	127
1987	12	13	0	0	0	74.46	-93.71	5.35	0.14	248
1987	12	22	0	0	0	-36.11	141.54	4.75	0.19	31
1988	1	3	0	0	0	-14.31	25.4	4.52	0.25	61
1988	1	5	0	0	0	-26.807	26.64	4.92	0.25	63
1988	1	7	0	0	0	0.56	18.43	4.71	0.25	73
1988	1	22	0	0	0	-19.896	133.856	6.56	0.05	13
1988	1	28	0	0	0	32.33	21.2	5.3	0.25	90
1988	1	28	0	0	0	48	-65.58	3.55	0.06	222
1988	1	31	0	0	0	67.81	10.2	4.67	0.25	183
1988	2	6	0	0	0	-16.679	124.663	5.09	0.14	13
1988	3	10	0	0	0	-17.2	13.4	4.52	0.25	61
1988	3	26	0	0	0	33.2	13.34	5.2	0.37	90
1988	6	15	0	0	0	-31.51	126.51	4.88	0.25	19
1988	6	26	0	0	0	-36.27	-52.73	5	0.19	46
1988	8	8	0	0	0	63.673	2.397	5.53	0.17	183
1988	9	6	0	0	0	61.33	47.98	4.85	0.25	167
1988	9	12	0	0	0	-26.89	26.65	4.6	0.25	63
1988	9	30	0	0	0	-20.08	133.84	5.25	0.25	13
1988	11	10	0	0	0	21.2	108.57	4.6	0.25	129
1988	11	25	0	0	0	48.056	-71.28	5.84	0.08	226
1988	12	31	0	0	0	-26.88	26.64	4.8	0.25	63
1989	1	4	0	0	0	-7.486	133.25	4.67	0.25	1
1989	1	12	0	0	0	40.42	122.66	4.83	0.25	133
1989	1	23	0	0	0	61.949	4.504	5.12	0.10	183
1989	1	25	0	0	0	-27.96	26.72	5.14	0.19	63
1989	1	29	0	0	0	59.45	5.9	4.75	0.25	179
1989	3	10	0	0	0	-5.81	-35.56	5.17	0.19	56
1989	3	13	0	0	0	50.72	9.91	5.22	0.19	195
1989	3	16	0	0	0	-16.927	-65.005	5.22	0.14	51
1989	3	16	0	0	0	59.93	-69.66	4.97	0.17	239
1989	3	23	0	0	0	-11.148	123.737	4.75	0.25	1
1989	3	26	0	0	0	-5.05	-37.6	4.7	0.25	56

Year	Month	Day	Hour	Minute	Second	Latitude	Longitude	E[M]	sigma M	DN
1989	4	7	0	0	0	-12.516	122.161	5.1	0.25	1
1989	4	8	0	0	0	39.45	-8.92	4.89	0.19	199
1989	5	14	0	0	0	50.87	51.4	4.52	0.25	161
1989	5	28	0	0	0	-25.07	130.78	5.57	0.19	12
1989	6	5	0	0	0	-11.97	14.59	4.96	0.25	72
1989	6	12	0	0	0	21.829	89.754	5.76	0.08	118
1989	6	18	0	0	0	-12.449	121.52	5.20	0.14	1
1989	6	29	0	0	0	51.44	16.07	4.55	0.25	192
1989	7	18	0	0	0	76.865	12.972	4.88	0.19	182
1989	9	29	0	0	0	-30.6	28.7	4.82	0.19	60
1989	10	13	0	0	0	-17.59	122.4	5.47	0.14	11
1989	10	25	0	0	0	57.519	118.811	5.38	0.16	147
1989	10	28	0	0	0	51.6	16.01	4.67	0.25	192
1989	11	20	0	0	0	29.882	106.804	5.14	0.19	131
1989	11	25	0	0	0	23.72	114.52	5.40	0.27	125
1989	12	10	0	0	0	24.81	70.89	4.67	0.25	113
1989	12	25	0	0	0	60.045	-73.538	6.03	0.08	236
1989	12	27	0	0	0	-32.94	151.56	5.28	0.27	27
1990	1	17	0	0	0	-31.68	116.99	5.1	0.25	7
1990	2	7	0	0	0	-26.8301	26.6818	4.5	0.37	63
1990	2	9	0	0	0	31.72	121.03	4.92	0.19	132
1990	2	12	0	0	0	-31.22	-48.9	5.15	0.19	46
1990	2	14	0	0	0	-26.29	27.43	4.5	0.25	63
1990	2	20	0	0	0	32.5564	44.2181	4.6	0.25	81
1990	3	3	0	0	0	-26.9543	26.72	4.9	0.37	63
1990	3	13	0	0	0	-4.03	39.93	5.49	0.14	80
1990	4	2	0	0	0	52.32	-3	4.65	0.25	185
1990	5	20	0	0	0	5.121	32.145	7.22	0.15	82
1990	5	25	0	0	0	8.259	32.9262	4.7	0.25	82
1990	5	28	0	0	0	55.15	58.63	4.6	0.25	159
1990	6	9	0	0	0	75.12	113.1	4.75	0.25	152
1990	6	24	0	0	0	-17.6407	27.7695	4.5	0.25	67
1990	7	18	0	0	0	-26.8569	26.6248	4.6	0.25	63
1990	7	28	0	0	0	74.8794	-79.9866	4.5	0.37	248
1990	9	20	0	0	0	4.2221	9.0551	4.5	0.37	85
1990	9	26	0	0	0	-28.014	26.727	4.97	0.14	63
1990	10	19	0	0	0	46.4373	-75.5759	4.53	0.20	226
1990	10	24	0	0	0	73.3597	54.6741	5.1	0.47	156
1990	11	11	0	0	0	33.94	12.04	5.15	0.14	90
1990	11	29	0	0	0	78.4481	-108.4902	4.7	0.25	249
1990	12	6	0	0	0	-26.35	27.31	4.5	0.25	63
1990	12	31	0	0	0	47.7018	-72.6666	4.16	0.15	226
1991	1	13	0	0	0	65.628	-37.5123	4.6	0.25	239
1991	1	24	0	0	0	-13.1283	23.1763	4.8	0.25	61
1991	2	4	0	0	0	60.9412	-43.3441	4.9	0.25	244
1991	2	12	0	0	0	71.4432	-75.0874	5	0.37	248
1991	2	27	0	0	0	25.6762	103.9086	4.8	0.25	130

Year	Month	Day	Hour	Minute	Second	Latitude	Longitude	E[M]	sigma M	DN
1991	4	19	0	0	0	-4.006	-39.7315	4.7	0.25	56
1991	4	26	0	0	0	20.8118	89.6729	4.7	0.25	118
1991	5	10	0	0	0	-17.3484	24.982	4.7	0.25	61
1991	6	10	0	0	0	-26.8689	26.7138	4.7	0.25	63
1991	6	19	0	0	0	-20.0685	133.9655	5.1	0.25	13
1991	9	10	0	0	0	24.1675	68.6842	4.9	0.25	114
1991	9	30	0	0	0	43.0932	112.5325	4.8	0.25	134
1991	11	3	0	0	0	-26.8912	26.6395	4.9	0.37	63
1991	11	3	0	0	0	28.3437	104.0239	4.5	0.37	131
1991	11	8	0	0	0	26.28	70.58	5.36	0.14	113
1992	1	2	0	0	0	32.3641	-102.9665	4.66	0.16	231
1992	1	4	0	0	0	66.84	-94.46	5.37	0.17	239
1992	1	22	0	0	0	35.3276	121.09	5.02	0.10	132
1992	3	7	0	0	0	-26.4414	27.3387	4.9	0.25	63
1992	4	13	0	0	0	51.16	5.82	5.31	0.10	195
1992	4	17	0	0	0	-20.0236	133.7528	4.6	0.25	13
1992	6	6	0	0	0	-27.9762	26.7805	5	0.37	63
1992	6	12	0	0	0	44.2414	116.2393	4.6	0.37	135
1992	6	13	0	0	0	-23.8616	130.0962	5	0.25	12
1992	7	1	0	0	0	-19.0302	111.8556	4.5	0.25	2
1992	7	9	0	0	0	20.98	89.96	5.3	0.25	118
1992	7	9	0	0	0	-5.5221	137.9927	4.7	0.25	16
1992	7	15	0	0	0	-22.4264	126.5028	4.9	0.25	9
1992	8	31	0	0	0	43.93	106.92	5.33	0.14	135
1992	9	2	0	0	0	45.5822	117.9208	4.7	0.25	135
1992	9	18	0	0	0	21.286	117.6981	5.1	0.47	127
1992	9	29	0	0	0	34.501	14.4913	5.1	0.37	90
1992	9	30	0	0	0	-11.349	134.5335	5.26	0.17	17
1992	10	23	0	0	0	31.35	-4.33	5.55	0.04	95
1992	11	3	0	0	0	35.3446	123.2905	4.57	0.10	132
1992	11	8	0	0	0	61.9791	2.6797	4.5	0.37	183
1992	11	28	0	0	0	-26.9957	26.5164	4.6	0.37	63
1992	12	23	0	0	0	-23.8258	17.3111	4.8	0.25	61
1993	2	4	0	0	0	-7.9448	134.1146	4.8	0.37	13
1993	2	8	0	0	0	-8.8653	133.8904	4.8	0.37	13
1993	2	20	0	0	0	-7.7297	22.3845	4.6	0.25	73
1993	2	21	0	0	0	-20.1311	133.733	5	0.37	13
1993	2	23	0	0	0	-26.3566	27.3881	4.5	0.37	63
1993	3	13	0	0	0	71.211	-71.8438	4.9	0.25	248
1993	3	28	0	0	0	32.9404	123.7381	5	0.25	128
1993	5	5	0	0	0	30.0425	108.2326	4.5	0.37	131
1993	5	16	0	0	0	23.1388	86.8324	4.5	0.25	111
1993	6	2	0	0	0	28.91	47.5708	4.6	0.37	81
1993	6	15	0	0	0	79.7807	-16.6234	4.5	0.25	253
1993	6	30	0	0	0	51.4914	16.0949	4.5	0.25	192
1993	7	18	0	0	0	17.9312	-93.1846	4.5	0.25	215
1993	8	1	0	0	0	15.4	31.67	5.49	0.13	82

Year	Month	Day	Hour	Minute	Second	Latitude	Longitude	E[M]	sigma M	DN
1993	8	10	0	0	0	83.03	-27.92	5.56	0.14	251
1993	8	18	0	0	0	-26.9049	26.6872	4.6	0.25	63
1993	8	24	0	0	0	20.6973	71.4408	5.1	0.37	116
1993	8	28	0	0	0	17.2402	73.7331	5.1	0.25	106
1993	8	29	0	0	0	-26.3489	27.3139	5.2	0.47	63
1993	9	3	0	0	0	19.8473	-13.0178	4.6	0.25	98
1993	9	9	0	0	0	32.2394	20.3859	4.8	0.25	90
1993	9	13	0	0	0	66.3237	5.8379	4.8	0.47	183
1993	9	29	0	0	0	18.077	76.486	6.2	0.37	106
1993	10	13	0	0	0	28.6253	103.3757	4.8	0.25	131
1993	11	1	0	0	0	51.625	16.0294	4.6	0.37	192
1993	12	6	0	0	0	6.8278	78.3202	5.3	0.25	117
1993	12	18	0	0	0	-11.8274	133.8567	4.8	0.37	13
1993	12	20	0	0	0	-26.9098	26.7103	4.7	0.25	63
1993	12	30	0	0	0	38.1635	122.7901	4.6	0.25	133
1994	2	6	0	0	0	3.5021	27.5524	5	0.37	73
1994	2	8	0	0	0	-19.9992	133.5254	5.1	0.25	13
1994	2	11	0	0	0	64.9006	-52.0772	4.6	0.37	246
1994	3	2	0	0	0	26.32	118.64	4.8	0.25	125
1994	5	5	0	0	0	51.648	133.3765	4.9	0.25	139
1994	5	10	0	0	0	-26.8869	26.7634	4.7	0.25	63
1994	6	4	0	0	0	49.0688	129.811	4.5	0.37	139
1994	7	25	0	0	0	34.97	124.43	5.14	0.16	132
1994	8	1	0	0	0	47.994	67.5271	5	0.25	158
1994	8	6	0	0	0	-32.9377	151.1628	5	0.25	27
1994	8	31	0	0	0	25.8963	78.6269	4.8	0.25	112
1994	10	2	0	0	0	-26.4123	27.4682	4.7	0.25	63
1994	10	30	0	0	0	-28.0213	26.7184	5.3	0.25	63
1994	11	30	0	0	0	-30.6245	137.608	4.9	0.25	21
1994	12	29	0	0	0	29.09	103.85	5.12	0.12	131
1995	1	5	0	0	0	59.6137	56.6197	4.9	0.25	166
1995	1	10	0	0	0	20.4195	109.4385	5.53	0.04	126
1995	1	15	0	0	0	20.69	109.8	5	0.25	126
1995	2	10	0	0	0	-26.8338	26.669	4.8	0.37	63
1995	2	25	0	0	0	24.3716	118.6643	5	0.25	127
1995	2	27	0	0	0	-2.9306	39.9749	4.8	0.25	80
1995	3	8	0	0	0	82.3577	-71.7175	5	0.25	249
1995	3	12	0	0	0	17.3784	73.9096	4.6	0.25	106
1995	4	14	0	0	0	30.2885	-103.3188	5.64	0.05	226
1995	4	28	0	0	0	-6.2142	-73.2034	4.6	0.25	51
1995	6	3	0	0	0	47.138	-76.2833	3.28	0.17	226
1995	6	14	0	0	0	-20.149	133.7148	4.8	0.37	13
1995	6	21	0	0	0	21.7637	85.286	4.5	0.47	109
1995	7	4	0	0	0	79.9971	94.8377	5	0.37	154
1995	7	24	0	0	0	38.0329	124.285	5.1	0.25	133
1995	8	25	0	0	0	-23.7538	112.1831	4.6	0.25	4
1995	9	22	0	0	0	1.0903	19.3548	5.24	0.22	73

Year	Month	Day	Hour	Minute	Second	Latitude	Longitude	E[M]	sigma M	DN
1995	10	20	0	0	0	61.5656	116.4441	4.8	0.25	149
1995	10	28	0	0	0	-26.3378	27.5454	4.7	0.25	63
1995	10	30	0	0	0	-49.6603	-42.775	4.6	0.25	35
1995	11	14	0	0	0	68.41	51.61	4.8	0.25	168
1995	11	25	0	0	0	-26.9224	26.6805	4.8	0.37	63
1995	11	29	0	0	0	42.9189	-7.2295	5	0.25	200
1995	12	5	0	0	0	57.6977	107.0928	4.7	0.25	149
1995	12	17	0	0	0	-27.9673	26.6594	4.5	0.25	63
1996	1	14	0	0	0	51.5986	16.1205	4.5	0.37	192
1996	1	15	0	0	0	52.9635	83.7387	4.5	0.25	156
1996	2	7	0	0	0	27.4584	106.5679	4.7	0.25	130
1996	2	28	0	0	0	29.0782	104.7045	5.2	0.25	131
1996	3	29	0	0	0	82.8988	-43.6804	5	0.25	251
1996	6	9	0	0	0	-34.1658	135.8155	4.5	0.25	19
1996	6	15	0	0	0	51.5675	16.2235	5.2	0.37	192
1996	6	26	0	0	0	-18.3579	48.4751	4.98	0.50	71
1996	7	22	0	0	0	44.2	-105.68	4.6	0.37	238
1996	8	13	0	0	0	-30.0363	143.5507	4.9	0.25	27
1996	9	8	0	0	0	-4.4521	-76.7274	4.6	0.37	51
1996	9	11	0	0	0	51.4666	11.7071	4.8	0.37	192
1996	9	16	0	0	0	-26.857	26.7031	4.5	0.25	63
1996	9	25	0	0	0	-37.7783	146.258	4.7	0.25	27
1996	10	30	0	0	0	32.4343	20.5326	4.7	0.25	90
1996	11	9	0	0	0	31.6311	123.3463	5.59	0.03	128
1996	12	11	0	0	0	-27.8959	26.729	4.7	0.25	63
1996	12	13	0	0	0	37.1873	128.7499	5	0.25	128
1997	1	23	0	0	0	17.1421	76.6916	4.7	0.25	106
1997	2	10	0	0	0	-26.933	26.7087	5	0.37	63
1997	3	5	0	0	0	-33.7067	138.9698	4.8	0.25	21
1997	5	2	0	0	0	28.94	122.77	4.5	0.25	125
1997	5	21	0	0	0	23.062	80.088	5.81	0.02	111
1997	5	21	0	0	0	42.85	-7.1535	5.33	0.15	200
1997	6	15	0	0	0	23.98	89.91	4.6	0.37	118
1997	7	21	0	0	0	-26.8706	26.7773	4.7	0.25	63
1997	7	27	0	0	0	33.5481	122.2349	5.1	0.68	132
1997	7	29	0	0	0	-27.9521	26.6442	5.1	0.37	63
1997	8	10	0	0	0	-16.154	124.338	6.24	0.02	14
1997	8	13	0	0	0	29.4139	105.6148	4.9	0.25	131
1997	9	11	0	0	0	-3.6376	-76.9265	4.9	0.37	51
1997	9	11	0	0	0	-31.4593	117.5452	4.6	0.37	7
1997	9	22	0	0	0	54.7642	19.6155	4.7	0.37	175
1997	9	25	0	0	0	-26.372	27.3481	4.7	0.25	63
1997	10	3	0	0	0	-22.7886	147.1643	4.6	0.37	27
1997	10	11	0	0	0	-10.6132	24.6701	4.8	0.25	77
1997	10	24	0	0	0	31.1933	-87.1997	4.88	0.10	217
1997	11	6	0	0	0	46.7275	-71.3546	4.41	0.12	222
1997	12	6	0	0	0	64.904	-88.0878	5.2	0.25	239

Year	Month	Day	Hour	Minute	Second	Latitude	Longitude	E[M]	sigma M	DN
1997	12	11	0	0	0	-26.8974	26.6575	4.5	0.25	63
1998	3	3	0	0	0	-3.7548	-77.322	4.6	0.37	51
1998	3	5	0	0	0	0.8049	17.3948	4.98	0.21	73
1998	3	10	0	0	0	-11.745	-56.9634	5.2	0.25	52
1998	3	29	0	0	0	-12.3957	139.2206	5.1	0.25	13
1998	4	12	0	0	0	-12.4435	25.5442	4.8	0.37	61
1998	4	16	0	0	0	25.0379	107.9586	4.7	0.25	129
1998	4	16	0	0	0	25.2458	108.2534	4.5	0.25	129
1998	5	11	0	0	0	27.0812	71.7594	4.8	0.25	113
1998	5	28	0	0	0	31.4459	27.6426	5.50	0.03	90
1998	6	3	0	0	0	29.15	103.19	4.6	0.25	131
1998	7	13	0	0	0	-27.9098	26.8024	4.5	0.25	63
1998	8	29	0	0	0	43.445	109.0753	4.8	0.25	135
1998	9	24	0	0	0	46.3059	106.3265	5.56	0.03	136
1998	9	25	0	0	0	41.4444	-80.3388	4.55	0.17	226
1998	10	14	0	0	0	60.6616	-44.0581	4.99	0.15	244
1998	11	2	0	0	0	-19.8618	113.8855	4.5	0.37	2
1998	11	5	0	0	0	27.0812	71.7594	4.8	0.25	113
1998	11	17	0	0	0	-26.8668	26.6823	4.5	0.25	63
1998	12	1	0	0	0	26.385	103.938	4.9	0.37	130
1998	12	5	0	0	0	-26.2962	27.5215	4.6	0.25	63
1998	12	22	0	0	0	79.9756	-90.6722	4.8	0.25	249
1999	1	1	0	0	0	80.003	-111.51	5.00	0.24	250
1999	1	5	0	0	0	4.239	44.062	5.6	0.37	79
1999	1	18	0	0	0	33.408	-87.258	4.7	0.25	224
1999	1	25	0	0	0	43.67	-105.094	4.5	0.37	238
1999	1	27	0	0	0	-22.221	16.291	5.1	0.37	61
1999	1	29	0	0	0	2.12	45.721	5.4	0.25	80
1999	1	29	0	0	0	44.648	115.721	5	0.25	135
1999	2	10	0	0	0	32.944	15.277	4.7	0.25	90
1999	2	14	0	0	0	-19.27	21.256	4.6	0.37	61
1999	3	9	0	0	0	-10.8895	128.7734	5.5	0.25	1
1999	4	15	0	0	0	-20.124	134.061	4.7	0.25	13
1999	4	22	0	0	0	-27.939	26.675	5.3	0.25	63
1999	7	18	0	0	0	-6.3221	141.8213	4.8	0.37	16
1999	8	6	0	0	0	-8.543	21.517	4.5	0.25	72
1999	8	17	0	0	0	29.406	105.607	4.8	0.47	131
1999	8	17	0	0	0	67.813	34.498	4.5	0.47	171
1999	8	28	0	0	0	22.915	89.795	4.8	0.25	118
1999	12	7	0	0	0	75.588	-121.197	4.9	0.25	249
1999	12	30	0	0	0	43.735	-105.137	4.9	0.37	238
2000	1	1	0	0	0	46.875	-78.756	4.62	0.11	226
2000	2	8	0	0	0	-26.438	27.474	4.5	0.25	63
2000	3	12	0	0	0	17.244	73.707	4.87	0.28	106
2000	4	11	0	0	0	51.418	16.043	4.7	0.25	192
2000	7	13	0	0	0	-26.383	27.537	4.7	0.25	63
2000	8	13	0	0	0	21.212	71.105	4.7	0.25	113

Year	Month	Day	Hour	Minute	Second	Latitude	Longitude	E[M]	sigma M	DN
2000	9	5	0	0	0	17.332	73.79	5.17	0.15	106
2000	9	5	0	0	0	1.029	25.835	4.5	0.2	78
2000	10	11	0	0	0	-20.065	112.905	4.93	0.27	2
2000	11	8	0	0	0	77.042	-77.829	6	0.25	248
2000	12	8	0	0	0	59.749	1.924	4.9	0.25	188
2000	12	23	0	0	0	-7.832	135.889	6	0.47	13
2001	1	22	0	0	0	65.879	-52.497	4.7	0.25	246
2001	1	24	0	0	0	-26.742	26.844	4.8	0.37	63
2001	1	26	0	0	0	23.442	70.31	7.6	0.25	114
2001	2	3	0	0	0	-16.906	28.542	4.9	0.25	67
2001	2	28	0	0	0	18.1	-87.9	5.4	0.25	214
2001	3	18	0	0	0	-14.4643	137.0496	5.6	0.37	13
2001	4	5	0	0	0	-15.5248	122.6804	5.3	0.37	13
2001	4	9	0	0	0	43.783	-105.109	4.8	0.37	238
2001	4	12	0	0	0	60.3706	64.5696	5.7	0.37	159
2001	4	14	0	0	0	56.04	-119.583	5.27	0.04	242
2001	4	17	0	0	0	-6.196	22.71	4.7	0.25	73
2001	4	21	0	0	0	46.2	-105.4	5.3	0.25	238
2001	5	2	0	0	0	49.91	130.15	5	0.37	139
2001	5	5	0	0	0	18	-90.6	5.3	0.25	214
2001	5	20	0	0	0	42.806	-7.612	4.7	0.37	200
2001	6	12	0	0	0	22.24	83.918	4.8	0.25	110
2001	6	23	0	0	0	29.325	105.563	4.8	0.25	131
2001	6	25	0	0	0	35.1035	43.4952	5.6	0.25	81
2001	6	26	0	0	0	-26.34	27.487	4.5	0.25	63
2001	6	27	0	0	0	-12.1	-63.7	5.2	0.25	51
2001	7	12	0	0	0	21.2717	70.8706	4.6	0.25	113
2001	7	13	0	0	0	18.1502	78.8564	5.1	0.37	106
2001	7	16	0	0	0	75.5434	-23.5549	5.5	0.25	253
2001	7	25	0	0	0	33.4073	118.8967	4.5	0.25	132
2001	7	25	0	0	0	-12.663	-59.8357	4.5	0.25	52
2001	7	26	0	0	0	30.6635	21.6633	4.8	0.25	90
2001	7	26	0	0	0	48.5692	0.6203	4.8	0.25	196
2001	7	31	0	0	0	80.6	-80.3	5.4	0.25	249
2001	7	31	0	0	0	-9.2026	-70.0348	5.1	0.25	51
2001	7	31	0	0	0	-26.896	26.737	4.8	0.25	63
2001	8	5	0	0	0	-9.2812	137.2033	5	0.25	13
2001	8	5	0	0	0	-6.3181	137.017	4.8	0.25	13
2001	8	9	0	0	0	-26.543	150.3748	4.9	0.25	28
2001	8	13	0	0	0	-8.4663	138.0104	5.2	0.37	13
2001	8	14	0	0	0	76.658	-107.228	5.2	0.25	249
2001	8	16	0	0	0	12.4503	107.3692	4.6	0.25	123
2001	8	18	0	0	0	63.3427	-106.1729	5	0.25	239
2001	8	19	0	0	0	-13.365	119.5607	4.8	0.25	1
2001	8	20	0	0	0	-25.585	133.2451	4.9	0.25	9
2001	8	20	0	0	0	-17.426	129.9737	4.8	0.25	13
2001	8	23	0	0	0	-17.344	140.6926	5.6	0.25	18

Year	Month	Day	Hour	Minute	Second	Latitude	Longitude	E[M]	sigma M	DN
2001	8	25	0	0	0	36.2641	125.3343	5	0.25	132
2001	8	26	0	0	0	76.3339	-20.322	6.1	0.25	253
2001	8	26	0	0	0	-14.256	123.8186	5	0.25	1
2001	8	30	0	0	0	28.274	19.4471	5	0.25	90
2001	8	30	0	0	0	19.0558	31.2686	4.9	0.25	82
2001	9	2	0	0	0	-6.7649	10.4997	5.1	0.25	76
2001	9	2	0	0	0	37.673	129.78	4.9	0.25	127
2001	9	5	0	0	0	75.1661	-106.1823	5.1	0.25	249
2001	9	5	0	0	0	77.984	-114.673	4.7	0.25	249
2001	9	5	0	0	0	37.109	-104.528	4.42	0.10	255
2001	9	7	0	0	0	28.1113	15.1375	4.9	0.25	89
2001	9	7	0	0	0	29.7381	123.8315	4.6	0.25	127
2001	9	10	0	0	0	29.8725	104.5288	4.8	0.25	131
2001	9	11	0	0	0	18.5	-92.2	5.7	0.25	215
2001	9	13	0	0	0	27.9811	20.8813	5.7	0.25	90
2001	9	14	0	0	0	-40.278	149.7071	5.2	0.25	26
2001	9	14	0	0	0	-20.019	133.804	5	0.25	13
2001	9	15	0	0	0	19.7238	-91.9038	4.7	0.25	214
2001	9	16	0	0	0	32.6497	19.2837	5.5	0.25	90
2001	9	17	0	0	0	23.0733	117.7519	5	0.25	127
2001	9	17	0	0	0	45.3943	113.7827	4.7	0.25	135
2001	9	21	0	0	0	51.508	15.924	4.6	0.25	192
2001	9	22	0	0	0	34.3917	6.15	4.8	0.25	93
2001	9	22	0	0	0	-14.177	124.448	4.5	0.25	14
2001	9	23	0	0	0	18.3224	32.8639	4.9	0.25	82
2001	9	25	0	0	0	11.984	80.225	5.2	0.25	117
2001	9	25	0	0	0	31.7297	29.0631	5.1	0.25	90
2001	9	26	0	0	0	-13.243	147.2773	5.2	0.25	34
2001	9	26	0	0	0	-34.763	151.8227	5.1	0.25	30
2001	9	26	0	0	0	25.8207	22.8831	5	0.25	89
2001	9	28	0	0	0	-32.995	120.9596	5.2	0.25	8
2001	9	28	0	0	0	-30.399	117.319	4.9	0.25	8
2001	9	28	0	0	0	38.0842	126.5439	4.5	0.25	132
2001	9	30	0	0	0	-12.991	126.7785	5.1	0.25	15
2001	10	1	0	0	0	68.8555	-127.6986	4.8	0.25	241
2001	10	2	0	0	0	-16.542	129.5569	4.9	0.25	13
2001	10	2	0	0	0	27.5382	118.6441	4.8	0.25	125
2001	10	3	0	0	0	-6.9671	137.0515	6.2	0.25	13
2001	10	8	0	0	0	34.8007	121.2051	5	0.25	132
2001	10	8	0	0	0	-6.2523	137.4915	4.8	0.25	13
2001	10	9	0	0	0	21.7104	-92.8017	5.1	0.25	214
2001	10	16	0	0	0	47.4945	112.7612	5	0.25	136
2001	10	16	0	0	0	26.8645	49.1077	4.8	0.25	81
2001	10	17	0	0	0	-10.052	133.2564	4.6	0.25	17
2001	10	19	0	0	0	-7.941	12.104	5.3	0.25	76
2001	10	19	0	0	0	-33.712	120.628	5.1	0.25	8
2001	10	20	0	0	0	-31.605	147.4204	4.8	0.25	27

Year	Month	Day	Hour	Minute	Second	Latitude	Longitude	E[M]	sigma M	DN
2001	10	21	0	0	0	-13.734	122.9126	4.5	0.25	1
2001	10	23	0	0	0	27.8303	18.7848	4.7	0.25	89
2001	10	24	0	0	0	-9.0099	133.5067	4.5	0.25	13
2001	10	25	0	0	0	29.1506	122.51	4.7	0.25	125
2001	10	28	0	0	0	27.2492	70.5076	4.8	0.25	113
2001	10	29	0	0	0	-19.293	115.2423	4.8	0.25	2
2001	10	30	0	0	0	19.1093	19.1265	4.7	0.25	89
2001	11	1	0	0	0	23.513	55.6403	4.6	0.25	81
2001	11	2	0	0	0	23.7152	49.4	5.2	0.25	81
2001	11	2	0	0	0	27.658	19.7634	4.8	0.25	90
2001	11	2	0	0	0	-16.8054	134.754	4.5	0.25	13
2001	11	4	0	0	0	26.8836	21.4003	5.3	0.25	89
2001	11	4	0	0	0	25.3812	47.0527	4.9	0.25	81
2001	11	4	0	0	0	9.4009	4.7531	4.7	0.25	89
2001	11	5	0	0	0	-15.767	126.3471	5.1	0.25	14
2001	11	7	0	0	0	20.8091	74.3352	4.8	0.37	106
2001	11	7	0	0	0	43.775	-105.215	4.7	0.37	238
2001	11	7	0	0	0	24.3326	70.5843	4.6	0.37	113
2001	11	10	0	0	0	-12.809	12.6848	5	0.25	75
2001	11	14	0	0	0	7.8137	105.9438	6.5	0.25	122
2001	11	14	0	0	0	-22.876	151.377	4.8	0.25	32
2001	11	16	0	0	0	31.84	43.2838	4.7	0.25	81
2001	11	17	0	0	0	27.5644	49.4508	4.7	0.25	81
2001	11	18	0	0	0	32.7764	42.6509	4.5	0.25	81
2001	11	19	0	0	0	23.0845	72.7343	4.9	0.25	115
2001	11	19	0	0	0	-26.675	150.897	4.7	0.25	28
2001	11	20	0	0	0	26.1886	19.0605	4.8	0.25	89
2001	11	20	0	0	0	-19.373	128.96	4.8	0.25	13
2001	11	20	0	0	0	-17.96	135.7664	4.8	0.25	13
2001	11	21	0	0	0	-16.784	152.113	4.9	0.25	34
2001	11	21	0	0	0	33.1923	123.9614	4.5	0.25	132
2001	11	23	0	0	0	-16.497	121.1809	4.8	0.25	1
2001	11	23	0	0	0	24.5701	71.1103	4.6	0.25	113
2001	11	25	0	0	0	22.594	52.9846	5	0.25	81
2001	11	26	0	0	0	30.993	18.9136	5.6	0.25	90
2001	11	26	0	0	0	50.1921	16.3672	5	0.25	192
2001	11	26	0	0	0	28.8118	20.472	4.9	0.25	90
2001	12	13	0	0	0	31.157	110.781	4.8	0.25	130
2002	1	7	0	0	0	69.11	-95.87	4.7	0.25	239
2002	1	8	0	0	0	-29.268	24.112	4.7	0.37	63
2002	2	20	0	0	0	51.561	16.082	4.8	0.25	192
2002	2	28	0	0	0	-27.982	26.789	4.8	0.25	63
2002	3	5	0	0	0	-11.779	24.762	5.1	0.25	61
2002	3	5	0	0	0	-30.52	117.18	4.8	0.25	7
2002	3	21	0	0	0	-26.496	27.346	4.6	0.25	63
2002	3	23	0	0	0	-26.877	26.574	4.8	0.25	63
2002	4	16	0	0	0	40.705	128.67	4.6	0.37	133

Year	Month	Day	Hour	Minute	Second	Latitude	Longitude	E[M]	sigma M	DN
2002	4	19	0	0	0	-23.306	26.115	4.5	0.25	66
2002	4	20	0	0	0	44.513	-73.699	4.91	0.18	227
2002	4	30	0	0	0	29.459	105.647	4.8	0.37	131
2002	5	31	0	0	0	30.293	104.219	4.6	0.25	131
2002	6	13	0	0	0	-20.76	113.752	4.5	0.37	2
2002	6	15	0	0	0	-42.223	147.37	4.7	0.25	26
2002	6	18	0	0	0	38.069	-87.68	4.48	0.10	230
2002	7	12	0	0	0	-26.412	29.015	4.7	0.25	63
2002	7	22	0	0	0	50.889	6.103	4.8	0.25	195
2002	7	23	0	0	0	35.571	122.181	4.9	0.25	132
2002	8	10	0	0	0	35.353	123.252	4.5	0.25	132
2002	9	22	0	0	0	52.52	-2.15	4.8	0.25	187
2002	10	3	0	0	0	31.695	73.704	4.6	0.25	113
2002	10	8	0	0	0	-25.409	115.888	4.6	0.37	3
2002	10	20	0	0	0	44.621	117.371	4.6	0.25	135
2002	12	8	0	0	0	50.91	124.726	4.5	0.25	135
2003	1	23	0	0	0	41.541	-6.005	4.5	0.37	200
2003	2	22	0	0	0	48.342	6.57	4.78	0.31	195
2003	3	22	0	0	0	35.056	124.411	5.1	0.37	132
2003	3	22	0	0	0	48.21	9	4.7	0.37	192
2003	3	23	0	0	0	-13.763	14.273	4.8	0.25	72
2003	3	30	0	0	0	37.573	123.821	4.7	0.25	132
2003	4	29	0	0	0	34.494	-85.629	4.57	0.10	224
2003	5	24	0	0	0	6.498	-65.147	4.5	0.25	52
2003	6	4	0	0	0	75.154	16.726	4.8	0.25	181
2003	6	18	0	0	0	72.07	15.525	4.5	0.25	183
2003	7	4	0	0	0	76.372	23.282	5.4	0.25	169
2003	7	19	0	0	0	-26.425	27.333	4.6	0.25	63
2003	8	4	0	0	0	65.989	5.477	4.8	0.25	183
2003	8	10	0	0	0	27.216	75.739	4.5	0.37	113
2003	8	11	0	0	0	-18.436	147.114	4.8	0.25	33
2003	8	16	0	0	0	43.77	119.643	5.42	0.04	137
2003	10	5	0	0	0	51.517	16.201	4.8	0.25	192
2004	2	6	21	29	21.4	-4.5	137.31	4.87	0.08	16
2004	2	11	9	30	39	-22.51	130.17	4.85	0.13	5
2004	3	24	1	53	49.4	45.38	118.15	5.37	0.02	135
2004	5	29	10	14	28.4	36.66	129.95	5.10	0.03	127
2004	7	10	8	56	20.5	-8.72	130.57	4.81	0.08	1
2004	8	10	10	26	14.7	27.16	103.78	5.35	0.02	130
2004	9	21	13	32	30.8	54.79	20.11	4.74	0.09	175
2004	10	16	10	4	38	33.56	45.63	4.79	0.18	81
2004	12	5	1	52	37.2	48.03	8.04	4.73	0.15	195
2005	1	22	10	48	45.7	-10.76	124.19	5.15	0.07	1
2005	2	22	23	14	17.8	-65.64	133.54	5.46	0.02	213
2005	3	14	9	43	49.1	17.1	73.79	4.91	0.07	106
2005	7	18	2	6	53.8	-10.33	124.72	5.47	0.05	1
2005	7	20	21	54	5.7	43.04	109.04	5.21	0.02	135

Year	Month	Day	Hour	Minute	Second	Latitude	Longitude	E[M]	sigma M	DN
2005	7	25	15	43	41.1	46.86	124.88	5.01	0.03	137
2005	8	5	14	14	48	26.46	103.19	5.26	0.03	130
2005	8	10	22	8	22.6	36.9	-104.79	4.93	0.07	255
2005	9	19	3	27	53.2	49.72	120.93	4.46	0.24	135
2005	11	8	7	54	39	10.12	108.26	5.33	0.03	122
2005	11	10	19	29	54.1	57.48	120.63	5.86	0.01	147
2005	11	26	0	49	37.7	29.66	115.71	5.20	0.03	130
2006	2	15	1	46	4.1	-9.63	126.57	4.74	0.18	1
2006	3	7	18	20	46.1	23.72	70.77	5.48	0.01	114
2006	3	10	7	50	14.4	32.62	73.51	4.96	0.08	113
2006	3	31	12	23	17.9	44.65	124.08	4.76	0.06	137
2006	4	6	17	59	16.4	23.25	70.35	5.56	0.02	114
2006	6	8	16	29	13.3	4.88	-51.96	5.07	0.03	52
2006	8	25	5	51	44.4	28	104.31	5.04	0.08	131
2006	11	17	9	25	21.4	-4.7	138.27	5.08	0.09	16
2007	1	7	1	50	53.8	62.08	1.22	4.85	0.07	184
2007	1	20	11	56	53.7	37.65	128.43	4.76	0.06	132
2007	7	9	15	58	22.3	34.1	6.89	4.85	0.05	93
2007	11	4	20	35	37.3	-67.27	111.53	5.72	0.01	202
2007	11	6	9	38	5.8	21.04	70.49	5.13	0.04	113
2007	11	28	15	16	8.5	10.02	108.28	5.20	0.03	122
2007	12	23	12	56	13	-4.08	39.45	4.90	0.05	80
2008	2	21	2	46	17.9	77.02	19.28	6.10	0.01	181
2008	3	6	12	19	16.4	-24.92	-64.29	4.97	0.05	41
2008	4	18	9	36	59.1	38.49	-87.86	5.3	0.09	229
2008	4	20	7	30	44.3	-3.66	25.97	5.27	0.03	72
2008	4	26	13	14	52.2	50.71	51.8	5.13	0.04	161
2008	6	10	6	5	4.7	49.07	122.47	4.96	0.06	135
2008	8	15	15	52	50.8	82.23	-18.58	4.78	0.05	239
2008	10	7	10	0	48.1	79.77	-116.02	5.77	0.01	250
2008	12	16	5	20	1.5	55.55	13.76	4.30	0.11	177

Table K-2
SCR Domains Updated from Johnston et al. (1994)

Notes:

DN	Domain Number
Type	Domain type E – Extended crust NE – Non-extended crust (crustal age domain)
Age	Domain age assigned in Johnston et al. (1994) CZ – Cenozoic MZ – Mesozoic PZ – Paleozoic PC – PreCambrian
MRE Age	Age of most recent extension. For Type NE domains, this equals Age CZ – Cenozoic MZ – Mesozoic PZ – Paleozoic PC – PreCambrian
Stress	Crustal Stress State in Domain C – Compressive E – Extensive U – Unknown
SS_Ang	Classification of angle between maximum horizontal stress vector and strike of major domain structures with respect to reactivation F – Favorable orientation NF – Unfavorable orientation UK – Unknown
Area	Area of domain in km^2
Mmax_obs	Largest observed magnitude in domain
N ≥ 4.5	Number of earthquakes in domain with magnitudes ≥ **M**, adjusted for completeness
SDNT	Indicates which Superdomain the domain is assigned to when TYPE is included in the classification
SDNC	Indicates which Superdomain the domain is assigned to when Type is not included in the classification

Table K-2
SCR Domains Updated from Johnston et al. (1994)

DN	Type	Age	MRE Age	Stress	SS_Ang	Area	Mmax_obs	N ≥ 4.5	SDNT	SDNC
1	E	MZ	CZ	C	F	542655	6.3	35.4	SE01	SD01
2	E	MZ	CZ	C	NF	383752	7.2	29.4	SE02	SD02
3	NE	PC	PC	C	UK	369232	4.8	4	SN07	SD15
4	E	MZ	MZ	C	UK	420994	5.1	4	SE08	SD08
5	NE	PC	PC	C	NF	279587	5.8	4	SN06	SD14
6	E	MZ	MZ	C	UK	115589	6.2	3.3	SE08	SD08
7	NE	PC	PC	C	NF	237858	6.7	20.3	SN06	SD14
8	NE	PC	PC	C	NF	501577	5.2	4.6	SN06	SD14
9	NE	PC	PC	C	UK	853794	6	12.5	SN07	SD15
10	NE	PC	PC	C	UK	192642	4.5	1	SN07	SD15
11	E	MZ	CZ	C	F	118809	5.5	4	SE01	SD01
12	E	PC	PZ	C	NF	200768	6.5	7.2	SE18	SD21
13	NE	PC	PC	C	UK	2010402	6.8	81.2	SN07	SD15
14	NE	PC	PC	C	UK	197610	6.2	6.8	SN07	SD15
15	E	PZ	MZ	C	UK	140443	5.1	1	SE08	SD08
16	E	MZ	CZ	C	UK	310194	7.3	23.3	SE03	SD03
17	E	PZ	PZ	C	UK	27315	5.3	3	SE19	SD22
18	NE	PC	PC	C	NF	645753	5.6	1	SN06	SD14
19	NE	PC	PC	C	UK	838499	5.4	5.2	SN07	SD15
20	E	MZ	MZ	C	UK	430647	0	0	SE08	SD08
21	E	PC	CZ	C	NF	109798	5.8	21.6	SE02	SD02
22	E	PC	PC	C	F	31132	0	0	SE13	SD13
23	E	MZ	MZ	C	F	91577	6.2	7.1	SE06	SD06
24	E	MZ	CZ	C	UK	21214	0	0	SE03	SD03
25	E	MZ	CZ	C	NF	38206	0	0	SE02	SD02
26	E	MZ	CZ	C	NF	578458	6.4	16.9	SE02	SD02
27	NE	PZ	PZ	C	UK	1732818	5.4	26.2	SN14	SD22
28	NE	PZ	PZ	C	F	320334	5.1	6.2	SN12	SD20
29	NE	MZ	MZ	C	F	33900	0	0	SN01	SD06
30	E	MZ	MZ	C	NF	64704	5.1	1	SE07	SD07
31	NE	PZ	PZ	C	UK	203355	4.7	1	SN14	SD22
32	E	MZ	MZ	C	UK	465267	5.8	6	SE08	SD08
33	E	MZ	CZ	C	UK	130520	4.8	1	SE03	SD03
34	E	CZ	CZ	C	UK	330468	5.2	2.6	SE03	SD03
35	E	MZ	MZ	C	UK	1174158	6.5	4.3	SE08	SD08
36	NE	PC	PC	C	UK	88752	0	0	SN07	SD15
37	NE	PZ	PZ	C	UK	854067	0	0	SN14	SD22
38	NE	PZ	PZ	C	UK	136385	0	0	SN14	SD22
39	E	MZ	MZ	C	F	90689	0	0	SE06	SD06
40	NE	PZ	PZ	C	UK	239608	0	0	SN14	SD22
41	NE	PC	PC	C	UK	923063	5.1	4	SN07	SD15
42	NE	PC	PC	C	F	509261	4.9	1	SN05	SD13
43	E	MZ	MZ	C	NF	73005	0	0	SE07	SD07
44	NE	PC	PC	C	NF	286827	0	0	SN06	SD14
45	NE	PC	PC	C	NF	718524	0	0	SN06	SD14

DN	Type	Age	MRE Age	Stress	SS_Ang	Area	Mmax_obs	N ≥ 4.5	SDNT	SDNC
46	E	MZ	MZ	C	F	784433	6.1	4.2	SE06	SD06
47	NE	PC	PC	C	UK	941052	4.7	1	SN07	SD15
48	NE	PC	PC	C	UK	324268	0	0	SN07	SD15
49	NE	PC	PC	C	UK	860086	5.3	3	SN07	SD15
50	NE	PC	PC	C	UK	229524	0	0	SN07	SD15
51	NE	PC	PC	C	NF	2130122	5.3	15.1	SN06	SD14
52	NE	PC	PC	C	UK	4715337	6.3	22.2	SN07	SD15
53	E	PZ	CZ	C	NF	281647	5.3	1	SE02	SD02
54	E	MZ	MZ	C	NF	680267	4.7	1	SE07	SD07
55	NE	PC	PC	C	UK	90225	0	0	SN07	SD15
56	NE	PC	PC	C	F	1052751	5.4	8.4	SN05	SD13
57	E	MZ	MZ	C	NF	17869	0	0	SE07	SD07
58	NE	PZ	PZ	C	F	141370	6.4	10.2	SN12	SD20
59	E	MZ	MZ	C	UK	392983	5.2	3.3	SE08	SD08
60	NE	PC	PC	E	UK	577400	5.6	7.5	SN10	SD18
61	NE	PC	PC	E	NF	1197397	5.8	33.2	SN09	SD17
62	E	MZ	MZ	C	F	527118	0	0	SE06	SD06
63	NE	PC	PC	E	NF	480297	6.6	368	SN09	SD17
64	E	PC	PC	E	UK	22629	6.5	2	SE15	SD18
65	E	PC	MZ	E	UK	46793	5.2	1	SE11	SD11
66	NE	PC	PC	E	UK	295236	5	3.9	SN10	SD18
67	NE	PC	PC	E	F	655453	5.7	19	SN08	SD16
68	NE	PC	PC	E	F	60012	5.3	1	SN08	SD16
69	NE	PC	PC	E	NF	11451	0	0	SN09	SD17
70	E	MZ	MZ	E	NF	28193	5.9	1	SE10	SD10
71	E	MZ	MZ	E	NF	701414	5.6	4.1	SE10	SD10
72	NE	PC	PC	C	F	1004603	6.2	13.6	SN05	SD13
73	NE	PC	PC	C	UK	1985264	6.3	28.7	SN07	SD15
74	NE	PC	PC	C	NF	132886	6.4	1	SN06	SD14
75	E	MZ	MZ	U	UK	80902	5	1	SE12	SD12
76	E	MZ	MZ	U	UK	372829	5.6	3	SE12	SD12
77	NE	PC	PC	U	UK	49528	4.8	1	SN11	SD19
78	NE	PC	PC	U	UK	45208	6.3	4.8	SN11	SD19
79	NE	PC	PC	E	F	803876	5.6	2	SN08	SD16
80	E	MZ	MZ	E	NF	492873	5.5	4.9	SE10	SD10
81	NE	PC	PC	C	NF	2971006	6.9	55.2	SN06	SD14
82	NE	PC	PC	C	NF	2034295	7.3	18.7	SN06	SD14
83	NE	PC	PC	C	UK	244105	5.7	1	SN07	SD15
84	NE	PC	PC	C	NF	2323466	6.1	6	SN06	SD14
85	E	CZ	CZ	C	NF	355539	4.9	2.9	SE02	SD02
86	E	MZ	MZ	U	UK	187366	0	0	SE12	SD12
87	E	MZ	MZ	U	UK	81856	0	0	SE12	SD12
88	E	MZ	MZ	U	UK	57545	0	0	SE12	SD12
89	NE	PC	PC	C	NF	3890522	5.3	9.3	SN06	SD14
90	E	MZ	MZ	C	NF	960298	6.8	86.9	SE07	SD07
91	E	MZ	MZ	C	NF	175410	6.5	1	SE07	SD07
92	NE	PC	PC	C	UK	689805	6.8	4	SN07	SD15

DN	Type	Age	MRE Age	Stress	SS_Ang	Area	Mmax_obs	N ≥ 4.5	SDNT	SDNC
93	NE	PC	PC	C	UK	421251	4.9	2	SN07	SD15
94	NE	PC	PC	U	UK	176032	0	0	SN11	SD19
95	NE	PZ	PZ	C	UK	164906	5.5	1	SN14	SD22
96	NE	PC	PC	U	UK	306656	0	0	SN11	SD19
97	NE	PC	PC	U	UK	396208	0	0	SN11	SD19
98	NE	PC	PC	U	UK	1128104	4.6	1	SN11	SD19
99	E	PC	PC	U	UK	429359	5.4	1	SE16	SD19
100	NE	PC	PC	C	UK	1374935	6.2	7	SN07	SD15
101	E	MZ	MZ	U	UK	188729	0	0	SE12	SD12
102	NE	PZ	PZ	U	UK	14966	0	0	SN15	SD23
103	NE	PZ	PZ	C	UK	19779	0	0	SN14	SD22
104	NE	PZ	PZ	U	UK	150047	0	0	SN15	SD23
105	E	MZ	MZ	E	F	1272700	6.2	4	SE09	SD09
106	NE	PC	PC	C	NF	781860	6.3	26.3	SN06	SD14
107	NE	PC	PC	C	UK	79382	5.5	2	SN07	SD15
108	NE	PC	PC	C	NF	155035	4.7	1	SN06	SD14
109	NE	PC	PC	C	UK	41141	5.1	3.9	SN07	SD15
110	NE	PC	PC	C	UK	142062	5.7	2.3	SN07	SD15
111	NE	PC	PC	C	NF	178946	5.8	11.8	SN06	SD14
112	NE	PC	PC	C	UK	504375	6.2	9	SN07	SD15
113	NE	PC	PC	C	F	810970	6.7	71.7	SN05	SD13
114	E	MZ	MZ	C	NF	76406	7.8	31	SE07	SD07
115	E	MZ	CZ	C	NF	39598	5.4	5	SE02	SD02
116	E	MZ	CZ	C	UK	248085	5.4	2	SE03	SD03
117	E	MZ	MZ	C	F	326551	5.6	6	SE06	SD06
118	E	MZ	CZ	C	F	243283	6.1	20.9	SE01	SD01
119	E	PZ	MZ	C	NF	65847	6.4	1	SE07	SD07
120	E	MZ	CZ	C	NF	55041	5.2	1	SE02	SD02
121	E	PZ	MZ	C	NF	61324	0	0	SE07	SD07
122	NE	PZ	PZ	C	UK	310144	6.5	5.1	SN14	SD22
123	NE	PC	PC	C	UK	377393	4.6	1	SN07	SD15
124	NE	PZ	PZ	C	UK	178223	0	0	SN14	SD22
125	E	MZ	MZ	C	NF	383113	7.3	307.5	SE07	SD07
126	E	CZ	CZ	C	NF	64880	7.5	12.1	SE02	SD02
127	E	CZ	CZ	C	NF	1258535	7.7	124.2	SE02	SD02
128	NE	MZ	MZ	C	NF	201788	5.6	4.5	SN02	SD07
129	NE	MZ	MZ	C	NF	603996	6.2	42	SN02	SD07
130	NE	MZ	MZ	C	UK	682979	6.4	91.6	SN03	SD08
131	NE	PC	PC	C	UK	261381	6.8	454.8	SN07	SD15
132	E	CZ	CZ	C	NF	495752	7.9	501.6	SE02	SD02
133	NE	PC	PC	C	F	312369	6.7	107.7	SN05	SD13
134	NE	PZ	PZ	C	F	127045	4.8	1	SN12	SD20
135	NE	PZ	PZ	C	F	712893	5.4	26	SN12	SD20
136	NE	PZ	PZ	C	F	641577	5.7	11.8	SN12	SD20
137	E	MZ	MZ	C	NF	333684	6.2	15.7	SE07	SD07
138	NE	MZ	MZ	C	UK	152897	5	1	SN03	SD08
139	NE	PZ	PZ	C	UK	173986	6.8	20.4	SN14	SD22

DN	Type	Age	MRE Age	Stress	SS_Ang	Area	Mmax_obs	N ≥ 4.5	SDNT	SDNC
140	NE	PC	PC	U	UK	229180	5	1	SN11	SD19
141	NE	MZ	MZ	U	UK	204323	5	2	SN04	SD12
142	NE	MZ	MZ	U	UK	234618	0	0	SN04	SD12
143	NE	MZ	MZ	U	UK	160531	0	0	SN04	SD12
144	E	MZ	MZ	U	UK	499042	4.9	1	SE12	SD12
145	E	CZ	CZ	U	UK	151400	0	0	SE05	SD05
146	NE	PC	PC	U	UK	296773	5.4	1	SN11	SD19
147	NE	PC	PC	U	UK	750750	6.2	14.5	SN11	SD19
148	E	PC	MZ	U	UK	200729	4.8	1	SE12	SD12
149	NE	PC	PC	U	UK	2249521	6.4	10.8	SN11	SD19
150	E	PC	PC	U	UK	72411	0	0	SE16	SD19
151	NE	PC	PC	U	UK	202499	0	0	SN11	SD19
152	NE	PZ	PZ	U	UK	436997	5.2	1	SN15	SD23
153	NE	PC	PC	U	UK	312722	0	0	SN11	SD19
154	NE	PZ	PZ	U	UK	155264	5	1	SN15	SD23
155	E	MZ	MZ	U	UK	1083894	0	0	SE12	SD12
156	NE	PZ	PZ	C	UK	1206616	5.2	9.8	SN14	SD22
157	NE	PZ	PZ	U	UK	178540	4.6	1	SN15	SD23
158	NE	PZ	PZ	U	UK	1145766	5.3	3.4	SN15	SD23
159	NE	PZ	PZ	U	UK	1334133	5.7	5.3	SN15	SD23
160	NE	PC	PC	U	UK	209438	5.3	1	SN11	SD19
161	E	PZ	PZ	U	UK	561624	5.1	2.9	SE20	SD23
162	E	PZ	PZ	C	NF	276360	0	0	SE18	SD21
163	NE	PC	PC	U	UK	561495	0	0	SN11	SD19
164	NE	PC	PC	C	F	371000	0	0	SN05	SD13
165	E	PC	PC	U	UK	54556	0	0	SE16	SD19
166	NE	PC	PC	U	UK	1276933	4.9	2	SN11	SD19
167	E	PC	PC	C	NF	182051	4.9	2	SE14	SD14
168	E	PC	PZ	U	UK	525509	4.9	2	SE20	SD23
169	NE	PC	PC	E	UK	1166510	5.4	2	SN10	SD18
170	E	CZ	CZ	U	UK	141010	5.1	2	SE05	SD05
171	NE	PC	PC	C	F	241485	4.7	2	SN05	SD13
172	NE	PC	PC	C	UK	96452	0	0	SN07	SD15
173	NE	PC	PC	C	F	821894	5.3	3	SN05	SD13
174	NE	PC	PC	C	F	76920	0	0	SN05	SD13
175	NE	PC	PC	C	F	1056504	4.8	2	SN05	SD13
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177	NE	PC	PC	C	F	174915	5.9	2	SN05	SD13
178	E	PZ	MZ	C	NF	26218	0	0	SE07	SD07
179	NE	PZ	PZ	C	NF	342539	6.4	26.6	SN13	SD21
180	E	MZ	MZ	C	NF	274830	0	0	SE07	SD07
181	NE	PZ	PZ	C	UK	109385	6.1	4.4	SN14	SD22
182	NE	PZ	PZ	U	UK	35620	4.9	1	SN15	SD23
183	E	MZ	CZ	C	NF	411360	5.8	33.5	SE02	SD02
184	E	MZ	CZ	C	UK	734600	4.9	2	SE03	SD03
185	NE	PZ	PZ	C	NF	399518	5.1	10	SN13	SD21
186	E	PZ	PZ	C	NF	66123	4.6	1	SE18	SD21

DN	Type	Age	MRE Age	Stress	SS_Ang	Area	Mmax_obs	N ≥ 4.5	SDNT	SDNC
187	NE	PC	PC	C	UK	123709	6.7	31.9	SN07	SD15
188	E	MZ	MZ	C	NF	150936	5.6	6	SE07	SD07
189	E	MZ	MZ	C	NF	15655	4.7	1	SE07	SD07
190	NE	PZ	PZ	C	UK	186309	4.6	1	SN14	SD22
191	E	PZ	CZ	C	F	101917	0	0	SE01	SD01
192	NE	PZ	PZ	C	F	360973	6.2	223.4	SN12	SD20
193	E	CZ	CZ	C	NF	11175	4.7	1	SE02	SD02
194	E	MZ	CZ	C	F	163623	5.7	3.5	SE01	SD01
195	E	CZ	CZ	C	NF	265266	6.6	104	SE02	SD02
196	NE	PZ	PZ	C	UK	540395	5.9	34.5	SN14	SD22
197	E	MZ	MZ	C	F	423541	5.3	2	SE06	SD06
198	E	MZ	MZ	E	NF	57097	5.3	3	SE10	SD10
199	E	MZ	MZ	C	NF	180858	7.1	45	SE07	SD07
200	NE	PZ	PZ	C	F	288764	5.5	15.8	SN12	SD20
201	E	MZ	CZ	C	F	156373	5.2	2	SE01	SD01
202	NE	PC	PC	C	UK	7263353	5.7	3.1	SN07	SD15
203	NE	PC	PC	U	UK	1028169	0	0	SN11	SD19
204	NE	PC	PC	U	UK	79414	0	0	SN11	SD19
205	NE	PC	PC	U	UK	152545	0	0	SN11	SD19
206	NE	PC	PC	U	UK	4175	0	0	SN11	SD19
207	E	MZ	CZ	U	UK	1250511	0	0	SE05	SD05
208	E	CZ	CZ	U	UK	606087	5.2	2	SE05	SD05
209	E	MZ	MZ	U	UK	14821	0	0	SE12	SD12
210	E	MZ	MZ	U	UK	122104	0	0	SE12	SD12
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213	E	MZ	MZ	U	UK	900281	5.5	2	SE12	SD12
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233	NE	PC	PC	C	UK	272794	0	0	SN07	SD15

DN	Type	Age	MRE Age	Stress	SS_Ang	Area	Mmax_obs	N ≥ 4.5	SDNT	SDNC
234	NE	PC	PC	C	F	130527	0	0	SN05	SD13
235	E	PC	PC	C	NF	325388	5.5	6.5	SE14	SD14
236	NE	PC	PC	C	F	2195241	6	2	SN05	SD13
237	NE	PC	PC	C	UK	1344617	5.7	5.3	SN07	SD15
238	NE	PC	PC	C	F	373331	5.3	9.3	SN05	SD13
239	NE	PC	PC	C	UK	3882973	5.4	20.6	SN07	SD15
240	NE	PC	PC	C	UK	483039	0	0	SN07	SD15
241	NE	PC	PC	C	NF	1067319	6.2	7	SN06	SD14
242	NE	PC	PC	C	F	550542	5.2	2.5	SN05	SD13
243	NE	PC	PC	C	UK	73011	0	0	SN07	SD15
244	NE	PC	PC	C	UK	96381	5	2.3	SN07	SD15
245	NE	PC	PC	U	UK	18765	0	0	SN11	SD19
246	NE	PC	PC	C	UK	296714	4.7	2	SN07	SD15
247	E	MZ	MZ	C	NF	235667	5.6	7.2	SE07	SD07
248	E	CZ	CZ	E	NF	1651160	6.2	16.1	SE04	SD04
249	E	MZ	MZ	C	NF	649859	6.3	20.6	SE07	SD07
250	E	MZ	MZ	C	NF	259139	5.8	4.3	SE07	SD07
251	NE	PZ	PZ	C	UK	189322	6.2	5	SN14	SD22
252	NE	PZ	PZ	U	UK	194188	0	0	SN15	SD23
253	E	PZ	PZ	U	UK	170849	6.1	6.4	SE20	SD23
254	E	MZ	CZ	C	UK	350276	5.7	2	SE03	SD03
255	NE	PC	PC	C	UK	601885	5.1	5.9	SN07	SD15

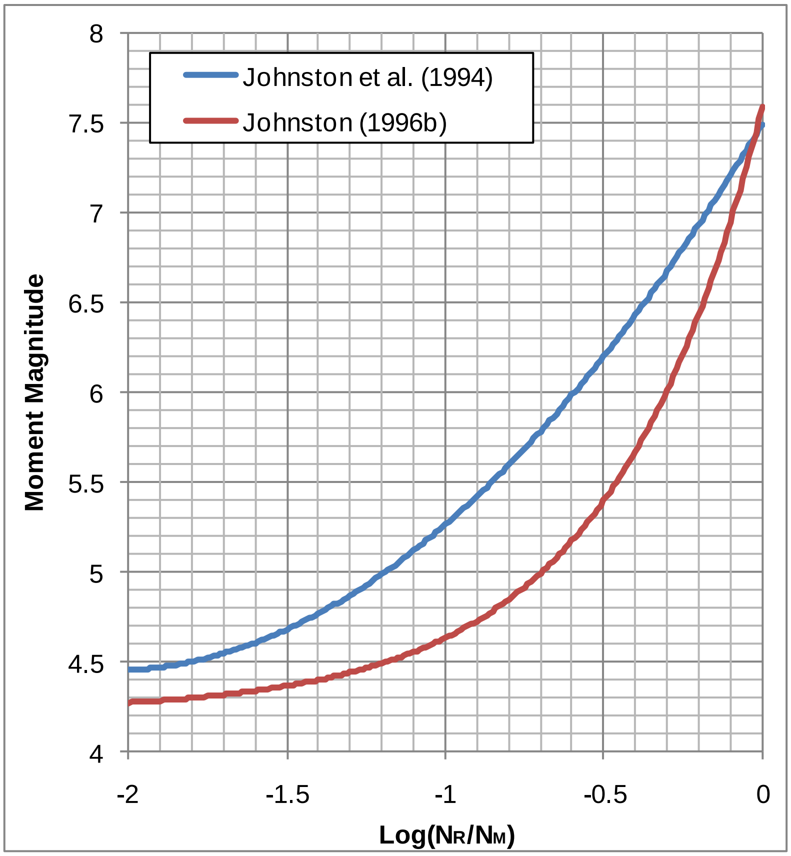

Figure K-1
Comparison of relationships between number of reporting stations and moment magnitude presented in Johnston et al. (1994) and Johnston (1996b).

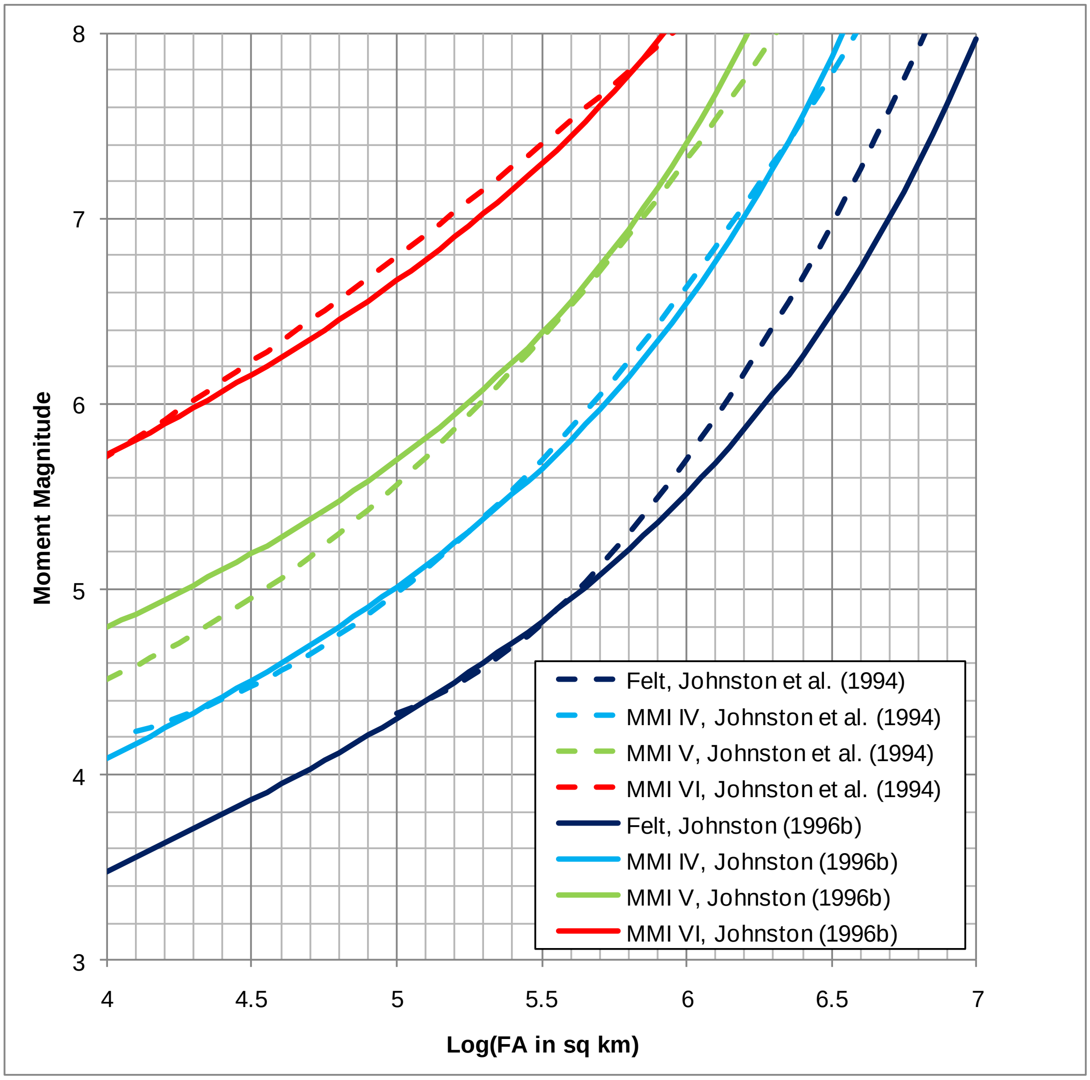

Figure K-2
Comparison of relationships between isoseismal areas and moment magnitude presented in Johnston et al. (1994) and Johnston (1996b).

APPENDIX L

Quality Assurance

L

APPENDIX
QUALITY ASSURANCE

L.1 BACKGROUND

Embedded in the SSHAC PSHA process described in NUREG/CR-6372 (*Recommendations for Probabilistic Seismic Hazard Analysis: Guidance on Uncertainty and Use of Experts*) and ANSI/ANS-2.29-2008 (*Probabilistic Seismic Hazard Analysis*) is "participatory peer review," defined as both process and technical review of the PSHA starting at an early stage and continuing through the life of a project. Participatory peer review is a fundamental element of ensuring the quality of the resulting PSHA product. Both ANSI/ANS-2.29-2008 and ANSI/ANS-2.27-2008 (*Criteria for Investigation of Nuclear Facility Sites for Seismic Hazard Assessments*) were developed to be consistent with ANSI/ASME NQA-1-2008 (*Quality Assurance Requirements for Nuclear Facility Applications*). Hence, for a regional study such as the Central and Eastern United States (CEUS) Seismic Source Characterization (SSC) for Nuclear Facilities Project, following the guidance contained in NUREG/CR-6372, ANSI/ANS-2.29-2008, and ANSI/ANS-2.27-2008 will result in adequate products and output. Site-specific assessments that start with a Level 3 or 4 regional model and perform a Level 2 refinement for site-specific applications will also need to comply with specific requirements in ASME NQA-1-2008 Parts I and II.

Within the SSHAC hazard assessment framework, a traditional verification and validation (V&V) program is limited to specific numerical tools, such as the software used to perform the PSHA calculations. A quality or "cross-check" protocol may also be used to ensure the accuracy of compiled tables, data sets, and other project products. However, it is not possible to apply a V&V program to the SSHAC process itself. Similarly, it does not make sense to impose a restriction on the use of data for cases where a formal quality assurance program for the collection of field data outside of the project cannot be verified (e.g., if a quality control program cannot be verified for a USGS or university data set). The rejection of data sets in these cases could seriously diminish, instead of enhance, the process. This is because a key part of a SSHAC Level 3 or 4 process is the evaluation of data by the evaluator experts. Therefore, the evaluator experts are able to make an informed assessment of the quality of various data sets, whether or not those data were gathered within a formal quality program. This does not mean, however, that nonqualified data used in a SSHAC process can be considered qualified after their use in the process.

Within the SSHAC hazard assessment framework, the collection and evaluation of existing scientific information is performed with the aim of ascertaining the current state of knowledge regarding a specific issue. The majority of existing information that may be used in a SSHAC Level 3 or 4 PSHA will have been published in some fashion previously. Moreover, the data, methods, and models considered and used will also undergo what effectively constitutes peer review by the TI Team, which is likely to be at least as rigorous as that conducted for journal publication. Thus, that information has been reviewed and "vetted" by the broad technical community. The systematic compilation of all pertinent information from the scientific literature (including specialized journals, technical reports, conference proceedings) or other relevant sources of information (e.g., databases of scientific data, historical or archival documents) is a vital element in a SSHAC PSHA study. In addition, in some cases, nontraditional types of data that may be beneficial to the project may be available. It is important that data not be dismissed without appropriate consideration, particularly in regions where data may be scarce.

Beyond the assurance of quality arising from that external scientific review process, a fundamental component of the SSHAC process is the *evaluation* of the data, models, and methods by the evaluator experts as a means of establishing the quality, relevance, technical basis, and uncertainties. Further, in the *integration* stage of the SSHAC assessment process, the TI team or evaluator experts build models and apply weights to elements of the model based on due consideration of the technical support for various models and methods proposed by the technical community. Therefore, it is the collective, informed judgment of the TI Team (via the process of data evaluation and model integration) and the concurrence of the PPRP (via the process of participatory peer review), as well as adherence to the national standards described above, that ultimately lead to the assurance of quality in the process followed and in the products resulting from the SSHAC hazard assessment framework.

L.2 CEUS SSC PROJECT

L.2.1 Introduction

The TI Team, Project Manager, and Sponsors determined the approach for quality control for the CEUS SSC Project in 2008, taking into account the SSHAC assessment process and national standards described above. The approach was documented in the CEUS SSC Project Plan, dated June 2008. The technical assessments made as part of the CEUS SSC entailed the use of a wide range of databases, including those that have been subject to peer review in the professional literature, those that have been gathered for scholarly research, and those that have been developed for site-specific commercial application. In creating the CEUS SSC model, the TI Team had extensive interactions with the technical community about identifying data, evaluating alternative hypotheses, and collecting feedback regarding all assessments. These interactions helped ensure a high level of review for the TI Team's technical assessments.

A participatory peer review process was used for both the technical and process elements of the project. This process provides high confidence that the project assessments and results will be accepted by the technical community. The level of assurance exceeds that associated with publication in a peer-reviewed technical journal. In addition to the peer review process that is afforded by the SSHAC Level 3 process, certain other activities were conducted as best business practices. These activities are described below.

L.3 BEST BUSINESS PRACTICES

L.3.1 General

A hazard input document (HID) was developed that documents and summarizes the key elements of the SSC model, including logic trees, parameter distributions, and derived Mmax and recurrence parameters. The HID specifies the exact inputs provided by the SSC model to the hazard calculations and thus provides a clear record of how the SSC model is translated into hazard calculations. As discussed in Task 2 of the CEUS SSC Project Plan, "Develop a Database," the management and documentation of the data were done in accordance with a data management procedure developed specifically for this project. As part of Task 7 of the Project Plan, "Construct a Preliminary SSC Model," new computer codes were developed for estimating seismicity rates and *b*-values. These computer codes were documented and are available as part of project documentation on the CEUS SSC Project website. All hazard calculations were conducted using software that had been previously qualified in accordance with 10 CFR 50, Appendix B (*Quality Assurance Criteria for Nuclear Power Plants and Fuel Reprocessing Plants*) requirements. Also, an internal documentation package was prepared to archive the hazard calculations. The results for seven test sites were documented as example calculations in Chapter 8 of the main project report.

L.4 CEUS SSC EARTHQUAKE CATALOG DEVELOPMENT

L.4.1 External Review of Earthquake Catalog

The initial earthquake catalog assembled for the project was submitted for external review by seismologists familiar with compiling and analyzing earthquake data in the CEUS. The reviewers are listed as follows:

- Charles Mueller and Margaret Hopper (U.S. Geological Survey)
- John Ebel (Boston College)
- Martin Chapman (Virginia Tech)
- Pradeep Talwani (University of South Carolina)
- Don Stevenson (Savannah River Nuclear Solutions, LLC)
- James Marrone (Bechtel)

These reviewers provided recommendations for additional sources of data and for treatment of the data from various catalog sources; they also provided specific recommendations on individual earthquakes. These recommendations were considered in developing the final project catalog.

L.4.2 Simulation Testing

A series of simulation tests were performed to verify a number of processes used in the development of the earthquake catalog, including the following:

- Verifying no adverse effect from rounding magnitudes reported in various catalogs to one decimal place when testing for differences in magnitudes from separate sources.
- Verifying the relationships developed by EPRI (1988) for developing uniform magnitude estimates, adjusting for bias in earthquake recurrence parameters due to magnitude uncertainty.
- Assessing the impact of catalog incompleteness on estimating earthquake recurrence parameters from uncertain magnitudes.
- Developing an improved method of correcting for bias in earthquake recurrence parameters from uncertain magnitudes and partially complete earthquake catalogs.

L.4.3 Checks for Consistency in Magnitude Conversion from Intensity

Because a large part of the earthquake catalog contains pre-instrumental earthquakes, relationships are needed to estimate earthquake magnitude from the reported level of shaking intensity. In past studies, the body-wave-magnitude scale has been used, and relationships have been developed to estimate body-wave magnitude from maximum shaking intensity in order to use the pre-instrumental earthquake data. However, the CEUS SSC Project earthquake catalog uses the moment magnitude scale as the uniform measure of earthquake size. As part of the catalog development, assessments were performed to ensure consistency between conversions from intensity to moment magnitude and conversions from intensity to body-wave magnitude, and consistency between body-wave magnitude and moment magnitude.

L.4.4 Use of Verified Computer Programs

Two principal computer programs were used in the development of the earthquake catalog: EQCLUST, which was used to identify dependent earthquakes, and EQPARAM, which was used to estimate earthquake catalog completeness. Both programs were checked as part of the verification process of the EPRI-SOG set of computer programs (EPRI, 1988).

L.5 RECURRENCE ANALYSIS AND SPATIAL SMOOTHING

L.5.1 Introduction

The recurrence parameters (i.e., rate and *b*-value) were calculated using penalized-likelihood formulation that allows for spatial variation in the rate and *b*-value and also quantifies the uncertainty in these parameters. The methodology divides the source zones into cells of dimensions a quarter- or half-degree and then calculates the rate and *b*-value in each cell using the likelihood function of the data in that cell, together with penalty functions that tend to smooth the cell-to-cell variation in the rate or the *b*-value. In addition, this procedure characterizes epistemic uncertainty in the recurrence parameters by generating eight alternative maps of the recurrence parameters. The following is a partial list of the tests and confirmation steps that were performed to ensure that the methodology was adequate for the desired purpose and that it was properly implemented in the software.

L.5.2 Recurrence Comparisons at the Source-Zone Level

The recurrence comparisons presented in Sections 6.4.2 and 7.5.2 compare the cumulative earthquake counts over an entire source zone, as predicted by the methodology, to the corresponding counts as observed in the catalog. These comparisons provide a consistency check for the methodology and its implementation in the software because the penalized-likelihood formulation operates at the level of each individual cell without explicitly considering the total rates. These comparisons indicate a good match to the catalog, after taking into account the error bars introduced by the size of the catalog.

L.5.3 Recurrence Comparisons for Portions of a Source Zone

Similar comparisons were performed for interesting portions of certain source zones, as presented in Section 5.3.2.3. These comparisons also indicate a good match to the catalog at these smaller spatial scales, after taking into account the error bars introduced by the size of the catalog.

L.5.4 Examination of Recurrence Maps

Maps were generated for the mean rates and *b*-values and associated uncertainties, as well as for the eight realizations of the recurrence parameters for each zone. These maps are presented in Sections 6.4.2 and 7.5.2 and Appendix J. All maps were examined to verify that the recurrence parameters were reasonable.

L.5.5 Test with a Synthetic Catalog Homogeneous Seismicity

The purpose of this test was to confirm that the methodology does not interpret chance variations in activity as spatial variations in rate and/or *b*-value. A synthetic catalog was generated, under the assumption of a spatially homogeneous rate, a *b*-value of 1, Poisson occurrences, and independent earthquake locations. The rate and duration were selected so that the mean number of earthquakes per cell was comparable to that of the Midcontinent source zone (approximately one event for every three cells). Calculations were performed for one rectangular source zone of dimensions 5 degrees by 5 degrees (containing 100 half-degree cells), using objective smoothing and unit weights for all magnitude bins. The methodology produced homogeneous rates and *b*-values, and these values were consistent with those used to generate the synthetic catalog. This confirms that the spatial variations detected by the program are not due to chance variations resulting from the limited duration of the catalog.

L.5.6 Test for the Adequacy of Eight Maps to Represent Epistemic Uncertainty

The purpose of this test was to verify that the eight alternative maps provide an adequate representation of the epistemic uncertainty in recurrence parameters. Two separate sets of eight alternative maps were generated for the Northern Appalachian source zone using different values of the seed for the Latin hypercube randomization algorithm, and then hazard calculations were performed. The two sets of hazard calculations produced consistent results, demonstrating that the eight alternative maps provide an adequate representation of epistemic uncertainty in hazard.

L.6 HAZARD CALCULATION SOFTWARE

L.6.1 Introduction

Modifications were required to the software that had been previously qualified in accordance with Appendix B of 10 CFR 50; these modifications were necessary to accommodate new elements in the source characterization. The modifications were checked by performing a number of tests that exercise the modified features of the software. This was done by comparing the results obtained with the new feature to either the equivalent results obtained with the qualified features of the software or the results from independent calculations. A brief summary of these tests is provided below.

L.6.2 Test for the Treatment of Variable b

Calculations were performed for a source zone with variable *b* and for an equivalent problem where each cell is modeled as a separate source zone with constant rate and *b*. This test showed consistent results.

L.6.3 Test for the Treatment of Dipping Ruptures Within a Source Zone

Calculations were performed for a number of options regarding dip, orientation, and behavior at boundaries. These tests showed consistent results.

L.6.4 Tests for Treatment of Epistemic Uncertainty from Sources that Make Small Contribution to Hazard

For the sake of efficiency, a new approach was developed to introduce “pinch points” in the portion of the logic tree associated with sources that make small contributions to total hazard. This approach was tested by comparing fractiles hazard curves with and without this pinch point, showing consistent results.

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10. SUPPLEMENTARY NOTES

11. ABSTRACT *(200 words or less)*

This report describes a new seismic source characterization (SSC) model for the Central and Eastern United States (CEUS). It will replace the Seismic Hazard Methodology for the Central and Eastern United States, EPRI Report NP-4726 (July 1986) and the Seismic Hazard Characterization of 69 Nuclear Plant Sites East of the Rocky Mountains, Lawrence Livermore National Laboratory Model, (Bernreuter et al., 1989). The objective of the CEUS SSC Project is to develop a new seismic source model for the CEUS using a Senior Seismic Hazard Analysis Committee (SSHAC) Level 3 assessment process. The goal of the SSHAC process is to represent the center, body, and range of technically defensible interpretations of the available data, models, and methods. Input to a probabilistic seismic hazard analysis (PSHA) consists of both seismic source characterization and ground motion characterization. These two components are used to calculate probabilistic hazard results (or seismic hazard curves) at a particular site. This report provides a new seismic source model.

12. KEY WORDS/DESCRIPTORS *(List words or phrases that will assist researchers in locating the report.)*

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Seismic source characterization (SSC)
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