AGENDA
WORKSHOP 3: FEEDBACK
CENTRAL AND EASTERN UNITED STATES (CEUS) SEISMIC SOURCE CHARACTERIZATION (SSC) PROJECT

August 25-26, 2009
Electric Power Research Institute
3420 Hillview Ave.
STARR Auditorium
Palo Alto, California 94304

GOALS OF THE WORKSHOP: The goals of Workshop #3 are:

- To review the project SSHAC Level 3 methodology, ground rules, expert roles, and peer review processes
- To review the progress of the project in terms of meeting key milestones, such as the database development and earthquake catalog
- To review the processes being followed to attain the SSHAC goal of capturing the informed technical community
- To discuss the seismicity catalog developed for the CEUS SSC project
- To discuss the seismic source characteristics of the SSC sensitivity model
- To present feedback to the TI team and staff in the form of SSC sensitivity analyses and hazard sensitivity analyses
- To identify the key issues of most significance to the SSC models
- To discuss the analyses being conducted related to hazard significance
- To discuss the path forward for the CEUS SSC project

APPROACH: The goals of the workshop will be accomplished by a series of presentations and discussions designed to provide the TI team and staff with feedback that will allow them to understand the SSC issues of most significance to the hazard at seven representative demonstration sites. After introductory presentations, a discussion of SSHAC processes, and a discussion of the project seismicity catalog, the bulk of the workshop will entail: (1) Presentation and discussion of the seismic source sensitivity model (i.e., logic trees, etc.) for particular regions of interest, (2) Presentation and discussion of SSC sensitivity for various elements of the model, and (3) Presentation and discussion of hazard sensitivity to various elements of the sensitivity model. This will be repeated for all of the regions of interest within the CEUS. The focus of this workshop will be the TI team and staff and significant time will be allocated for discussion.

Time	Topic	Presenter
TUESDAY AUGUST 25, 2009		
9:00 – 9:05	Welcome Opening Remarks	Rahn, Frank
9:05 – 9:15	Purpose of workshop and ground rules	Coppersmith, Kevin
9:15 – 9:30	Progress in meeting project milestones	Salomone, Larry
9:30 – 10:30	Processes to attain the SSHAC goal of capturing the informed technical community	Coppersmith, Kevin
10:30 – 10:45	**Break**	
10:45 – 12:00	Development of the CEUS SSC project	Youngs, Bob

	earthquake catalog	
12:00 – 1:00	**Lunch**	
1:00 – 3:00	**Presentations and Discussions of the CEUS SSC Sensitivity Model:** (1) Elements of the sensitivity model within regions of interest (2) SSC sensitivity analyses (3) Hazard sensitivity analyses for demonstration sites	B. Youngs (supported by TI Team and Staff) R. McGuire, G. Toro
3:00 – 3:30	**Break**	
3:30 – 5:00	Presentations and Discussions of the CEUS SSC Sensitivity Model (continued)	
WEDNESDAY AUGUST 26, 2009		
8:30 – 10:00	Presentations and Discussions of the CEUS SSC Sensitivity Model (continued)	
10:00 – 10:15	**Break**	
10:15 – 12:00	Presentations and Discussions of the CEUS SSC Sensitivity Model (continued)	
12:00 – 1:00	**Lunch**	
1:00 –2:00	Presentations and Discussions of the CEUS SSC Sensitivity Model (continued)	
2:00 – 3:00	Significance of hazard	R. McGuire
3:00 – 3:30	Path Forward on CEUS SSC	K. Coppersmith
3:30 – 3:35	Closing Remarks	L. Salomone
3:35 – 4:30	PPRP Caucus	PPRP
4:30 – 5:00	PPRP Feedback to TI Team and Staff	PPRP/Sponsor Reviewers/TI Team and Staff/PM
5:00	**Adjourn**	

Development of CEUS Seismic Source Characterization Model

Workshop #3 Status and Overview
August 25-26, 2009

Lawrence Salomone
Project Manager

Savannah River
Nuclear Solutions, LLC
A Fluor Daniel Partnership

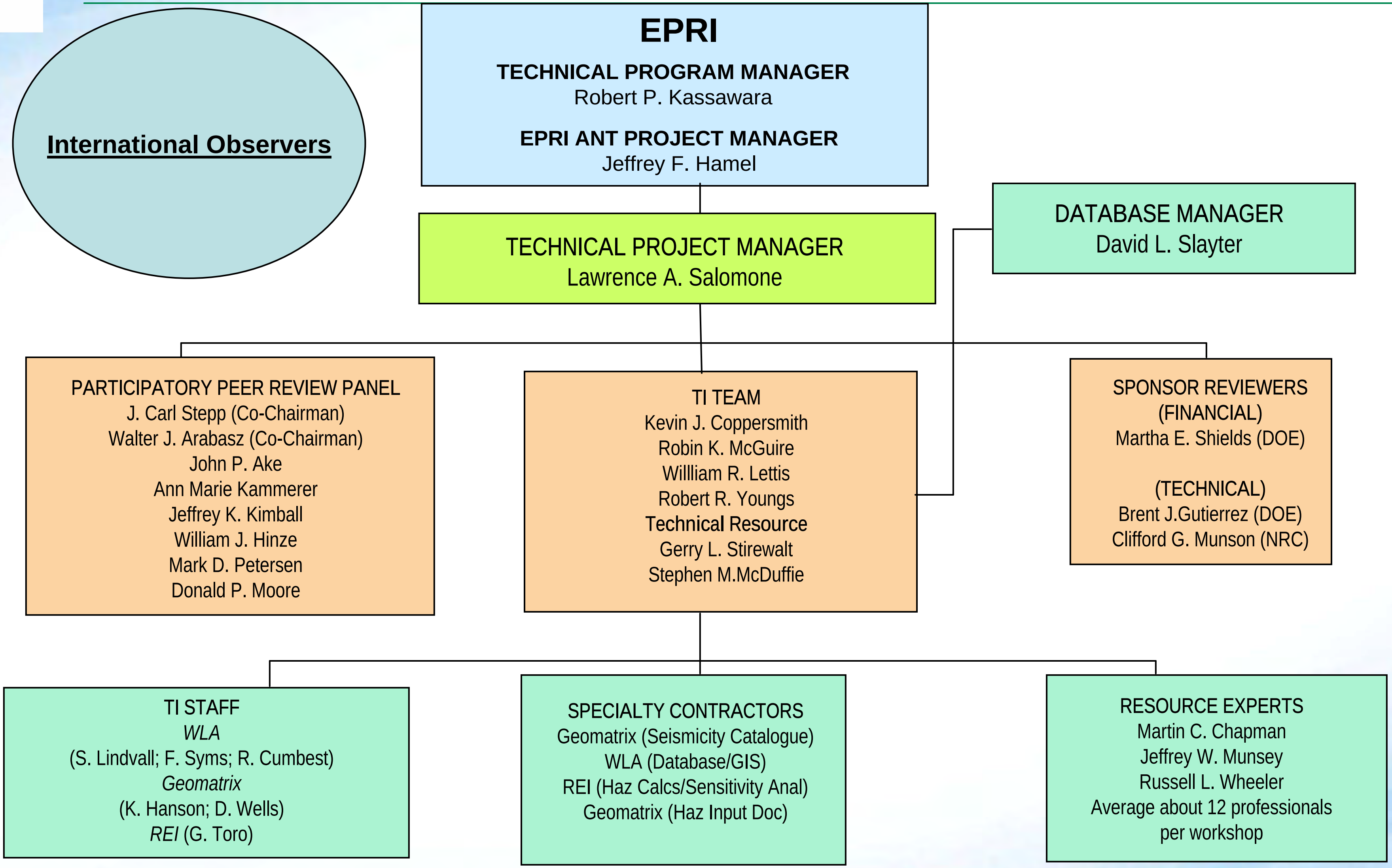
Project Goals

- Replace the EPRI (1989) and LLNL (1993) seismic source characterization models for the CEUS.

- Capture the knowledge and uncertainties of the informed scientific community using the SSHAC process.

- Provide an up-to-date, consistent, stable input, that has been vetted by multiple stakeholders, for a site-specific probabilistic seismic hazard assessment (PSHA) for locations in the Central and Eastern United States (CEUS)

Organization Chart



International Observers

EPRI

TECHNICAL PROGRAM MANAGER
Robert P. Kassawara

EPRI ANT PROJECT MANAGER
Jeffrey F. Hamel

DATABASE MANAGER
David L. Slayter

TECHNICAL PROJECT MANAGER
Lawrence A. Salomone

PARTICIPATORY PEER REVIEW PANEL
J. Carl Stepp (Co-Chairman)
Walter J. Arabasz (Co-Chairman)
John P. Ake
Ann Marie Kammerer
Jeffrey K. Kimball
William J. Hinze
Mark D. Petersen
Donald P. Moore

TI TEAM
Kevin J. Coppersmith
Robin K. McGuire
Willliam R. Lettis
Robert R. Youngs
Technical Resource
Gerry L. Stirewalt
Stephen M.McDuffie

SPONSOR REVIEWERS
(FINANCIAL)
Martha E. Shields (DOE)

(TECHNICAL)
Brent J.Gutierrez (DOE)
Clifford G. Munson (NRC)

TI STAFF
WLA
(S. Lindvall; F. Syms; R. Cumbest)
Geomatrix
(K. Hanson; D. Wells)
REI (G. Toro)

SPECIALTY CONTRACTORS
Geomatrix (Seismicity Catalogue)
WLA (Database/GIS)
REI (Haz Calcs/Sensitivity Anal)
Geomatrix (Haz Input Doc)

RESOURCE EXPERTS
Martin C. Chapman
Jeffrey W. Munsey
Russell L. Wheeler
Average about 12 professionals
per workshop

CEUS SSC Study Area and Test Sites

Seismic Source Characterization (SSC) Model - Project Milestones

- Project Plan as EPRI Technical Update – June, 2008 (Completed)
- Workshop #1: Significant Issues and Databases – July 21-23, 2008 (Completed)
- Workshop #2: Alternative Interpretations – February 18-20, 2009 (Completed)
- Complete Database and Seismicity Catalog Development – June 30, 2009 (Completed)
- Workshop #3: Feedback on Preliminary CEUS SSC Model – August 25-26, 2009
- Complete Hazard Input Document (HID) for Preliminary CEUS SSC model – February 26, 2010
- Construct Final CEUS SSC Model – April 30, 2010
- Prepare Draft Technical Report and Perform Other Report Preparation Tasks– July 31, 2010 to December 31, 2010
    - Review of Draft Report by PPRP
    - Incorporate Review Comments
    - Review project documentation for transparency
    - Prepare internal documentation package to document computer codes and archive hazard calculations
    - Obtain copyright releases for GIS database as required
- Publish Final Technical Report – December 31, 2010

Participatory Peer Review Panel (PPRP) Communications

- Tracking Milestones (PM Tool to Assess Project Progress)

- Six Conference Calls Prior to Workshop #2

- Other Conference Calls and Meetings with PPRP as needed

- Six Working Meetings (PPRP member can be invited to serve as a Resource Expert)

- Meeting and Conference Call following each Workshop:
  - PPRP Comment Letter
  - TI Team and Project Manager Response to PPRP Comment Letter
  - Meeting with PPRP to discuss preliminary seismic source characterization model (May 13, 2009)

PPRP Communications

- Intermediate Documents for PPRP:
  - Process to document TI response to PPRP comment letter – September 30, 2008
  - Criteria and Timeline for identifying demonstration sites:
    - Draft sites – October 1, 2008
    - Final sites following PPRP review – November 15, 2008
    - Sensitivity Analyses – August, 2009
  - Working Plan for conducting CEUS SSC assessments
  - Map of seismic reflection lines in GIS database
  - Sensitivity analyses from Workshop #1
  - List of candidate proponents/resource experts and Agenda for Workshop #2 for PPRP review
  - Specialized tools for SSC
  - Workshop #2 List of Participants
  - Workshop #2 and Workshop #3 Agendas
  - Background Information Prior to May 13, 2009 meeting and Workshop #3
  - Expanded Schedule
  - Seismicity Catalog and Text, Logic Trees and Tables 2 and 3
- FTP Site for PPRP and CEUS SSC Team Access to Project Information

Technical Developments

☐ Tectonic Framework - Criteria for Identifying Seismic Sources Being Developed

☐ Review of Seismic Source Characterization Models Developed for Regions of Interest:

- New Madrid, Wabash Valley, Oklahoma Aulocogen, Alabama-Louisiana-Mississippi-Paleoseismic Zone (ALM), Midwest/Mid-Continent, Charleston
- Southeast/East Tennessee, Northeastern U.S., Gulf Coast, Rio Grande Rift

☐ Review of Alternative Mmax Approaches

☐ Review of Approach to Characterize “Background” Zones

☐ Develop New Seismicity Catalog Based on Moment Magnitude

Status

- Completed tasks
  - Project Plan
  - Initial Funding
  - Government Funding Schedule for Balance of Project
  - Funding for Workshop #1 Additional Tasks and Items
  - USGS Agreement on Project Participation
  - Five (5) TI Team and Staff Working Meetings
  - Workshop #1
  - Workshop #2
  - CDs documenting Workshop #1 and Workshop #2 Proceedings
  - Reference Lists from Workshop #2 Proponents and Resource Experts
  - May 13, 2009 PPRP Meeting to discuss preliminary CEUS SSC model
  - Initial Database Compilation
  - Seismicity Catalog and Text Under External and PPRP Review

- On Track to Meet Target Completion Date (2010)

Tracking Milestones

- Working Conference Call – August 31, 2009
- Distribute Workshop #3 CD - October 15, 2009
- Working Meeting #6 – October 20-21, 2009
- Task 2.1 – Reprocessing Gravity Data – December 31, 2009
- Task 2.2 – Magnetic Field Compilation and Processing – December 31, 2009?
- Task 2.3 – Initial Results for Priority Study Areas and TI and Staff Guidance in Paleoliquefaction Task – December 31, 2009
- Task 2.4 – Update Current World Stress Map – October 30, 2009
- USGS Feedback on CEUS SSC Sensitivity Model – December 31, 2009?
- Working Meeting #7 – January 12-13, 2010
- PPRP Briefing with USGS representatives to review preliminary CEUS SSC model – March 3, 2010?
- Task 2.3 – Paleoliquefaction Task Report – June 15, 2010

Purpose of Workshop and Ground Rules

Kevin J. Coppersmith
CEUS SSC Workshop #3 Feedback
EPRI, Palo Alto, CA
25-26 August 2009

SSHAC Basic Principles for a PSHA

- Principle 1: The goal of a PSHA is "*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*"
  - Focuses experts on the larger purpose of the PSHA and on the critical importance of their role as scientific evaluators of processes and models, given available data
  - Experts must abandon all proponent bias – personal and peer
- Termed the "informed technical community" (ITC)

SSHAC Expert Roles

- *Evaluator*: an expert capable of evaluating the relative credibility of multiple alternative hypotheses to explain the observations
- To evaluate the alternatives, the evaluator:
  - <u>Considers</u> the available data
  - <u>Listens</u> to proponents and other evaluators
  - <u>Questions</u> the technical basis for their conclusions
  - <u>Challenges</u> the proponents' position
  - Interacts with other experts in workshops, to understand basis for their assessments
  - Considers feedback regarding the implications of assessments
  - Interacts with hazard analyst to ensure assessments are properly modeled for the PSHA computations
  - Documents the basis for assessments

SSHAC Expert Roles (continued)

- *Proponent*: an expert who advocates a particular hypothesis or technical position
- Common role in science
- Peer review in professional debates and literature
- Ideas either gain support or fade with time

SSHAC Expert Roles (continued)

- *Technical Integrator* [Level 3]: team that serves as evaluators for the technical assessments
- Structures and documents information exchanges
- Stages effective debates and interactions in critical areas
- Responsible as integrators for capturing views of larger technical community and considering them in the evaluation process
- Responsible for documentation

CEUS SSC Task Schedule

Task	Schedule
Database Development	April 2008 – July 2009
Seismicity Catalog	April 2008 – July 2009
Assessment of Hazard-Significant Issues	April - July 2008
Workshop 1 Significant Issues and Databases	July 2008
Workshop 2 Alternative Interpretations	February 18-20 2009
Construct Sensitivity SSC Model	December 2008 – Aug 2009
Develop Hazard Input Document and SSC Sensitivity Analyses	May – June 2009
Perform Preliminary Hazard Calculations and Sensitivity Analyses	June – August 2009
Workshop 3 Feedback	August 25-26 2009
Complete Preliminary SSC Model	February 2010
Finalize SSC Model	April 2010
Document CEUS SSC Project in Draft Report	July 2010
Review of Draft Report by PPRP and Others	August 2010
Finalize and Issue CEUS SSC report	December 2010
Meeting with NRC and DNFSB	1st Quarter 2011

Ground Rules for Workshop

- Workshops are an opportunity for the TI Team and Staff to:
  - Exchange data
  - Understand viewpoints of technical community
  - Challenge and defend technical hypotheses
  - Gain information on the project
  - Interact and ask questions
- Therefore, the focus of this workshop is the TI Team.

Ground Rules for Workshops

(continued)

- Conduct of the technical discussions at the workshops will be at the highest professional level.
- Discussions will be primarily among the TI team and the presenters; all others will be considered observers
- Observers will be provided with opportunities for questions and comments, as the schedule allows
- The TI team runs the workshop and is responsible for keeping to the schedule, logistics, etc.

Workshop 3 Feedback
Goals of the Workshop

- To review the project SSHAC Level 3 methodology, ground rules, expert roles, and peer review processes
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- To review the processes being followed to attain the SSHAC goal of capturing the informed technical community
- To discuss the seismicity catalog developed for the CEUS SSC project

Workshop 3 Feedback
Goals of the Workshop (continued)

- To present feedback to the TI team and staff in the form of SSC sensitivity analyses and hazard sensitivity analyses
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Workshop #3 Feedback
Workshop Process

- TI team has developed a sensitivity SSC model that is complete in that it captures the range of views in the technical community
- Data evaluation process has been conducted with focus on identifying and evaluating the data, models, and methods that have credibility
    - Data evaluation and data summary tables have been developed *in draft form* to assist in developing the sensitivity SSC model
    - Tables are incomplete and subject to revision
- TI Team and Staff are anxious to see the sensitivity and relative importance of elements of their evaluations

Workshop #3 Feedback
Workshop Process (continued)

- Format has been designed to ensure maximum focus and discussion on sensitivity results
- Streamlined summary of the master logic tree and elements of the model
  - TI Team and Staff are ready to respond to questions regarding technical bases for assessments
  - Data evaluation and data summary tables have been provided to the PPRP as a framework for the model
- SSC sensitivity analyses presented to understand importance to intermediate assessments
- Hazard sensitivity analyses presented and discussed for demonstration sites
- Purpose is to understand the potentially important elements of the SSC model and to prioritize the subsequent work to develop the full preliminary SSC model
- Additional sensitivity studies may be identified during the course of the discussions

SSHAC Goal of Capturing the Informed Technical Community

Kevin Coppersmith, TI Lead
WS-3 CEUS SSC Project
Palo Alto, CA
August 25, 2009

Overview of Talk

- Historical context to expert assessments and treatment of uncertainties, leading to SSHAC
- SSHAC concept of integration: capturing views of informed technical community (ITC)
- Steps being taken in CEUS SSC project to assure ITC has been captured
- Proposed standard of proof that goal has been achieved

Historical Context

- Increasing recognition of importance of uncertainties
  - “Increases” in hazard from early studies often related to treatment of uncertainties/variability
    - “Although several factors may contribute to the higher estimates of seismic hazard in modern studies, the main reason for these increases is that in the earlier studies the ground-motion variability was either completely neglected or treated in a way that artificially reduced its influence on the hazard estimates.” (Bommer and Abrahamson, 2006)
  - Probabilistic hazard is important to risk analysis and uncertainties are important to hazard

Historical Context (continued)

- Early probabilistic risk studies began the use of expert judgment as basis for making assessments
  - Regulatory processes have long looked to considering all sides of issues for regulatory stability (e.g., independent parallel studies, intervention)
  - Range of views in expert community believed to provide more stable estimates
  - Fragility parameters elicited from panels of experts, given set of stated assumptions
  - Began the concern regarding expert issues:
    - Representativeness, independence, consensus, aggregation

Historical Context (continued)

- Parallel studies conducted to assess hazard at CEUS NPP sites: EPRI-SOG, LLNL
  - Shared concern for uncertainty treatment
  - Differed in processes for conducting the study
  - Differed in calculated mean hazard
  - Highlighted importance of process, as well as uncertainties
- Ground motion component of LLNL study highlighted the issues associated with expert panel make-up and dynamics
  - Single outlier expert drives mean hazard (1 of 5)
  - Panels may not work well if consist of proponents
  - How aggregate when not representative of larger community?

Historical Context (continued)

- SSHAC charge included finding a scheme that does not allow an outlier to unreasonably drive the mean, and does not suffer from classic sampling problems of experts:
  - Non-random samples
  - Unevenly informed experts
  - Different expert motivations
  - Ownership of individual and aggregate results
- Probabilistic analyses typically conducted in framework of contentious, regulatory processes where differing views are highlighted
  - Decisions must be made in face of uncertainty
  - Resources are not unlimited
  - Dynamic between involving large numbers from technical community and resource requirements

Mechanical vs. Behavioral Aggregation of Expert Judgments

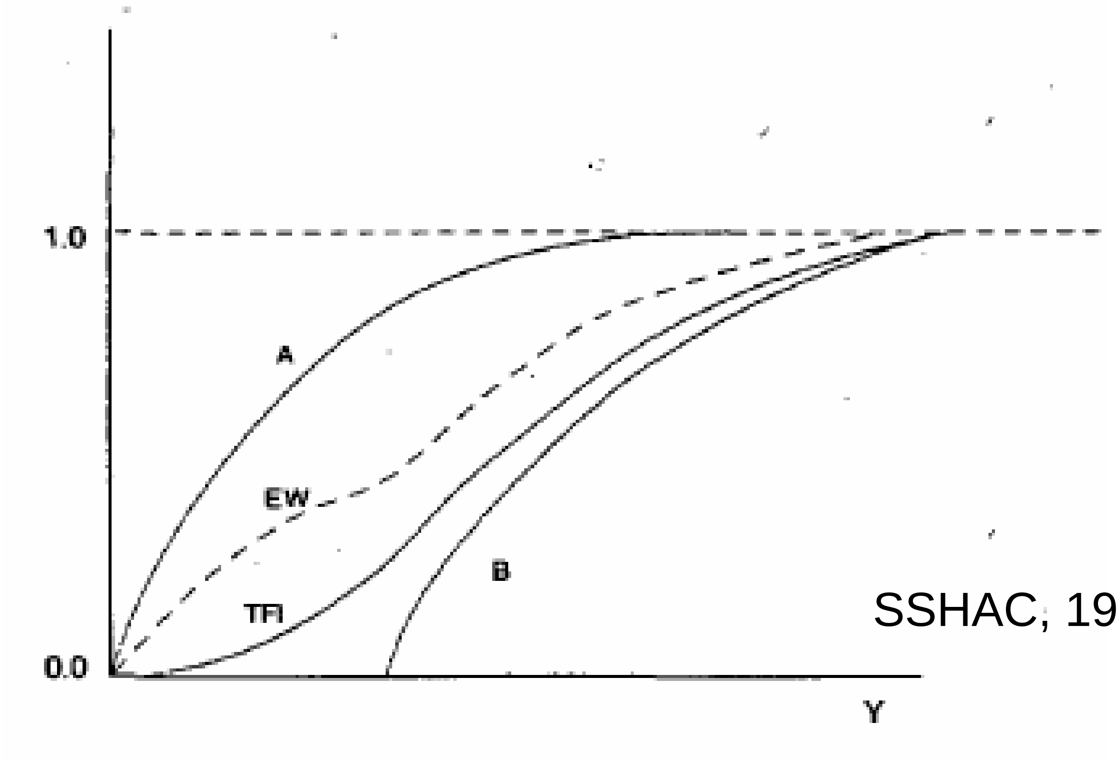


Figure 3-2 An Example of Behavioral Aggregation

SSHAC, 1997, p. 40

- SSHAC: Allows TFI weighing versus weighting to deal with obvious problems in “rare” situations
- Endorsement of behavioral aggregation: interaction

Historical Context (continued)

- SSHAC: Expert issues dealt with by establishing and defining two important activities:
  - Evaluation
    - Identification of important issues and applicable data
    - Interaction among experts
    - Consideration and weighting of proponent viewpoints
  - Integration
    - Represent the informed technical community
    - Use expert assessments but consider rest of community

Historical Context (continued)

SSHAC defines several key concepts and roles:

- Expert roles
    - Evaluator expert
    - Resource expert
    - Proponent expert
    - Normative expert
- Technical integrator
- Technical facilitator/integrator

Integration

- New concept: represent the views of the ***informed technical community***
  - "Regardless of the scale of the PSHA study, the goal remains the same: to represent 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]
- Informed:
  - Familiar with site-specific databases
  - Have been through the same interactive process
- Not just aggregation process for parameter values across a panel of experts
  - Very few parameters can be directly assessed in PSHA
  - Need to evaluate data, develop models, quantify uncertainties in conceptual models
  - Consensus required only that composite (community distribution) is appropriate

Integration (continued)

- Views of informed technical community are *hypothetical* because:
  1) Only a subset of community know site-specific data, and
  2) Have gone through interactive process
  - Conducted by both TFI and experts (Level 4) and entire TI team (Level 3), not just the project lead
  - SSHAC calls for two-step process to emphasize the importance of experts assisting in the process
  - In practice, the two steps are not distinct: preliminary assessments prior to feedback and post-feedback finalization

Integration (continued)

- Consider just: Represent the *larger technical community* (no “informed”)
  - Many issues are site-specific and community has no detailed knowledge
  - Structured interactive process of challenge and defense leads to clearer understanding of uncertainties
  - Community doesn’t evaluate or weight alternative models; proponents are the norm
  - Places focus on the manner in which the subset of experts are sampled, other expert issues

Integration (continued)

- Despite being hypothetical, more valuable to consider the *informed* community
- “Liberating concept” because places emphasis on center, body, and range of views
  - Broadens ownership to entire TI team
  - Increases assurance that uncertainties have been captured
  - Can be peer reviewed by those with comparable knowledge of the community

Steps Taken in CEUS SSC to Assure the ITC Been Captured

- All participants understood their roles and agreed to abide by them within the framework of a SSHAC process
  - TI team and staff members understand their roles as evaluators and to serve as integrators that capture the views of the ITC.
  - PPRP also aware of their need to review both the process and technical aspects
- TI team and Staff have extensive experience in SSC for the CEUS
  - First-hand knowledge of datasets and their specific application in SSC
  - Understanding of all uncertainty tools, and their use in capturing the ITC
  - Within team, experience in both process aspects and technical aspects
  - Network of establishing contacts in technical community such that aware of ongoing work (e.g., paleoliquefaction, SSHAC implementation guidance, Mmax workshop)
  - TI team and staff includes both SSC evaluators and hazard analysts, thus identifying the most significant issues, and maintaining a focus on those issues throughout the project

Steps Taken in CEUS SSC to Assure the ITC Been Captured (continued)

- Instituted more explicit data evaluation processes to demonstrate thorough awareness of all applicable data
  - Document the evaluation of the quality of the data, their usefulness, and the degree of reliance for the SSC modeling
  - Valuable for future to show what data were considered and the current state at the time the evaluations were conducted
- First two workshops provided key opportunities to provide first-hand information and viewpoints of the technical community
  - WS1: Identified the key issues of importance to the PSHA (most are well-known to the TI team based on numerous hazard studies)
  - Identified a variety of datasets and resource experts provided descriptions of their data and their uncertainties.
  - Followed with each resource expert providing lists of references as follow-up to provide another mechanism to ensure that all applicable data have been identified

Steps Taken in CEUS SSC to Assure the ITC Been Captured (continued)

- WS2: Focused on alternative viewpoints and proponent experts
  - Proponents present their models
  - TI team and staff ask questions, hear the issues related to uncertainties, juxtapose alternative viewpoints, and have the experts themselves respond to questions from their counterparts.
  - Prior to the workshop, the TI team and staff developed several expert-specific questions focused on uncertainties and implications to seismic source characteristics

Steps Taken in CEUS SSC to Assure the ITC Been Captured (continued)

- The interactive workshop process has been proven to be a highly effective mechanism for identifying all available data and models that presently exist or are under development within the technical community
  - Members of TI team have conducted such workshops for several projects and have participated as evaluators
  - PPRP has extensive experience in technical and process issues
    - Provide advice on potentially significant issues and databases that might address those issues
    - Has a hazard focus because of the wide range of seemingly applicable data
    - Experience with the evaluation process; to understand the uncertainty quantification process, the need to capture both aleatory and epistemic uncertainties, and the knowledge to know the difference

Steps Taken in CEUS SSC to Assure the ITC Been Captured (continued)

- TI Team and Staff have experience with the integration process and how a small subset of the technical community can imagine the positions of the community if they had gone through the same process
- WS3: Feedback workshop and processes
  - Complete sensitivity model developed
  - Representative sites for evaluating relative importance of components of model
  - Feedback will focus efforts over ensuing months on developing complete preliminary model
- USGS review
  - Charged with keeping current with available data and implications to SSC and hazard issues
  - Provides another opportunity to identify data or models that exist within the community

Steps Taken in CEUS SSC to Assure the ITC Been Captured (continued)

- PPRP review of preliminary model to ensure all applicable data, models, and methods have been considered
- PPRP review of draft project report to ensure the ITC has been documented

- Bottom Line: *CEUS SSC project has put in place process steps that will assure that the ITC data, models, and methods have been considered by the TI Team and Staff.*

Case History

- Trace a viewpoint from the technical community through the CEUS SSC process
- To illustrate the consideration by the TI Team and Staff
- Evaluation and integration process is still underway and will be until the final SSC model is complete

Geodetic Data for Lack of Deformation

Science 13 March 2009:
Vol. 323. no. 5920, p. 1442
DOI: 10.1126/science.1168122

Time-Variable Deformation in the New Madrid Seismic Zone

Eric Calais[1] and Seth Stein[2]

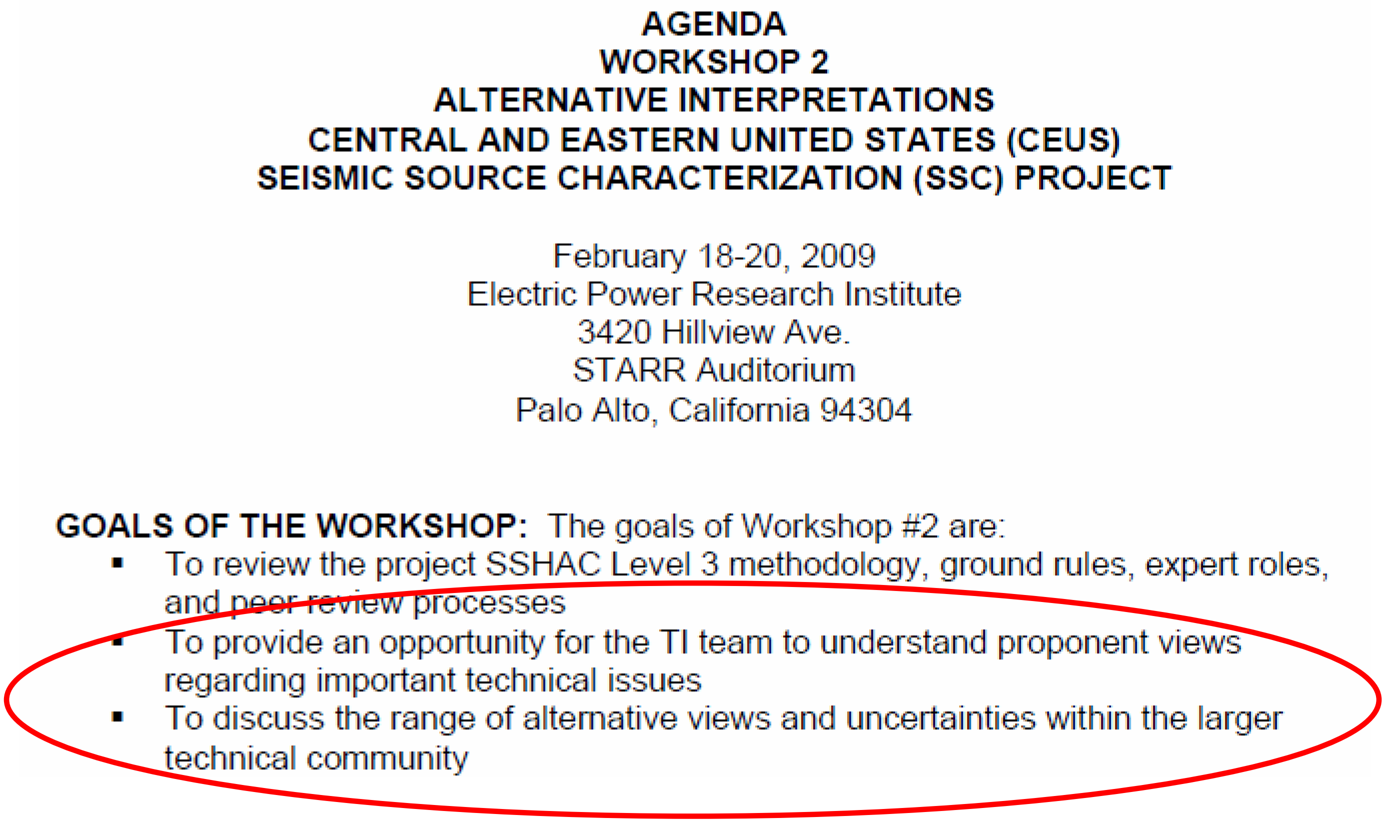
New geodetic measurements show that the New Madrid is currently deforming too slowly, if at all, to account for large earthquakes in the region over the past 5000 years. This result, together with increasing evidence for temporal clustering and spatial migration of earthquake sequences in continental interiors, indicates that either tectonic loading rates or fault properties vary over a few thousand years.

[1] Department of Earth and Atmospheric Sciences, Purdue University, West Lafayette, IN 47906, USA.
[2] Department of Earth and Planetary Sciences, Northwestern University, Evanston, IL 60208, USA.

Model of Episodic and Temporally Migrating Seismicity

- “A special complexity is that the seismicity is likely to be a transient phenomenon that migrates among many similar fossil weak zones. In many cases, it appears that continental intraplate faults have episodic seismicity separated by quiescent periods (Crone *et al. 2003;* Camelbeeck *et al. 2007; Leonard et al. 2007).* In particular, the NMSZ seems to have become active in the past few thousand years (Schweig and Ellis 1994), perhaps in a recent cluster of large earthquakes (Holbrook *et al. 2006)* that may be ending (Newman *et al. 1999; Stein and Newman 2004; McKenna et al.* 2007). This effect is not described by either time-independent or time-dependent models, both of which assume that the large earthquakes will continue as they have in the past thousand years. If the cluster is ending, the hazard would be much lower than either model predicts.”

(Hebden and Stein, 2008)

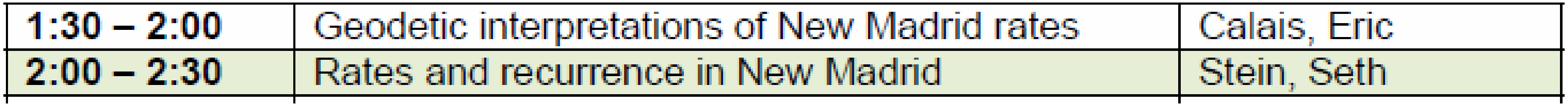


AGENDA
WORKSHOP 2
ALTERNATIVE INTERPRETATIONS
CENTRAL AND EASTERN UNITED STATES (CEUS)
SEISMIC SOURCE CHARACTERIZATION (SSC) PROJECT

February 18-20, 2009
Electric Power Research Institute
3420 Hillview Ave.
STARR Auditorium
Palo Alto, California 94304

GOALS OF THE WORKSHOP: The goals of Workshop #2 are:

- To review the project SSHAC Level 3 methodology, ground rules, expert roles, and peer review processes
- To provide an opportunity for the TI team to understand proponent views regarding important technical issues
- To discuss the range of alternative views and uncertainties within the larger technical community

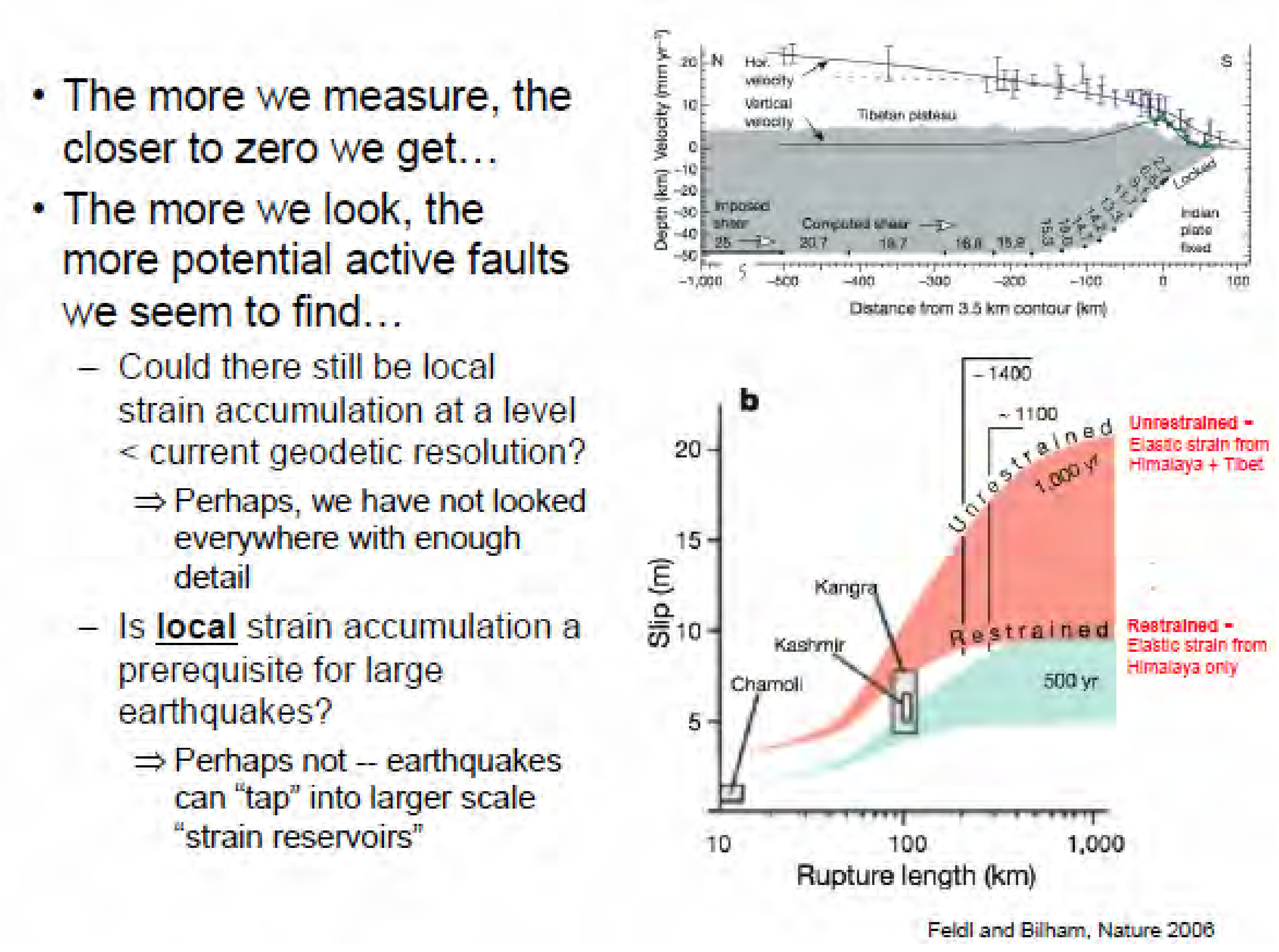


1:30 – 2:00	Geodetic interpretations of New Madrid rates	Calais, Eric
2:00 – 2:30	Rates and recurrence in New Madrid	Stein, Seth

Geodetic interpretations of New Madrid rates	Calais, Eric	•What is your confidence that observed geodetic rates reflect long-term tectonic deformation rates or short term seismicity pattern and rates? •What weight would you give geodetic vs seismicity in establishing rate of EQ occurrence? •Do current data allow one to discern tectonic rates from measurement uncertainties?
Rates and recurrence in New Madrid	Stein, Seth	•What is the relationship between geodetic deformation and earthquake occurrence? •Have you compared the geodetic signature of other zones of seismicity in stable continental regions? •Is the absence of evidence for geodetic deformation a definitive indicator of future earthquake potential?


EXIT

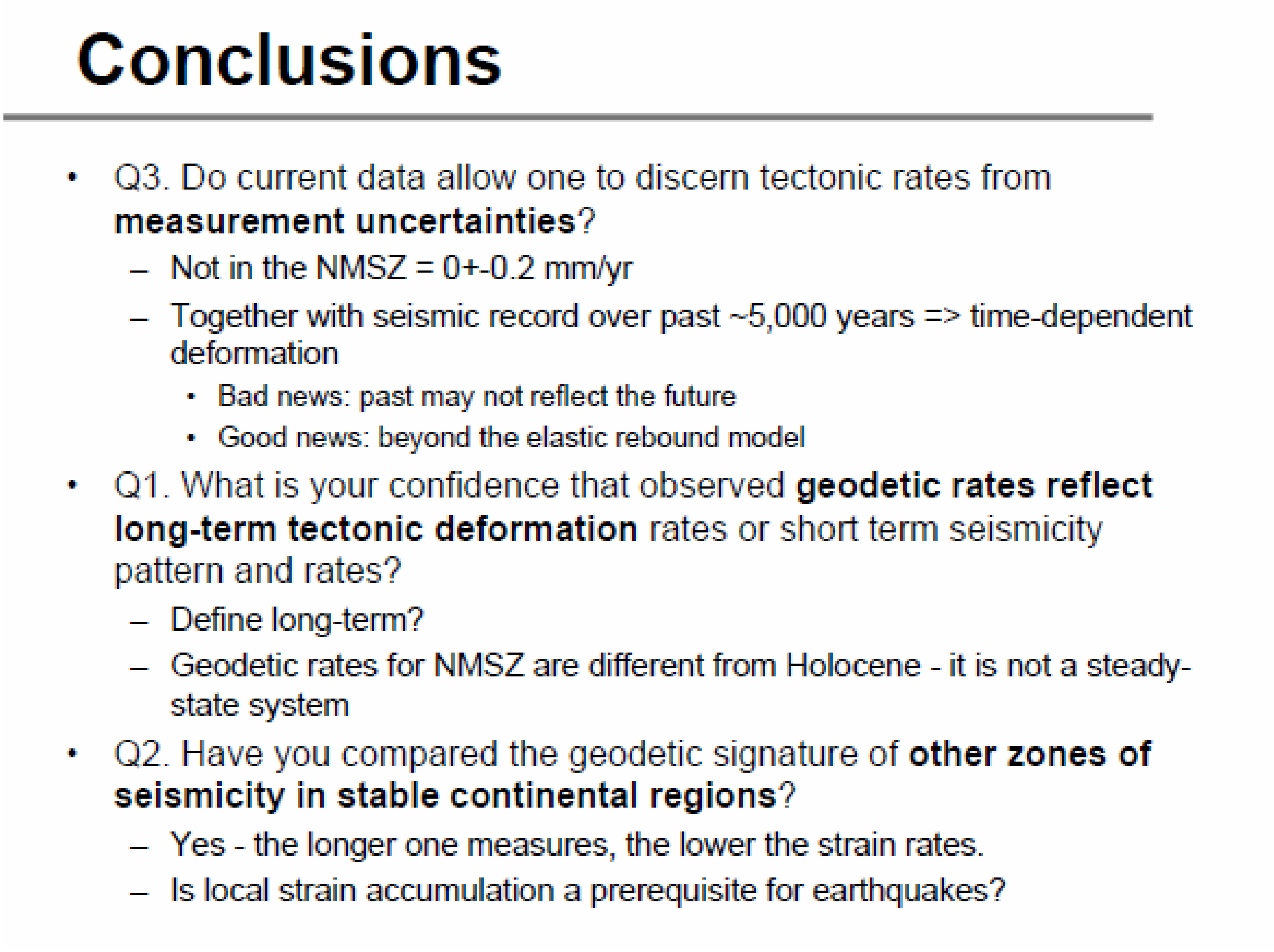
Presentation by E. Calais
CEUS SSC WS2



- The more we measure, the closer to zero we get…
- The more we look, the more potential active faults we seem to find…
  - Could there still be local strain accumulation at a level < current geodetic resolution?
    - ⇒ Perhaps, we have not looked everywhere with enough detail
  - Is **local** strain accumulation a prerequisite for large earthquakes?
    - ⇒ Perhaps not -- earthquakes can "tap" into larger scale "strain reservoirs"

Feldl and Bilham, Nature 2006

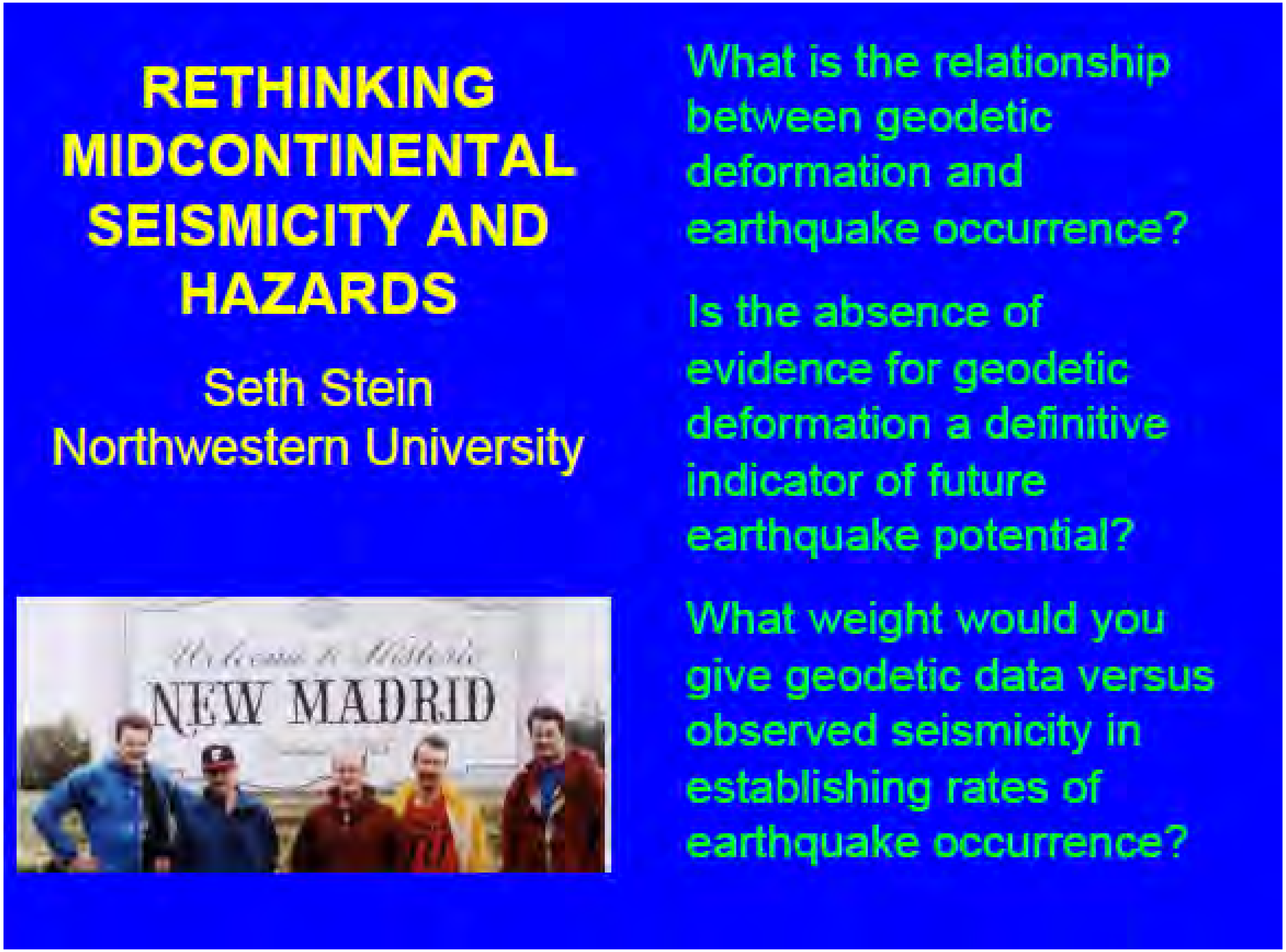
Presentation by E. Calais
CEUS SSC WS2



Conclusions

- Q3. Do current data allow one to discern tectonic rates from **measurement uncertainties**?
  - Not in the NMSZ = 0+-0.2 mm/yr
  - Together with seismic record over past ~5,000 years => time-dependent deformation
    - Bad news: past may not reflect the future
    - Good news: beyond the elastic rebound model
- Q1. What is your confidence that observed **geodetic rates reflect long-term tectonic deformation** rates or short term seismicity pattern and rates?
  - Define long-term?
  - Geodetic rates for NMSZ are different from Holocene - it is not a steady-state system
- Q2. Have you compared the geodetic signature of **other zones of seismicity in stable continental regions**?
  - Yes - the longer one measures, the lower the strain rates.
  - Is local strain accumulation a prerequisite for earthquakes?

Presentation by S. Stein
CEUS SSC WS2



RETHINKING MIDCONTINENTAL SEISMICITY AND HAZARDS

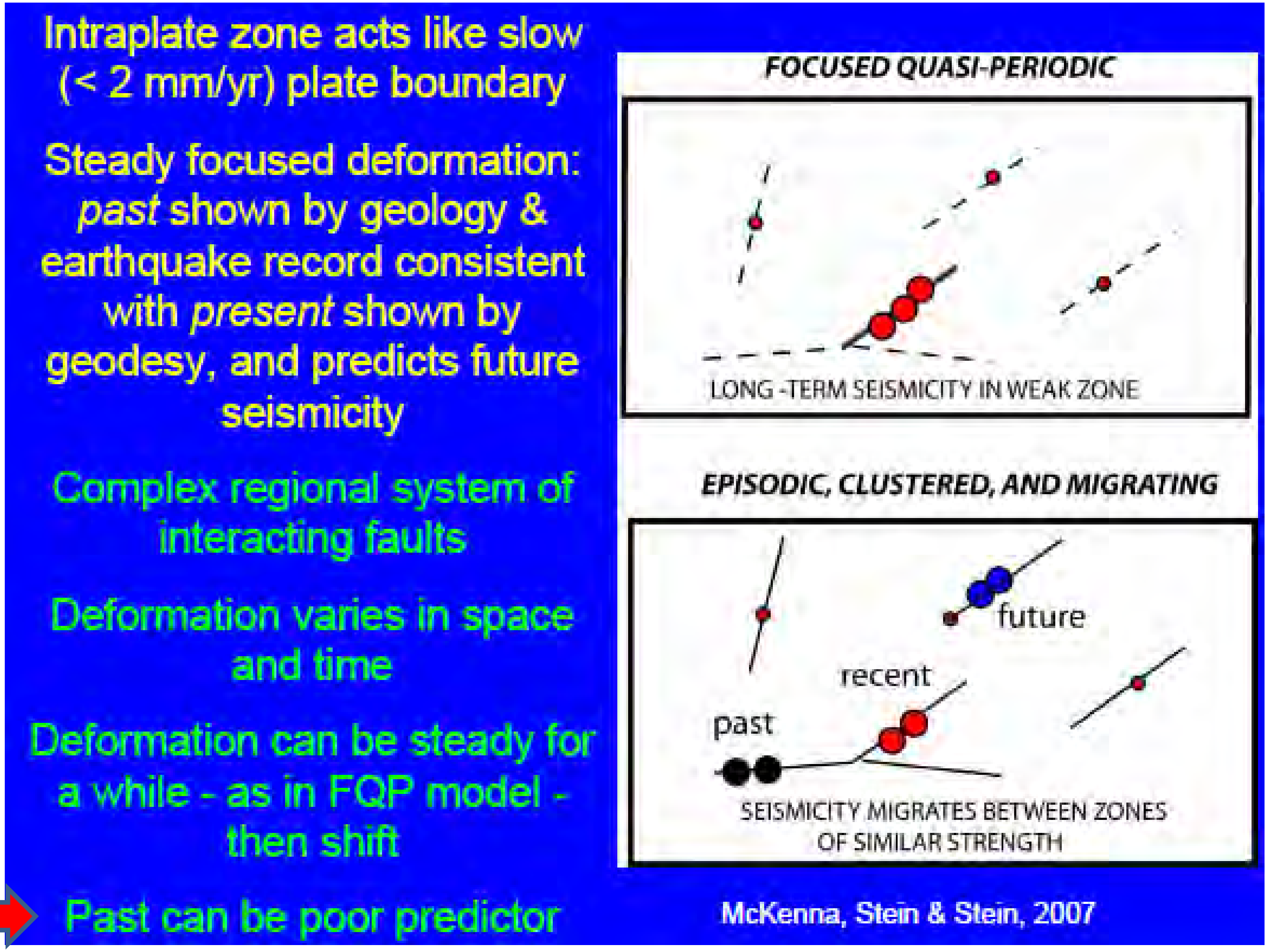
Seth Stein
Northwestern University

What is the relationship between geodetic deformation and earthquake occurrence?

Is the absence of evidence for geodetic deformation a definitive indicator of future earthquake potential?

What weight would you give geodetic data versus observed seismicity in establishing rates of earthquake occurrence?

Presentation by S. Stein
CEUS SSC WS2



Intraplate zone acts like slow (< 2 mm/yr) plate boundary

Steady focused deformation: *past* shown by geology & earthquake record consistent with *present* shown by geodesy, and predicts future seismicity

Complex regional system of interacting faults

Deformation varies in space and time

Deformation can be steady for a while - as in FQP model - then shift

Past can be poor predictor

FOCUSED QUASI-PERIODIC

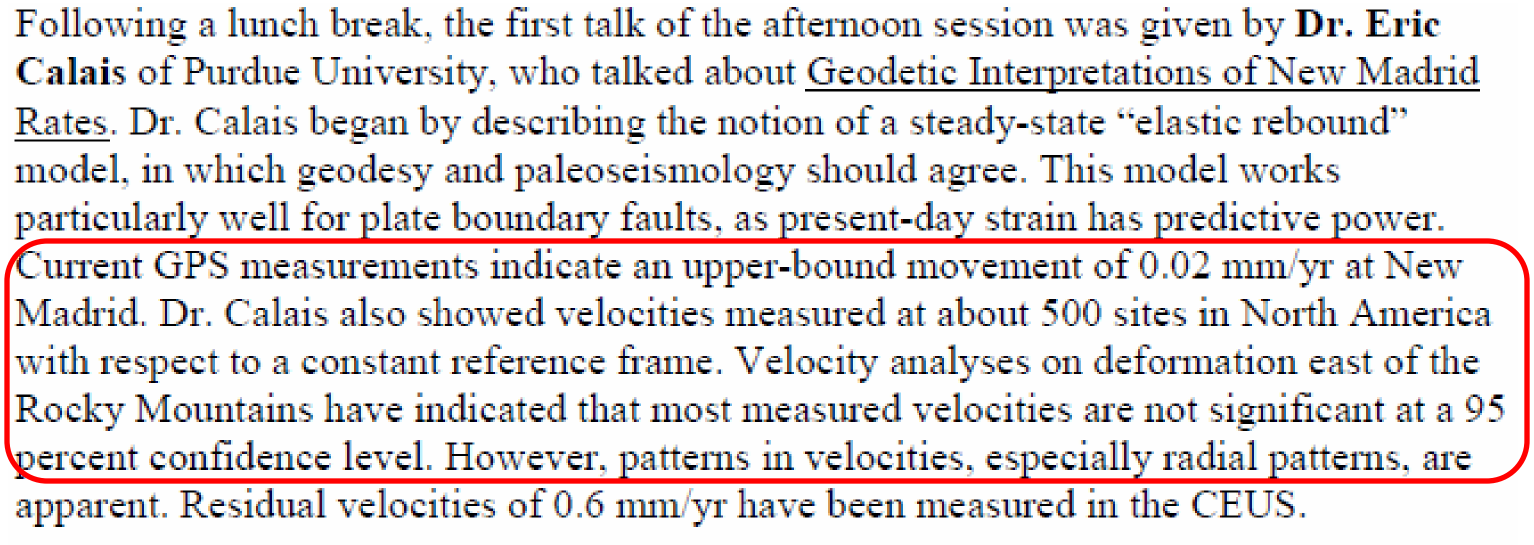
LONG -TERM SEISMICITY IN WEAK ZONE

EPISODIC, CLUSTERED, AND MIGRATING

SEISMICITY MIGRATES BETWEEN ZONES OF SIMILAR STRENGTH

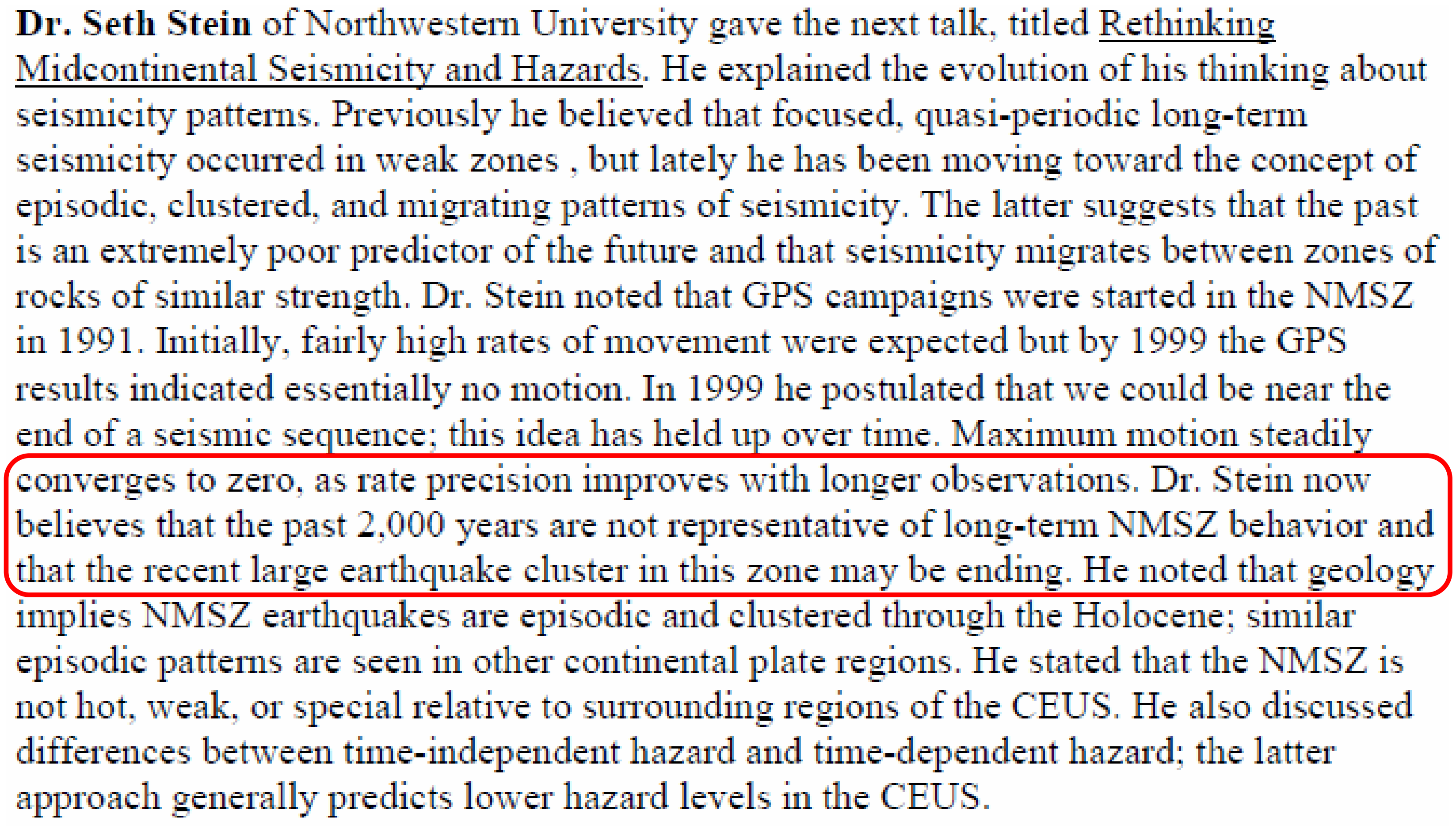
McKenna, Stein & Stein, 2007

WS2 Summary



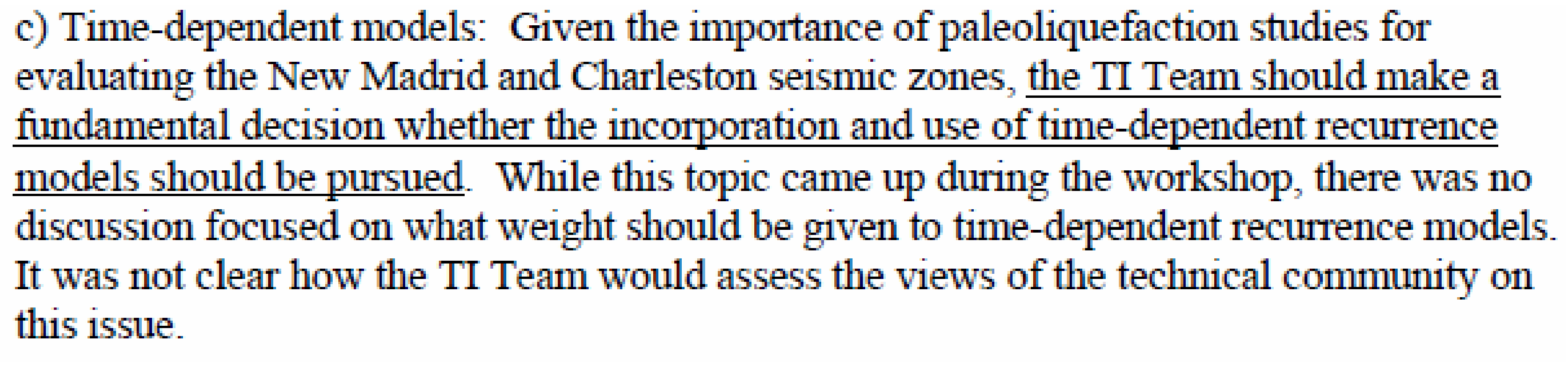
Following a lunch break, the first talk of the afternoon session was given by **Dr. Eric Calais** of Purdue University, who talked about Geodetic Interpretations of New Madrid Rates. Dr. Calais began by describing the notion of a steady-state "elastic rebound" model, in which geodesy and paleoseismology should agree. This model works particularly well for plate boundary faults, as present-day strain has predictive power. Current GPS measurements indicate an upper-bound movement of 0.02 mm/yr at New Madrid. Dr. Calais also showed velocities measured at about 500 sites in North America with respect to a constant reference frame. Velocity analyses on deformation east of the Rocky Mountains have indicated that most measured velocities are not significant at a 95 percent confidence level. However, patterns in velocities, especially radial patterns, are apparent. Residual velocities of 0.6 mm/yr have been measured in the CEUS.

WS2 Summary



Dr. Seth Stein of Northwestern University gave the next talk, titled Rethinking Midcontinental Seismicity and Hazards. He explained the evolution of his thinking about seismicity patterns. Previously he believed that focused, quasi-periodic long-term seismicity occurred in weak zones , but lately he has been moving toward the concept of episodic, clustered, and migrating patterns of seismicity. The latter suggests that the past is an extremely poor predictor of the future and that seismicity migrates between zones of rocks of similar strength. Dr. Stein noted that GPS campaigns were started in the NMSZ in 1991. Initially, fairly high rates of movement were expected but by 1999 the GPS results indicated essentially no motion. In 1999 he postulated that we could be near the end of a seismic sequence; this idea has held up over time. Maximum motion steadily converges to zero, as rate precision improves with longer observations. Dr. Stein now believes that the past 2,000 years are not representative of long-term NMSZ behavior and that the recent large earthquake cluster in this zone may be ending. He noted that geology implies NMSZ earthquakes are episodic and clustered through the Holocene; similar episodic patterns are seen in other continental plate regions. He stated that the NMSZ is not hot, weak, or special relative to surrounding regions of the CEUS. He also discussed differences between time-independent hazard and time-dependent hazard; the latter approach generally predicts lower hazard levels in the CEUS.

PPRP Letter
March 10, 2009



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.

Examples from Reference Lists from S. Stein and E. Calais

- Calais, E., and Stein, S., 2009, Time-variable deformation in the New Madrid seismic zone: Science, v. 323, pp. 1442, DOI: 10.1126/science.1168122.
- Calais, E., Han, J.Y., DeMets, C., and Nocquet, J.M., 2006, Deformation of the North American plate interior from a decade of continuous GPS measurements: Journal of Geophysical Research, v. 111, B06402, doi:10.1029/2005JB004253.
- Calais, E., Mattioli, G., DeMets, C., Nocquet, J.M., Stein, S., Newman, A., and Rydelek, P., 2005, Tectonic strain in the interior of the North American Plate? Nature, v. 438, doi:10.1038/nature04428.
- Stein, S., 2007, Approaches to continental intraplate earthquake issues: in Stein, S., and Mazzotti, S. (editors), *Continental Intraplate Earthquakes: Science, Hazard, and Policy Issues*, Geological Society of America Special Paper 425, pp. 1-16.

Model of Episodic and Temporally Migrating Seismicity (continued)

- Our sense is that the lower hazards predicted for the CEUS by the time-dependent models are more plausible. However, we think the more important point is that the uncertainties in these or any other estimates of the seismic hazard in the areas are even larger than have been discussed to date. The uncertainties associated with the choice of time-independent model vs. time dependent models can exceed and compound those due to the assumed maximum magnitude of the characteristic earthquakes and the resultant ground motion. As such, any seismic hazard map should incorporate these uncertainties, which should be recognized in efforts to formulate cost-effective earthquake hazard mitigation policies for the area. **(Hebden and Stein, 2008)**

DATA EVALUATION TABLE
Reelfoot Rift-New Madrid Seismic Zone
Central New Madrid Faults RLME

Data	Reference	Quality (1=low, 5=high)	Notes on Quality or Data	Source Considered (e.g., A, B)	Used in SSC and Reliance Level (0=no, 5=high)	Discussion of Data Use	In GIS Database
Geodetic Strain	Calais et al. (2008)	4	Two independent geodetic solutions from close to 300 continuous GPS stations. Relatively short record.	B1	1	Based on the observation that there is no detectable residual motion in the NMSZ at the 95% confidence level, some weight is assigned to the model that the central fault system in the NMSZ is 'out of the cluster.'	N
	Calais and Stein (2009)	4	Publication	A	1	Conclusion of paper suggests that the recurrence rate estimated from seismicity in the NMSZ is consistent with the rates suggested by geodetic measurements. This supports 'out of cluster' model.	N

Data Summary Table

Reelfoot Rift – New Madrid Seismic Zone Region

Citation	Title	Relevance to SSC
Calais and Stein (2009)	Time-variable Deformation in the New Madrid Seismic Zone:	This paper speculates that earthquake hazard estimates assuming that recent seismicity reflects long-term steady-state behavior may be inadequate for plate interiors and may overestimate the hazard near recent earthquakes and underestimate it elsewhere. Recent geodetic results in the NMSZ have shown motions between 0 to 1.4 mm/yr, allowing opposite interpretations. The upper bound is consistent with steady-state behavior, in which strain accumulates at a rate consistent with a repeat time for magnitude ~7 earthquakes of about 600 to 1500 years, as seen in the earthquake record. The lower bound cannot be reconciled with this record, implying that the recent cluster of large magnitude events does not reflect long-term fault behavior and may be ending. New analysis suggest strain rates lower than 1.3 x 10^{-9} /yr, less than predicted by a model in which large earthquake occur because the NMSZ continues to be loaded as a deeper weak zone relaxes (e.g., Kenner and Segall, 2000). At a steady state, a rate of 0.2 mm/yr implies a minimum repeat time of 10,000 years for low M=7 earthquakes with ~2m of coseismic slip and one longer than 100,000 years for M=8 events. Strain in the NMSZ over the past several years has accumulated too slowly to account for seismicity over the past ~5000 years, hence excluding steady-state fault behavior. Elsewhere throughout the plate interior, GPS data also show average deformation less than 0.7 mm/yr and paleoseismic records show earthquake migration and temporal earthquake clustering. These imply that fault loading, strength, or both vary with time in the plate interior. Time variations in stress could be due to local loading and unloading from ice sheets or sediments or after earthquakes on other faults.

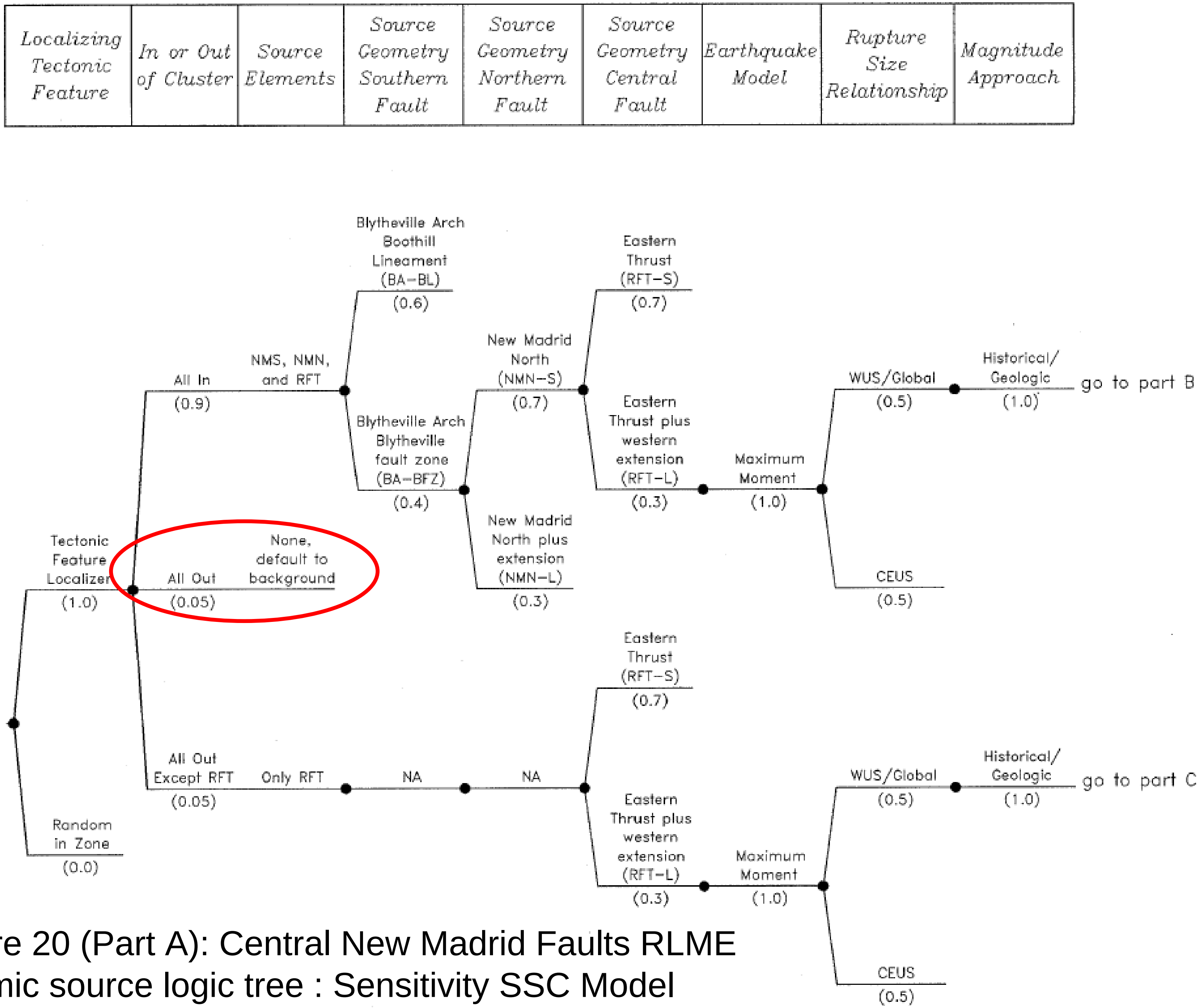


Figure 20 (Part A): Central New Madrid Faults RLME seismic source logic tree : Sensitivity SSC Model

Additional Documentation Steps

- Complete Preliminary SSC Model HID
- Final SSC Model: Documented in Draft and Final Project Reports
  - Discussion of all elements of logic tree
  - Discussion of considerations leading to branches and technical bases for weights
  - Reference lists
- These are the common means of documenting the key technical considerations

“Proof” that ITC has been captured

- SSHAC provides approaches that are instrumental in achieving the goal, but they do not guarantee or prove it
  - ITC is hypothetical so proof is not possible
  - If all steps have been followed, reviewed, and documented, there is a higher level of assurance that ITC has been captured

“Proof” that ITC has been captured

(continued)

- We can expect continued advancements in the methods and processes for conducting PSHAs
  - SSHAC evolved from lessons learned; better ideas will evolve to better capture our knowledge and uncertainties at a point in time
  - But if the goal remains the same, we will be able to compare existing studies with future studies to meaningfully see our evolution of thinking
  - Reduction in uncertainties
  - Continued confidence and stability
- For now, the various process steps provide reasonable assurance that ITC has been captured

Proposed Standard of Proof that ITC Has Been Captured

- The assessment that have captured ITC is very similar to the "reasonable assurance" standard used by regulatory community.
  - The NRC has a long history of making safety decisions by applying the reasonable assurance standard, which does not require a quantitative "proof" nor does it require a particular level of confidence.
  - " 'Reasonable assurance' is not quantified as equivalent to a 95% (or any other percent) confidence level, but is based on sound technical judgment of the particulars of a case and on compliance with our regulations. To satisfy this "reasonable assurance" standard, AmerGen must make a showing that meets the "preponderance of the evidence" threshold of compliance with the applicable regulations — *not* a 95% confidence level of compliance, as Citizens would have it. " UNITED STATES OF AMERICA NUCLEAR REGULATORY COMMISSION, CLI-09-07, MEMORANDUM AND ORDER
  - It is the preponderance of the evidence that allows a decision to be made in the face of uncertainty

Proposed Standard of Proof that ITC Has Been Captured (continued)

- SSHAC process specifies the processes for identifying data, its careful evaluation, interactions among the technical community, evaluation processes, integration processes, and documentation all under the watchful eye of the PPRP
- But there is no objective proof that the ITC represented is, in fact, correct
- In the end, a properly conducted SSHAC process will provide reasonable assurance that the ITC has been captured

CEUS Earthquake Catalog

CENTRAL AND EASTERN UNITED STATES
SEISMIC SOURCE CHARACTERIZATION (CEUS SSC) PROJECT

Workshop No. 3

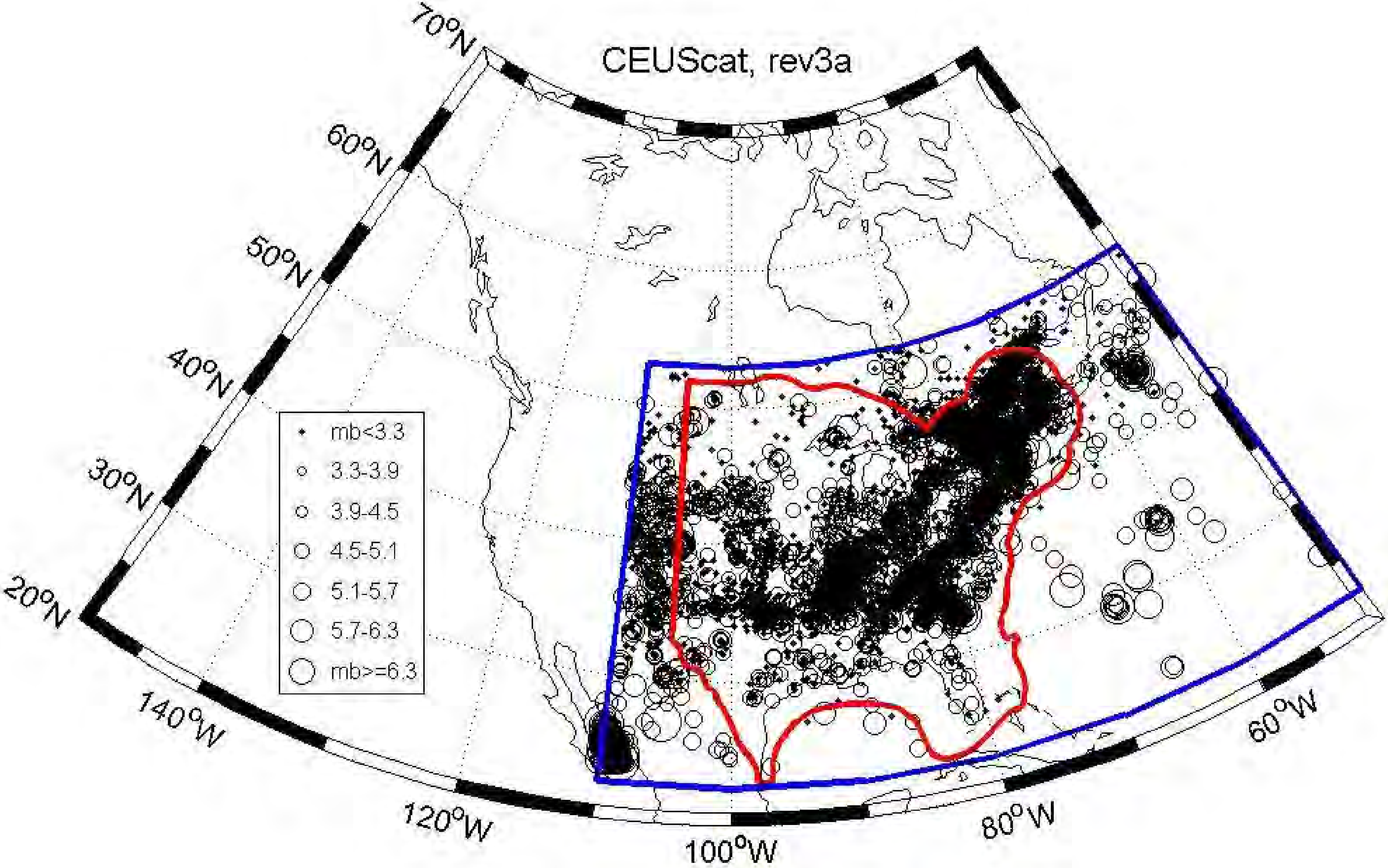
August 25-26, 2009

Valentina Montaldo-Falero
Laura Glaser
Bob Youngs
AMEC Geomatrix

Catalog Development

- Compile events from CEUS catalogs
- Assign each event a unique ID
- Create database that preserves duplicates
- Choose a preferred entry
- Update fields from literature (location, depth, etc.)
- Flag non-tectonic events
- Remove duplicates
- Develop conversions to moment magnitude
- Decluster
- Assess completeness

CEUS Project Catalog



Catalog Sources - National Catalogs:

- USGS (transmitted from Chuck Mueller)
- GSC SHEEF (Seismic Hazard Earthquake Epicentre File)
- NCEER
- EPRI-SOG
- ANSS
- National Earthquake Data Base (Canada)
- ISC

Catalog Sources - Regional Catalogs:

- CERI
- SUSN
- SLU
- Lamont Doherty
- Weston Observatory (NEUSSN)
- Ohio Seis
- Pennsylvania Catalog
- Sykes (NY-Philadelphia)
- Bechtel - VC

Historical Catalogs

- Metzger
- Hopper
- Munsey

Relocated Events

- Obtained from papers in the literature
    - Seeber and Armbruster (1993)
    - Ruff et al. (1994) – Western Ohio
    - Faust et al. (1994) – Michigan
    - Lamontagne and Ranalli (1997)
    - Dineva et al. (2004) – Great Lakes
    - Ma and Atkinson (2006)
    - Ma and Eaton (2007)
    - Ma et al. (2008)

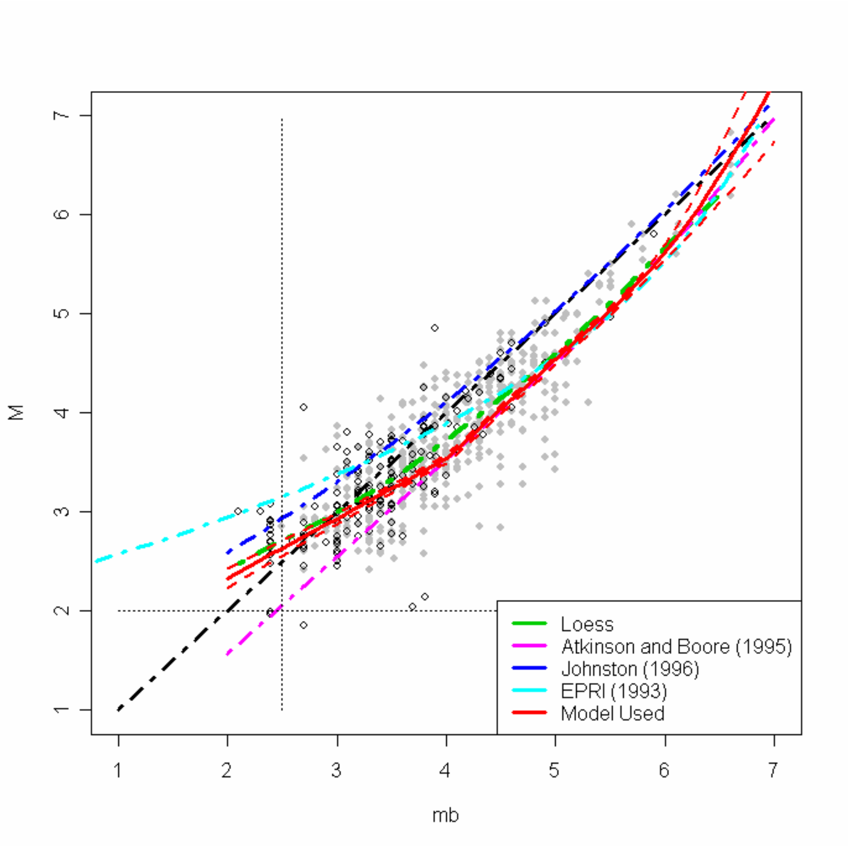
Non-Tectonic Events

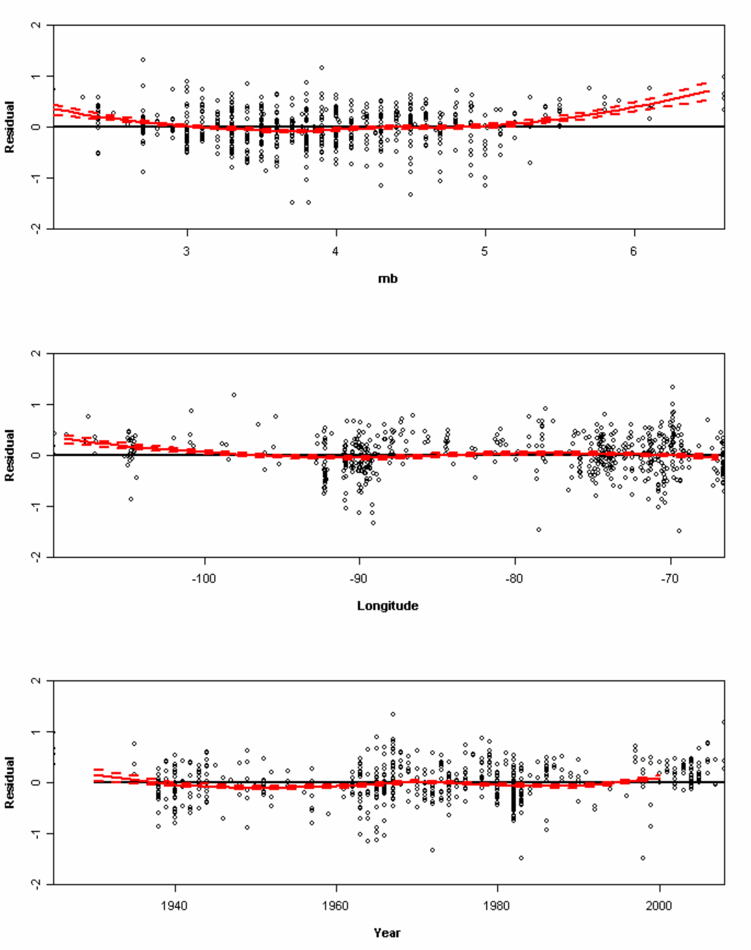
- Includes blasts, weather events, mining induced, etc.
- Nation Earthquake Data Base (Canada)
- ANSS
  - lists events on both earthquake list and blast list; removed events only on blast list
- ISC blast list
- COLAs
- Literature

Magnitude Conversion

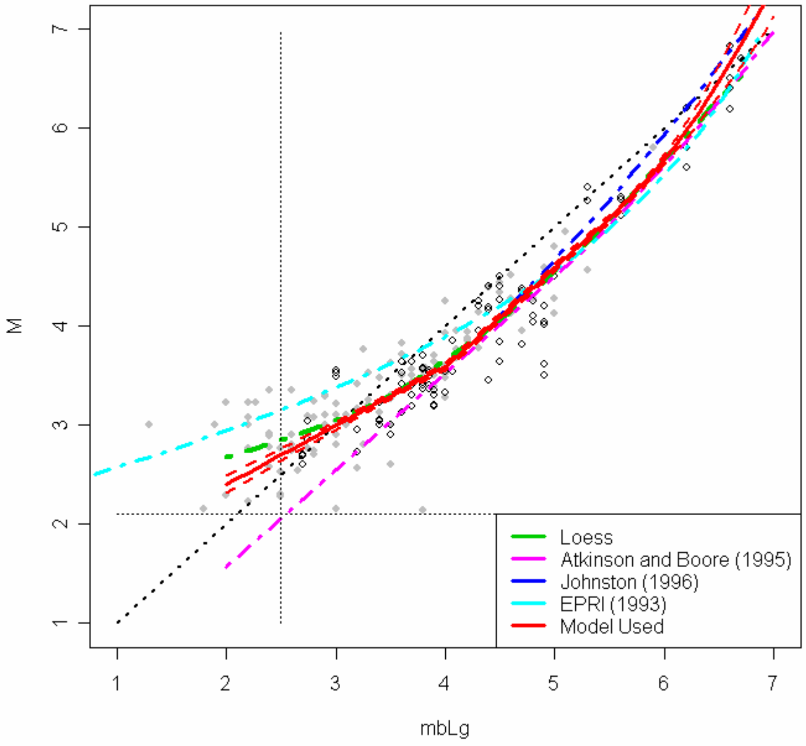
- Compile moment magnitudes for events in the catalog
  - Listed in source catalogs
  - Listed in the literature
  - Harvard MT catalog
- Develop regressions against various size measures
  - Account for data truncation

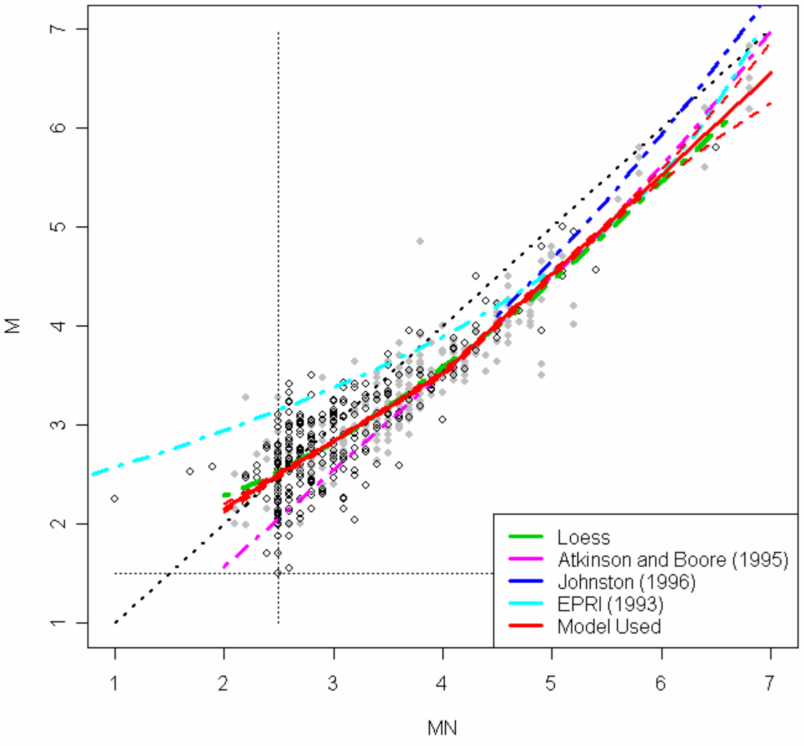
M = f(m_b) Small dependence on Location and Time



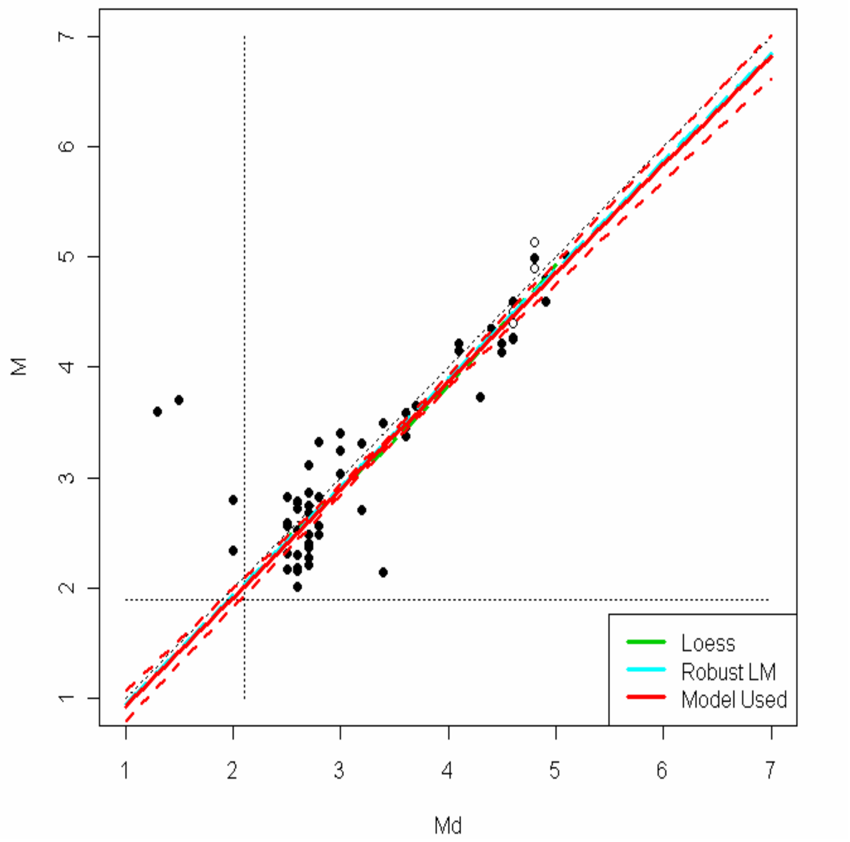


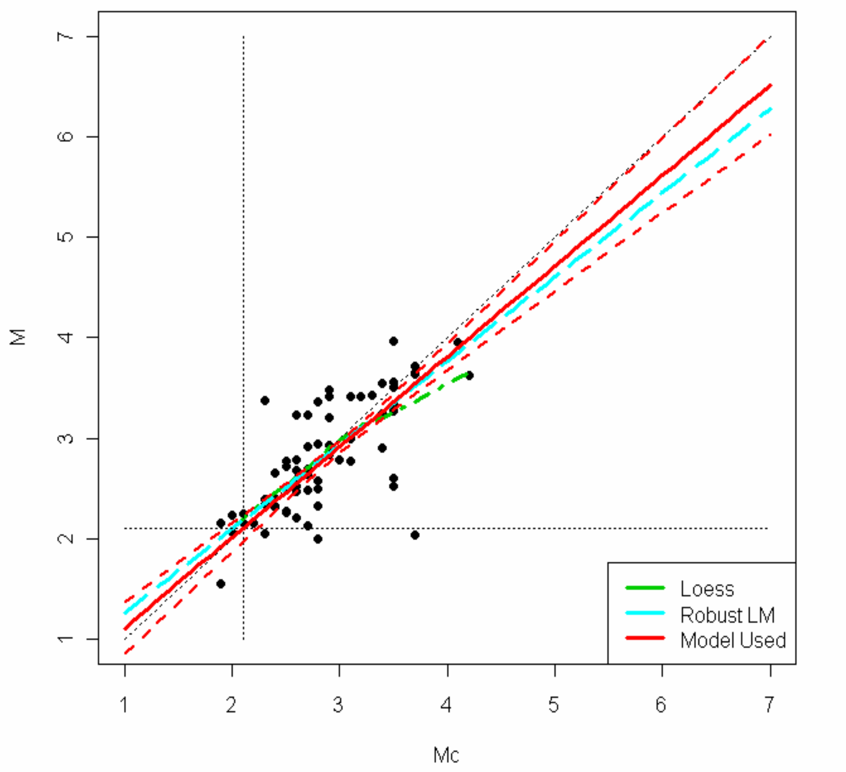
$\mathbf{M} = f(m_{bLg})$ & $f(M_N)$



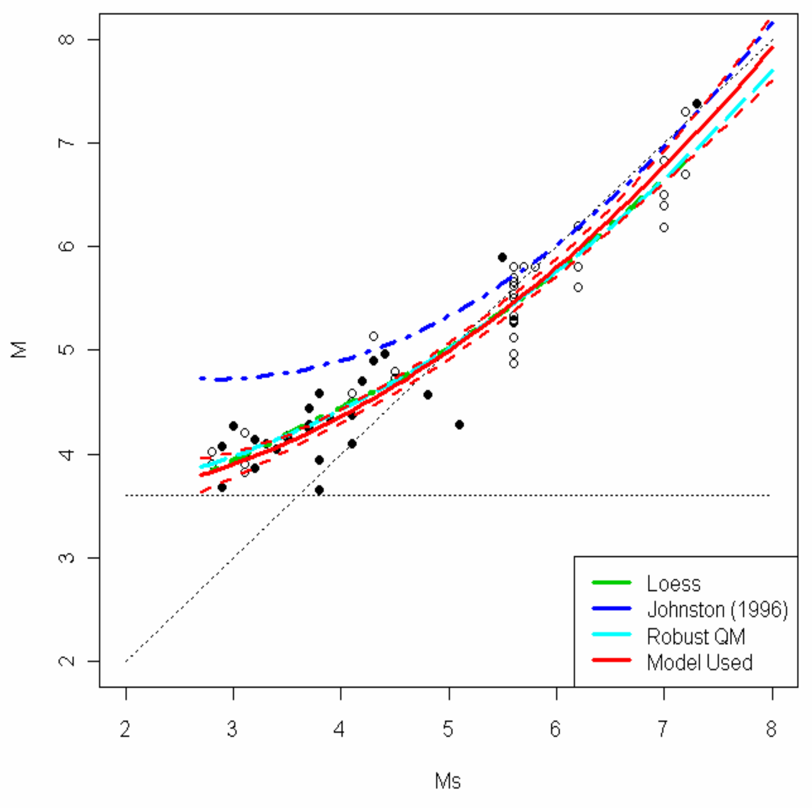


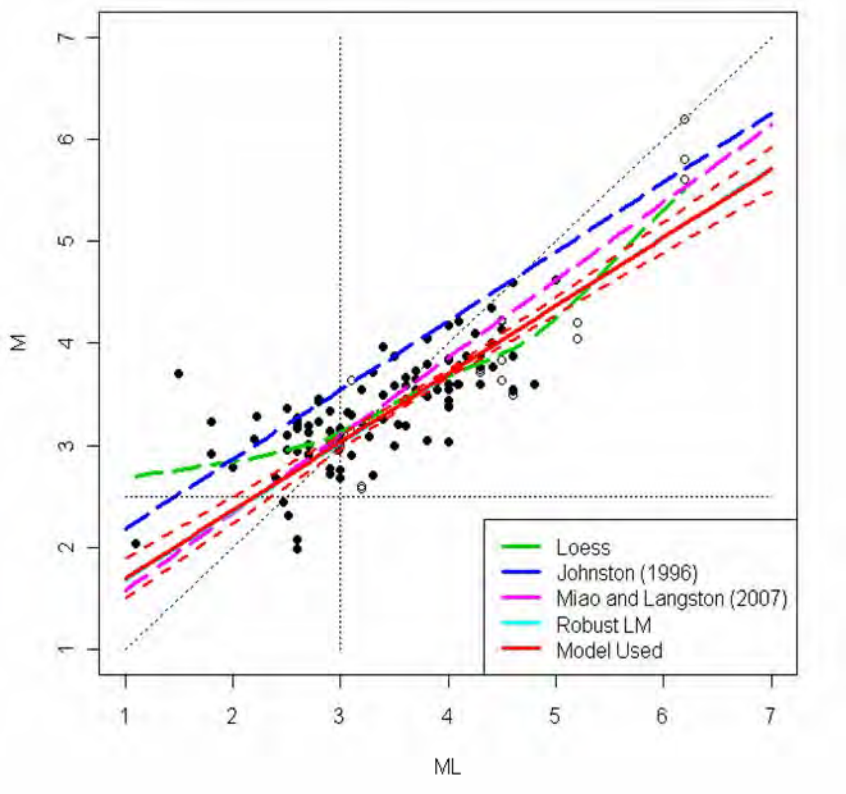
$\mathbf{M} = f(M_d)$ & $f(M_C)$



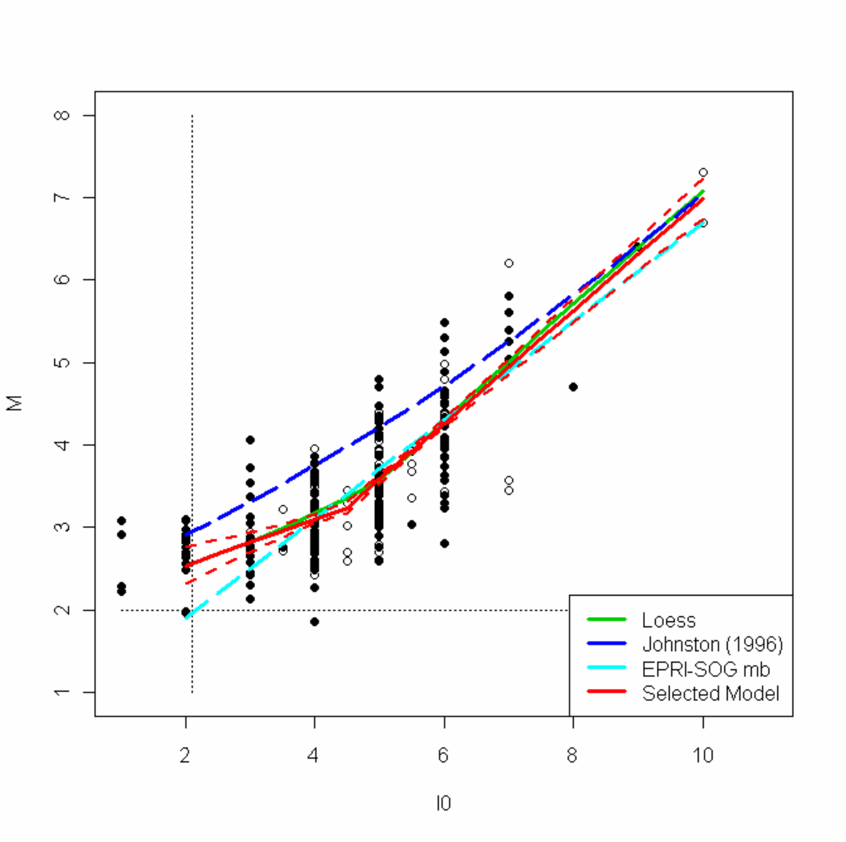


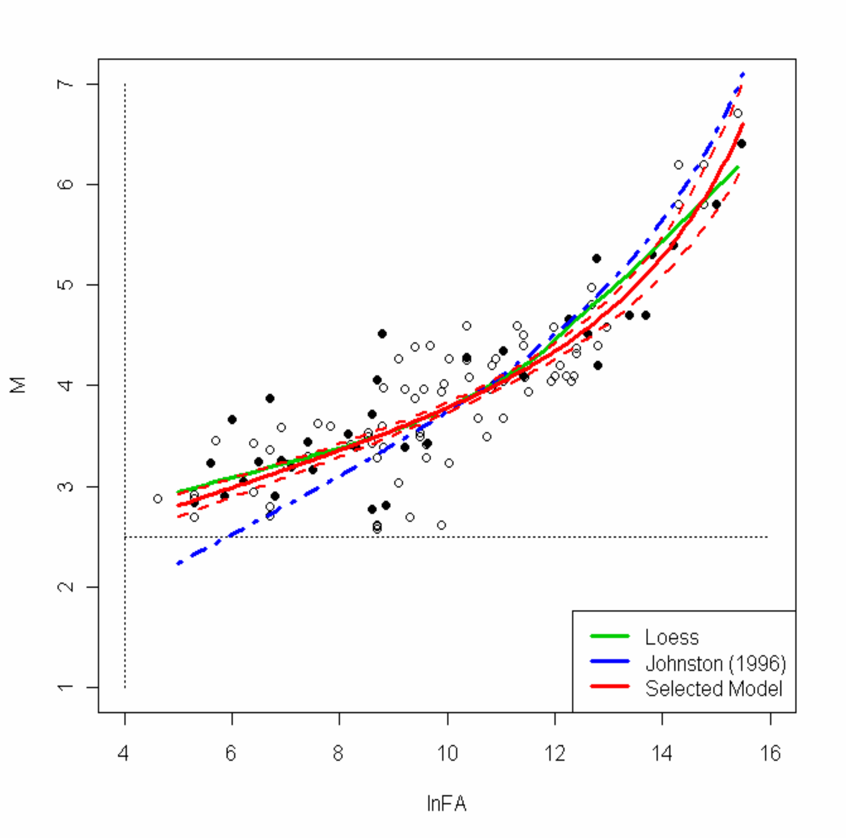
$\mathbf{M} = f(M_S)$ & $f(M_L)$





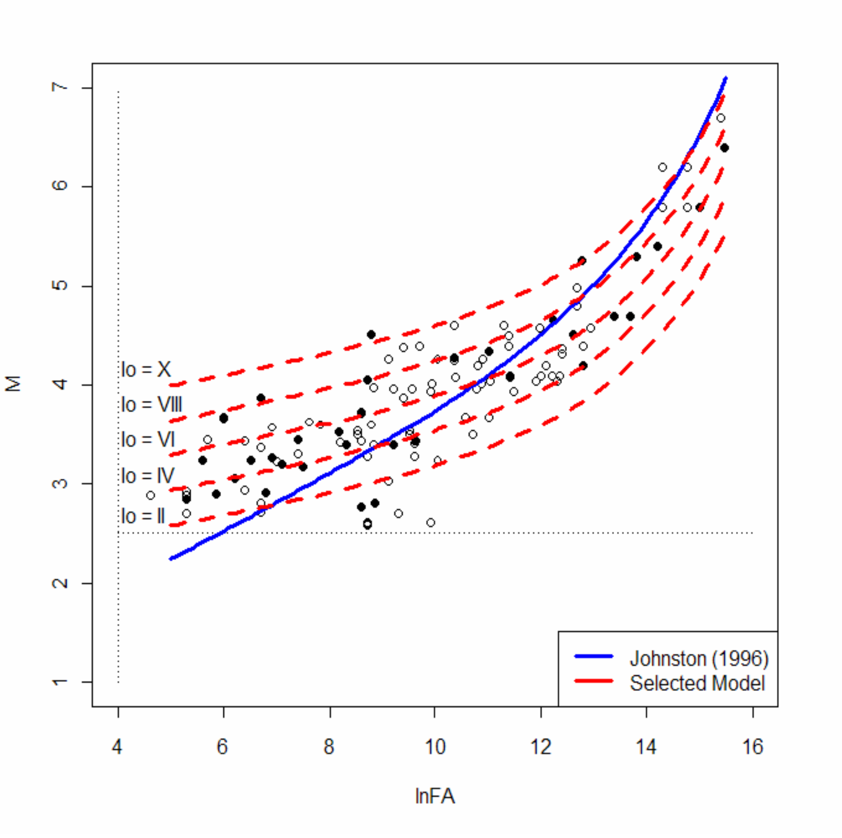
$\mathbf{M} = f(I_0)$ & $f(\ln[FA])$





M = f(I_0 and ln[FA])

- Check variance in estimate based on ln[FA] alone and based on ln[FA] and & I_0
- Used estimate with lower variance



Uniform Magnitude Scale

- Used approach developed in EPRI (1988) to combine estimates from multiple measures if available

$$\sigma_P = \sqrt{\sigma_{res}^2 + \sigma_{E[M|X]}^2}$$

$$E\left[\mathbf{M} \mid \underline{\hat{X}}\right] = \left\{ \sum_i \frac{\sigma_P^2\left[\mathbf{M} \mid \underline{\hat{X}}\right]}{\sigma_P^2\left[\mathbf{M} \mid \hat{X}_i\right]} \cdot E\left[\mathbf{M} \mid \hat{X}_i\right] \right\} + (r-1) \cdot \beta \cdot \sigma_P^2\left[\mathbf{M} \mid \underline{\hat{X}}\right]$$

$$\sigma_P^2\left[\mathbf{M} \mid \underline{\hat{X}}\right] = \left\{ \sum_i \frac{1}{\sigma_P^2\left[\mathbf{M} \mid \hat{X}_i\right]} \right\}^{-1}$$

Correction for Bias in Recurrence Parameters due to Magnitude Uncertainty

- Dependent on source of estimate
  - If obtained directly from moment magnitude

$$\mathbf{M}^* = E\mathbf{M} - \beta\sigma_M^2 / 2$$

  - If obtained from other size measures

$$\mathbf{M}^* = E\mathbf{M} + \beta\sigma_M^2 / 2$$

Declustering

- Declustering performed using EPRI (1988) declustering methodology (EQCLUST)
  - 26,426 total number of events
  - 14,674 dependent events identified

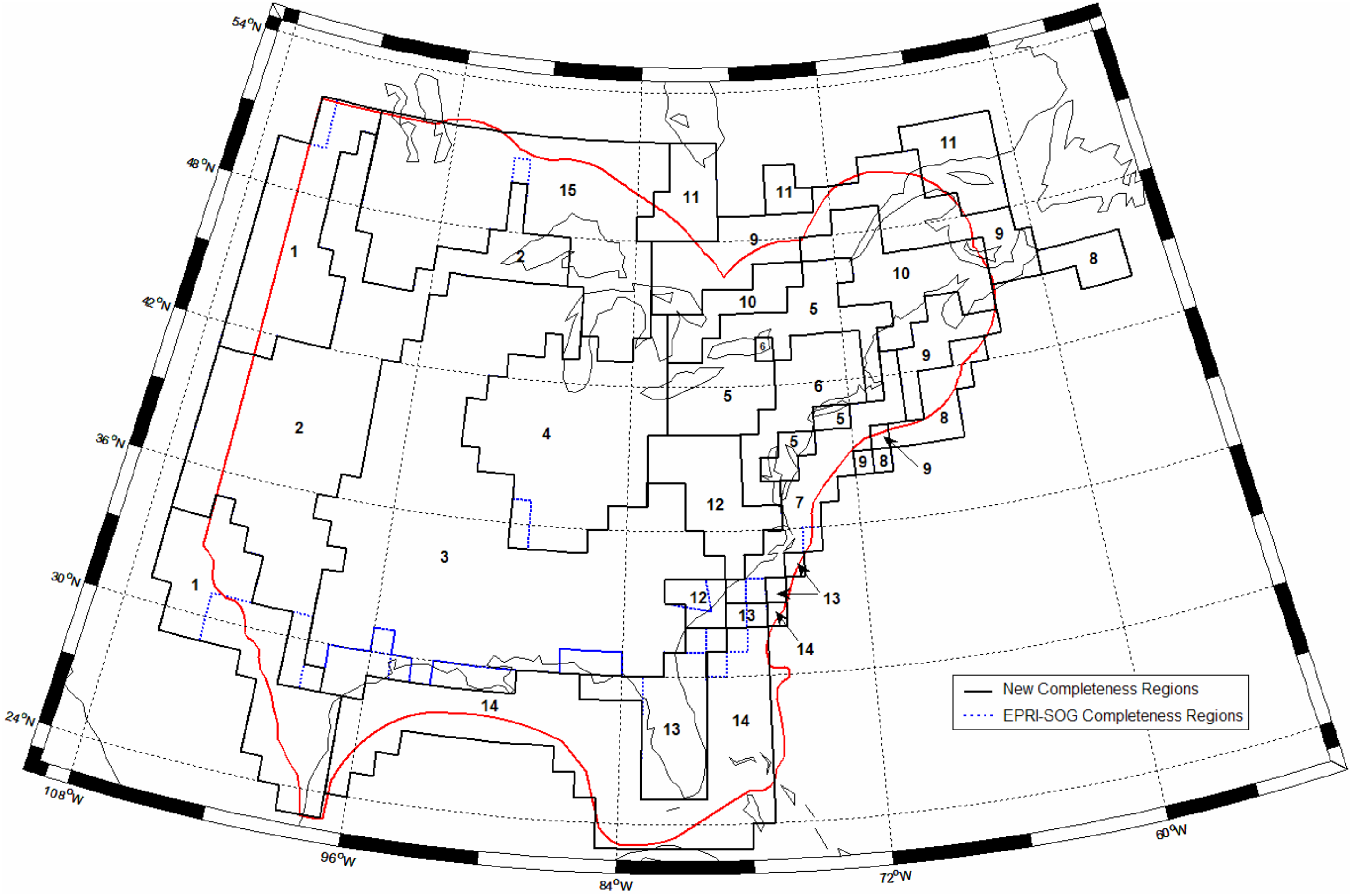
Completeness Assessments

- Used EPRI (1988) methodology
  - Include all of the “usable” catalog
  - Account for partial completeness through probability of detection and equivalent period of completeness

$$TE(m_i, CR_k) = \sum_j PD_{i,j,k} \times t_j$$

$$\lambda = \frac{N(\text{in usable period})}{TE}$$

Modified Catalog Regions



Catalog Now In Review

- Selection of preferential catalog entries
- Additional data sources that should be included
- Evaluation of conversions to moment magnitude
- Any other suggestions

The “EPRI” Bayesian M_{max} Approach for Stable Continental Regions (SCR)

Updated Priors

CENTRAL AND EASTERN UNITED STATES SEISMIC SOURCE CHARACTERIZATION (CEUS SSC) PROJECT

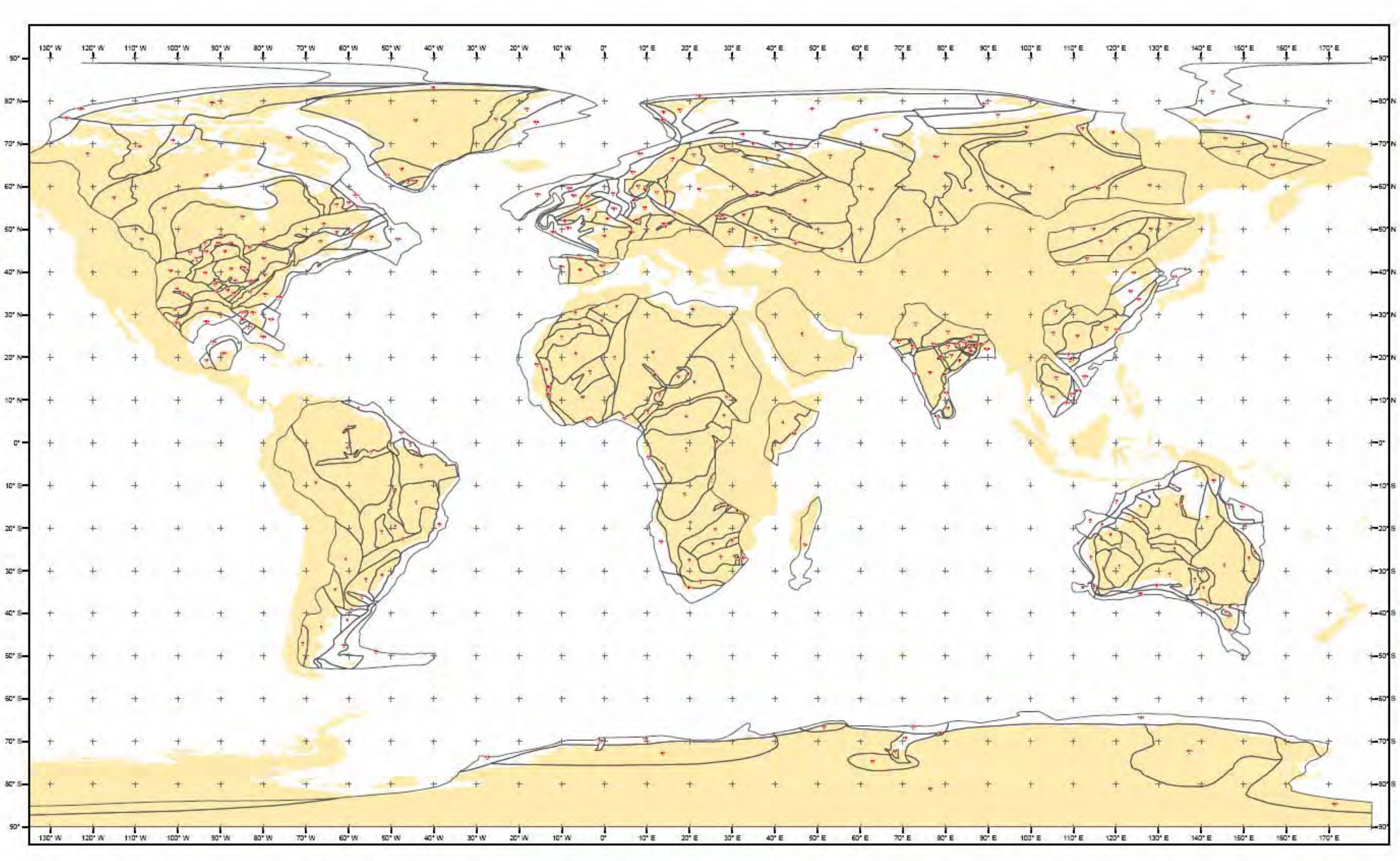
Workshop No. 3

August 25-26, 2009

Approach for EPRI (1994) SCR Priors

- Divide SCR into domains based on:
  - Crustal type (extended or non-extended)
  - Geologic age
  - Stress regime
  - Stress angle with structure
- Assess distribution of $m_{max\text{-}obs}$ for domains from catalog of SCR earthquakes
- Adjust for the fact that $m_{max\text{-}obs} \leq m^u$

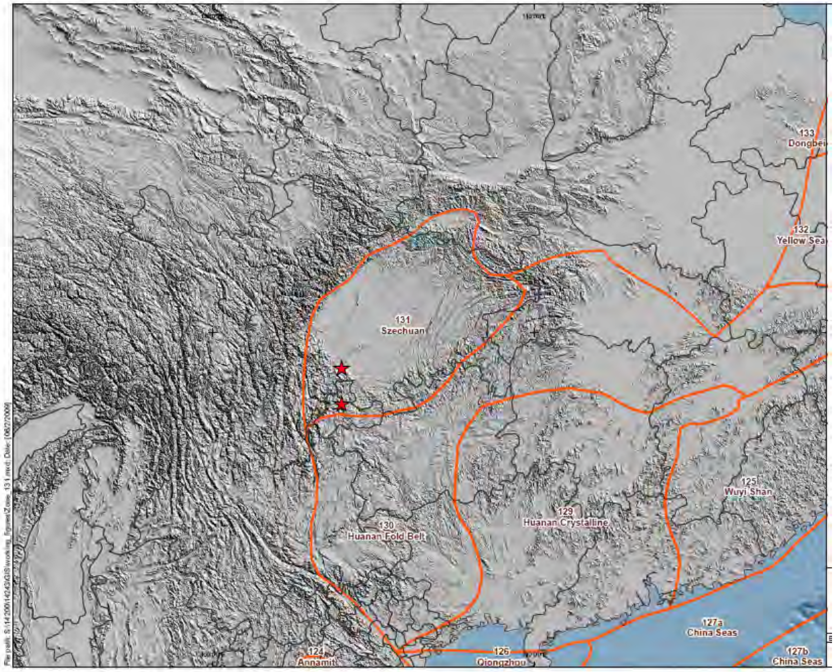
255 SCR Domains



Update SCR Catalog

- Revised magnitude estimates for New Madrid (**M** 7.8) and Charleston (**M** 6.9)
- Updated SCR catalog from Schulte and Mooney (2005)
- Add in Harvard MT values for 2004-2008
- Number of **M** > 4.5 in SCR goes from 940 to 1550 earthquakes
- Largest went from **M** 8.3 to 7.9

An Interesting Case

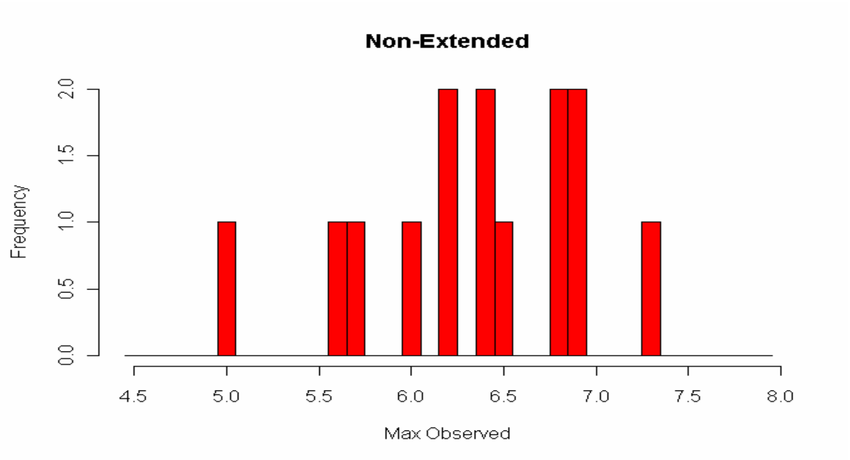


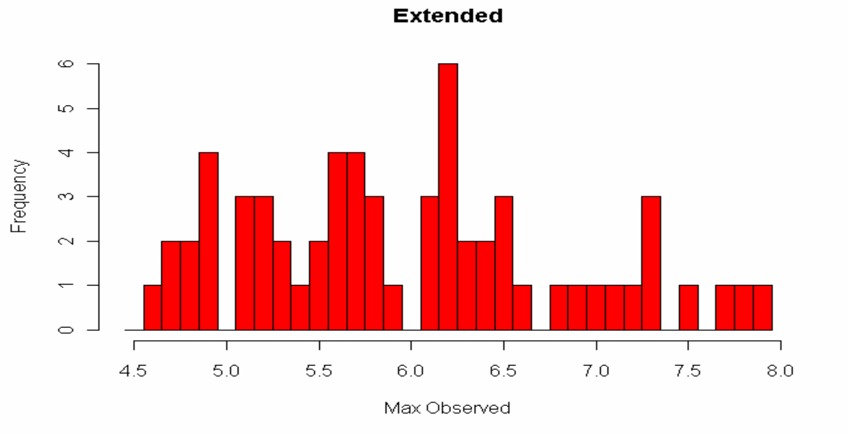
- Largest non-extended earthquake in Schulte and Mooney is 1917/07/30 **M** 7.4 event in domain 131 (China)
- Event not in Johnston et al. (1994)
- Source for magnitude traced to Swedish researcher using recordings in Sweden
- Other catalogs that use Chinese sources, including one with an isoseismal map, indicate a magnitude ~**M** 6.5

Domain “Pooling”

- Obtaining usable estimates of bias adjustment necessitated pooling “like” domains (trading space for time) to increase sample size
- “Super Domains” created by combining domains with the same characteristics
  - Extended crust - 99 domains become 61 active super domains, average *N* = 28 (corrected for completeness)
  - Non-extended crust – 146 domains become 14 active super domains, average *N* = 240 (corrected for completeness)

Distributions of Maximum Observed





- Non-Extended

$$\mu_{M_{\mathrm{max\_obs}}} = 6.3$$

$$\sigma_{M_{\mathrm{max\_obs}}} = 0.6$$

- Extended

$$\mu_{M_{\mathrm{max\_obs}}} = 6.0$$

$$\sigma_{M_{\mathrm{max\_obs}}} = 0.85$$

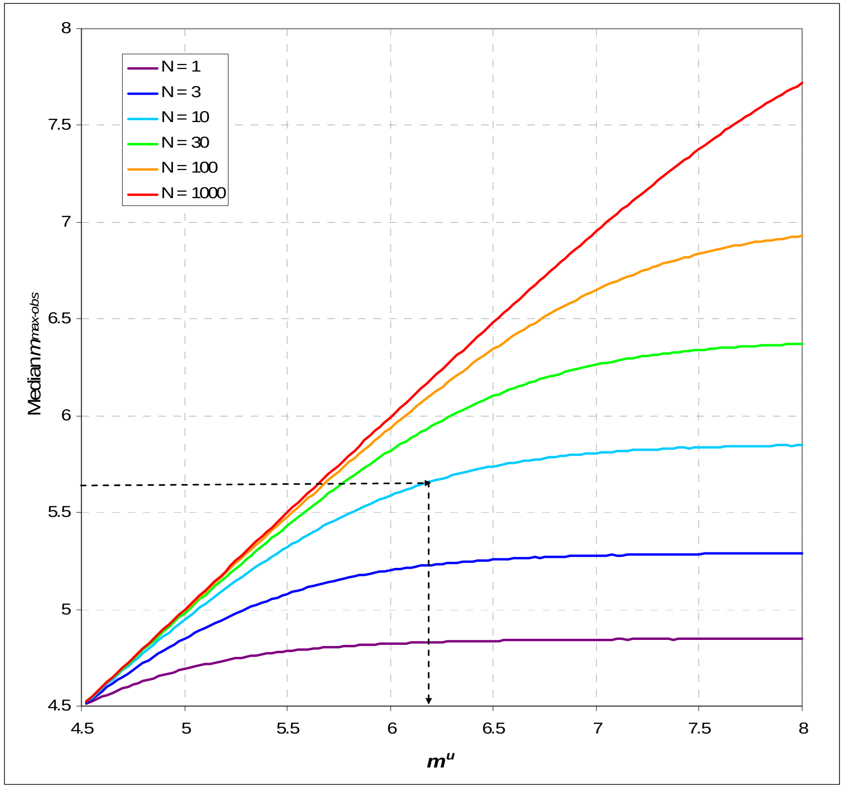
Bias Adjustment (1 of 2)

- Bias correction from $m_{max\text{-}obs}$ to m^u based on distribution for $m_{max\text{-}obs}$ given m^u
- For a given value of m^u and N estimate the median value of $m_{max\text{-}obs}$, $\hat{m}_{\max-obs}$

$$F[m_{\max-obs}]=\left[\frac{1-\exp\{-b\ln(10)(m_{\max-obs}-m_0)\}}{1-\exp\{-b\ln(10)(m^u-m_0)\}}\right]^N \quad \text{for } m_0 \le m_{\max-obs} \le m^u$$

- Use $m^u-\hat{m}_{\max-obs}$ to adjust from $m_{max\text{-}obs}$ to m^u

Bias Adjustment (2 of 2)



Example:

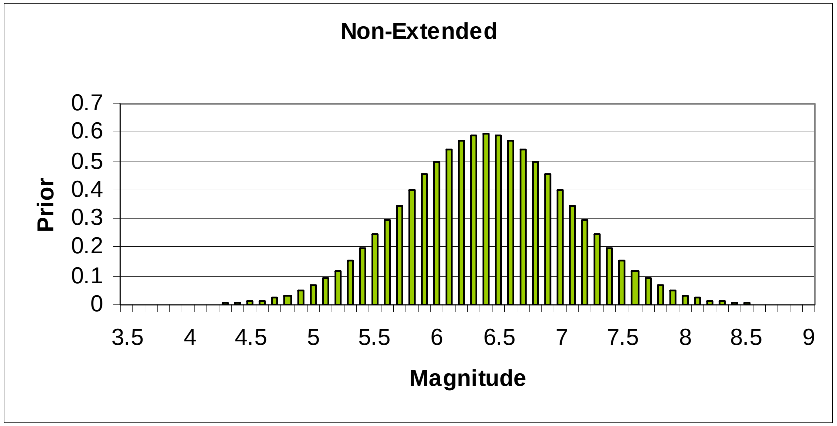
$m_{max\text{-}obs}$ = 5.7

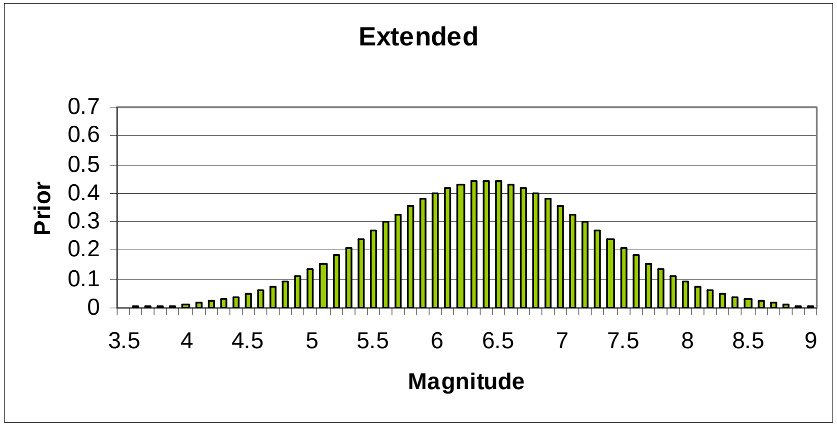
$N(m \leq 4.5)$ = 10

m^u = 6.2 produces

$\hat{m}_{\max - obs}$ = 5.7

M_{max} – Updated Priors)





- Preliminary Updated Priors
  - Non-Extended

$$\mu_{M_{\max}} \approx 6.4$$

$$\sigma_{M_{\max}} = 0.6$$

  - Extended

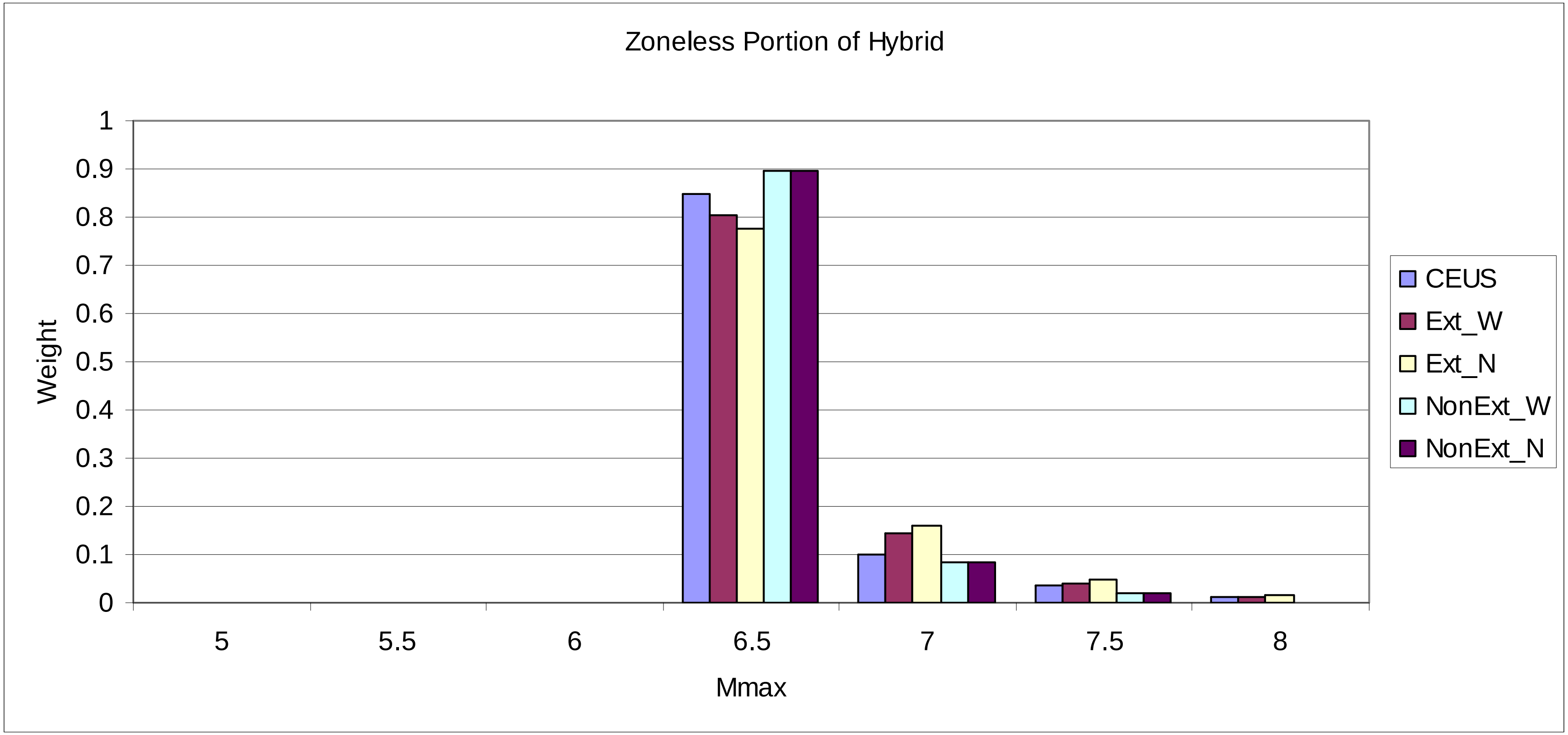
$$\mu_{M_{\max}} \approx 6.4$$

$$\sigma_{M_{\max}} = 0.85$$

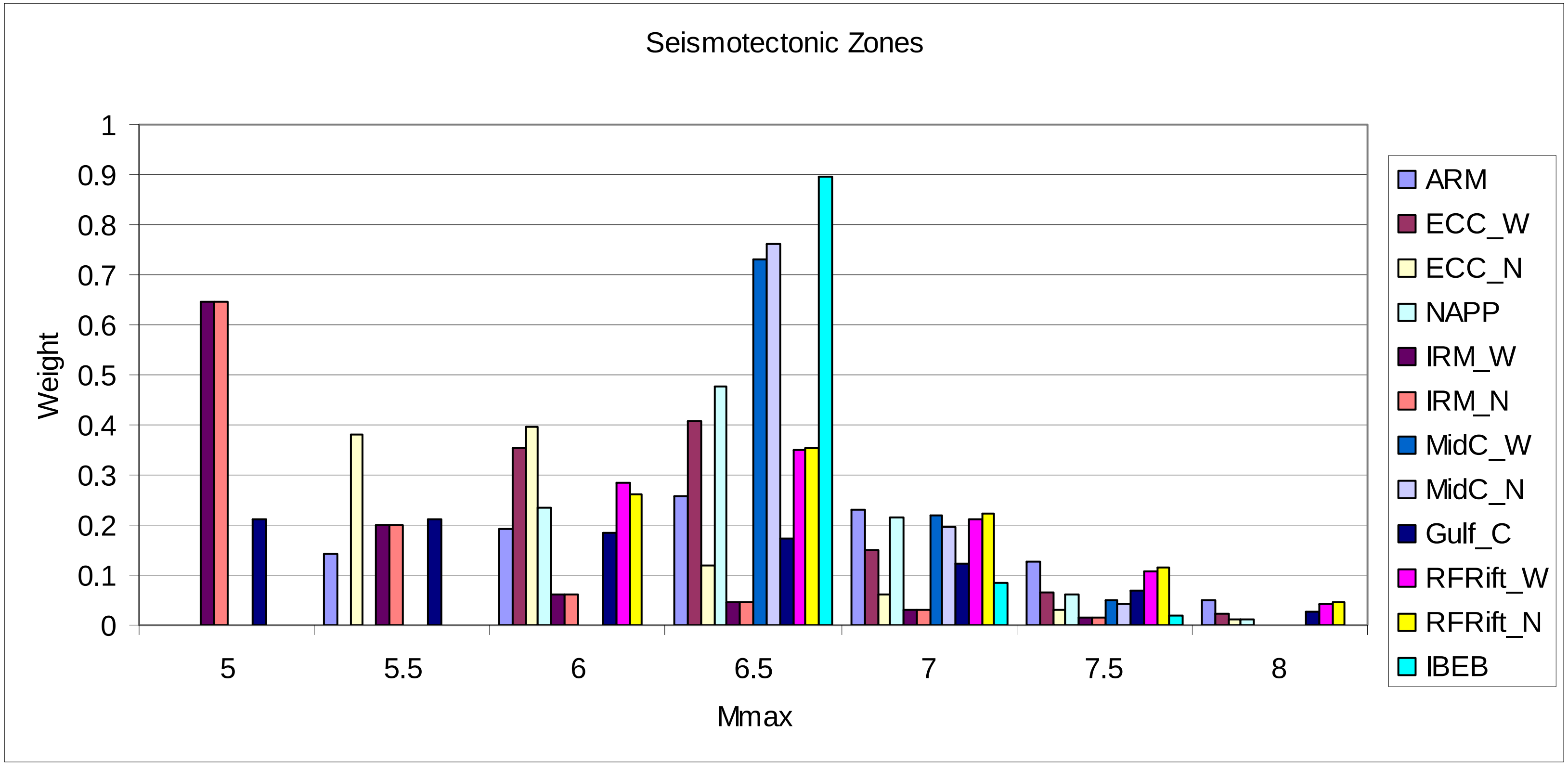
Work To Be Done

- Review criteria used to distinguish super domains, particularly for extended crust (perhaps there should be fewer)
- Examine bias correction, perhaps apply individually to super domains rather than make average correction at end
- Or develop an estimation technique that includes bias correction

Results For Zoneless Portion of Hybrid Model (excluding RLMEs)



Results For Seismotectonic Sources (excluding RLMEs)



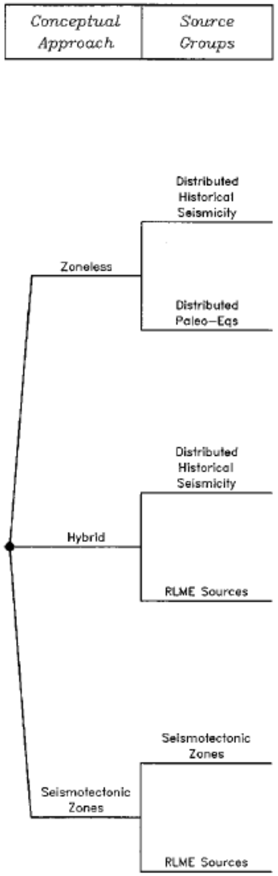
Logic Tree Structure for Seismic Source Sensitivity Model

CENTRAL AND EASTERN UNITED STATES SEISMIC SOURCE CHARACTERIZATION (CEUS SSC) PROJECT

Workshop No. 3

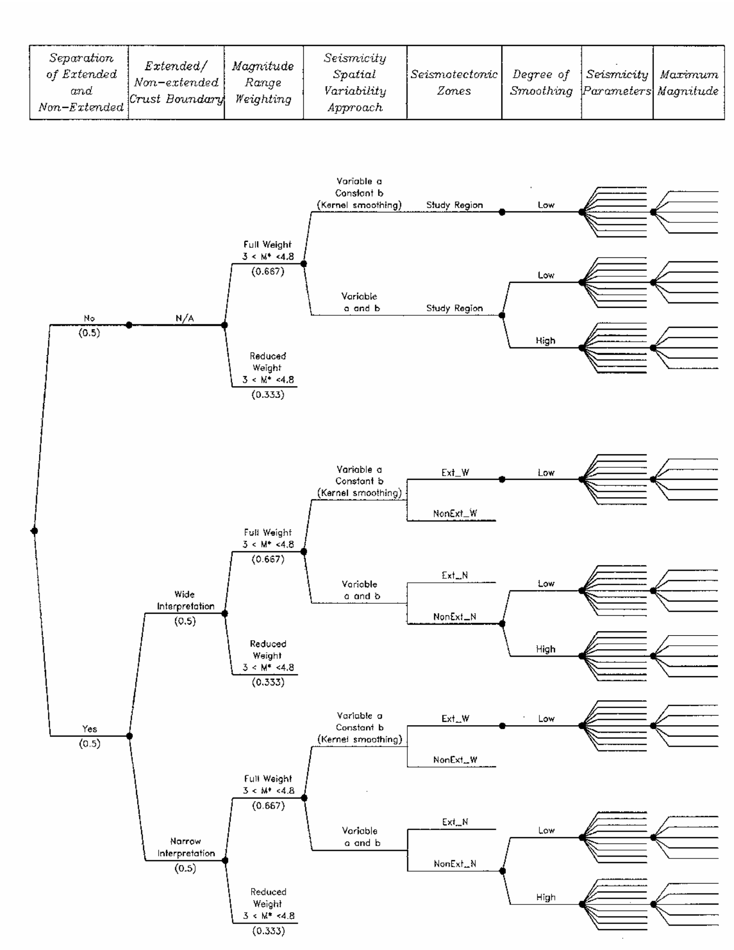
August 25-26, 2009

Master Logic Tree



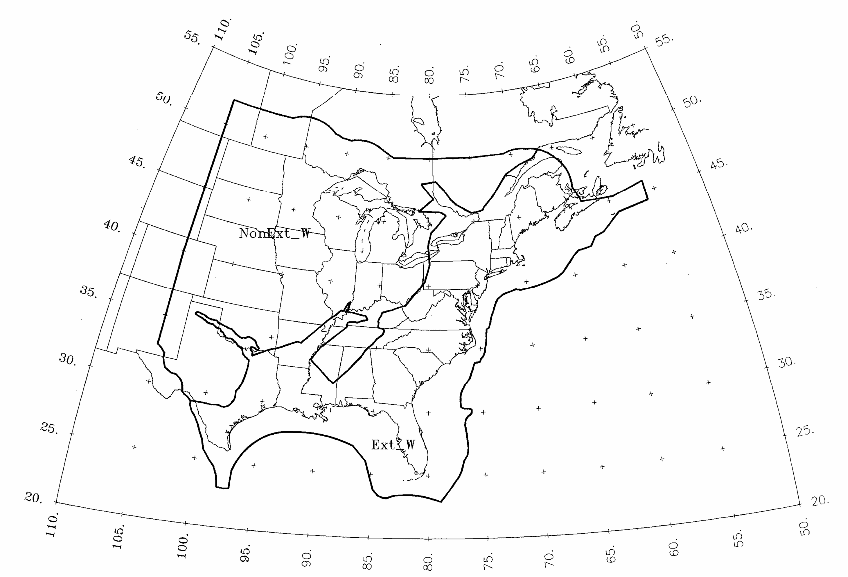
- Two types of seismic sources
  - Distributed seismicity characterized using historical and instrumental seismicity
  - Repeated large magnitude earthquakes (RLME) characterized using paleo-earthquake record
- Two approaches to characterize sources
  - Zoneless
  - Seismotectonic structures

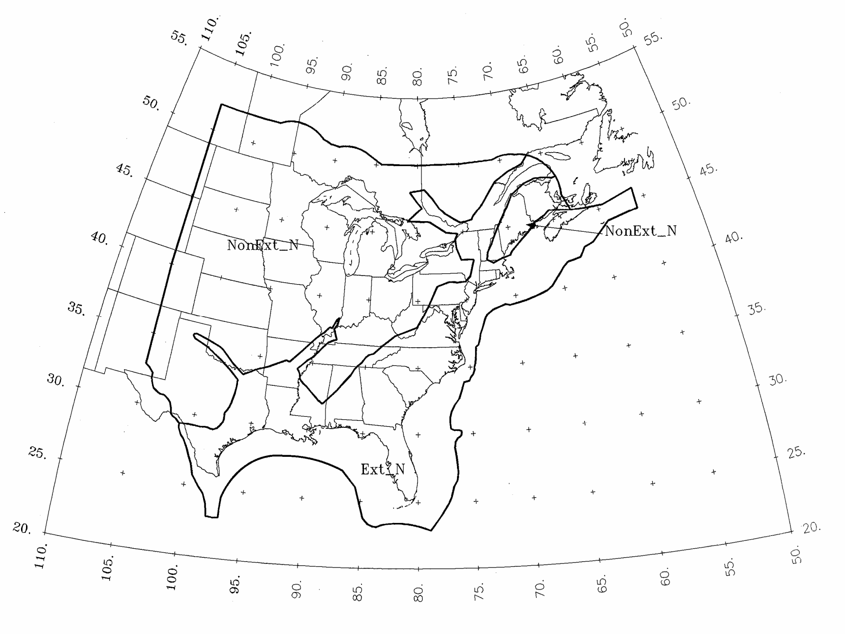
Distributed Seismicity – Zoneless Approach



- Is M_{max} different in extended and non-extended crust
- Where is the boundary between extended and non-extended
- How much weight to assign to magnitudes **M**<4 in estimation of rate for **M** ≥ 5
- How to characterize spatially varying seismicity
- Degree of smoothing

Alternative Extended/Non-Extended Boundaries





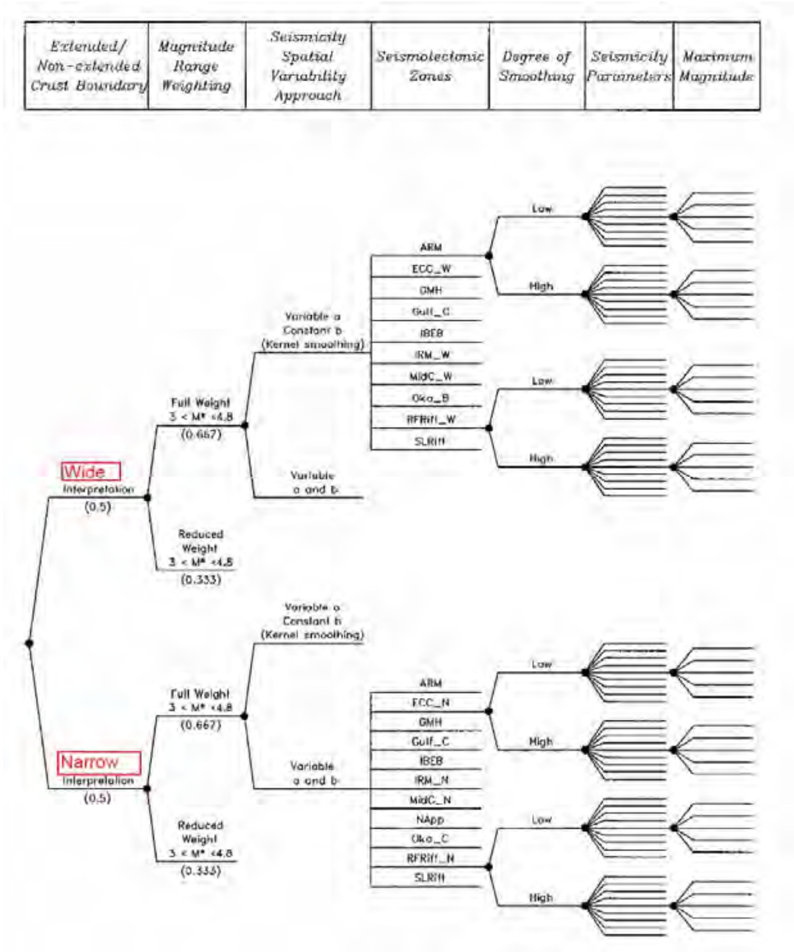
Weight to Assign to **M** < 4

- Smaller events generally show greater degree of clustering
- Application of truncated exponential model with constant *b*-value to full magnitude range
  - Potential issues with consistent conversion to moment magnitude over full magnitude range, particularly at lower magnitudes

Alternative Methods to Address Spatially Varying Seismicity Rates

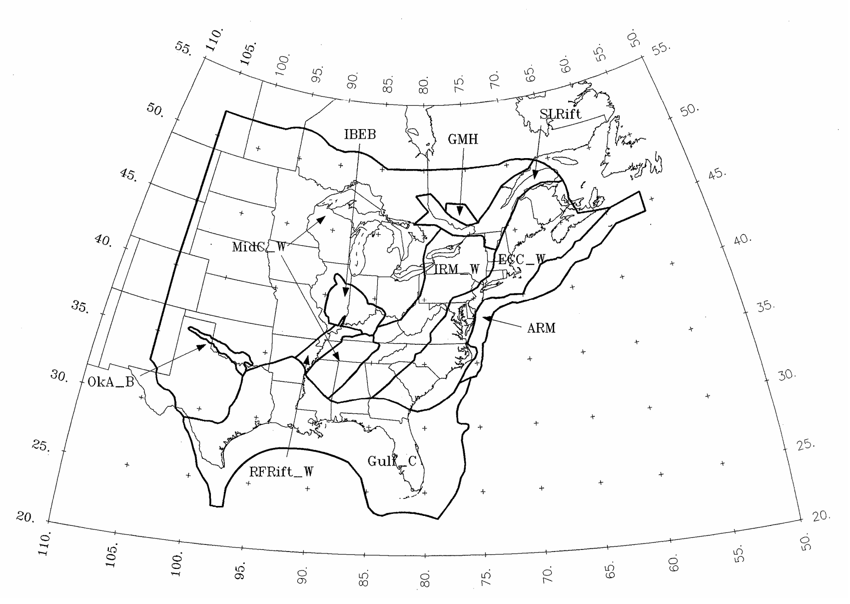
- Variable "*a*", constant "*b*" – kernel density
  - Pluses
    - Smooth transition spatially
    - Uncertainty in rate and spatial model can be treated separately
    - Degree of smoothing can vary locally within source
  - Minuses
    - Treatment of variable completeness
    - Assumption of constant "*b*" as size of region increases
- Variable "*a*" & "*b*" – cell by cell model
  - Pluses
    - Treatment of variable completeness
    - Allows "b" to vary
  - Minuses
    - Achieving smooth spatial transitions requires small cell size
    - Treatment of uncertainty requires simulation of multiple spatial models – potential larger PSHA overhead

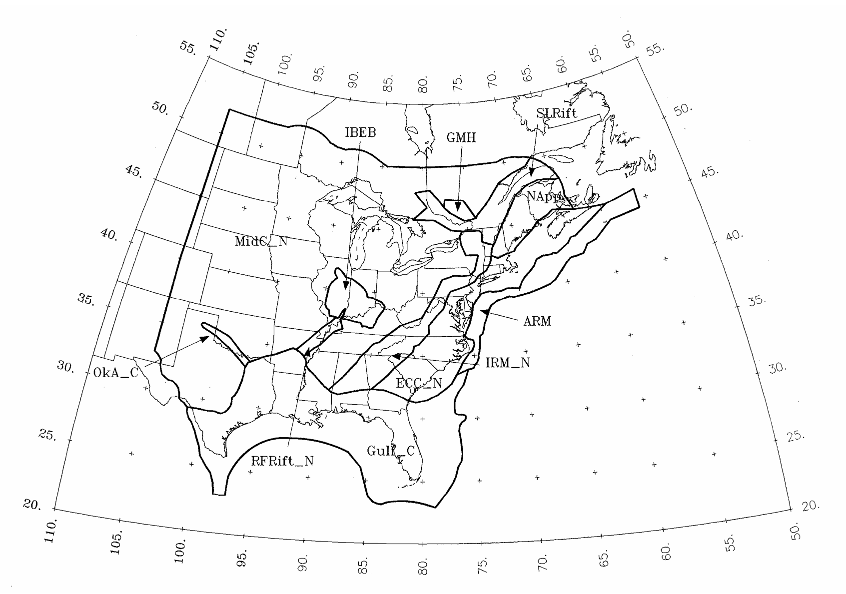
Distributed Seismicity – Seismotectonic Zones



- Zonation model
- How much weight to assign to magnitudes **M**<4 in estimation of rate for **M** ≥ 5
- How to characterize spatially varying seismicity
- Degree of smoothing

Alternative Zonation Models





Zoneless Treatment of RLMEs

- Develop a catalog of paleo-earthquakes
- Primary issue – completeness
  - Spatial coverage
  - Temporal coverage
- Adding paleo-earthquakes to historical-instrumental catalog?
  - Additional issue of departure from truncated exponential in limited source areas
- Model(s) not yet ready for prime time

Structure-Specific RLME Sources

- Developed logic trees to address
  - Association with specific geologic structures
  - Alternative configuration of source
  - Earthquake size distribution
  - Maximum magnitude
  - Earthquake occurrence data
  - Earthquake occurrence model
  - Specification of earthquake occurrence parameters
  - Modeling of earthquake ruptures in the seismic source

Spatially Varying Seismicity Variable “a” Constant “b”

- Assumes that the *b*-value is the same at all locations within the source region
- Spatial variation in activity rate computed using kernel density estimation (equivalent to USGS hazard mapping approach)
- Uncertainty in overall seismicity parameters is largely decoupled from estimation of spatial density

Testing for Spatial Non-Uniformity

- Musson (2000) proposed following test
  - Compute average nearest neighbor distance between earthquakes, $\overline{D}$
  - For Poisson spatial process (uniform spatial density)

$$\mu_{\overline{D}} = \frac{1}{2}\sqrt{A/n}$$

$$\sigma_{\overline{D}} = \sqrt{\frac{(4-\pi)A}{4\pi n^2}}$$

  - Use these values to test for departure from Poisson spatial process in sources

One Approach for Spatially Varying Seismicity

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Spatially Varying Seismicity Variable “a” Constant “b”

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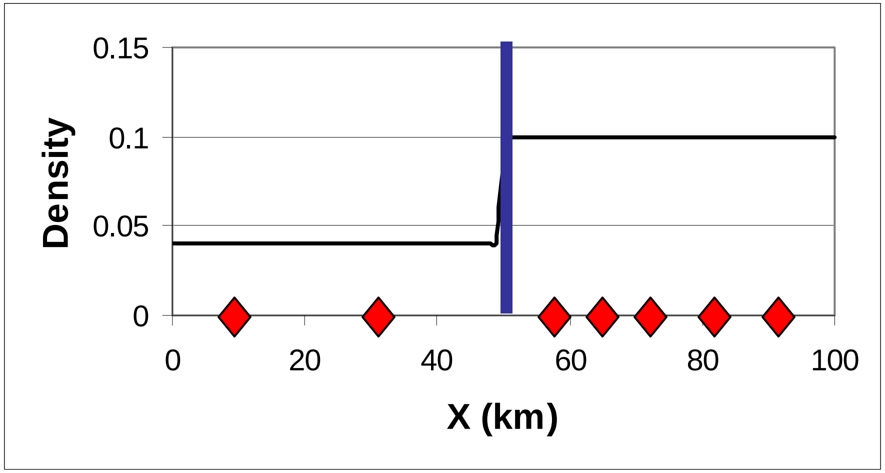
  - Use these values to test for departure from Poisson spatial process in sources

Table 6
Seismotectonic Source Zone Seismicity and Maximum Magnitude Distributions for the “Narrow” Interpretation

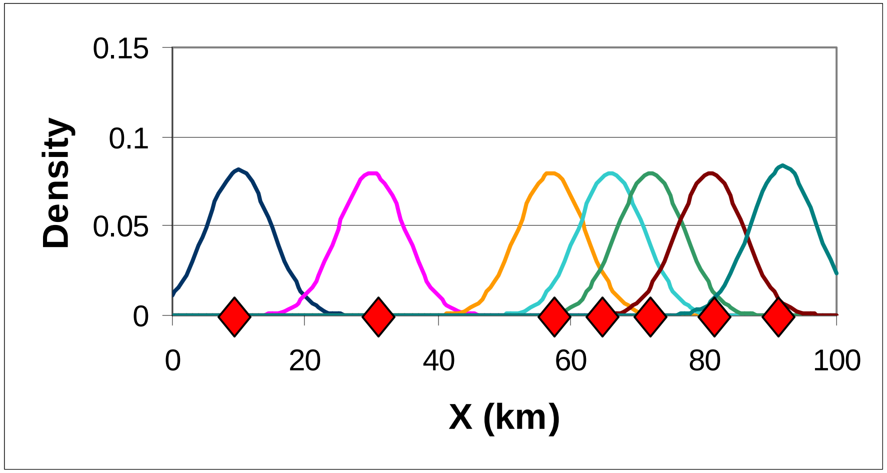
Seismotectonic Source Zone	**Magnitude Weighting Case**	**Degree of Spatial Smoothing [wt]**	**Spatial Density File**	**Seismicity Parameter File**	**Maximum Magnitude Distribution File**
ARM	Full Weight	Low [0.95]	ARM-FW.xyd	ARM-FW.rec	ARM.mmx
		High [0.05]	Uniform		
	Reduced Weight	Low [0.95]	ARM-RW.xyd	ARM-RW.rec	
		High [0.05]	Uniform		
ECC_N	Full Weight	Low [0.95]	ECC_N-FW.xyd	ECC_N-FW.rec	ECC_N.mmx
		High [0.05]	Uniform		
	Reduced Weight	Low [0.95]	ECC_N-RW.xyd	ECC_N-RW.rec	
		High [0.05]	Uniform		
GMH	Full Weight	Low [0.5]	GMH-FW.xyd	GMH-FW.rec	GMH.mmx
		High [0.5]	Uniform		
	Reduced Weight	Low [0.75]	GMH-RW.xyd	GMH-RW.rec	
		High [0.25]	Uniform		
Gulf_C	Full Weight	Low [0.95]	GulfC-FW.xyd	GulfC-FW.rec	GulfC.mmx
		High [0.05]	Uniform		
	Reduced Weight	Low [0.8]	GulfC-RW.xyd	GulfC-RW.rec	
		High [0.2]	Uniform		

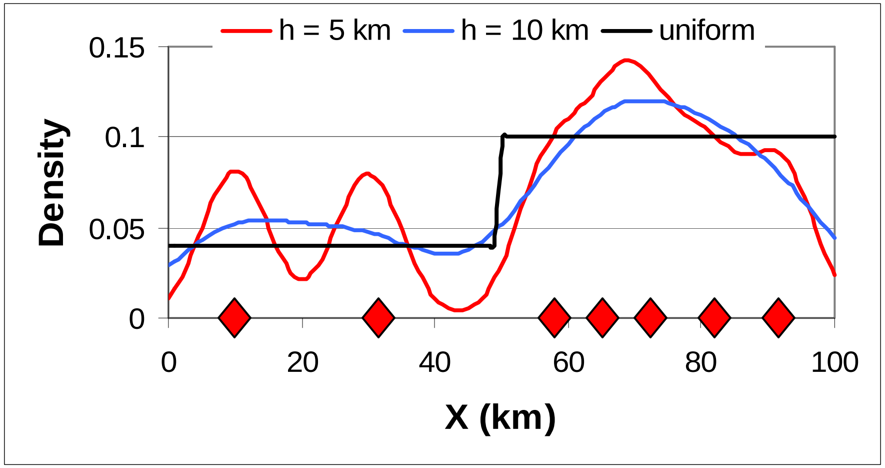
Kernel Density Estimation in 1-D

“Classical” Uniform Density
Two sources: 0 - 50 and 50 - 100



Gaussian Kernels with h = 5

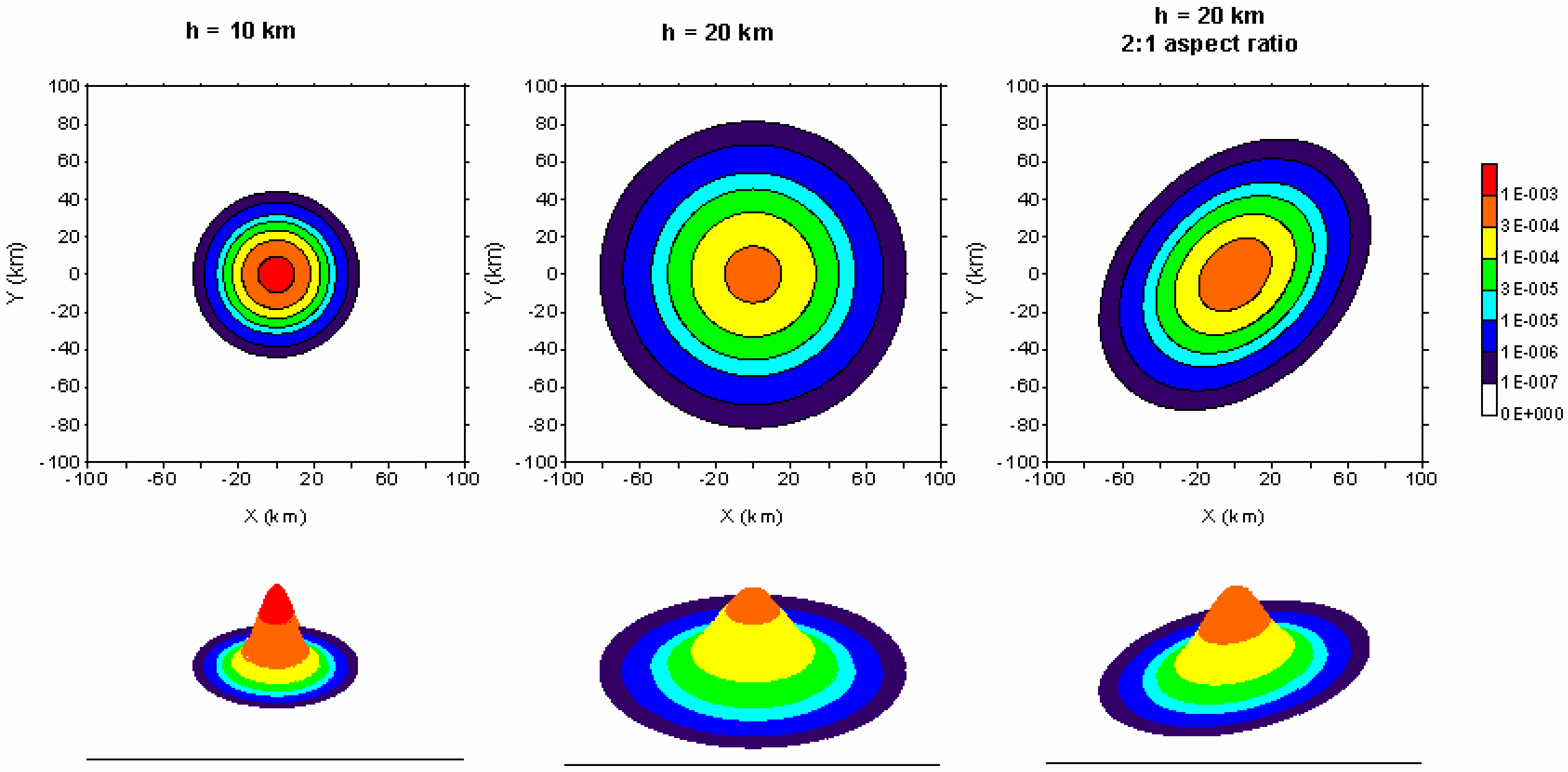




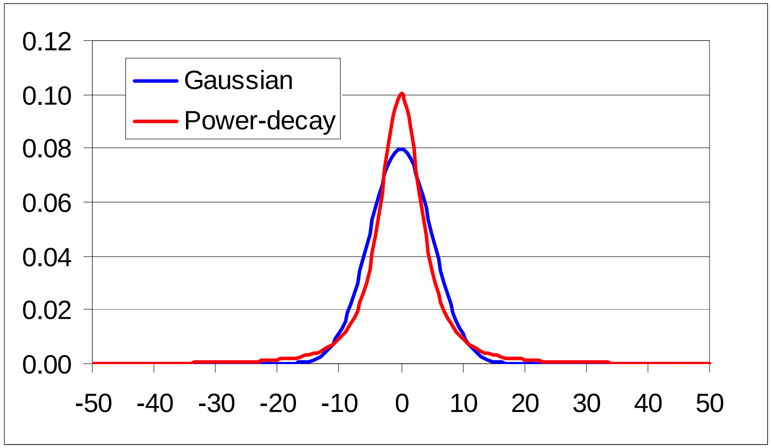
Defining the Kernel

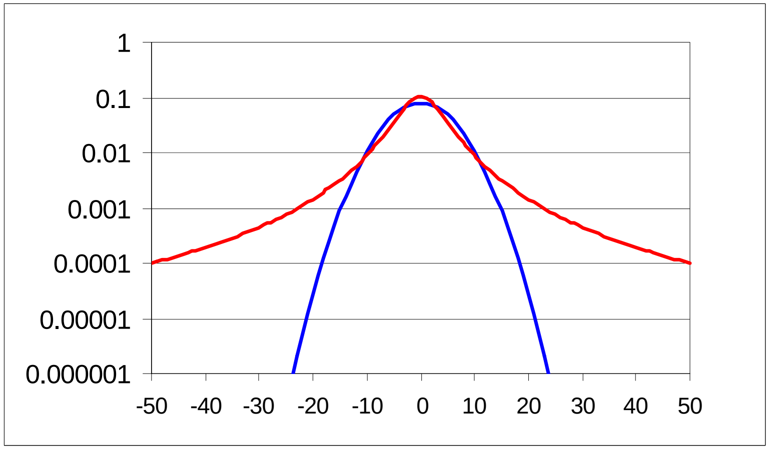
- Size – most important parameter
- Shape – can be used to address preferential direction
- Kernel form

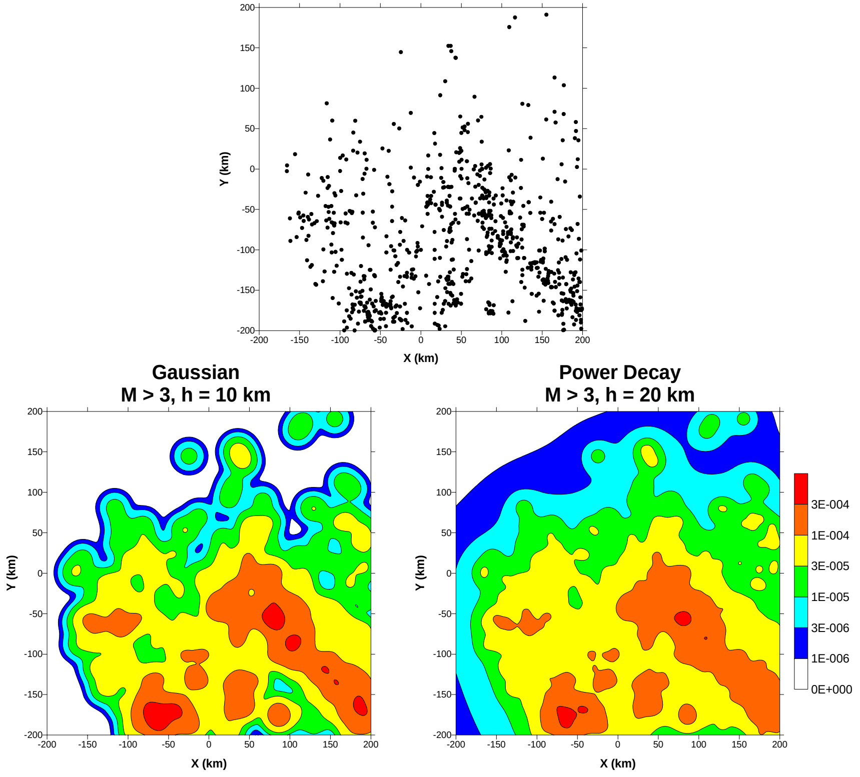
Gaussian Kernels



Alternate Kernel Form






Gaussian
M > 3, h = 10 km

Power Decay
M > 3, h = 20 km

Adaptive Kernel

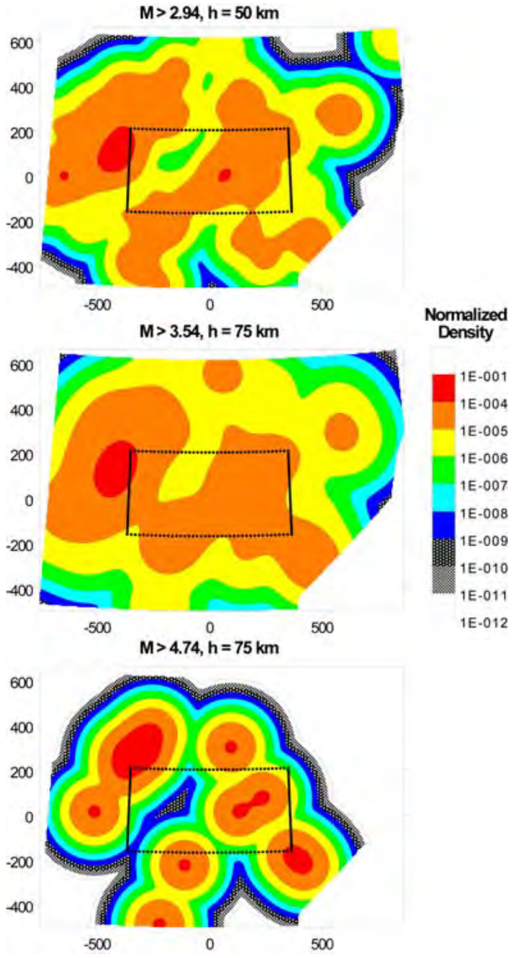
- Adjust kernel size as a function of the data density
  - Size decreases in areas of high data density and increases in area of low data density
  - Kernel adjustment for *i* th earthquake

$$K_i^{Adj} = \sqrt{\frac{\hat{D}}{D_i}}$$

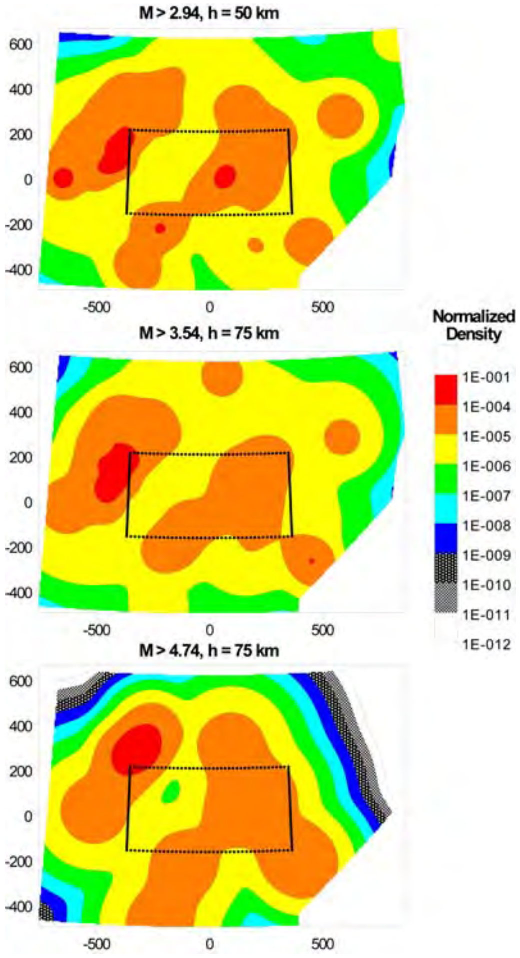
  - Example application in Stock and Smith (2002, BSSA)

Examples

Fixed kernel estimates



Adaptive kernel estimates



Additional Issue – Varying Completeness

- Use minimum completeness for lowest magnitude used (minimum data)
- Weight each earthquake by the relative completeness for each magnitude interval
- Weight each earthquake by the average relative completeness over all magnitude (appears to work best in limited tests)

Process Used for Variable “a” Constant “b”

- High smoothing – use uniform spatial density
- Low smoothing – use adaptive kernel density estimation
  - Use average relative completeness to weight events
  - Select starting kernel size and shape by computing the “optimum” kernel from the data (maximizing the density at event *i* computed from the remaining events)
  - Normalize density to sum to 1 within smoothing region

Estimation of Seismicity Rate

- Maximum likelihood estimation using the entire catalog for the zone, allowing for spatially varying completeness

$$L = \prod_j \prod_i \frac{(\lambda_{i,j} T^E_{i,j})^{n_{i,j}} e^{-\lambda_{i,j} T^E_{i,j}}}{n_{i,j}!} \times e^{-W(\beta-\beta_p)^2/2}$$

$$\lambda_{i,j} = \frac{A_j}{\sum_j A_j} N(m_0) \frac{e^{\beta(m_t - m_0)} - e^{\beta(m_{t+1} - m_0)}}{1 - e^{\beta(m^u - m_0)}}$$

T^E_{ij} is equivalent period of completeness for the ith magnitude interval in the jth portion of the source zone

Distribution for $N(m_0)$ and β

1. Compute relative likelihoods for a grid of $N(m_0)$ and β values
2. Normalize relative likelihoods from 1. to develop joint distribution
3. Compute marginal distribution for $N(m_0)$ from 2. and represent by 3-point discrete distribution
4. For each $N(m_0)$ compute conditional distribution for β from 2. and represent by 3-point discrete distribution.
5. Result is a 9-point joint distribution that captures the correlation between $N(m_0)$ and β

Characterization of Variable Seismicity: Penalty Approach with Variable a and b

Presentation by
Gabriel R. Toro, Risk Engineering, Inc

EPRI CEUS Seismic Source Characterization
Workshop III

Palo Alto, CA; August 25-26, 2009

William Lettis & Associates, Inc.

Outline

- Quick overview of EPRI 1988 approach (Veneziano & Van Dyke, 1988)
- New features & solution algorithm
- Some results
- Conclusions
- To do

Overview of EPRI Approach (Veneziano and VanDyke)

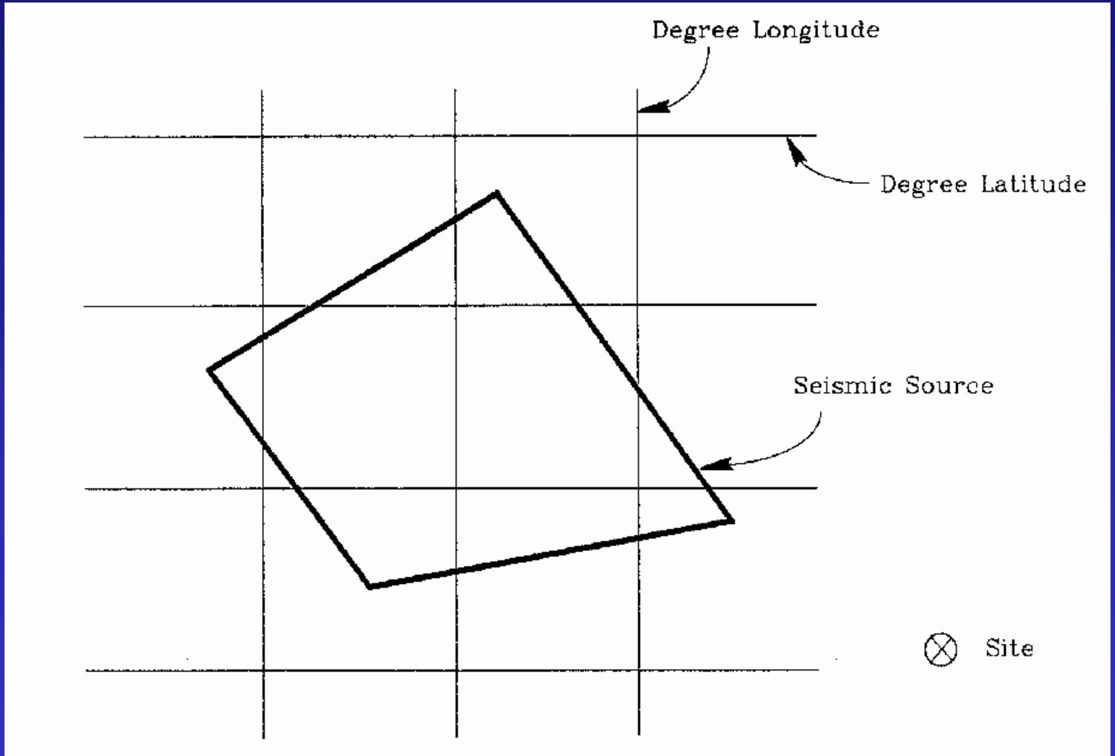


Figure 4-2. Illustration of a seismic source divided into a grid of one-degree cells.

- Source zone is divided by lat-lon grid
- Zone geometry is honored (counting events, PSHA)

Veneziano & Van Dyke: Model

- Within cell: Model:

$$n_i(m < M \le m + dm) = A_i T_E(m,i)\exp[\alpha_i + \beta_i(m-3)]dm$$

Likelihood formulation based on Poisson events+exponential distribution of magnitude (Aki, 1965;…; Weichert, 1980).

- Smoothness penalty functions (prior distribution on roughness) for α and β

$$\bar{\alpha}_i = \frac{1}{n}\sum_{i=1}^{n(\text{neighbors})} \alpha_j \qquad f_{\Delta\alpha} = \frac{1}{\sqrt{2\pi\sigma_{\Delta\alpha}}}\exp\left[-\frac{1}{2}\left(\frac{\alpha_i - \bar{\alpha}_i}{\sigma_{\Delta\alpha}}\right)^2\right]$$

*** Typo in eq. fixed after presentation**

Veneziano & Van Dyke: Model (cont'd)

- Prior distribution on b

$$f_b = \frac{1}{\sqrt{2\pi}\,\sigma_b}\exp\left[\frac{1}{2}\left(\frac{b-b_{prior}}{\sigma_b}\right)^2\right]; \quad b = \frac{\beta}{\ln(10)}$$

*** Typo in eq. fixed after presentation**

- Magnitude weights (down-weight lower magnitudes; modifies likelihood)

$$\Rightarrow p(\mathbf{X}) = l\,(\alpha_{1,2,\ldots,n}, \beta_{1,2,\ldots,n},;\text{catalog, completeness, weights})\, f_{\Delta\alpha}\, f_{\Delta\beta}\, f_b$$

$$\mathbf{X} = [\alpha_{1,2,\ldots,n}, \beta_{1,2,\ldots,n}; \sigma_{\Delta\alpha}, \sigma_{\Delta\beta}]$$

New Features

- Use ¼ degree cell size
- Use updated catalog and completeness
- New solution algorithm provides additional capabilities:
  - Estimates of uncertainty in α and β
    - Estimates at each cell
    - Alternative maps of α and β
  - Objective estimation of penalty terms

Solution algorithm: Markov-Chain Monte Carlo (MCMC)

- Simulate realizations of a Markov chain with “state” **X**
- Metropolis et al.: if transition probabilities are defined in a certain way, the stationary distribution of **X** is the desired posterior distribution p(**X**)

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Metropolis algorithm

- Generate candidate state **X’** from current state $\mathbf{X}^{(t)}$ by sampling at random from a “proposal distribution” (must be symmetrical)
- Accept candidate state **X’** with probability

$$P_{\text{accept}} = \min\left(1, \frac{p(\mathbf{x}')}{p(\mathbf{x}^{(t)})}\right)$$

- After “burn-in” period, compute statistics of $\mathbf{X}(t_1)$, … $\mathbf{X}(t_n)$
  - →best estimates of α’s & β’s
  - →uncertainties in α’s & β’s

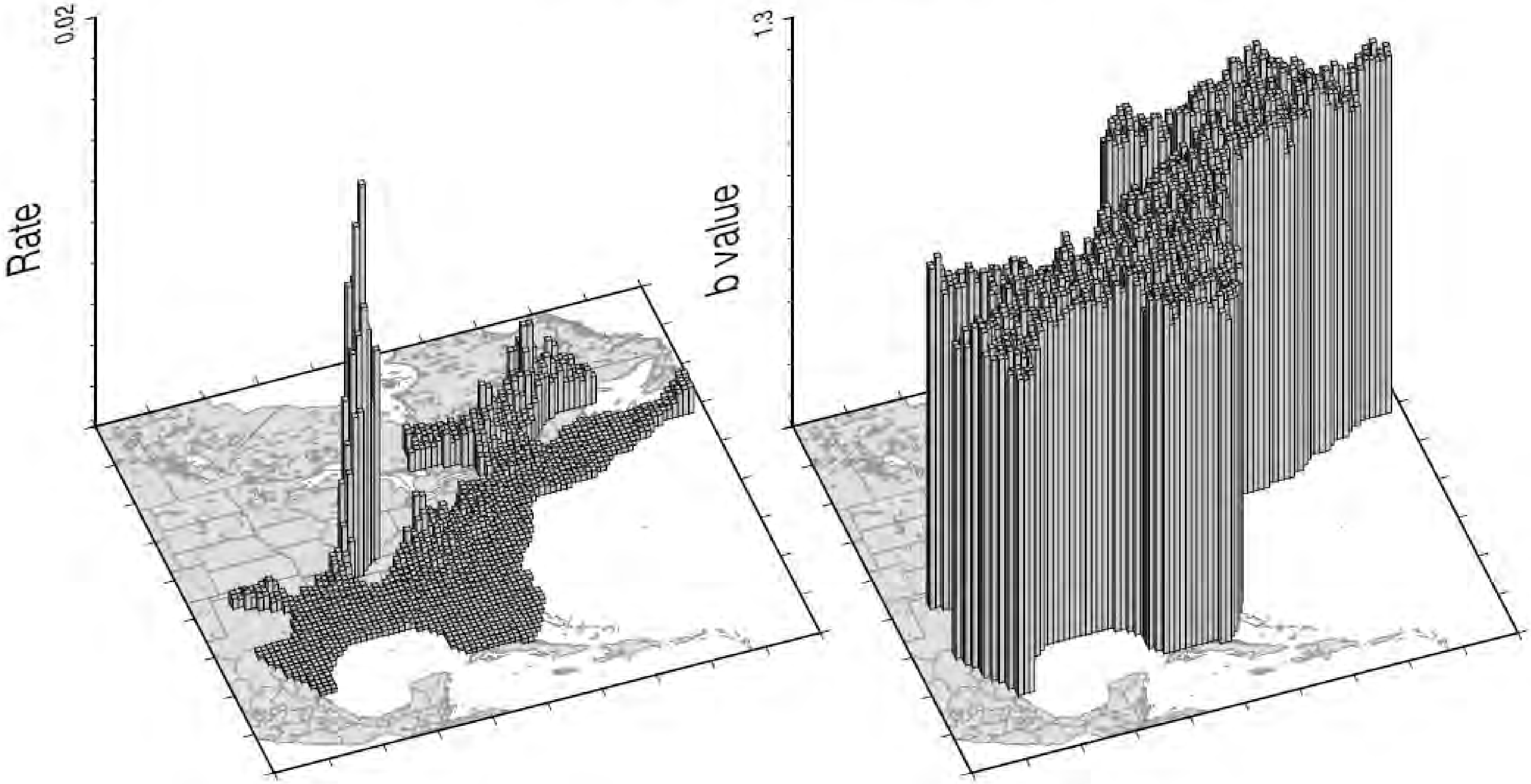
Note: t **does not** represent time

Application: Cases Considered

- Low Smoothing
  - objectively determined smoothness penalty terms
  - low prior of b=1 (sigma=0.4; equivalent to “weak prior” in EPRI, 1988)
  - Full and reduced weights
- High Smoothing
  - Fixed smoothness penalty terms (σ_Δ’s equivalent to “high smoothing” in EPRI, 1988)
  - No prior on b
  - Full and reduced weights

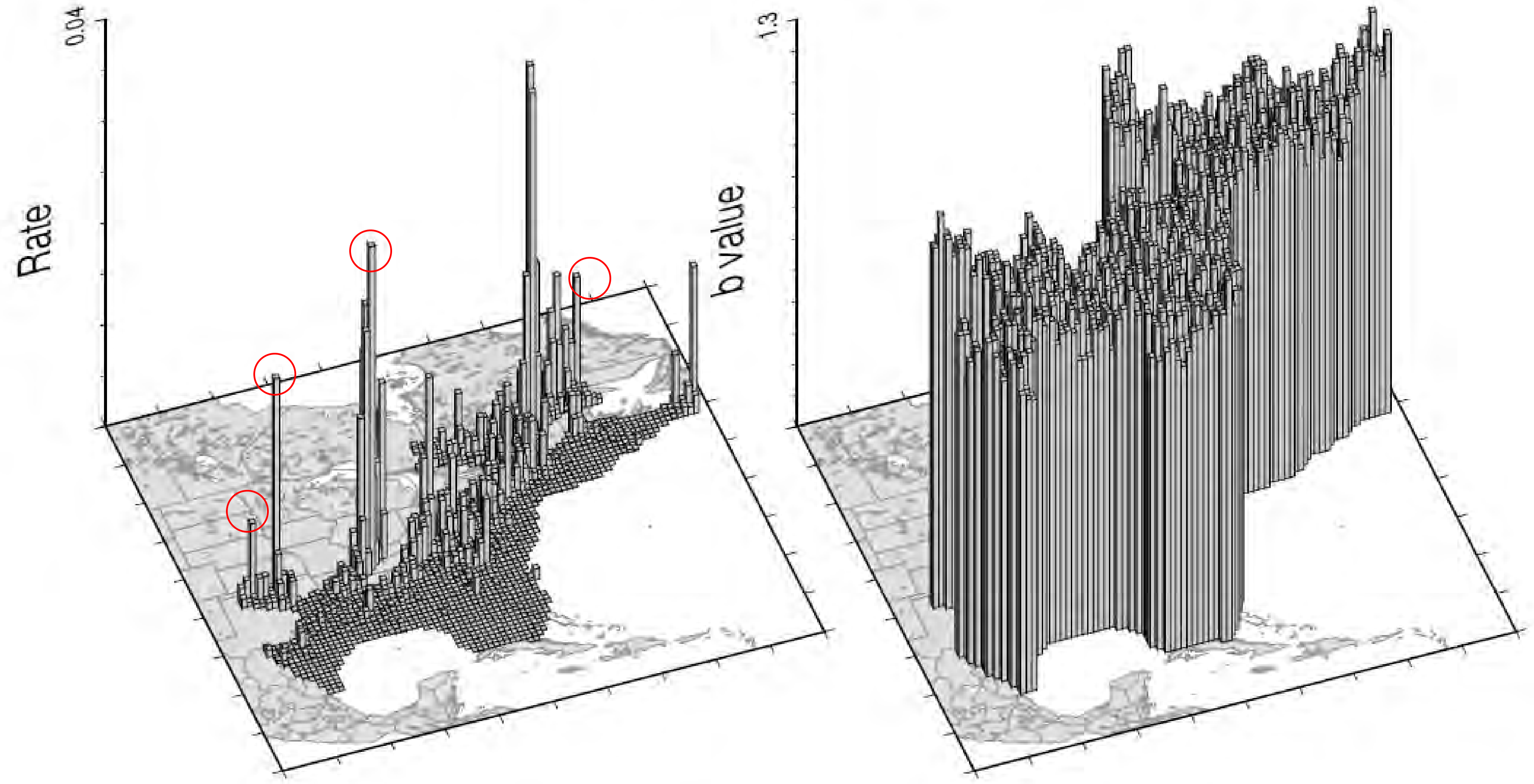
Extended Crust narrow - high smoothing - full weights

EXT_N_HSFWH_MED_XYAB

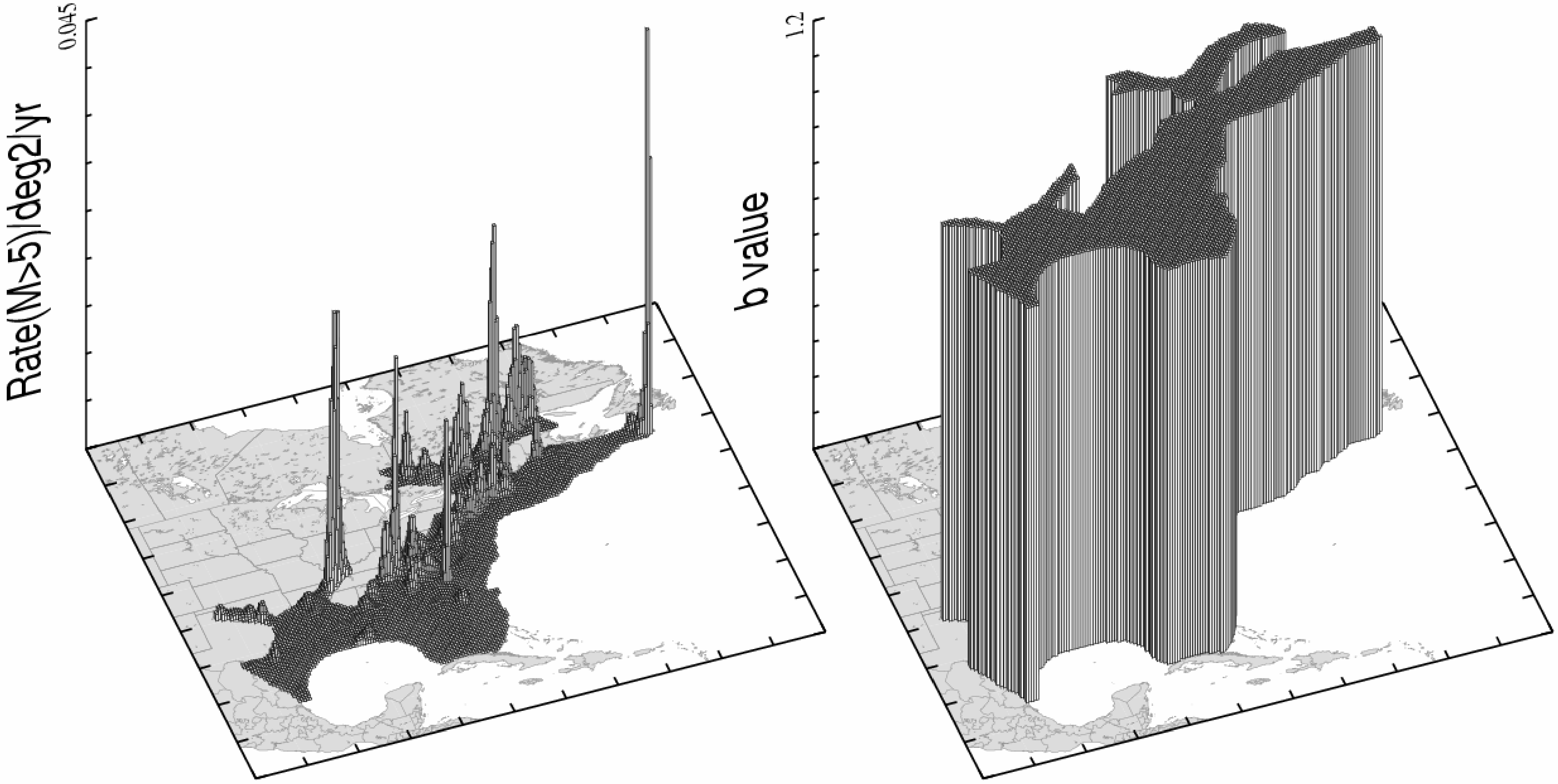


Extended Crust narrow - low smoothing - full weights

EXT_N_LSFWH_MED_XYAB

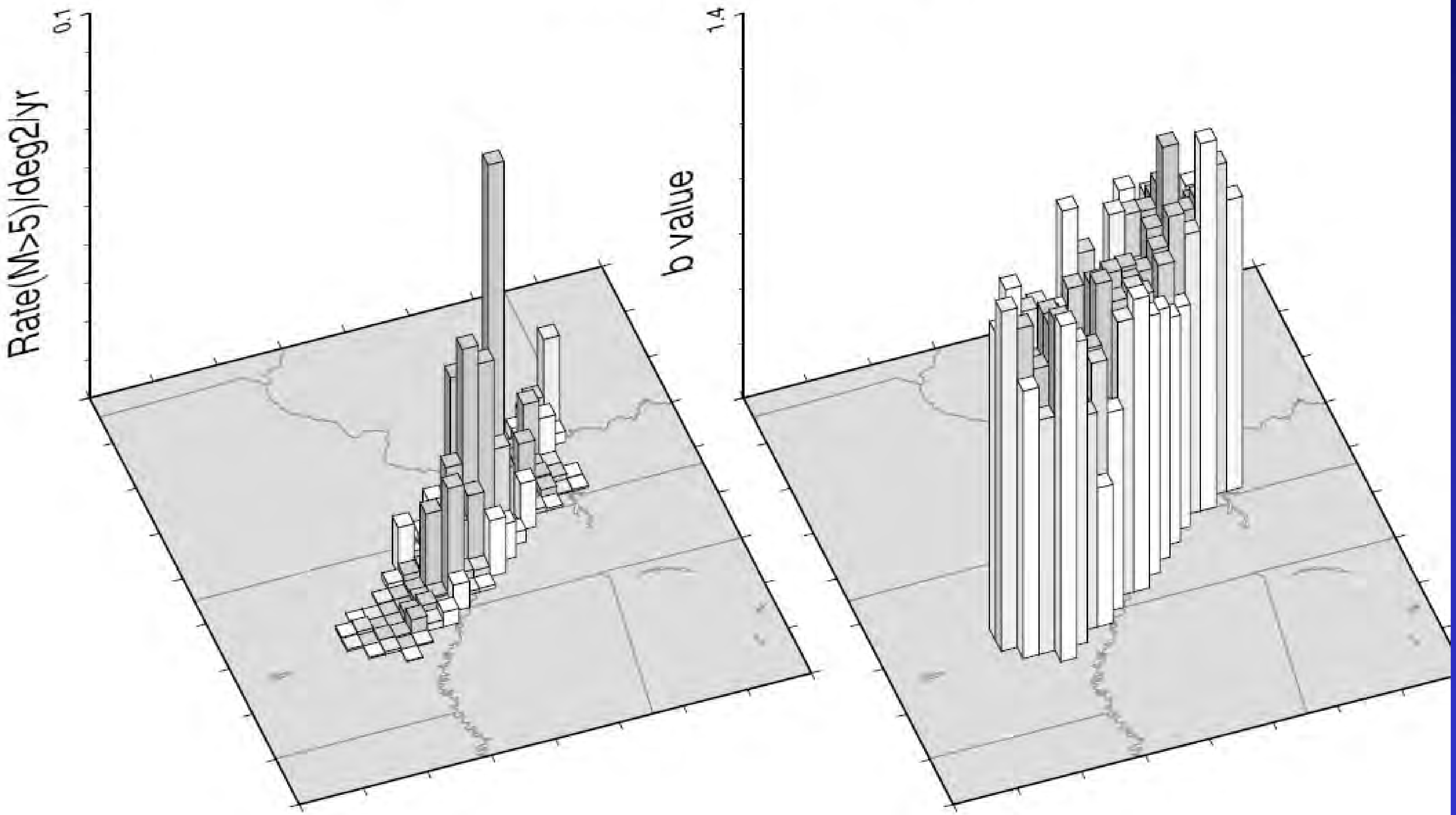


EXT_N-FW_05_XYAB

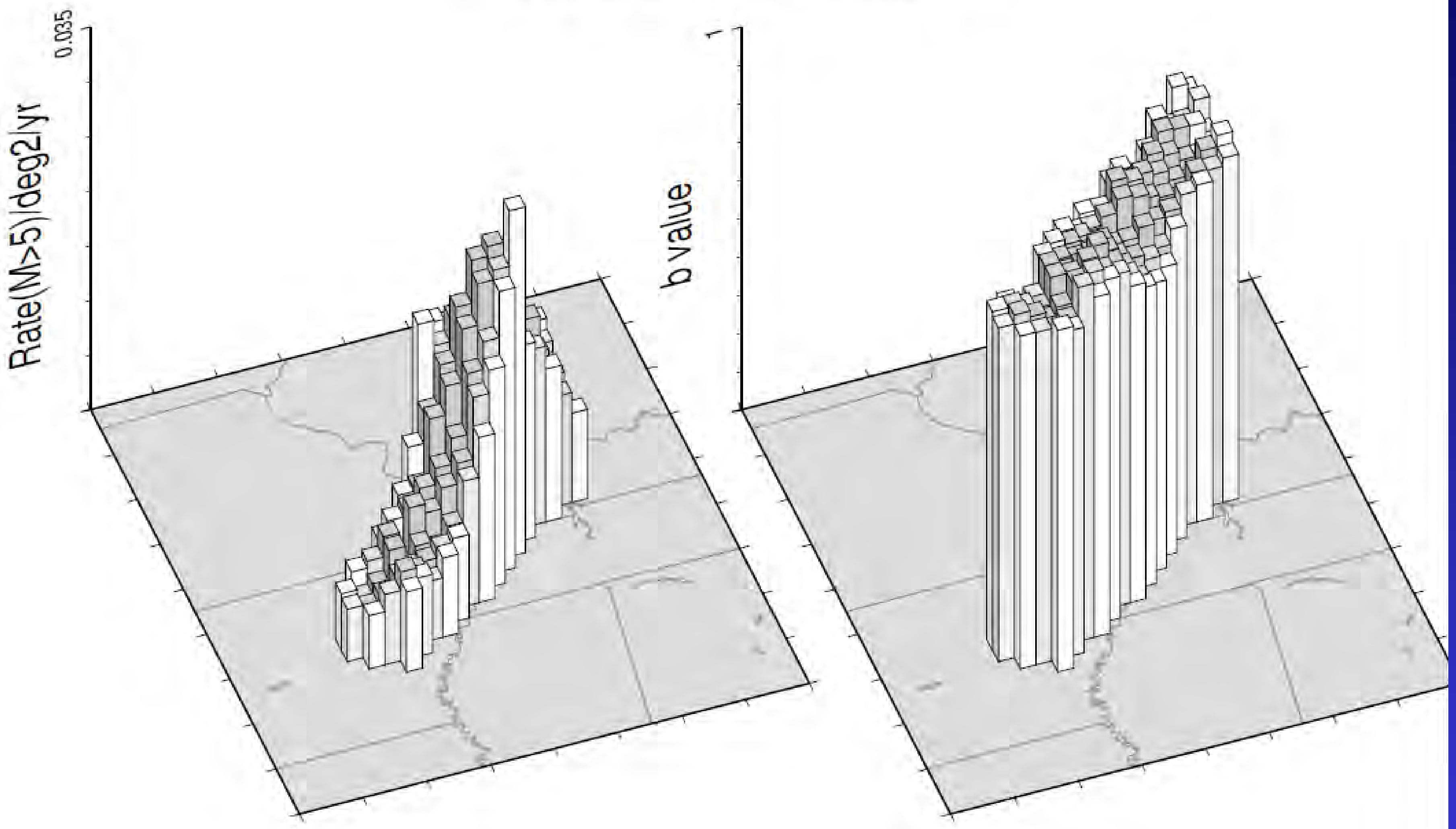


Reelfoot Rift narrow - low smoothing - full weights

RFRIFT_N_LSFW_MED_XYAB



Reelfoot Rift narrow - high smoothing - full weights
RFRIFT_N_HSFW_MED_XYAB



Characterization of Uncertainty: Alternative Rate/Area and b maps

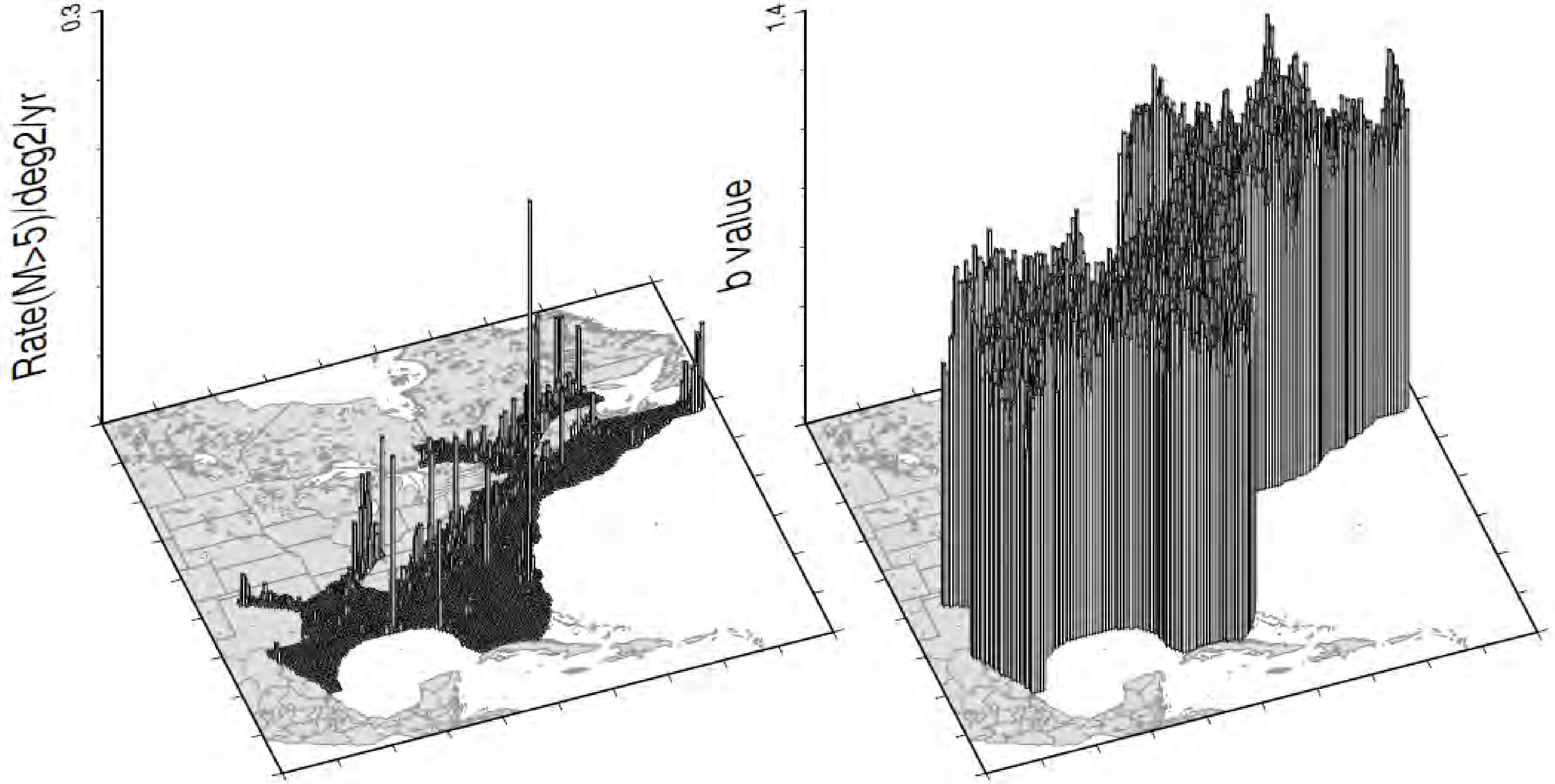
- Objective:
  - Capture within-cell uncertainty in α and β (including correlation)
  - Capture spatial correlation between cells
- Approach
  - Use realizations to construct covariance matrix of **X**
  - Principal component analysis (i.e., eigenvalue analysis of covariance matrix)
    - Eigenvectors: dominant shapes
    - Eigenvalues: variances
  - $\pm$ 1 σ discretization of distributions associated with shapes
  - Randomization:
    - Full enumeration for first three shapes
    - Latin hypercubes for other shapes

→2^3=8 equally likely realizations

Low-Smoothing example

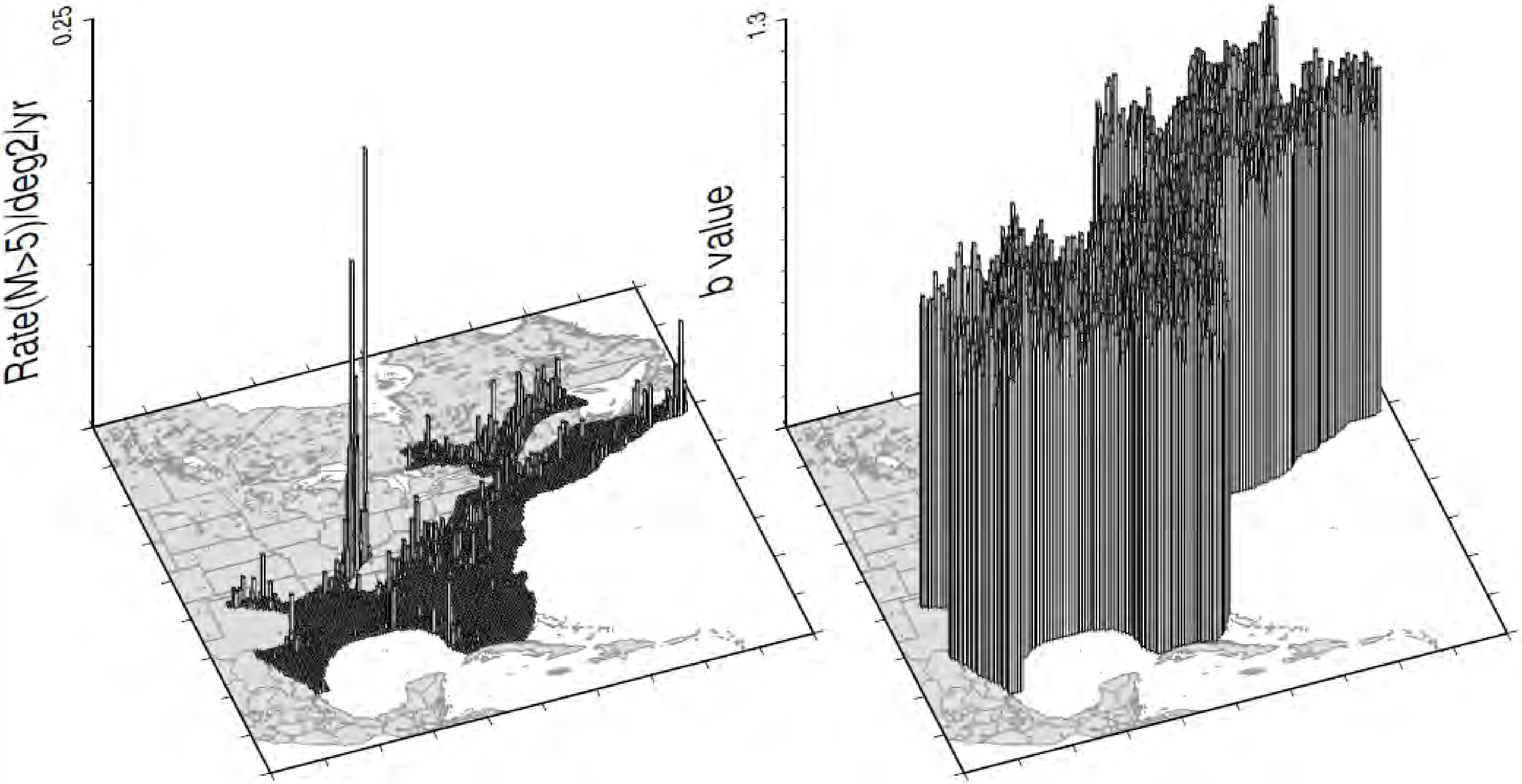
Extended Crust narrow - low smoothing - full weights Realization 01

EXT_N_LSFW_01_XYAB



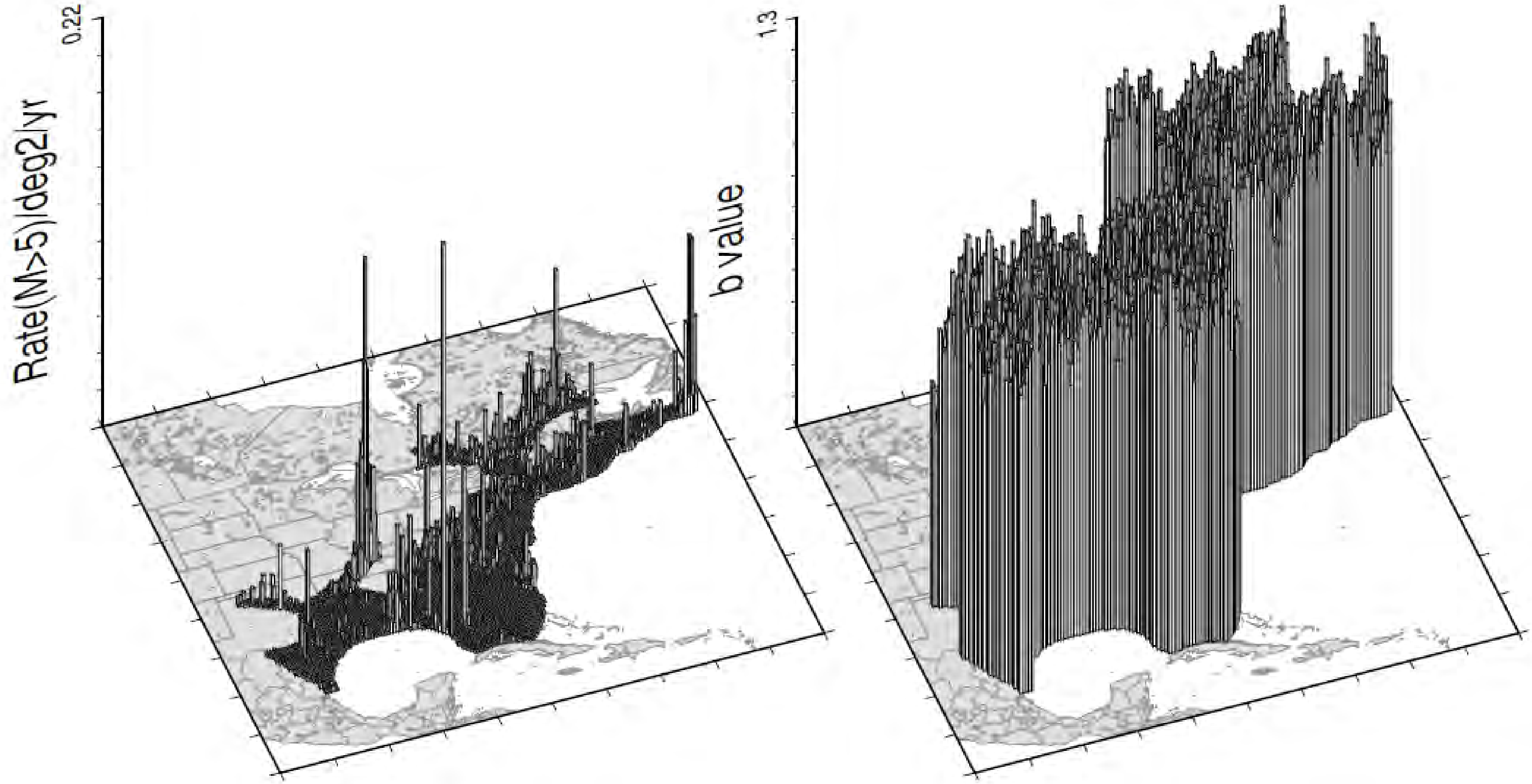
Extended Crust narrow - low smoothing - full weights Realization 02

EXT_N_LSFW_02_XYAB



Extended Crust narrow - low smoothing - full weights Realization 03

EXT_N_LSFW_03_XYAB



High smoothing example

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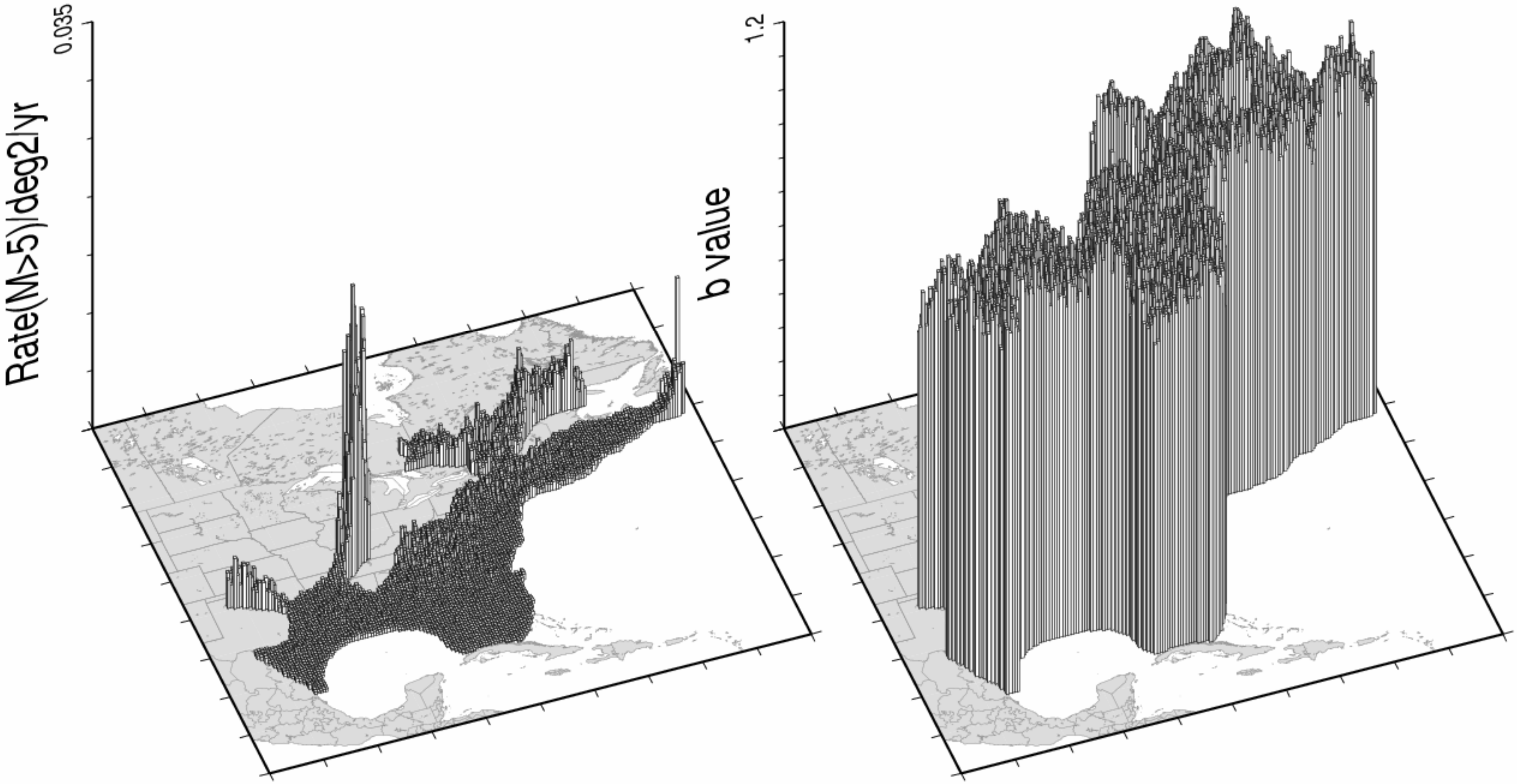
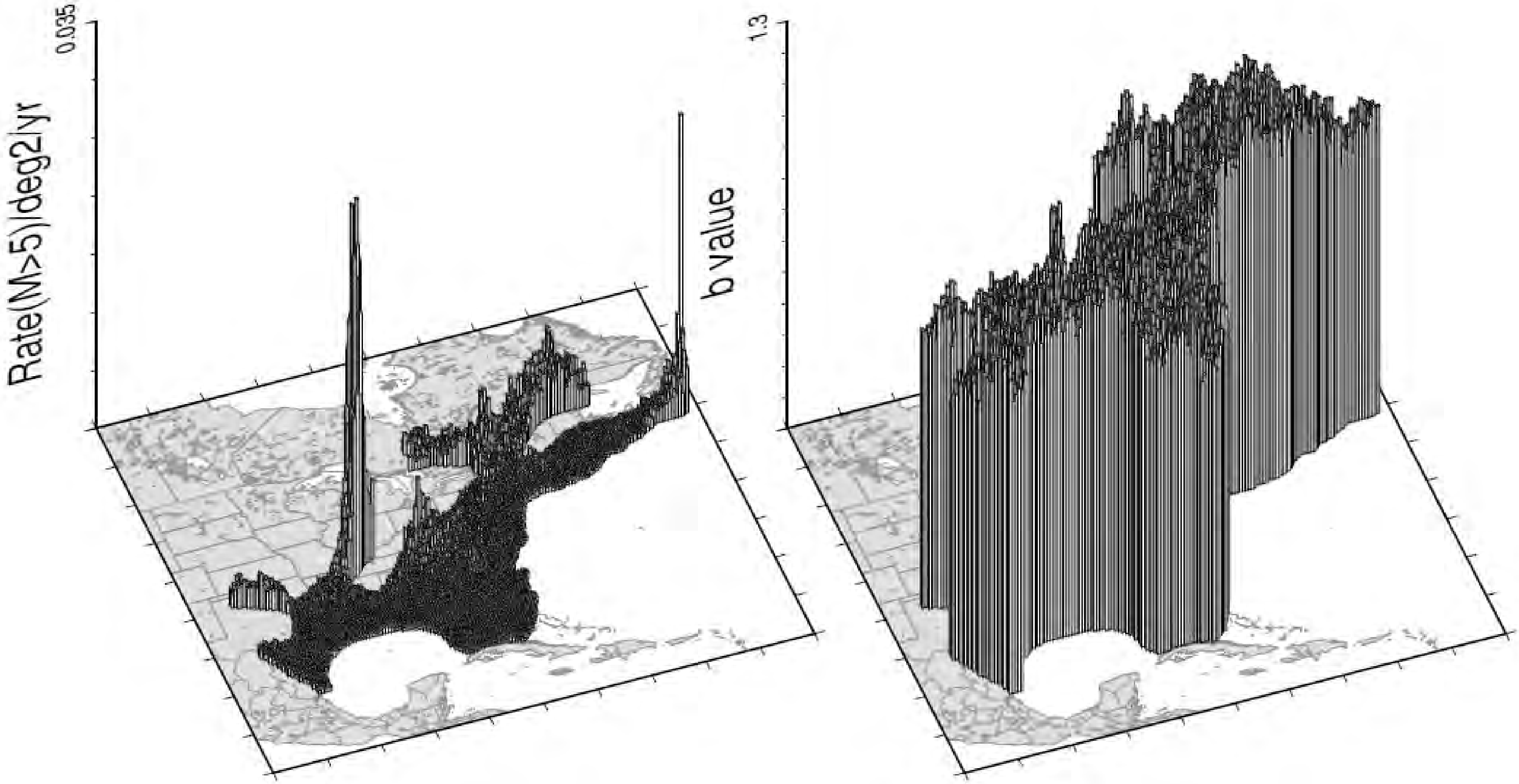
Extended Crust narrow - high smoothing - full weights Realization 01

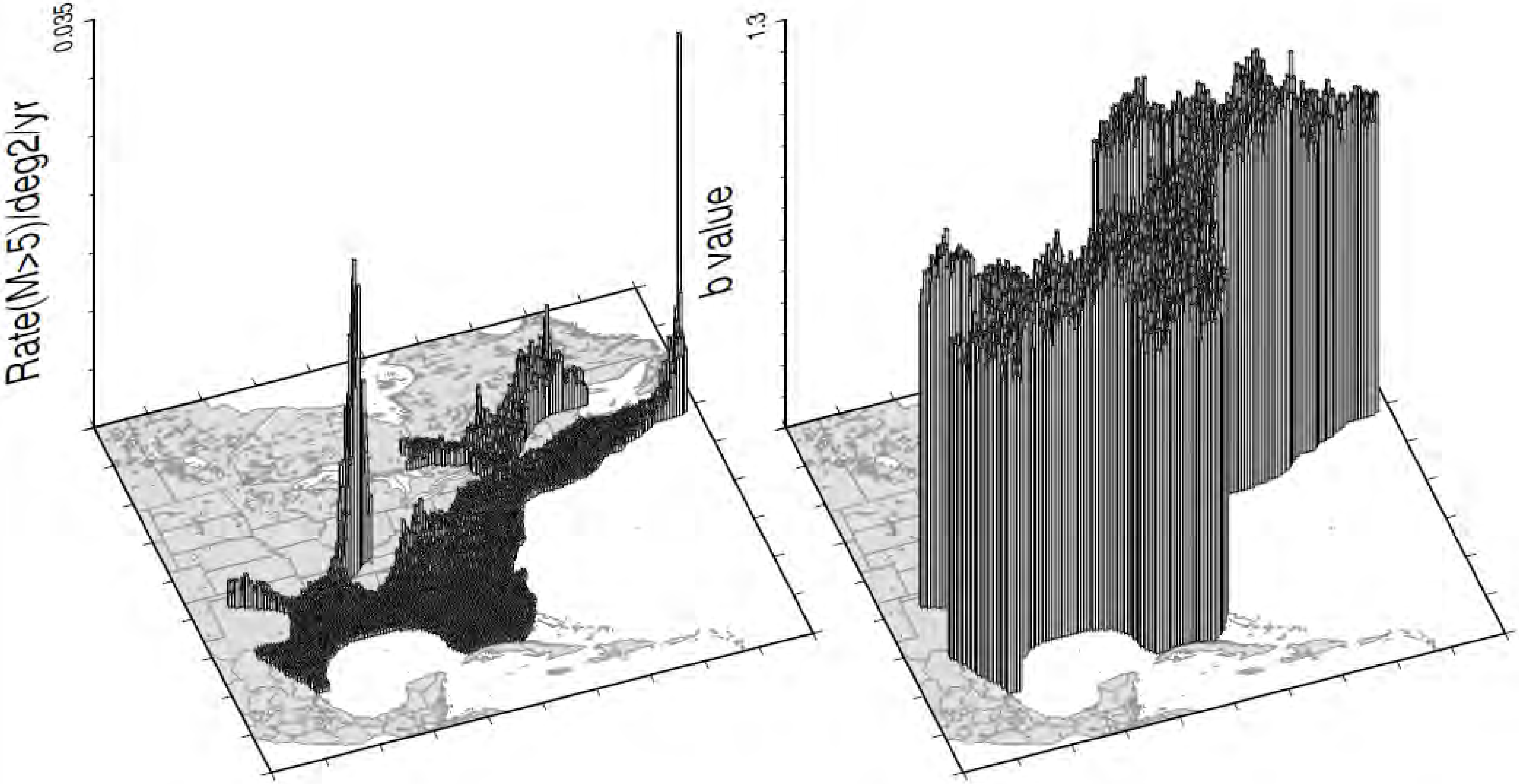
EXT_N_HSFW_01_XYAB



Extended Crust narrow - high smoothing - full weights Realization 02
EXT_N_HSFW_02_XYAB



Extended Crust narrow - high smoothing - full weights Realization 03
EXT_N_HSFW_03_XYAB



Conclusions

- New (actually, re-born) penalized-likelihood procedure provides an alternative model for characterization of seismicity in source zones
- Variable b makes approach particularly suited for large source zone
- Allows both objective (data driven) and subjective specification of smoothing parameters (penalty terms)
- Provides realistic characterization of uncertainty in seismicity within zones
  - Due to limited catalog duration
  - Due to uncertainty in proper level of smoothing (in objective mode)

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To do

- Bias in rate? (predicting 5-30% more events than one would predict with full smoothing)
  - Quantify (hot spots vs. quiet spots; edges vs. interior)
  - Introduce global penalty or Lagrange term to correct bias, if needed
- Edge cells with small area
- Uncertainty in hypocentral location
  - events at or near cell boundaries
  - events with more uncertain locations

Apply Veneziano’s “Salomonic” solution?

- Number of Markov realizations of **X** and jaggedness of maps
- More comparisons with kernel approach
- TI Team and Staff feedback on smoothing parameters, etc.

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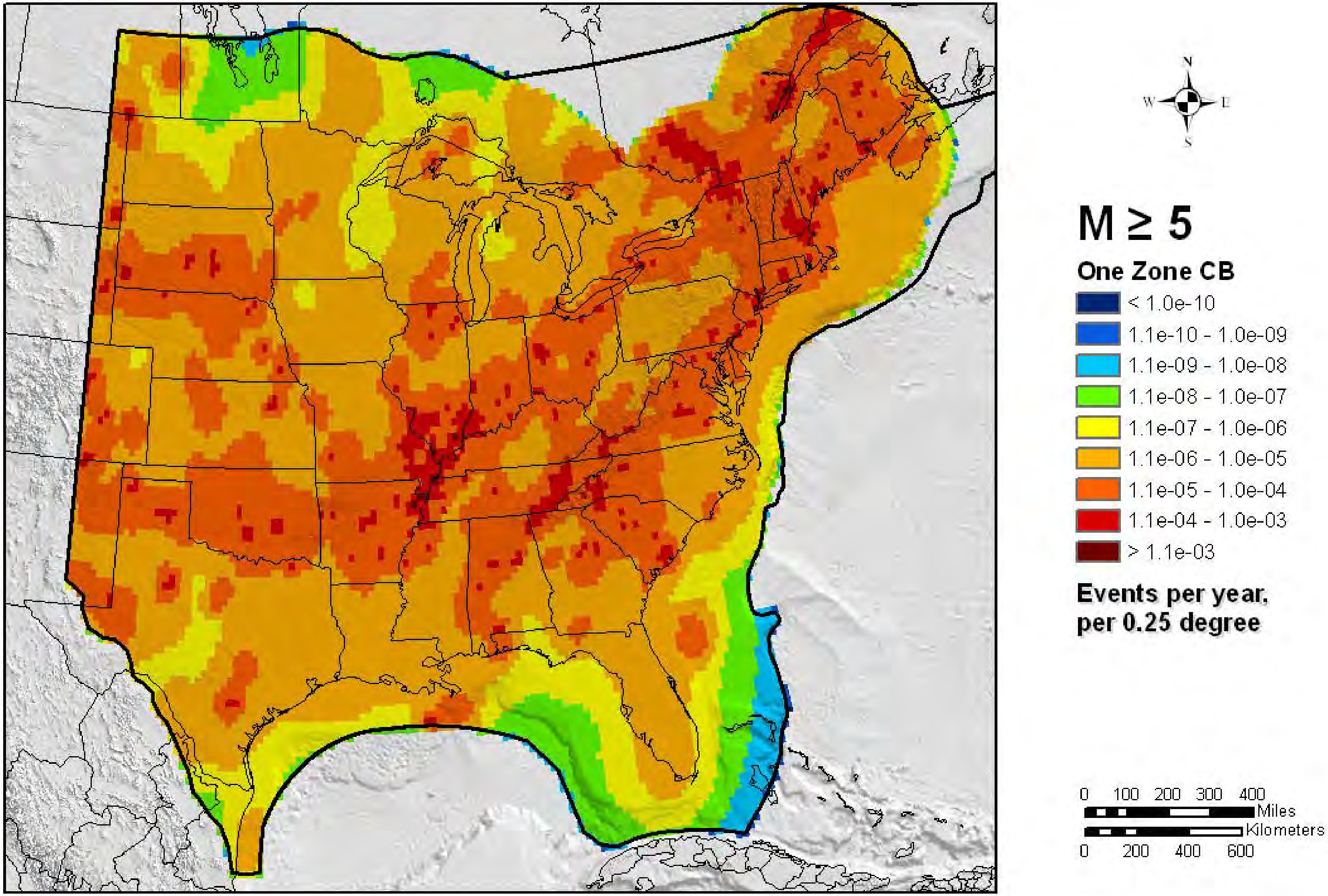
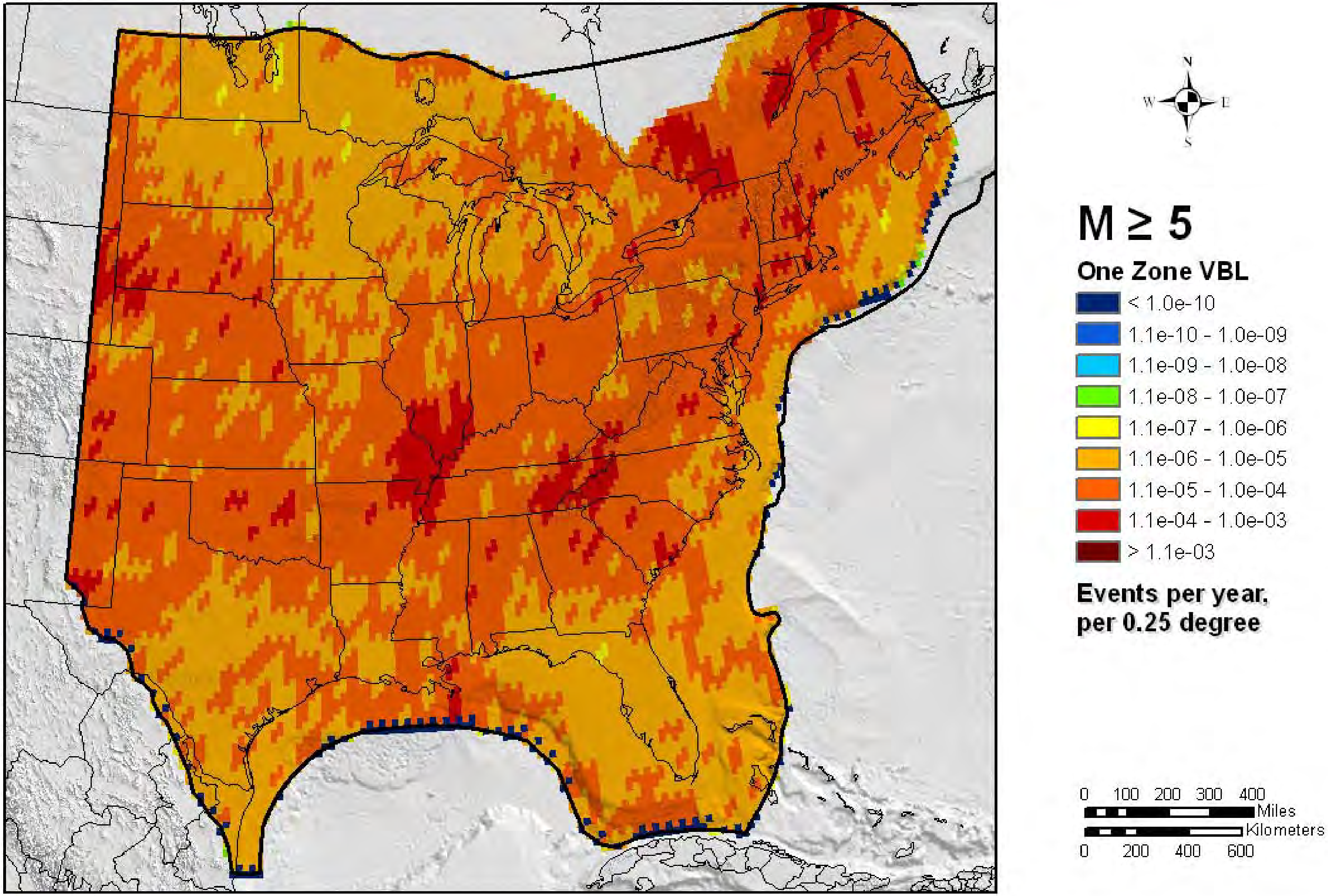
Spatial Density Model of Historical Seismicity



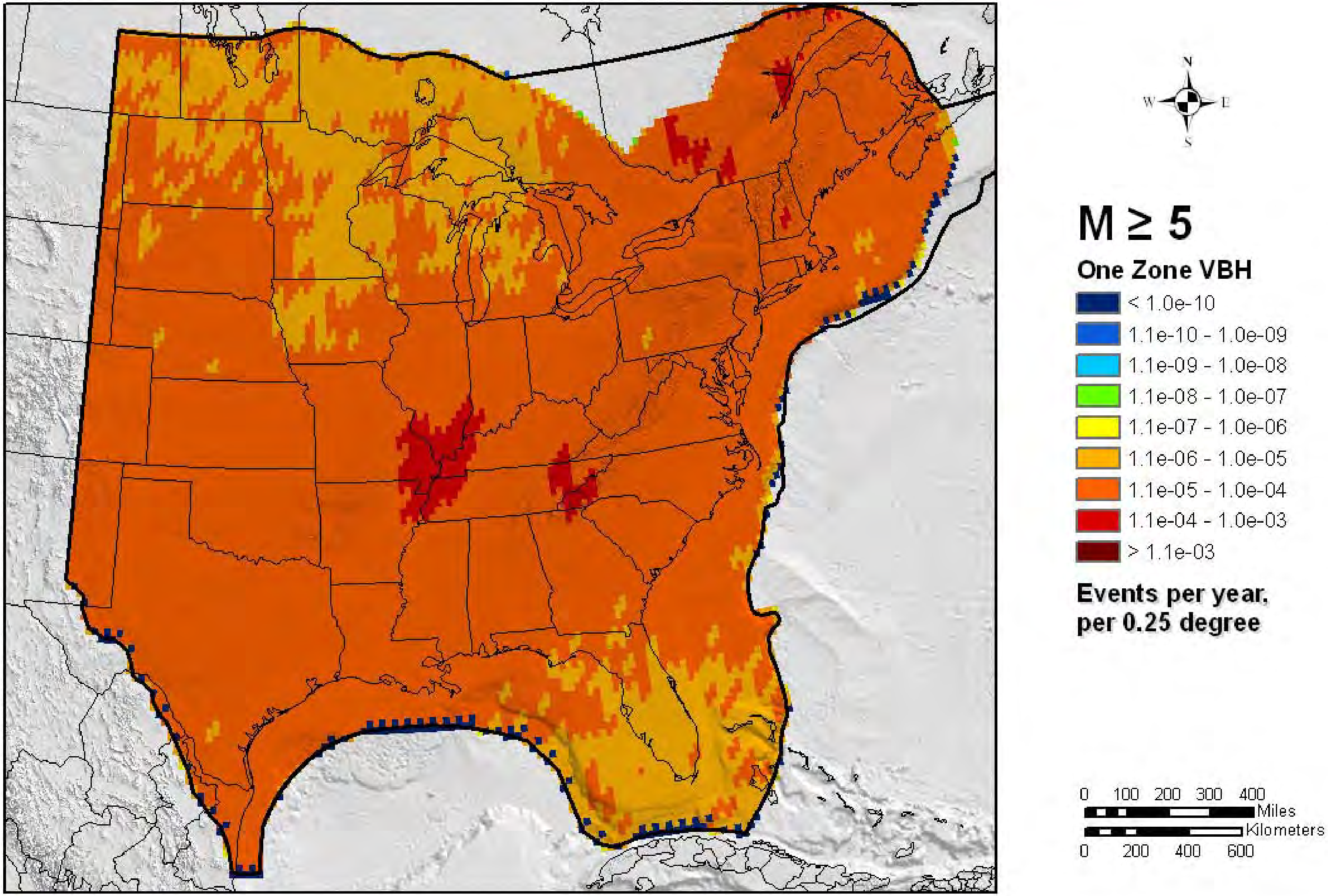
AMEC Geomatrix

Spatial Density Model of Historical Seismicity

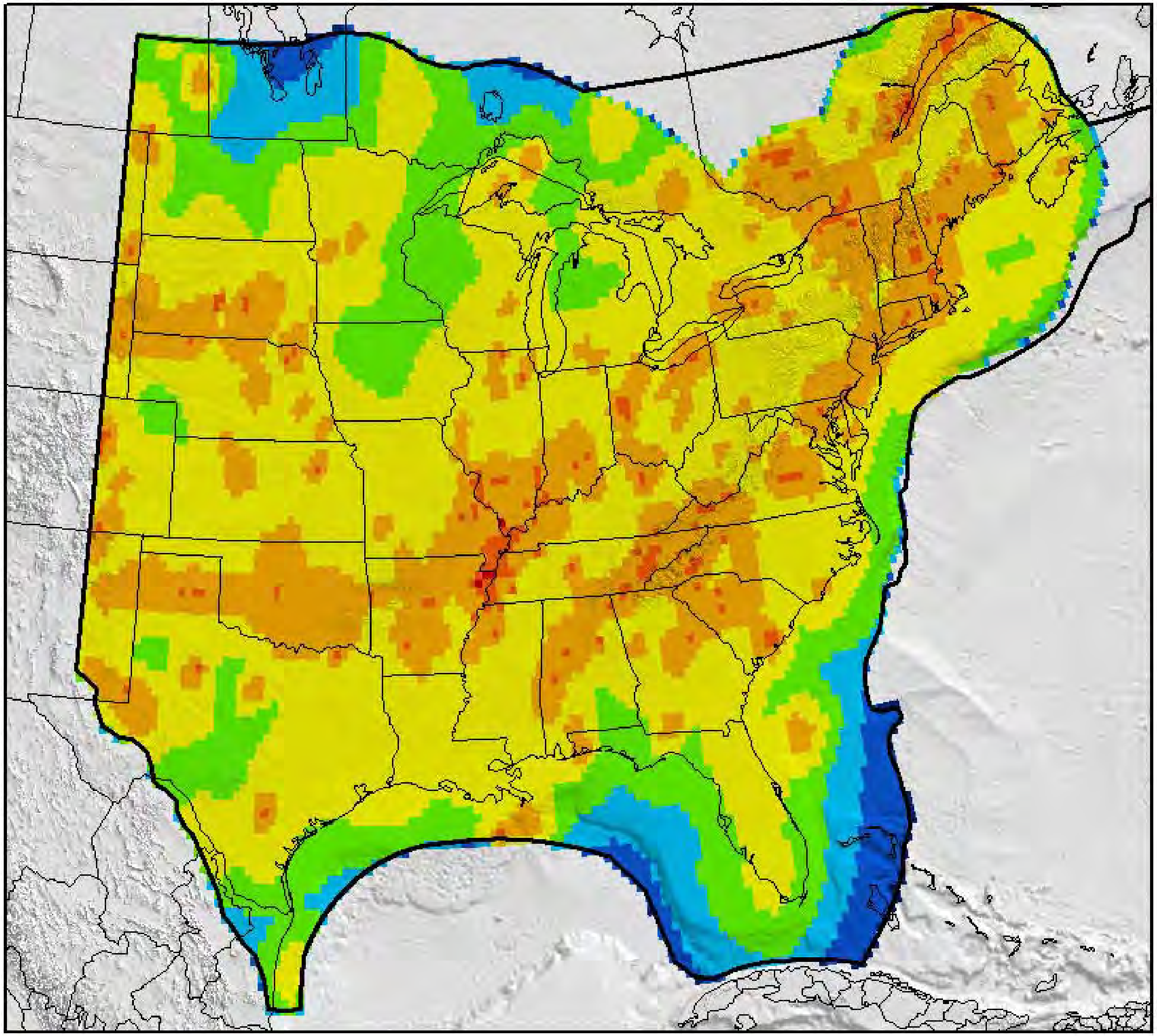


AMEC Geomatrix

Spatial Density Model of Historical Seismicity



Spatial Density Model of Historical Seismicity



N
W E
S

M ≥ 6

One Zone CB

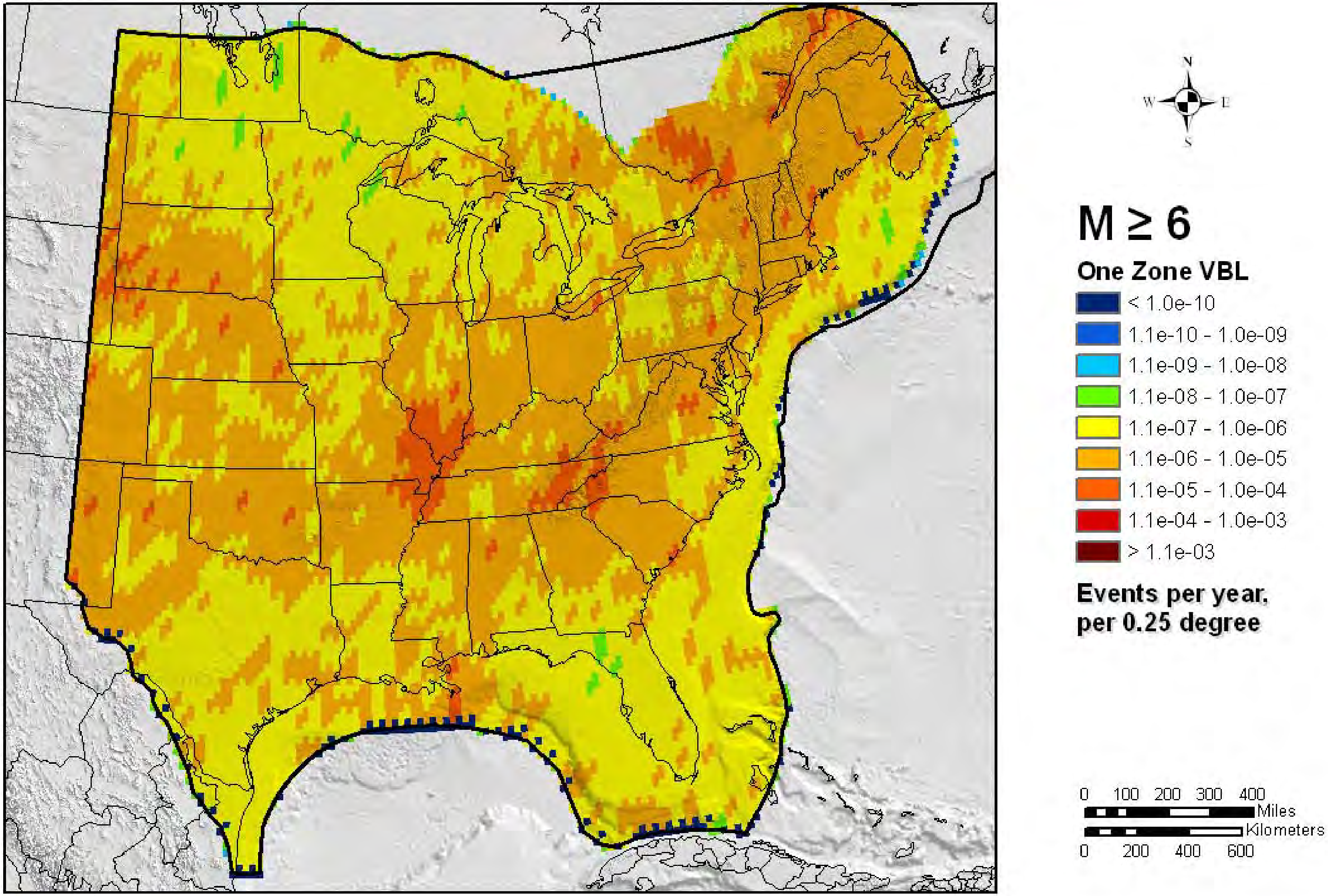
🟦	< 1.0e-10
🟦	1.1e-10 - 1.0e-09
🟦	1.1e-09 - 1.0e-08
🟩	1.1e-08 - 1.0e-07
🟨	1.1e-07 - 1.0e-06
🟧	1.1e-06 - 1.0e-05
🟧	1.1e-05 - 1.0e-04
🟥	1.1e-04 - 1.0e-03
🟫	> 1.1e-03

Events per year, per 0.25 degree

0 100 200 300 400 Miles
Kilometers
0 200 400 600

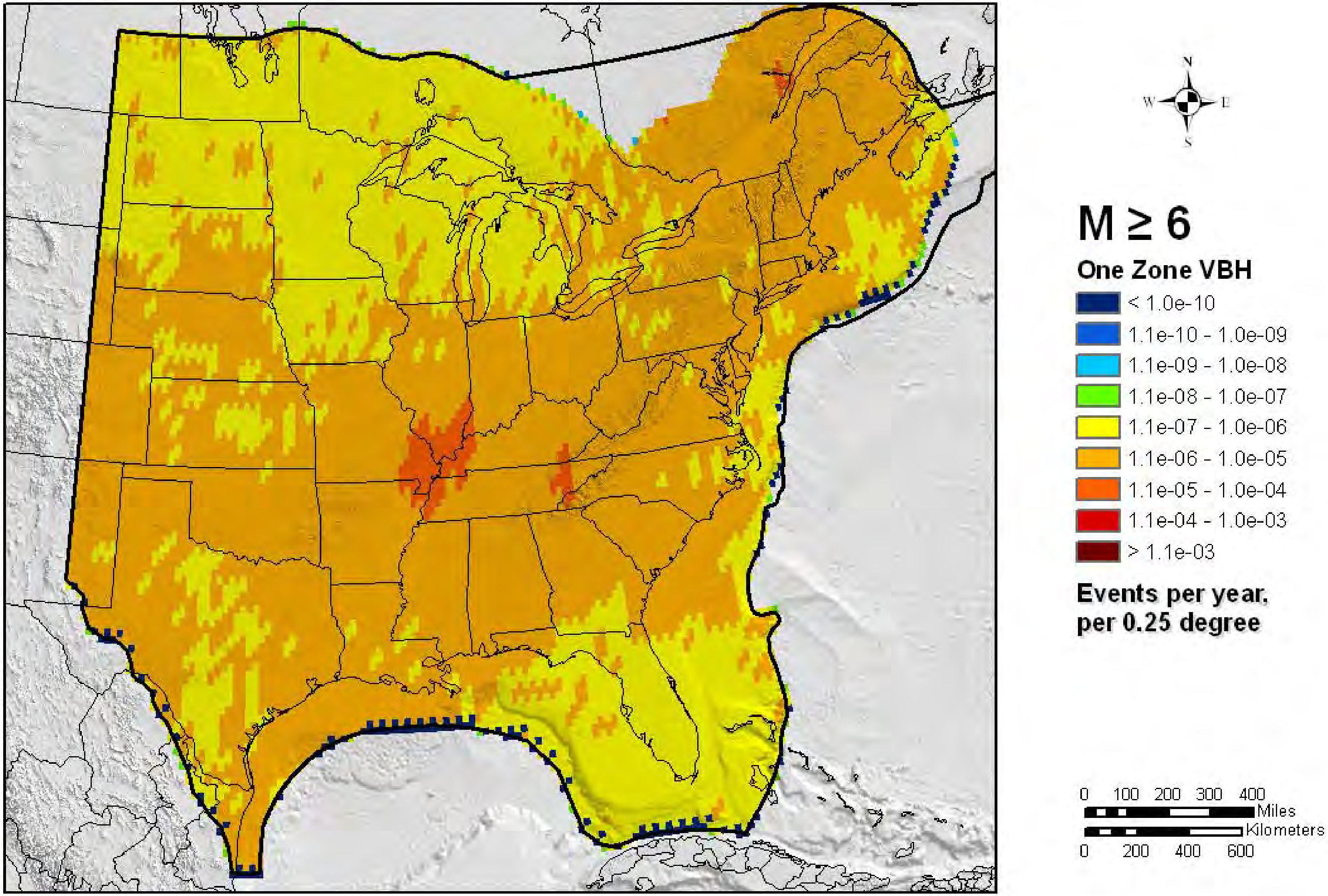
AMEC Geomatrix

Spatial Density Model of Historical Seismicity



AMEC Geomatrix

Spatial Density Model of Historical Seismicity



M ≥ 6

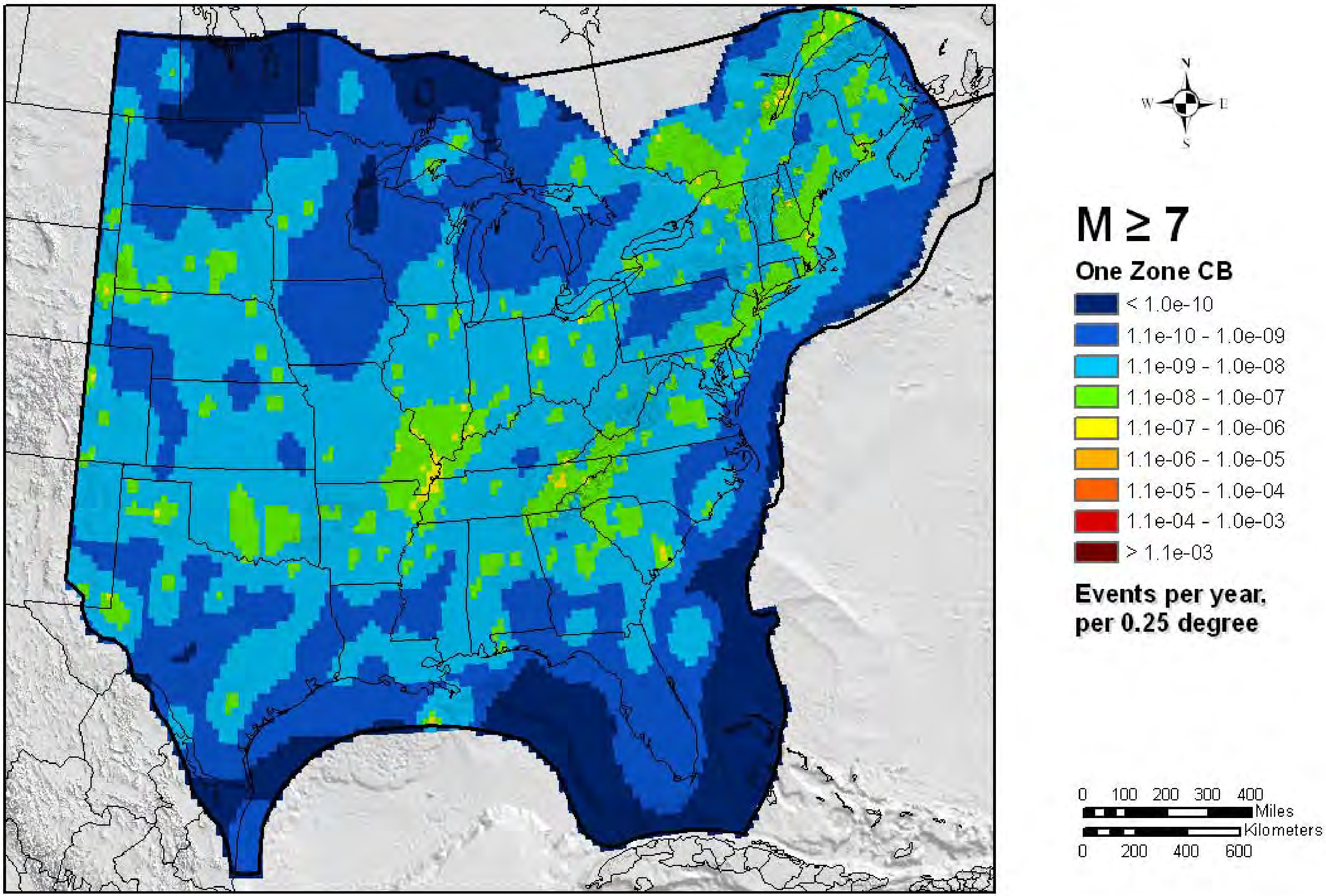
One Zone VBH

- 🟦 < 1.0e-10
- 🟦 1.1e-10 - 1.0e-09
- 🟦 1.1e-09 - 1.0e-08
- 🟩 1.1e-08 - 1.0e-07
- 🟨 1.1e-07 - 1.0e-06
- 🟧 1.1e-06 - 1.0e-05
- 🟧 1.1e-05 - 1.0e-04
- 🟥 1.1e-04 - 1.0e-03
- 🟫 > 1.1e-03

Events per year, per 0.25 degree

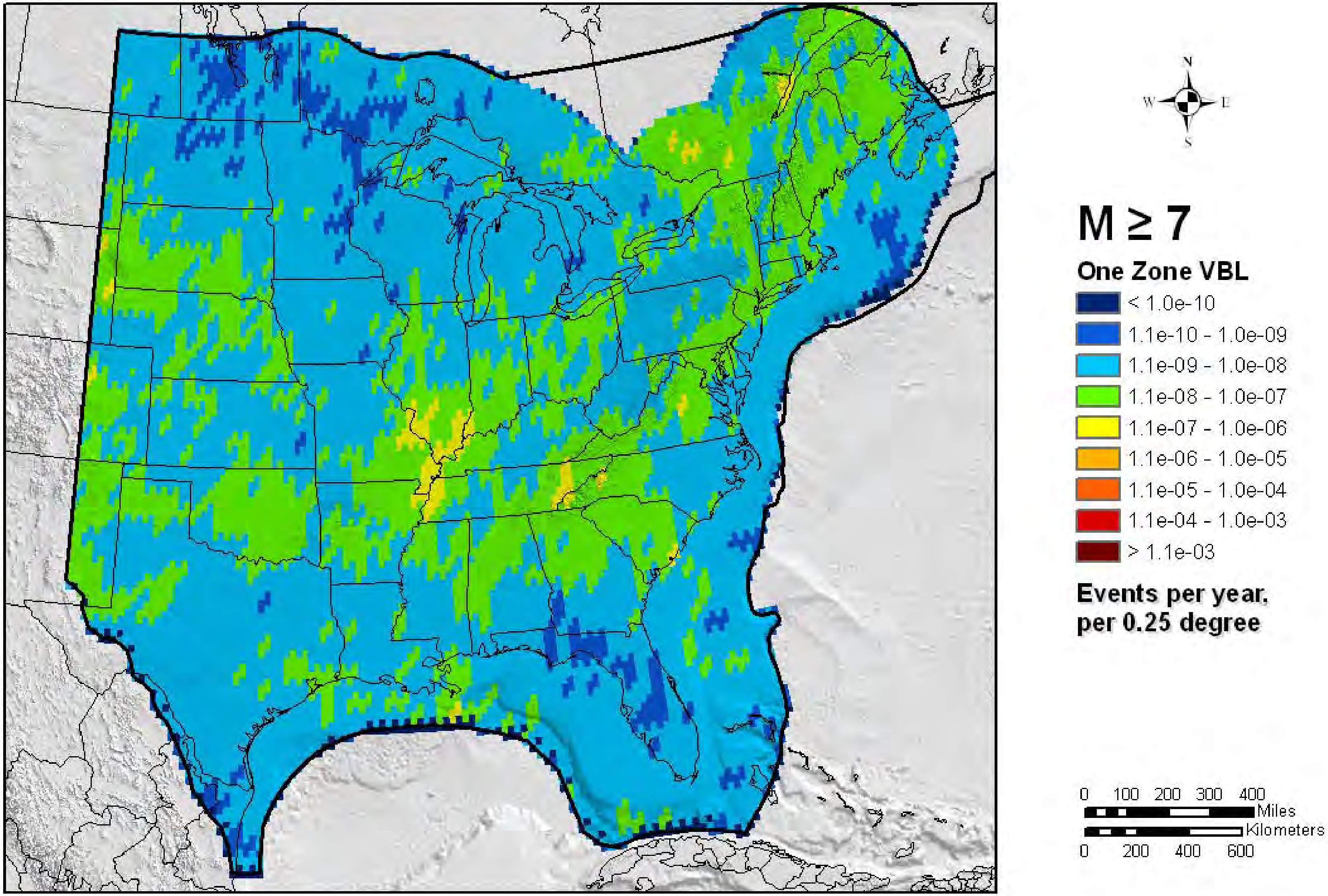
AMEC Geomatrix

Spatial Density Model of Historical Seismicity



AMEC Geomatrix

Spatial Density Model of Historical Seismicity



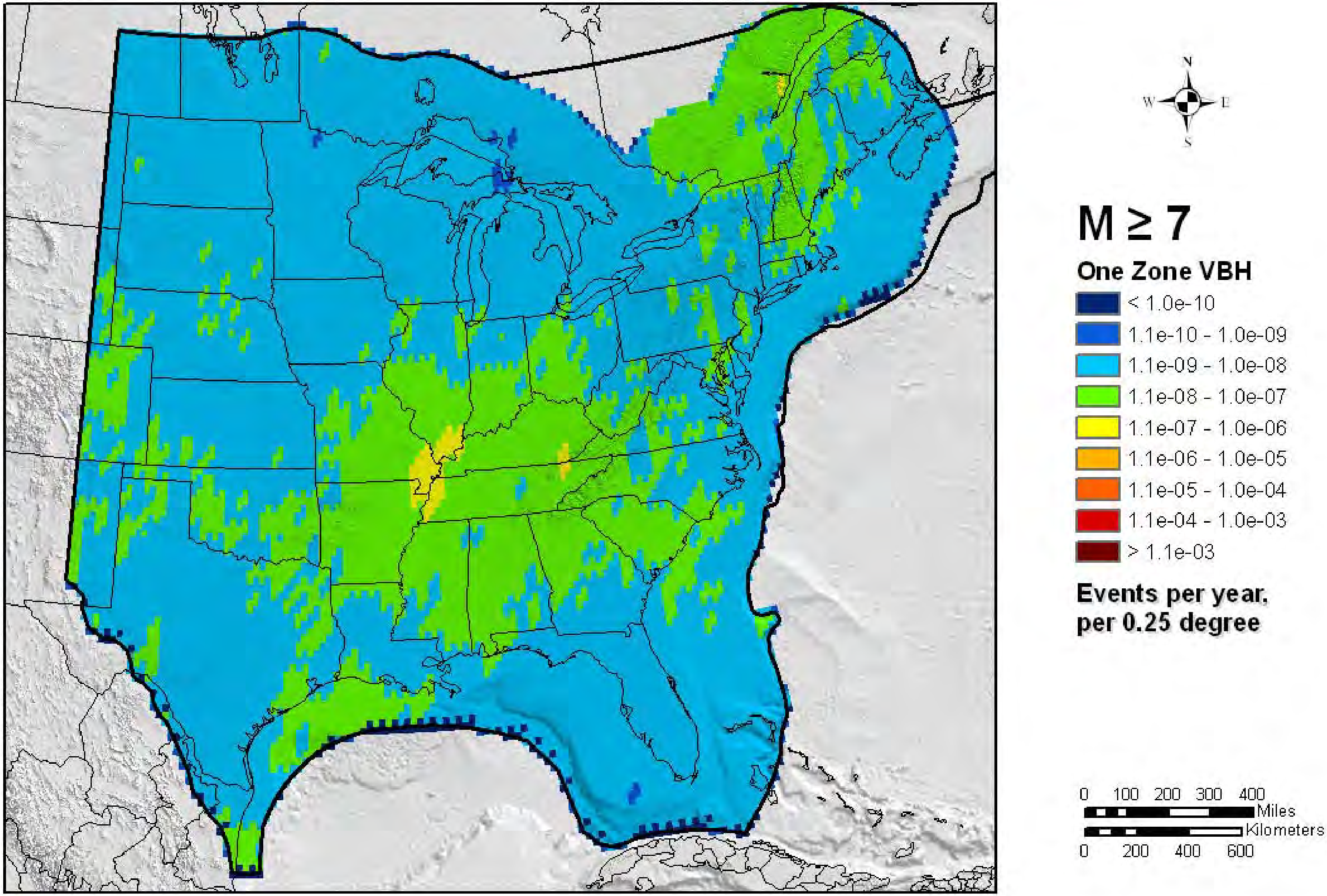
M ≥ 7

One Zone VBL

- 🟦 < 1.0e-10
- 🟦 1.1e-10 - 1.0e-09
- 🟦 1.1e-09 - 1.0e-08
- 🟩 1.1e-08 - 1.0e-07
- 🟨 1.1e-07 - 1.0e-06
- 🟧 1.1e-06 - 1.0e-05
- 🟧 1.1e-05 - 1.0e-04
- 🟥 1.1e-04 - 1.0e-03
- 🟫 > 1.1e-03

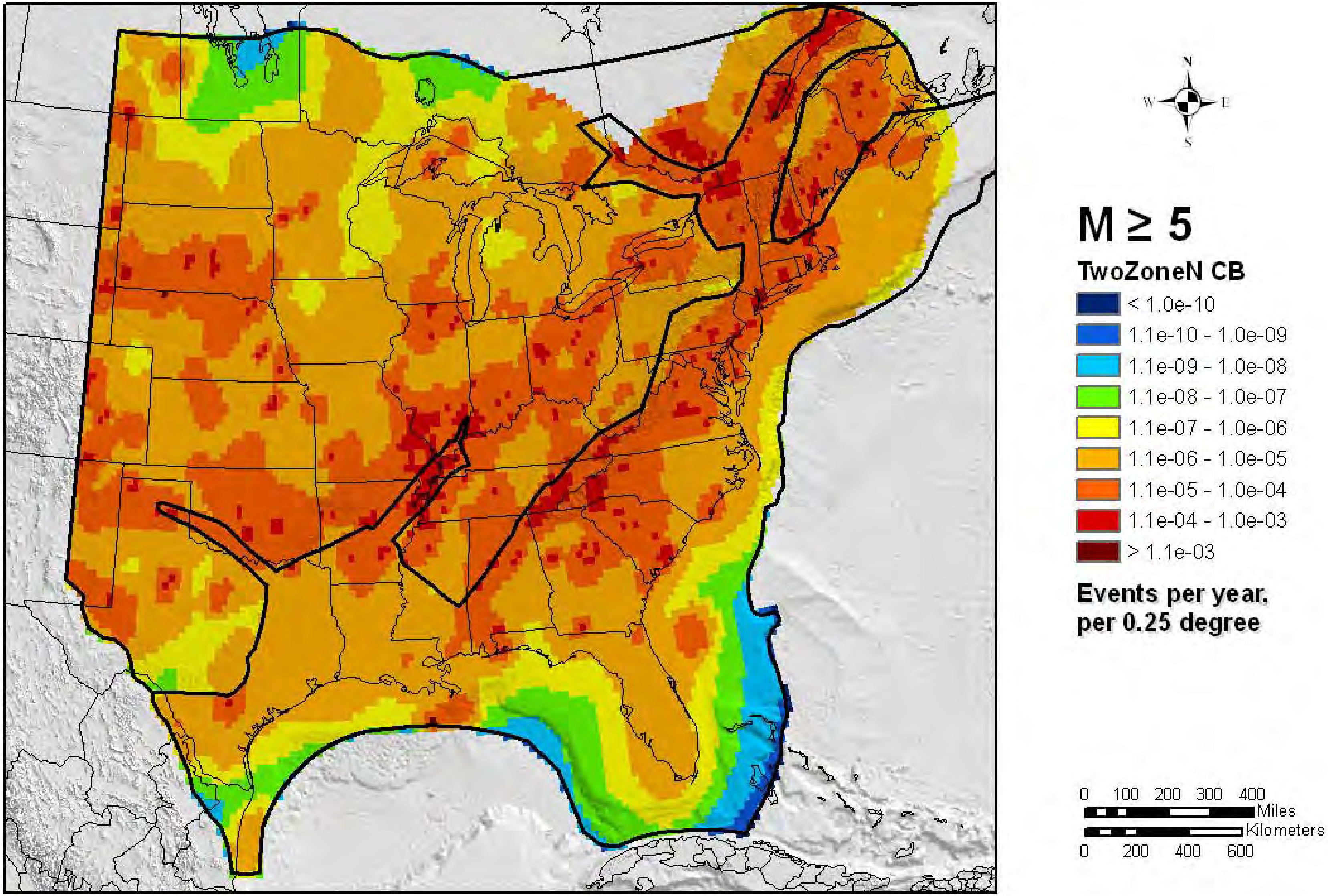
Events per year, per 0.25 degree

Spatial Density Model of Historical Seismicity



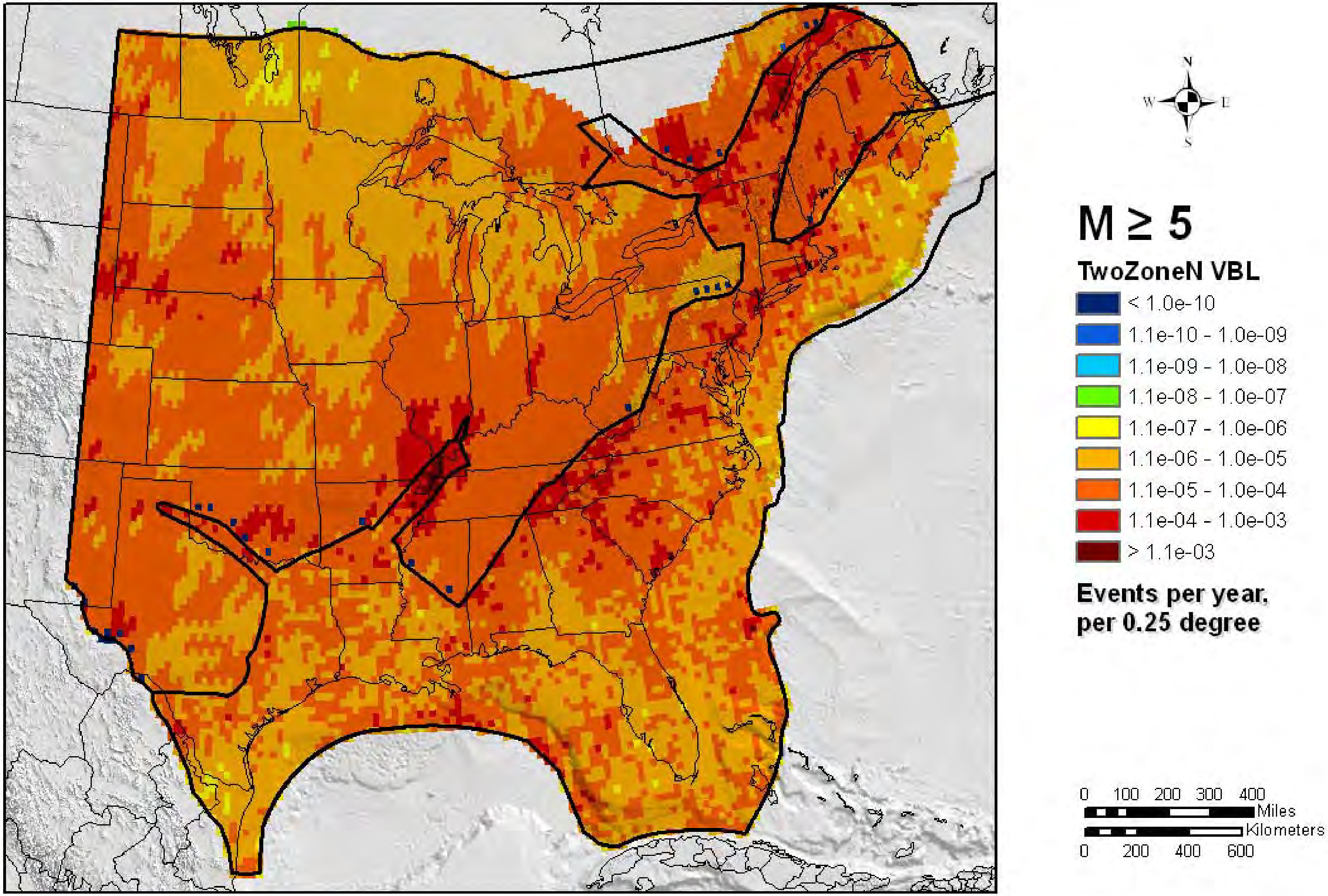
AMEC Geomatrix

Spatial Density Model of Historical Seismicity



AMEC Geomatrix

Spatial Density Model of Historical Seismicity



M ≥ 5

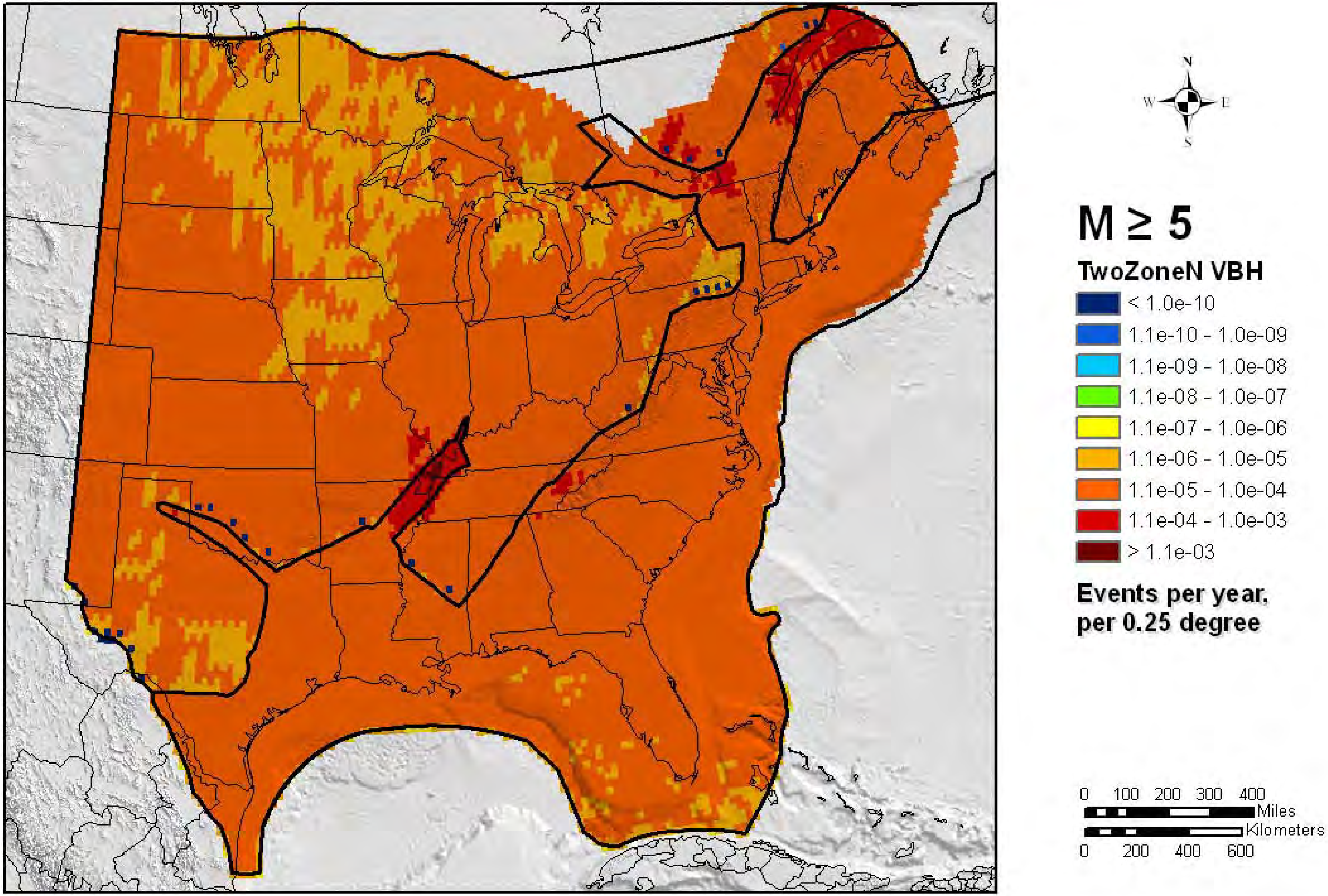
TwoZoneN VBL

- 🟦 < 1.0e-10
- 🟦 1.1e-10 - 1.0e-09
- 🟦 1.1e-09 - 1.0e-08
- 🟩 1.1e-08 - 1.0e-07
- 🟨 1.1e-07 - 1.0e-06
- 🟧 1.1e-06 - 1.0e-05
- 🟧 1.1e-05 - 1.0e-04
- 🟥 1.1e-04 - 1.0e-03
- 🟥 > 1.1e-03

Events per year, per 0.25 degree

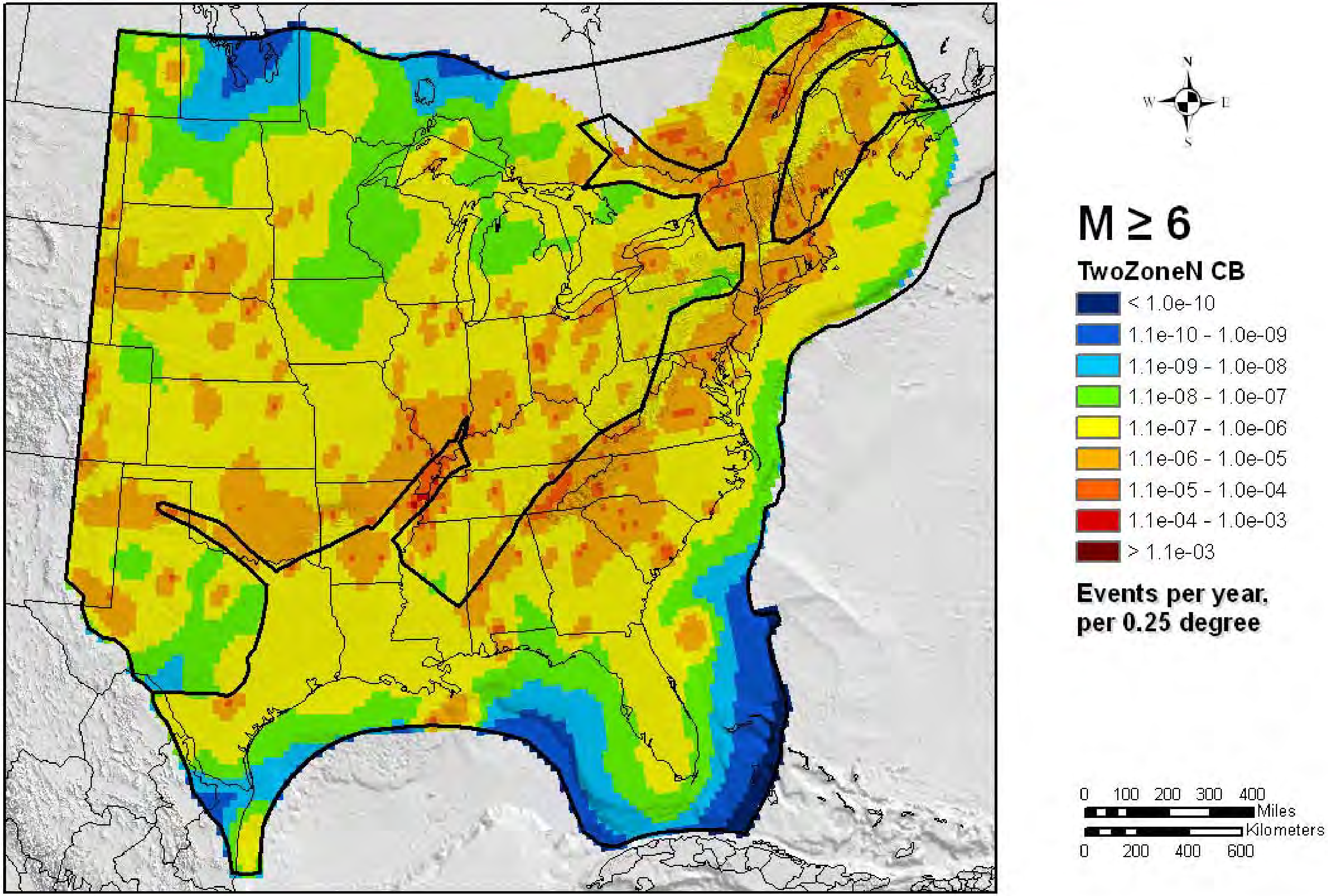
AMEC Geomatrix

Spatial Density Model of Historical Seismicity



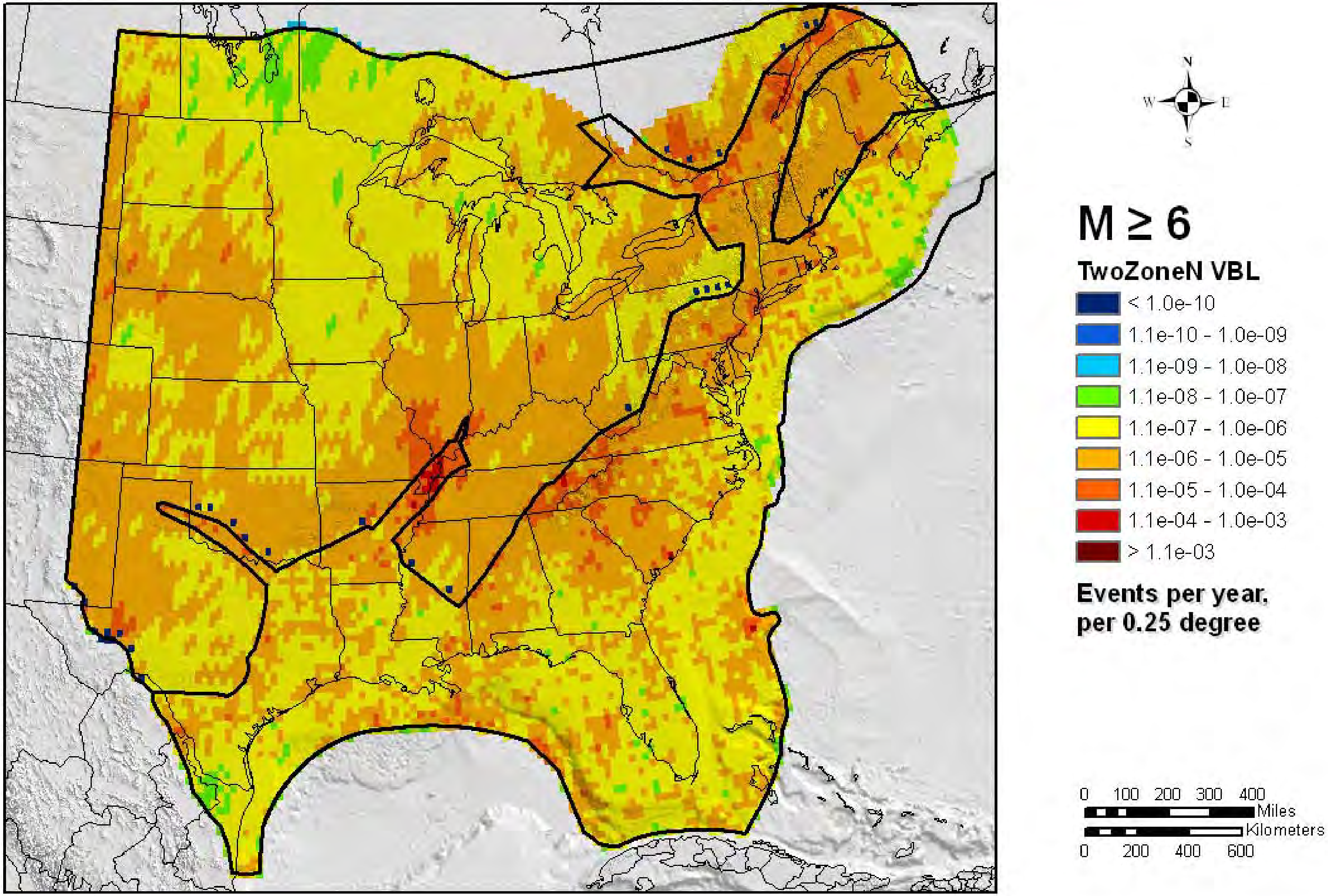
AMEC Geomatrix

Spatial Density Model of Historical Seismicity



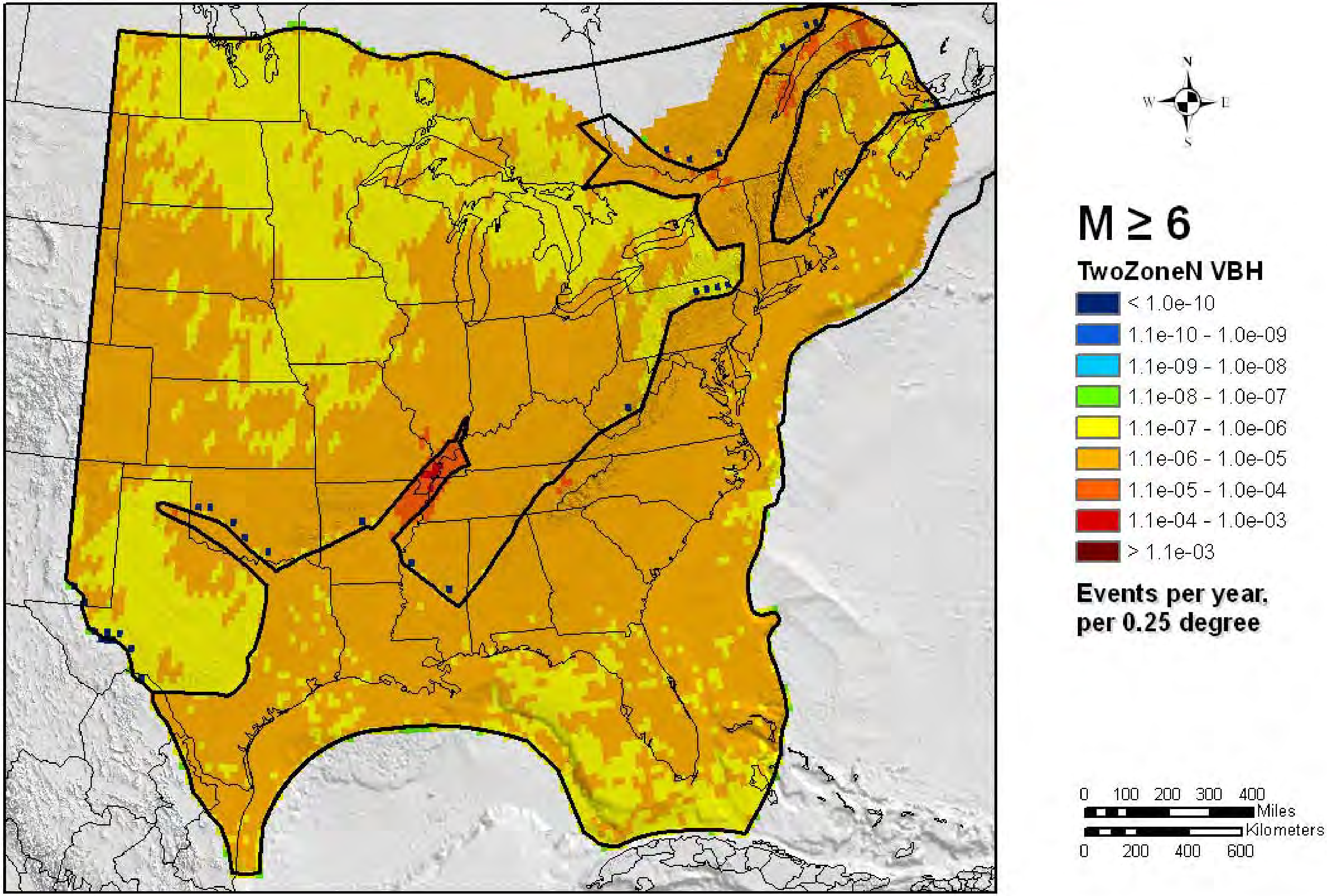
AMEC Geomatrix

Spatial Density Model of Historical Seismicity



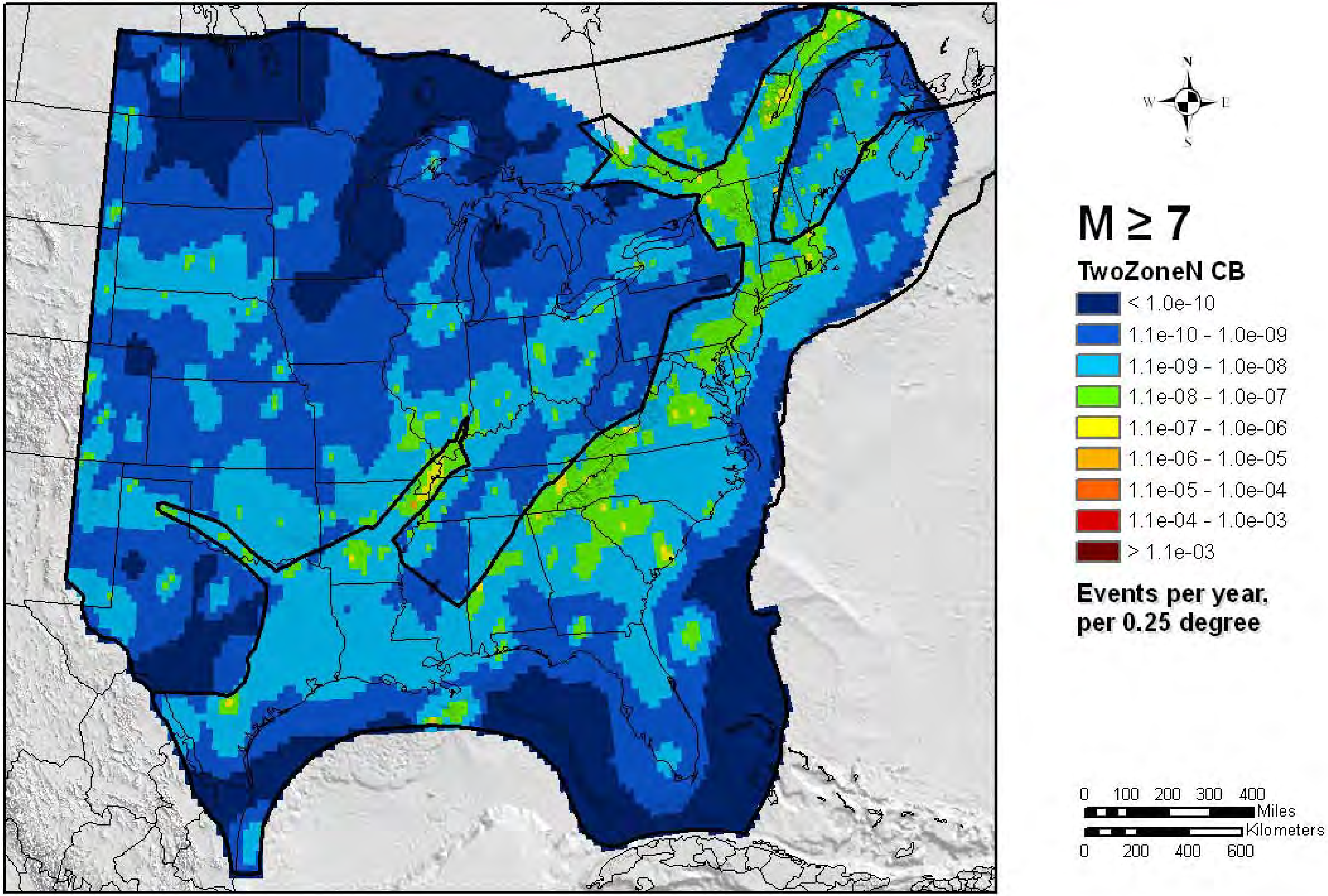
AMEC Geomatrix

Spatial Density Model of Historical Seismicity



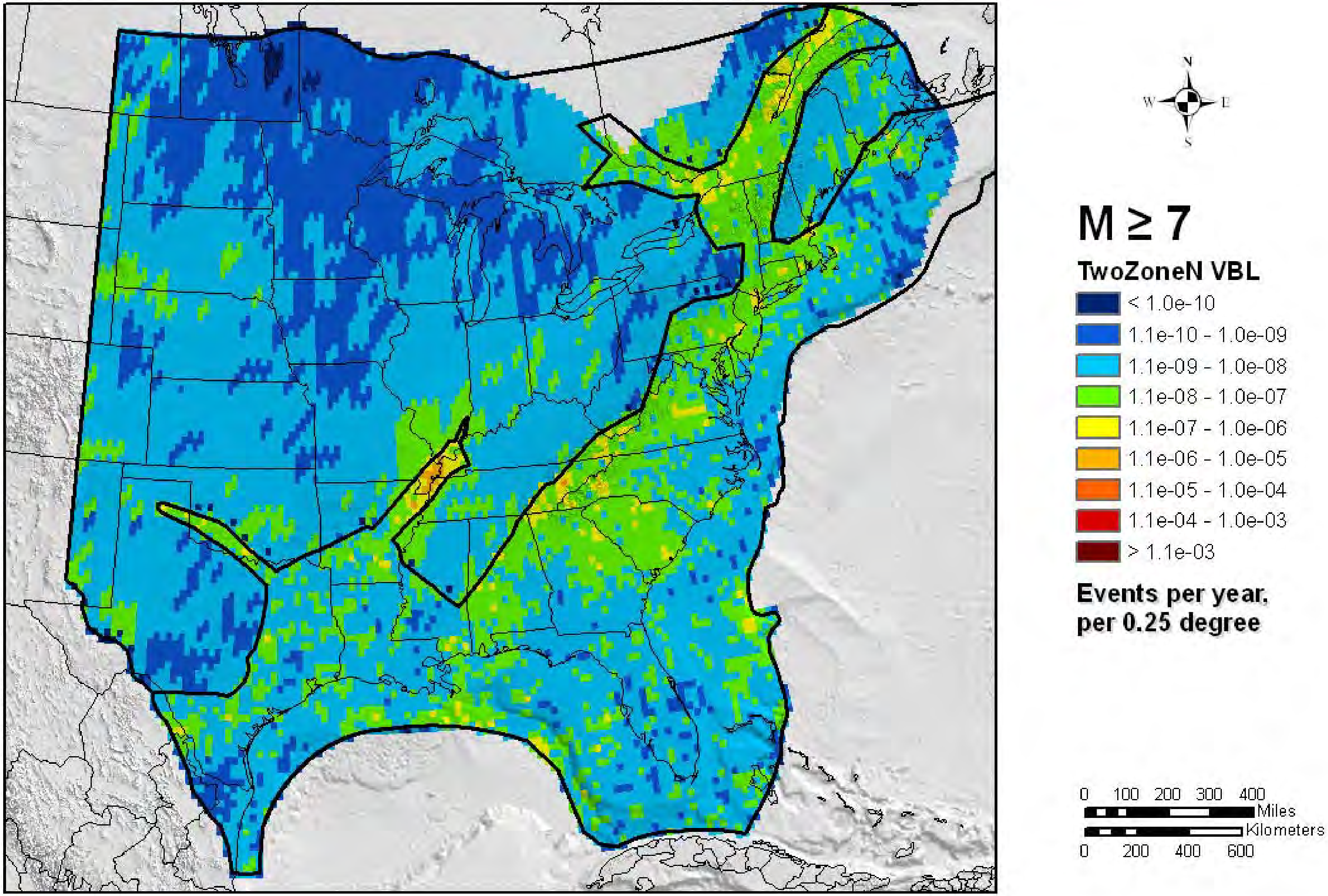
AMEC Geomatrix

Spatial Density Model of Historical Seismicity



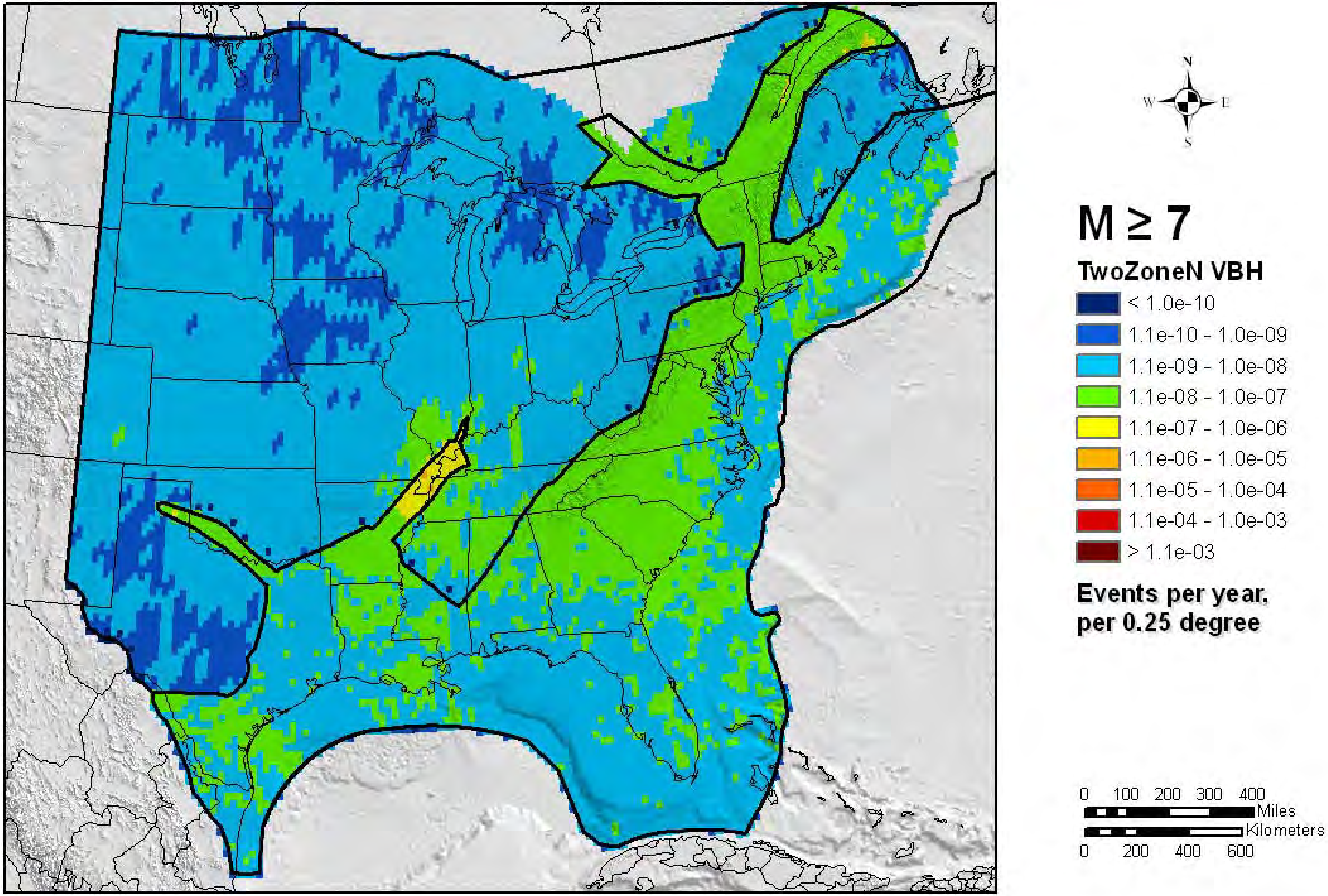
AMEC Geomatrix

Spatial Density Model of Historical Seismicity



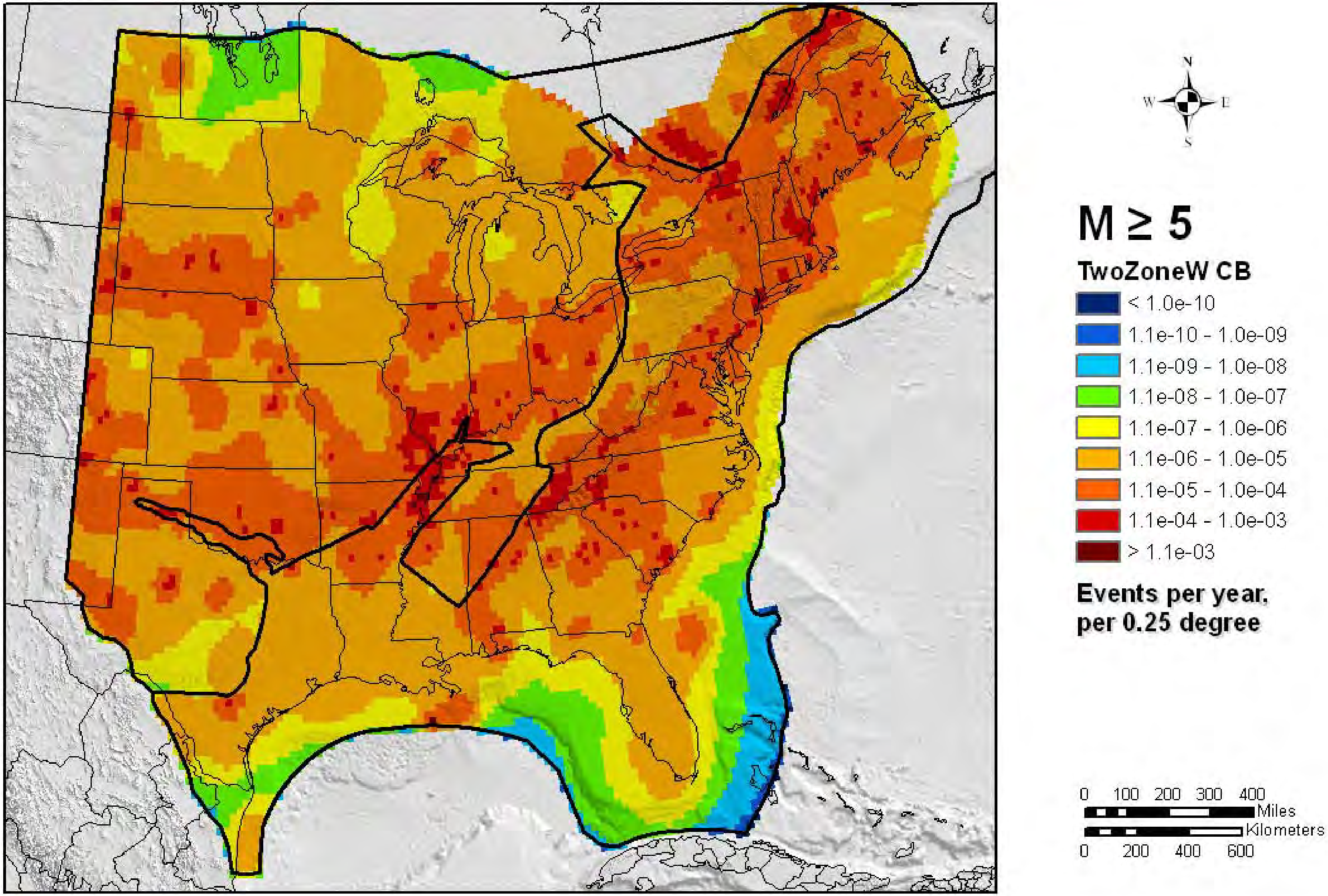
AMEC Geomatrix

Spatial Density Model of Historical Seismicity



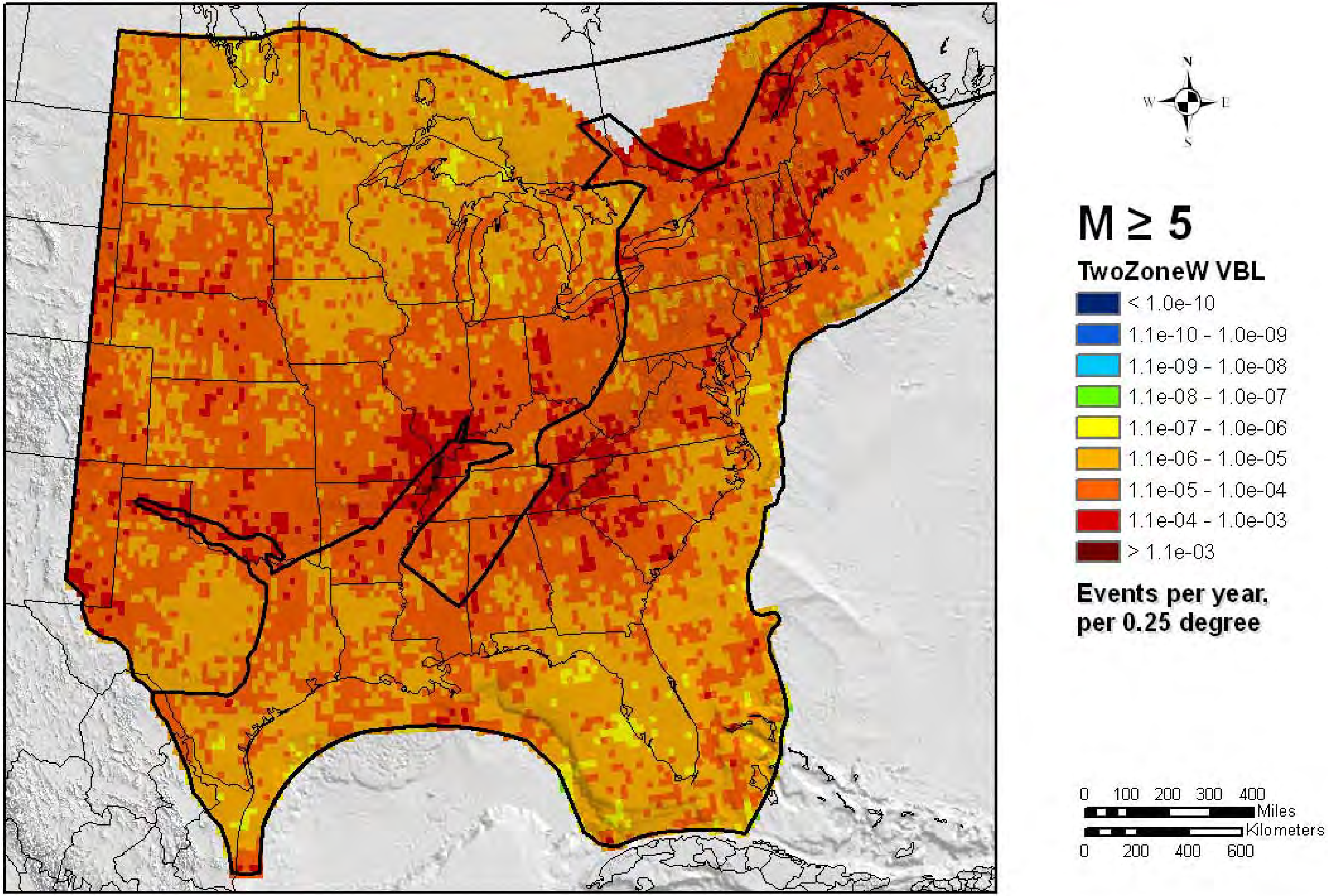
AMEC Geomatrix

Spatial Density Model of Historical Seismicity



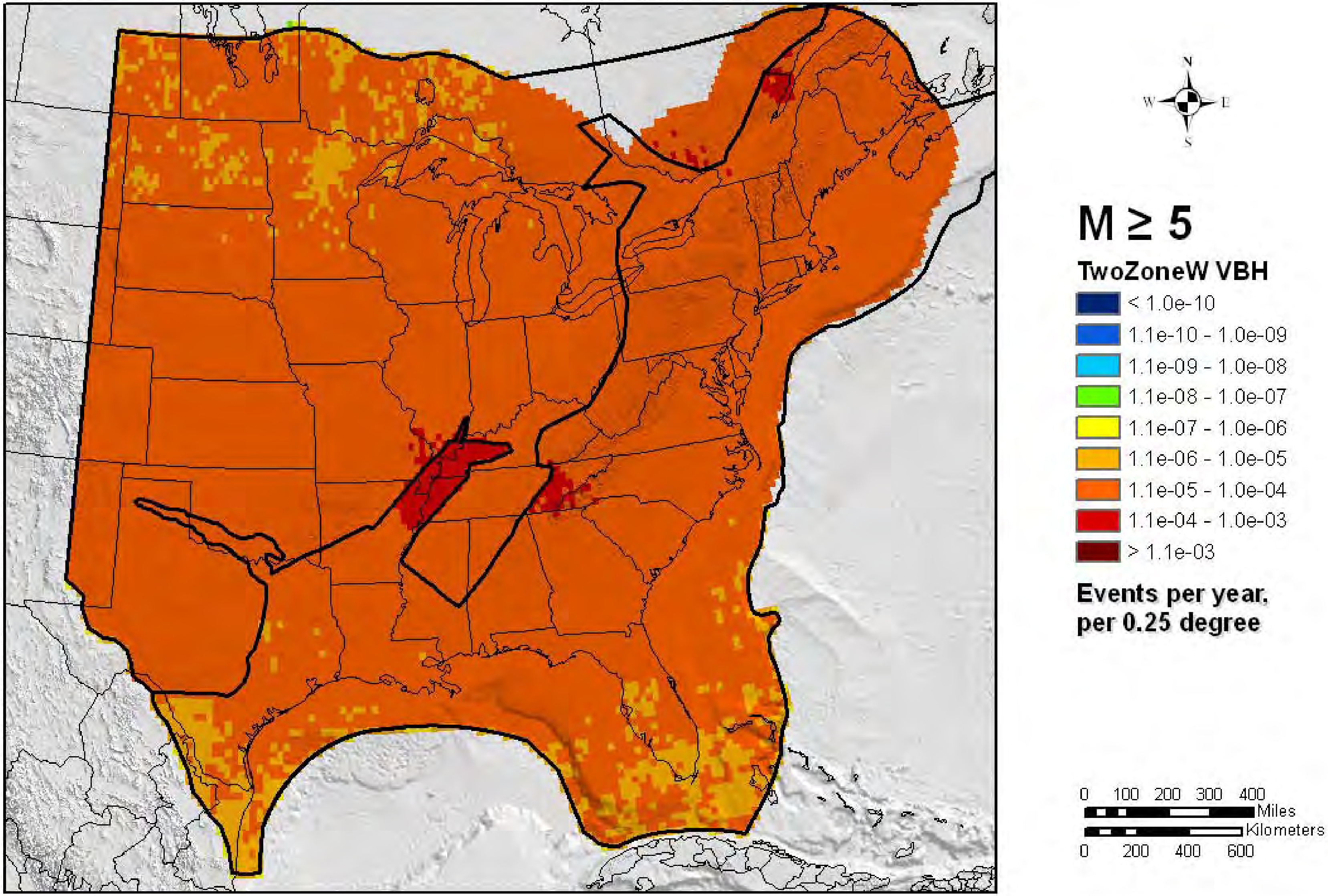
AMEC Geomatrix

Spatial Density Model of Historical Seismicity



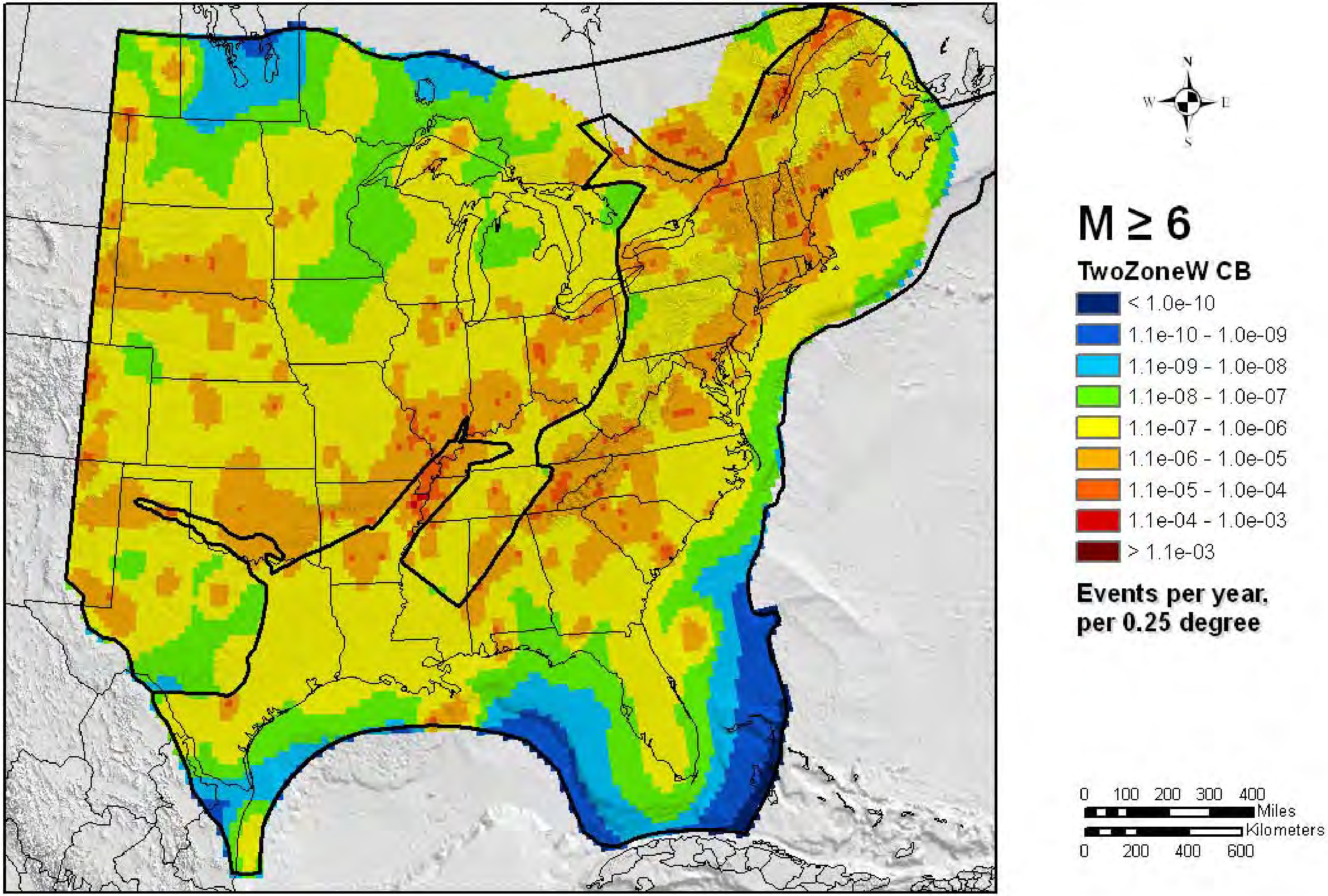
AMEC Geomatrix

Spatial Density Model of Historical Seismicity



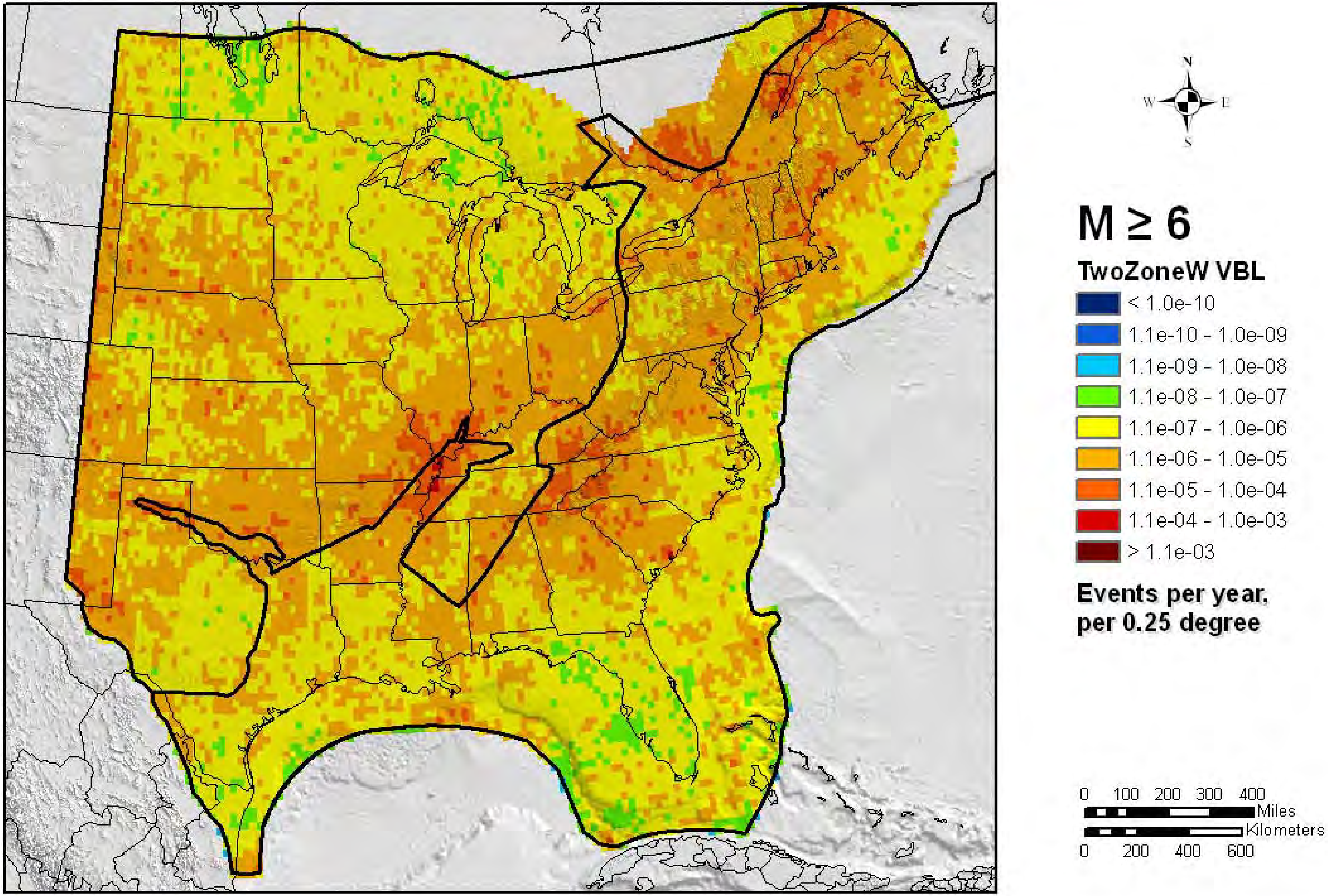
AMEC Geomatrix

Spatial Density Model of Historical Seismicity



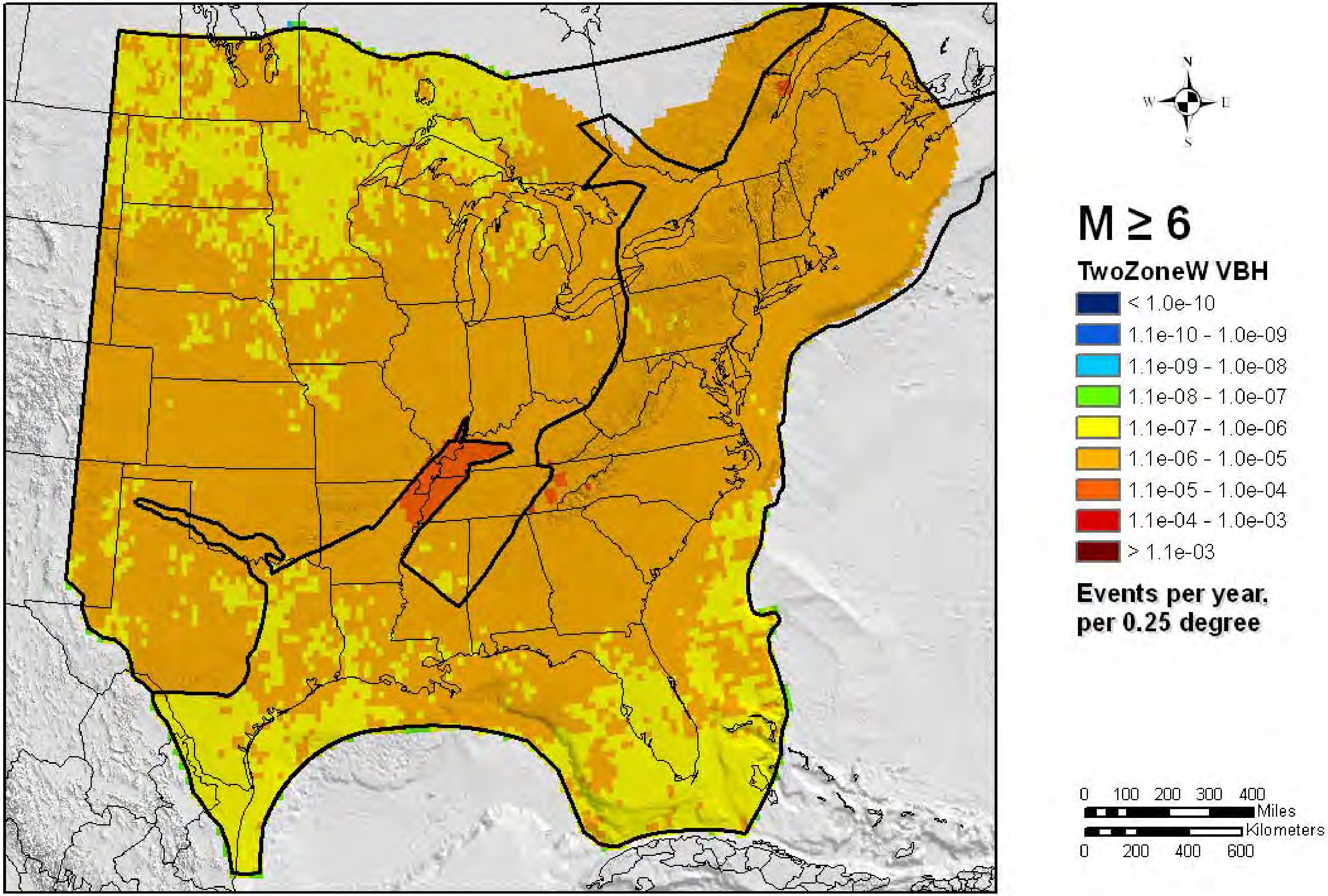
AMEC Geomatrix

Spatial Density Model of Historical Seismicity



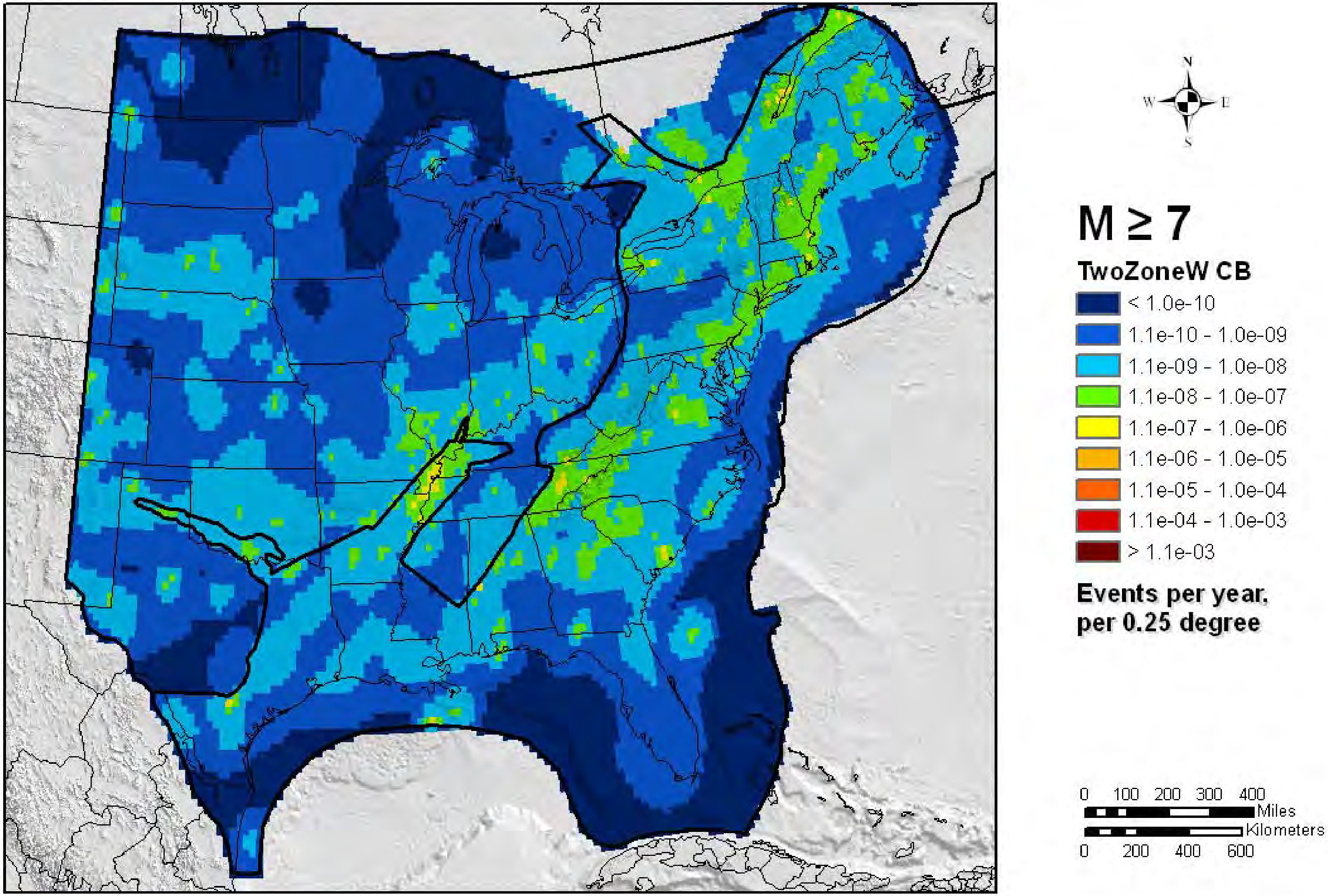
AMEC Geomatrix

Spatial Density Model of Historical Seismicity



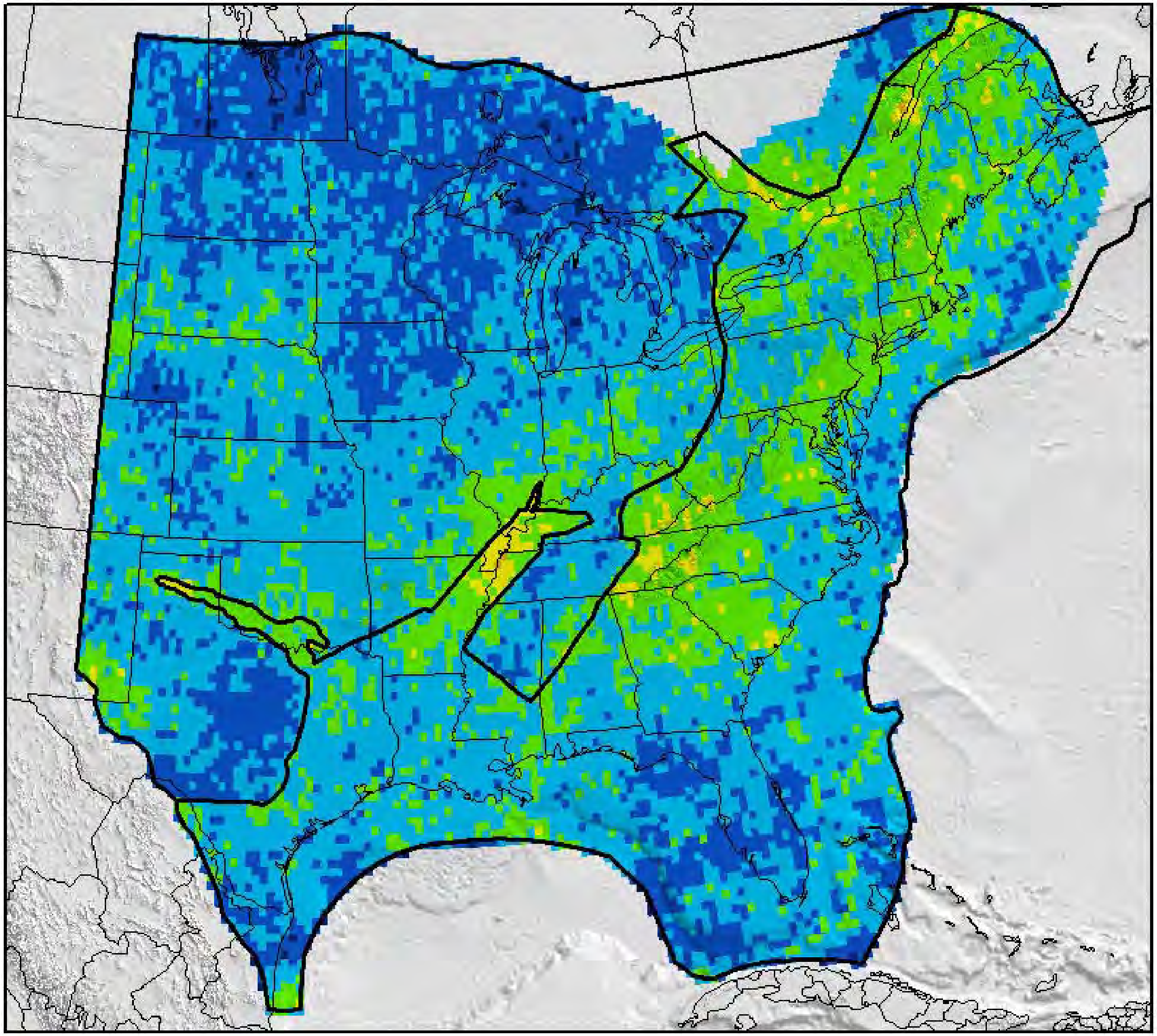
AMEC Geomatrix

Spatial Density Model of Historical Seismicity



AMEC Geomatrix

Spatial Density Model of Historical Seismicity



N
W E
S

$M \geq 7$

TwoZoneW VBL

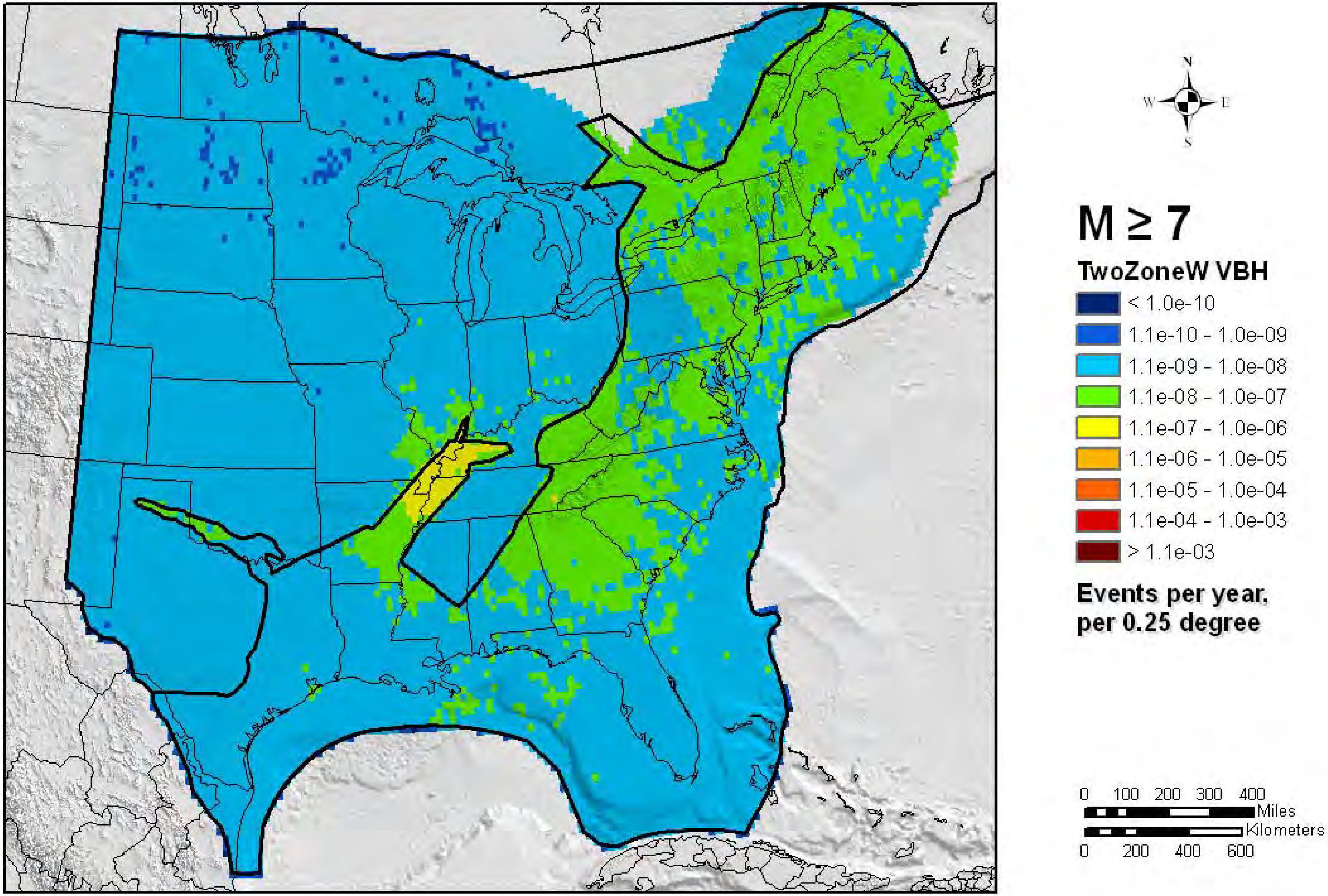
🟦 < 1.0e-10
🟦 1.1e-10 - 1.0e-09
🟦 1.1e-09 - 1.0e-08
🟩 1.1e-08 - 1.0e-07
🟨 1.1e-07 - 1.0e-06
🟧 1.1e-06 - 1.0e-05
🟧 1.1e-05 - 1.0e-04
🟥 1.1e-04 - 1.0e-03
🟫 > 1.1e-03

Events per year, per 0.25 degree

0 100 200 300 400 Miles
Kilometers 0 200 400 600

AMEC Geomatrix

Spatial Density Model of Historical Seismicity



AMEC Geomatrix

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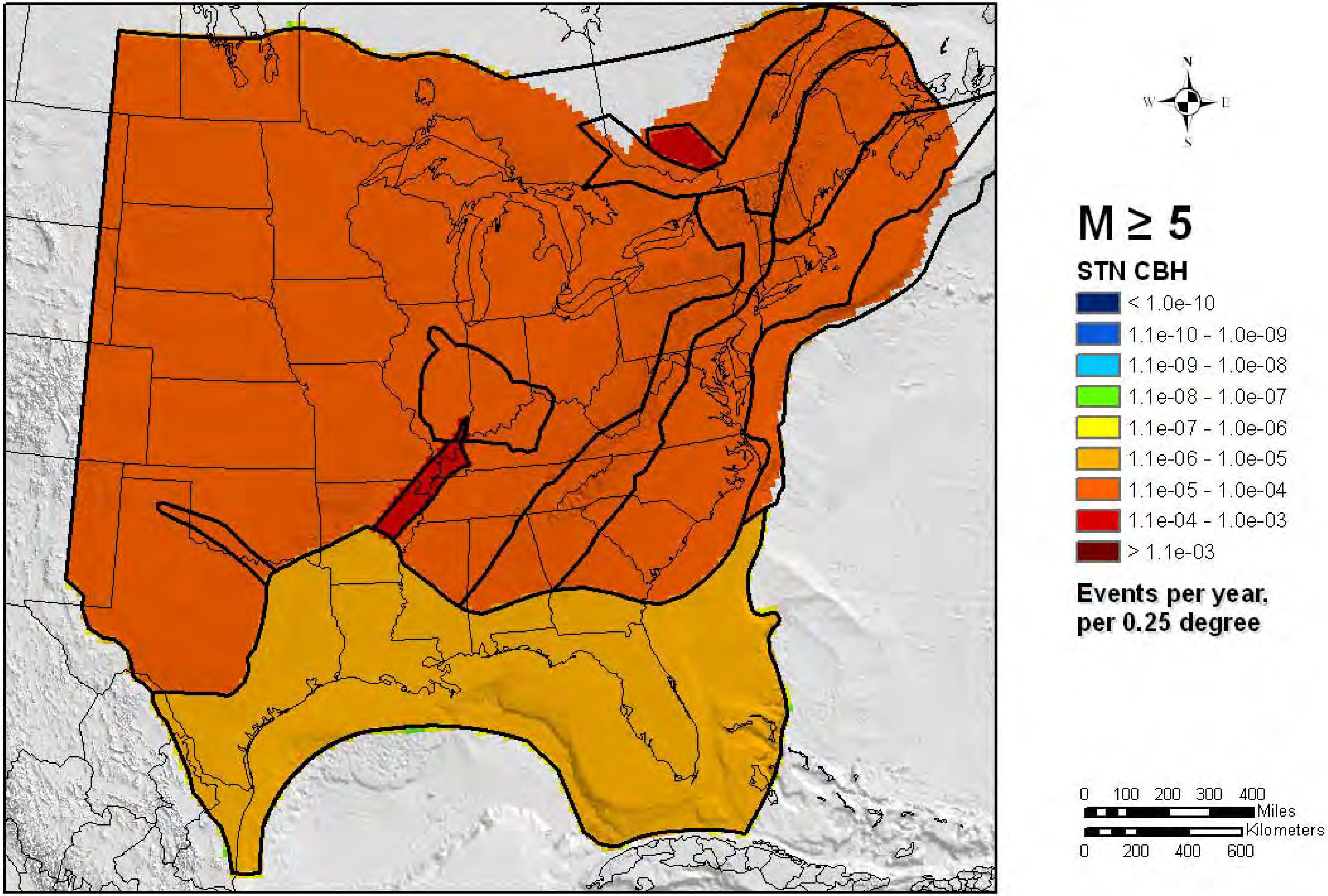
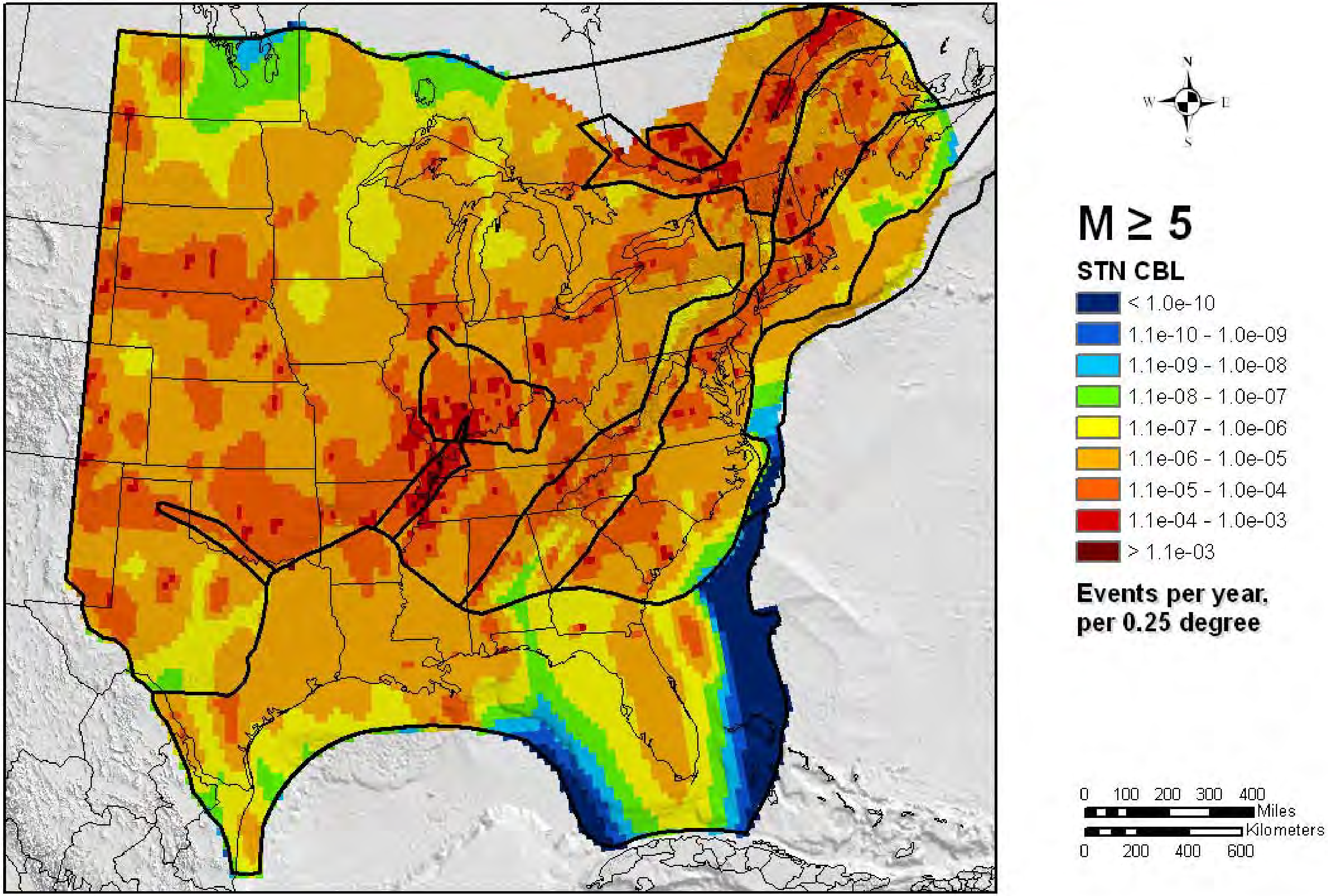


AMEC Geomatrix

Spatial Density Model of Historical Seismicity



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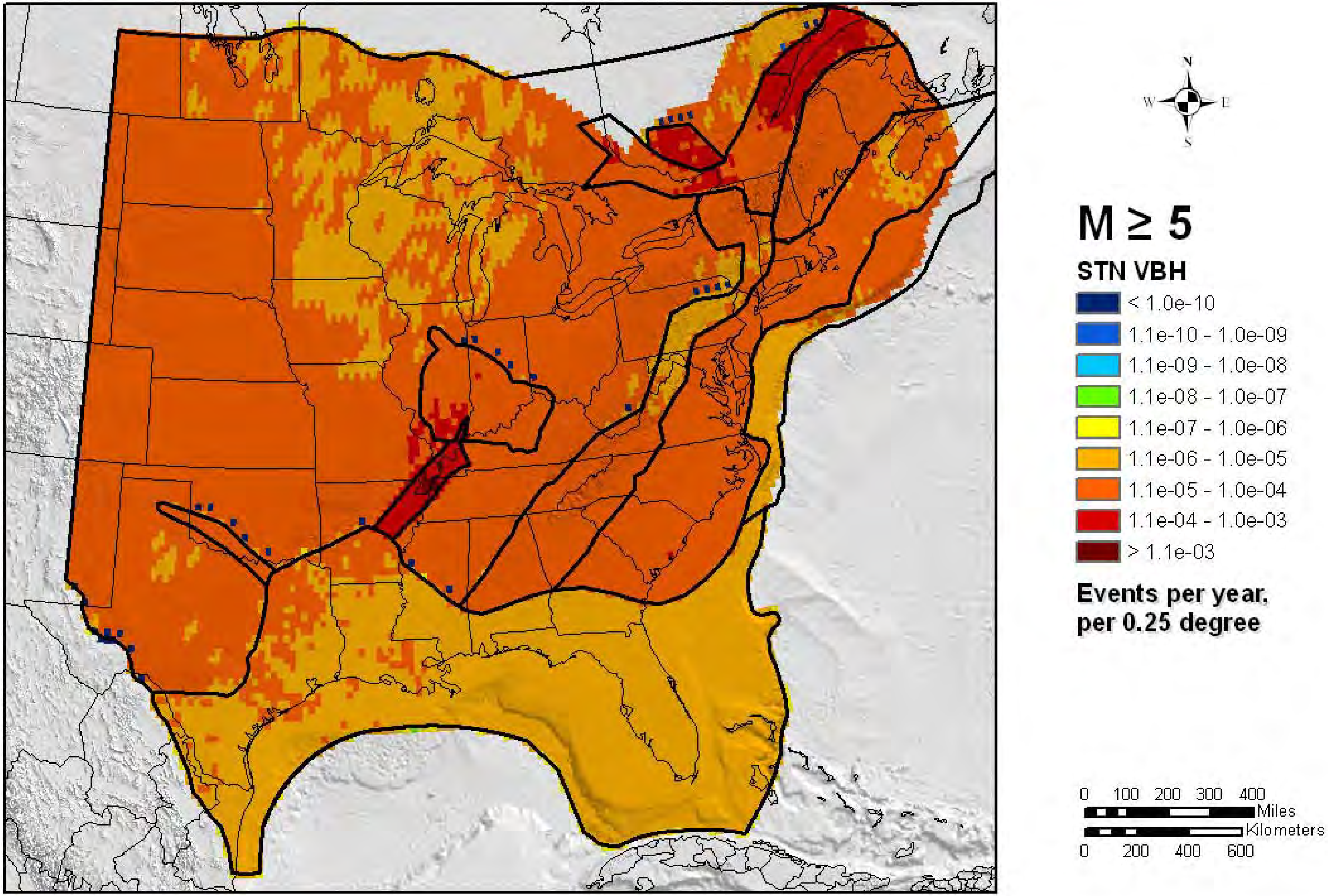

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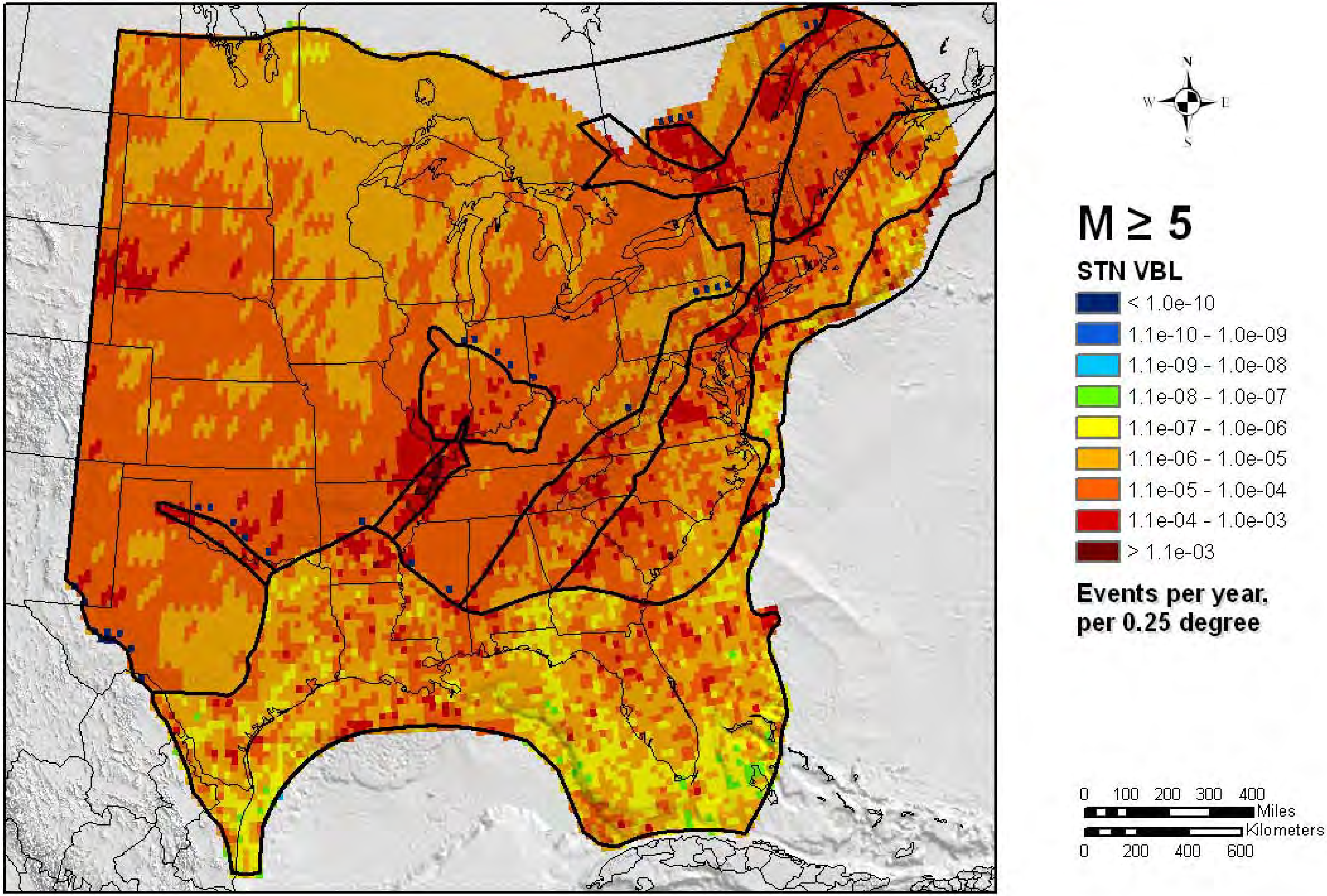

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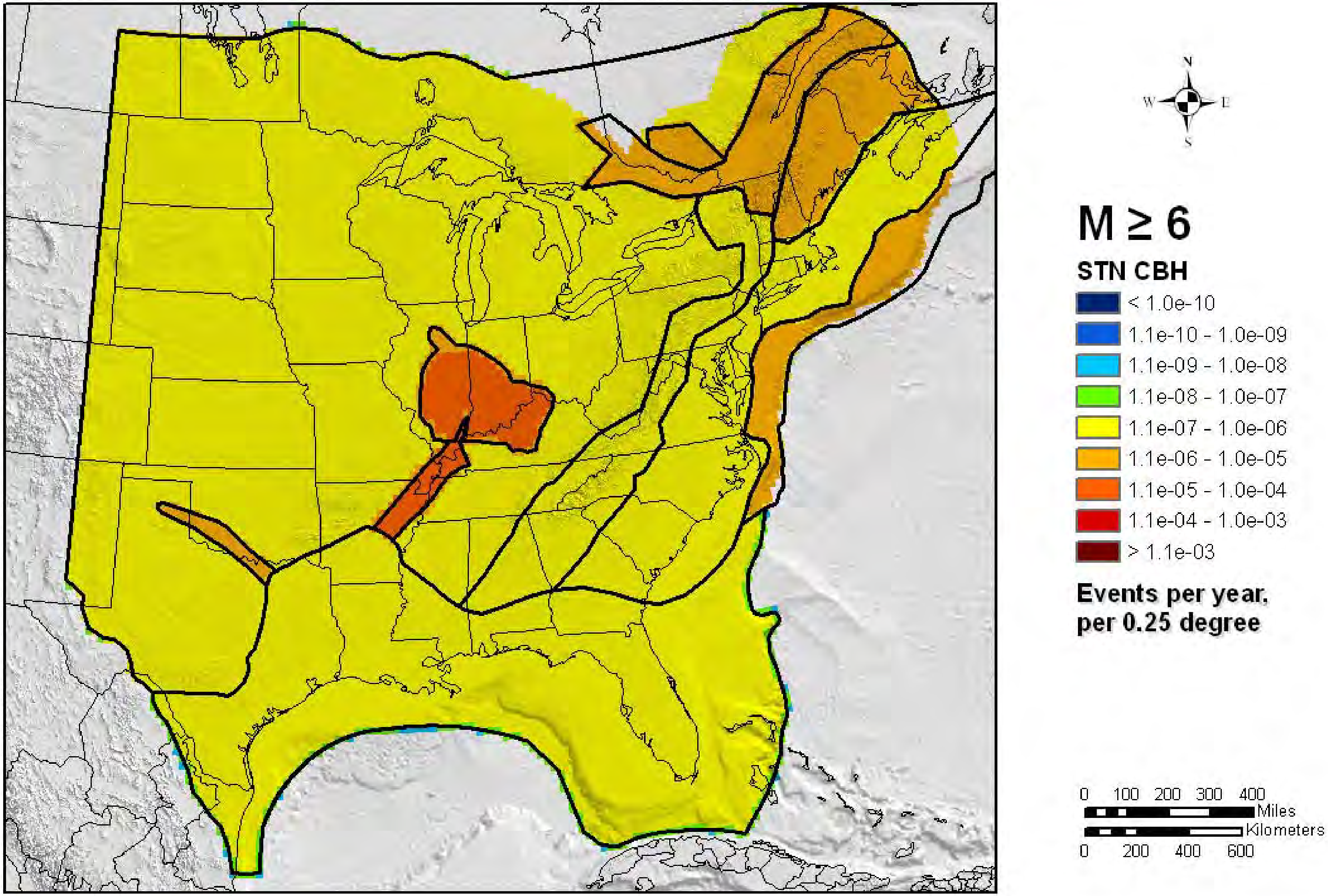

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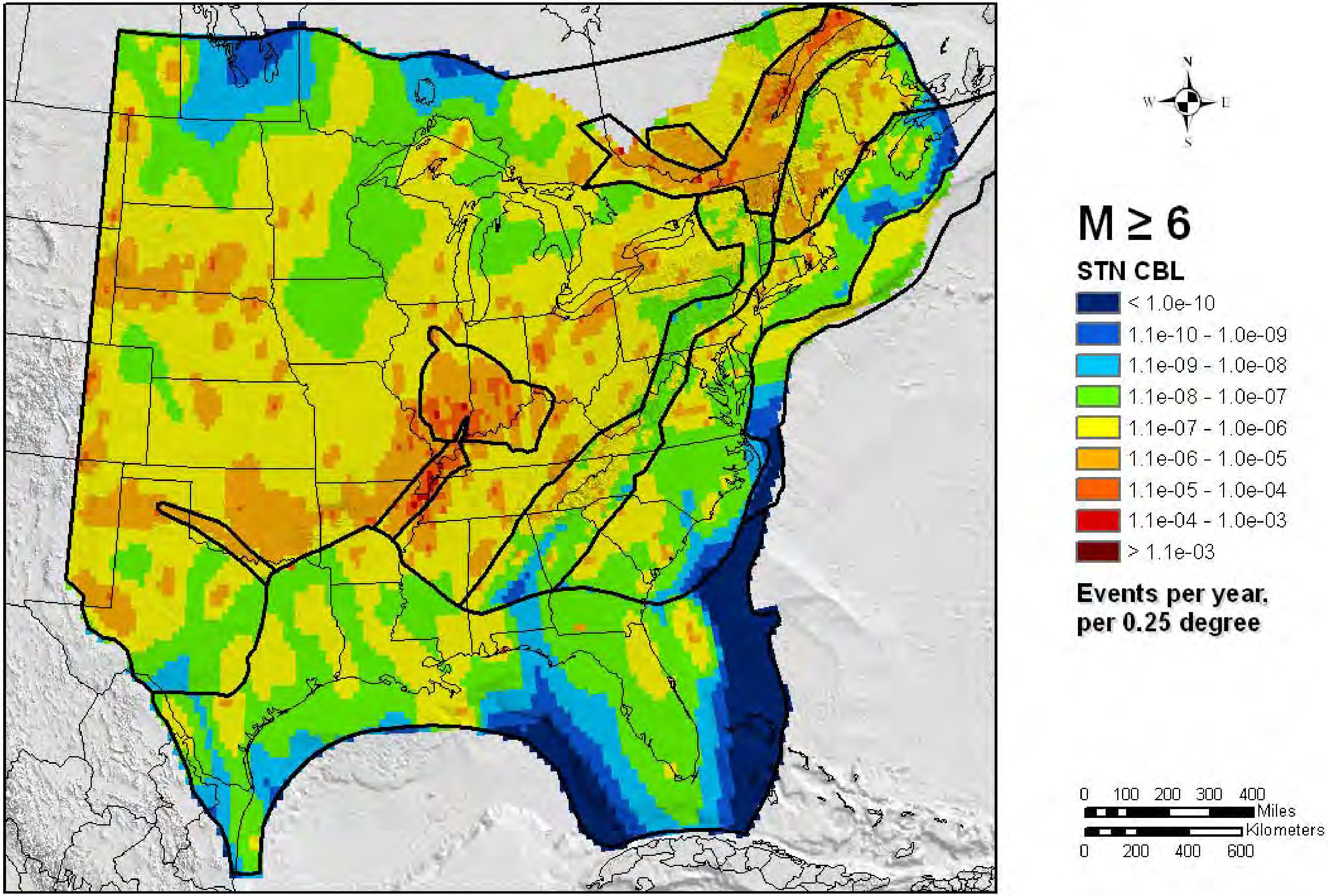

AMEC Geomatrix

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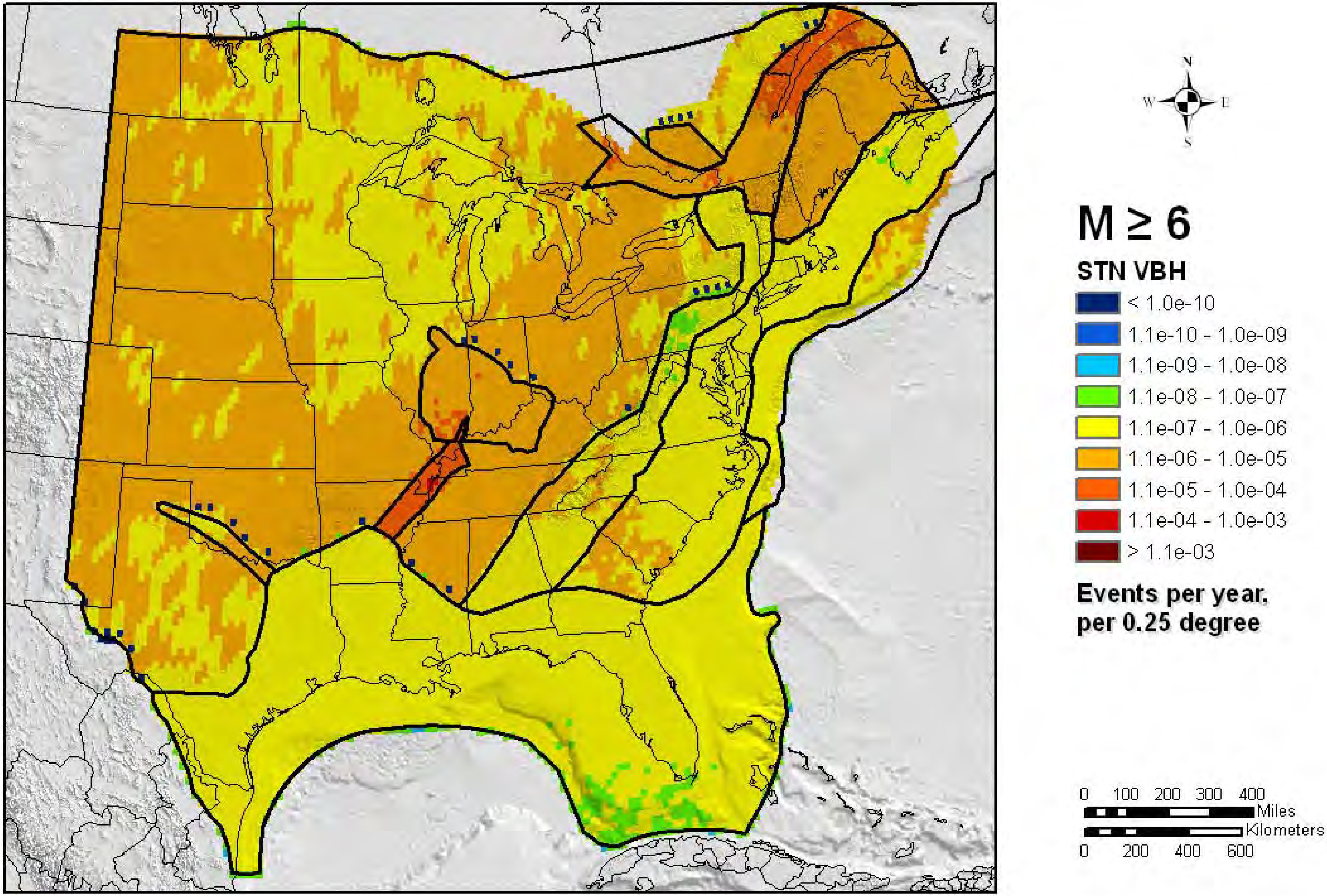

AMEC Geomatrix

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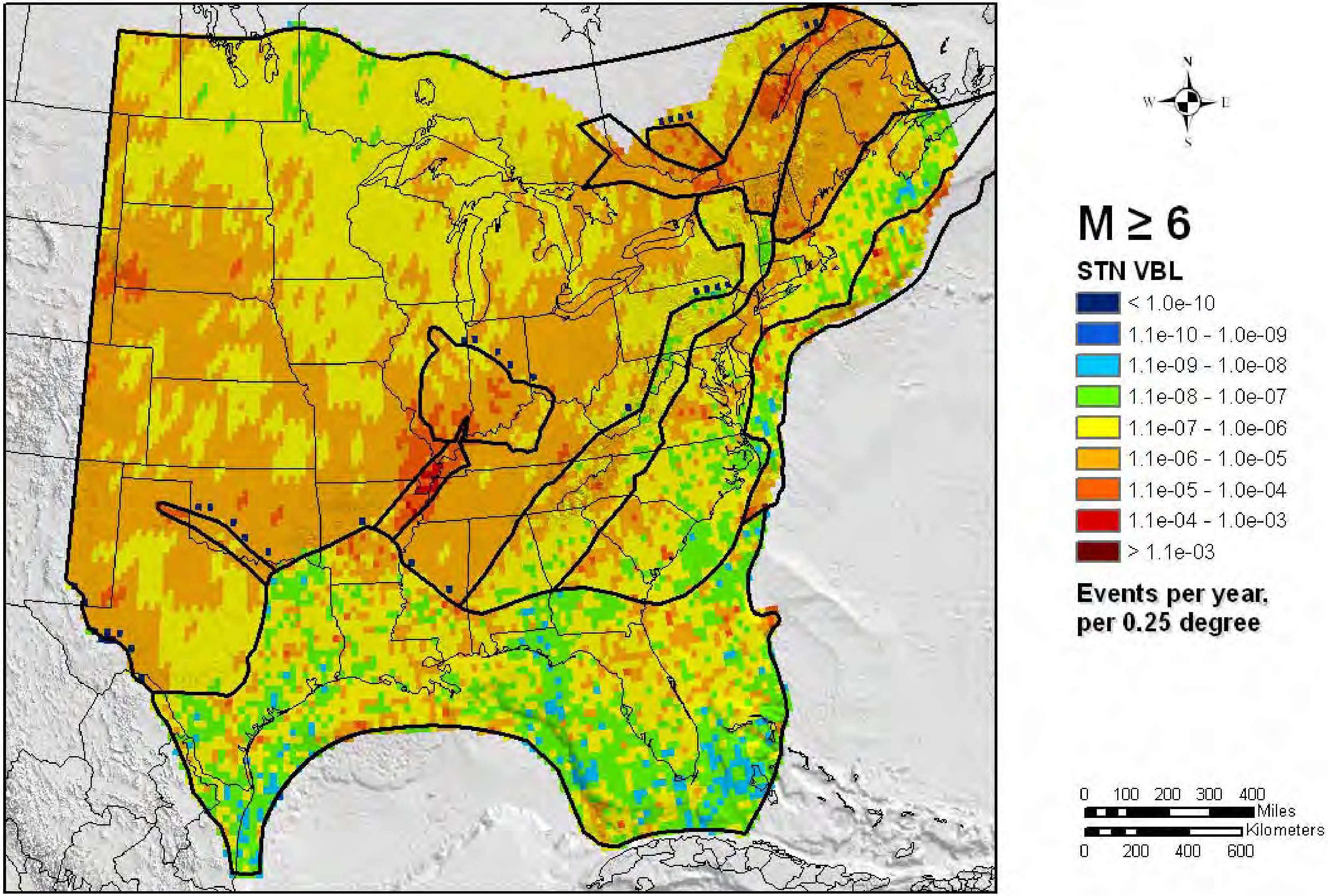

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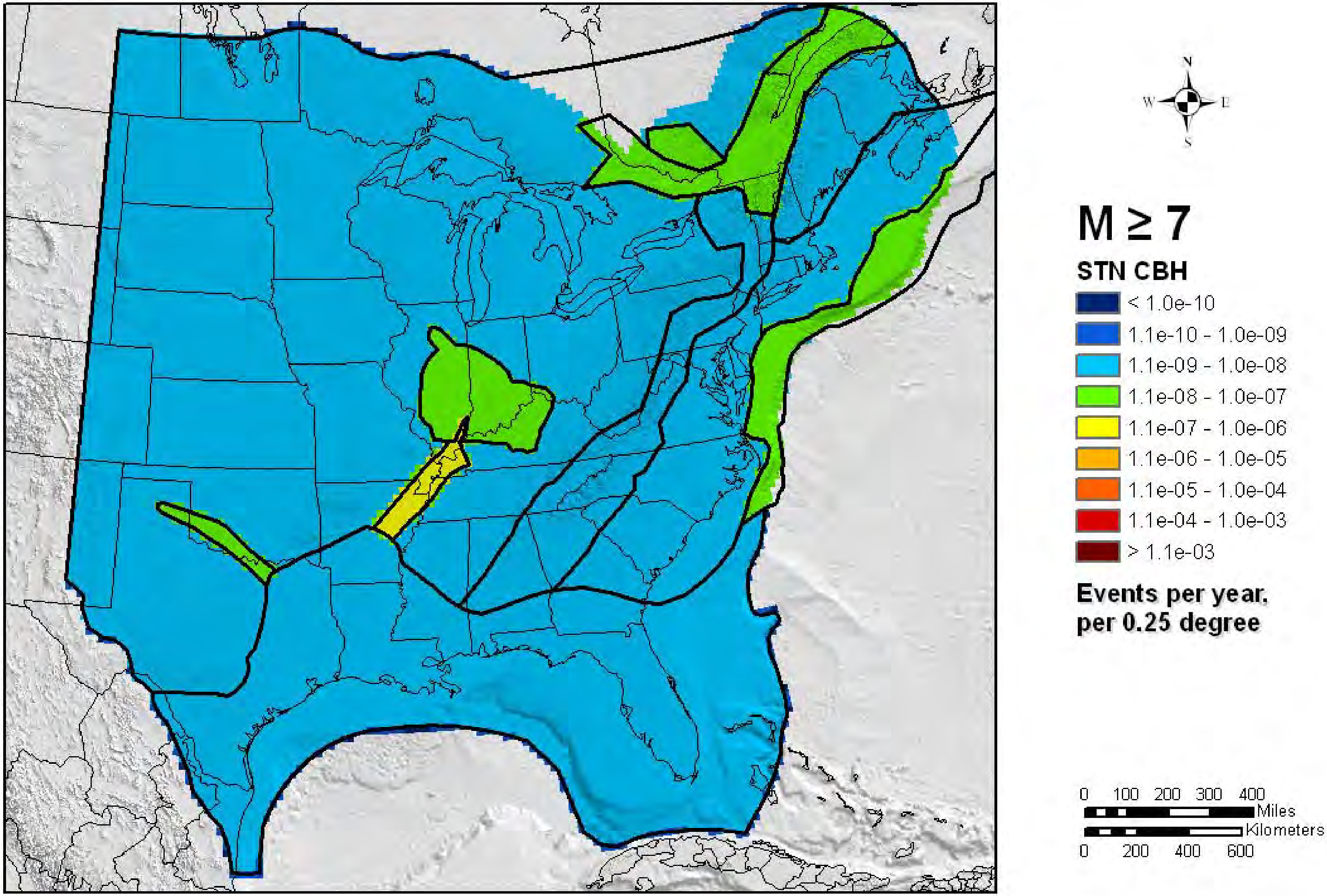

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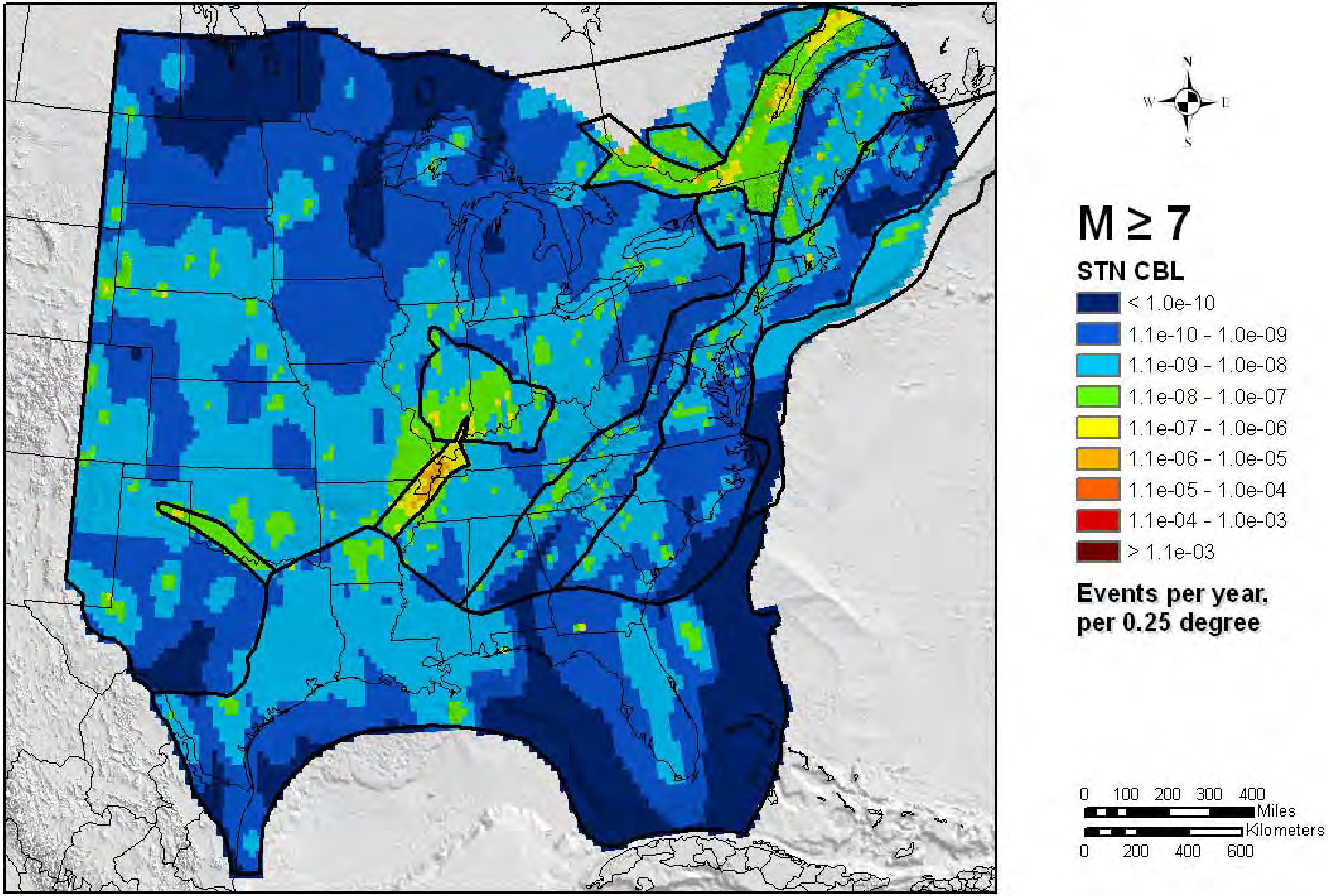
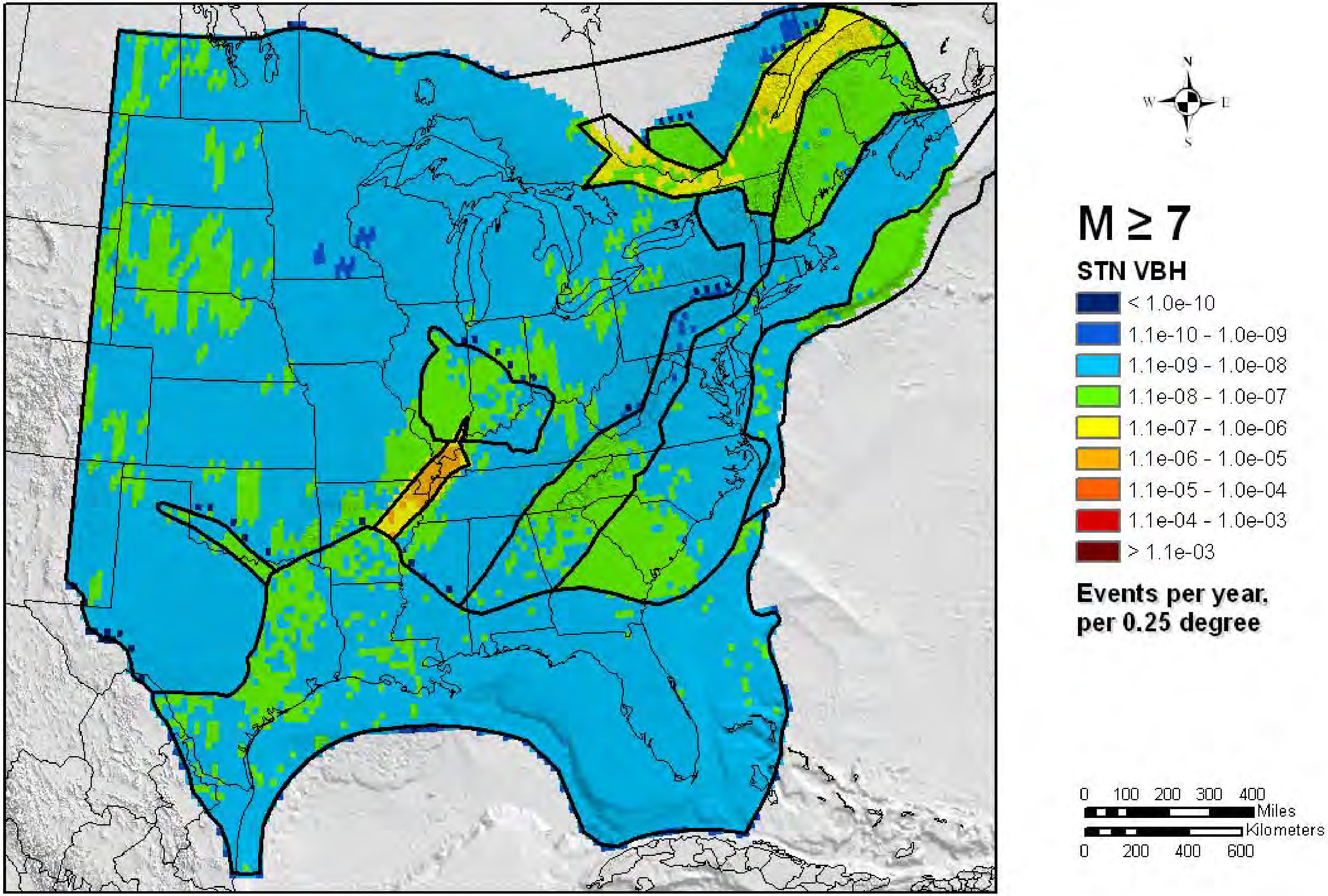


AMEC Geomatrix

Spatial Density Model of Historical Seismicity



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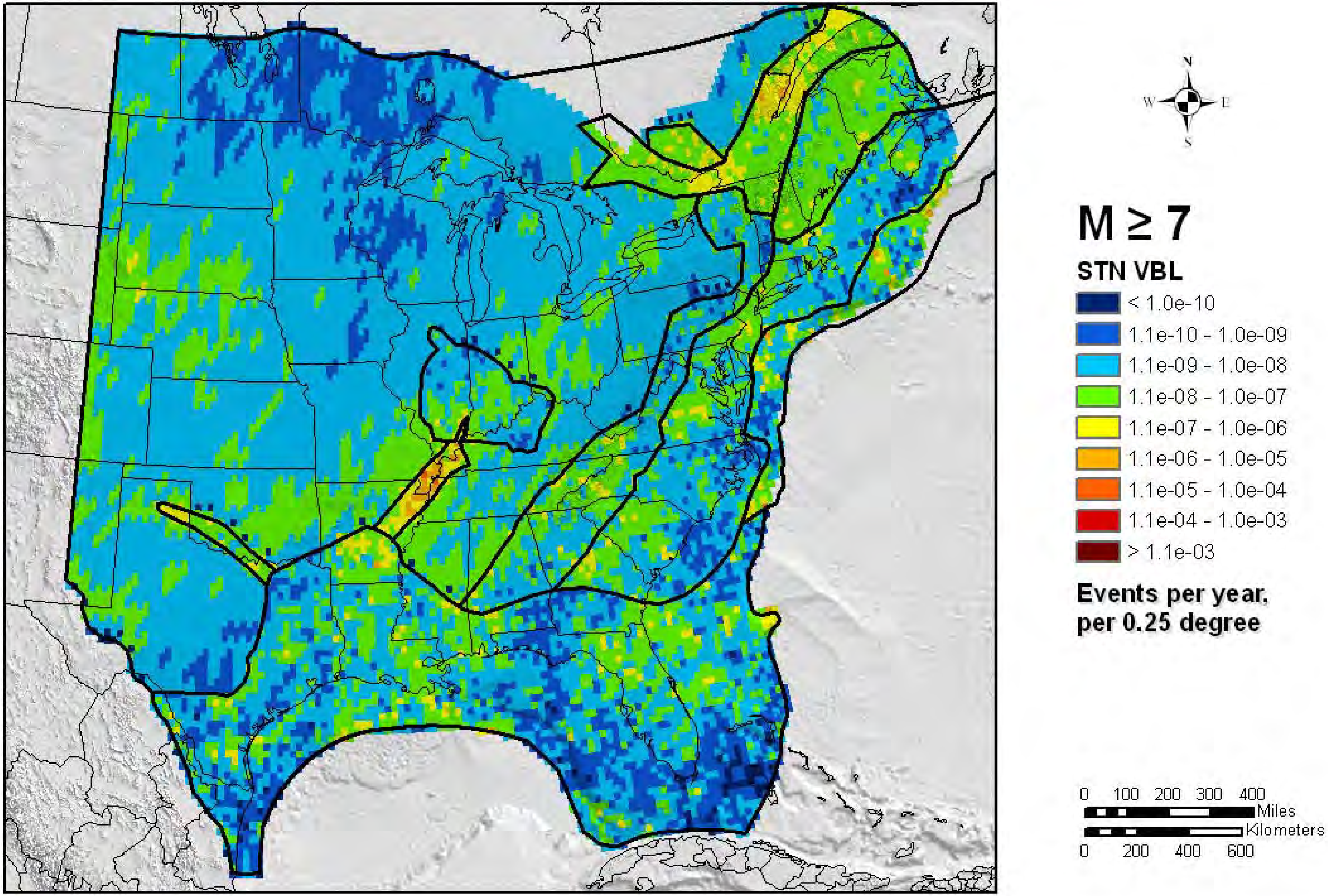

AMEC Geomatrix

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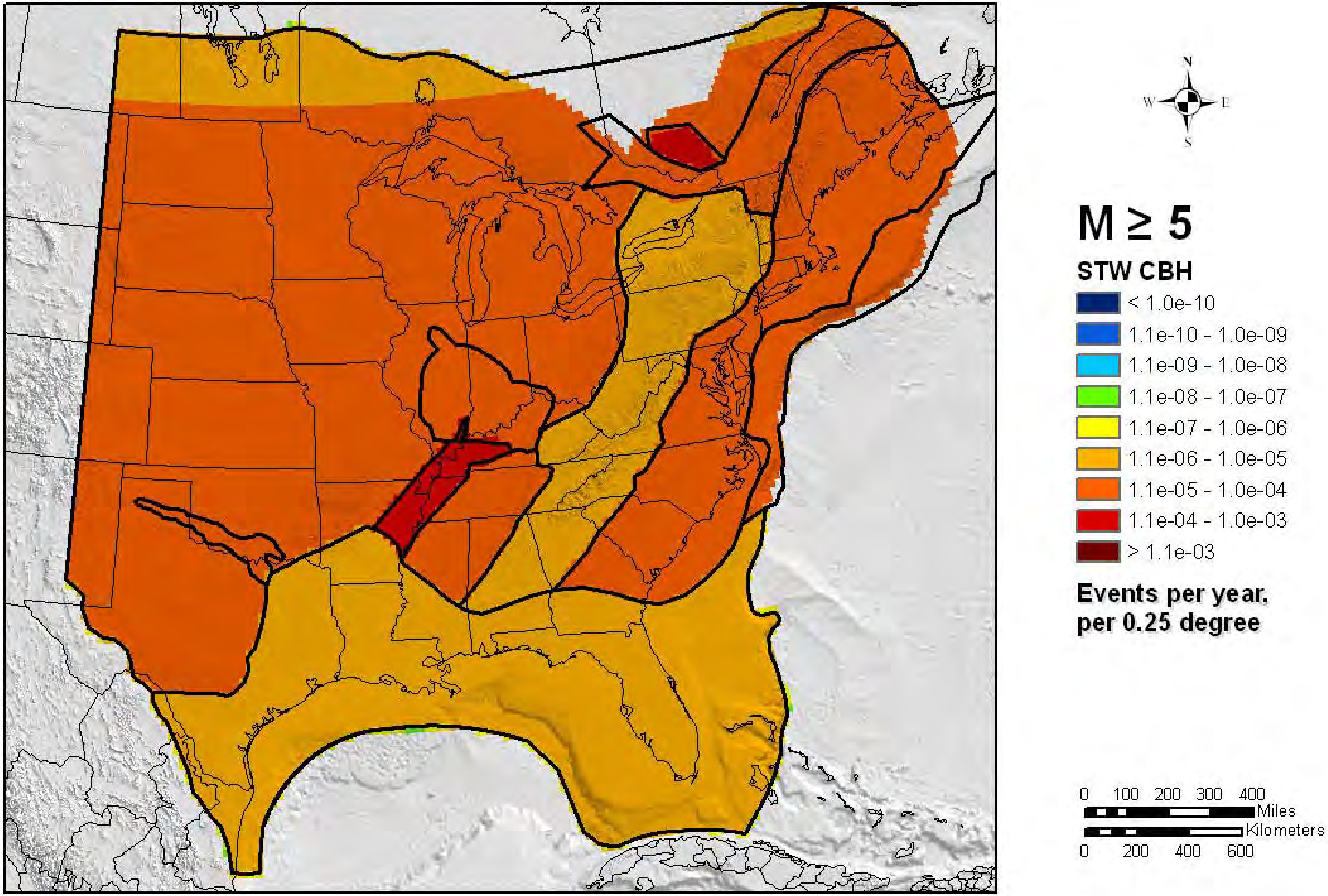

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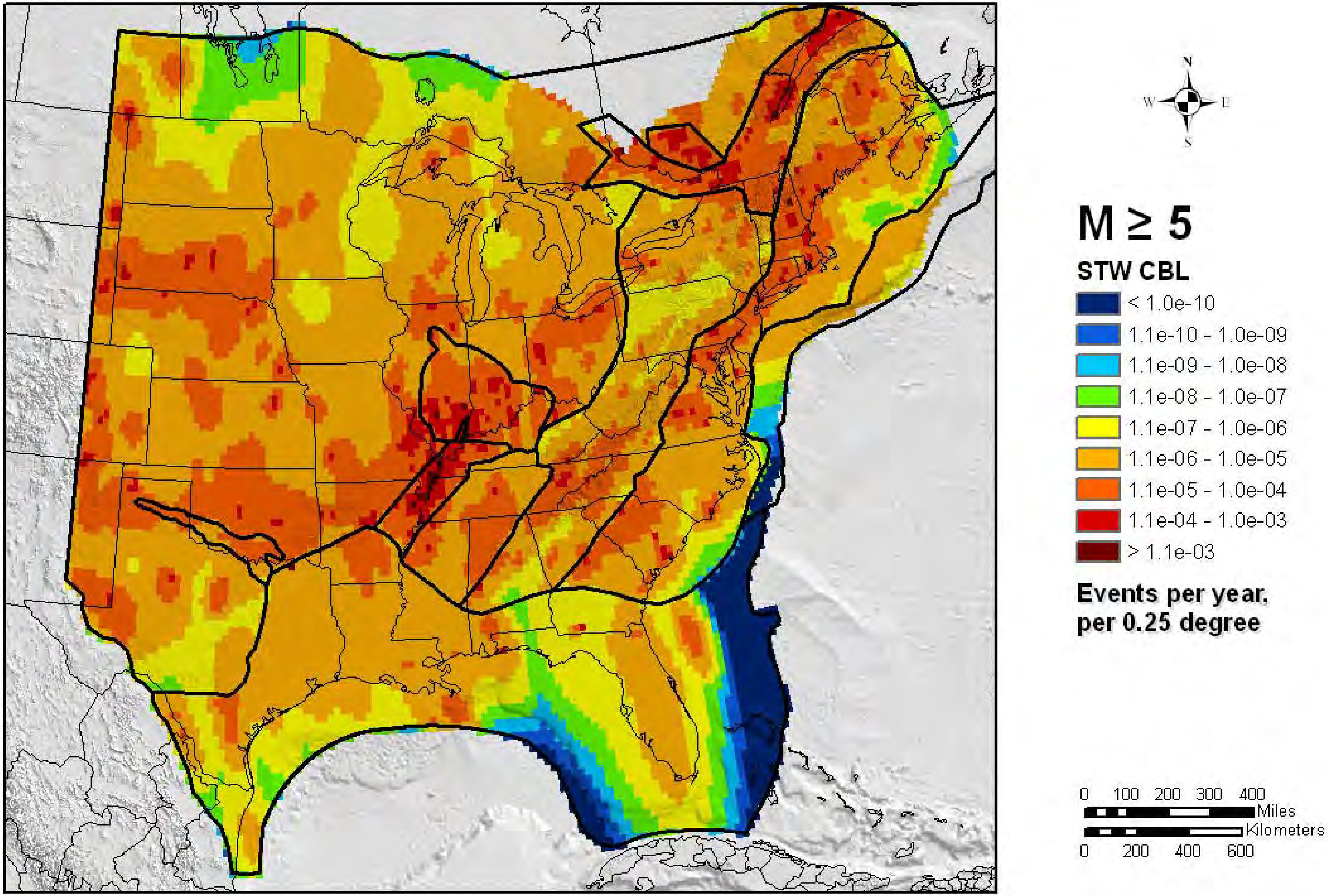

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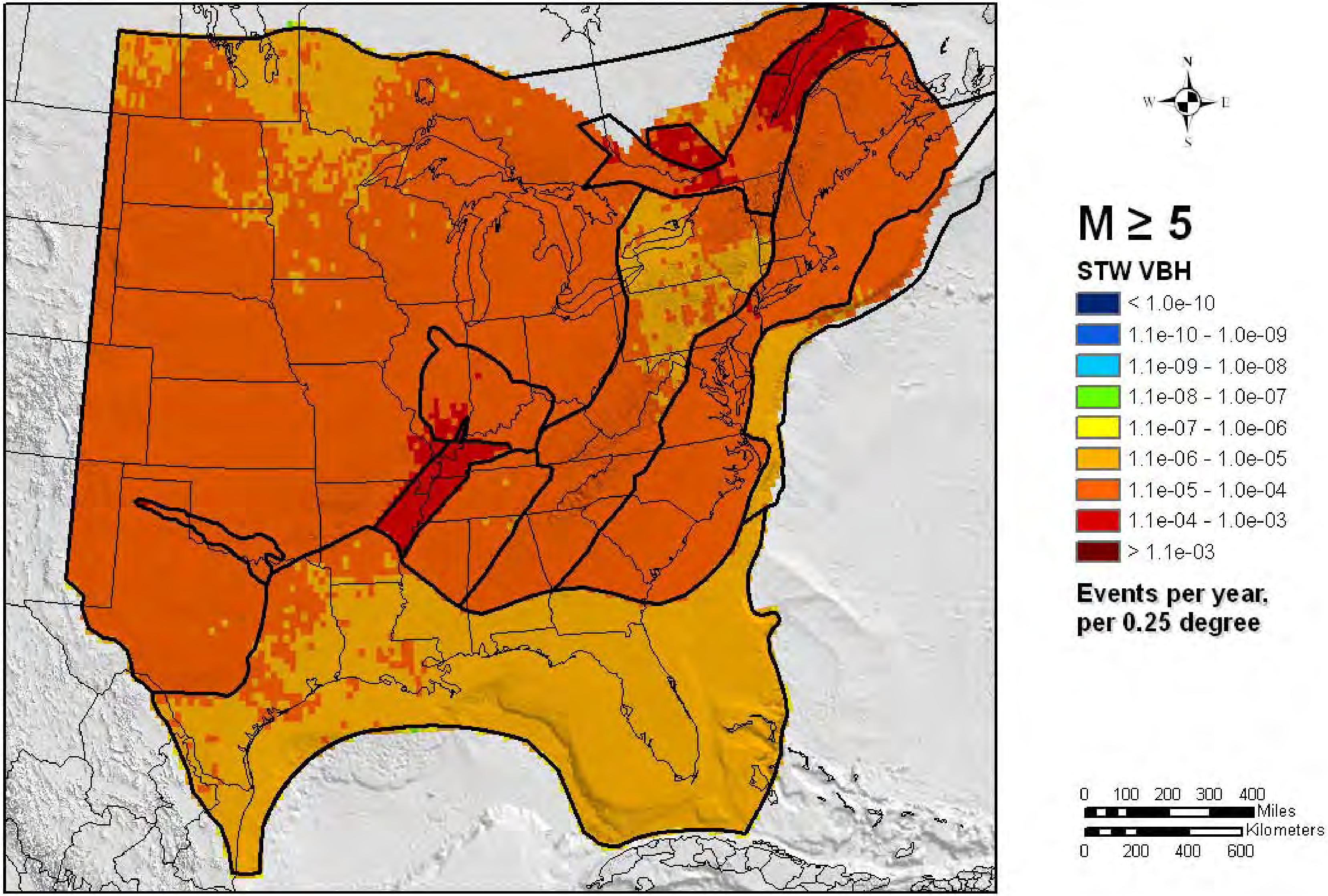

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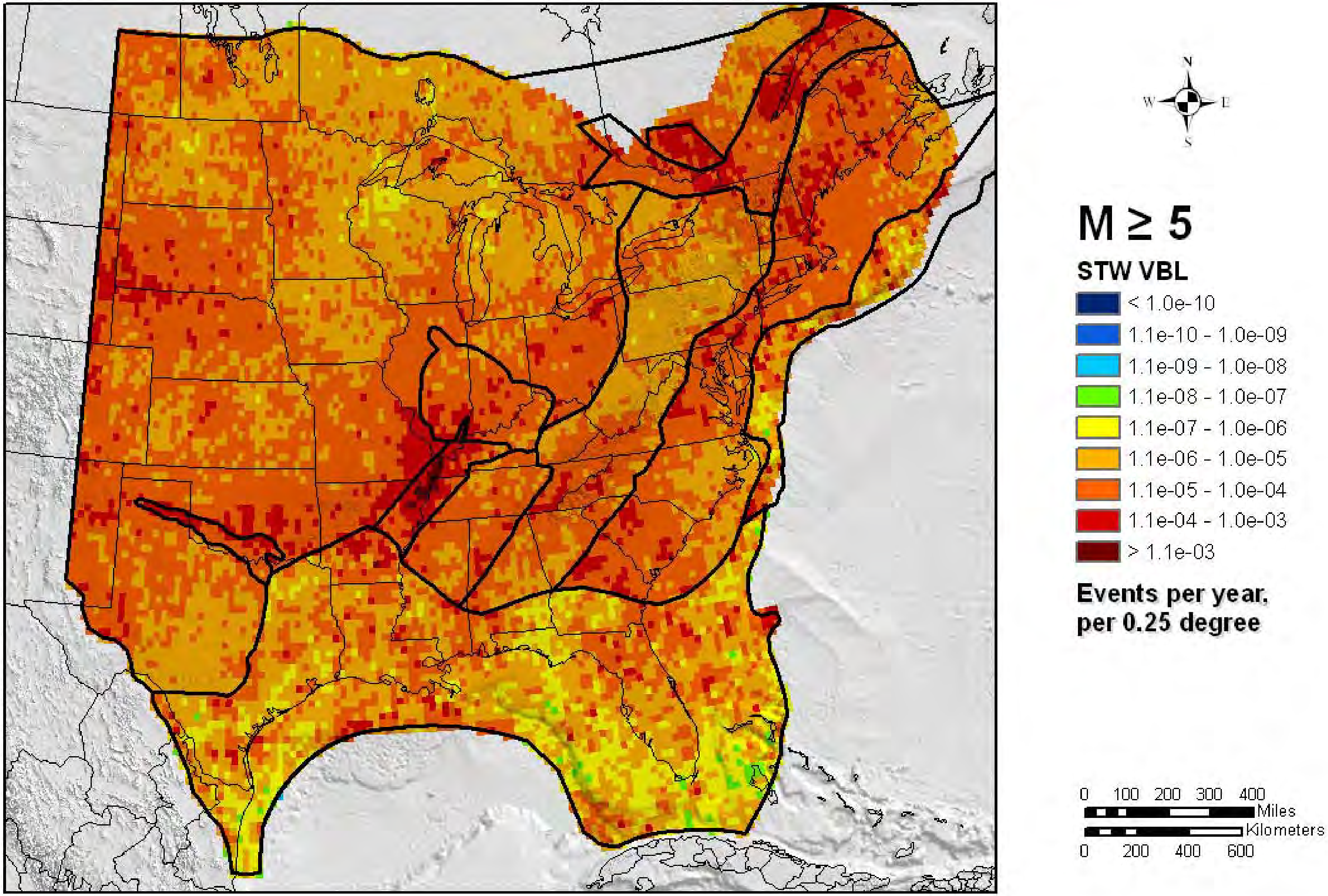

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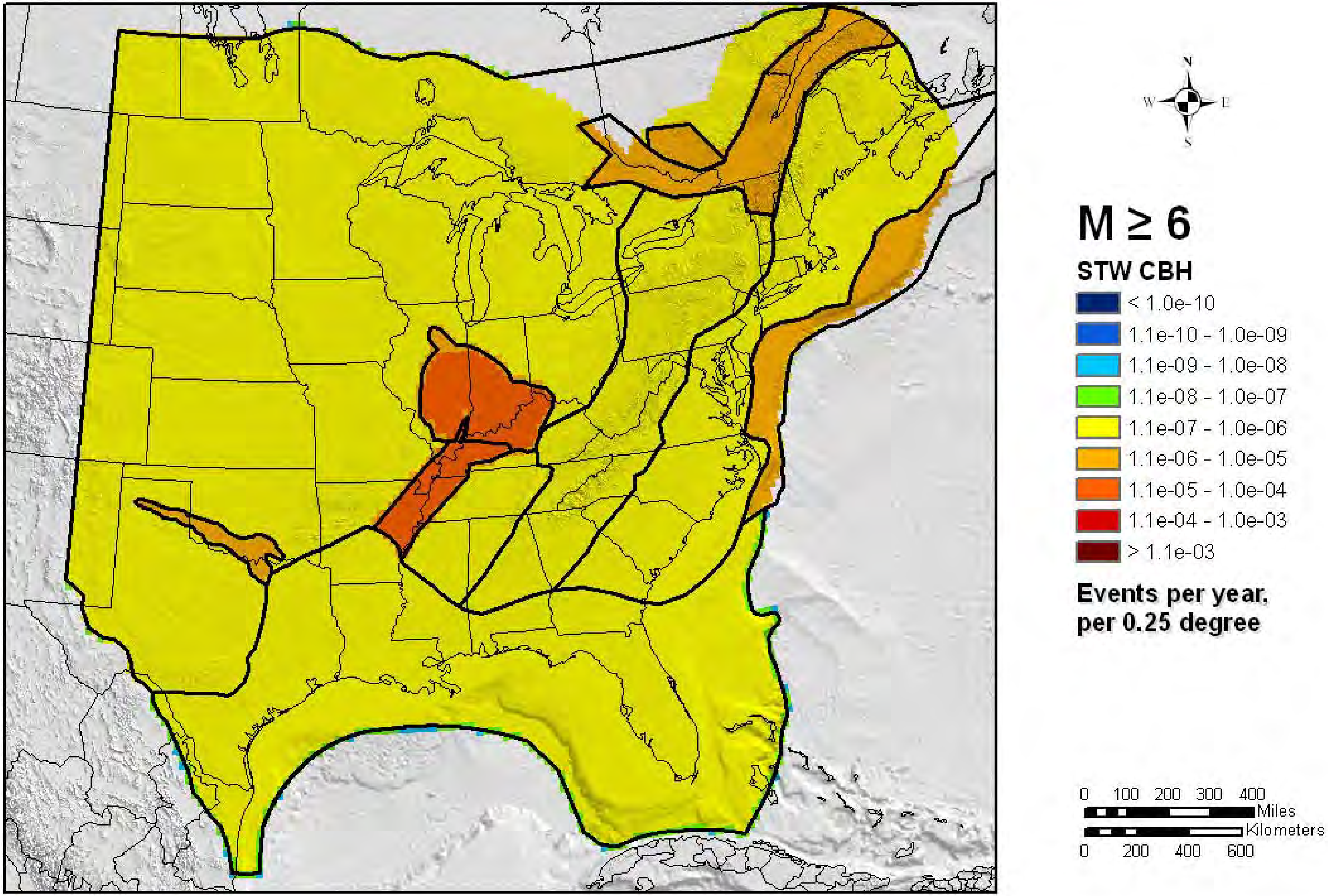

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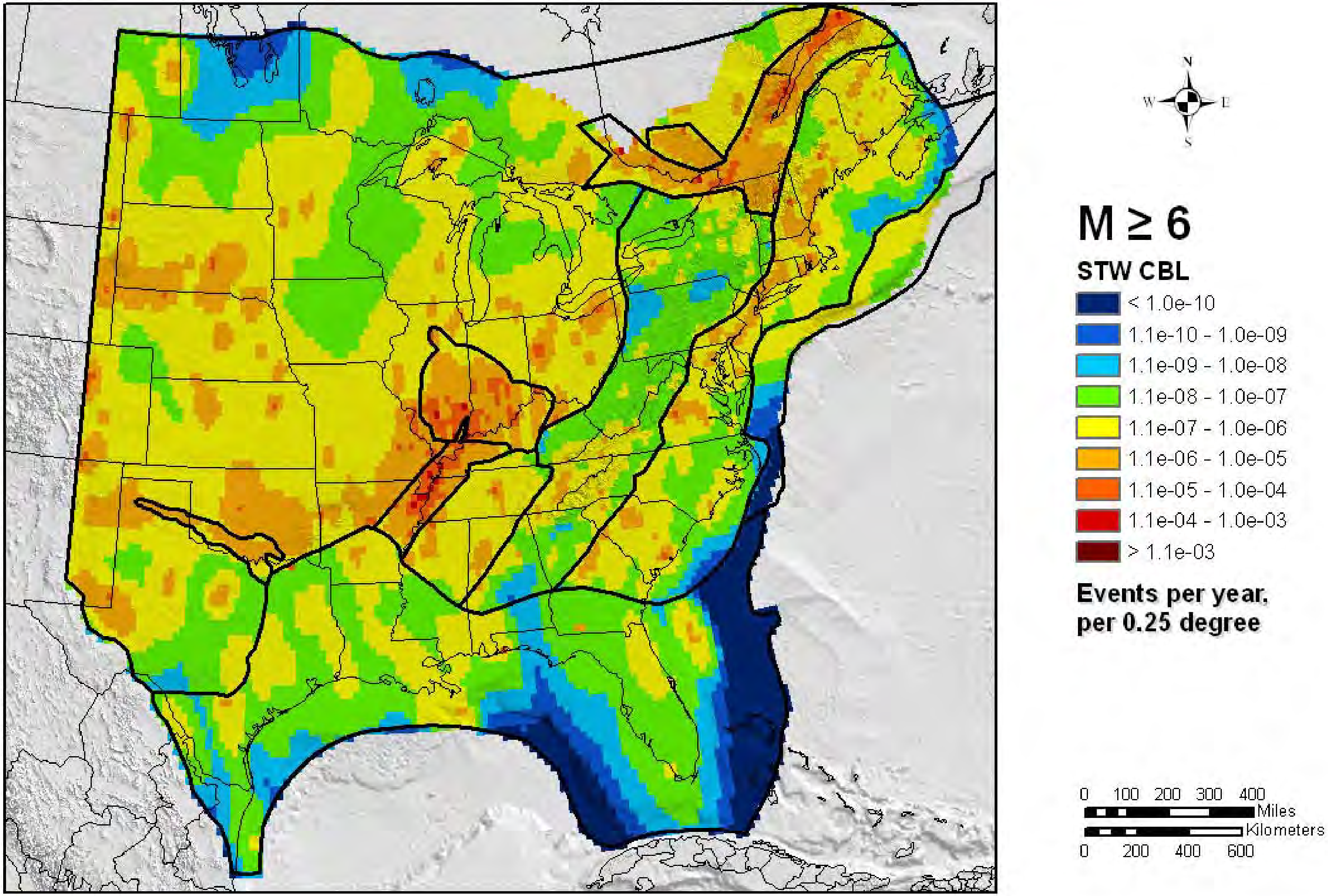

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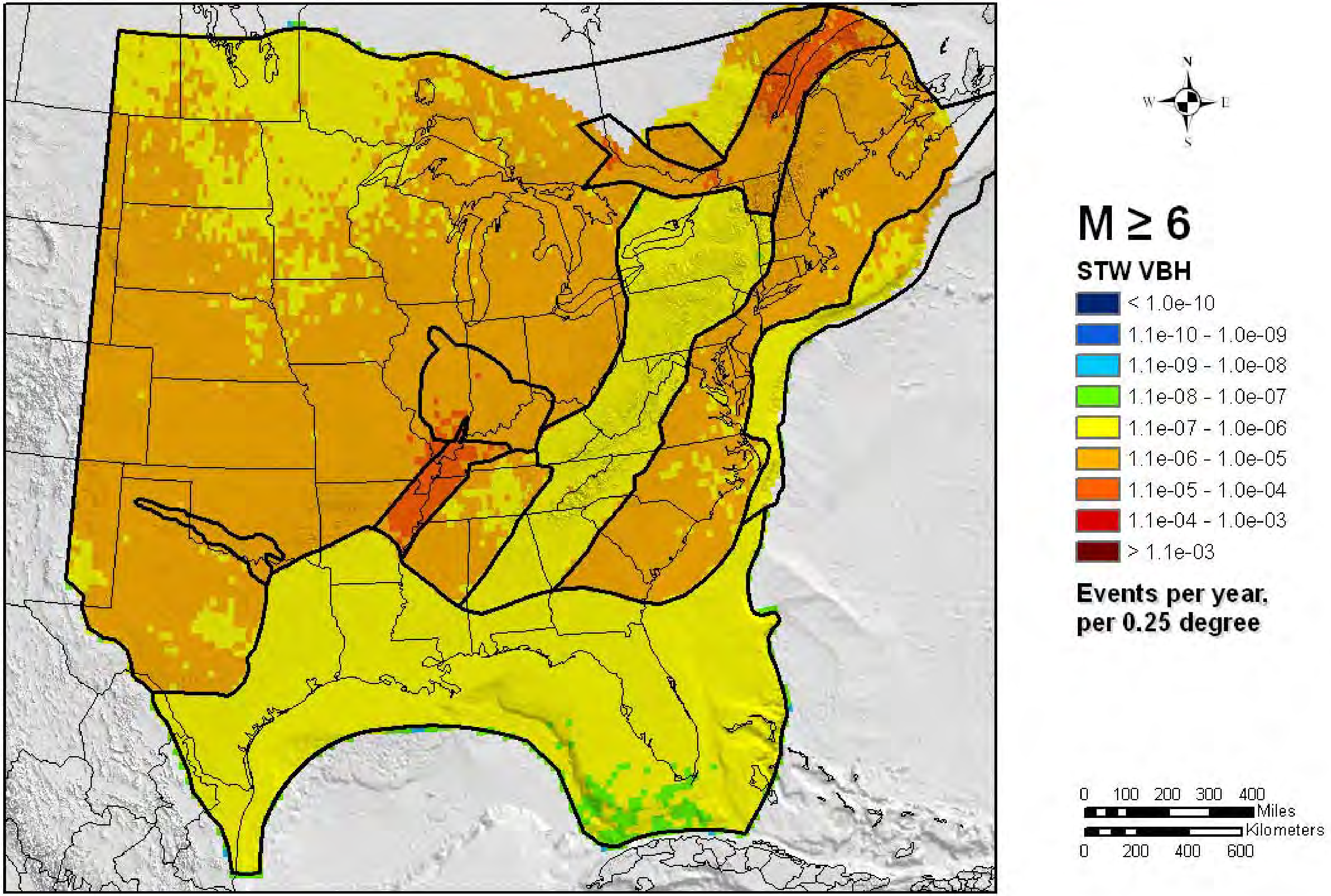

AMEC Geomatrix

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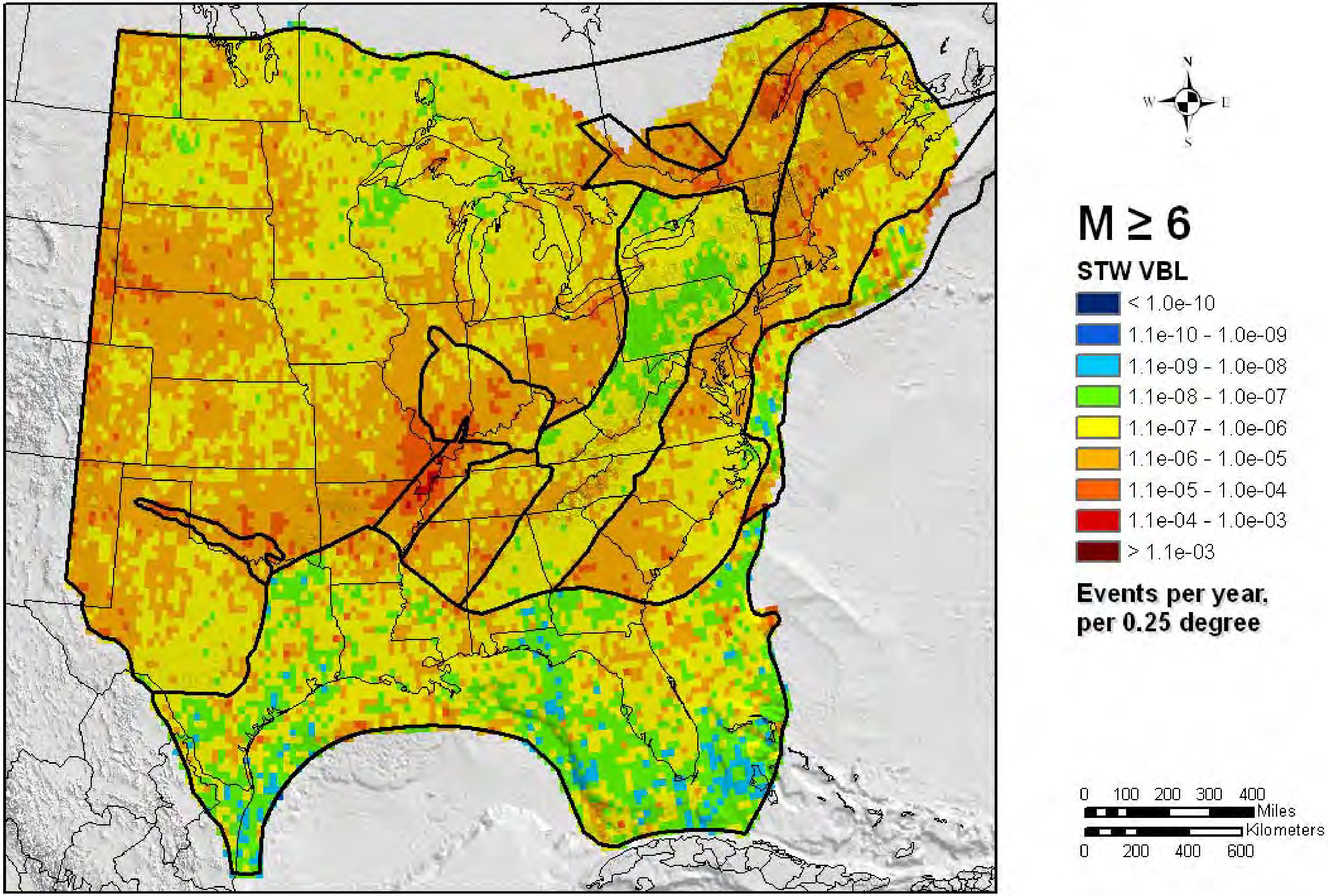

AMEC Geomatrix

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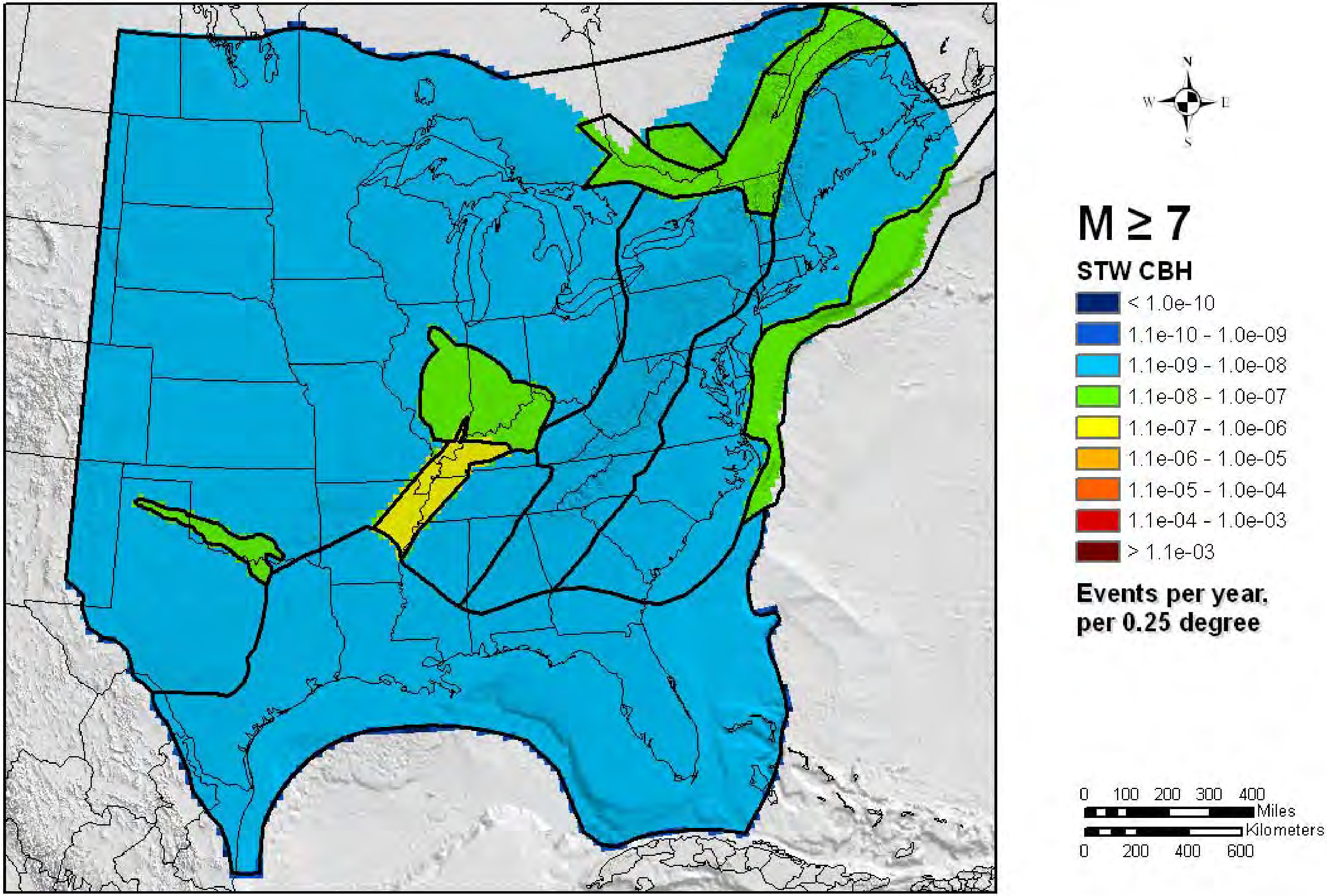

AMEC Geomatrix

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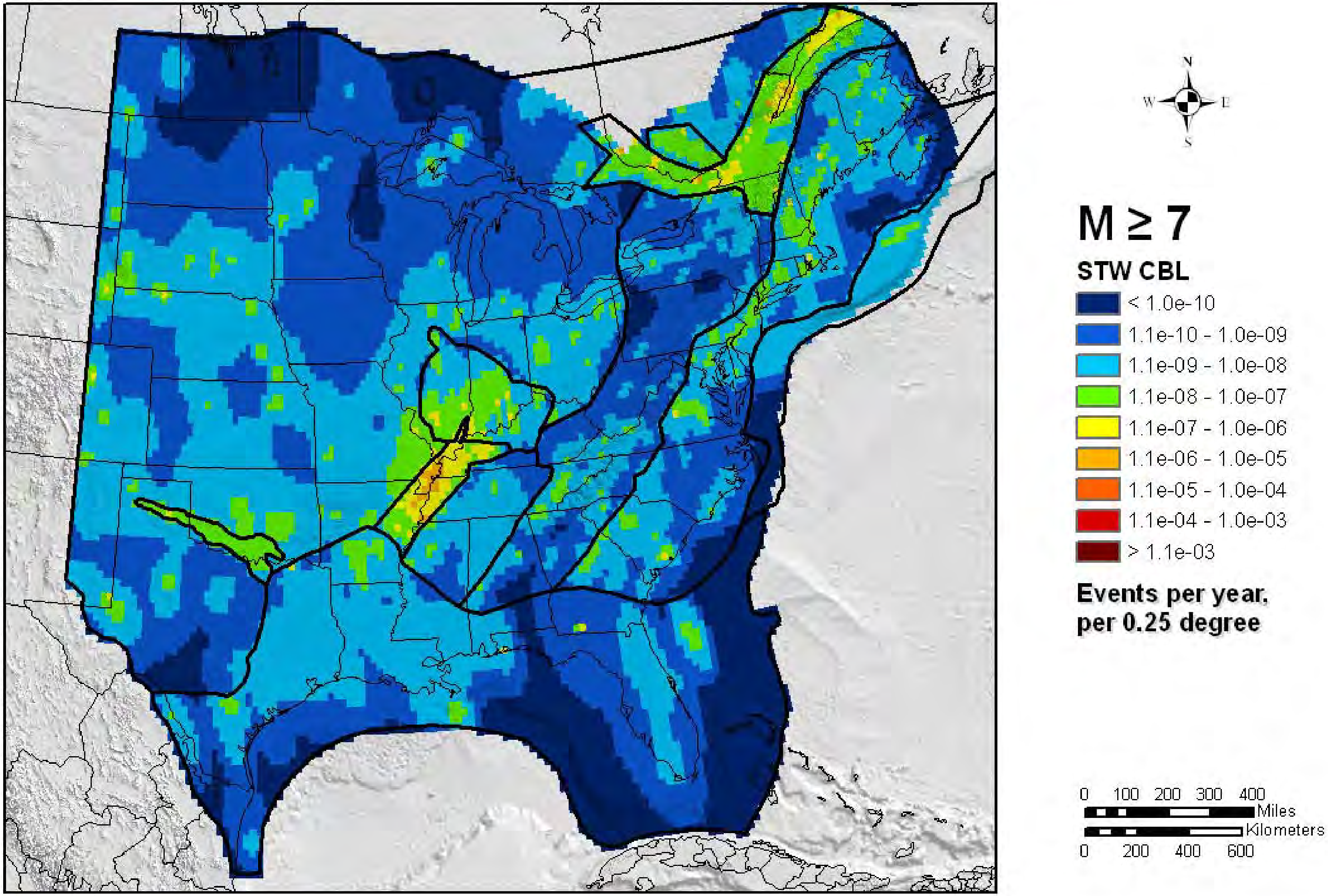
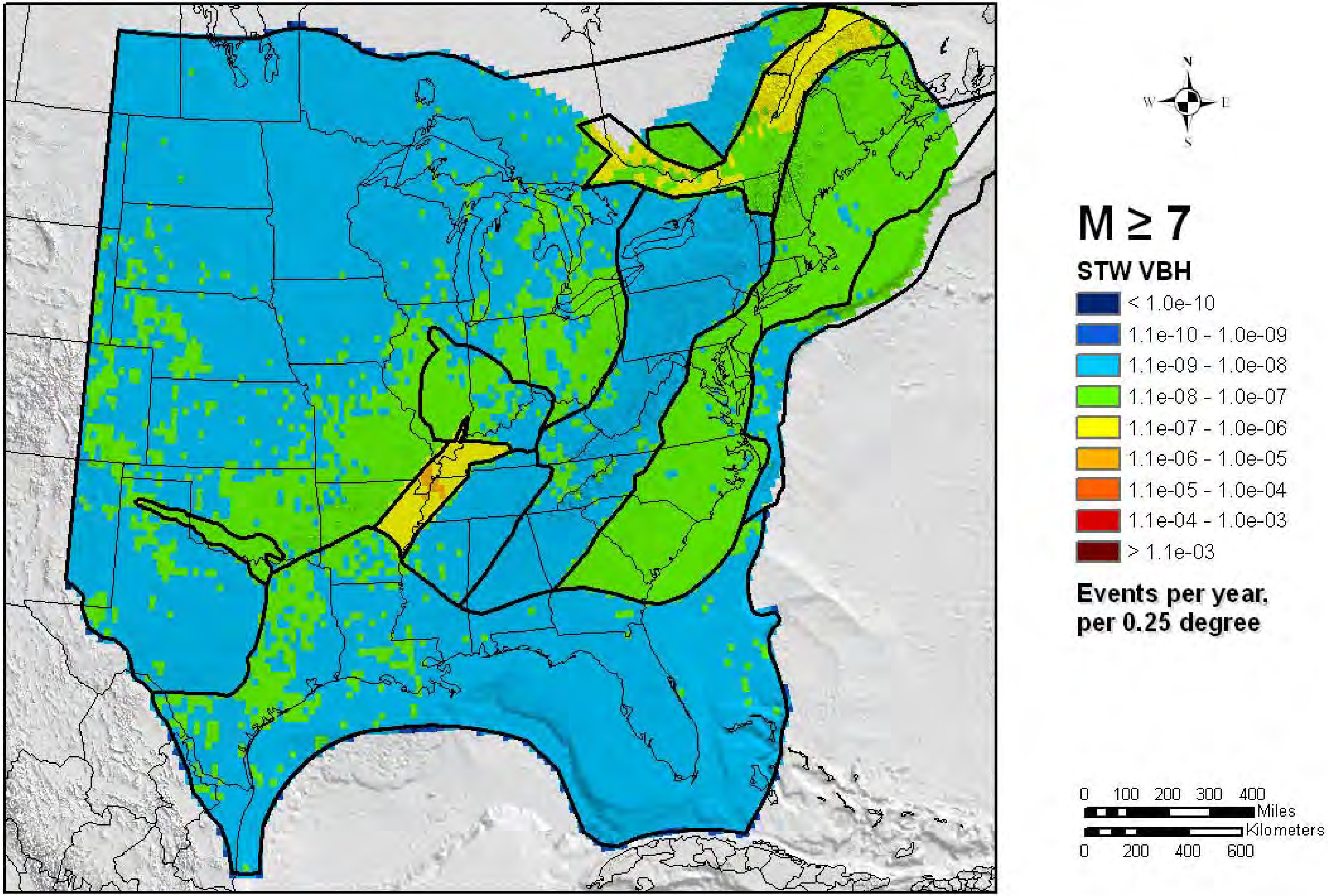


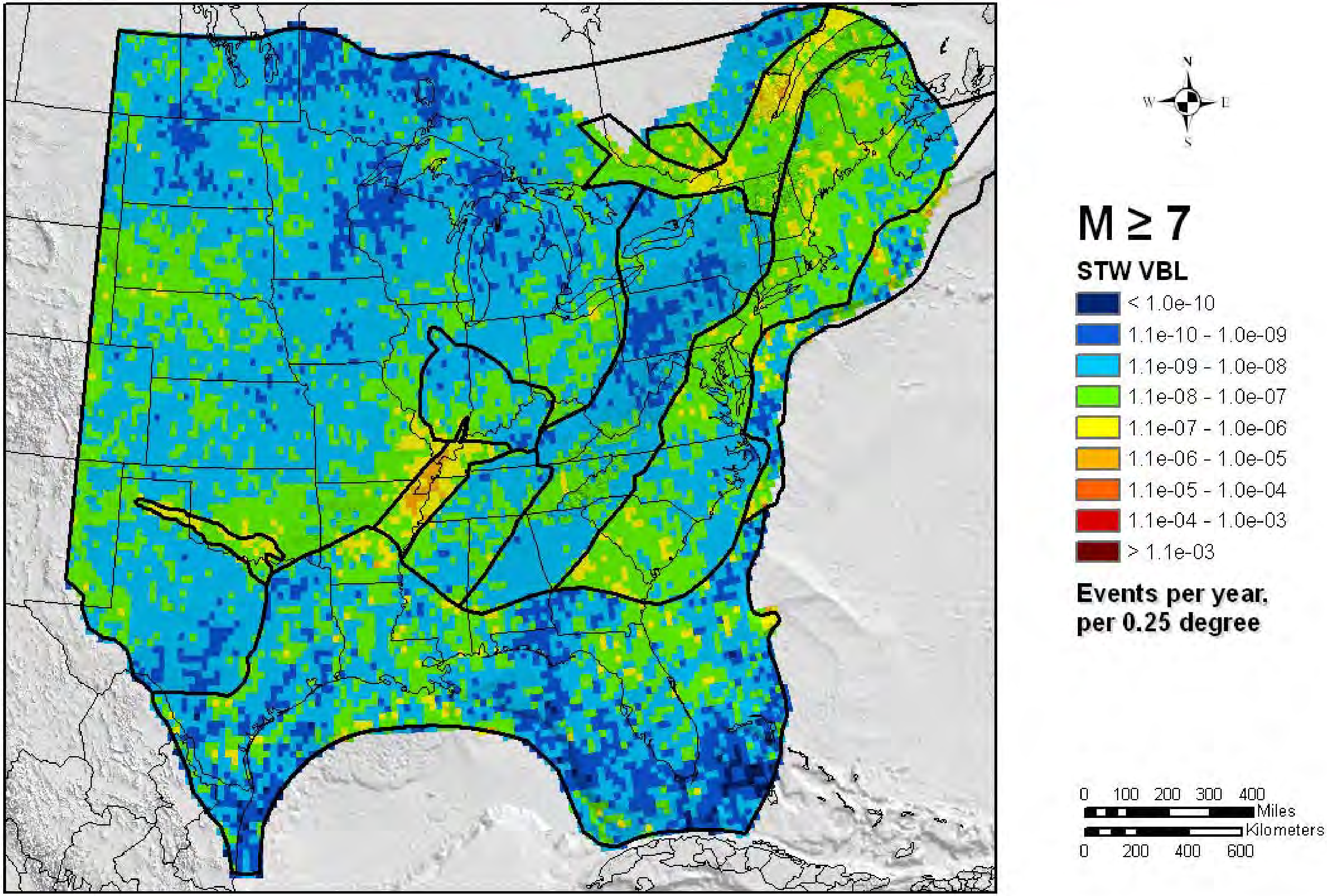
AMEC Geomatrix

Spatial Density Model of Historical Seismicity



AMEC Geomatrix

Spatial Density Model of Historical Seismicity



M ≥ 7

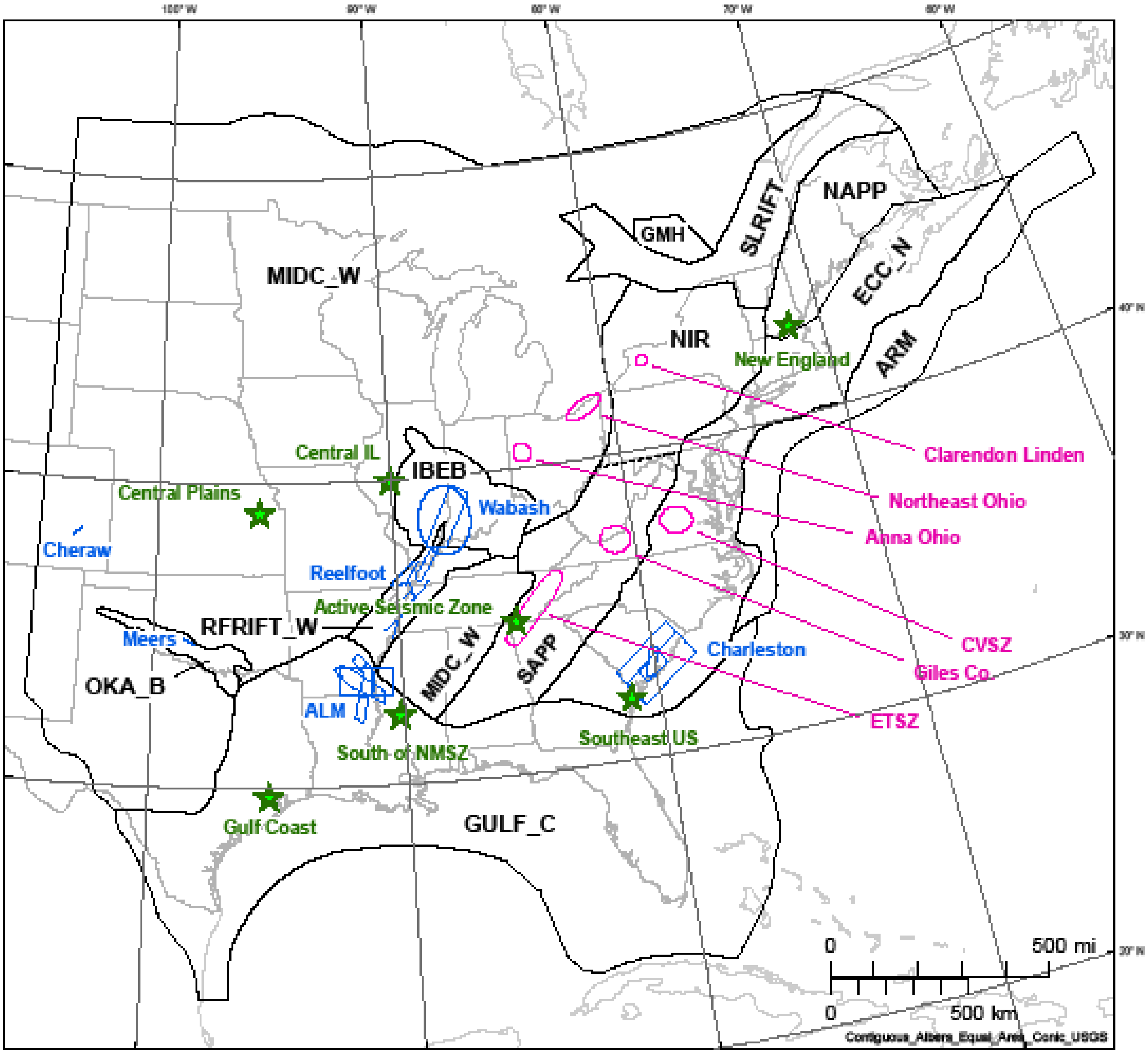
STW VBL

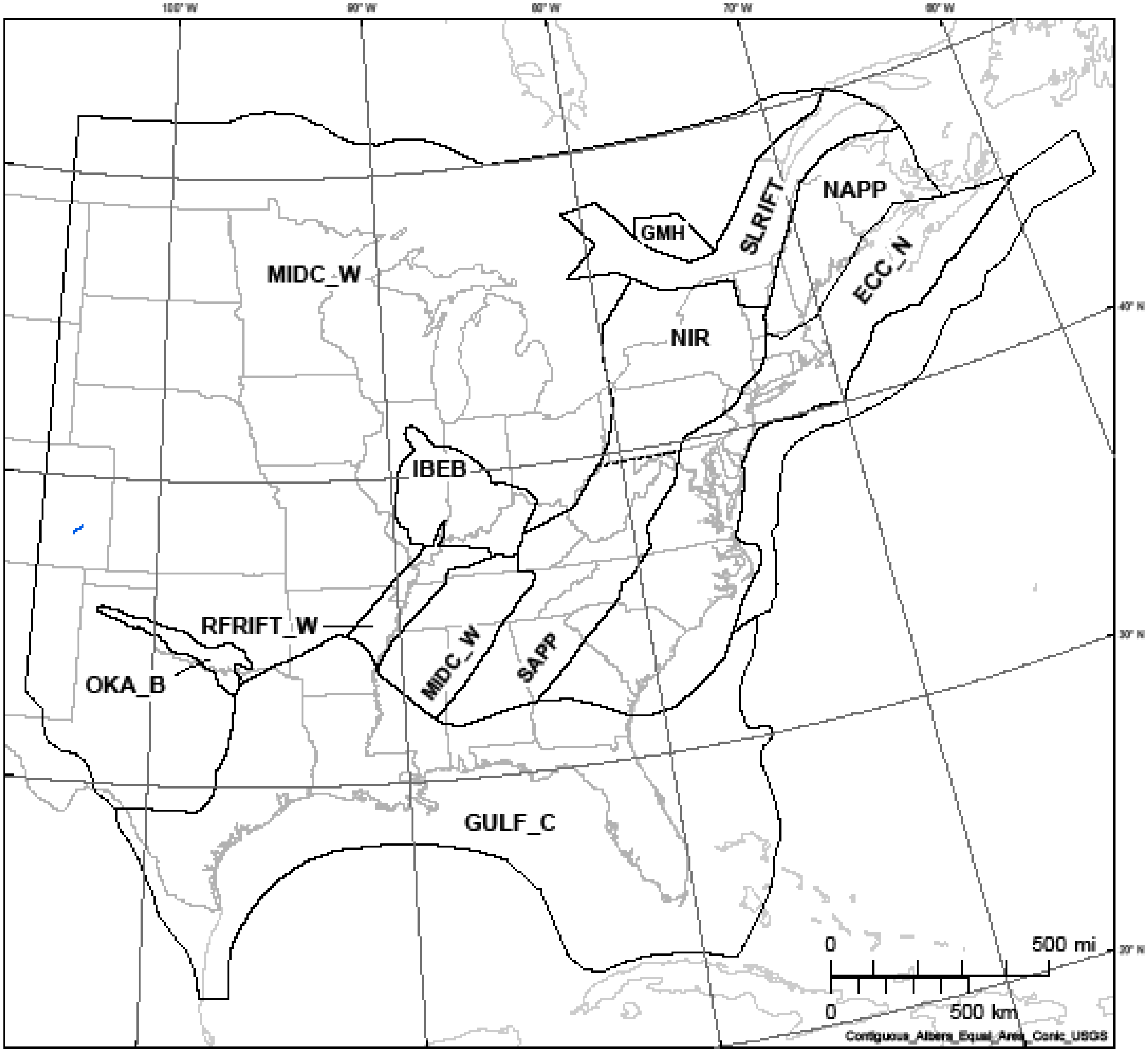
Events per year, per 0.25 degree

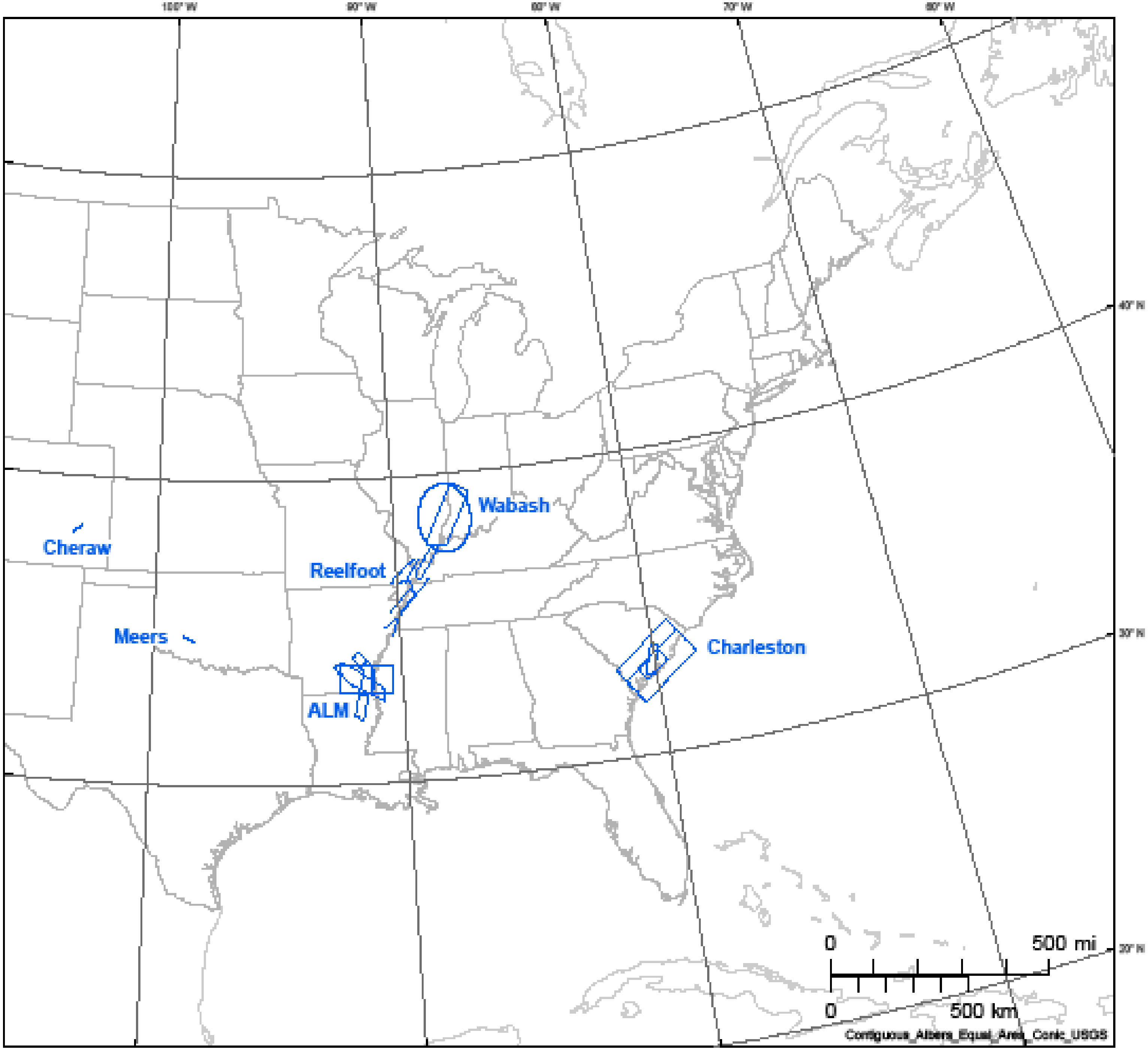
AMEC Geomatrix

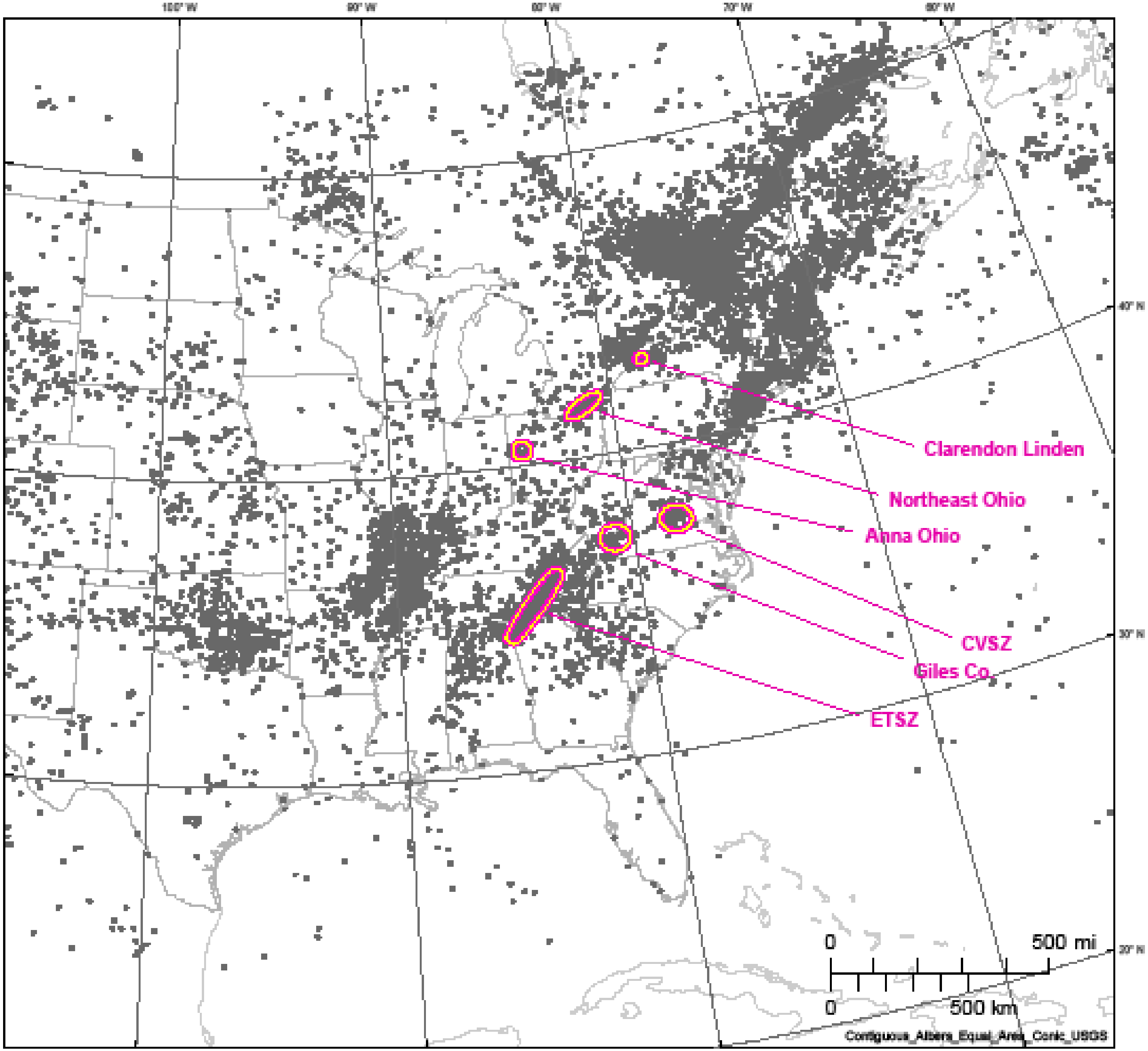
HID Figures and Tables

CEUS SSC Workshop #3
August 25-26, 2009
Robert Youngs (AMEC Geomatrix)

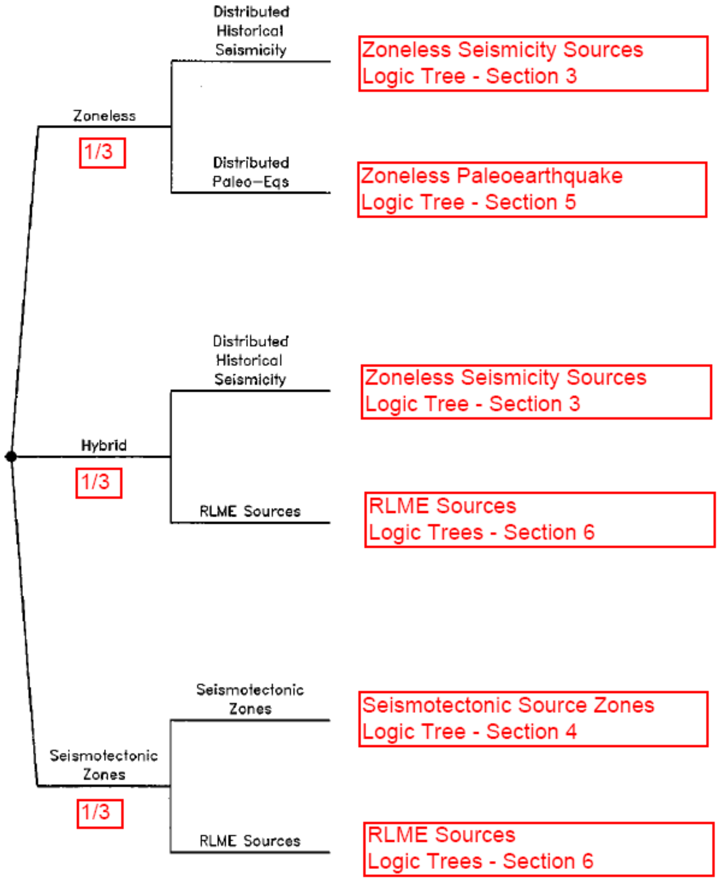

100° W
90° W
80° W
70° W
60° W
40° N
30° N
20° N
MIDC_W
GMH
SLRIFT
NAPP
ECC_N
NIR
New England
ARM
Clarendon Linden
Northeast Ohio
Anna Ohio
Central IL
IBEB
Central Plains
Wabash
Cheraw
Reelfoot
Active Seismic Zone
RFRIFT_W
Meers
OKA_B
MIDC_W
SAPP
Charleston
CVSZ
Giles Co.
ETSZ
ALM
South of NMSZ
Southeast US
Gulf Coast
GULF_C
0
500 mi
0
500 km
Contiguous_Albers_Equal_Area_Conic_USGS


100° W
90° W
80° W
70° W
60° W
40° N
30° N
20° N
MIDC_W
GMH
SLRIFT
NAPP
ECC_N
NIR
IBEB
RFRIFT_W
OKA_B
MIDC_W
SAPP
GULF_C
0
500 mi
0
500 km
Contiguous_Albers_Equal_Area_Conic_USGS


100° W
90° W
80° W
70° W
60° W
40° N
30° N
20° N
Wabash
Cheraw
Reelfoot
Meers
Charleston
ALM
0
500 mi
0
500 km
Contiguous_Albers_Equal_Area_Conic_USGS


100° W
90° W
80° W
70° W
60° W
40° N
30° N
20° N
Clarendon Linden
Northeast Ohio
Anna Ohio
CVSZ
Giles Co.
ETSZ
0
500 mi
0
500 km
Contiguous_Albers_Equal_Area_Conic_USGS

Master Logic Tree



Zoneless Seismicity Sources
Logic Tree - Section 3

Zoneless Paleoearthquake
Logic Tree - Section 5

Zoneless Seismicity Sources
Logic Tree - Section 3

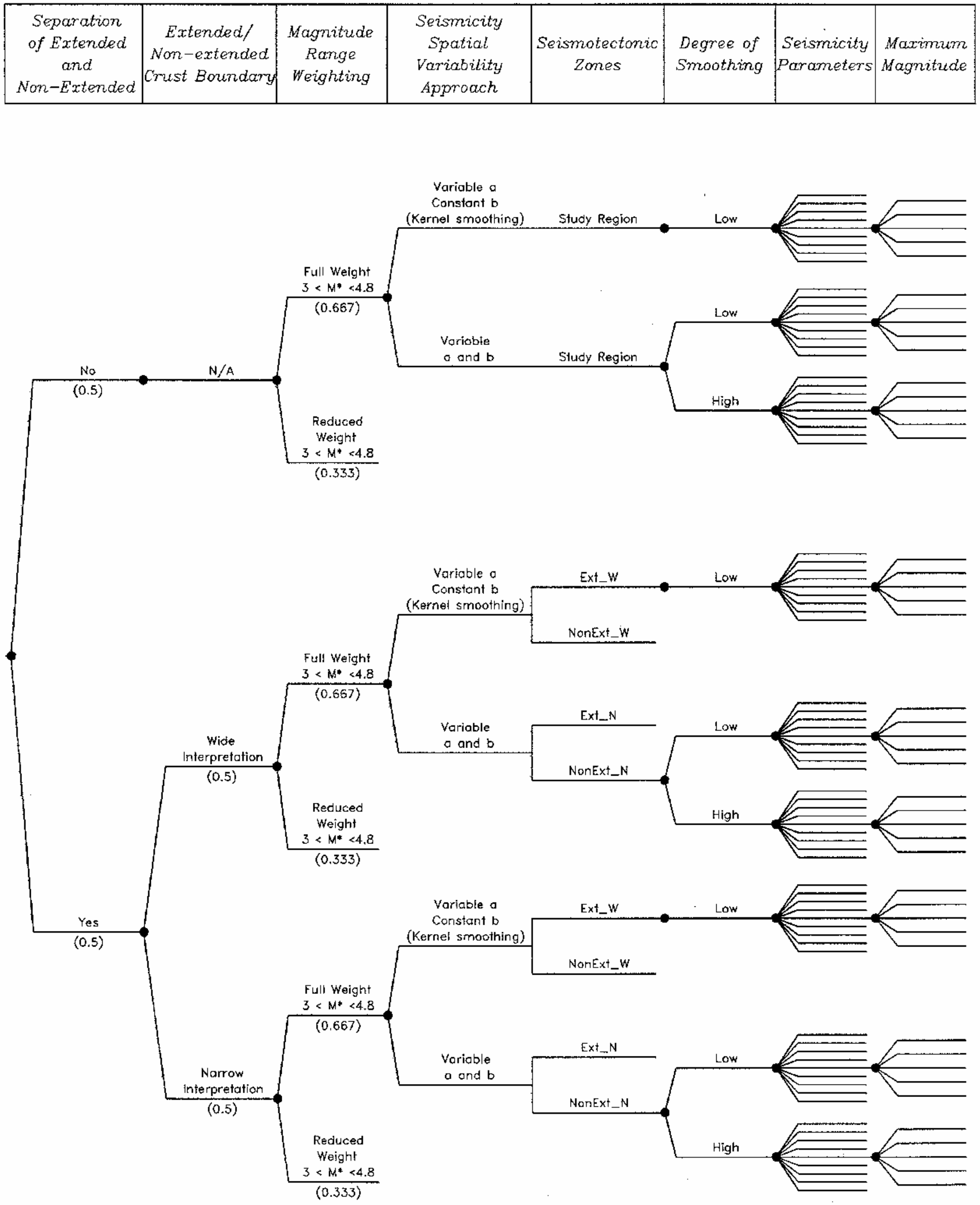
RLME Sources
Logic Trees - Section 6

Seismotectonic Source Zones
Logic Tree - Section 4

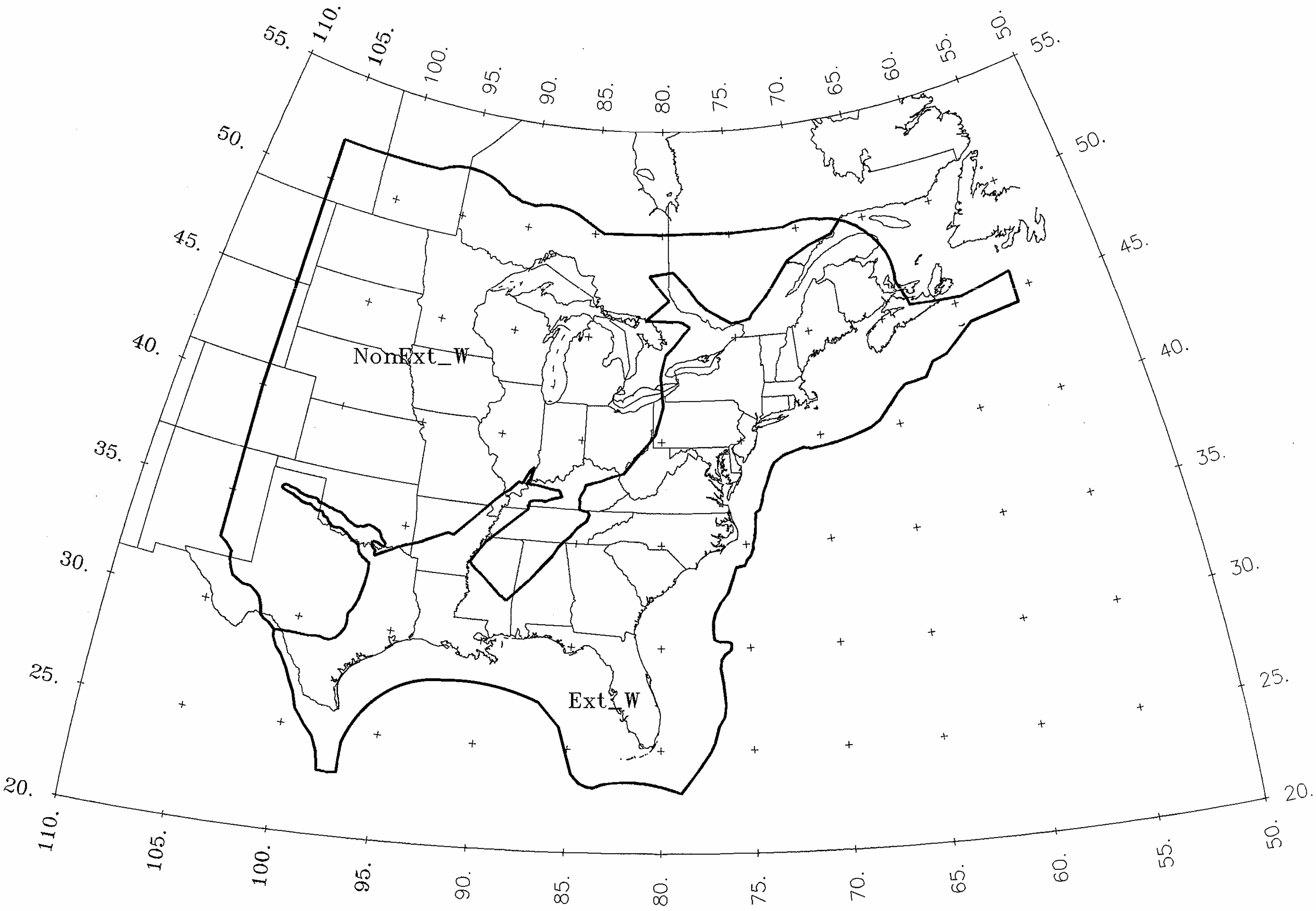
RLME Sources
Logic Trees - Section 6

Magnitude Interval Weights for “Reduced Weight” Model for Seismicity Parameter Estimation

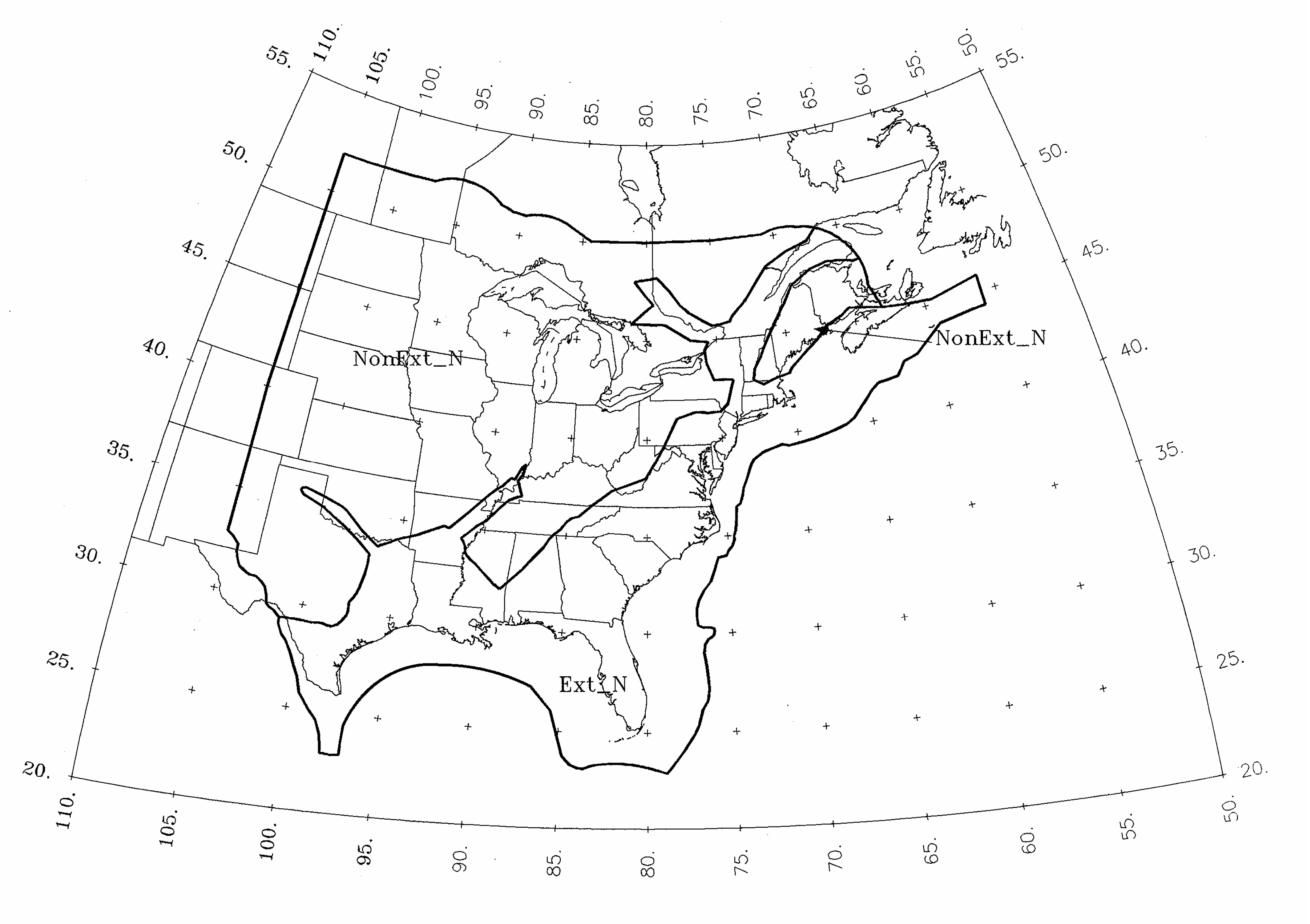
Magnitude Interval	Weight for Maximum Likelihood Assessment of Occurrence Parameters	Weight for Kernel Density Estimation
3.0 ≤ **M*** < 3.6	0.1	0.01
3.6 ≤ **M*** < 4.2	0.4	0.04
4.2 ≤ **M*** < 4.8	0.8	0.8
4.8 ≤ **M***	1.0	1.0


Separation of Extended and Non-Extended
Extended/ Non-extended Crust Boundary
Magnitude Range Weighting
Seismicity Spatial Variability Approach
Seismotectonic Zones
Degree of Smoothing
Seismicity Parameters
Maximum Magnitude
No
(0.5)
N/A
Full Weight
3 < M* <4.8
(0.667)
Reduced Weight
3 < M* <4.8
(0.333)
Variable a
Constant b
(Kernel smoothing)
Study Region
Low
Variable
a and b
Study Region
Low
High
Yes
(0.5)
Wide Interpretation
(0.5)
Full Weight
3 < M* <4.8
(0.667)
Reduced Weight
3 < M* <4.8
(0.333)
Variable a
Constant b
(Kernel smoothing)
Ext_W
NonExt_W
Low
Variable
a and b
Ext_N
NonExt_N
Low
High
Narrow Interpretation
(0.5)
Full Weight
3 < M* <4.8
(0.667)
Reduced Weight
3 < M* <4.8
(0.333)
Variable a
Constant b
(Kernel smoothing)
Ext_W
NonExt_W
Low
Variable
a and b
Ext_N
NonExt_N
Low
High

Extended and Non-extended crust for the "Wide" Interpretation.



Extended and Non-extended crust for the “Narrow” Interpretation.



Seismicity and Maximum Magnitude Distributions for the Distributed Seismicity Sources of the Hybrid Branch of the Master Logic Tree

Source Zone	Magnitude Weighting Case	Degree of Spatial Smoothing [wt]	Spatial Density File	Seismicity Parameter File	Maximum Magnitude Distribution File
Study Region	Full Weight	Low [1.0]	OneZone-FW.xyd	OneZone-FW.rec	OneZone.mmx
	Reduced Weight	Low [1.0]	OneZone-RW.xyd	OneZone-RW.rec	
Ext_W	Full Weight	Low [1.0]	Ext_W-FW.xyd	Ext_W-FW.rec	Ext_W.mmx
	Reduced Weight	Low [1.0]	Ext_W-RW.xyd	Ext_W-RW.rec	
Ext_N	Full Weight	Low [1.0]	Ext_N-FW.xyd	Ext_N-FW.rec	Ext_N.mmx
	Reduced Weight	Low [1.0]	Ext_N-RW.xyd	Ext_N-RW.rec	
NonExt_W	Full Weight	Low [1.0]	NonExt_W-FW.xyd	NonExt_W-FW.rec	NonExt_W.mmx
	Reduced Weight	Low [1.0]	NonExt_W-RW.xyd	NonExt_W-RW.rec	
NonExt_N	Full Weight	Low [1.0]	NonExt_N-FW.xyd	NonExt_N-FW.rec	NonExt_N.mmx
	Reduced Weight	Low [1.0]	NonExt_N-RW.xyd	NonExt_N-RW.rec	

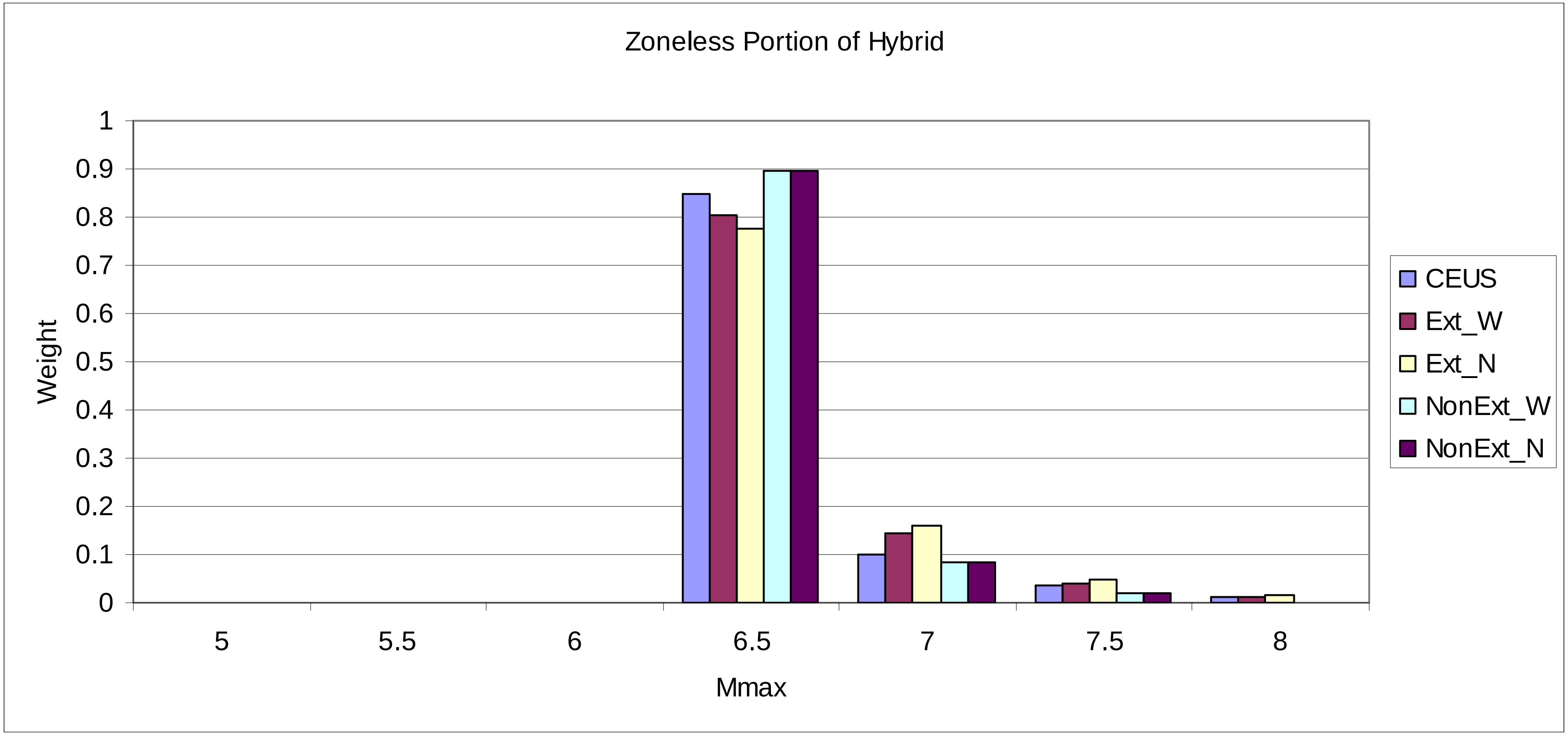
Seismotectonic Source Zones for the “Wide” Interpretation

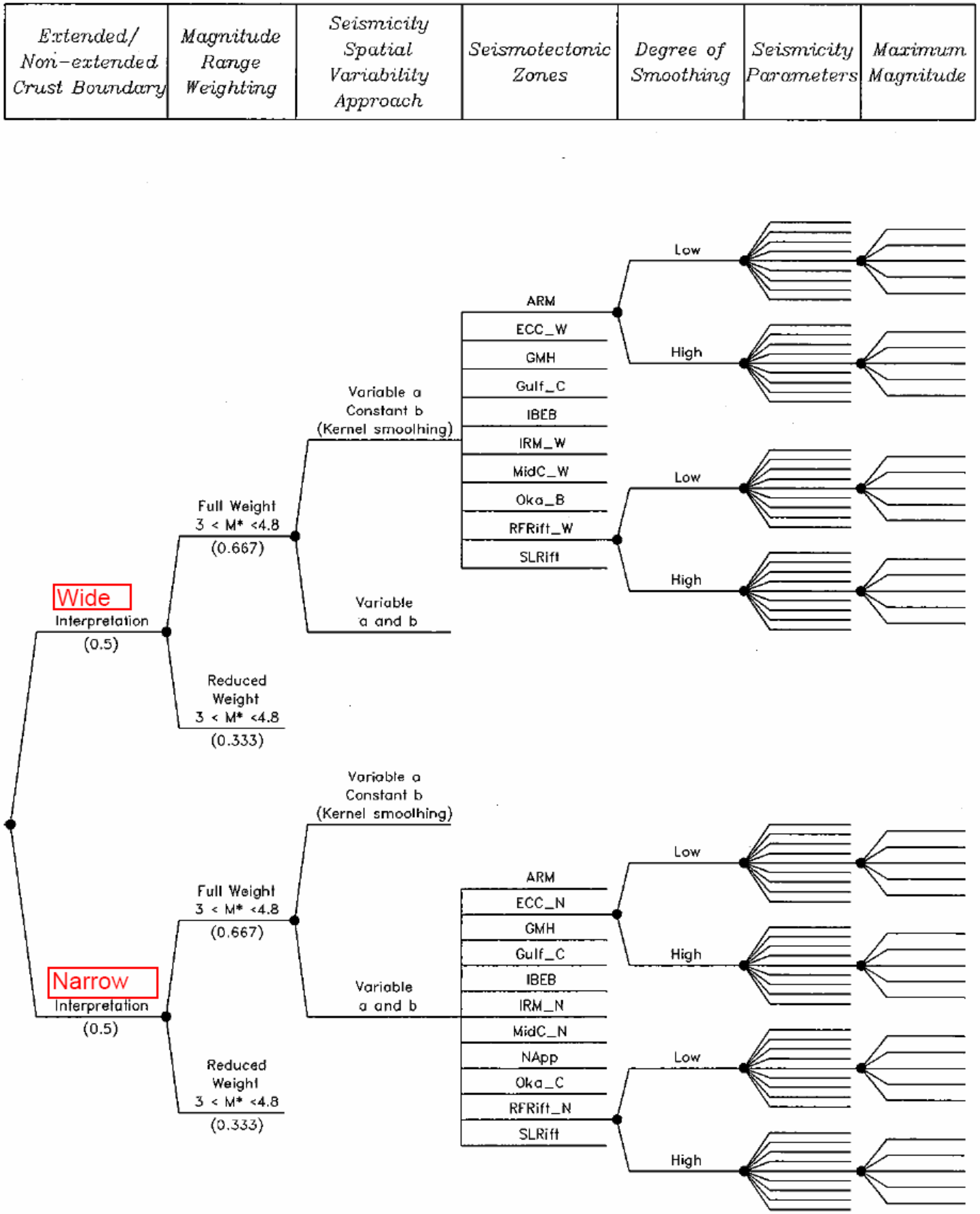
Zone File	**Seismotectonic Source Zone**	**Class**
ARM	Atlantic Rifted Margin	Extended
ECC_W.zon	Extended Continental Crust (wide)	Extended
GMH.zon	Great Meteor Hotspot	Non-extended
Gulf_C.zon	Gulf Coast extended continental crust	Extended
IBEB.zon	Illinois Basin Extended Basement	Non-extended
IRM_W.zon	Iapetan Rifted Margin (wide), including the Rome Trough	Extended
MidC_W.zon	Mid-continent Crust (wide)	Non-extended
OkA_B.zon	Oklahoma Aulacogen Model B (broad)	Extended
RFRift_W.zon	Reelfoot Rift (wide) including the southeast margin and the Rough Creek Graben	Extended
SLRift	St Lawrence Rift, including the Ottawa Graben	Extended

Seismotectonic Source Zones for the “Narrow” Interpretation

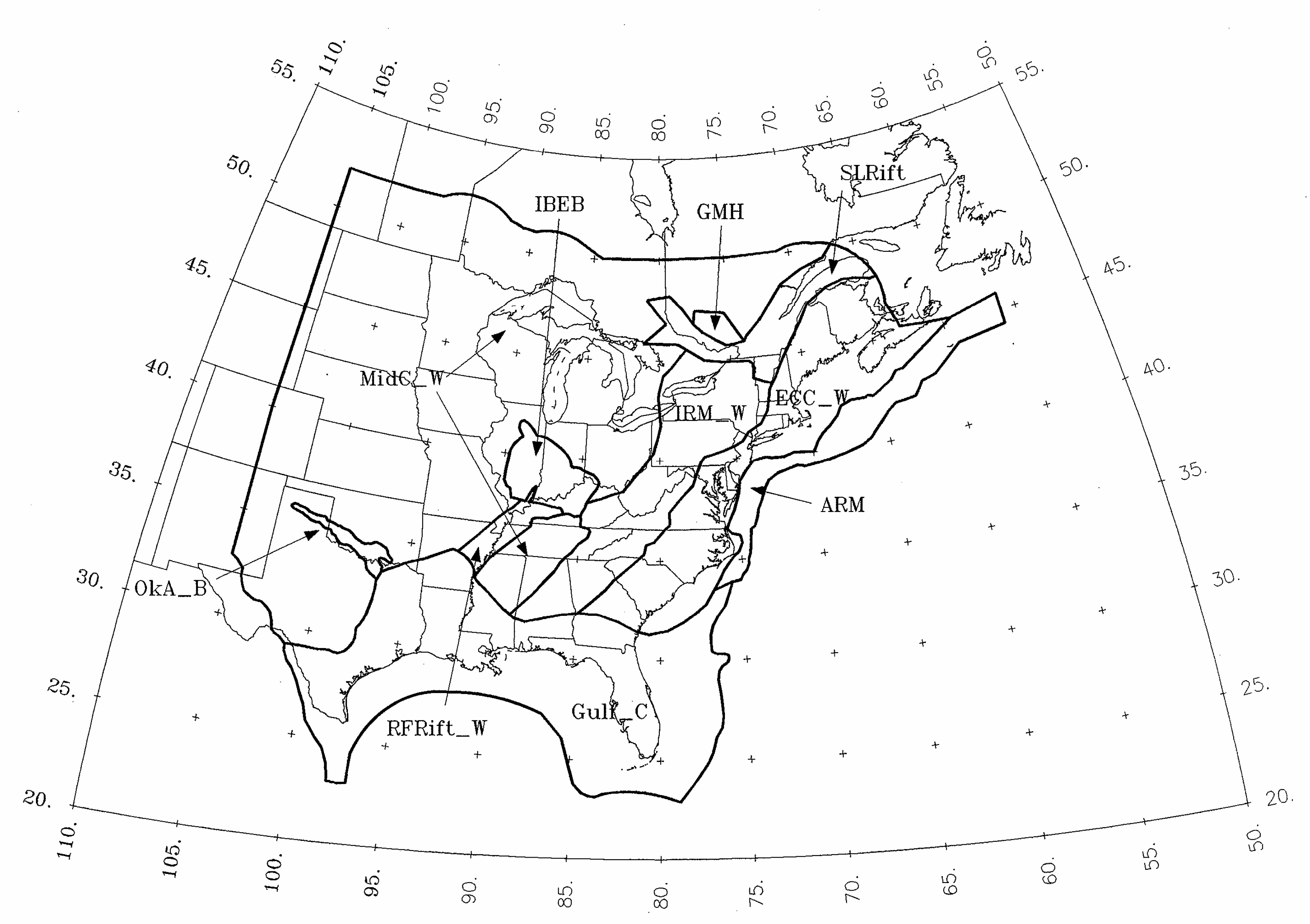
Zone File	**Seismotectonic Source Zone**	**Class**
ARM	Atlantic Rifted Margin	Extended
ECC_N.zon	Extended Continental Crust (narrow)	Extended
GMH.zon	Great Meteor Hotspot	Non-extended
Gulf_C.zon	Gulf Coast extended continental crust	Extended
IBEB.zon	Illinois Basin Extended Basement	Non-extended
IRM_N.zon	Iapetan Rifted Margin (narrow), without the Rome Trough	Extended
MidC_N.zon	Mid-continent Crust (narrow)	Non-extended
NApp	Northern Appalachia	Non-extended
OkA_C.zon	Oklahoma Aulacogen Model C (narrow)	Extended
RFRift_N.zon	Reelfoot Rift (narrow) without the southeast margin and the Rough Creek Graben	Extended
SLRift	St Lawrence Rift, including the Ottawa Graben	Extended

Results For Zoneless Portion of Hybrid Model (excluding RLMEs)




Extended/ Non-extended Crust Boundary
Magnitude Range Weighting
Seismicity Spatial Variability Approach
Seismotectonic Zones
Degree of Smoothing
Seismicity Parameters
Maximum Magnitude
Wide
Interpretation
(0.5)
Full Weight
3 < M* <4.8
(0.667)
Reduced Weight
3 < M* <4.8
(0.333)
Variable a
Constant b
(Kernel smoothing)
Variable a and b
ARM
ECC_W
GMH
Gulf_C
IBEB
IRM_W
MidC_W
Oka_B
RFRift_W
SLRift
Low
High
Low
High
Narrow
Interpretation
(0.5)
Full Weight
3 < M* <4.8
(0.667)
Reduced Weight
3 < M* <4.8
(0.333)
Variable a
Constant b
(Kernel smoothing)
Variable a and b
ARM
ECC_N
GMH
Gulf_C
IBEB
IRM_N
MidC_N
NApp
Oka_C
RFRift_N
SLRift
Low
High
Low
High

Seismotectonic Source Zones for the “Wide” Seismotectonic model.



Seismotectonic Source Zones for the “Narrow” Seismotectonic model

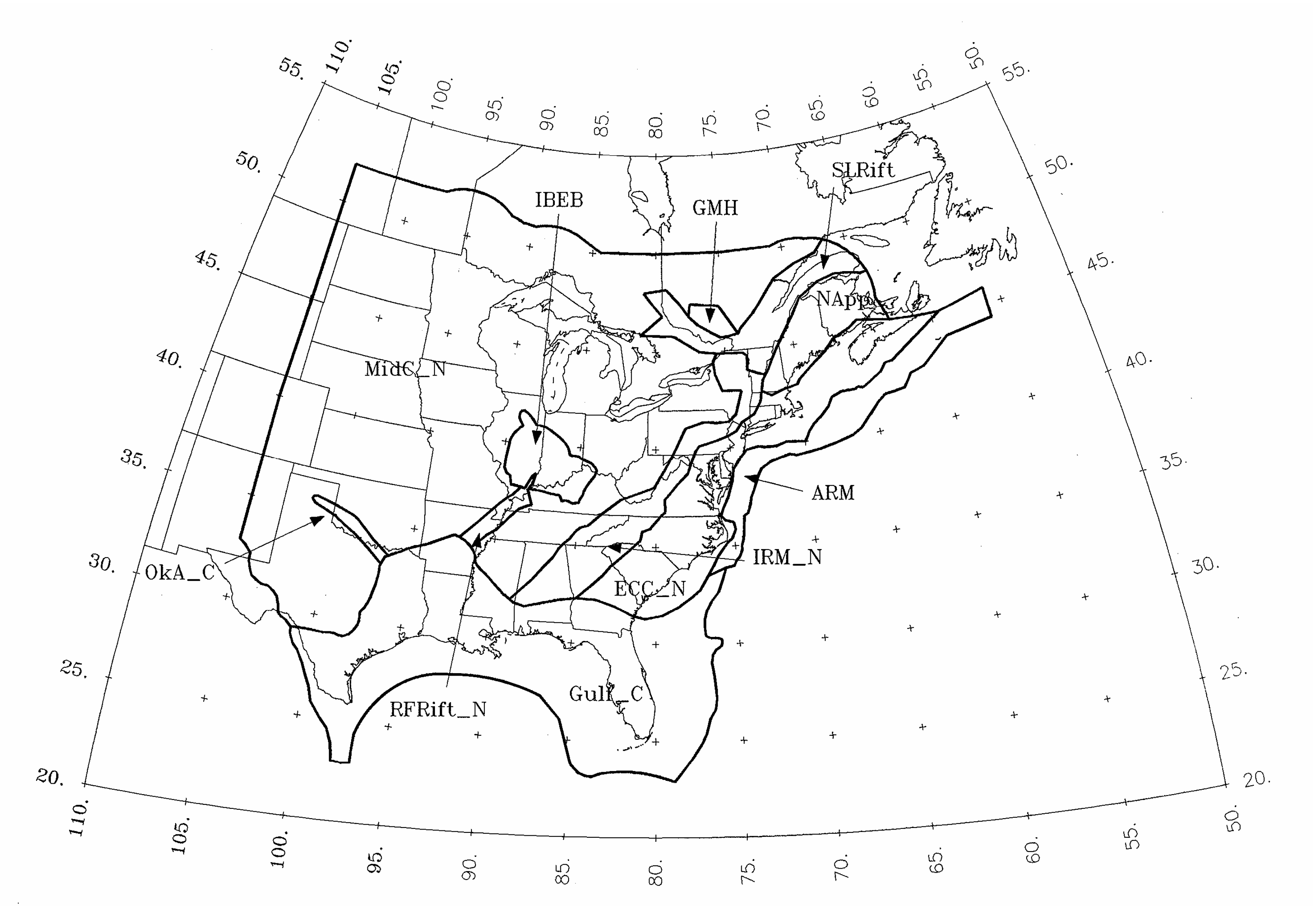


Table 5
Seismotectonic Source Zone Seismicity and Maximum Magnitude Distributions for the “Wide” Interpretation

Seismotectonic Source Zone	Magnitude Weighting Case	Degree of Spatial Smoothing [wt]	Spatial Density File	Seismicity Parameter File	Maximum Magnitude Distribution File
ARM	Full Weight	Low [0.95]	ARM-FW.xyd	ARM-FW.rec	ARM.mmx
		High [0.05]	Uniform		
	Reduced Weight	Low [0.95]	ARM-RW.xyd	ARM-RW.rec	
		High [0.05]	Uniform		
ECC_W	Full Weight	Low [0.95]	ECC_W-FW.xyd	ECC_W-FW.rec	ECC_W.mmx
		High [0.05]	Uniform		
	Reduced Weight	Low [0.95]	ECC_W-RW.xyd	ECC_W-RW.rec	
		High [0.05]	Uniform		
GMH	Full Weight	Low [0.5]	GMH-FW.xyd	GMH-FW.rec	GMH.mmx
		High [0.5]	Uniform		
	Reduced Weight	Low [0.75]	GMH-RW.xyd	GMH-RW.rec	
		High [0.25]	Uniform		
Gulf_C	Full Weight	Low [0.95]	GulfC-FW.xyd	GulfC-FW.rec	GulfC.mmx
		High [0.05]	Uniform		
	Reduced Weight	Low [0.8]	GulfC-RW.xyd	GulfC-RW.rec	
		High [0.2]	Uniform		

Table 5
Seismotectonic Source Zone Seismicity and Maximum Magnitude Distributions for the “Wide” Interpretation

Seismotectonic Source Zone	Magnitude Weighting Case	Degree of Spatial Smoothing [wt]	Spatial Density File	Seismicity Parameter File	Maximum Magnitude Distribution File
IBEB	Full Weight	Low [0.95]	IBEB-FW.xyd	IBEB-FW.rec	IBEB.mmx
		High [0.05]	Uniform		
	Reduced Weight	Low [0.8]	IBEB -RW.xyd	IBEB -RW.rec	
		High [0.2]	Uniform		
IRM_W	Full Weight	Low [0.95]	IRM_W-FW.xyd	IRM_W-FW.rec	IRM_W.mmx
		High [0.05]	Uniform		
	Reduced Weight	Low [0.25]	IRM_W -RW.xyd	IRM_W-RW.rec	
		High [0.75]	Uniform		
MidC_W	Full Weight	Low [0.95]	MidC_W-FW.xyd	MidC_W-FW.rec	MidC_W.mmx
		High [0.05]	Uniform		
	Reduced Weight	Low [0.95]	MidC_W -RW.xyd	MidC_W-RW.rec	
		High [0.05]	Uniform		
OkA_B	Full Weight*	Defined in Section 4.2 * Note that parameters that are provided for the Full Weight Case should also be used for the Reduced Weight Case as there are too few data above **M*** 4.2 to assess parameters			
	Reduced Weight*				
RFRift_W	Full Weight	Low [0.95]	RFRift_W-FW.xyd	RFRift_W-FW.rec	RFRift_W.mmx
		High [0.05]	Uniform		
	Reduced Weight	Low [0.25]	RFRift_W -RW.xyd	RFRift_W-RW.rec	
		High [0.75]	Uniform		
SLRift	Full Weight	Low [0.95]	SLRift-FW.xyd	SLRift-FW.rec	SLRift.mmx
		High [0.05]	Uniform		
	Reduced Weight	Low [0.95]	SLRift -RW.xyd	SLRift-RW.rec	
		High [0.05]	Uniform		

Table 6
Seismotectonic Source Zone Seismicity and Maximum Magnitude Distributions for the “Narrow” Interpretation

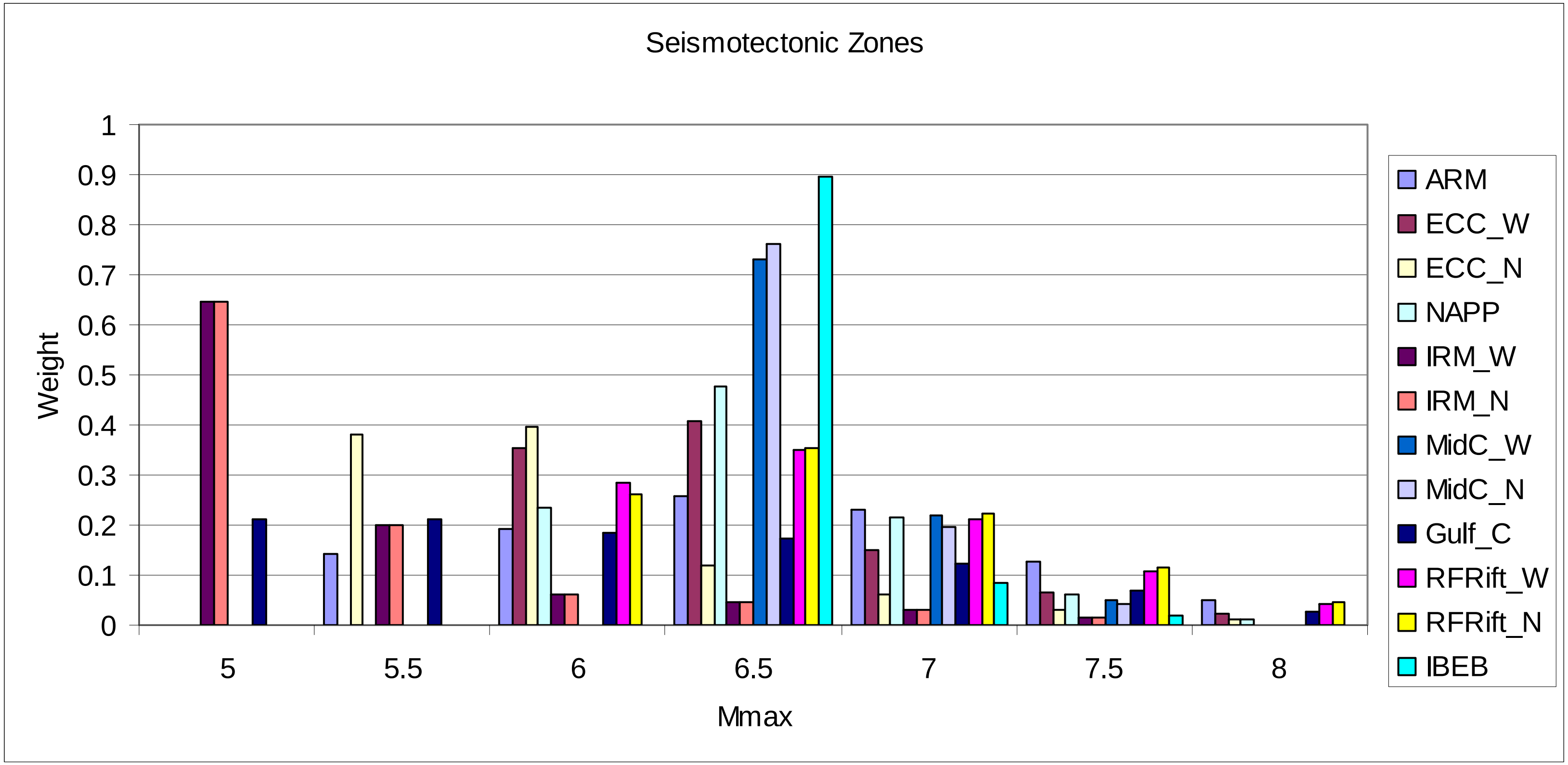
Seismotectonic Source Zone	Magnitude Weighting Case	Degree of Spatial Smoothing [wt]	Spatial Density File	Seismicity Parameter File	Maximum Magnitude Distribution File
ARM	Full Weight	Low [0.95]	ARM-FW.xyd	ARM-FW.rec	ARM.mmx
		High [0.05]	Uniform		
	Reduced Weight	Low [0.95]	ARM-RW.xyd	ARM-RW.rec	
		High [0.05]	Uniform		
ECC_N	Full Weight	Low [0.95]	ECC_N-FW.xyd	ECC_N-FW.rec	ECC_N.mmx
		High [0.05]	Uniform		
	Reduced Weight	Low [0.95]	ECC_N-RW.xyd	ECC_N-RW.rec	
		High [0.05]	Uniform		
GMH	Full Weight	Low [0.5]	GMH-FW.xyd	GMH-FW.rec	GMH.mmx
		High [0.5]	Uniform		
	Reduced Weight	Low [0.75]	GMH-RW.xyd	GMH-RW.rec	
		High [0.25]	Uniform		
Gulf_C	Full Weight	Low [0.95]	GulfC-FW.xyd	GulfC-FW.rec	GulfC.mmx
		High [0.05]	Uniform		
	Reduced Weight	Low [0.8]	GulfC-RW.xyd	GulfC-RW.rec	
		High [0.2]	Uniform		
IBEB	Full Weight	Low [0.95]	IBEB-FW.xyd	IBEB-FW.rec	IBEB.mmx
		High [0.05]	Uniform		
	Reduced Weight	Low [0.8]	IBEB -RW.xyd	IBEB -RW.rec	
		High [0.2]	Uniform		

Table 6

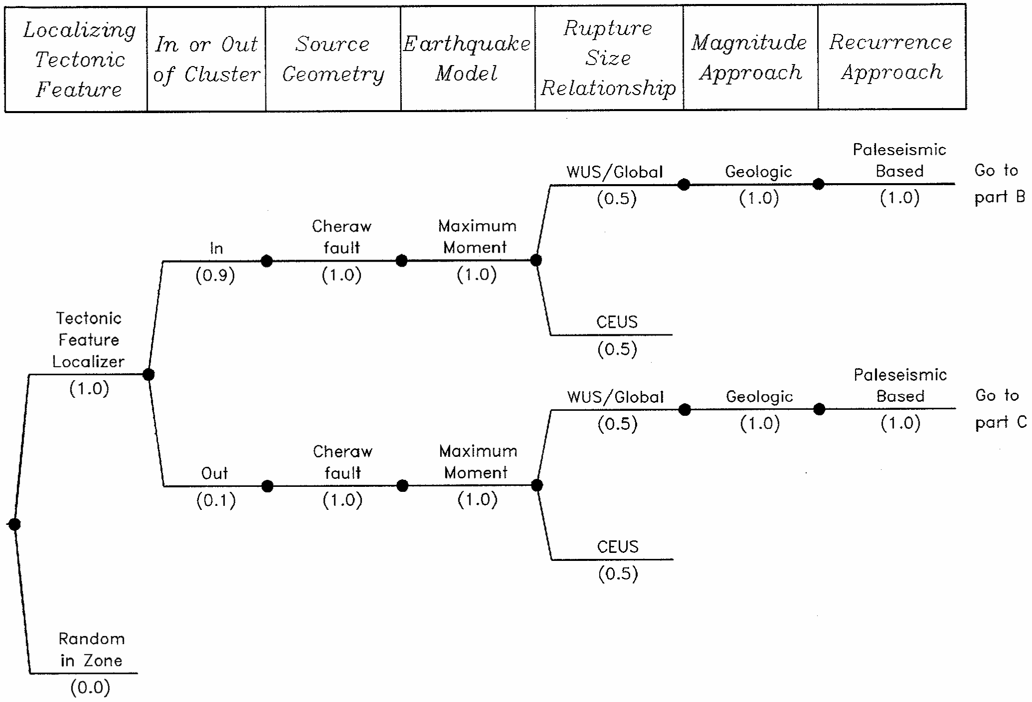
Seismotectonic Source Zone Seismicity and Maximum Magnitude Distributions for the “Narrow” Interpretation

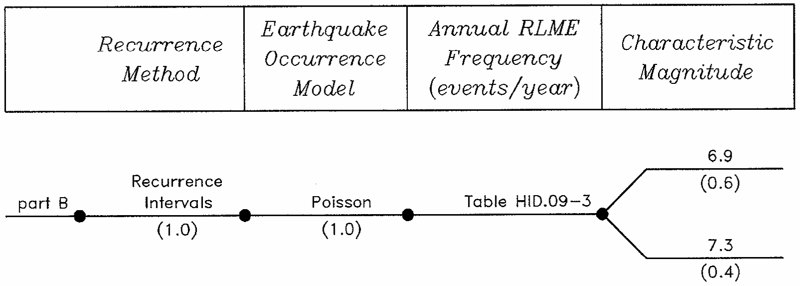
Seismotectonic Source Zone	Magnitude Weighting Case	Degree of Spatial Smoothing [wt]	Spatial Density File	Seismicity Parameter File	Maximum Magnitude Distribution File
IRM_N	Full Weight	Low [0.95]	IRM_N-FW.xyd	IRM_N-FW.rec	IRM_N.mmx
		High [0.05]	Uniform		
	Reduced Weight	Low [0.95]	IRM_N -RW.xyd	IRM_N-RW.rec	
		High [0.05]	Uniform		
MidC_N	Full Weight	Low [0.95]	MidC_N-FW.xyd	MIDC_N-FW.rec	MidC_N.mmx
		High [0.05]	Uniform		
	Reduced Weight	Low [0.95]	MidC_N -RW.xyd	MIDC_N-RW.rec	
		High [0.05]	Uniform		
NApp	Full Weight	Low [0.95]	NApp-FW.xyd	NApp-FW.rec	NApp.mmx
		High [0.05]	Uniform		
	Reduced Weight	Low [0.05]	NApp-RW.xyd	NApp-RW.rec	
		High [0.95]	Uniform		
OkA_C	Full Weight*	Defined in Section 4.2 * Note that parameters that are provided for the Full Weight Case should also be used for the Reduced Weight Case as there are too few data above **M*** 4.2 to assess parameters			
	Reduced Weight*				
RFRift_N	Full Weight	Low [0.95]	RFRift_N-FW.xyd	RFRift_N-FW.rec	RFRift_N.mmx
		High [0.05]	Uniform		
	Reduced Weight	Low [0.2]	RFRift_N -RW.xyd	RFRift_N-RW.rec	
		High [0.8]	Uniform		
SLRift	Full Weight	Low [0.95]	SLRift-FW.xyd	SLRift-FW.rec	SLRift.mmx
		High [0.05]	Uniform		
	Reduced Weight	Low [0.95]	SLRift -RW.xyd	SLRift-RW.rec	
		High [0.05]	Uniform		

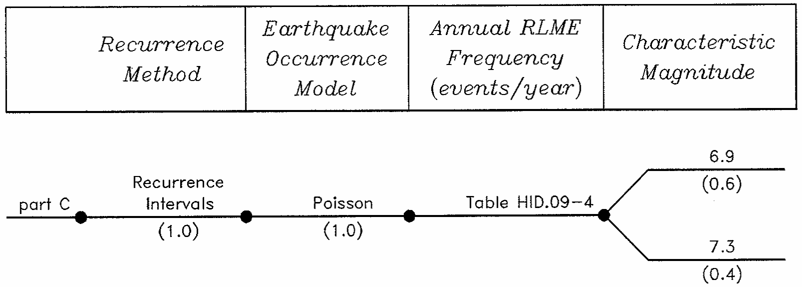
Results For Seismotectonic Sources (excluding RLMEs)

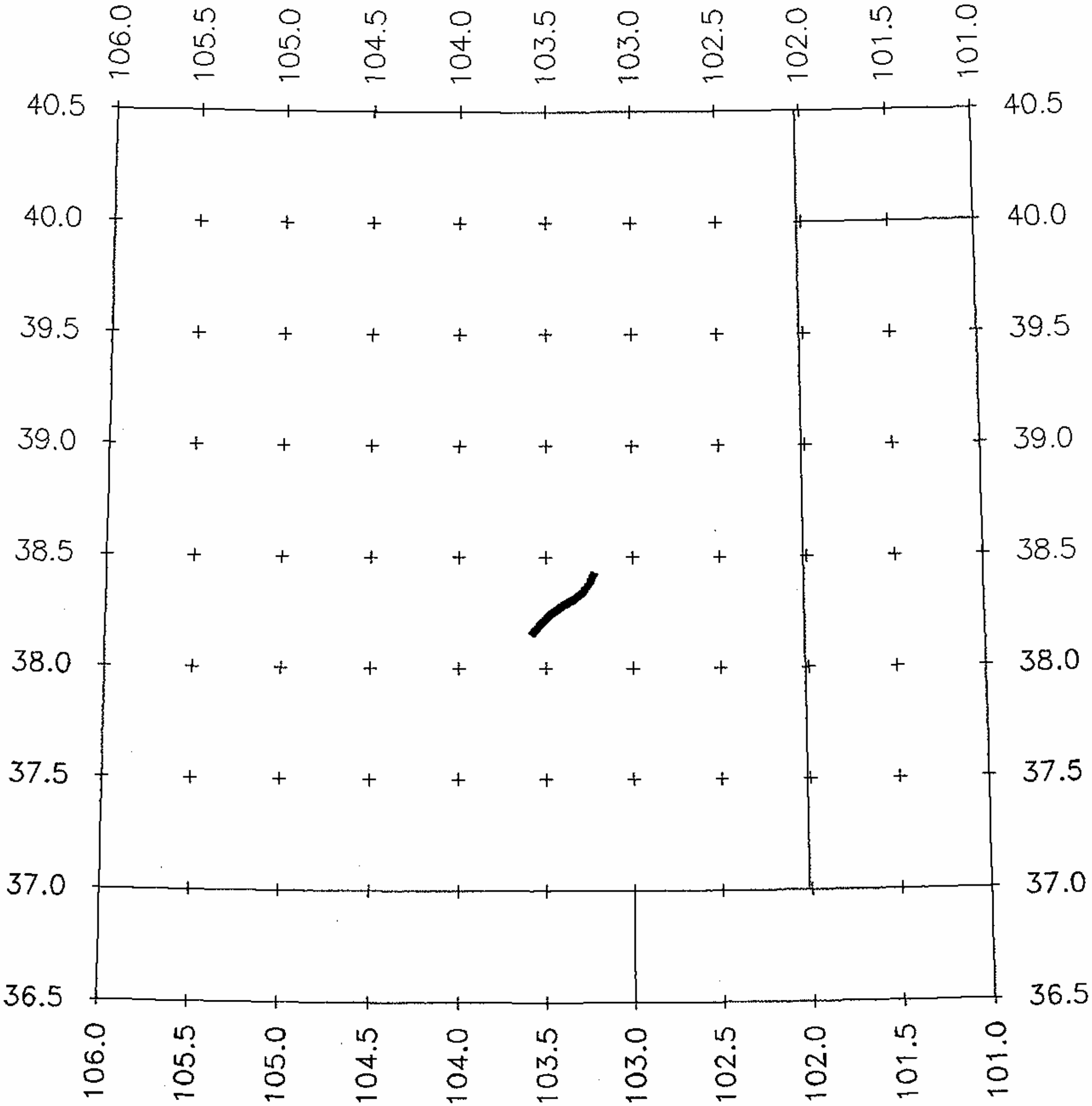


Cheraw


Localizing Tectonic Feature
In or Out of Cluster
Source Geometry
Earthquake Model
Rupture Size Relationship
Magnitude Approach
Recurrence Approach
Tectonic Feature Localizer (1.0)
In (0.9)
Cheraw fault (1.0)
Maximum Moment (1.0)
WUS/Global (0.5)
Geologic (1.0)
Paleseismic Based (1.0)
Go to part B
CEUS (0.5)
Out (0.1)
Cheraw fault (1.0)
Maximum Moment (1.0)
WUS/Global (0.5)
Geologic (1.0)
Paleseismic Based (1.0)
Go to part C
CEUS (0.5)
Random in Zone (0.0)


Recurrence Method
Earthquake Occurrence Model
Annual RLME Frequency (events/year)
Characteristic Magnitude
part B
Recurrence Intervals (1.0)
Poisson (1.0)
Table HID.09-3
6.9 (0.6)
7.3 (0.4)


Recurrence Method
Earthquake Occurrence Model
Annual RLME Frequency (events/year)
Characteristic Magnitude
part C
Recurrence Intervals (1.0)
Poisson (1.0)
Table HID.09-4
6.9 (0.6)
7.3 (0.4)


106.0
105.5
105.0
104.5
104.0
103.5
103.0
102.5
102.0
101.5
101.0
40.5
40.0
39.5
39.0
38.5
38.0
37.5
37.0
36.5
40.5
40.0
39.5
39.0
38.5
38.0
37.5
37.0
36.5
106.0
105.5
105.0
104.5
104.0
103.5
103.0
102.5
102.0
101.5
101.0

Annual Frequencies for Cheraw For The “In Cluster Branch”

Mean Recurrence Interval		**RLME Frequency (Events/year)**
Value (years)	**Weight**	
2,941	0.10108	3.40E-04
5,000	0.24429	2.00E-04
7,143	0.30926	1.40E-04
12,500	0.24429	8.00E-05
25,000	0.10108	4.00E-05

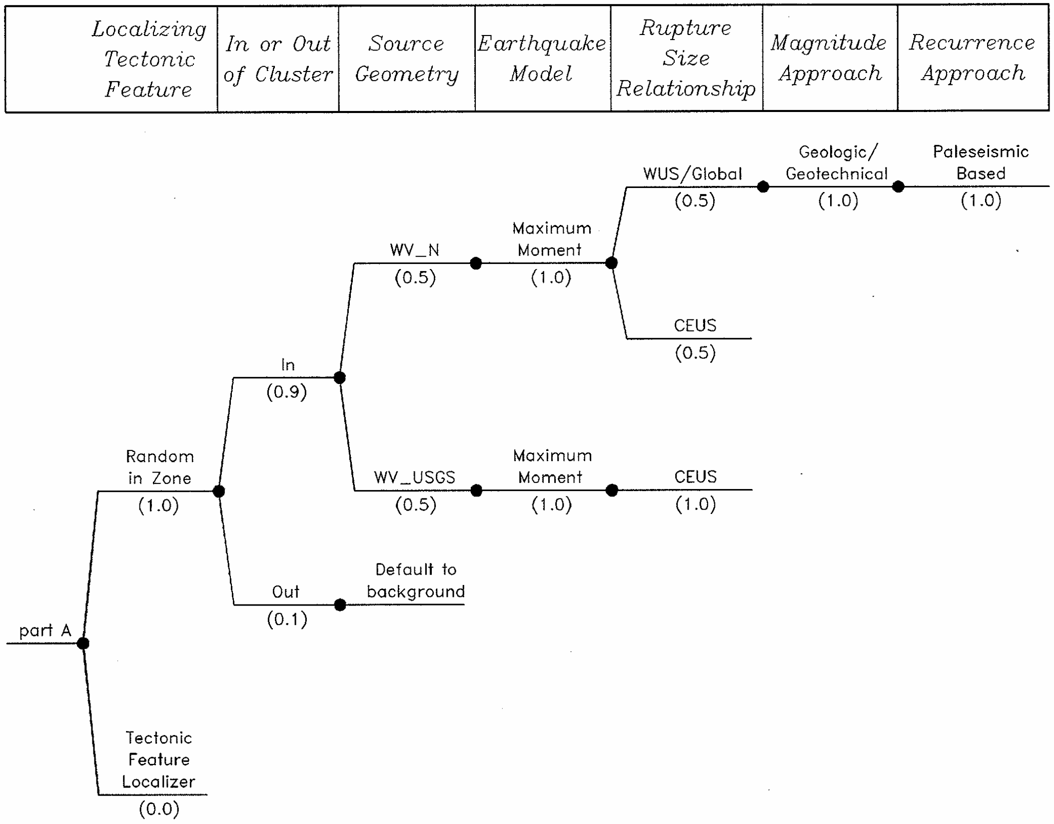
Annual Frequencies for Cheraw RLME Events For the “Out of Cluster Branch”

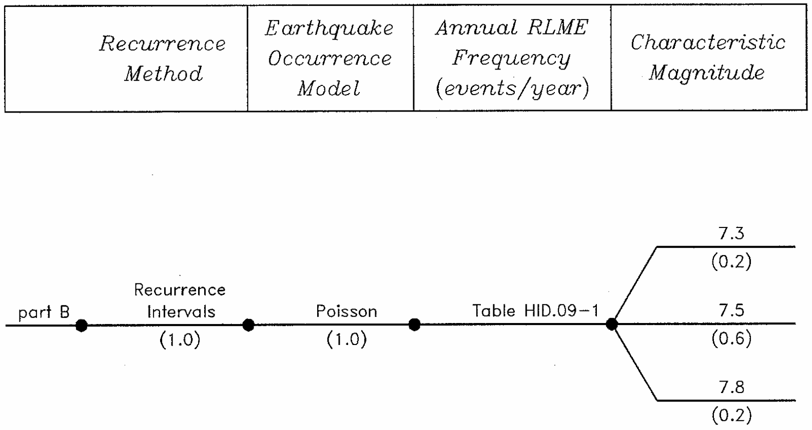
Mean Recurrence Interval		**RLME Frequency (Events/year)**
Value (years)	**Weight**	
100,000	0.5	1.00E-05
200,000	0.5	5.00E-06

Cheraw RLME Characteristic Magnitude Distribution

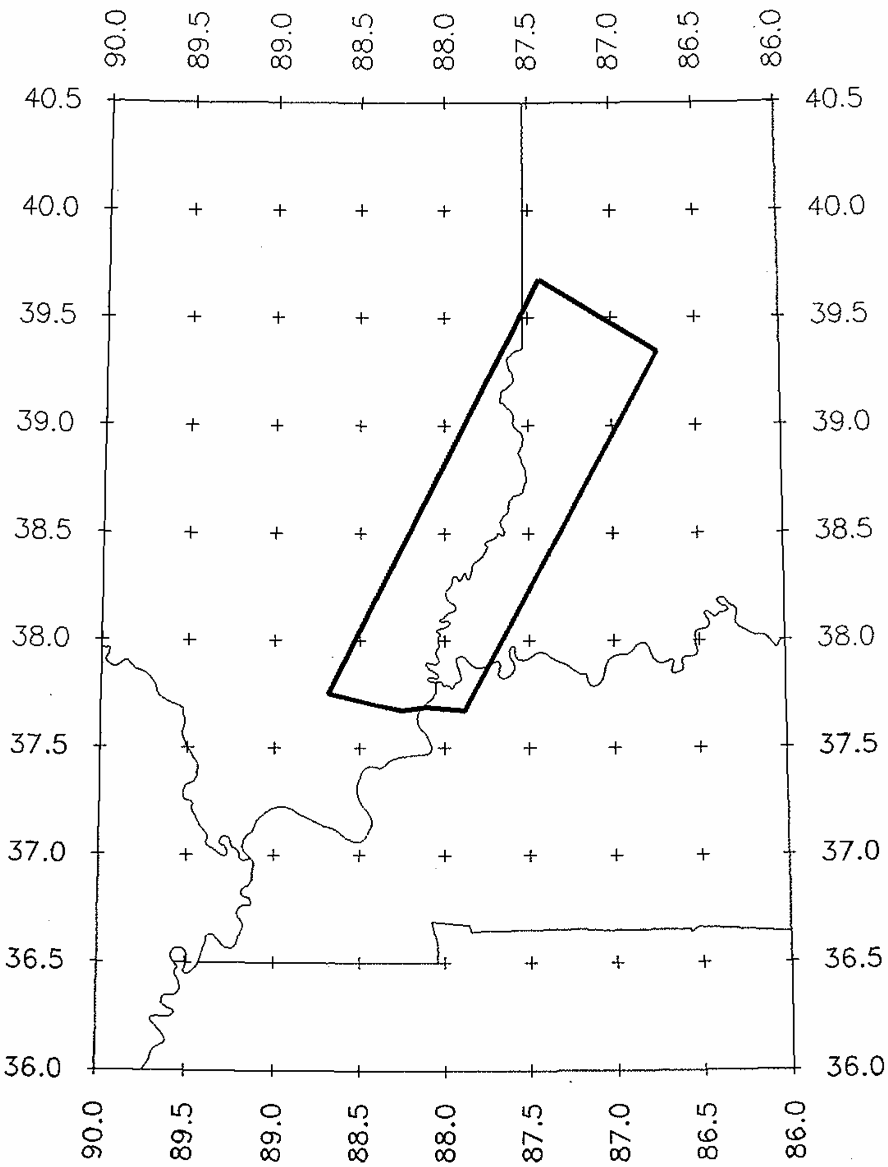
Moment Magnitude	**Weight**
6.9	0.6
7.3	0.4

Wabash

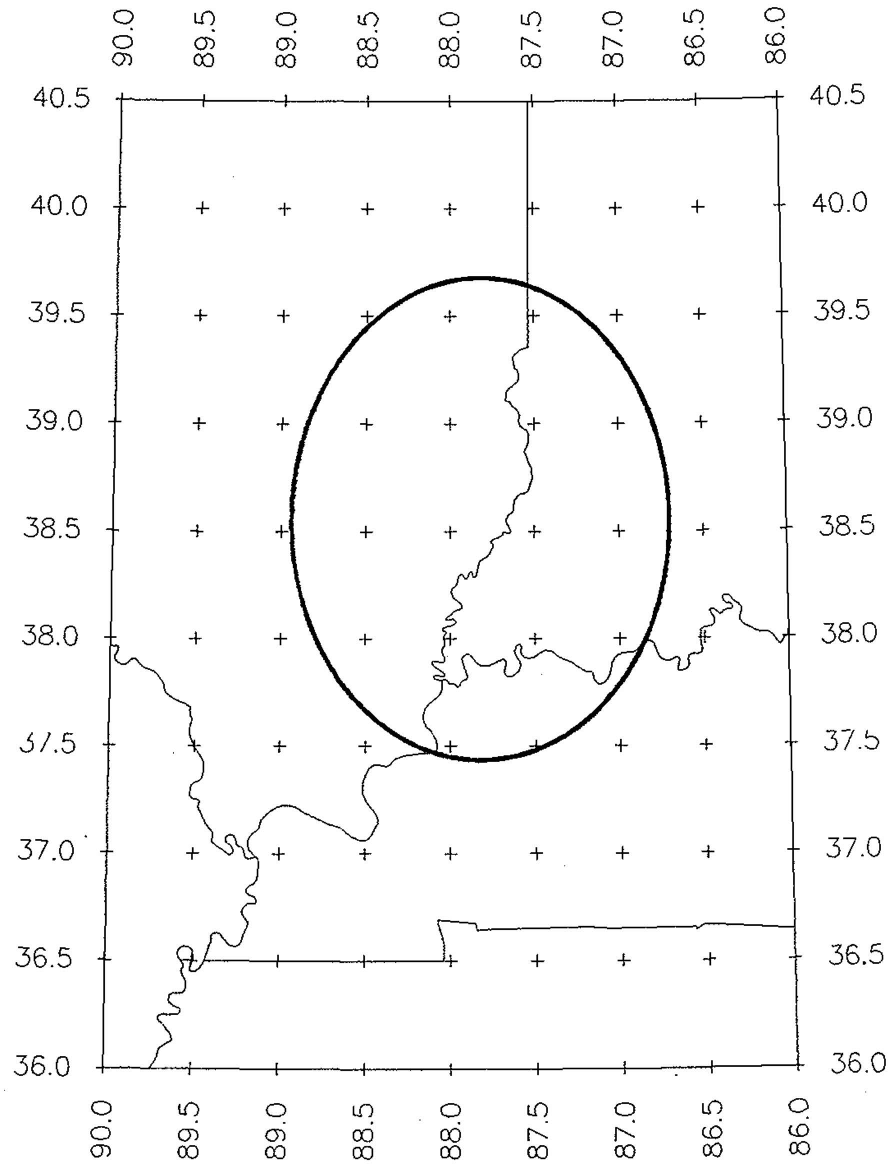

Localizing Tectonic Feature
In or Out of Cluster
Source Geometry
Earthquake Model
Rupture Size Relationship
Magnitude Approach
Recurrence Approach
part A
Random in Zone (1.0)
Tectonic Feature Localizer (0.0)
In (0.9)
Out (0.1)
Default to background
WV_N (0.5)
WV_USGS (0.5)
Maximum Moment (1.0)
Maximum Moment (1.0)
WUS/Global (0.5)
CEUS (0.5)
CEUS (1.0)
Geologic/ Geotechnical (1.0)
Paleseismic Based (1.0)


Recurrence Method
Earthquake Occurrence Model
Annual RLME Frequency (events/year)
Characteristic Magnitude
part B
Recurrence Intervals (1.0)
Poisson (1.0)
Table HID.09-1
7.3 (0.2)
7.5 (0.6)
7.8 (0.2)

Wabash Valley – Narrow



Wabash Valley – USGS



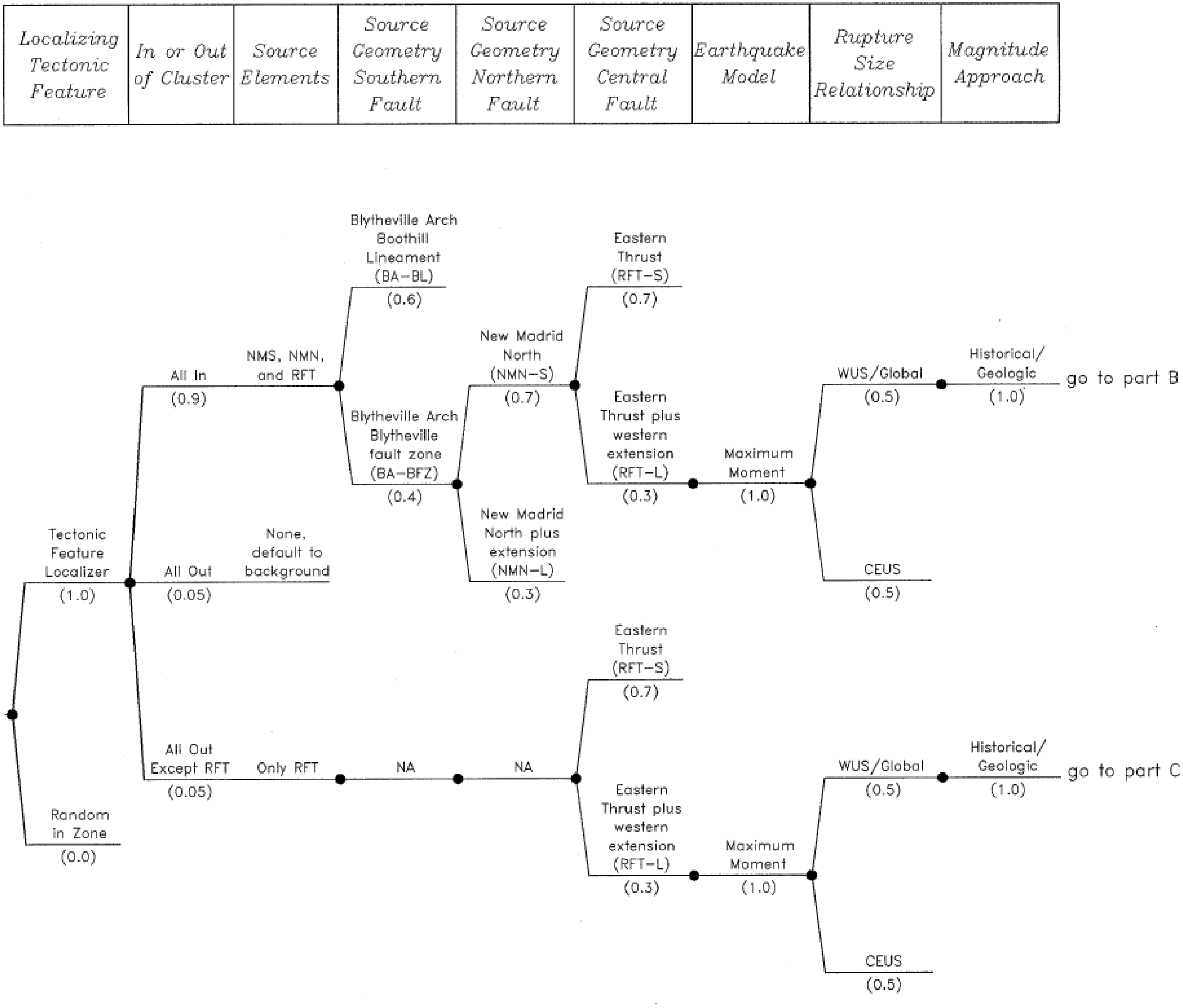
Annual Frequencies for Wabash Valley RLME Events

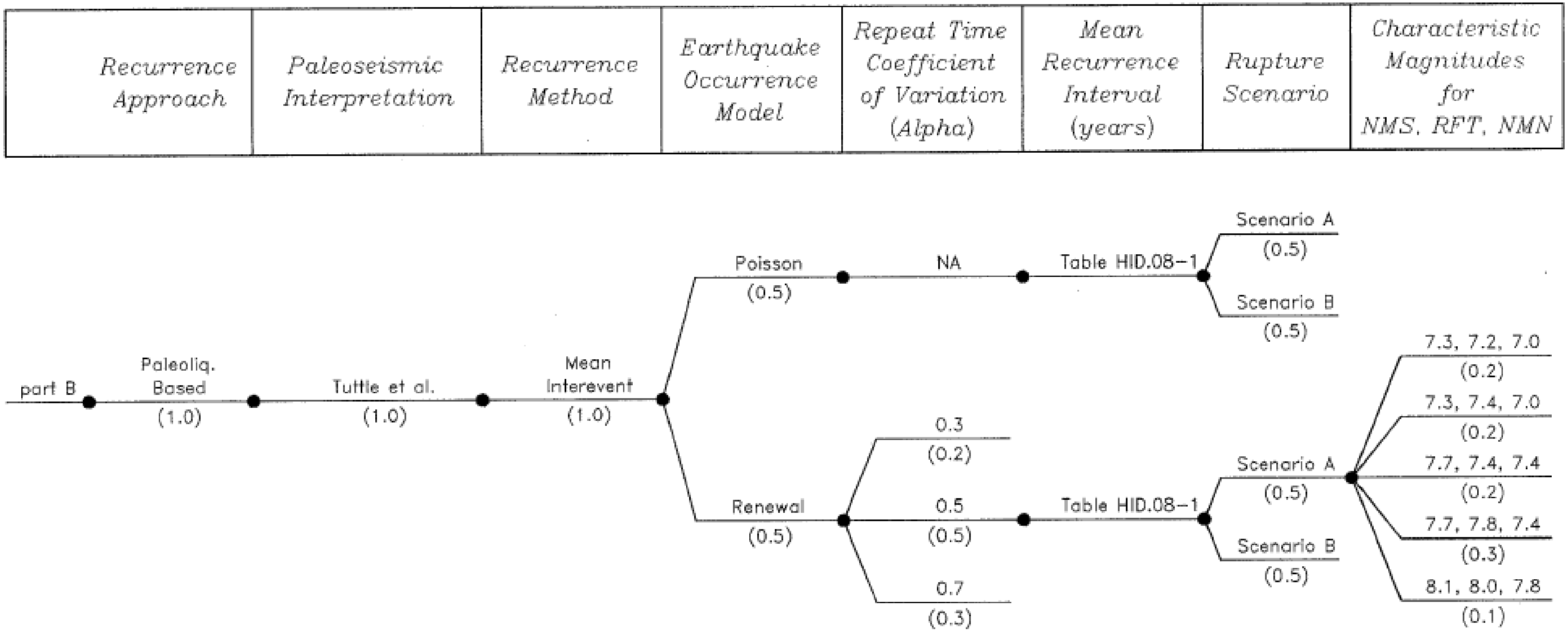
Mean Recurrence Interval		RLME Frequency (Events/year)
Value (years)	**Weight**	
1,767	0.10108	5.66E-04
2,857	0.24429	3.50E-04
4,505	0.30926	2.22E-04
7,576	0.24429	1.32E-04
17,241	0.10108	5.80E-05

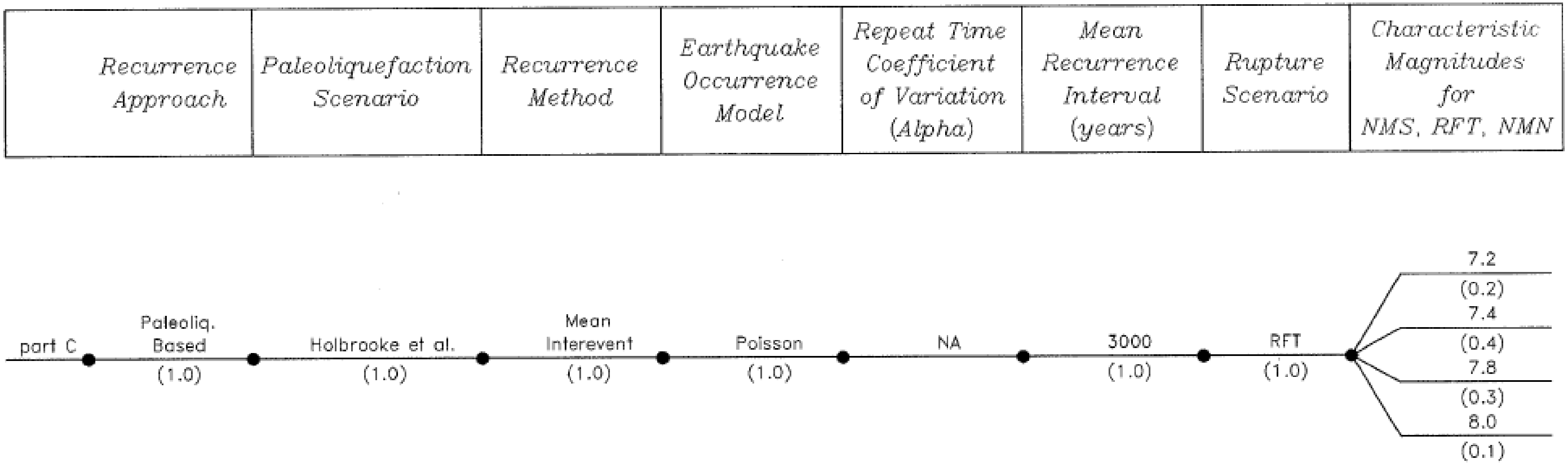
Wabash Valley RLME Characteristic Magnitude Distribution

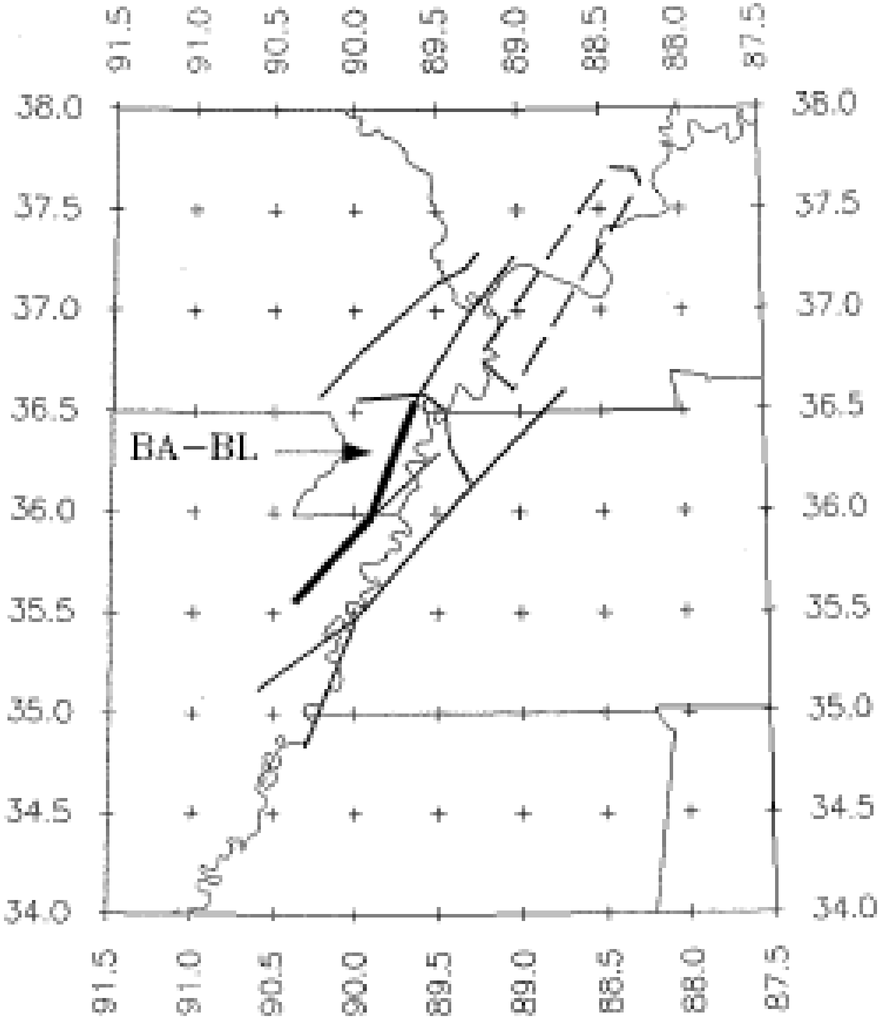
Moment Magnitude	**Weight**
7.3	0.2
7.5	0.6
7.8	0.2

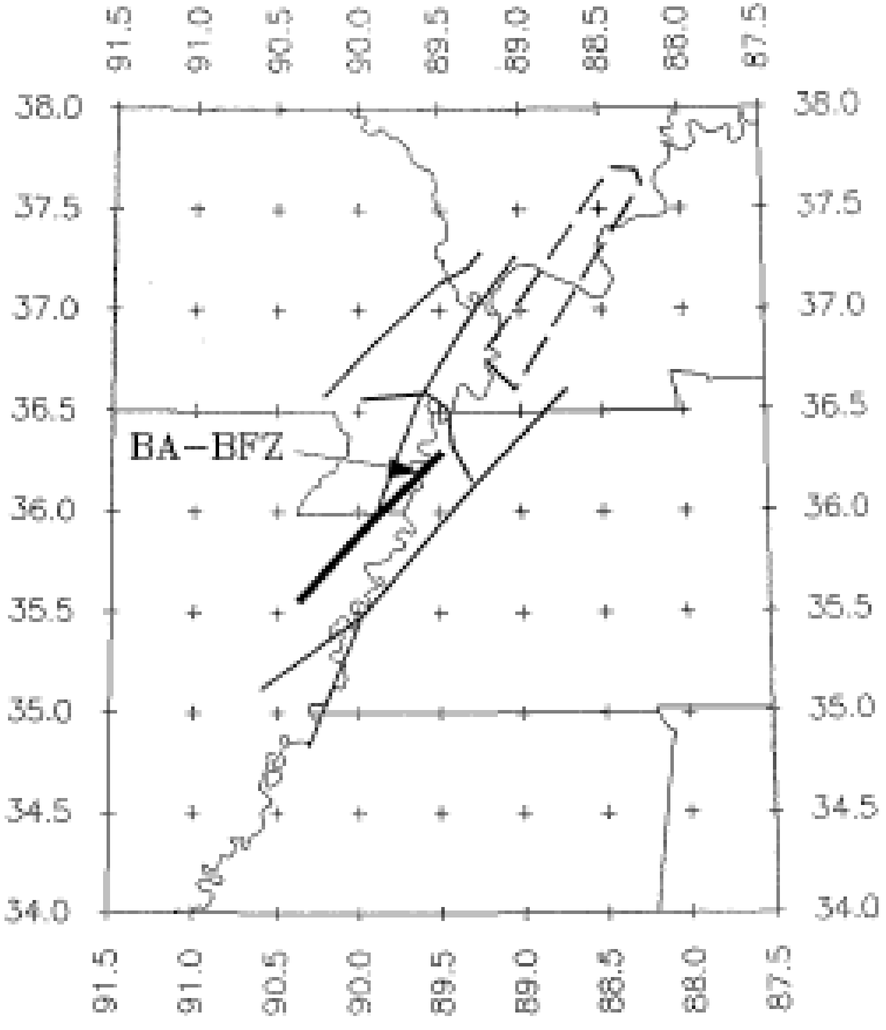
New Madrid

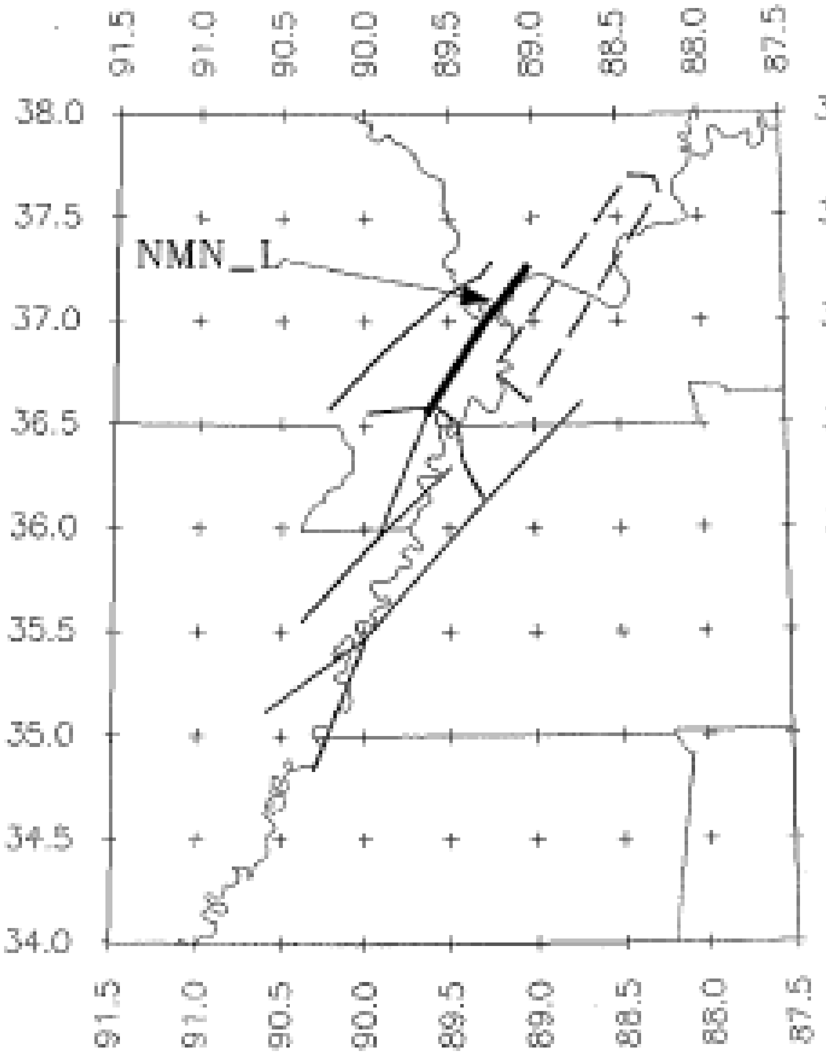

Localizing Tectonic Feature
In or Out of Cluster
Source Elements
Source Geometry Southern Fault
Source Geometry Northern Fault
Source Geometry Central Fault
Earthquake Model
Rupture Size Relationship
Magnitude Approach
Tectonic Feature Localizer
(1.0)
Random in Zone
(0.0)
All In
(0.9)
All Out
(0.05)
All Out Except RFT
(0.05)
NMS, NMN, and RFT
None, default to background
Only RFT
Blytheville Arch Boothill Lineament (BA-BL)
(0.6)
Blytheville Arch Blytheville fault zone (BA-BFZ)
(0.4)
NA
New Madrid North (NMN-S)
(0.7)
New Madrid North plus extension (NMN-L)
(0.3)
NA
Eastern Thrust (RFT-S)
(0.7)
Eastern Thrust plus western extension (RFT-L)
(0.3)
Maximum Moment
(1.0)
WUS/Global
(0.5)
CEUS
(0.5)
Historical/ Geologic
(1.0)
go to part B
Eastern Thrust (RFT-S)
(0.7)
Eastern Thrust plus western extension (RFT-L)
(0.3)
Maximum Moment
(1.0)
WUS/Global
(0.5)
CEUS
(0.5)
Historical/ Geologic
(1.0)
go to part C

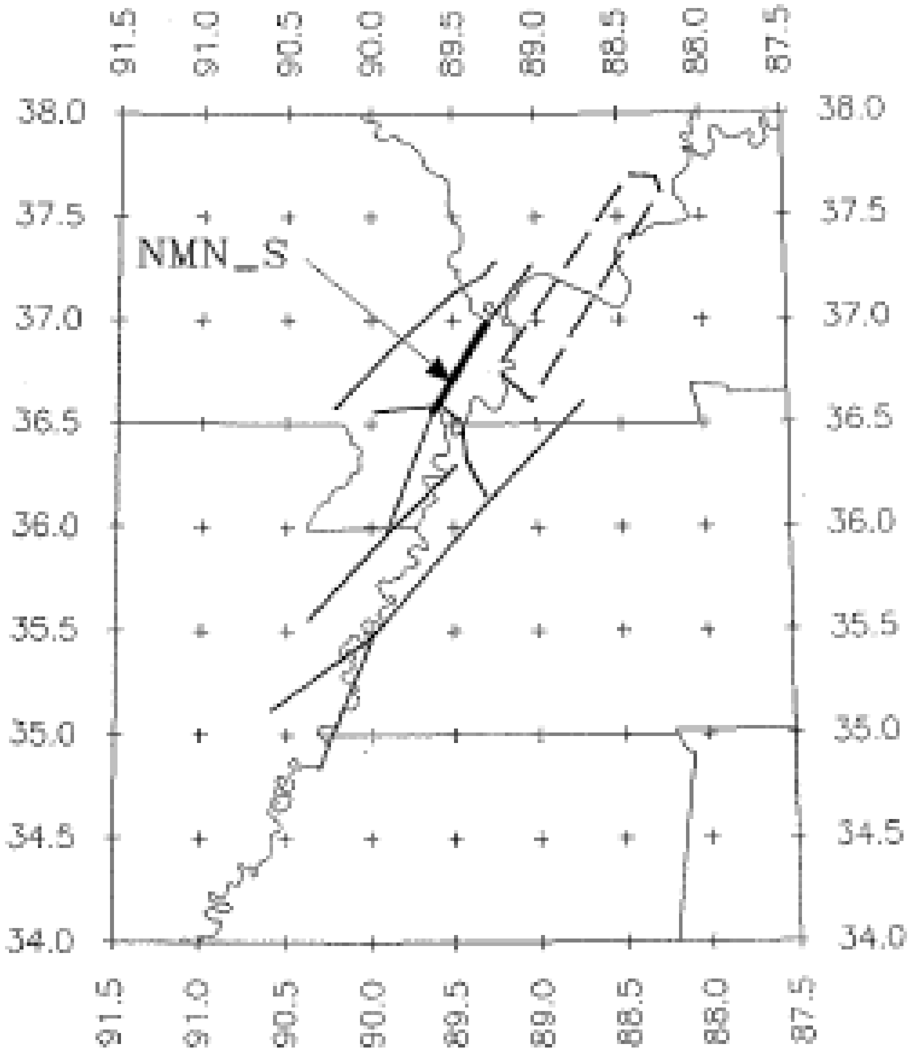

Recurrence Approach
Paleoseismic Interpretation
Recurrence Method
Earthquake Occurrence Model
Repeat Time Coefficient of Variation (Alpha)
Mean Recurrence Interval (years)
Rupture Scenario
Characteristic Magnitudes for NMS, RFT, NMN
part B
Paleoliq. Based
(1.0)
Tuttle et al.
(1.0)
Mean Interevent
(1.0)
Poisson
(0.5)
NA
Table HID.08-1
Scenario A
(0.5)
Scenario B
(0.5)
Renewal
(0.5)
0.3
(0.2)
0.5
(0.5)
0.7
(0.3)
Table HID.08-1
Scenario A
(0.5)
Scenario B
(0.5)
7.3, 7.2, 7.0
(0.2)
7.3, 7.4, 7.0
(0.2)
7.7, 7.4, 7.4
(0.2)
7.7, 7.8, 7.4
(0.3)
8.1, 8.0, 7.8
(0.1)


Recurrence Approach
Paleoliquefaction Scenario
Recurrence Method
Earthquake Occurrence Model
Repeat Time Coefficient of Variation (Alpha)
Mean Recurrence Interval (years)
Rupture Scenario
Characteristic Magnitudes for NMS, RFT, NMN
part C
Paleoliq. Based
(1.0)
Holbrooke et al.
(1.0)
Mean Interevent
(1.0)
Poisson
(1.0)
NA
3000
(1.0)
RFT
(1.0)
7.2
(0.2)
7.4
(0.4)
7.8
(0.3)
8.0
(0.1)


BA−BL
38.0
37.5
37.0
36.5
36.0
35.5
35.0
34.5
34.0
91.5
91.0
90.5
90.0
89.5
89.0
88.5
88.0
87.5


BA−BFZ
38.0
37.5
37.0
36.5
36.0
35.5
35.0
34.5
34.0
91.5
91.0
90.5
90.0
89.5
89.0
88.5
88.0
87.5


NMN_L
91.5
91.0
90.5
90.0
89.5
89.0
88.5
88.0
87.5
38.0
37.5
37.0
36.5
36.0
35.5
35.0
34.5
34.0


NMN_S
91.5
91.0
90.5
90.0
89.5
89.0
88.5
88.0
87.5
38.0
37.5
37.0
36.5
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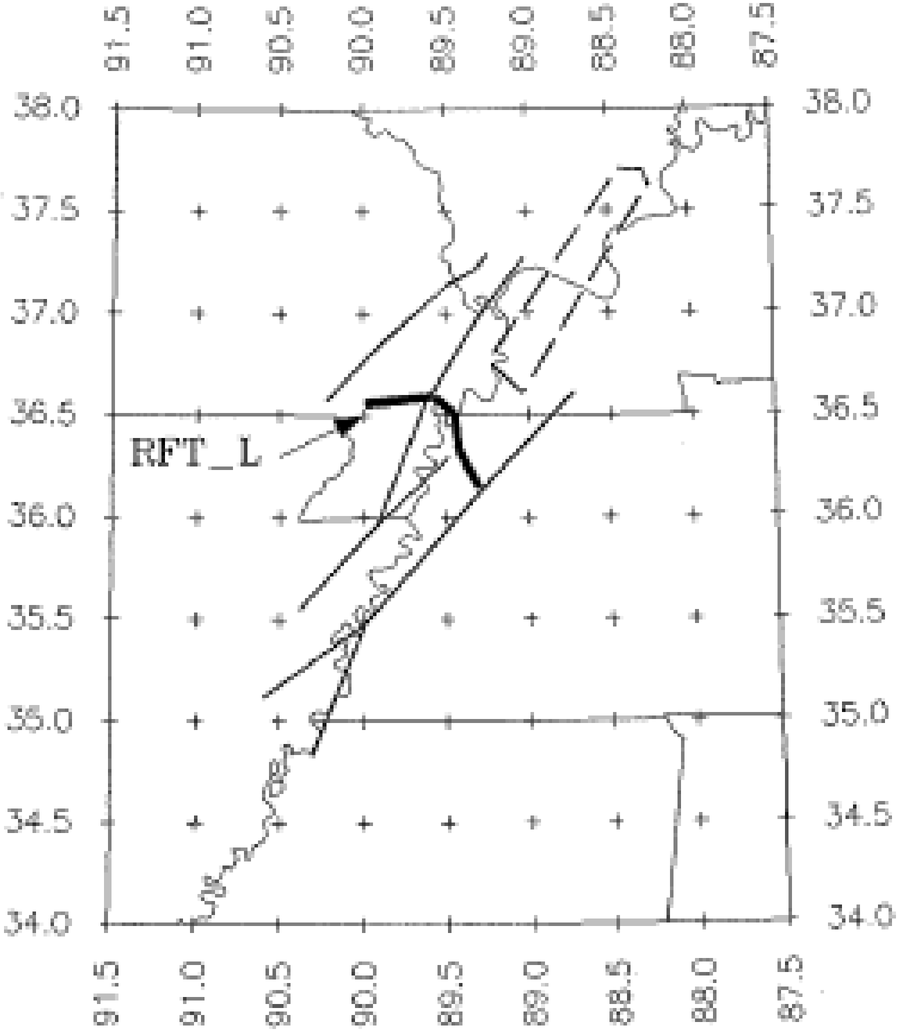
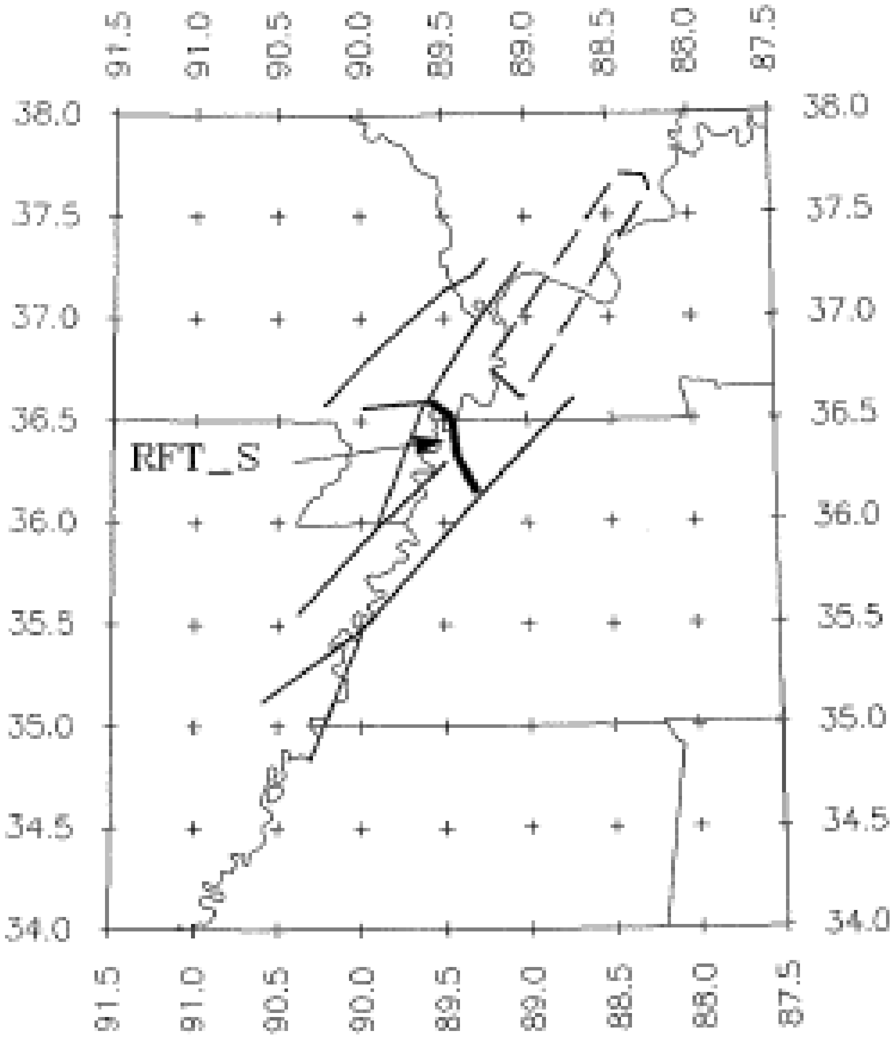
35.5
35.0
34.5
34.0



91.5
91.0
90.5
90.0
89.5
89.0
88.5
88.0
87.5
38.0
37.5
37.0
36.5
36.0
35.5
35.0
34.5
34.0
RFT_L

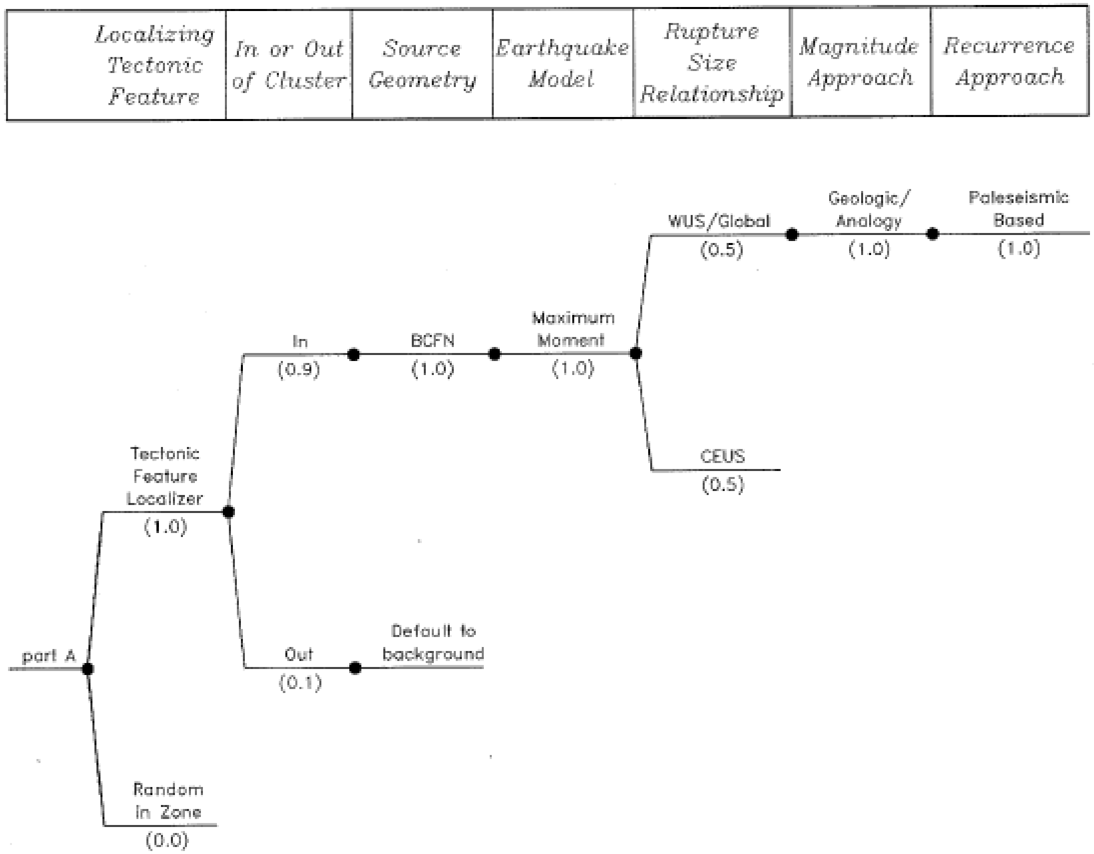


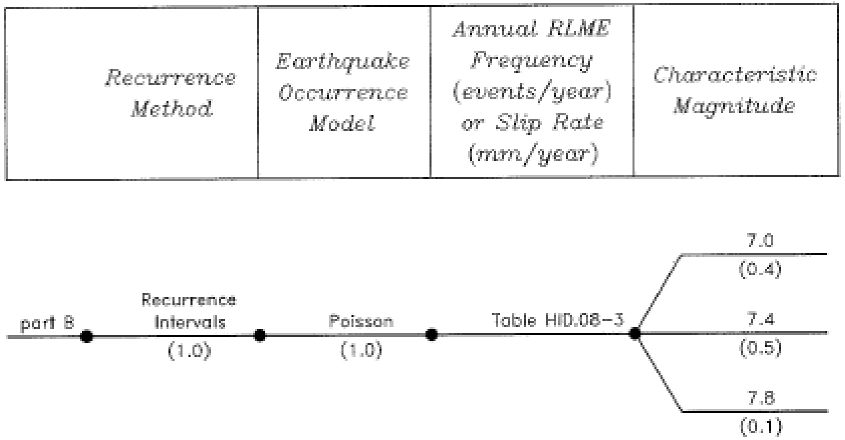
91.5
91.0
90.5
90.0
89.5
89.0
88.5
88.0
87.5
38.0
37.5
37.0
36.5
36.0
35.5
35.0
34.5
34.0
RFT_S

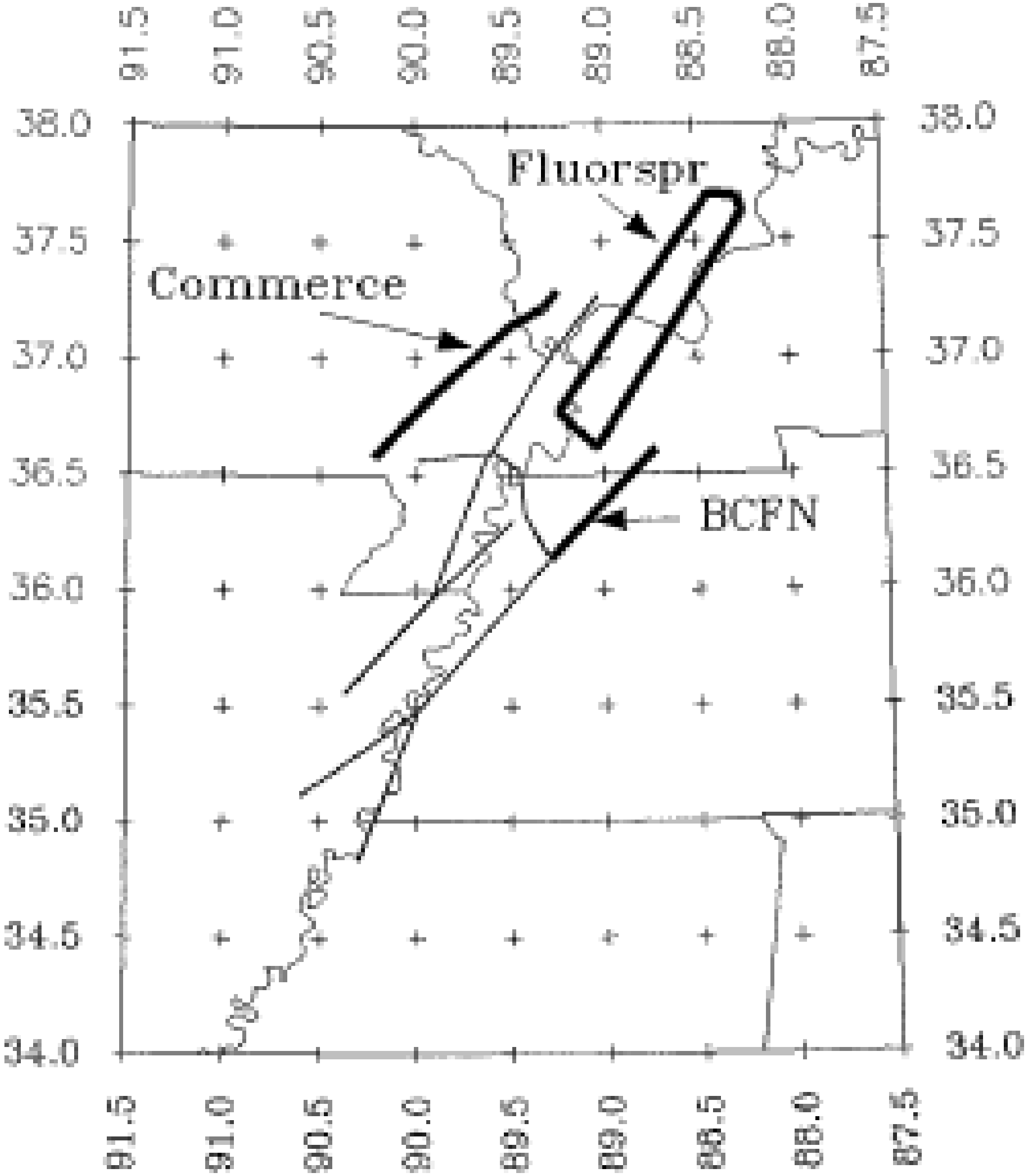
In Cluster Branch [wt]	Recurrence Model [wt]	Alpha [wt]	Mean Recurrence Interval (years)	Weight	RLME Frequency (Events/year)
All in [0.9]	Poisson [0.5]	NA	161	0.10108	6.22E-03
			260	0.24429	3.84E-03
			407	0.30926	2.46E-03
			694	0.24429	1.44E-03
			1563	0.10108	6.40E-04
	Renewal (BPT) [0.5]	0.3 [0.2]	326	0.10108	3.68E-03
			402	0.24429	1.17E-03
			475	0.30926	3.39E-04
			562	0.24429	6.78E-05
			695	0.10108	4.85E-06
		0.5 [0.5]	311	0.10108	5.00E-03
			431	0.24429	2.31E-03
			561	0.30926	9.55E-04
			729	0.24429	2.83E-04
			1009	0.10108	3.36E-05
		0.7 [0.3]	320	0.10108	4.53E-03
			496	0.24429	2.32E-03
			703	0.30926	1.08E-03
			988	0.24429	3.63E-04
			1486	0.10108	5.01E-05
All out except RFT [0.05]	Poisson [1.0]	NA	3000	1	3.33E-04

Central New Madrid Fault System RLME Characteristic Magnitude Distribution

Moment Magnitude for:			**Weight**
NMS	**RFT**	**RMN**	
7.3	7.2	7.0	0.2
7.3	7.4	7.0	0.2
7.7	7.4	7.4	0.2
7.7	7.8	7.4	0.3
8.1	8.0	7.8	0.1


Localizing Tectonic Feature
In or Out of Cluster
Source Geometry
Earthquake Model
Rupture Size Relationship
Magnitude Approach
Recurrence Approach
part A
Tectonic Feature Localizer
(1.0)
Random in Zone
(0.0)
In
(0.9)
Out
(0.1)
Default to background
BCFN
(1.0)
Maximum Moment
(1.0)
WUS/Global
(0.5)
CEUS
(0.5)
Geologic/ Analogy
(1.0)
Paleseismic Based
(1.0)


Recurrence Method
Earthquake Occurrence Model
Annual RLME Frequency (events/year) or Slip Rate (mm/year)
Characteristic Magnitude
part B
Recurrence Intervals
(1.0)
Poisson
(1.0)
Table HID.08-3
7.0
(0.4)
7.4
(0.5)
7.8
(0.1)

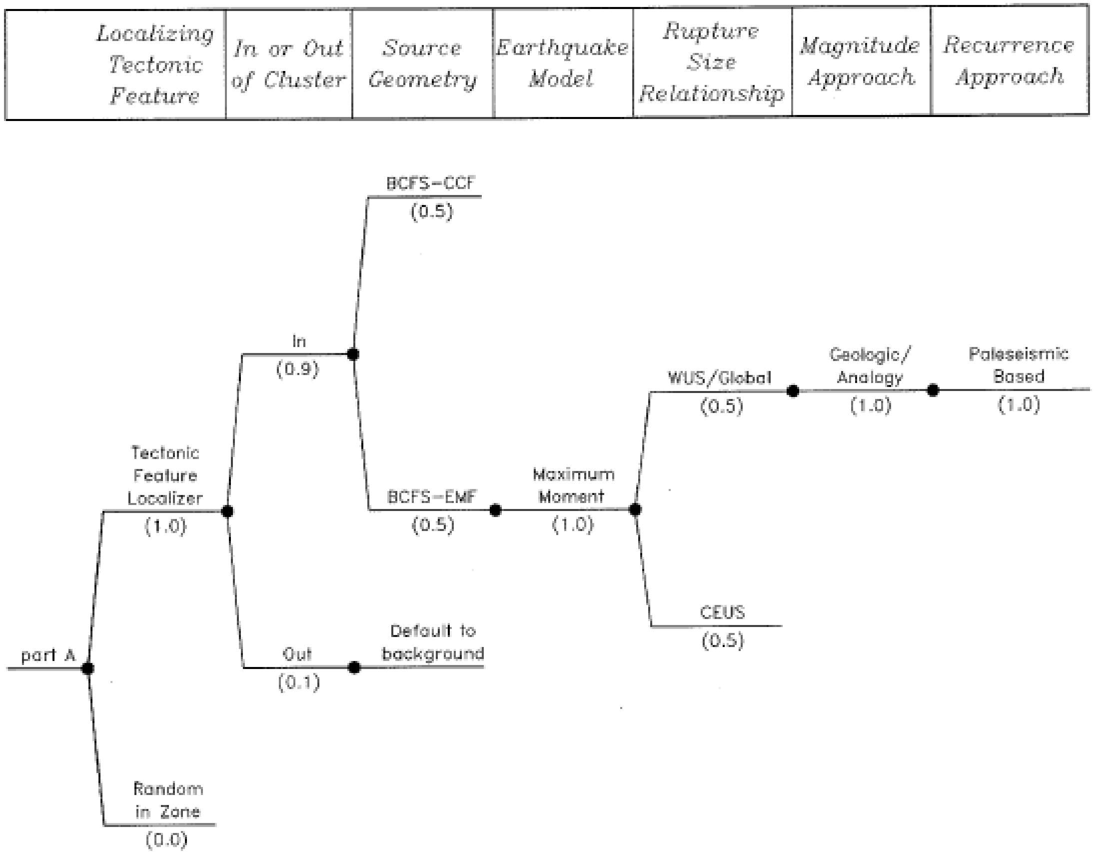

Fluorspr
Commerce
BCFN
38.0
37.5
37.0
36.5
36.0
35.5
35.0
34.5
34.0
91.5
91.0
90.5
90.0
89.5
89.0
88.5
88.0
87.5

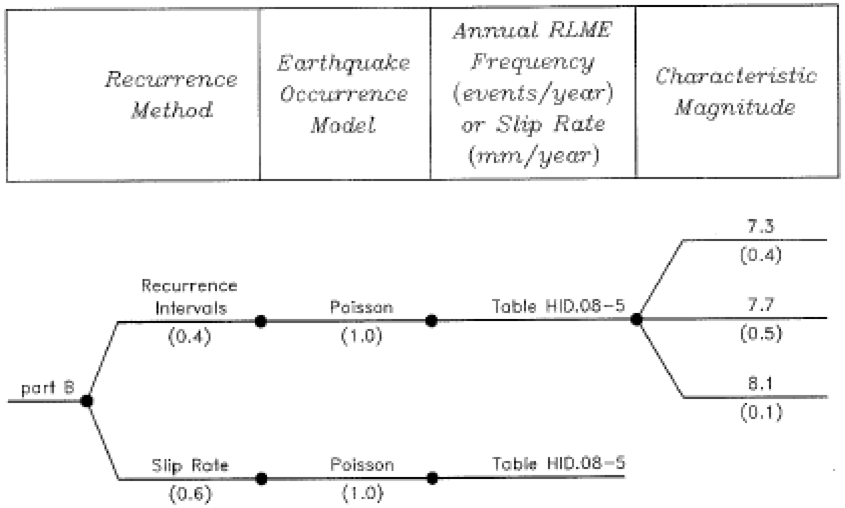
Annual Frequencies for BCFN RLME Events

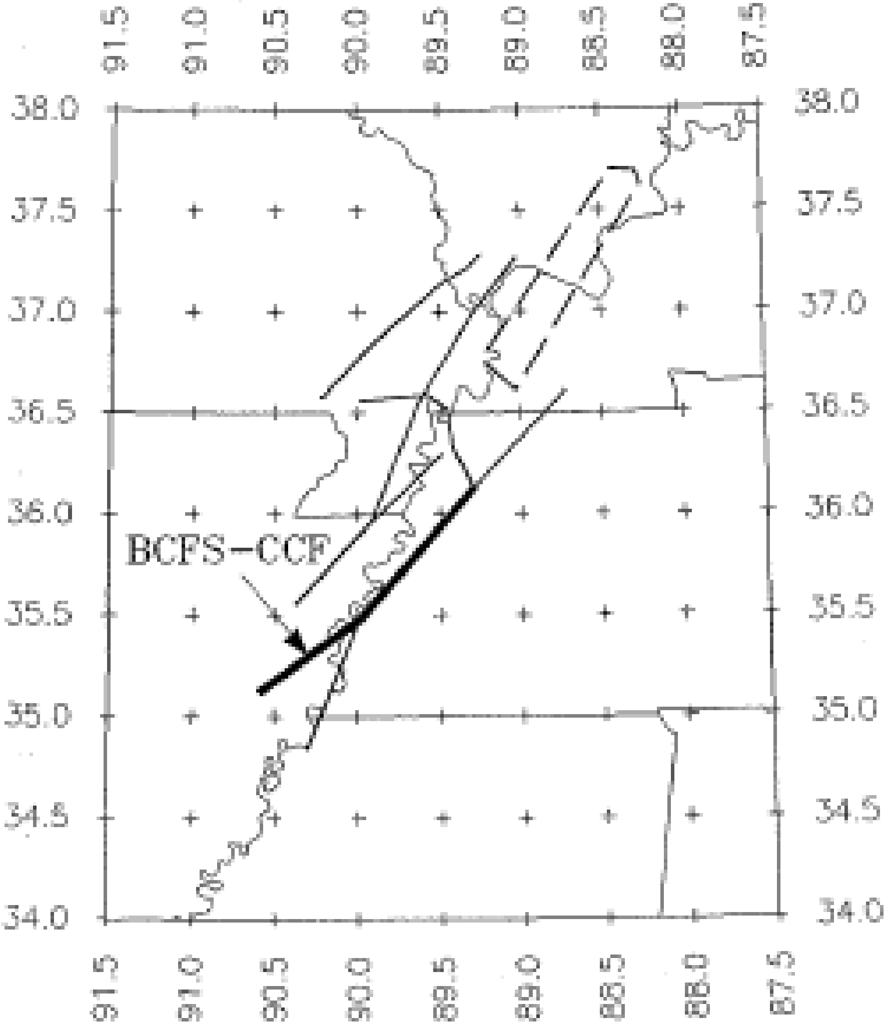
Mean Recurrence Interval		RLME Frequency (Events/year)
Value (years)	**Weight**	
2,717	0.10108	3.68E-04
5,495	0.24429	1.82E-04
10,638	0.30926	9.40E-05
22,222	0.24429	4.50E-05
66,667	0.10108	1.50E-05

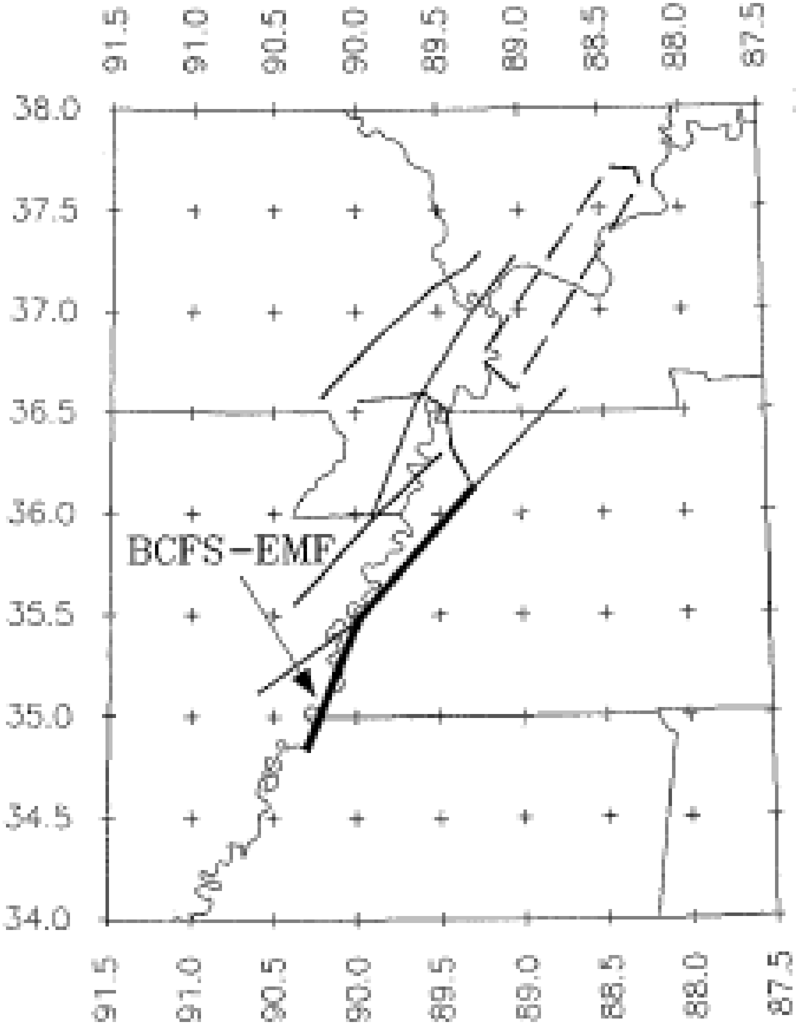
BCFN RLME Characteristic Magnitude Distribution

Moment Magnitude	**Weight**
7.0	0.4
7.4	0.5
7.8	0.1


Localizing Tectonic Feature
In or Out of Cluster
Source Geometry
Earthquake Model
Rupture Size Relationship
Magnitude Approach
Recurrence Approach
part A
Tectonic Feature Localizer
(1.0)
Random in Zone
(0.0)
In
(0.9)
Out
(0.1)
BCFS-CCF
(0.5)
BCFS-EMF
(0.5)
Default to background
Maximum Moment
(1.0)
WUS/Global
(0.5)
CEUS
(0.5)
Geologic/ Analogy
(1.0)
Paleseismic Based
(1.0)


Recurrence Method
Earthquake Occurrence Model
Annual RLME Frequency (events/year) or Slip Rate (mm/year)
Characteristic Magnitude
part B
Recurrence Intervals
(0.4)
Slip Rate
(0.6)
Poisson
(1.0)
Poisson
(1.0)
Table HID.08-5
Table HID.08-5
7.3
(0.4)
7.7
(0.5)
8.1
(0.1)


BCFS−CCF
91.5
91.0
90.5
90.0
89.5
89.0
88.5
88.0
87.5
38.0
37.5
37.0
36.5
36.0
35.5
35.0
34.5
34.0

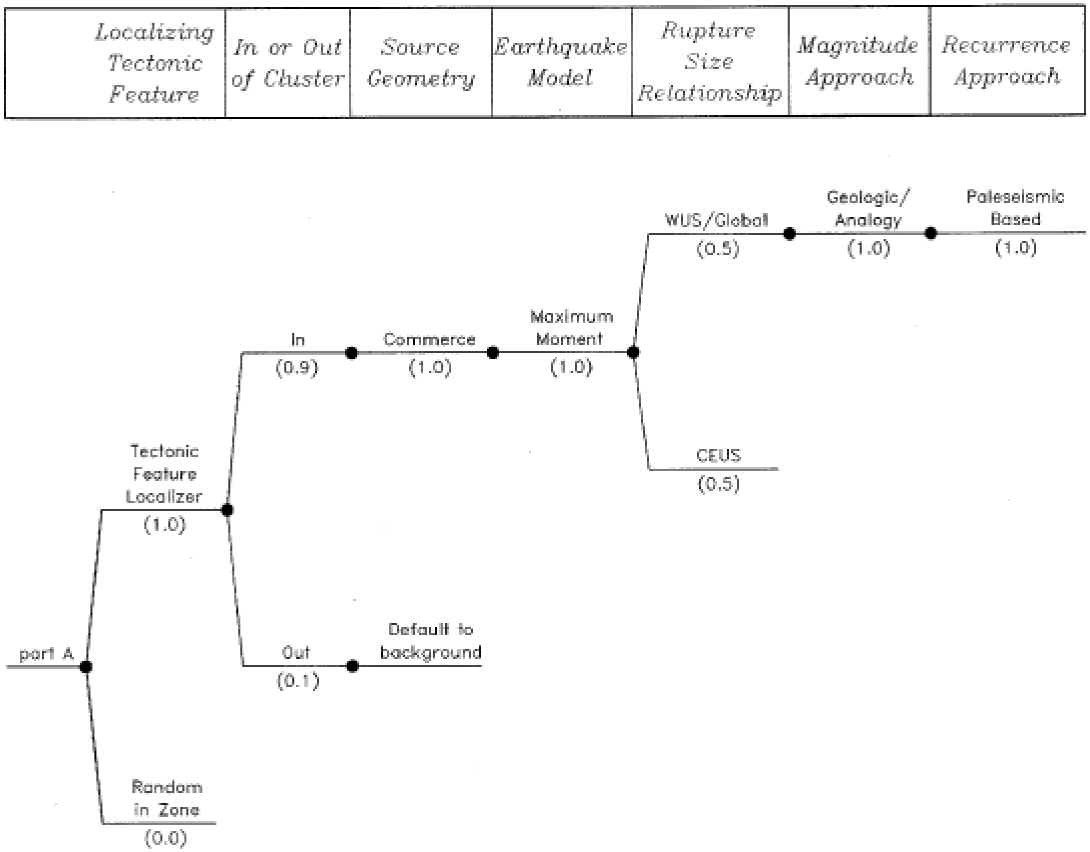

BCFS−EMF
91.5
91.0
90.5
90.0
89.5
89.0
88.5
88.0
87.5
38.0
37.5
37.0
36.5
36.0
35.5
35.0
34.5
34.0

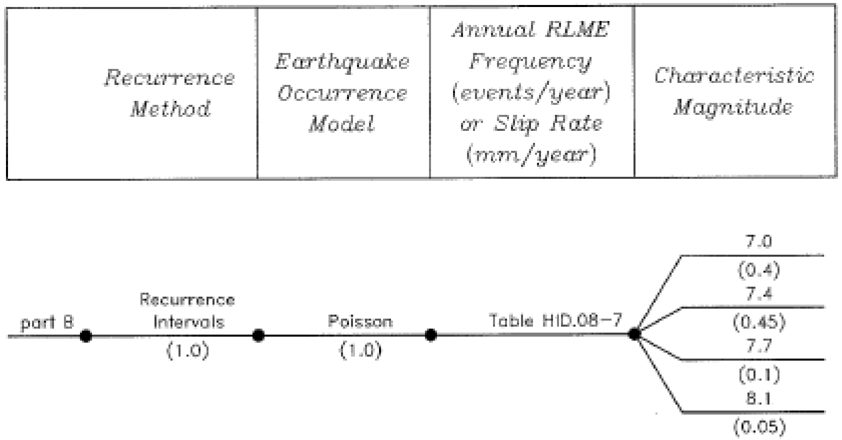
Annual Frequencies for BCFS RLME Events

Recurrence Method [wt]	Value	Weight	RLME Frequency (Events/year)
Mean Recurrence Interval [0.40	2,778 years	0.10108	3.60E-04
	4,505 years	0.24429	2.22E-04
	7,092 years	0.30926	1.41E-04
	12,048 years	0.24429	8.30E-05
	27,027 years	0.10108	3.70E-05
Slip Rate [0.6]	0.4 mm/year	0.333	*
	0.6 mm/year	0.334	*
	1.0 mm/year	0.333	*

BCFS RLME Characteristic Magnitude Distribution

Moment Magnitude	**Weight**
7.3	0.4
7.7	0.5
8.1	0.1


Localizing Tectonic Feature
In or Out of Cluster
Source Geometry
Earthquake Model
Rupture Size Relationship
Magnitude Approach
Recurrence Approach
part A
Tectonic Feature Localizer
(1.0)
In
(0.9)
Commerce
(1.0)
Maximum Moment
(1.0)
WUS/Global
(0.5)
Geologic/ Analogy
(1.0)
Paleseismic Based
(1.0)
CEUS
(0.5)
Out
(0.1)
Default to background
Random in Zone
(0.0)

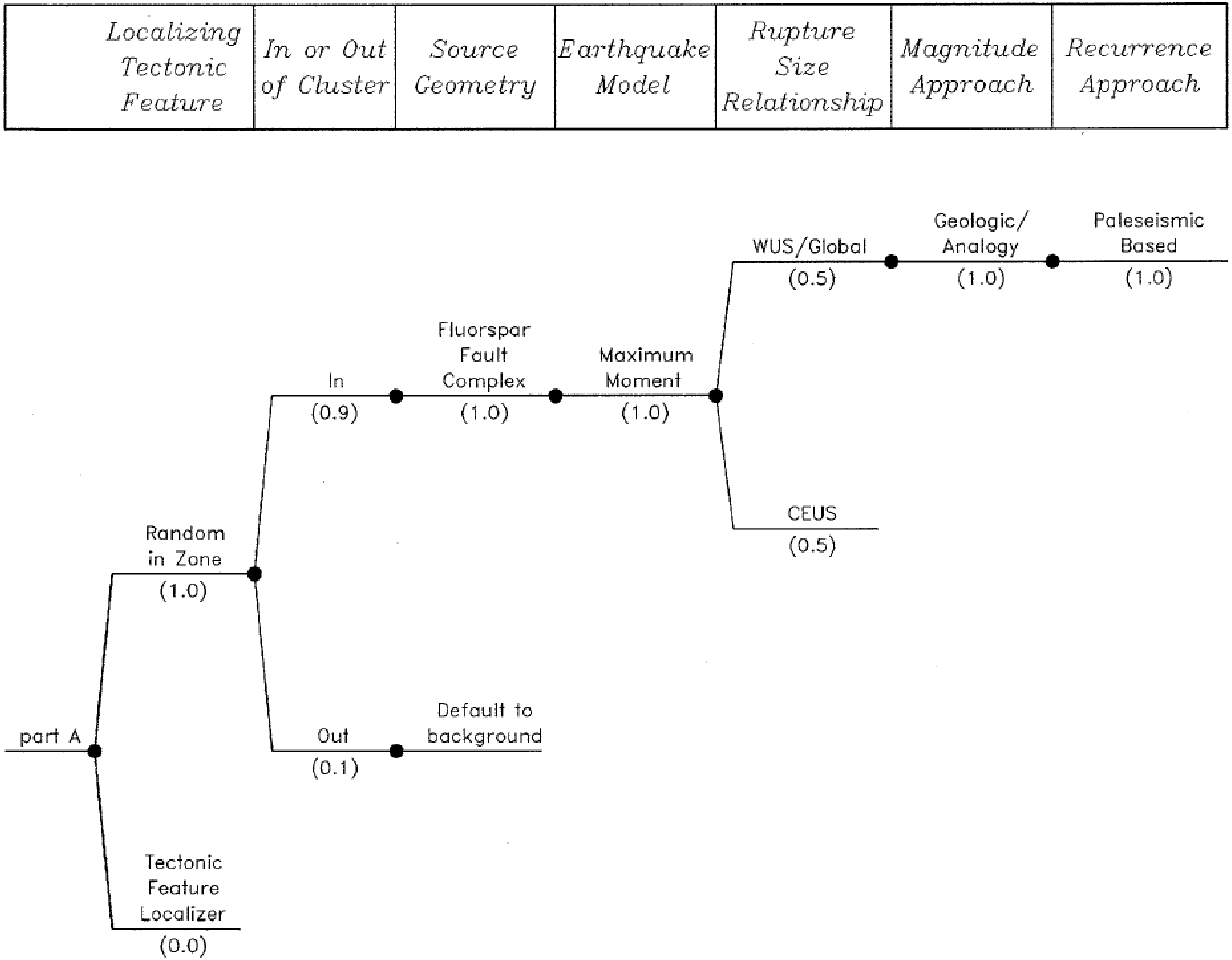

Recurrence Method
Earthquake Occurrence Model
Annual RLME Frequency (events/year) or Slip Rate (mm/year)
Characteristic Magnitude
part B
Recurrence Intervals
(1.0)
Poisson
(1.0)
Table HID.08-7
7.0
(0.4)
7.4
(0.45)
7.7
(0.1)
8.1
(0.05)

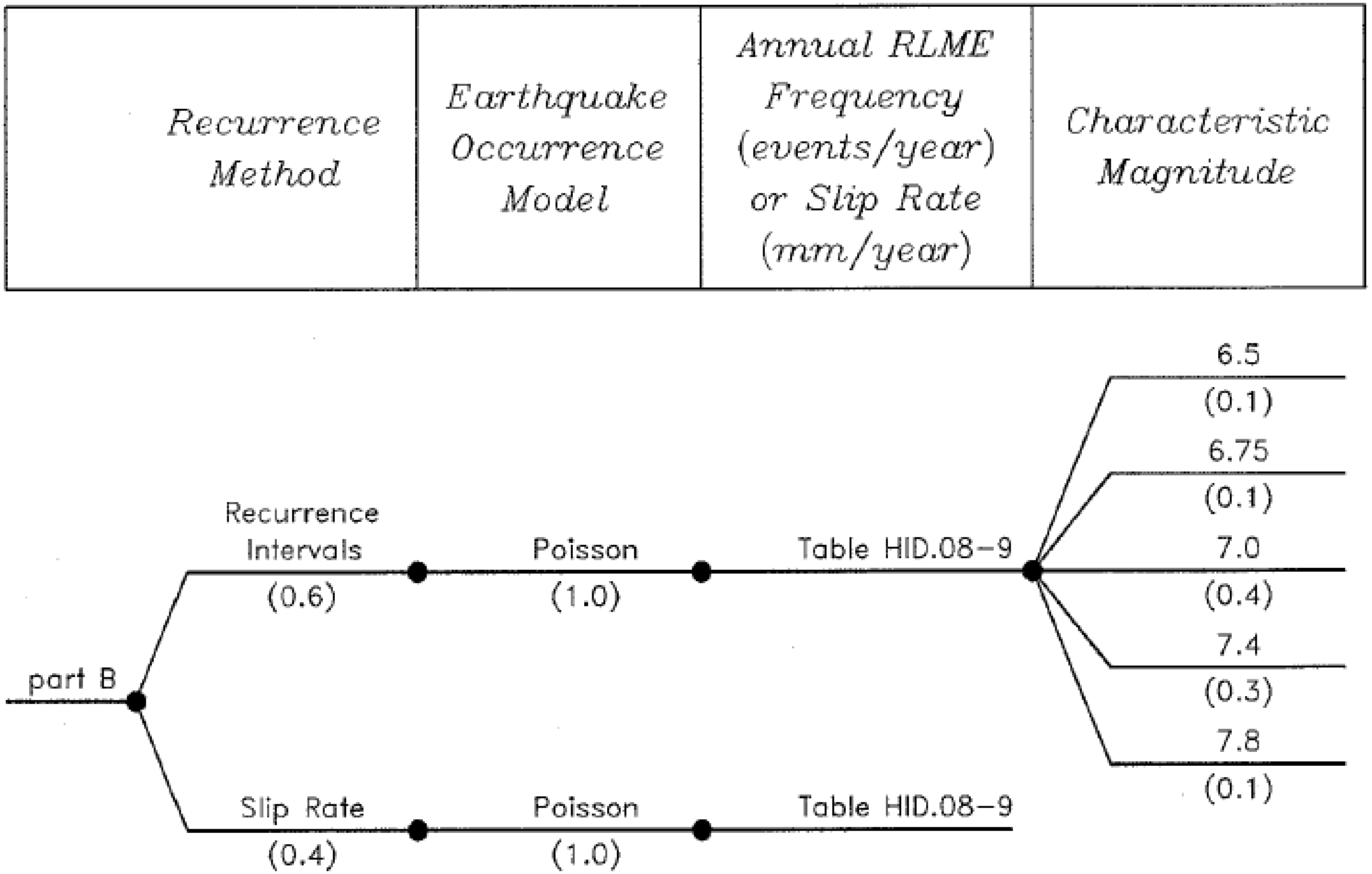
Annual Frequencies for Commerce RLME Events

Mean Recurrence Interval		RLME Frequency (Events/year)
Value (years)	**Weight**	
1,042	0.10108	9.60E-04
1,894	0.24429	5.28E-04
3,401	0.30926	2.94E-04
6,494	0.24429	1.54E-04
16,667	0.10108	6.00E-05

Commerce RLME Characteristic Magnitude Distribution

Moment Magnitude	**Weight**
7.0	0.4
7.4	0.45
7.7	0.1
8.1	0.05


Localizing Tectonic Feature
In or Out of Cluster
Source Geometry
Earthquake Model
Rupture Size Relationship
Magnitude Approach
Recurrence Approach
part A
Random in Zone
(1.0)
Tectonic Feature Localizer
(0.0)
In
(0.9)
Out
(0.1)
Fluorspar Fault Complex
(1.0)
Default to background
Maximum Moment
(1.0)
WUS/Global
(0.5)
CEUS
(0.5)
Geologic/ Analogy
(1.0)
Paleseismic Based
(1.0)


Recurrence Method
Earthquake Occurrence Model
Annual RLME Frequency (events/year) or Slip Rate (mm/year)
Characteristic Magnitude
part B
Recurrence Intervals
(0.6)
Poisson
(1.0)
Table HID.08-9
6.5
(0.1)
6.75
(0.1)
7.0
(0.4)
7.4
(0.3)
7.8
(0.1)
Slip Rate
(0.4)
Poisson
(1.0)
Table HID.08-9

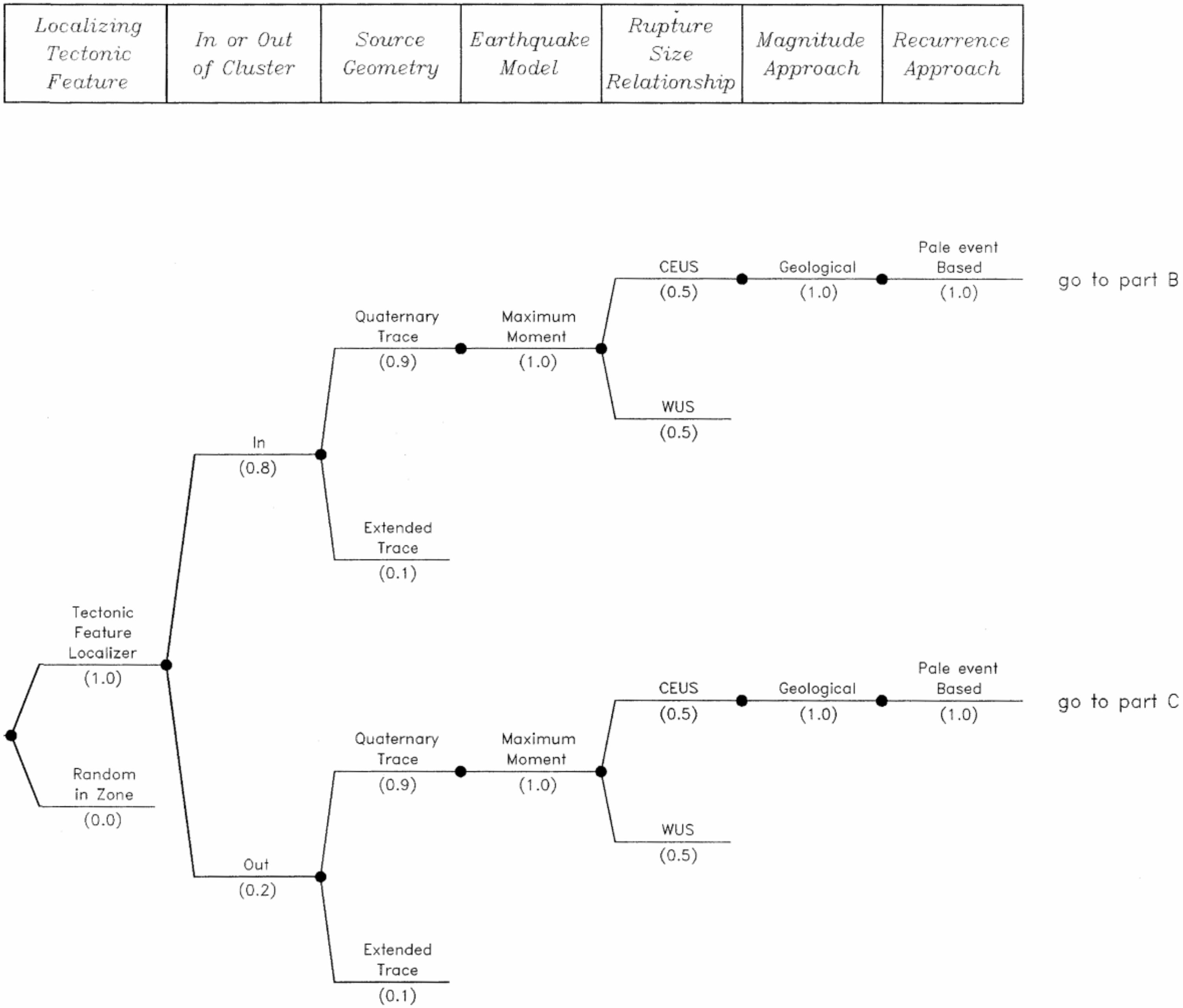
Annual Frequencies for Fluorspar RLME Events

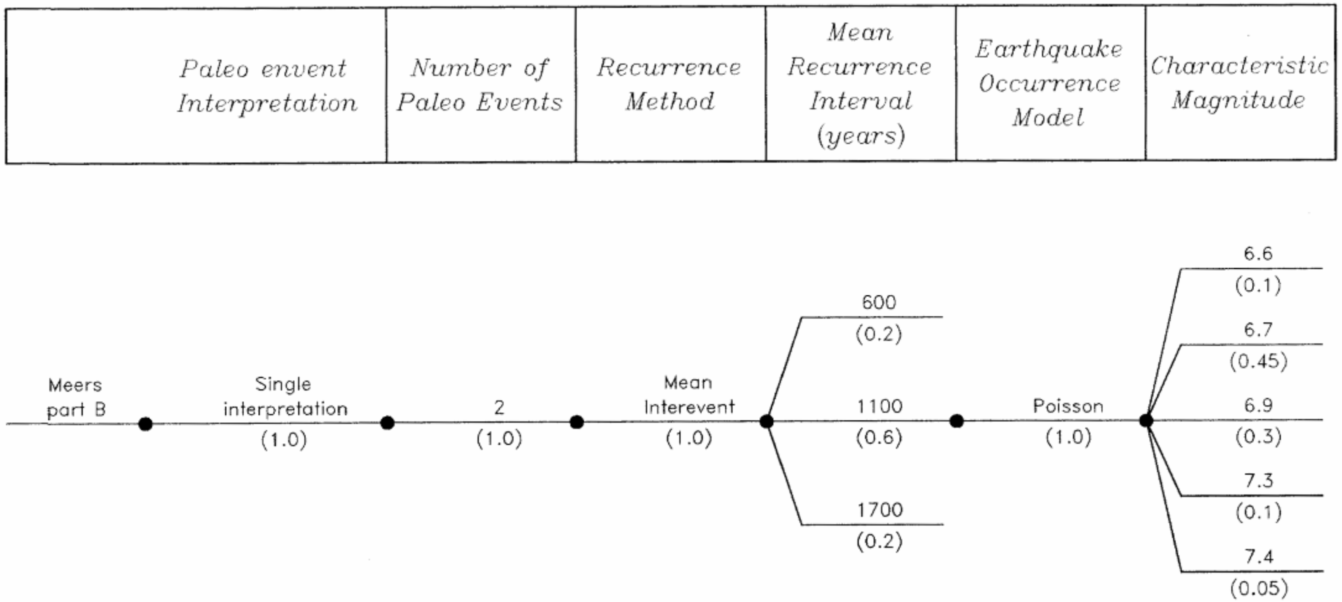
Recurrence Method [wt]	**Value**	**Weight**	**RLME Frequency (Events/year)**
Mean Recurrence Interval [0.40	2,242 years	0.10108	4.46E-04
	3,922 years	0.24429	2.55E-04
	6,757 years	0.30926	1.48E-04
	12,987 years	0.24429	7.70E-05
	38,462 years	0.10108	2.60E-05
Slip Rate [0.6]	0.01 mm/year	0.3	*
	0.02 mm/year	0.4	*
	0.03 mm/year	0.3	*

Fluorspar RLME Characteristic Magnitude Distribution

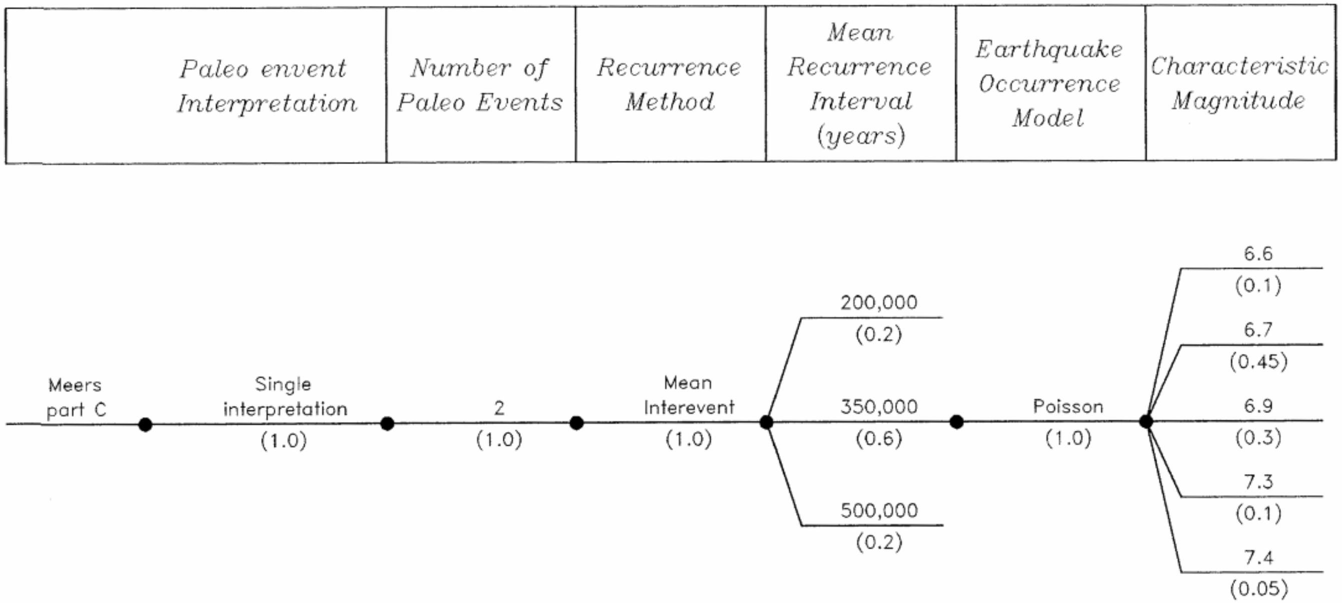
Moment Magnitude	**Weight**
6.5	0.1
6.75	0.1
7.0	0.4
7.4	0.3
7.8	0.1

OK Aulacogen/Meers Slides


Localizing Tectonic Feature
In or Out of Cluster
Source Geometry
Earthquake Model
Rupture Size Relationship
Magnitude Approach
Recurrence Approach
Tectonic Feature Localizer (1.0)
Random in Zone (0.0)
In (0.8)
Out (0.2)
Quaternary Trace (0.9)
Extended Trace (0.1)
Maximum Moment (1.0)
CEUS (0.5)
WUS (0.5)
Geological (1.0)
Pale event Based (1.0)
go to part B
Quaternary Trace (0.9)
Extended Trace (0.1)
Maximum Moment (1.0)
CEUS (0.5)
WUS (0.5)
Geological (1.0)
Pale event Based (1.0)
go to part C

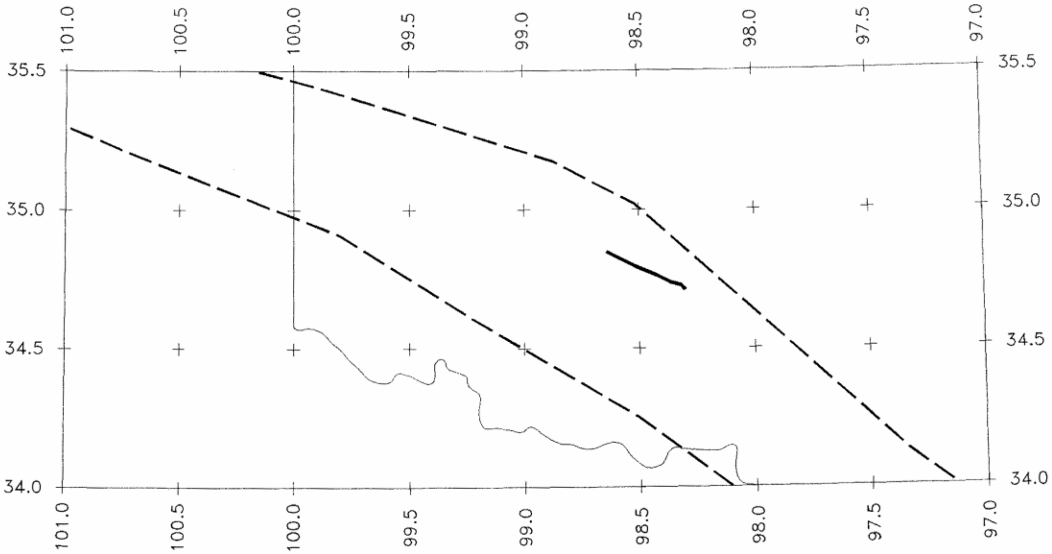


Paleo envent Interpretation
Number of Paleo Events
Recurrence Method
Mean Recurrence Interval (years)
Earthquake Occurrence Model
Characteristic Magnitude
Meers part B
Single interpretation (1.0)
2 (1.0)
Mean Interevent (1.0)
600 (0.2)
1100 (0.6)
1700 (0.2)
Poisson (1.0)
6.6 (0.1)
6.7 (0.45)
6.9 (0.3)
7.3 (0.1)
7.4 (0.05)

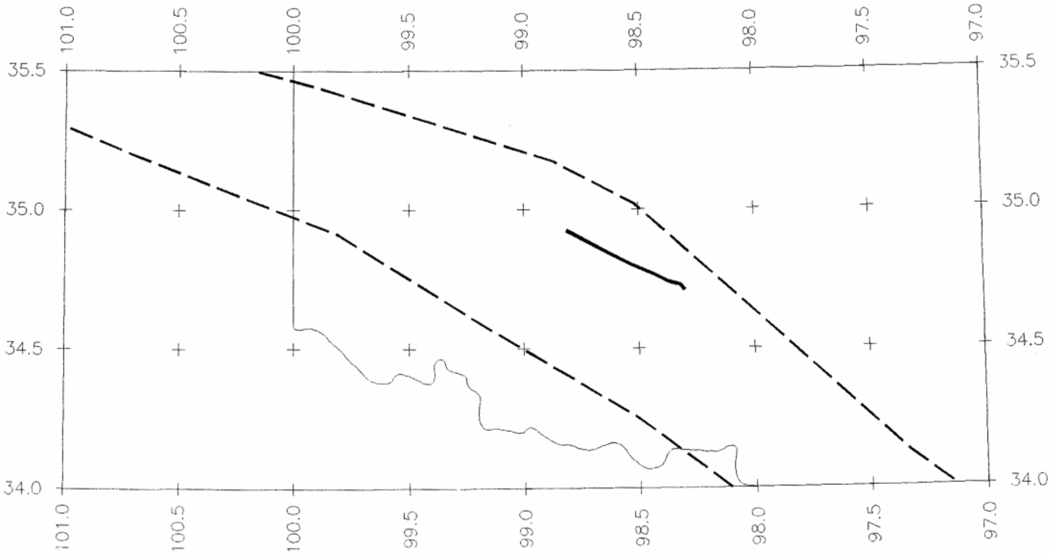


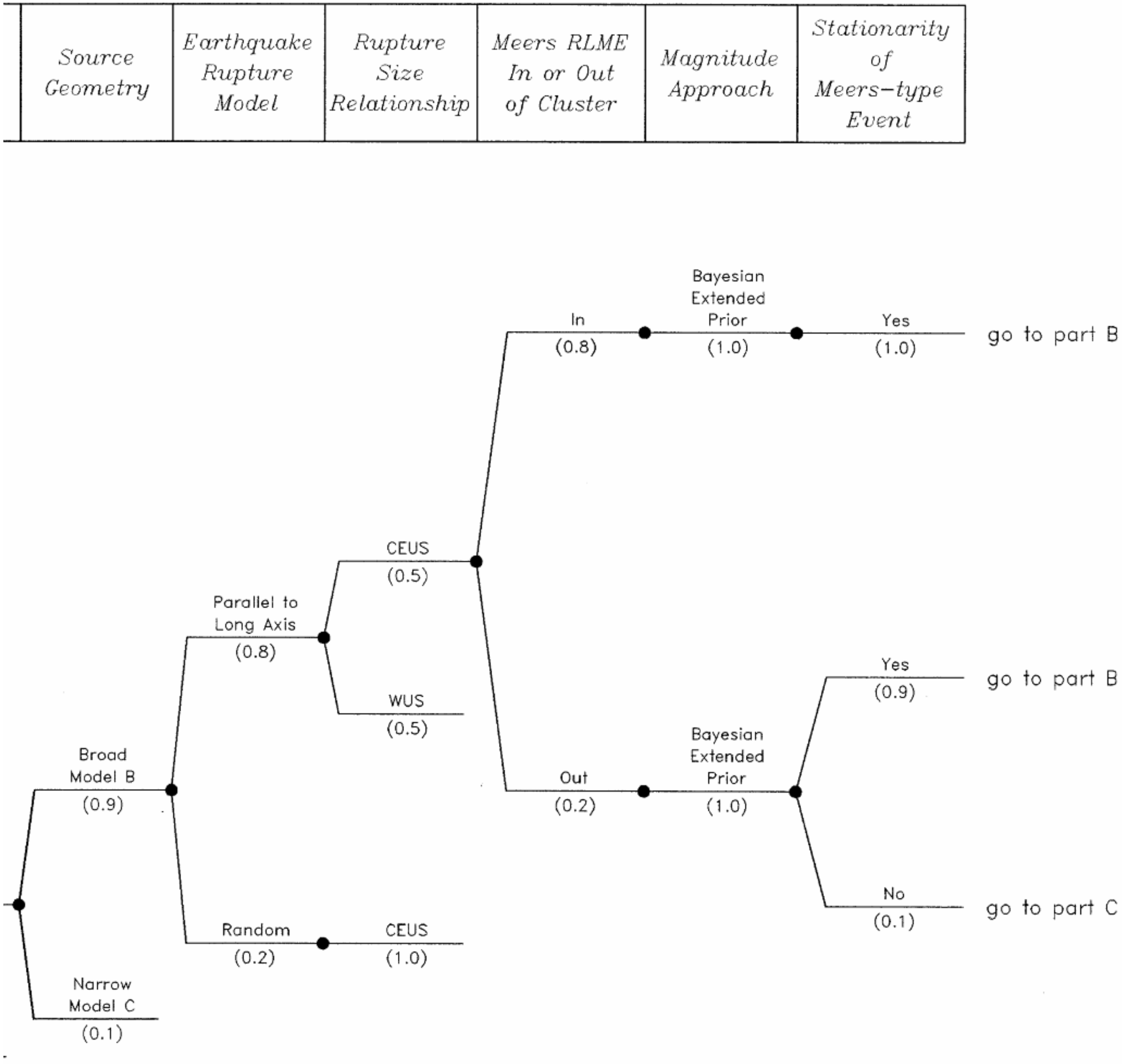
Paleo envent Interpretation
Number of Paleo Events
Recurrence Method
Mean Recurrence Interval (years)
Earthquake Occurrence Model
Characteristic Magnitude
Meers part C
Single interpretation (1.0)
2 (1.0)
Mean Interevent (1.0)
200,000 (0.2)
350,000 (0.6)
500,000 (0.2)
Poisson (1.0)
6.6 (0.1)
6.7 (0.45)
6.9 (0.3)
7.3 (0.1)
7.4 (0.05)

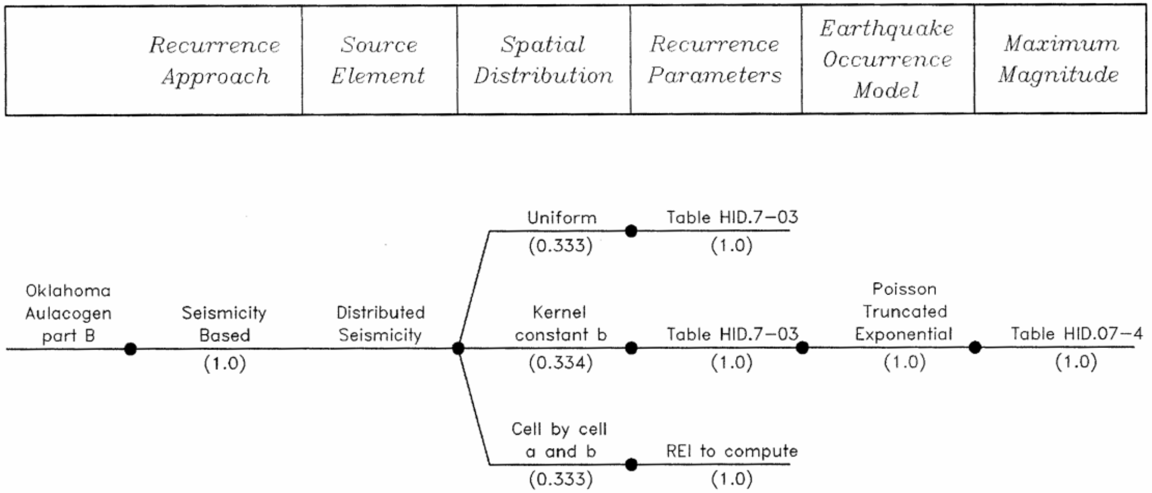
Meers fault – Quaternary

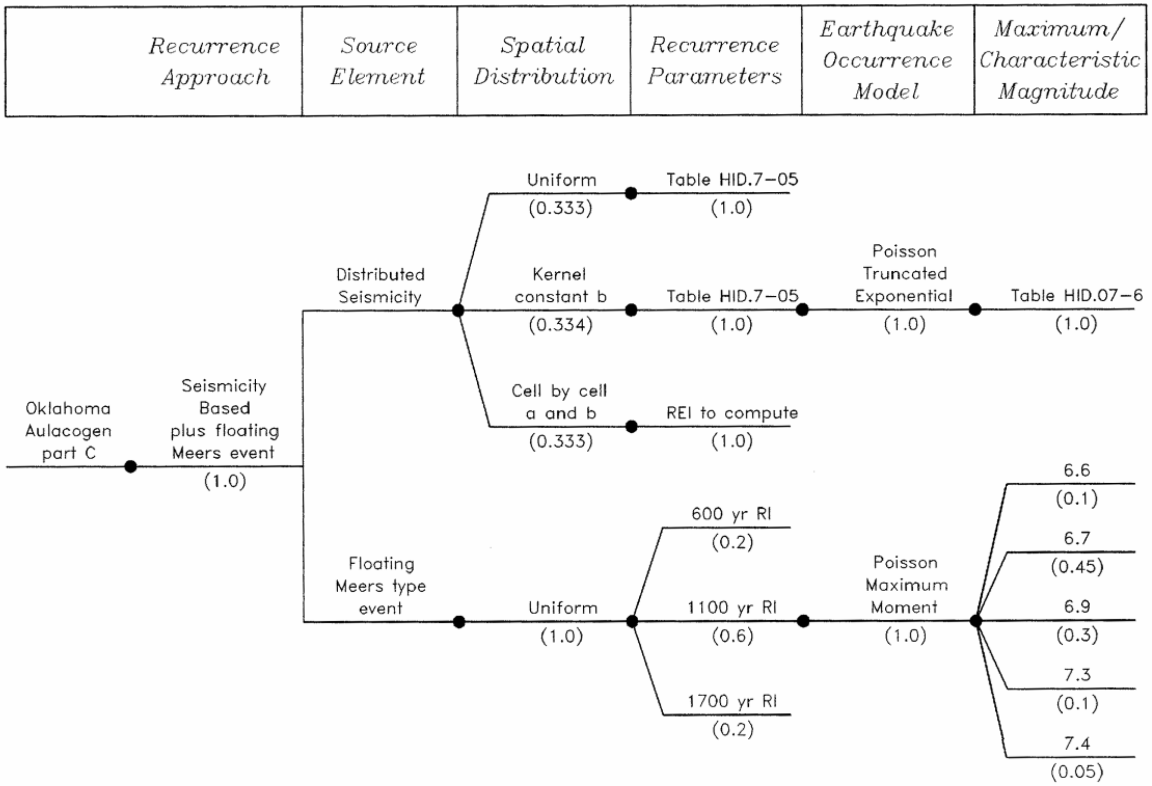


Meers fault – Extended




Source Geometry
Earthquake Rupture Model
Rupture Size Relationship
Meers RLME In or Out of Cluster
Magnitude Approach
Stationarity of Meers–type Event
Broad Model B
(0.9)
Narrow Model C
(0.1)
Parallel to Long Axis
(0.8)
Random
(0.2)
CEUS
(0.5)
WUS
(0.5)
CEUS
(1.0)
In
(0.8)
Out
(0.2)
Bayesian Extended Prior
(1.0)
Bayesian Extended Prior
(1.0)
Yes
(1.0)
Yes
(0.9)
No
(0.1)
go to part B
go to part B
go to part C


Recurrence Approach
Source Element
Spatial Distribution
Recurrence Parameters
Earthquake Occurrence Model
Maximum Magnitude
Oklahoma Aulacogen part B
Seismicity Based
(1.0)
Distributed Seismicity
Uniform
(0.333)
Table HID.7−03
(1.0)
Kernel constant b
(0.334)
Table HID.7−03
(1.0)
Cell by cell a and b
(0.333)
REI to compute
(1.0)
Poisson Truncated Exponential
(1.0)
Table HID.07−4
(1.0)


Recurrence Approach
Source Element
Spatial Distribution
Recurrence Parameters
Earthquake Occurrence Model
Maximum/ Characteristic Magnitude
Oklahoma Aulacogen part C
Seismicity Based plus floating Meers event
(1.0)
Distributed Seismicity
Uniform
(0.333)
Table HID.7−05
(1.0)
Kernel constant b
(0.334)
Table HID.7−05
(1.0)
Cell by cell a and b
(0.333)
REI to compute
(1.0)
Poisson Truncated Exponential
(1.0)
Table HID.07−6
(1.0)
Floating Meers type event
Uniform
(1.0)
600 yr RI
(0.2)
1100 yr RI
(0.6)
1700 yr RI
(0.2)
Poisson Maximum Moment
(1.0)
6.6
(0.1)
6.7
(0.45)
6.9
(0.3)
7.3
(0.1)
7.4
(0.05)

Annual Frequencies for Meers RLME Events

In or Out of Cluster [wt]	**Mean Recurrence Interval**		**RLME Frequency (Events/year)**
	Value (years)	**Wt**	**Total**
In [0.8]	600	0.2	1.67E-03
	1,100	0.6	9.09E-04
	1,700	0.2	5.88E-04
Out [0.2]	200,000	0.2	5.00E-06
	350,000	0.6	2.86E-06
	500,000	0.2	2.00E-06

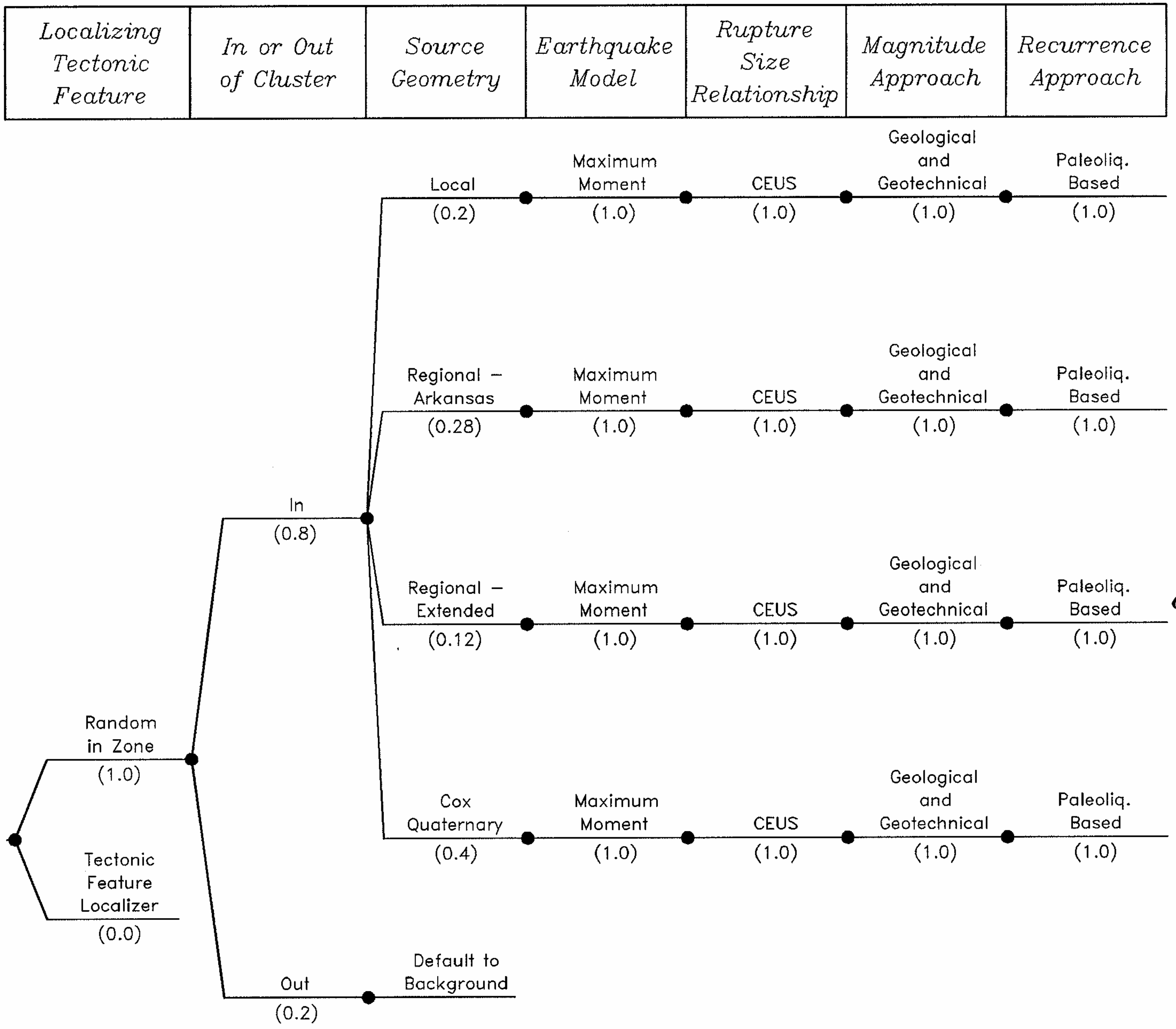
Meers RLME Characteristic Magnitude Distribution

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

Seismicity Parameter Distribution Files for Oklahoma Aulacogen Seismotectonic Source Zone

Zone Model	**Stationarity of Meers type Events**	**Spatial Distribution**	**Spatial Distribution File**	**Seismicity Parameters File**	**Maximum Magnitude Distribution File**
B	Yes	Uniform	Uniform	OkA_B.rec	OkA_B.mmx
		Variable *a*, constant *b*	OkA_B.xcd	OkA_B.rec	
		Variable *a* and *b*	*	*	
	No	Uniform	Uniform	OkA_B_M.rec	OkA_B_M.mmx
		Variable *a*, constant *b*	OkA_B.xcd	OkA_B_M.rec	
		Variable *a* and *b*	*	*	
C	Yes	Uniform	Uniform	OkA_C.rec	OkA_C.mmx
		Variable *a*, constant *b*	OkA_C.xcd	OkA_C.rec	
		Variable *a* and *b*	*	*	
	No	Uniform	Uniform	OkA_C_M.rec	OkA_C_M.mmx
		Variable a, constant b	OkA_C.xcd	OkA_C_M.rec	
		Variable a and b	*	*	

ALM RLME

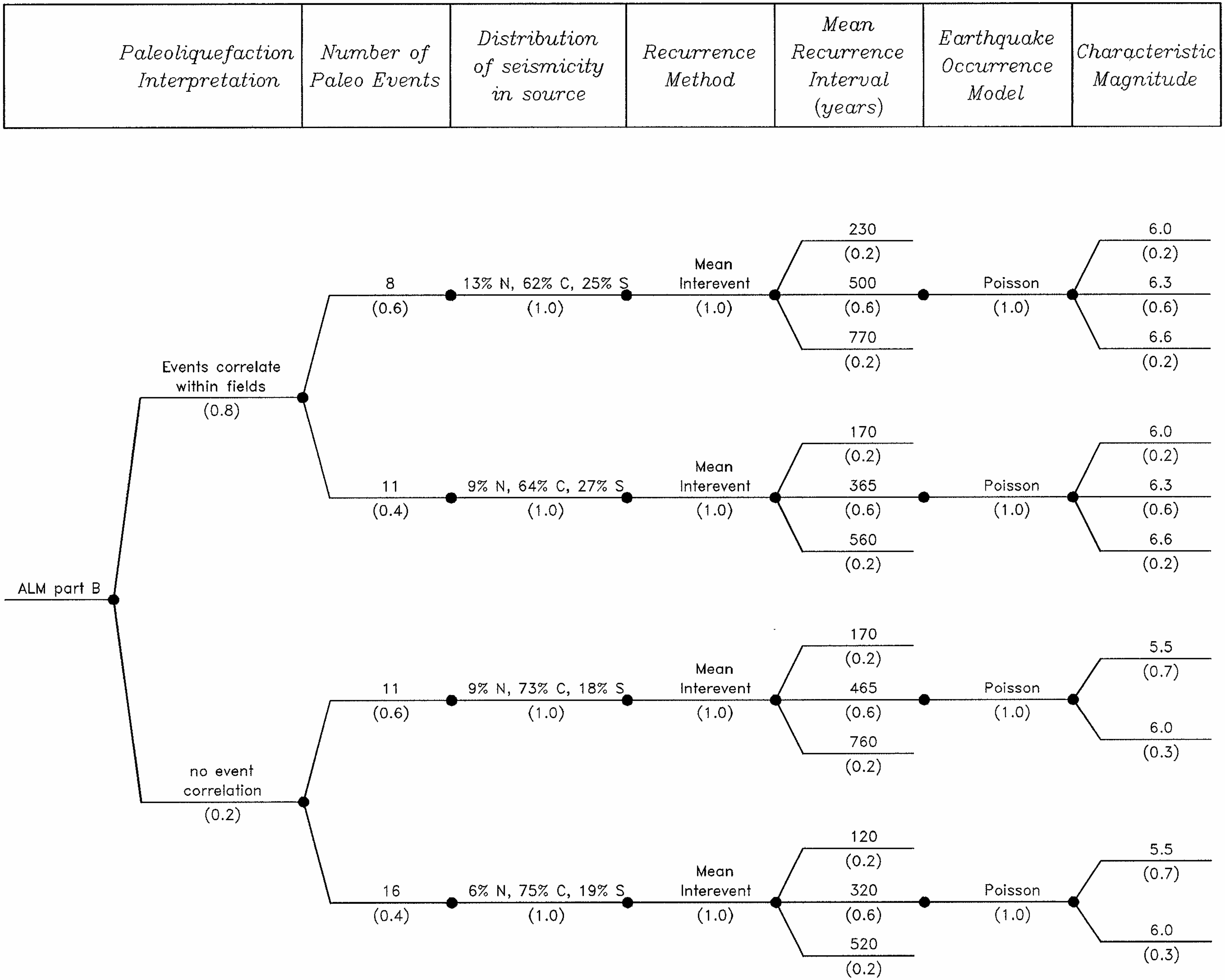


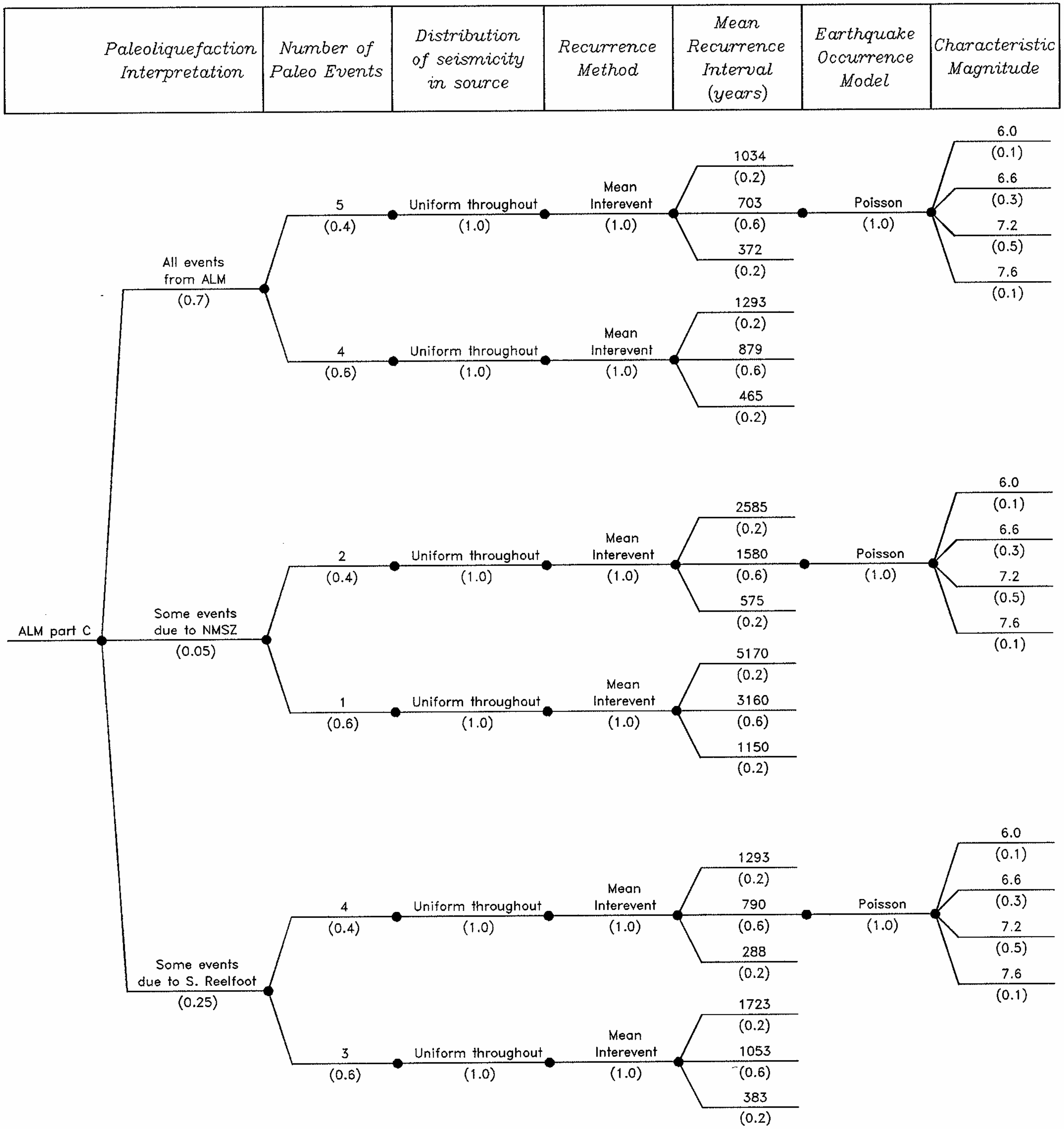
Part B

Part C

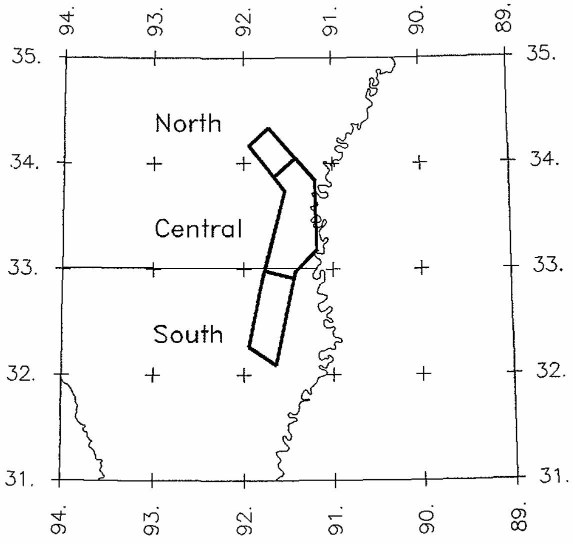
Part C

Part C

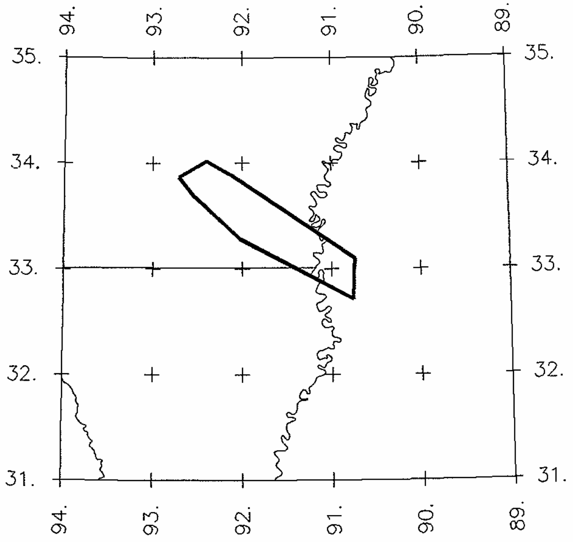

Paleoliquefaction Interpretation
Number of Paleo Events
Distribution of seismicity in source
Recurrence Method
Mean Recurrence Interval (years)
Earthquake Occurrence Model
Characteristic Magnitude
ALM part B
Events correlate within fields
(0.8)
no event correlation
(0.2)
8
(0.6)
13% N, 62% C, 25% S
(1.0)
Mean Interevent
(1.0)
230
(0.2)
500
(0.6)
770
(0.2)
Poisson
(1.0)
6.0
(0.2)
6.3
(0.6)
6.6
(0.2)
11
(0.4)
9% N, 64% C, 27% S
(1.0)
Mean Interevent
(1.0)
170
(0.2)
365
(0.6)
560
(0.2)
Poisson
(1.0)
6.0
(0.2)
6.3
(0.6)
6.6
(0.2)
11
(0.6)
9% N, 73% C, 18% S
(1.0)
Mean Interevent
(1.0)
170
(0.2)
465
(0.6)
760
(0.2)
Poisson
(1.0)
5.5
(0.7)
6.0
(0.3)
16
(0.4)
6% N, 75% C, 19% S
(1.0)
Mean Interevent
(1.0)
120
(0.2)
320
(0.6)
520
(0.2)
Poisson
(1.0)
5.5
(0.7)
6.0
(0.3)


Paleoliquefaction Interpretation
Number of Paleo Events
Distribution of seismicity in source
Recurrence Method
Mean Recurrence Interval (years)
Earthquake Occurrence Model
Characteristic Magnitude
ALM part C
All events from ALM
(0.7)
Some events due to NMSZ
(0.05)
Some events due to S. Reelfoot
(0.25)
5
(0.4)
4
(0.6)
2
(0.4)
1
(0.6)
4
(0.4)
3
(0.6)
Uniform throughout
(1.0)
Mean Interevent
(1.0)
1034
(0.2)
703
(0.6)
372
(0.2)
1293
(0.2)
879
(0.6)
465
(0.2)
2585
(0.2)
1580
(0.6)
575
(0.2)
5170
(0.2)
3160
(0.6)
1150
(0.2)
1293
(0.2)
790
(0.6)
288
(0.2)
1723
(0.2)
1053
(0.6)
383
(0.2)
Poisson
(1.0)
6.0
(0.1)
6.6
(0.3)
7.2
(0.5)
7.6
(0.1)

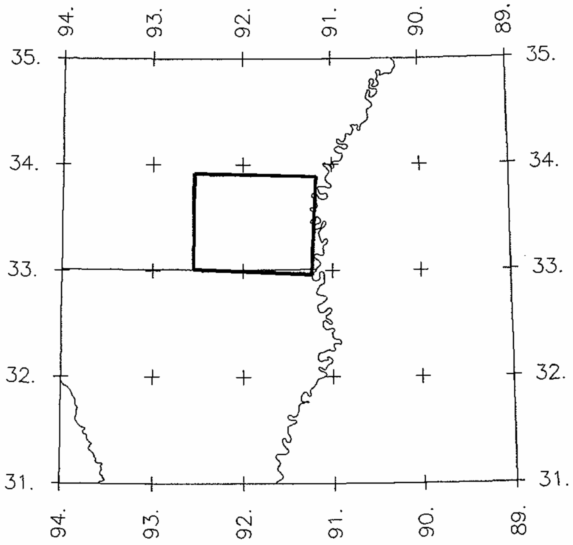
ALM – Local



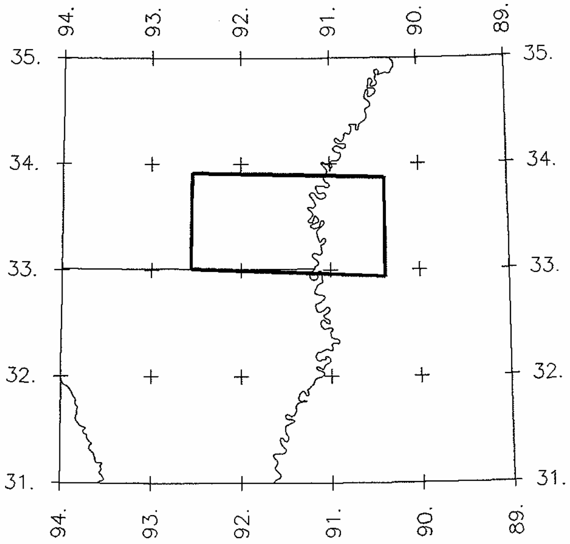
ALM – Cox Quaternary



ALM – Regional – Arkansas



ALM – Regional – Extended



Annual Frequencies for ALM RLME Events for the “Local” Source Geometry

Paleoliquefaction Interpretation [wt]	Number of Paleo Events [wt]	Distribution of seismicity in source			Mean Recurrence Interval		RLME Frequency (Events/year)			
		North	Central	South	Value (years)	Wt	Total	North	Central	South
Events correlate within fields [0.8]	8 [0.6]	13%	62%	25%	230	0.2	4.35E-03	5.65E-04	2.70E-03	1.09E-03
					500	0.6	2.00E-03	2.60E-04	1.24E-03	5.00E-04
					770	0.2	1.30E-03	1.69E-04	8.05E-04	3.25E-04
	11 [0.4]	9%	64%	27%	170	0.2	5.88E-03	5.29E-04	3.76E-03	1.59E-03
					365	0.6	2.74E-03	2.47E-04	1.75E-03	7.40E-04
					560	0.2	1.79E-03	1.61E-04	1.14E-03	4.82E-04
No correlation [0.2]	11 [0.6]	9%	73%	18%	170	0.2	5.88E-03	5.29E-04	4.29E-03	1.06E-03
					465	0.6	2.15E-03	1.94E-04	1.57E-03	3.87E-04
					760	0.2	1.32E-03	1.18E-04	9.61E-04	2.37E-04
	16 [0.4]	6%	75%	19%	120	0.2	8.33E-03	5.00E-04	6.25E-03	1.58E-03
					320	0.6	3.13E-03	1.88E-04	2.34E-03	5.94E-04
					520	0.2	1.92E-03	1.15E-04	1.44E-03	3.65E-04

ALM RLME Characteristic Magnitude Distributions for the “Local” Source Geometry

Paleoliquefaction Interpretation [wt]	**Moment Magnitude**	**Weight**
Events correlate within fields [0.8]	6.0	0.2
	6.3	0.6
	6.6	0.2
No correlation [0.2]	5.5	0.7
	6.0	0.3

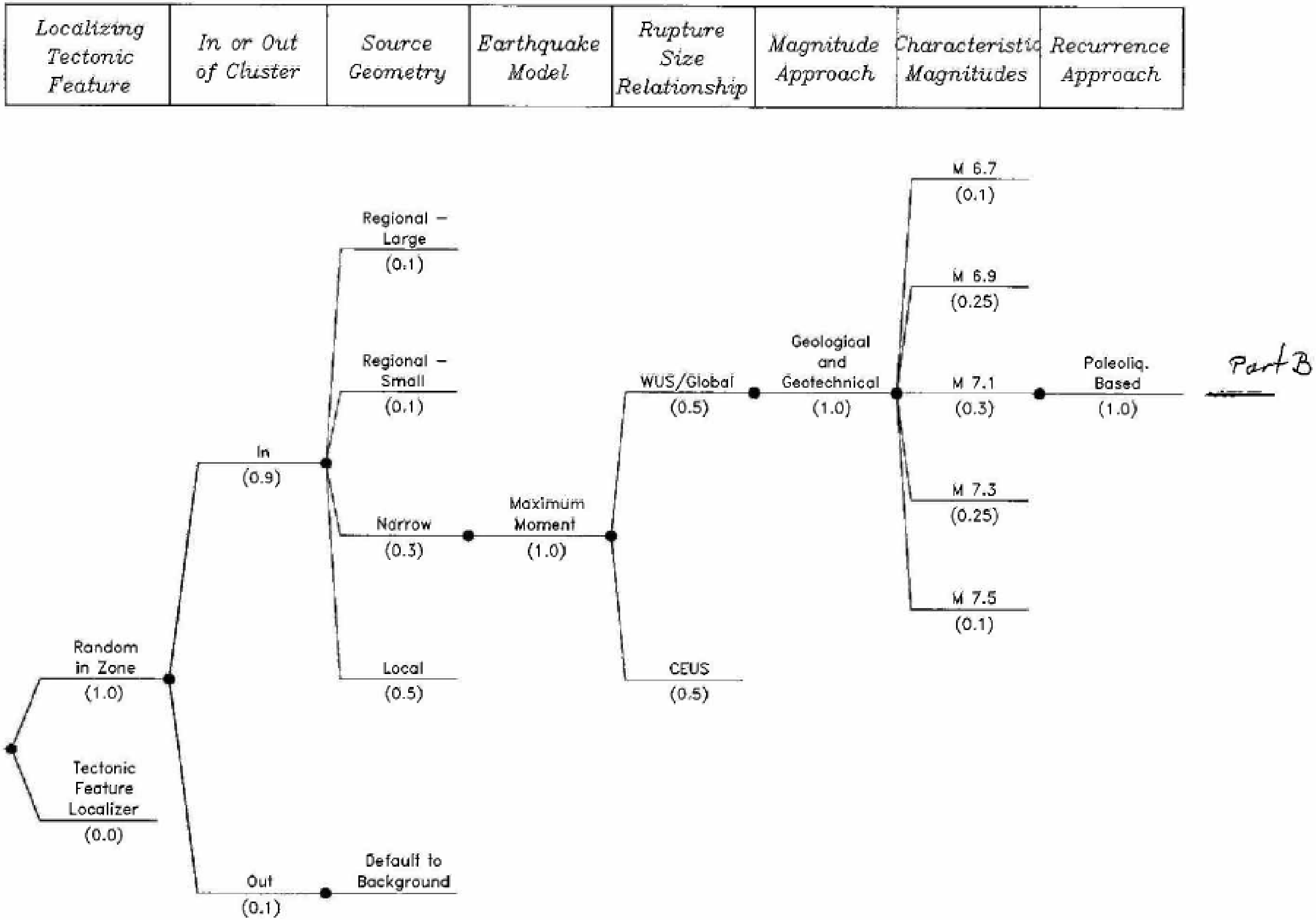
Annual Frequencies for ALM RLME Events for the “Regional – Arkansas”, Regional – Extended” and “Cox Quaternary” Source Geometries

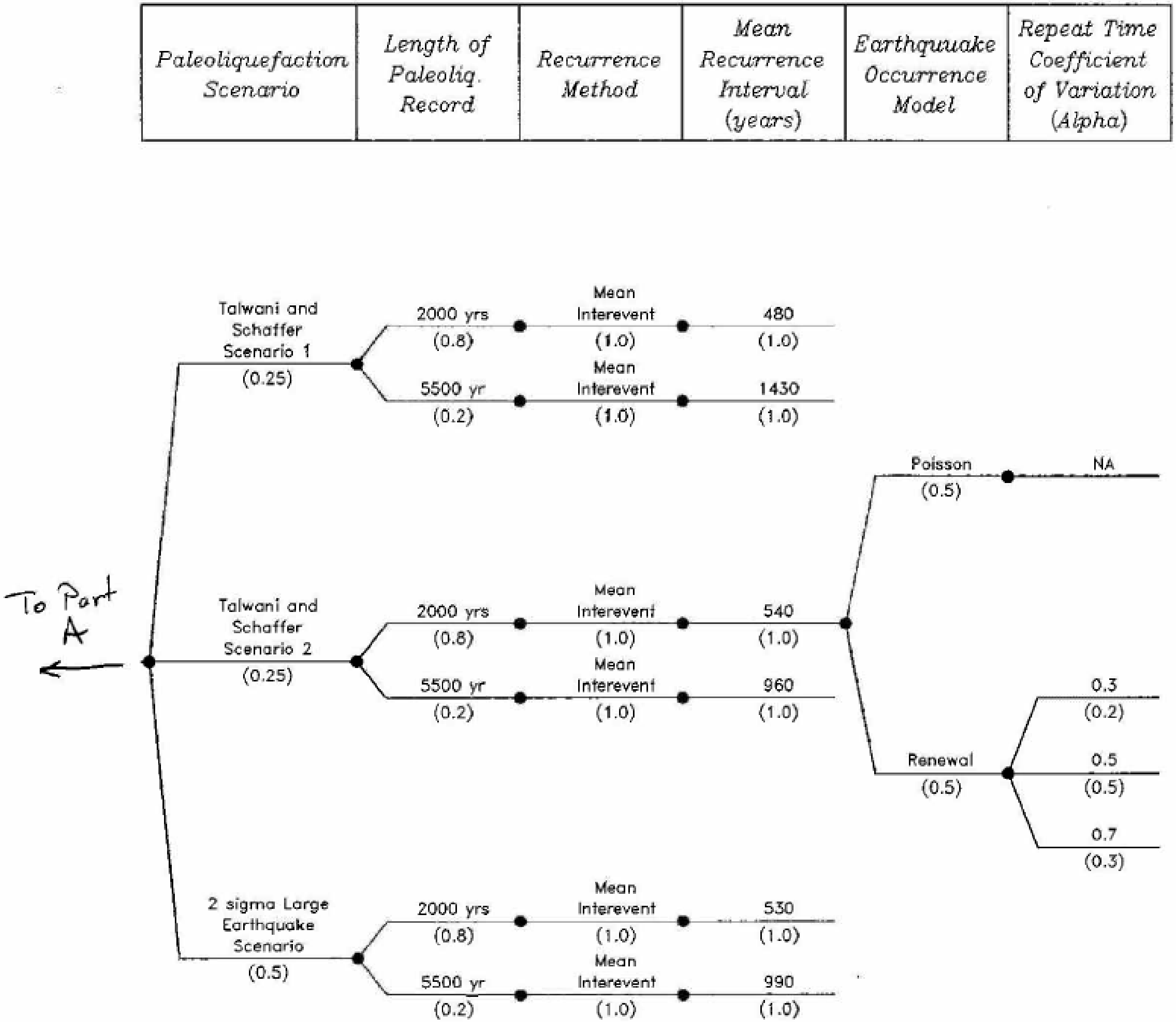
Paleoliquefaction Interpretation [wt]	**Moment Magnitude**	**Weight**
Events correlate within fields [0.8]	6.0	0.2
	6.3	0.6
	6.6	0.2
No correlation [0.2]	5.5	0.7
	6.0	0.3

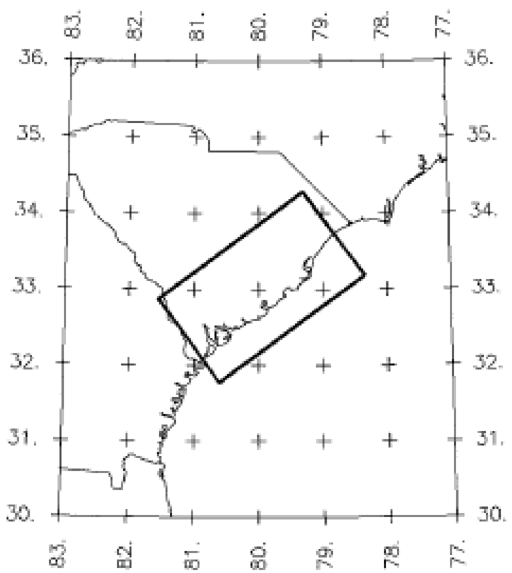
ALM RLME Characteristic Magnitude Distribution for the “Regional – Arkansas”, Regional – Extended” and “Cox Quaternary” Source Geometries

Moment Magnitude	**Weight**
6.0	0.1
6.3	0.3
7.2	0.5
7.2	0.1

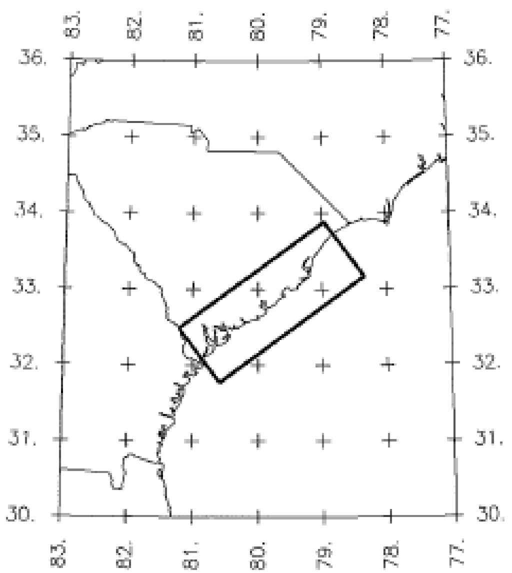
Charleston Figures


Localizing Tectonic Feature
In or Out of Cluster
Source Geometry
Earthquake Model
Rupture Size Relationship
Magnitude Approach
Characteristic Magnitudes
Recurrence Approach
Random in Zone (1.0)
Tectonic Feature Localizer (0.0)
In (0.9)
Out (0.1)
Default to Background
Regional – Large (0.1)
Regional – Small (0.1)
Narrow (0.3)
Local (0.5)
Maximum Moment (1.0)
WUS/Global (0.5)
CEUS (0.5)
Geological and Geotechnical (1.0)
M 6.7 (0.1)
M 6.9 (0.25)
M 7.1 (0.3)
M 7.3 (0.25)
M 7.5 (0.1)
Paleoliq. Based (1.0)
Part B

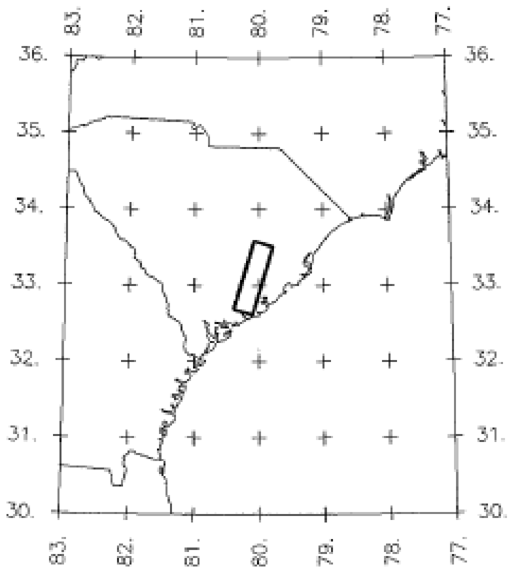

Paleoliquefaction Scenario
Length of Paleoliq. Record
Recurrence Method
Mean Recurrence Interval (years)
Earthquake Occurrence Model
Repeat Time Coefficient of Variation (Alpha)
To Part A
Talwani and Schaffer Scenario 1
(0.25)
2000 yrs
(0.8)
Mean Interevent
(1.0)
480
(1.0)
5500 yr
(0.2)
Mean Interevent
(1.0)
1430
(1.0)
Poisson
(0.5)
NA
Talwani and Schaffer Scenario 2
(0.25)
2000 yrs
(0.8)
Mean Interevent
(1.0)
540
(1.0)
5500 yr
(0.2)
Mean Interevent
(1.0)
960
(1.0)
0.3
(0.2)
Renewal
(0.5)
0.5
(0.5)
0.7
(0.3)
2 sigma Large Earthquake Scenario
(0.5)
2000 yrs
(0.8)
Mean Interevent
(1.0)
530
(1.0)
5500 yr
(0.2)
Mean Interevent
(1.0)
990
(1.0)



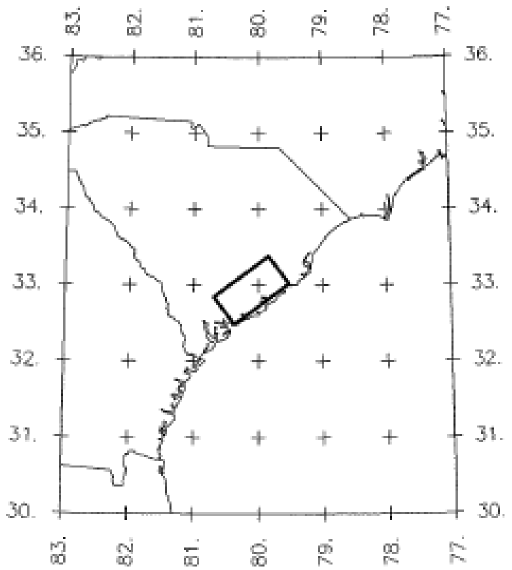
Charleston – Regional-Large



Charleston – Regional-Small



Charleston – Narrow



Charleston – Local

Charleston RLME Characteristic Magnitudes

Moment Magnitude	**Weight**
6.7	0.1
6.9	0.25
7.1	0.3
7.3	0.25
7.5	0.1

Table 13

Charleston RLME Equivalent Annual Frequencies Talwani and Schaefer Scenario 1

Paleoliquefacton Scenario	**Liquefaction Record (wt)**	**Mean Recurrence Interval (wt)**	**Occurrence Method (wt)**	**Alpha (wt)**	**RLME Frequency (Events/year)**
Talwani and Schaffer Scenario 1 (0.25)	2000 years (0.8)	480 (1.0)	Poisson (0.5)	NA	2.08E-03
			Renewal BPT (0.5)	0.3 (0.2)	5.87E-06
				0.5 (0.5)	4.62E-04
				0.7 (0.3)	1.51E-03
	5500 years (0.2)	1430 (1.0)	Poisson (0.5)	NA	6.99E-04
			Renewal BPT (0.5)	0.3 (0.2)	0.00E+00
				0.5 (0.5)	7.99E-09
				0.7 (0.3)	5.44E-06

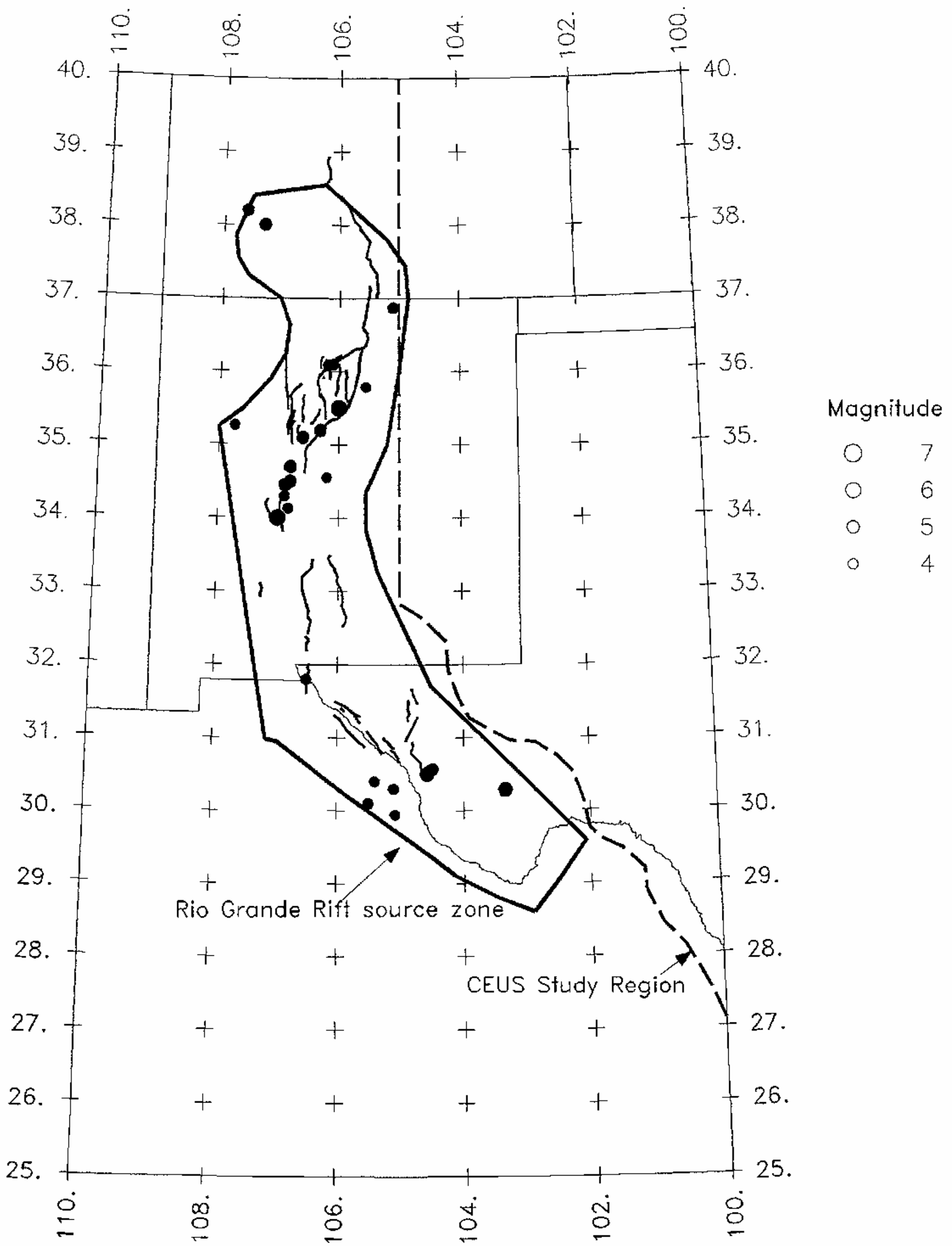
Charleston RLME Equivalent Annual Frequencies Talwani and Schaefer Scenario 2

Paleoliquefacton Scenario	Liquefaction Record (wt)	Mean Recurrence Interval (wt)	Occurrence Method (wt)	Alpha (wt)	RLME Frequency (Events/year)
Talwani and Schaffer Scenario 2 (0.25)	2000 years (0.8)	540 (1.0)	Poisson (0.5)	NA	1.85E-03
			Renewal BPT (0.5)	0.3 (0.2)	9.92E-07
				0.5 (0.5)	2.39E-04
				0.7 (0.3)	1.08E-03
	5500 years (0.2)	960 (1.0)	Poisson (0.5)	NA	1.04E-03
			Renewal BPT (0.5)	0.3 (0.2)	2.20E-12
				0.5 (0.5)	1.95E-06
				0.7 (0.3)	9.25E-05

Charleston RLME Equivalent Annual Frequencies Two Sigma Large Event

Paleoliquefacton Scenario	Liquefaction Record (wt)	Mean Recurrence Interval (wt)	Occurrence Method (wt)	Alpha (wt)	RLME Frequency (Events/year)
Two Sigma large events (0.5)	2000 years (0.8)	530 (1.0)	Poisson (0.5)	NA	1.89E-03
			Renewal BPT (0.5)	0.3 (0.2)	1.34E-06
				0.5 (0.5)	2.67E-04
				0.7 (0.3)	1.14E-03
	5500 years (0.2)	990 (1.0)	Poisson (0.5)	NA	1.01E-03
			Renewal BPT (0.5)	0.3 (0.2)	8.52E-13
				0.5 (0.5)	1.37E-06
				0.7 (0.3)	7.73E-05

Rio Grande Rift


110.
108.
106.
104.
102.
100.
40.
39.
38.
37.
36.
35.
34.
33.
32.
31.
30.
29.
28.
27.
26.
25.
Magnitude
○ 7
○ 6
○ 5
○ 4
Rio Grande Rift source zone
CEUS Study Region

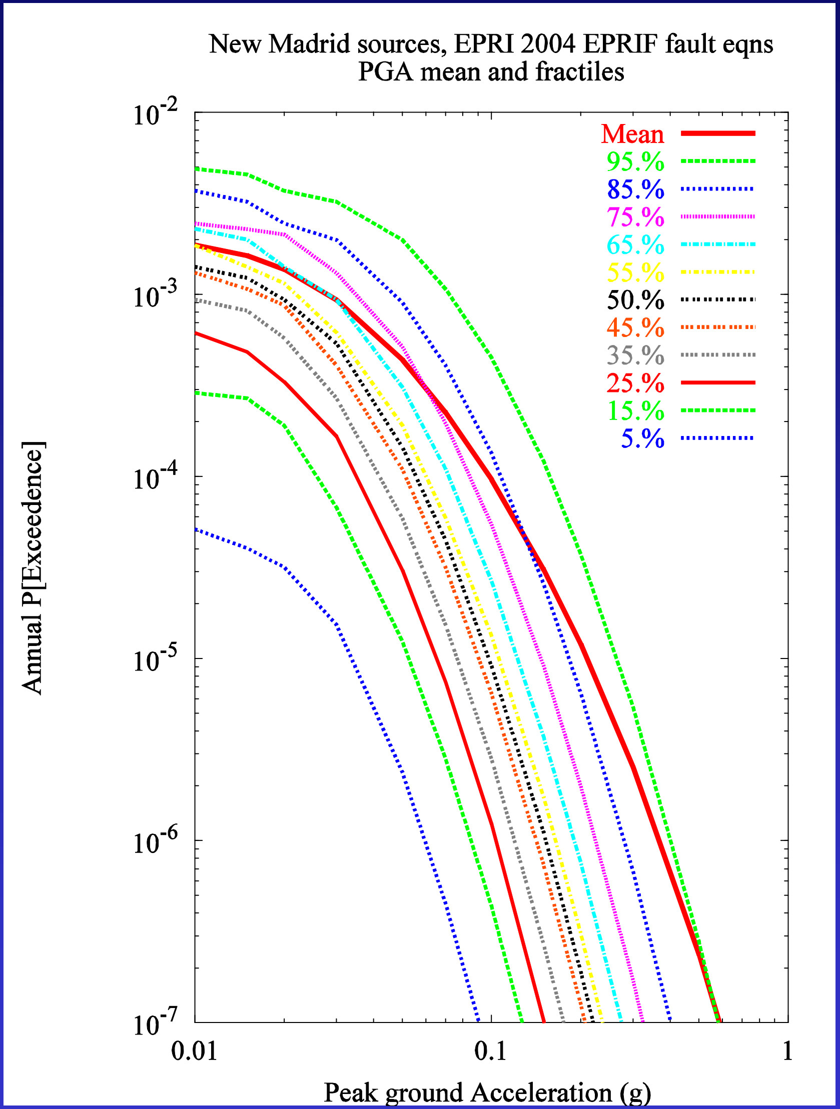
Seismic hazard sensitivity in the CEUS

Robin K. McGuire
Risk Engineering, Inc.
Boulder, Colorado

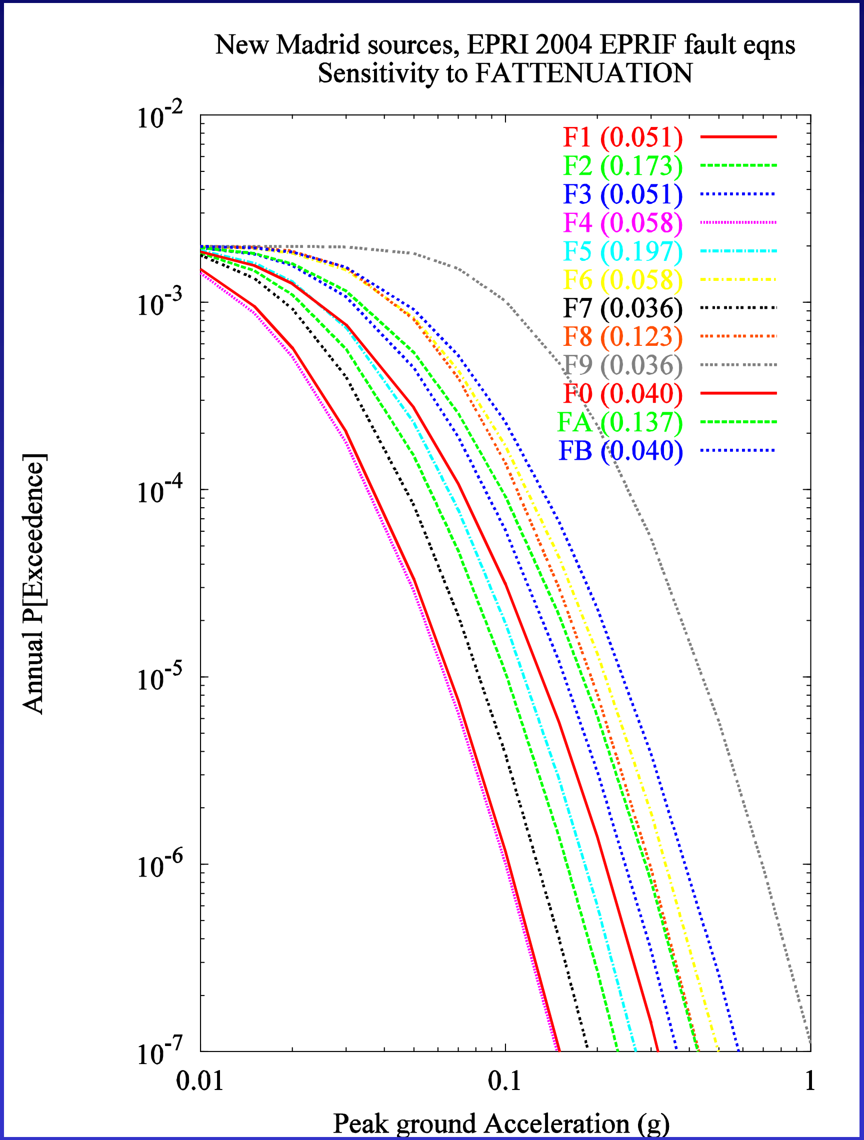
August 26, 2009

RISK ENGINEERING

Central IL site: PGA hazard fractiles

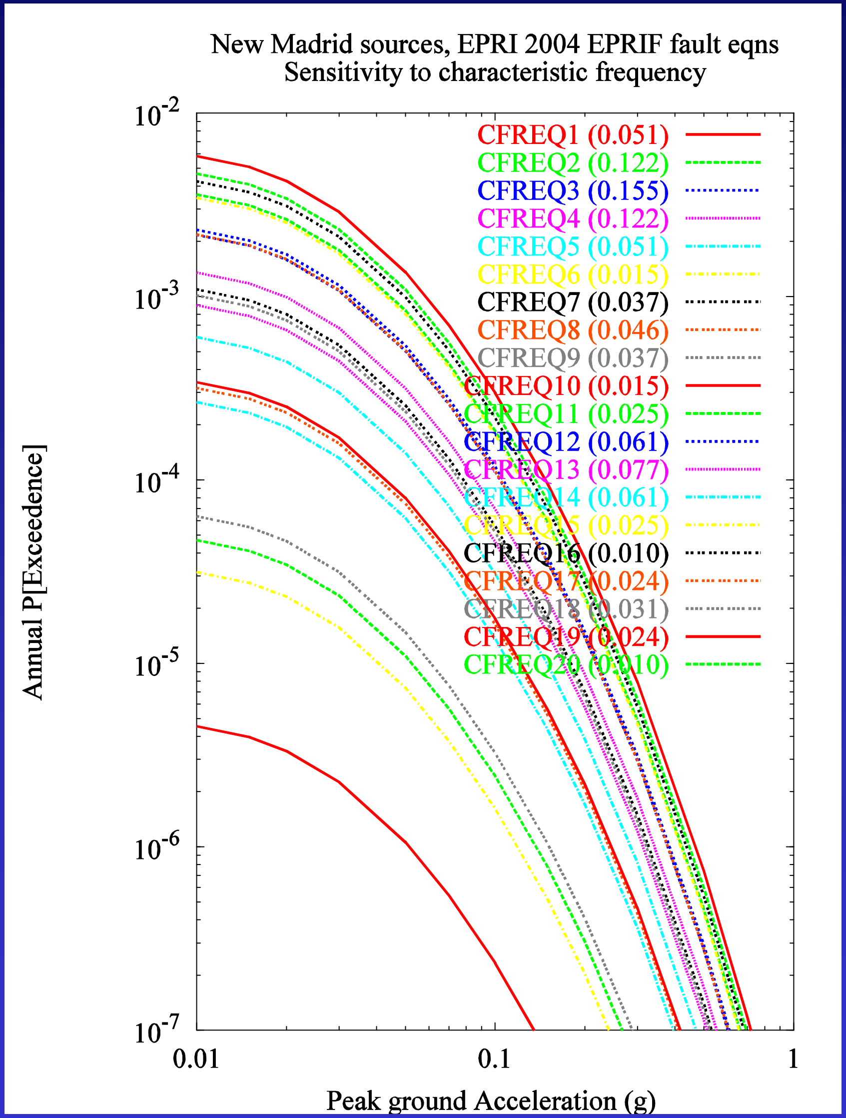


Central IL site, PGA dependence on G.M. model

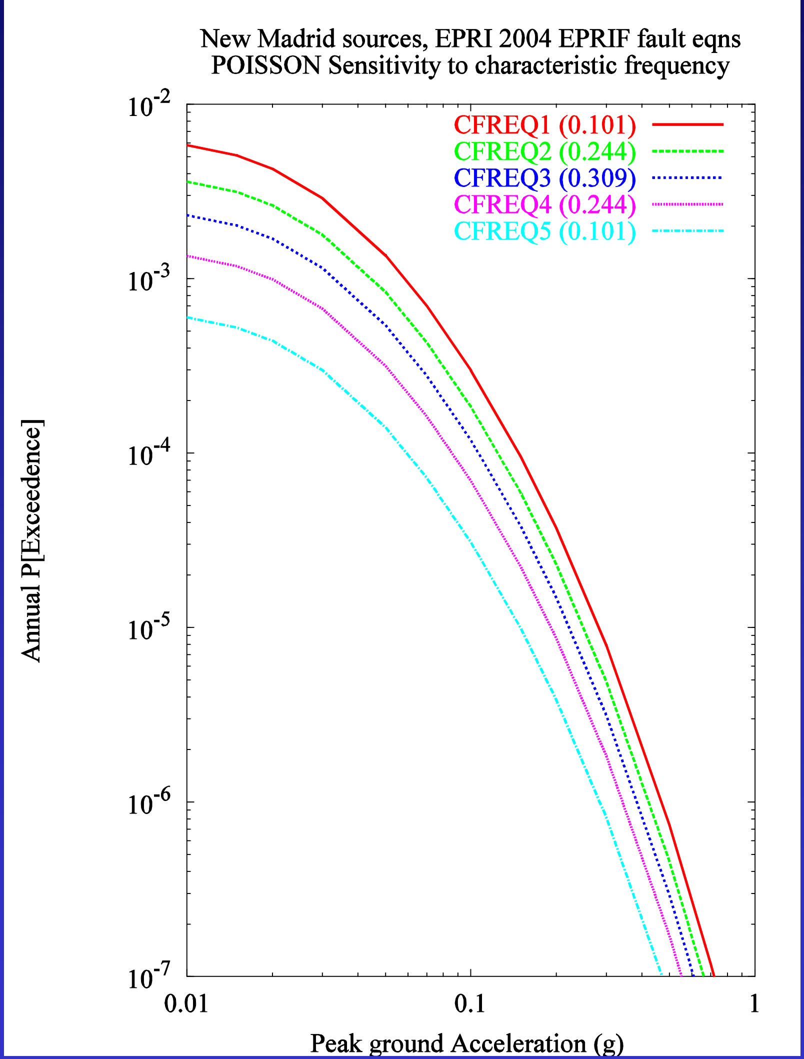


RISK ENGINEERING

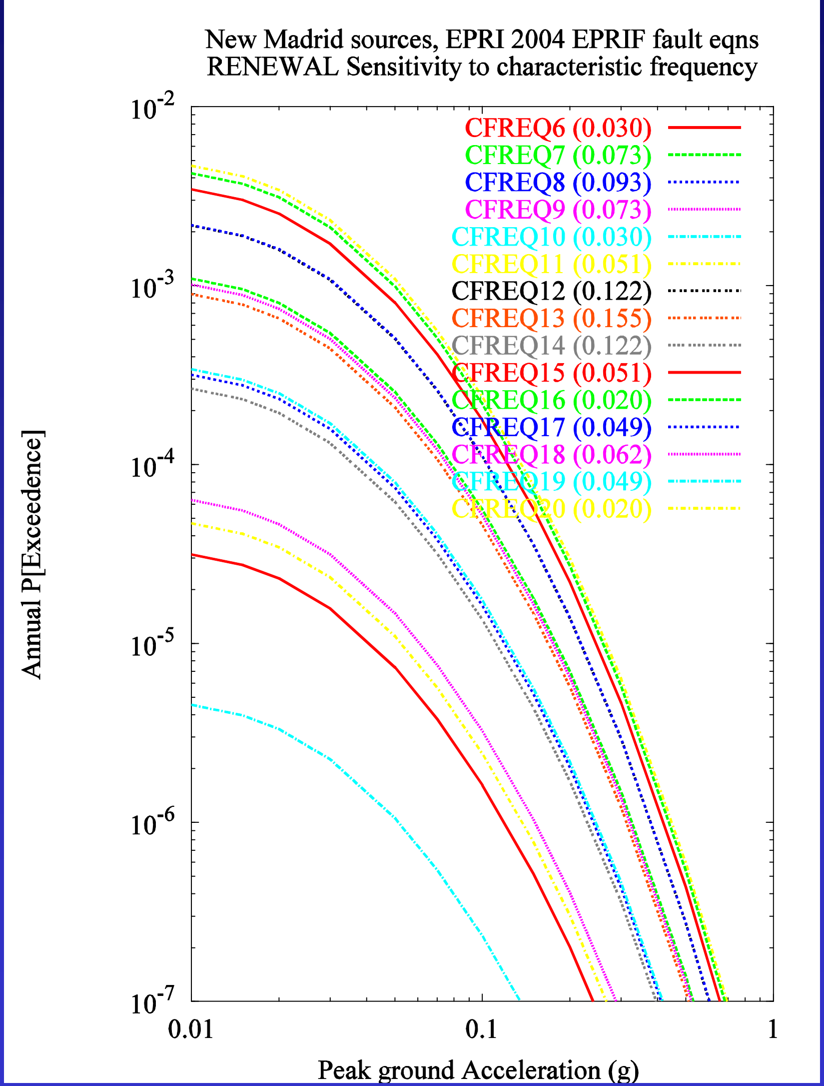
Central IL site, dependence on cluster frequency, PGA



Central IL site, PGA dependence on cluster frequency (Poisson model)

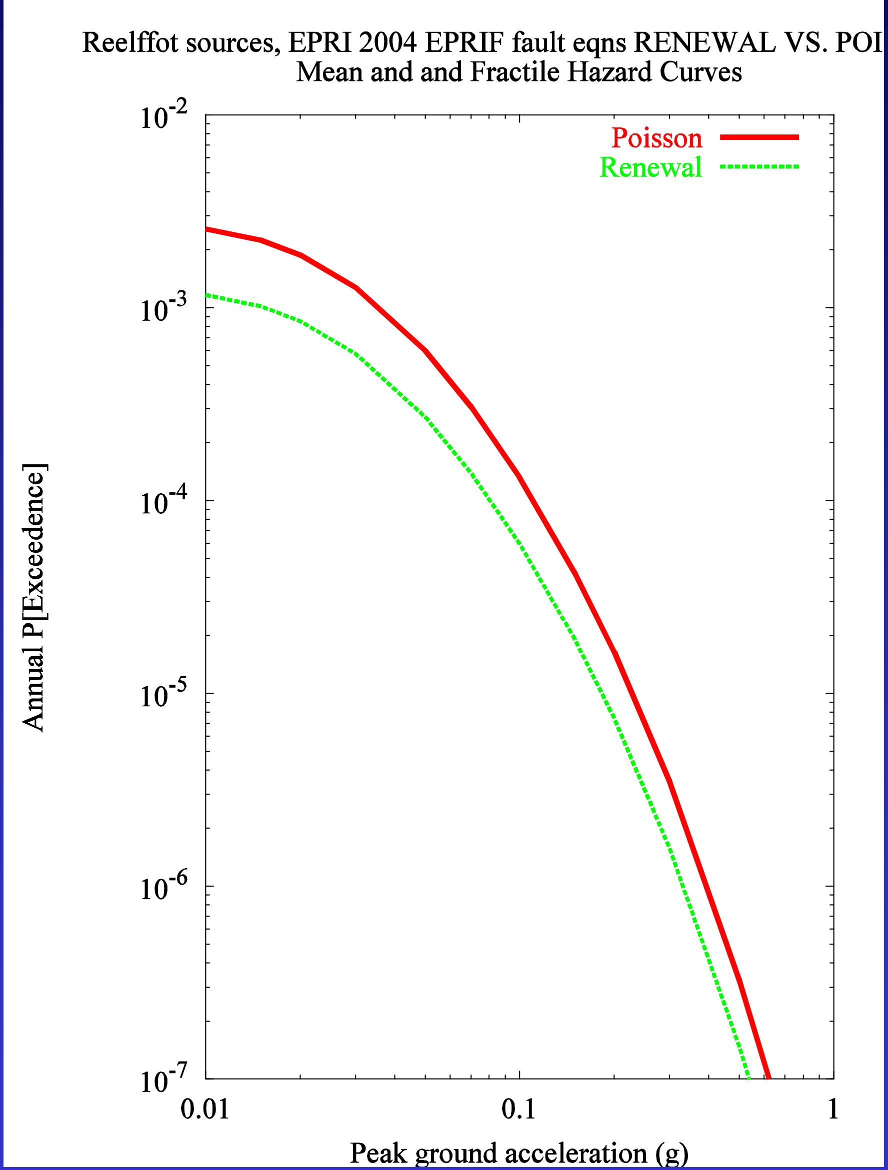


Central IL site, PGA dependence on cluster frequency (renewal model)



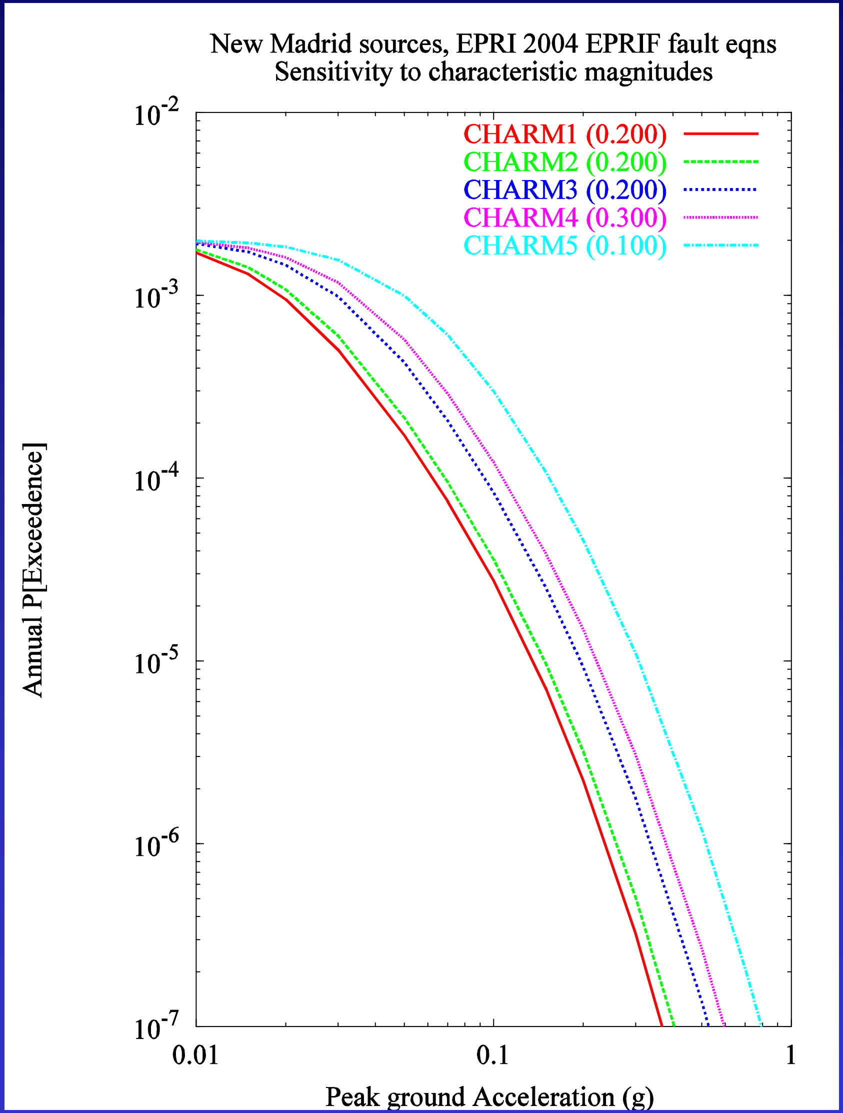
RISK ENGINEERING

Central IL site, PGA dependence on renewal vs. Poisson model

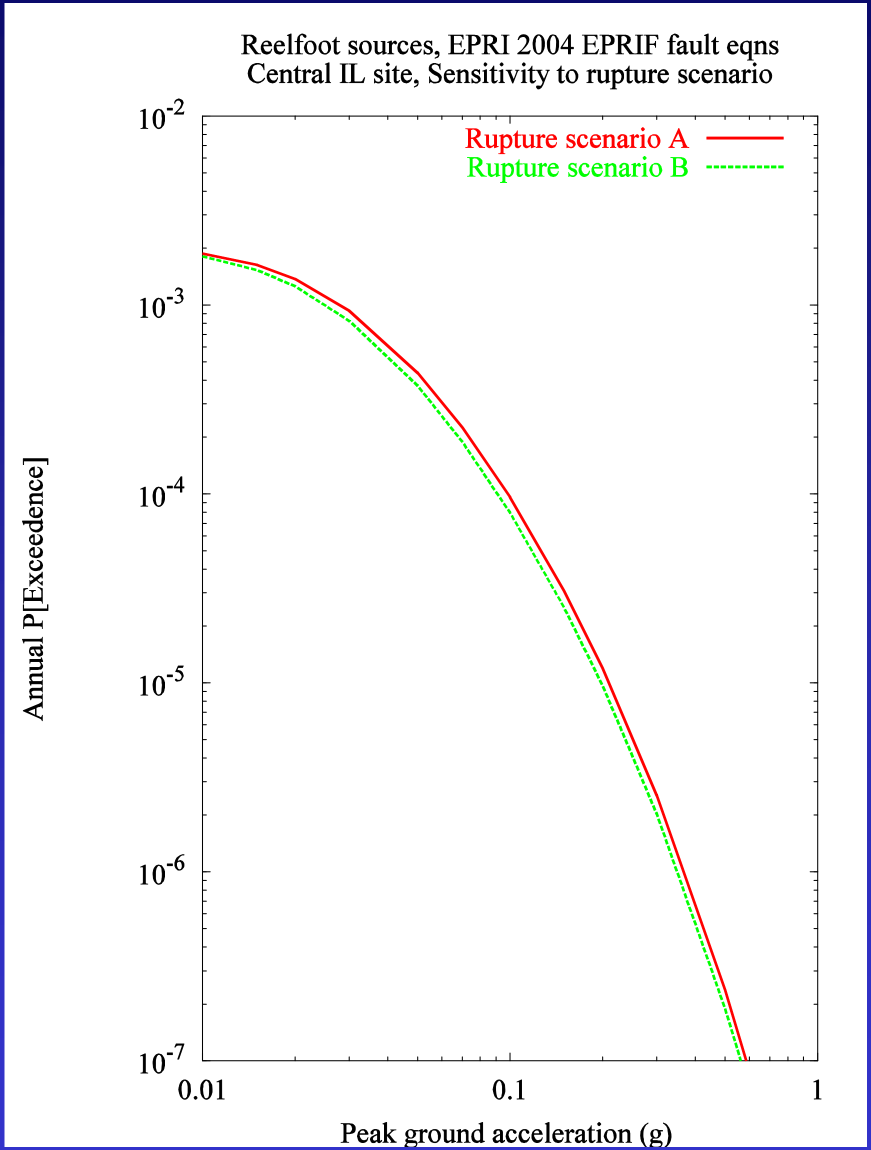


RISK ENGINEERING

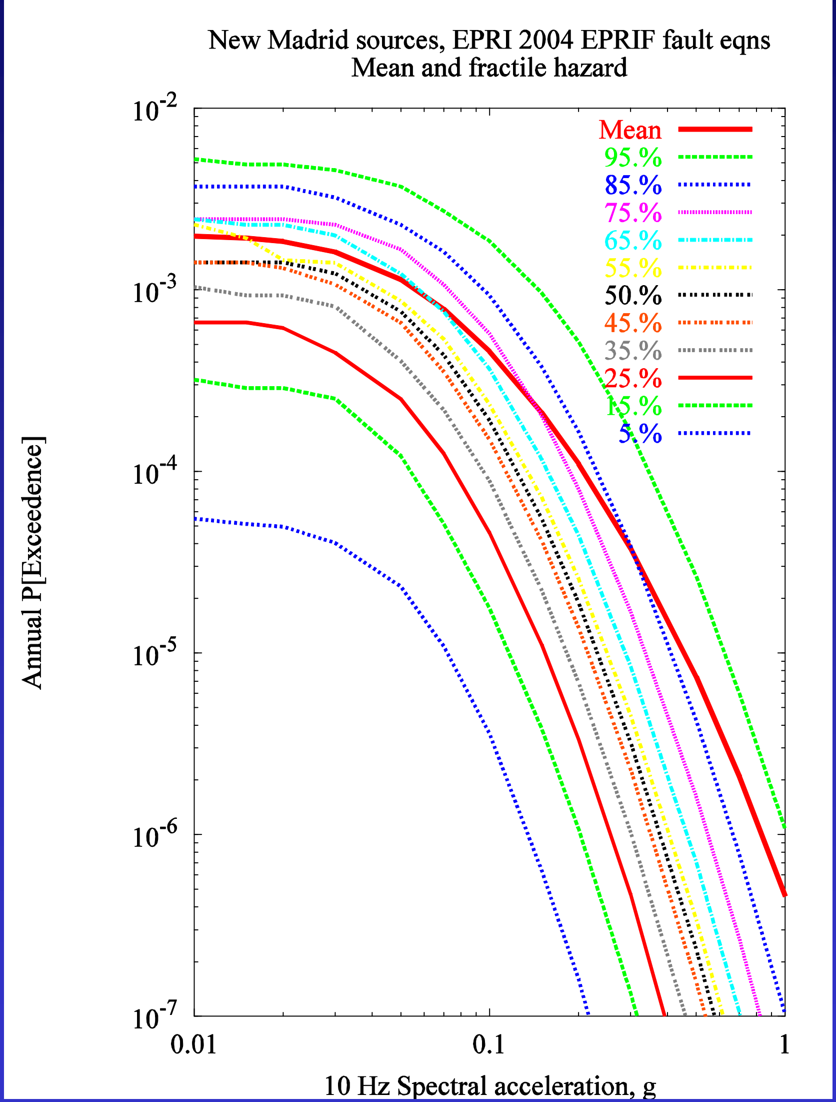
Central IL site, PGA dependence on characteristic **M**



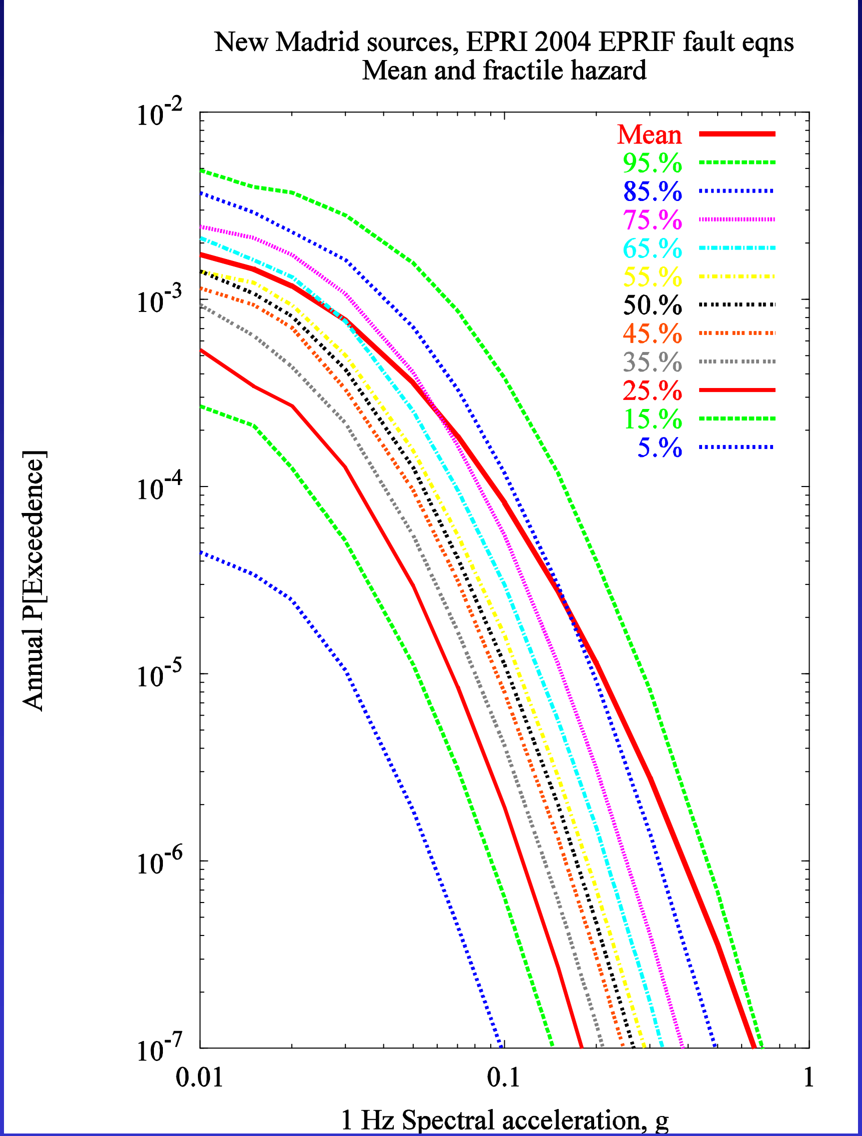
Central IL site, PGA dependence on cluster rupture scenarios



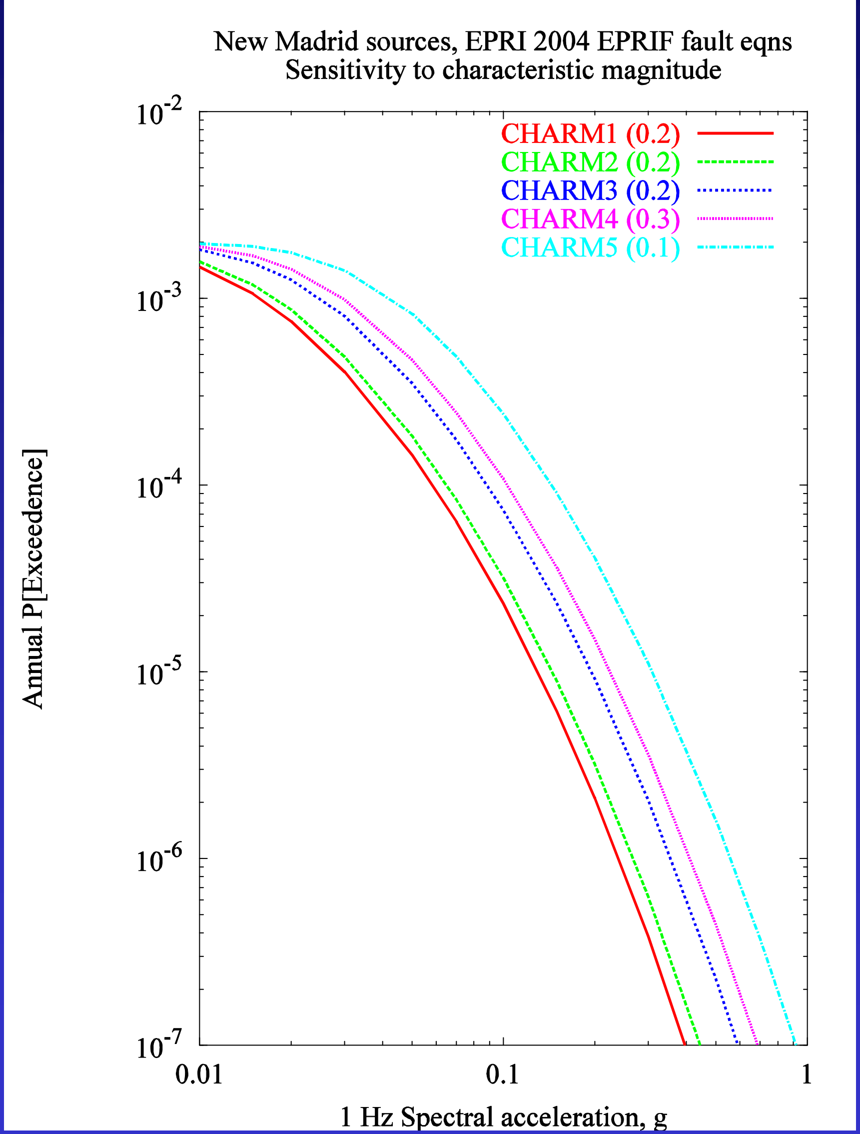
Central IL site, 10 Hz mean and fractile hazard curves



Central IL site, 1 Hz mean and fractile hazard curves

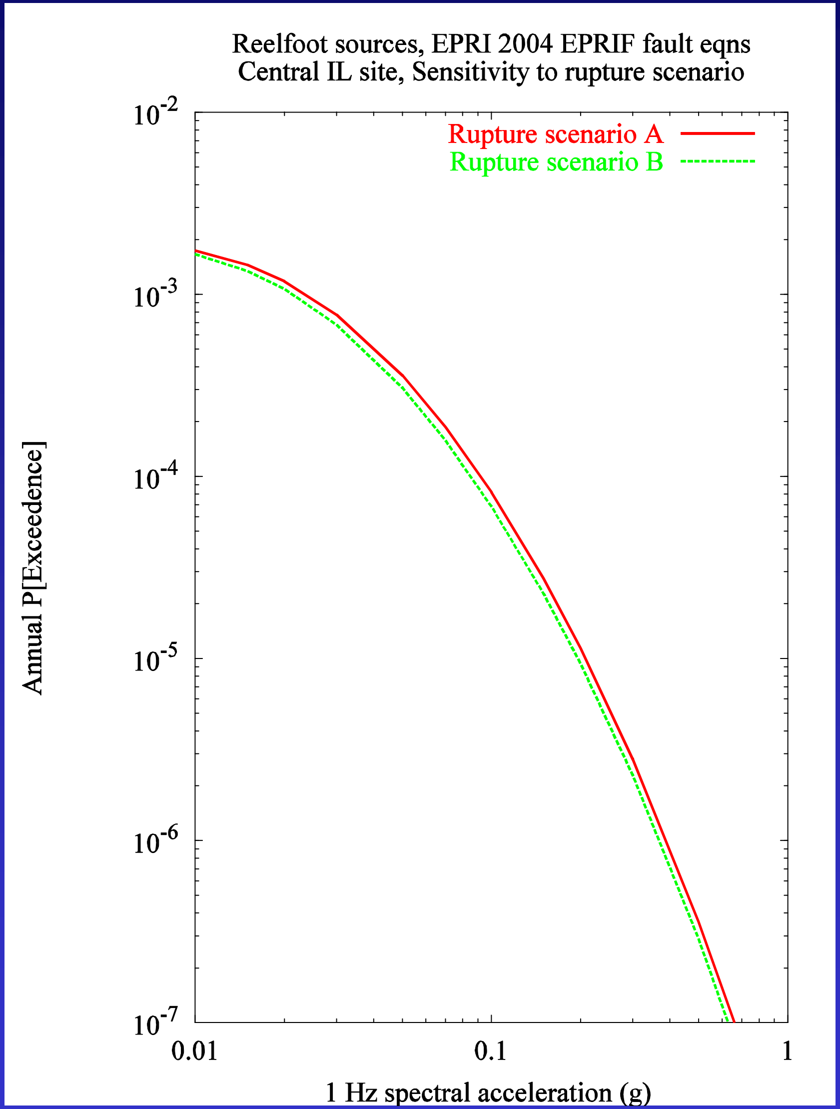


Central IL site, 1 Hz dependence on characteristic **M**



RISK ENGINEERING

1 Hz hazard at Central IL, sensitivity to rupture scenario

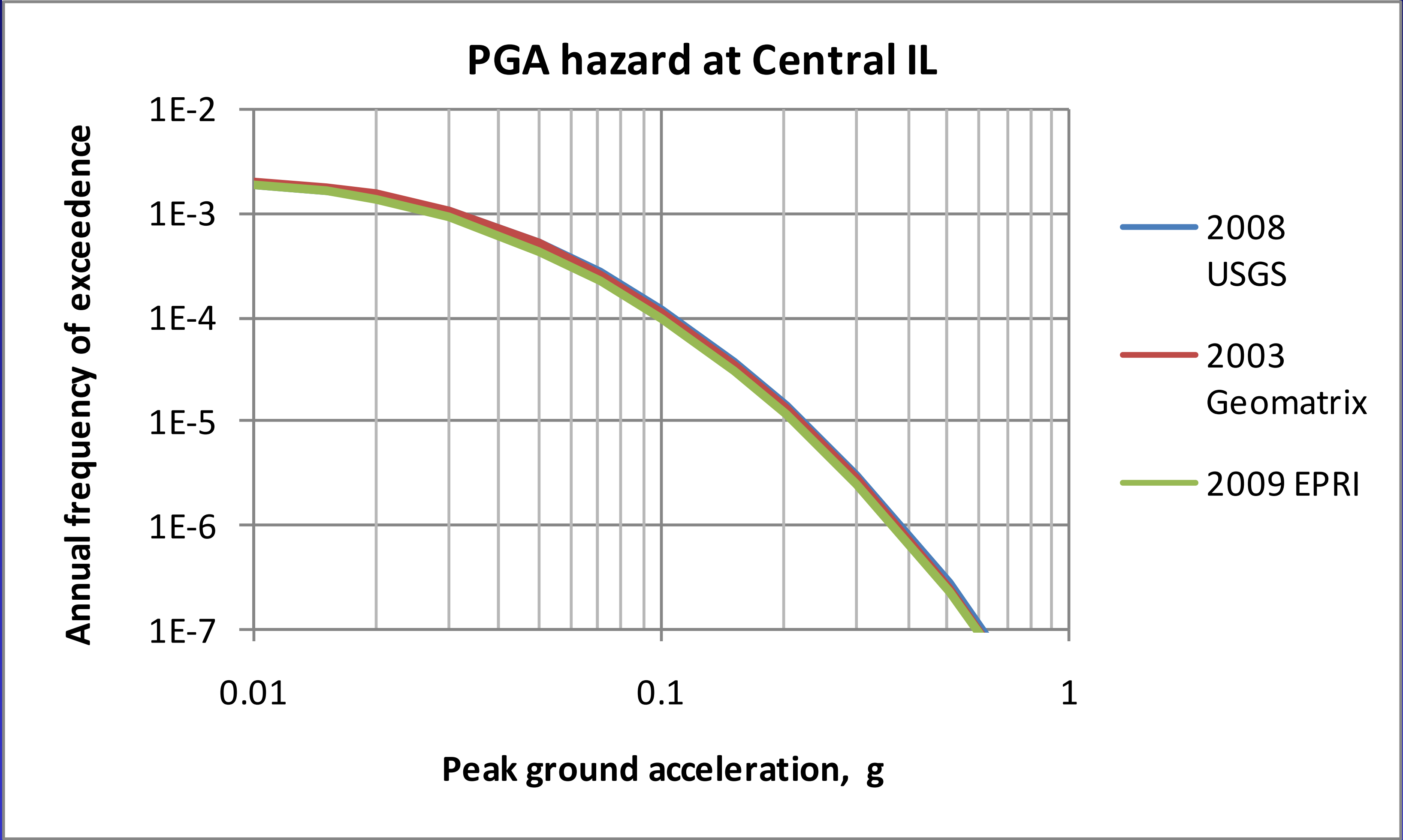


Rupture lengths in NMSZ

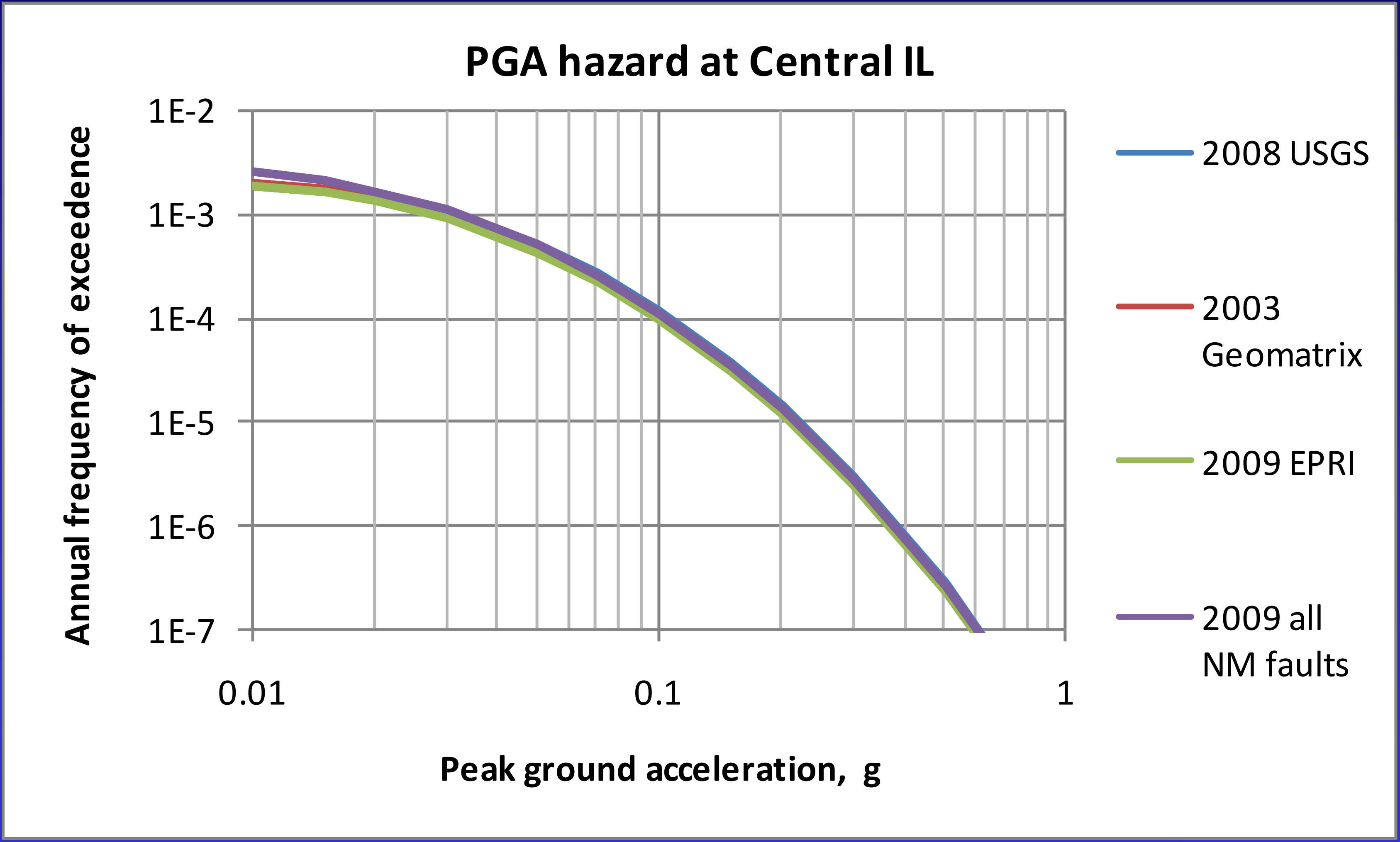
Pink events rupture entire fault

		Approx. length	M 7		M 7.5		M 8	
			EUS RL	WUS RL	EUS RL	WUS RL	EUS RL	WUS RL
NMN	short	50	22	38	68	108	215	308
	long	90	22	38	68	108	215	308
NMS	short	110	22	38	68	108	215	308
	long	130	22	38	68	108	215	308
RFT	short	50	21	27	48	76	152	218
	long	80	21	27	48	76	152	218

PGA hazard from 3 NMSZ models (EPRI 2004 GM)

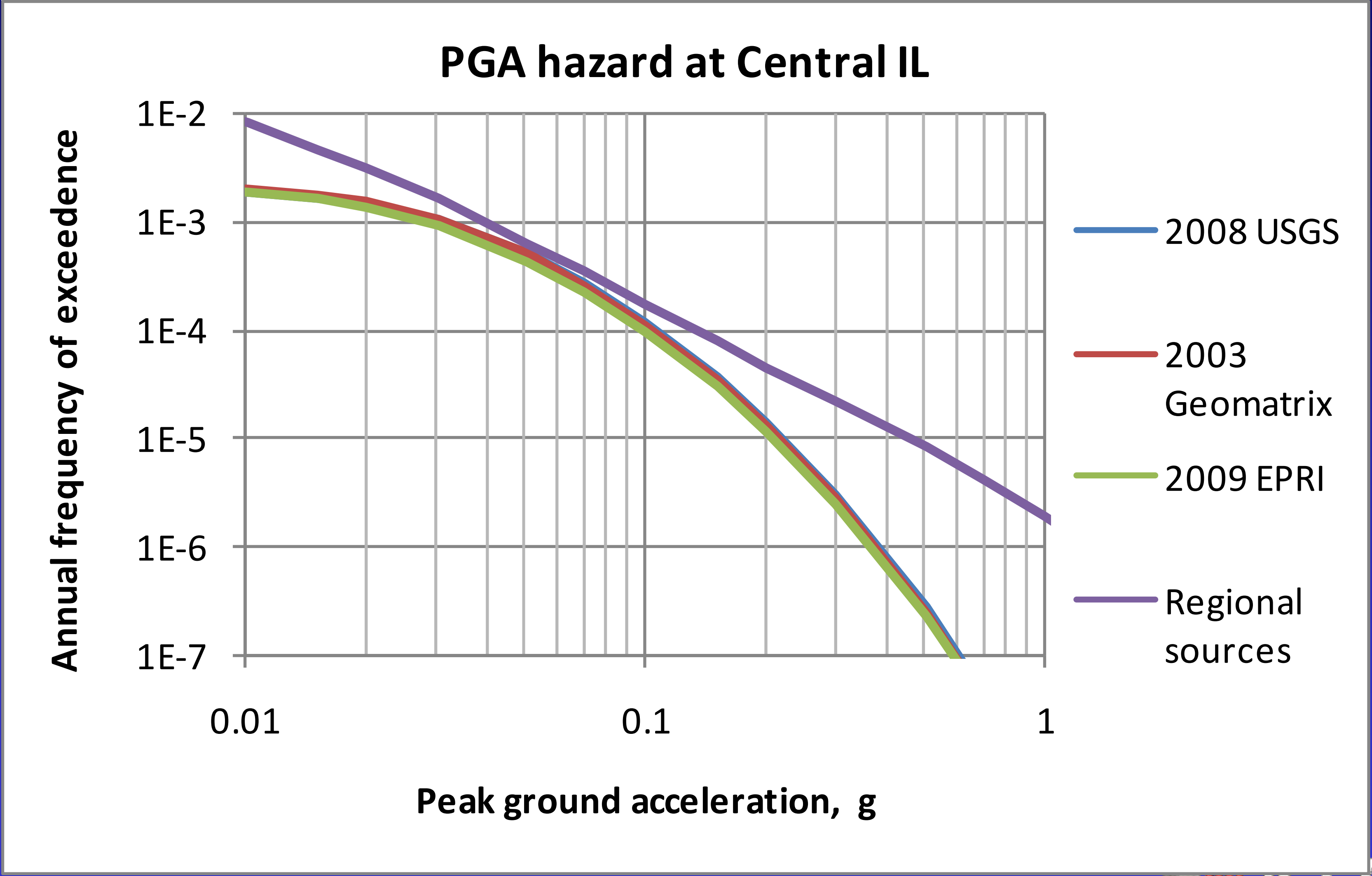


PGA hazard from 4 NMSZ models (EPRI 2004 GM)



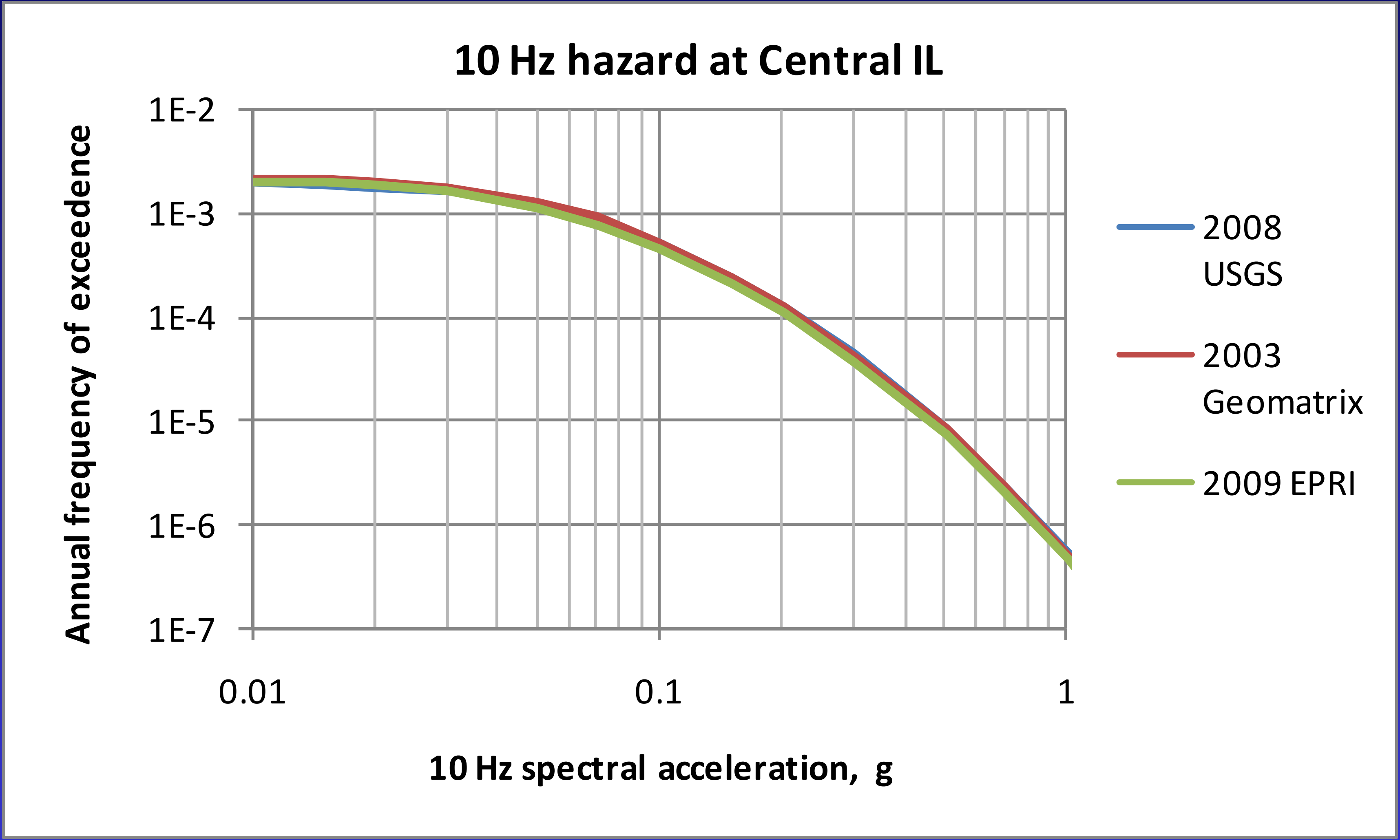
RISK ENGINEERING

PGA hazard from 3 NMSZ models (EPRI 2004 GM) and regional sources

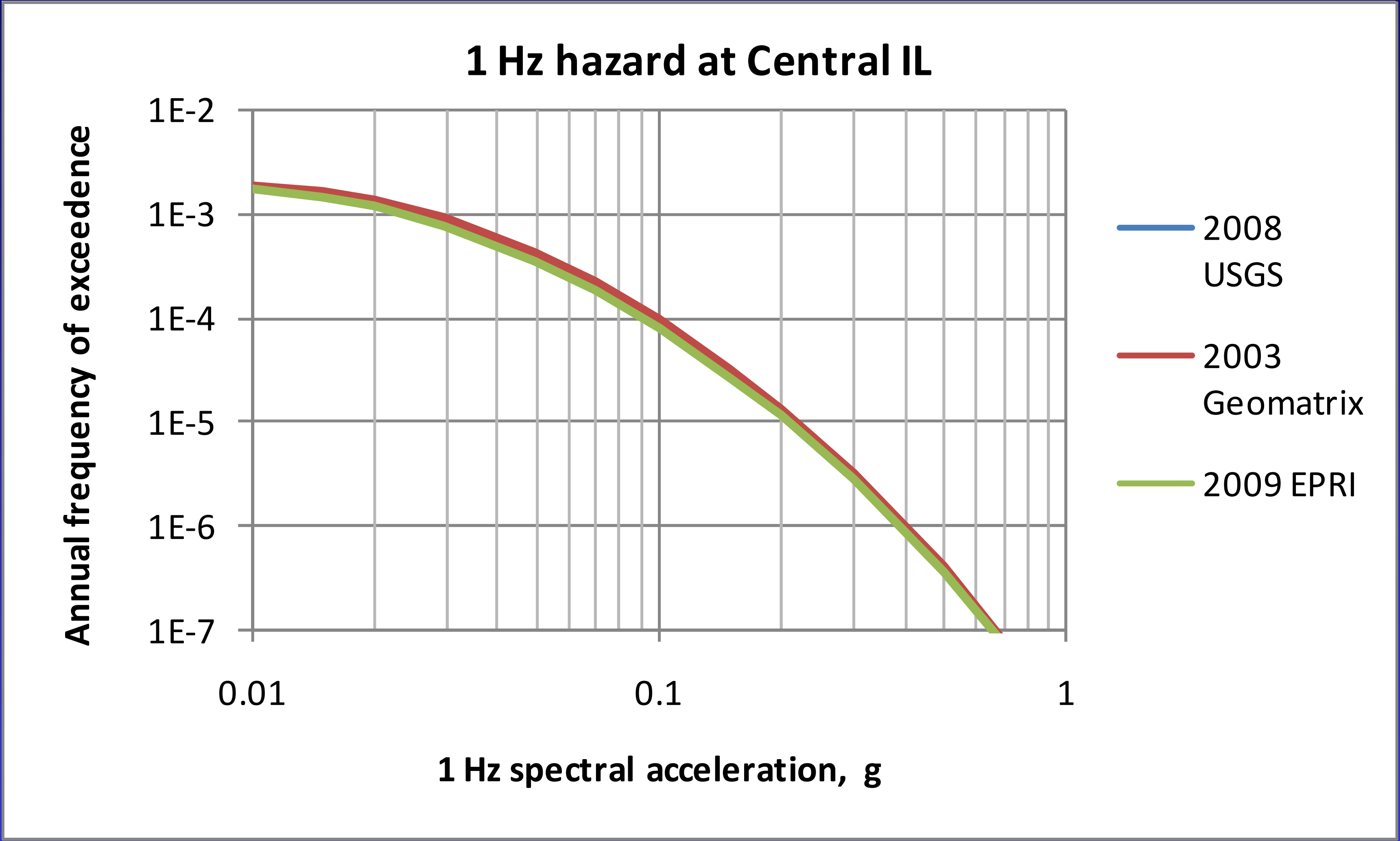


RISK ENGINEERING

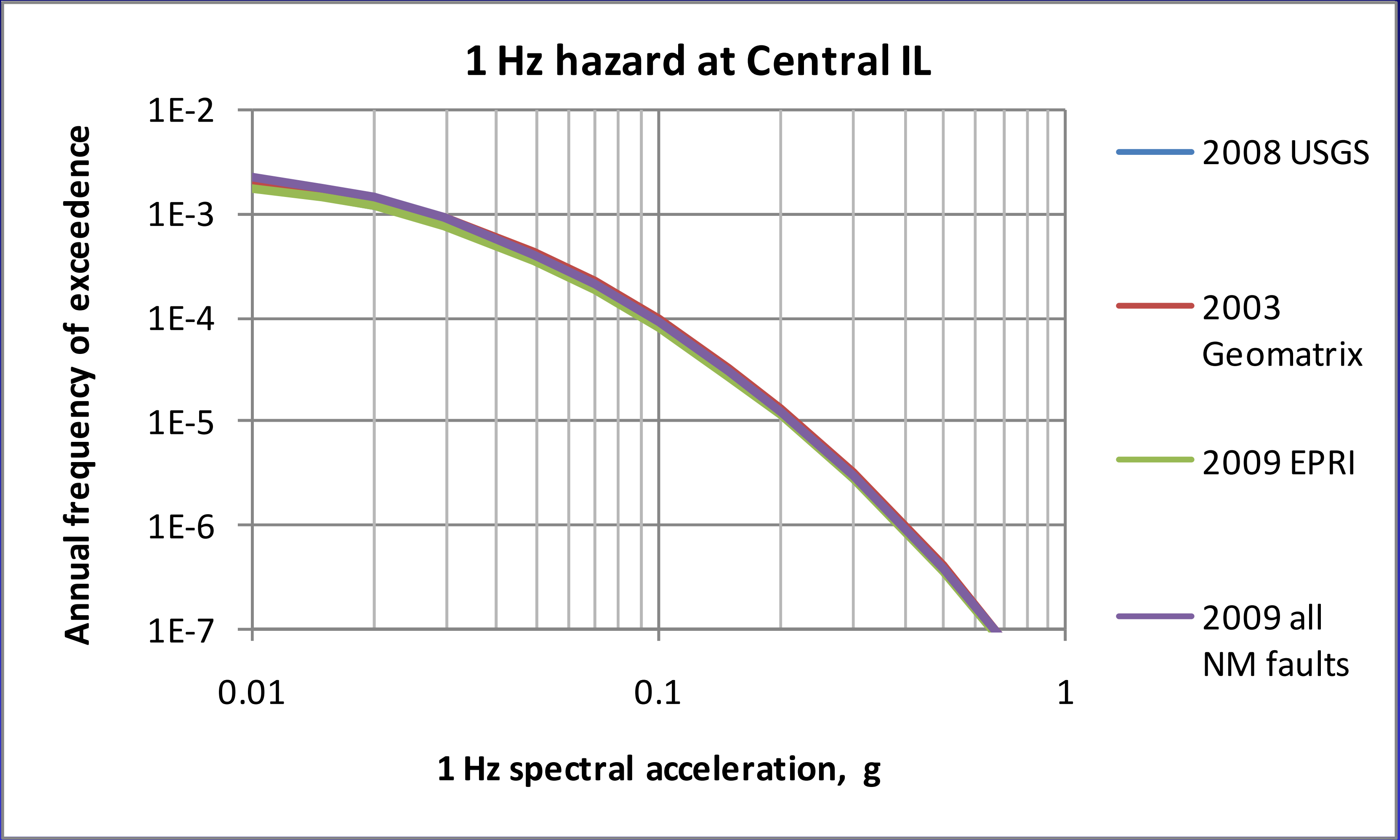
10 Hz hazard from 3 NMSZ models (EPRI 2004 GM)



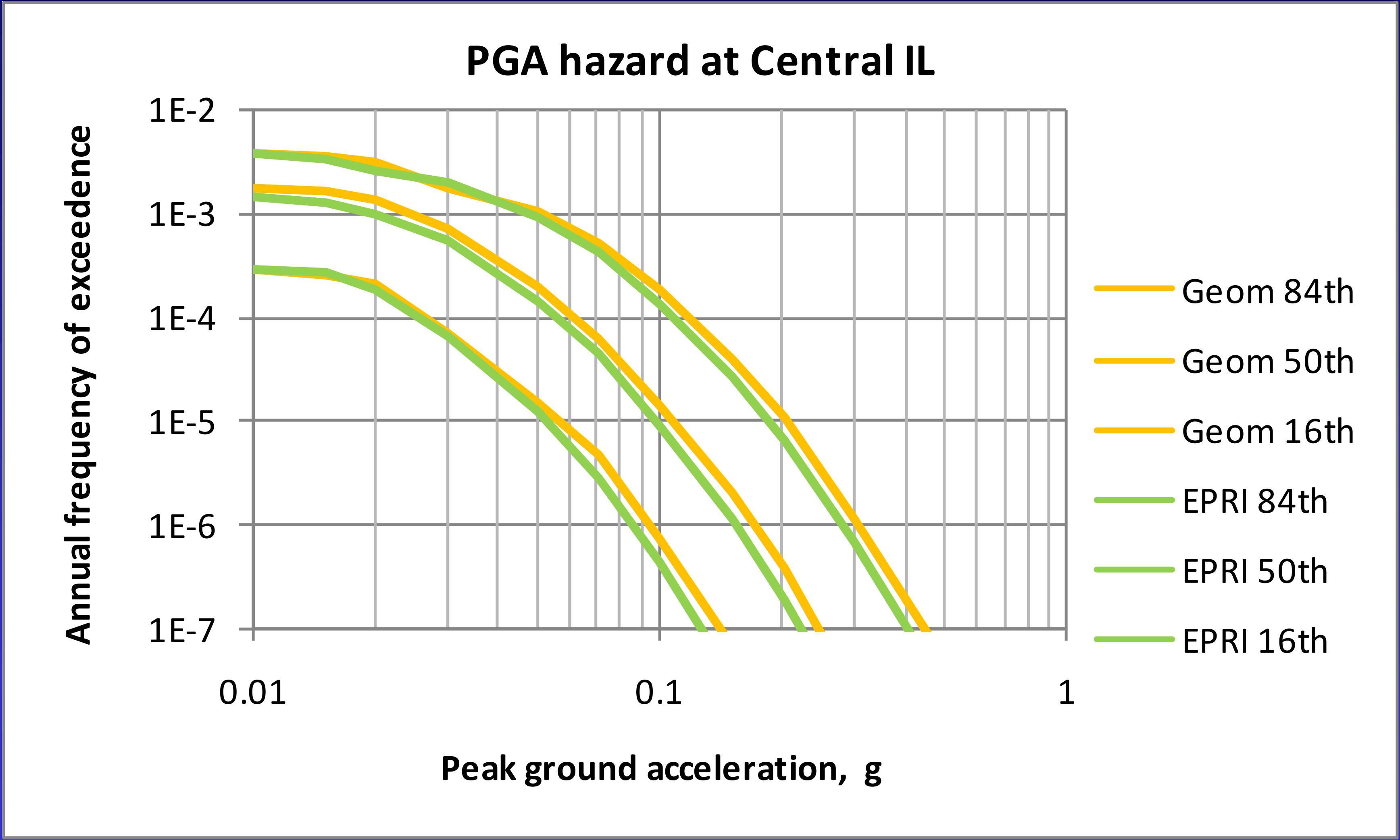
1 Hz hazard from 3 NMSZ models (EPRI 2004 GM)



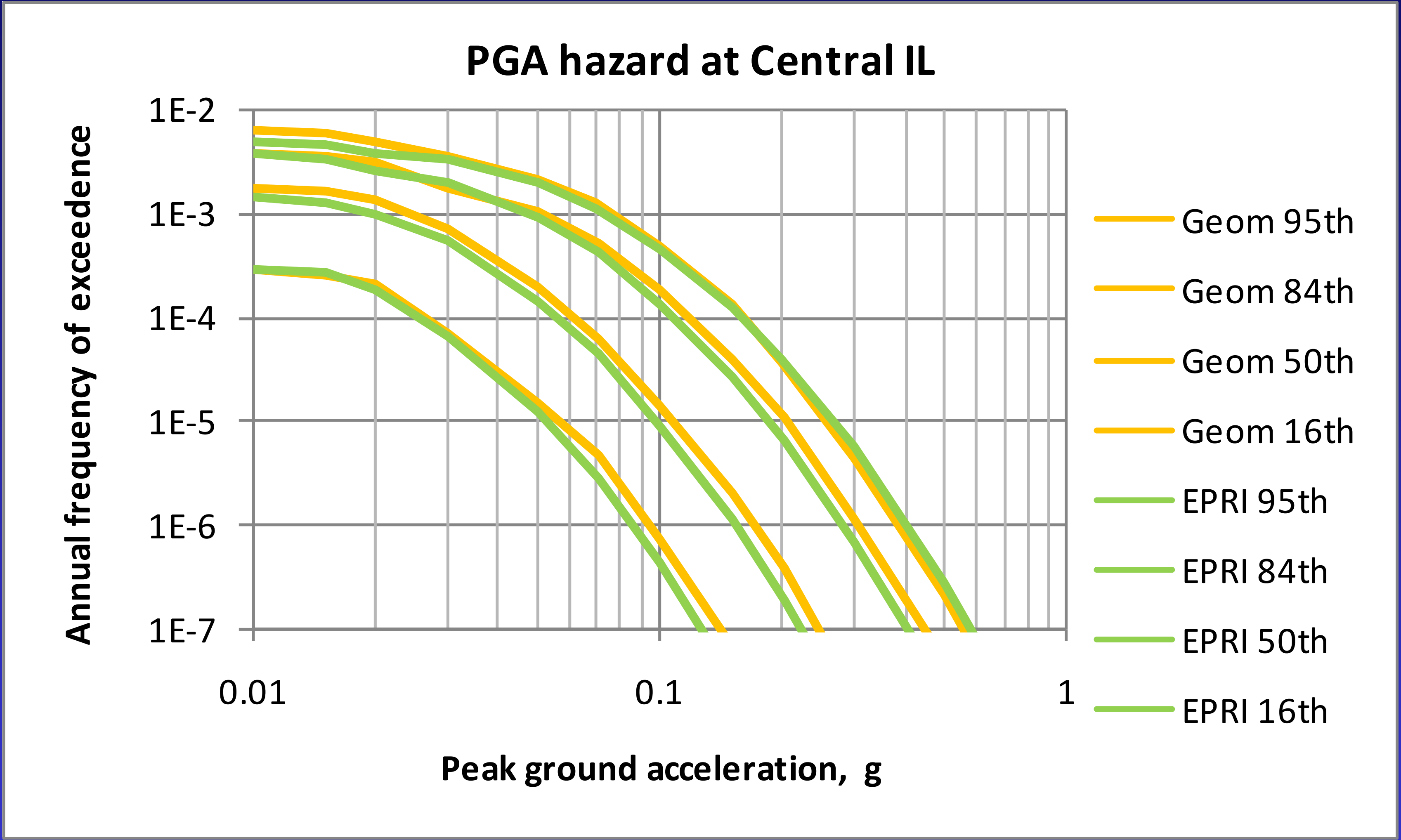
1 Hz hazard from 4 NMSZ models (EPRI 2004 GM)



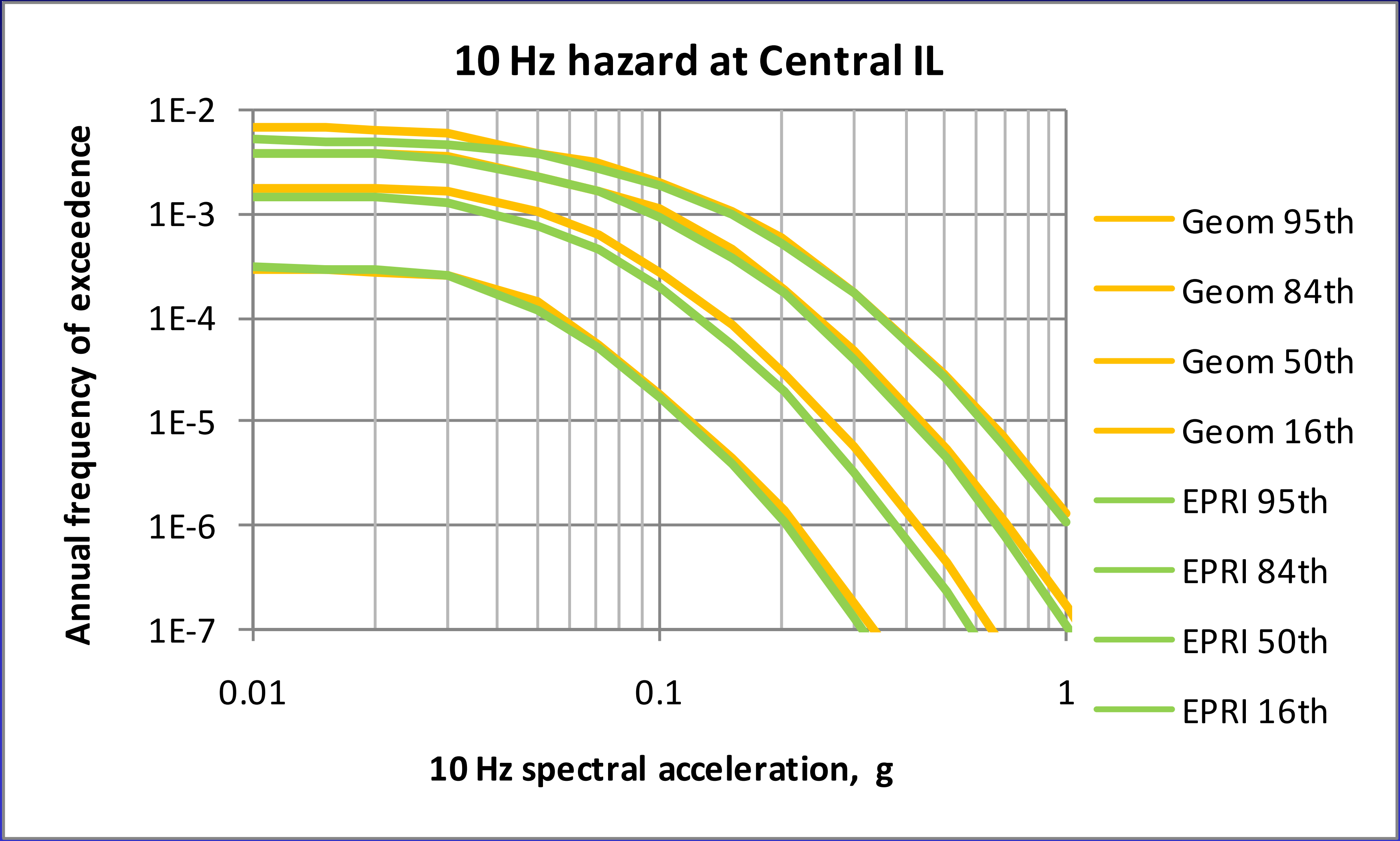
PGA fractile hazard curves, Central IL



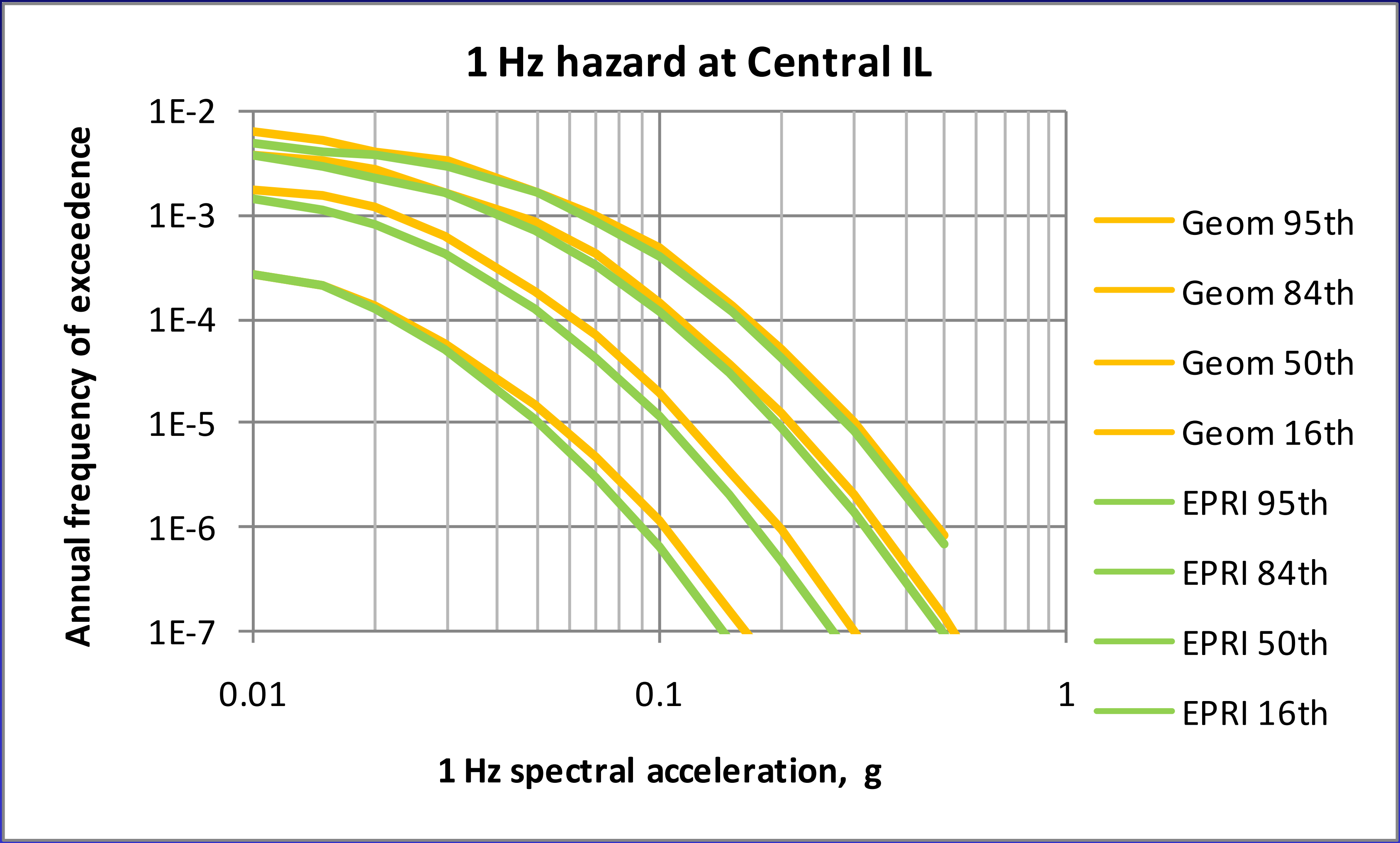
PGA fractile hazard curves, Central IL



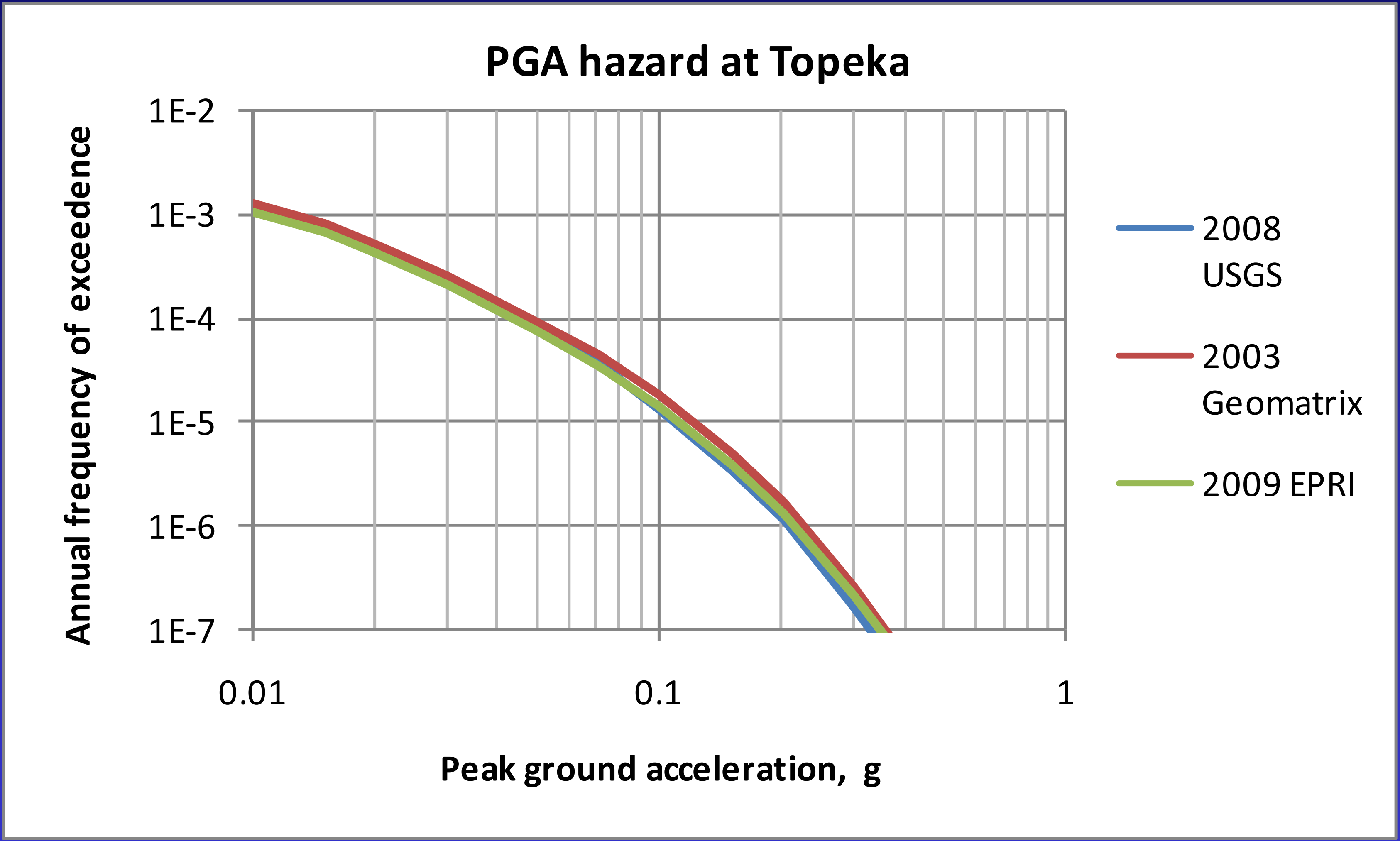
10 Hz fractile hazard curves, Central IL



1 Hz fractile hazard curves, Central IL

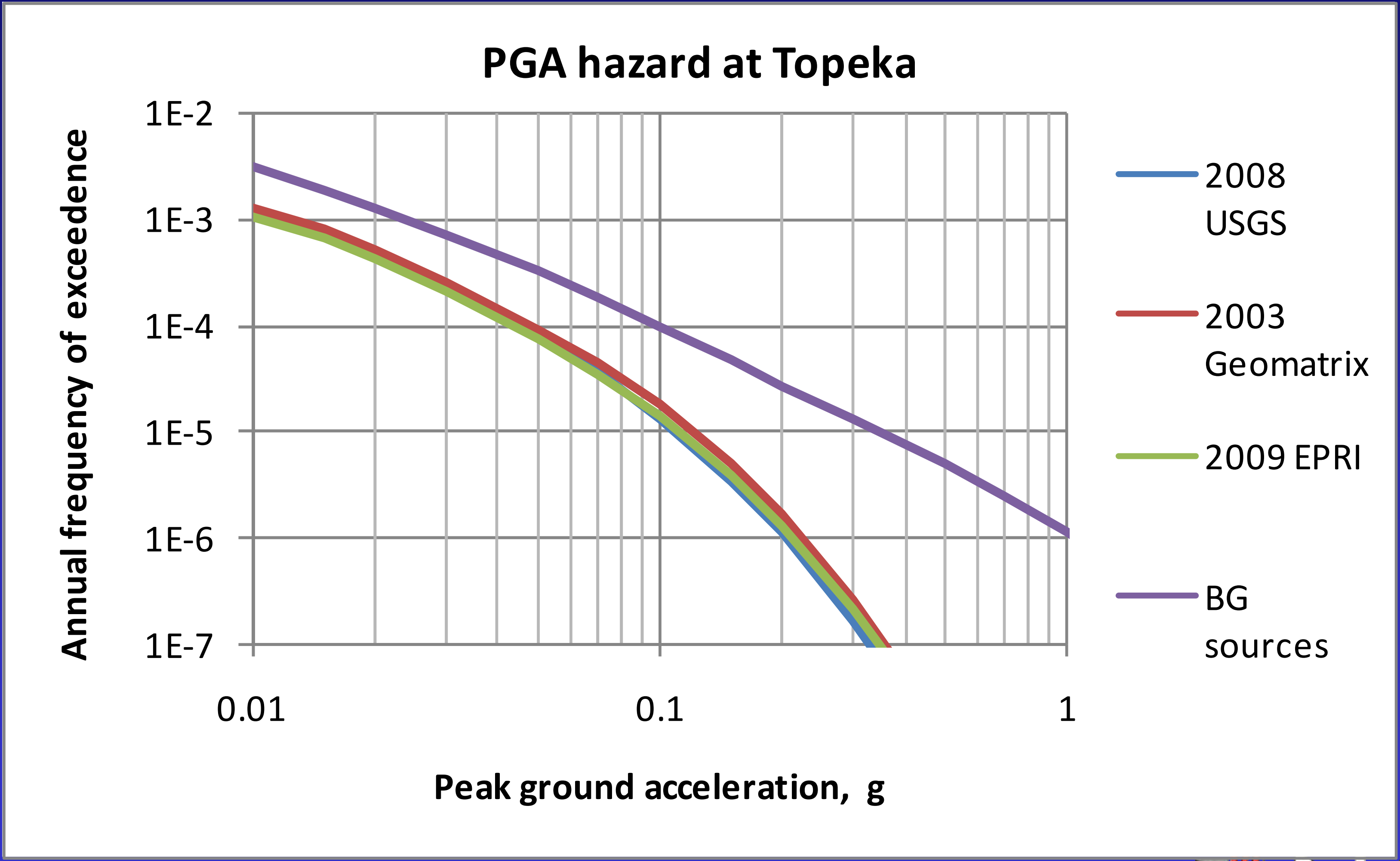


PGA hazard from 3 NMSZ models (EPRI 2004 GM)

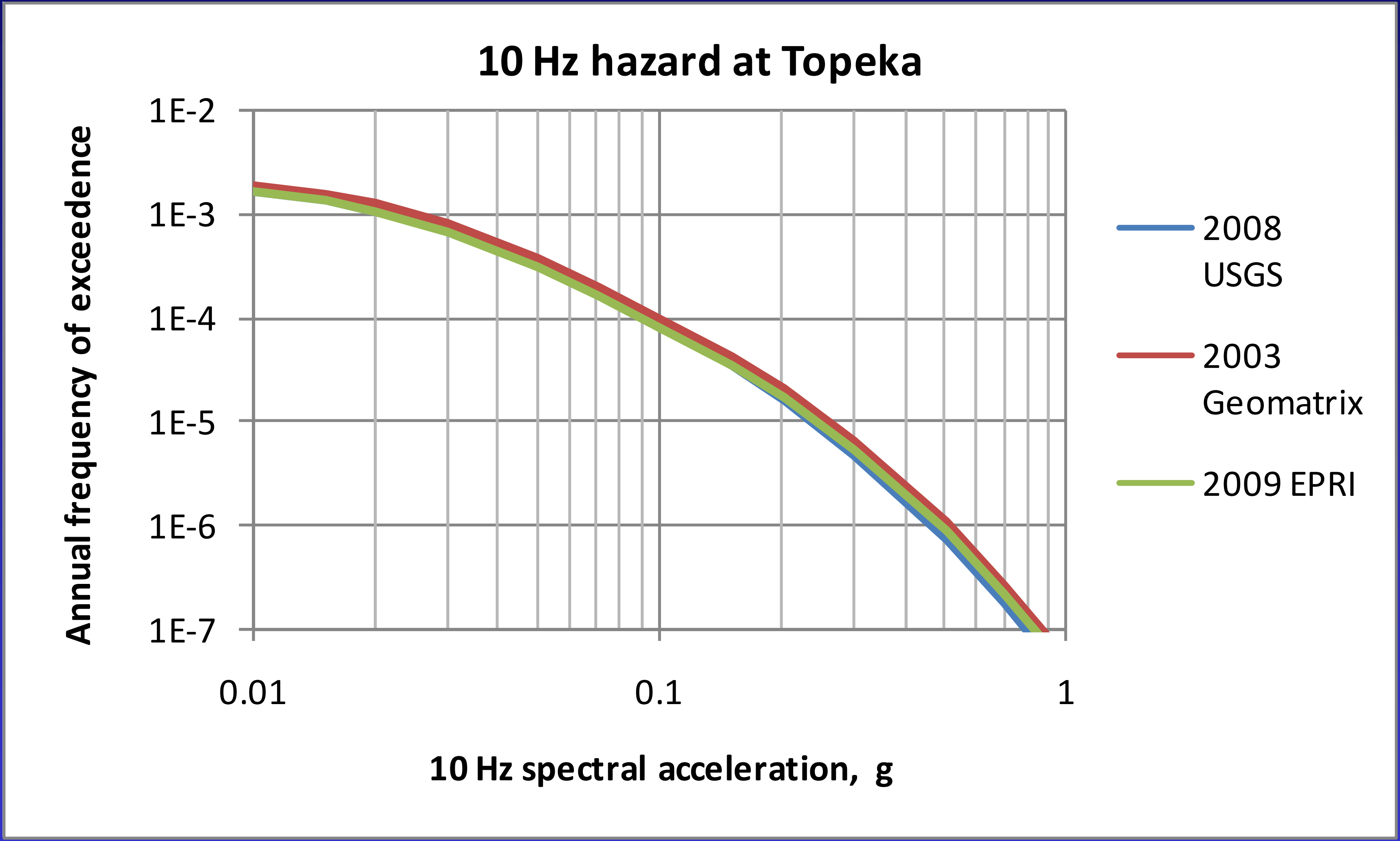


RISK ENGINEERING

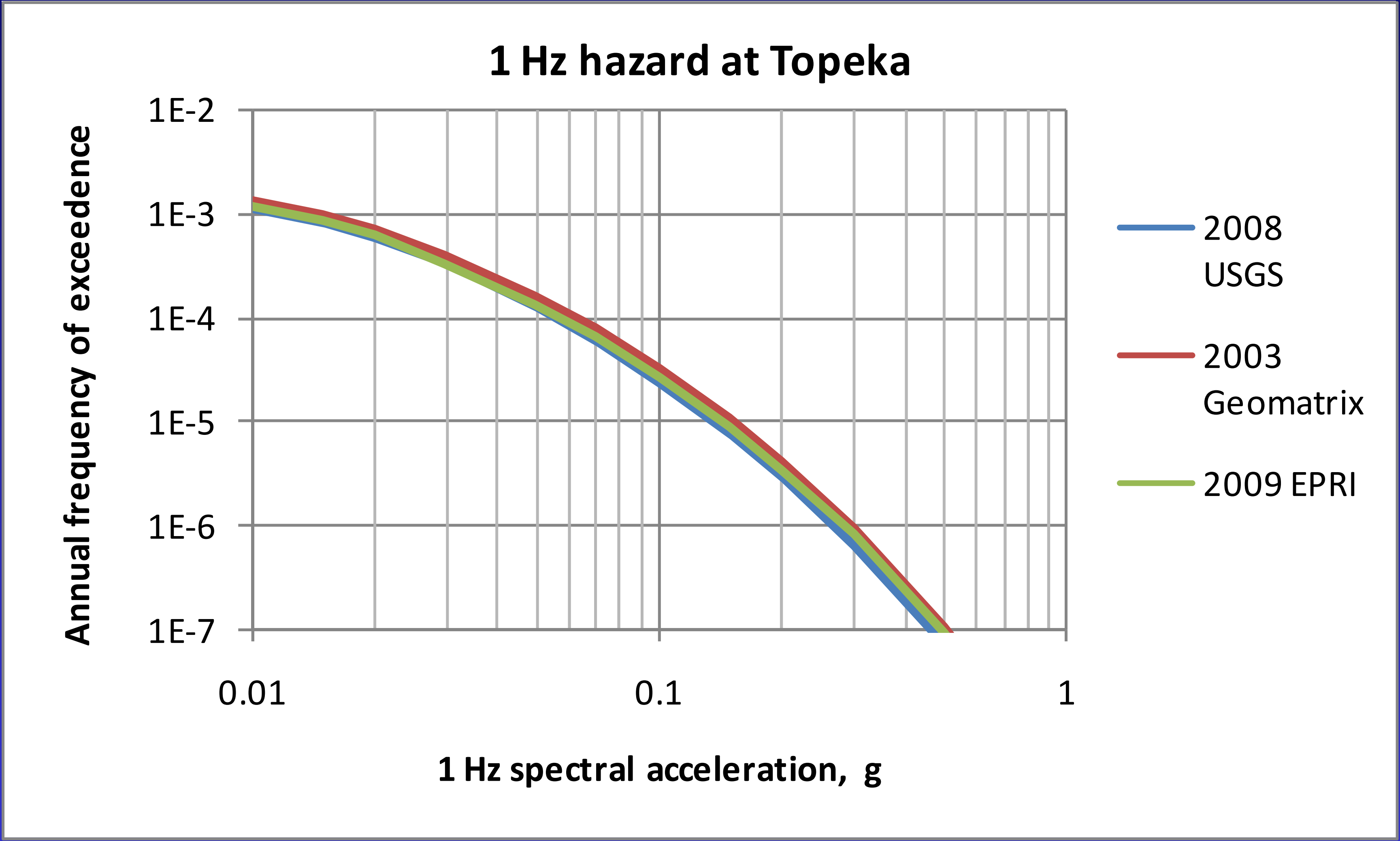
PGA hazard from 3 NMSZ models (EPRI 2004 GM) and local regional sources



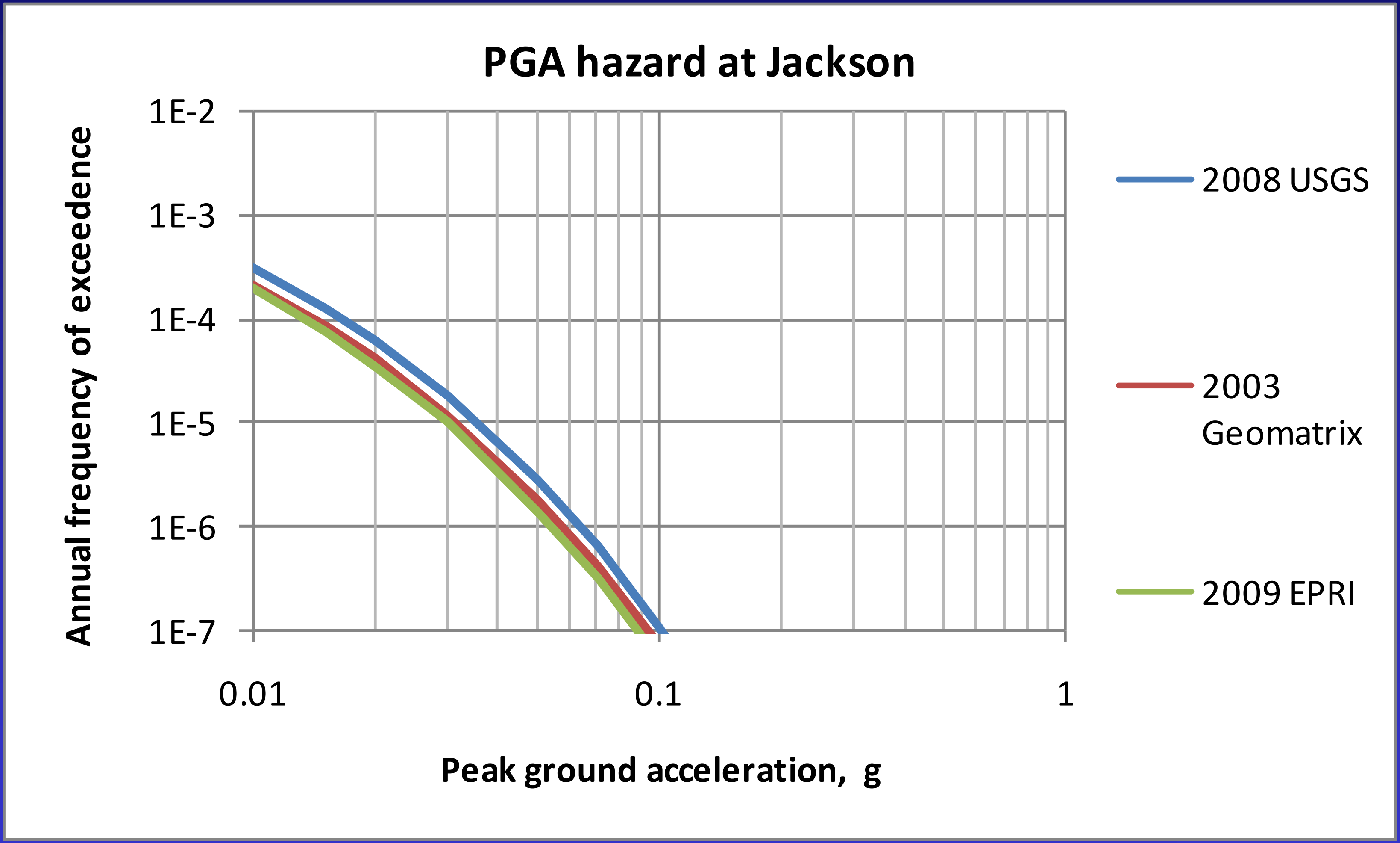
10 Hz hazard from 3 NMSZ models (EPRI 2004 GM)



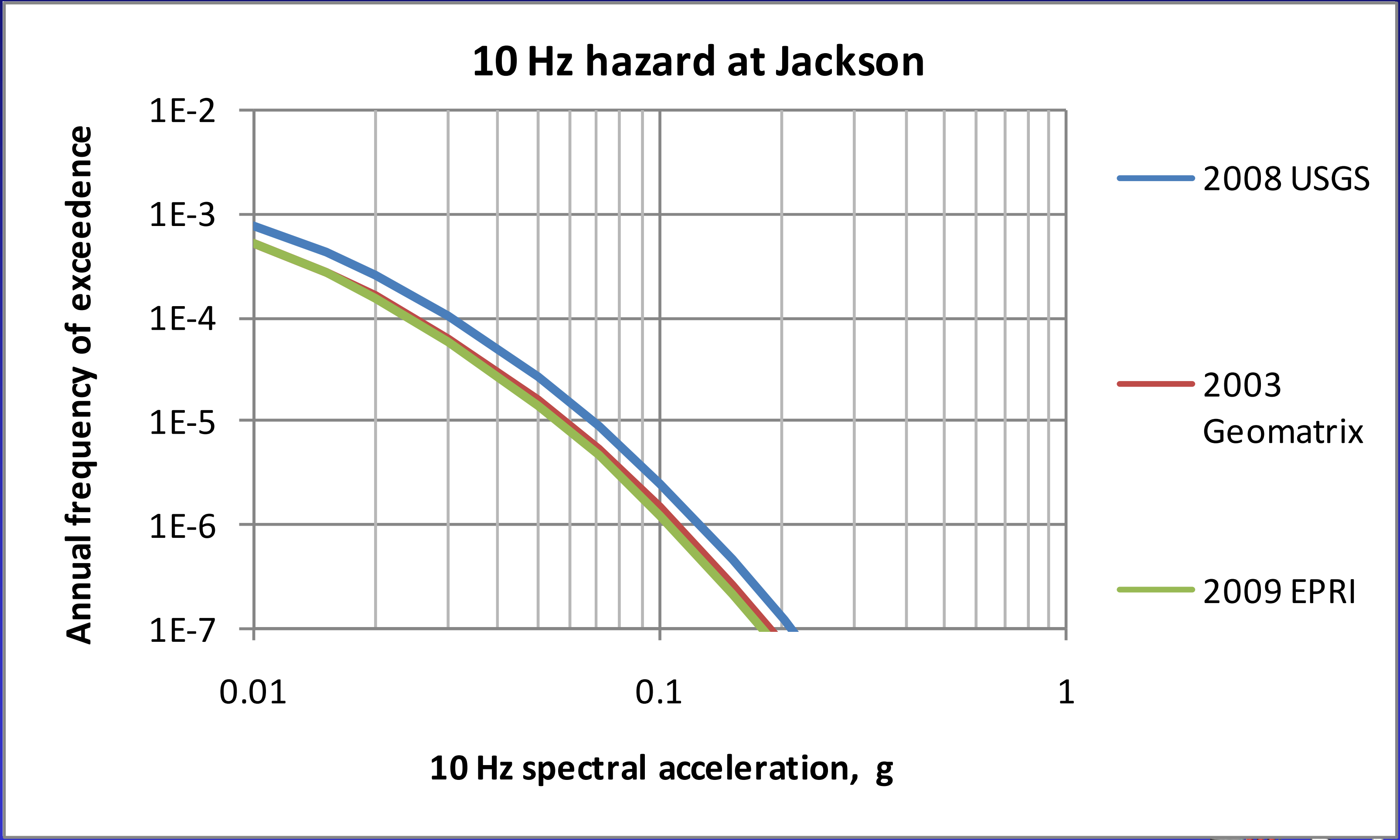
PGA hazard from 3 NMSZ models (EPRI 2004 GM)



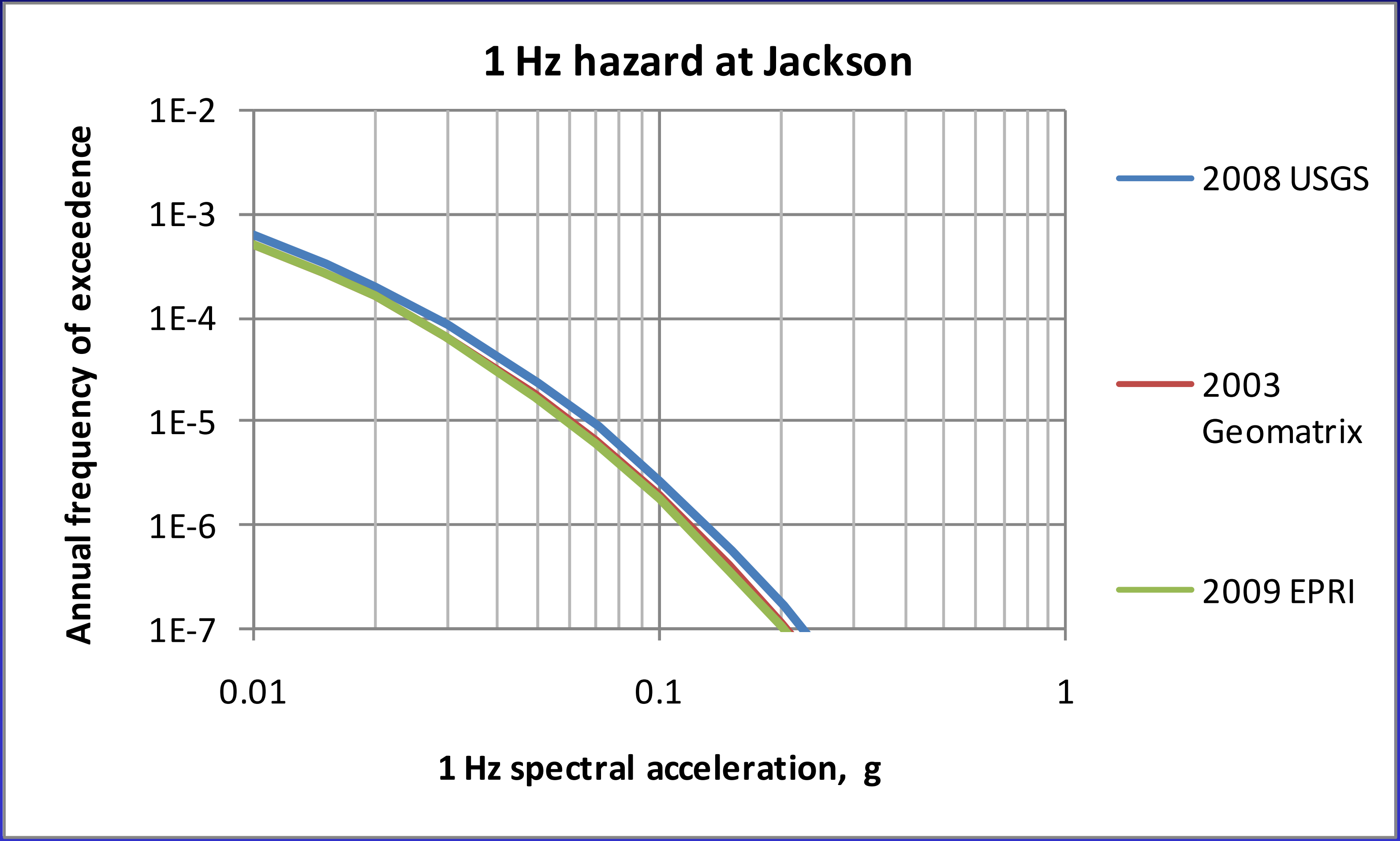
PGA hazard at Jackson from 3 NMSZ models (EPRI 2004 GM)



10 Hz hazard at Jackson from 3 NMSZ models (EPRI 2004 GM)



1 Hz hazard at Jackson from 3 NMSZ models (EPRI 2004 GM)



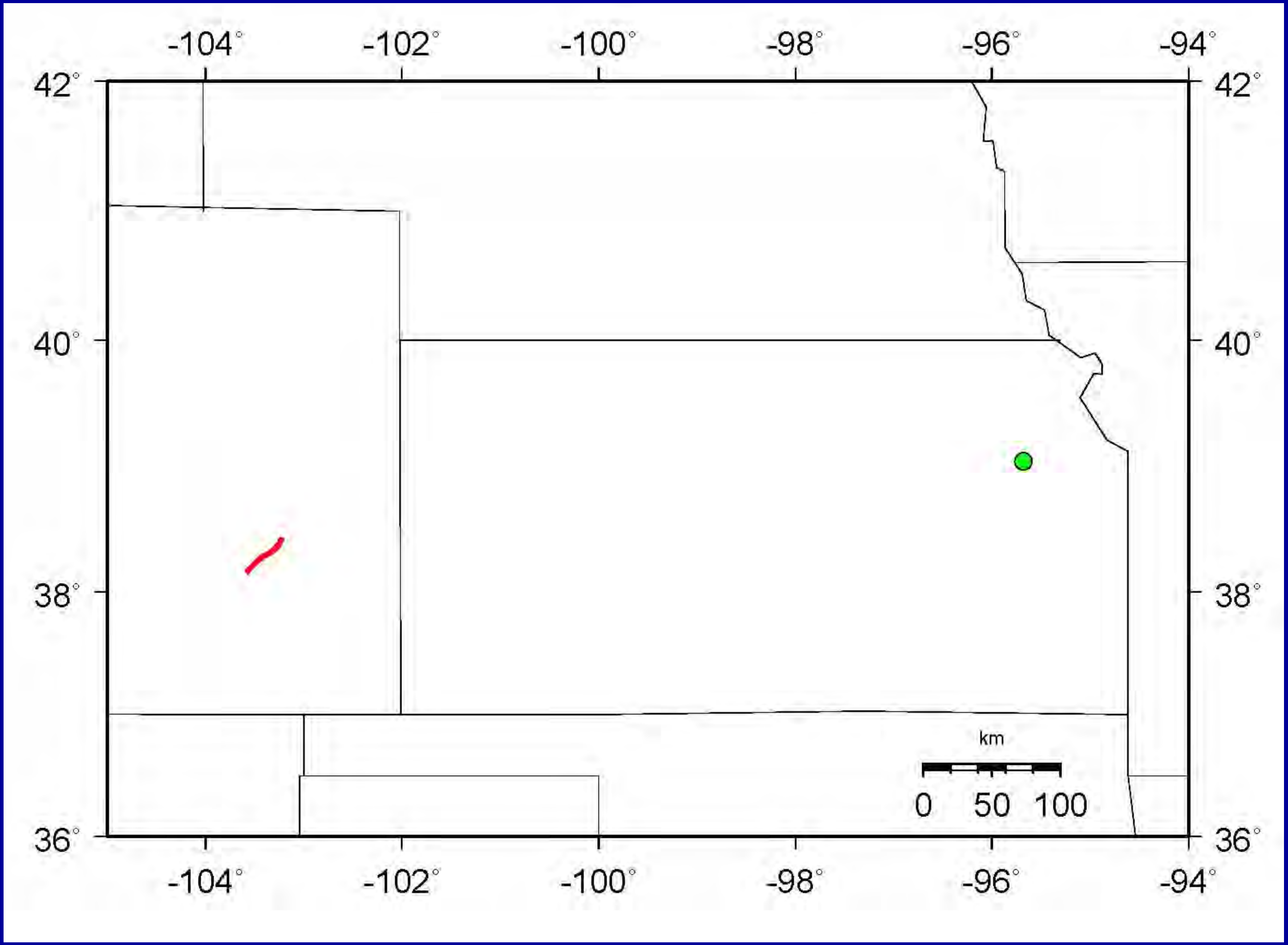
RLME Seismic Source Sensitivity Studies

Allison Shumway
William Lettis & Associates, Inc.
Workshop #3
August 25-26, 2009

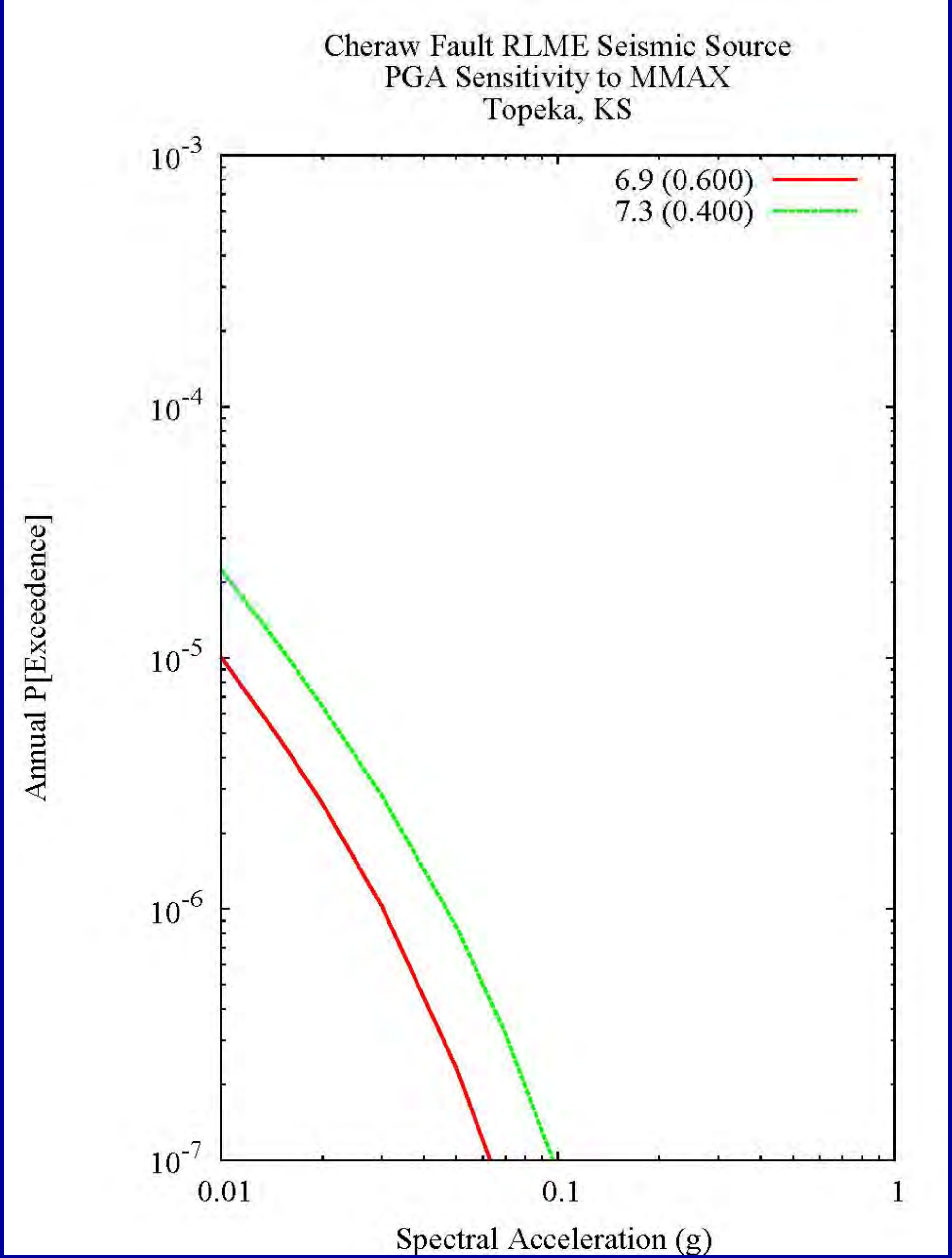
Cheraw RLME Seismic Source

- Sensitivity studies: geometry, rate, and Mmax
- Source: Cheraw Fault
- Frequencies: 1 Hz, 10 Hz, and PGA
- Site : Topeka, KS

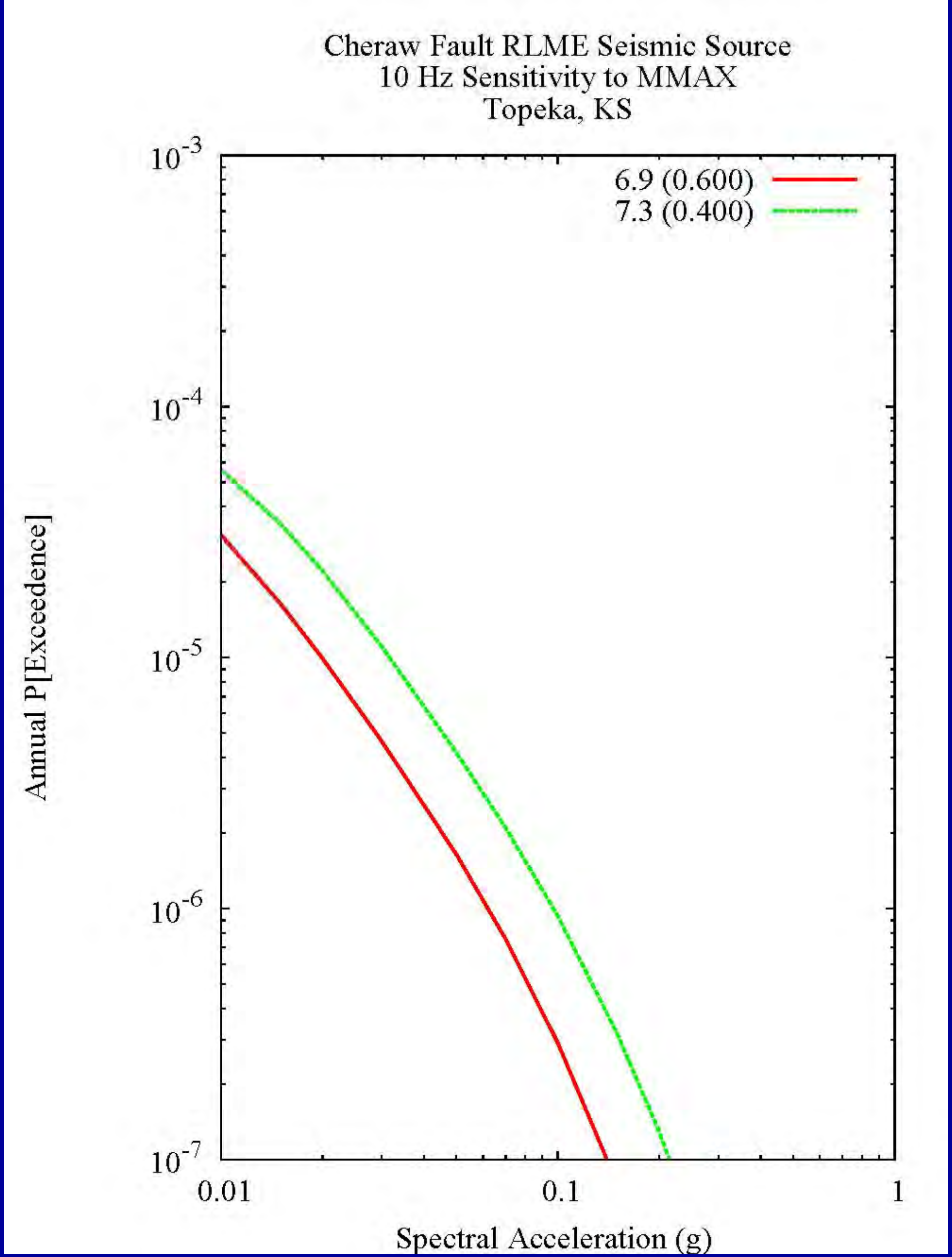
Cheraw RLME Seismic Source and Site Location: Topeka, KS



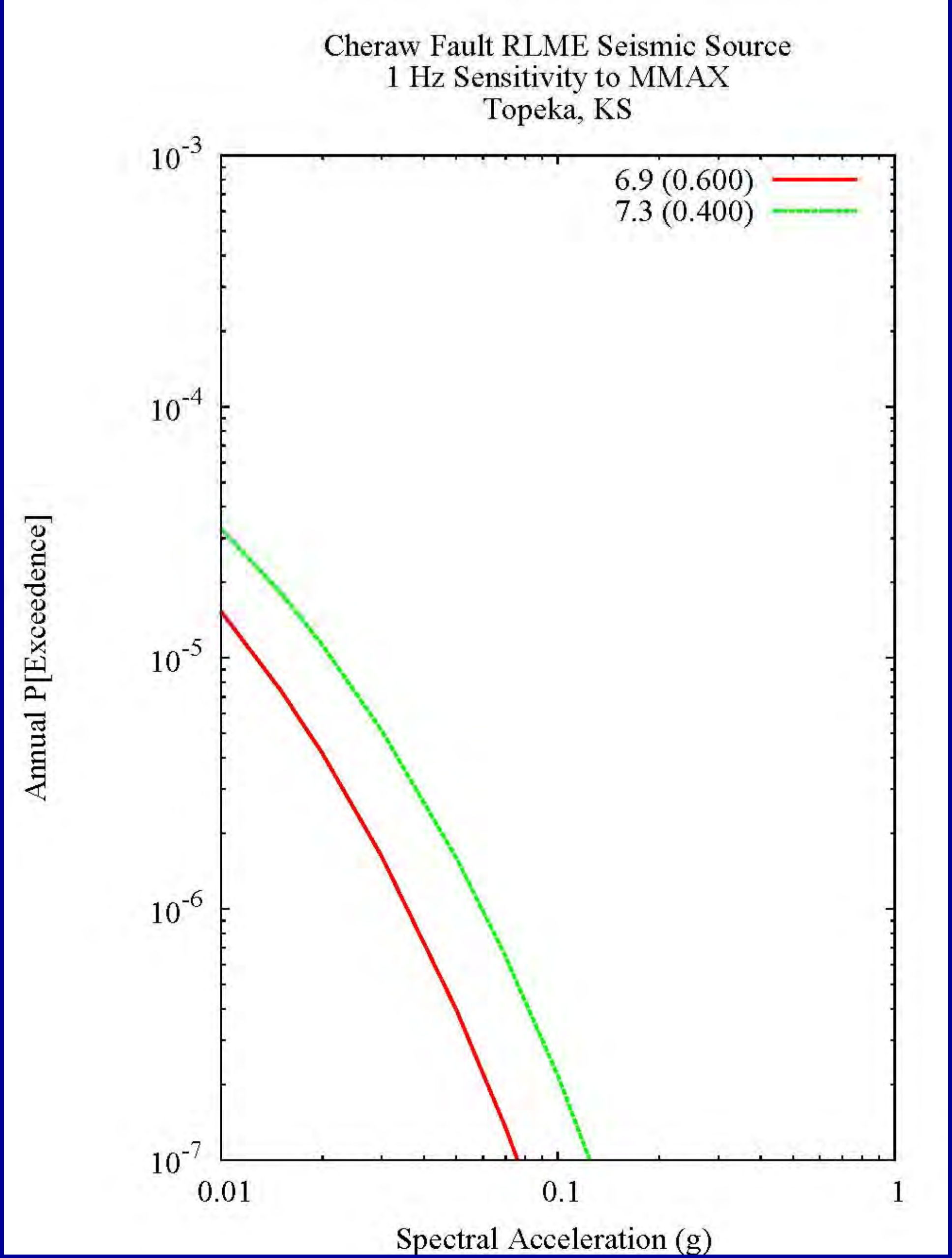
Results for Topeka, KS : PGA, Mmax



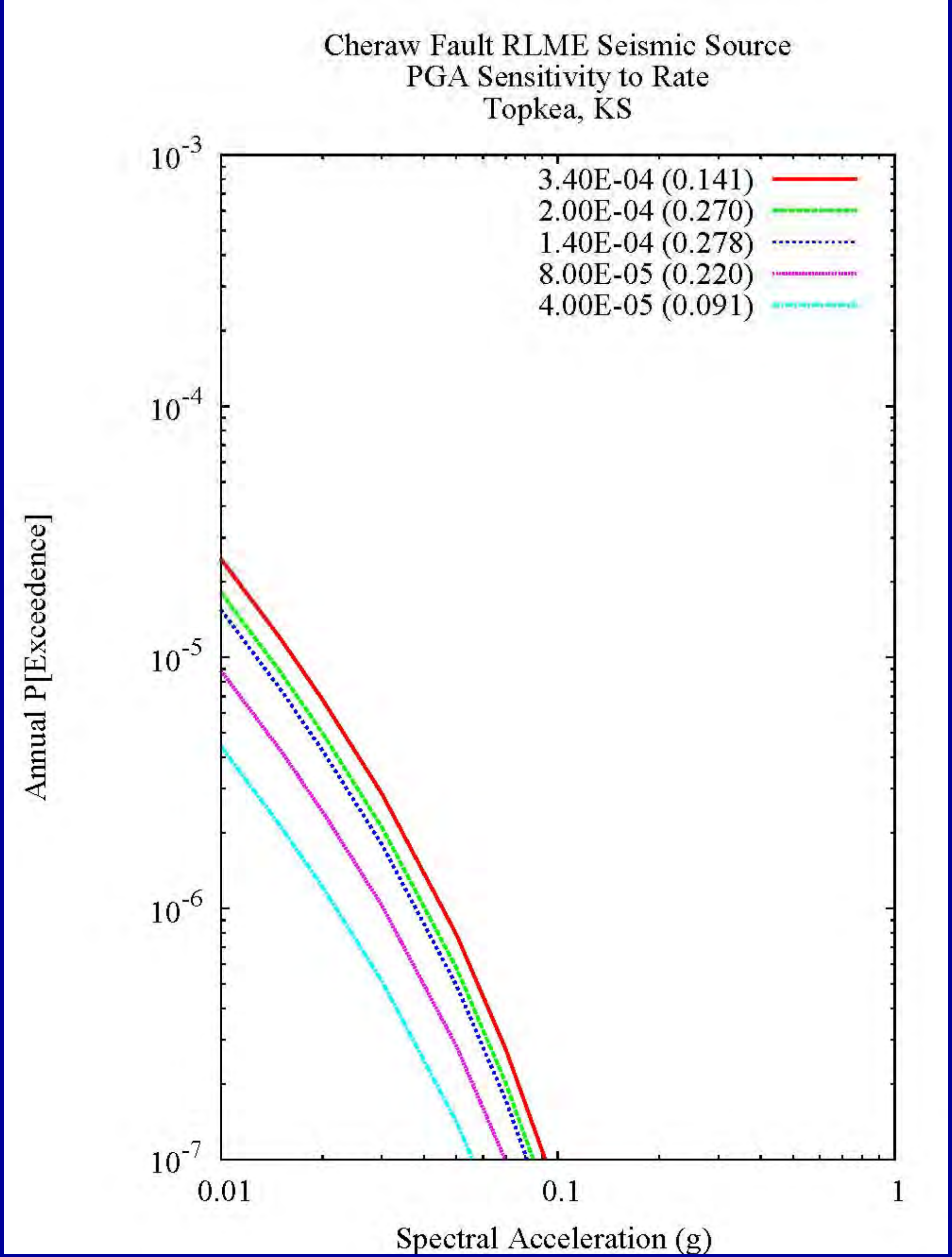
Results for Topeka, KS : 10 Hz, Mmax



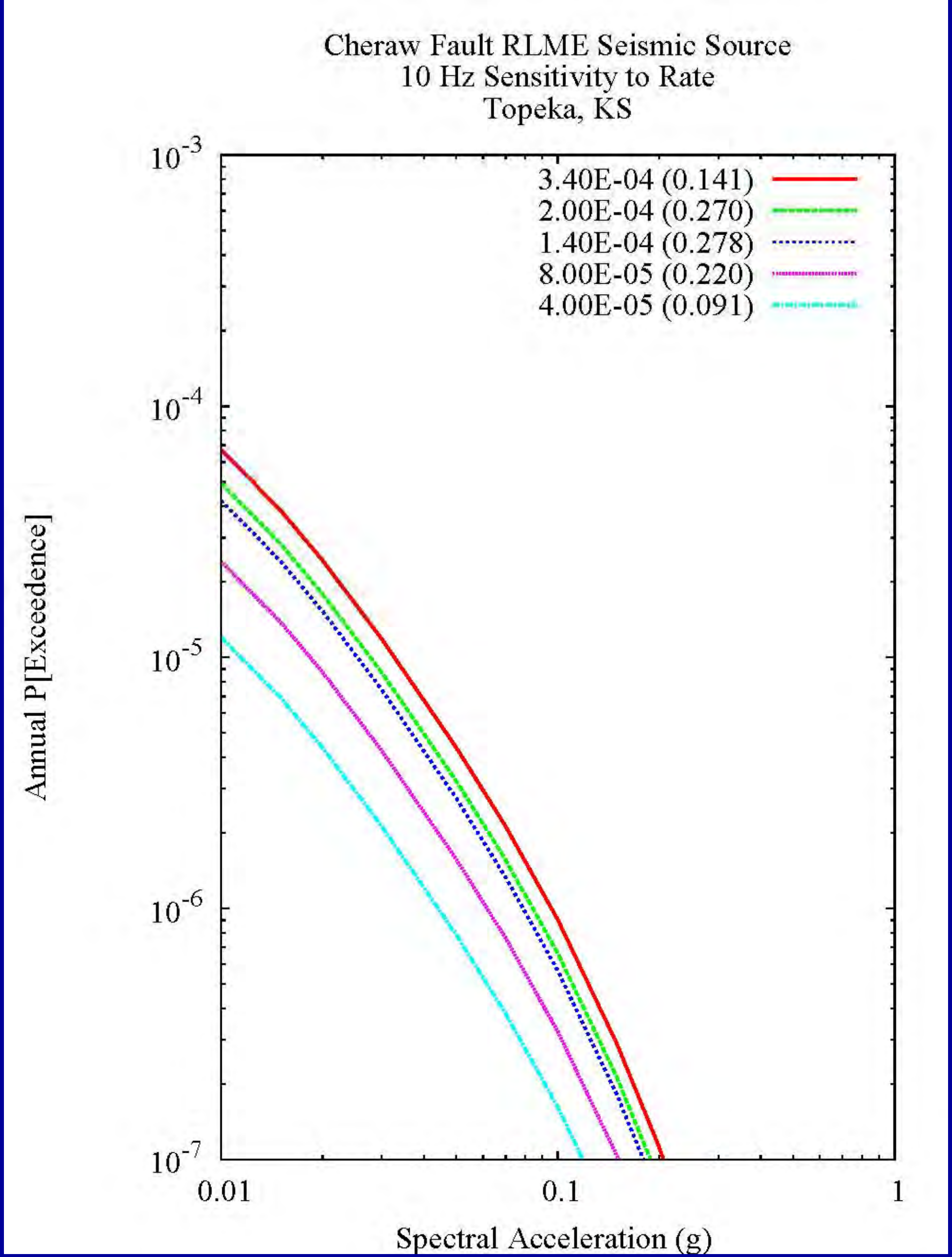
Results for Topeka, KS : 1 Hz, Mmax



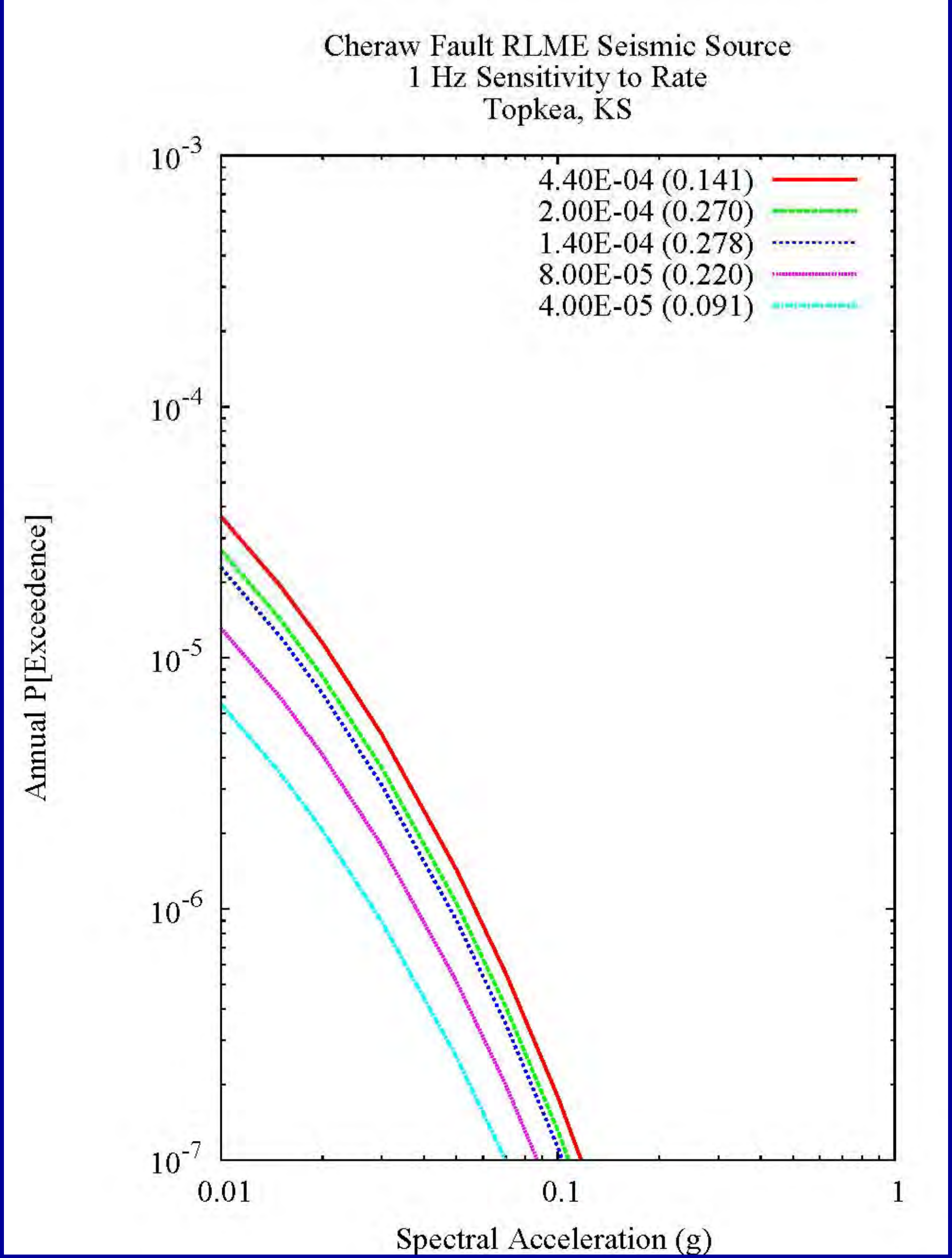
Results for Topeka, KS : PGA, Rate



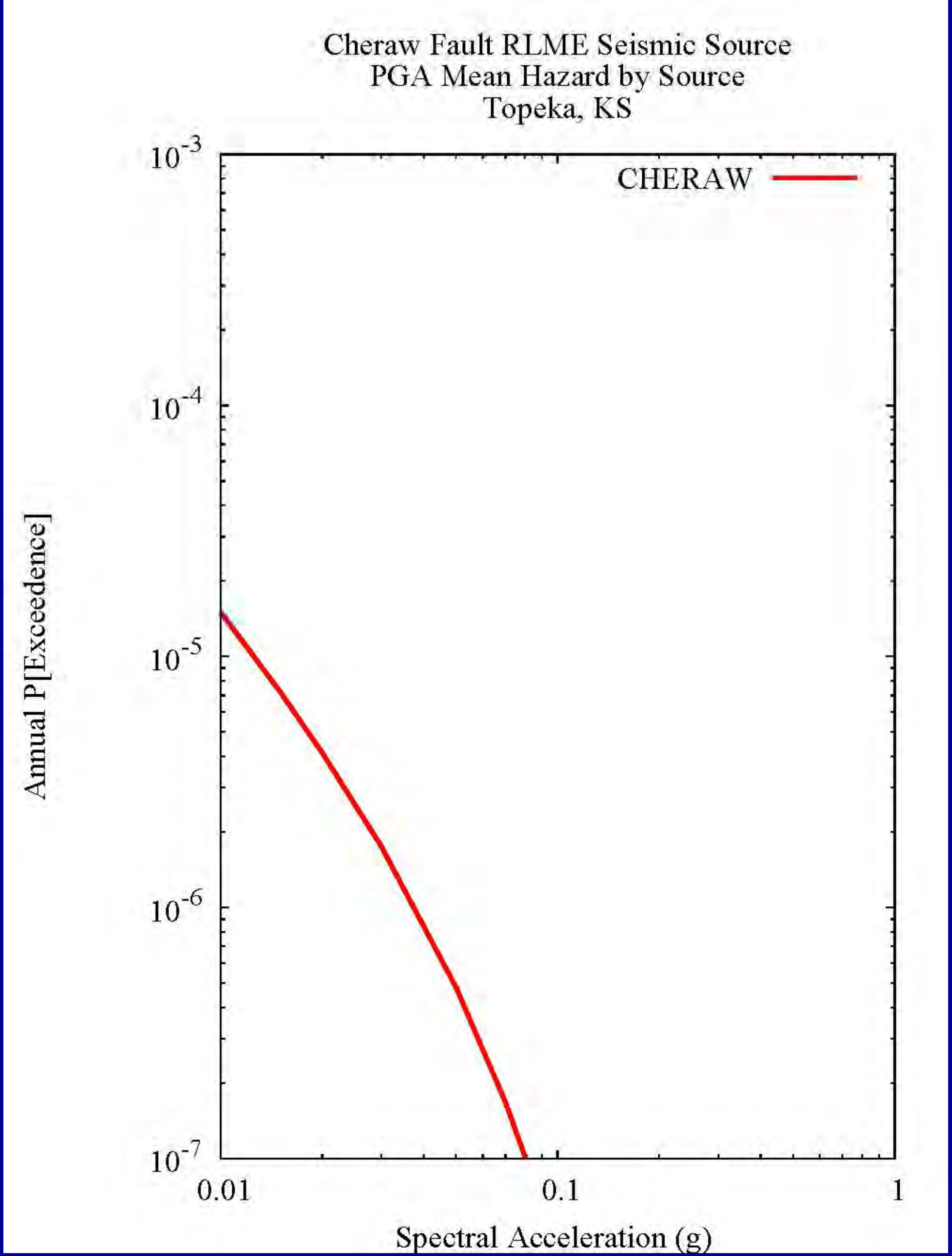
Results for Topeka, KS : 10 Hz, Rate



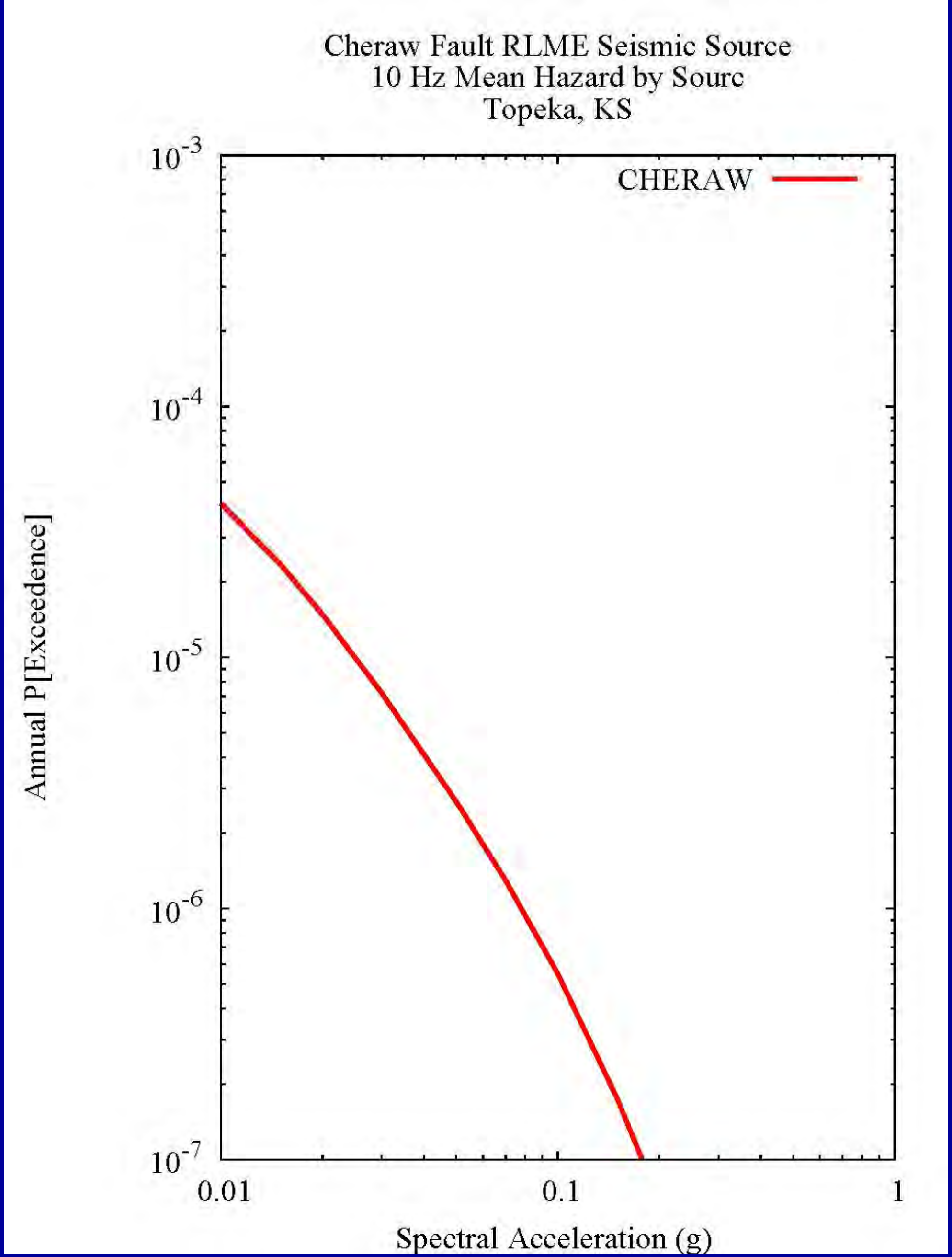
Results for Topeka, KS : 1 Hz, Rate



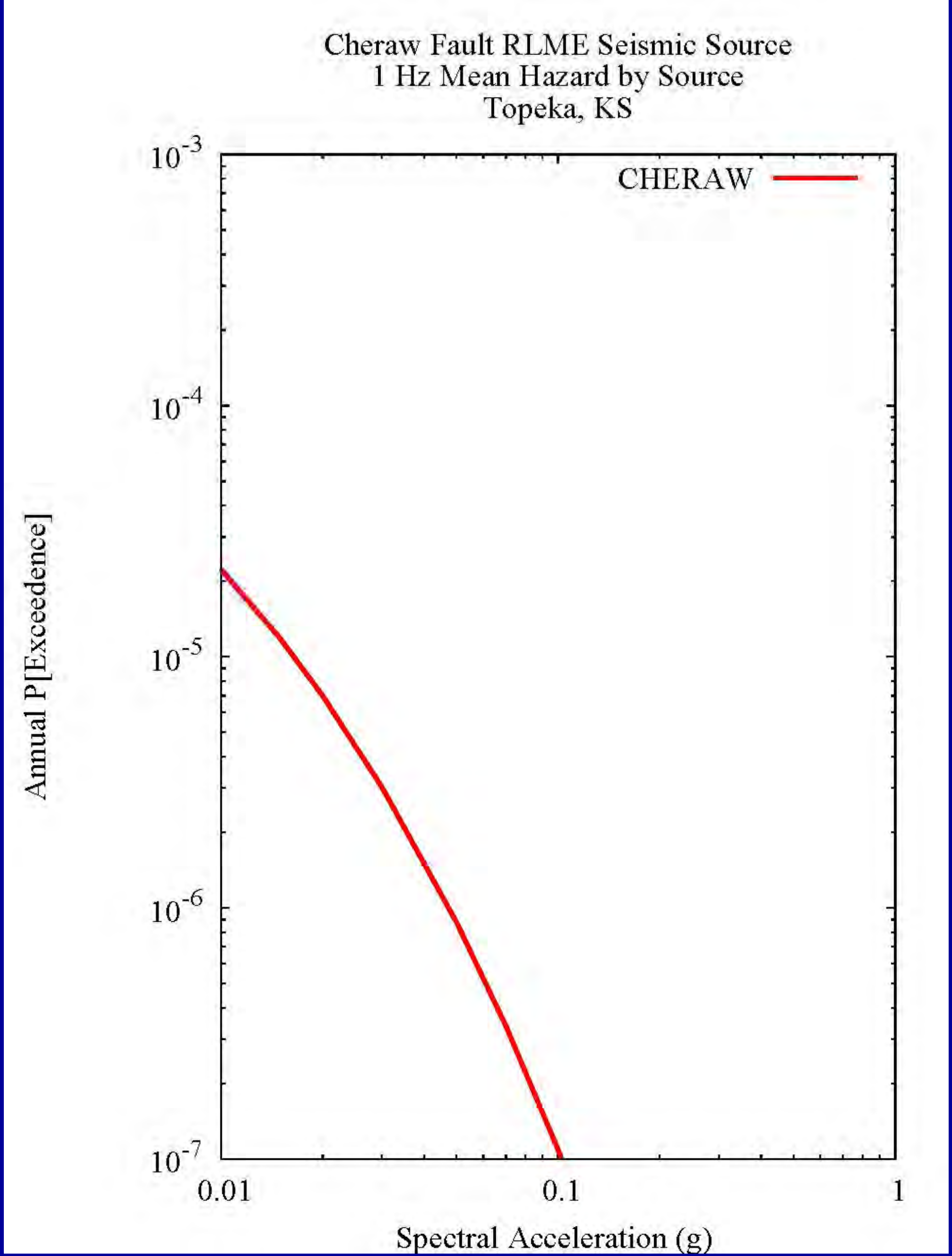
Results for Topeka, KS: PGA, Geometry



Results for Topeka, KS: 10 Hz, Geometry



Results for Topeka, KS: 1 Hz, Geometry



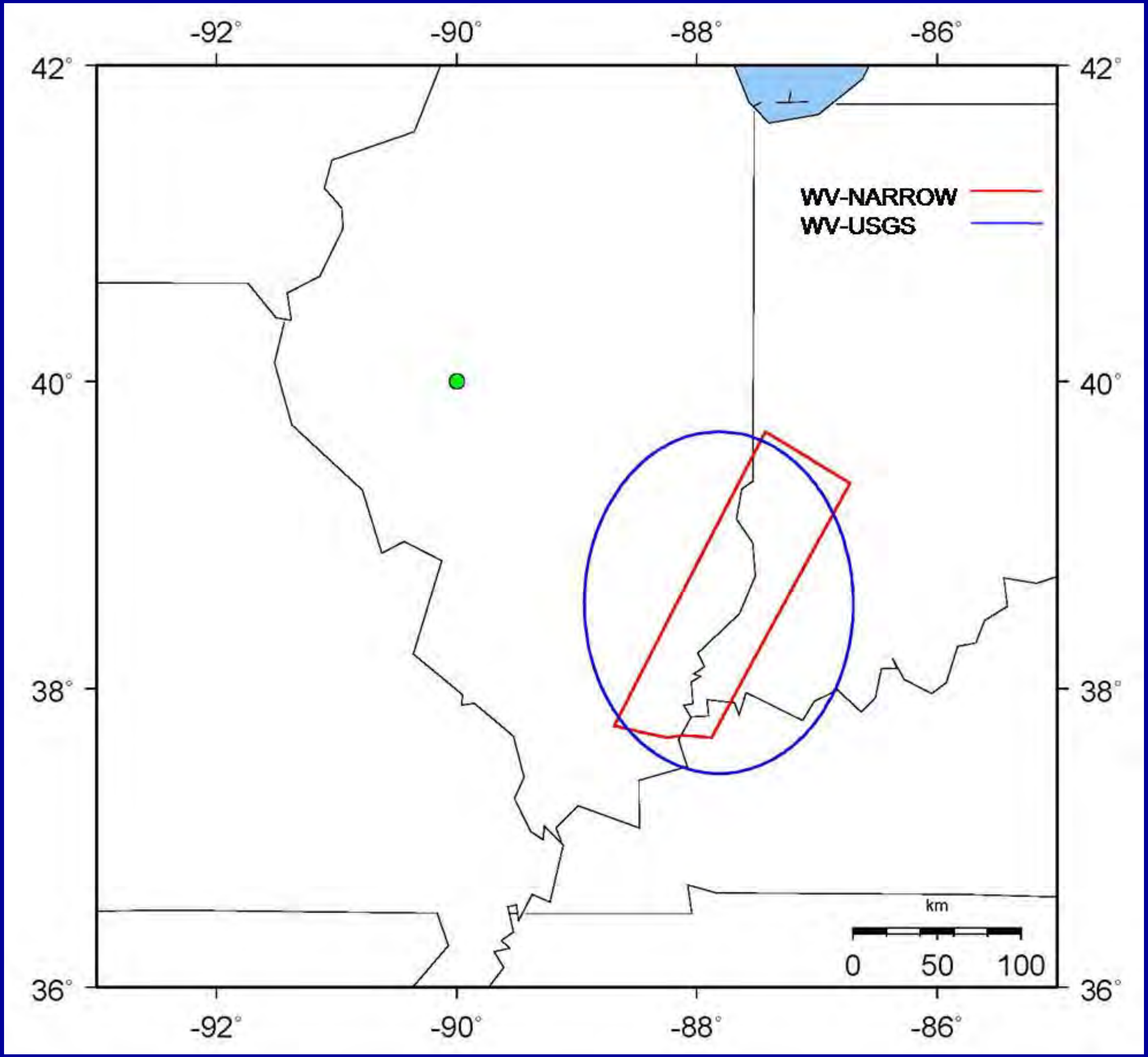
RLME Seismic Source Sensitivity Studies

Allison Shumway
William Lettis & Associates, Inc.
Workshop #3
August 25-26, 2009

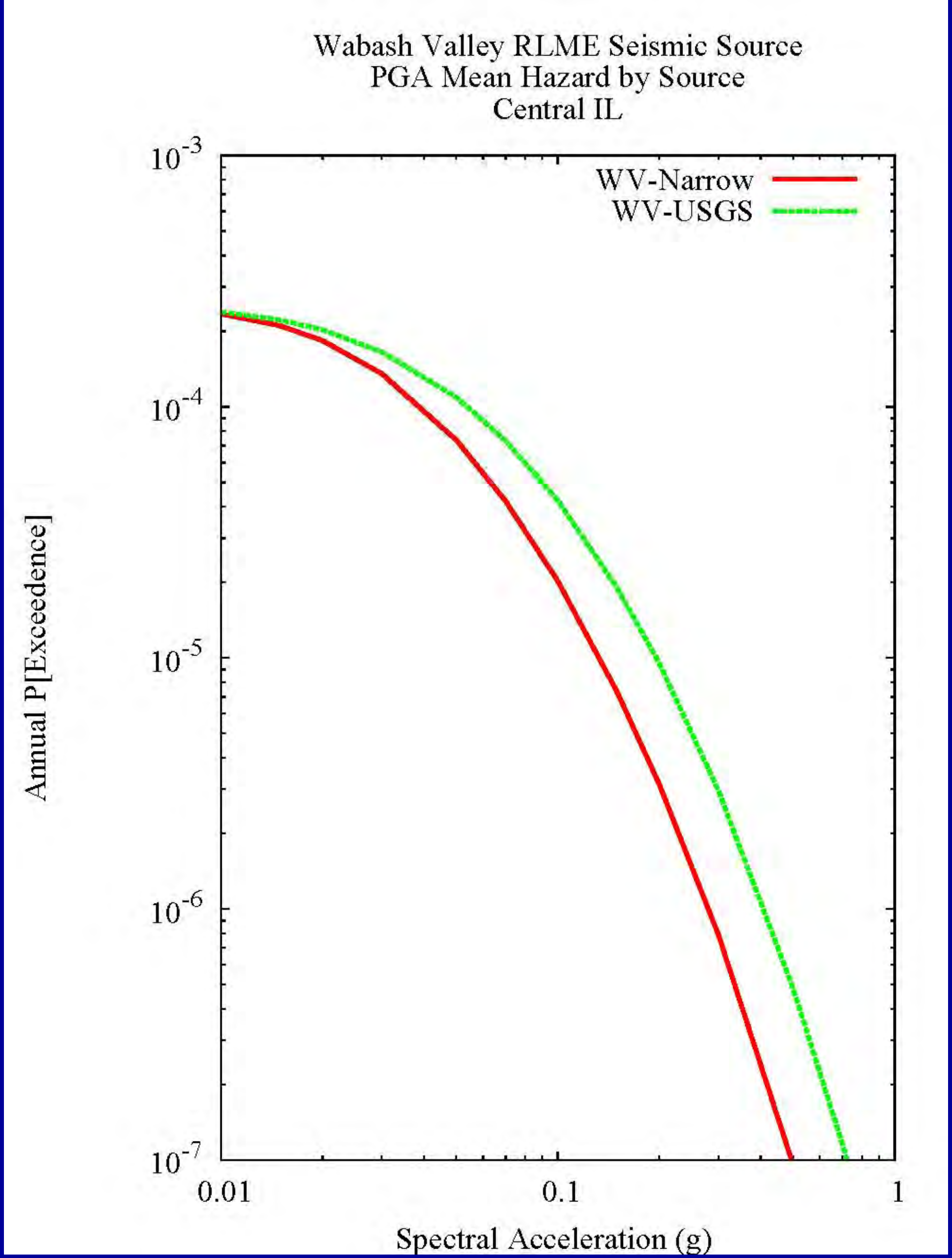
Wabash Valley RLME Seismic Source

- Sensitivity studies: geometry, rate, and Mmax
- Source: WV-Narrow (0.5 wt) (and WV-USGS (0.5 wt))
- Frequencies: 1 Hz, 10 Hz, and PGA
- Site : Central IL

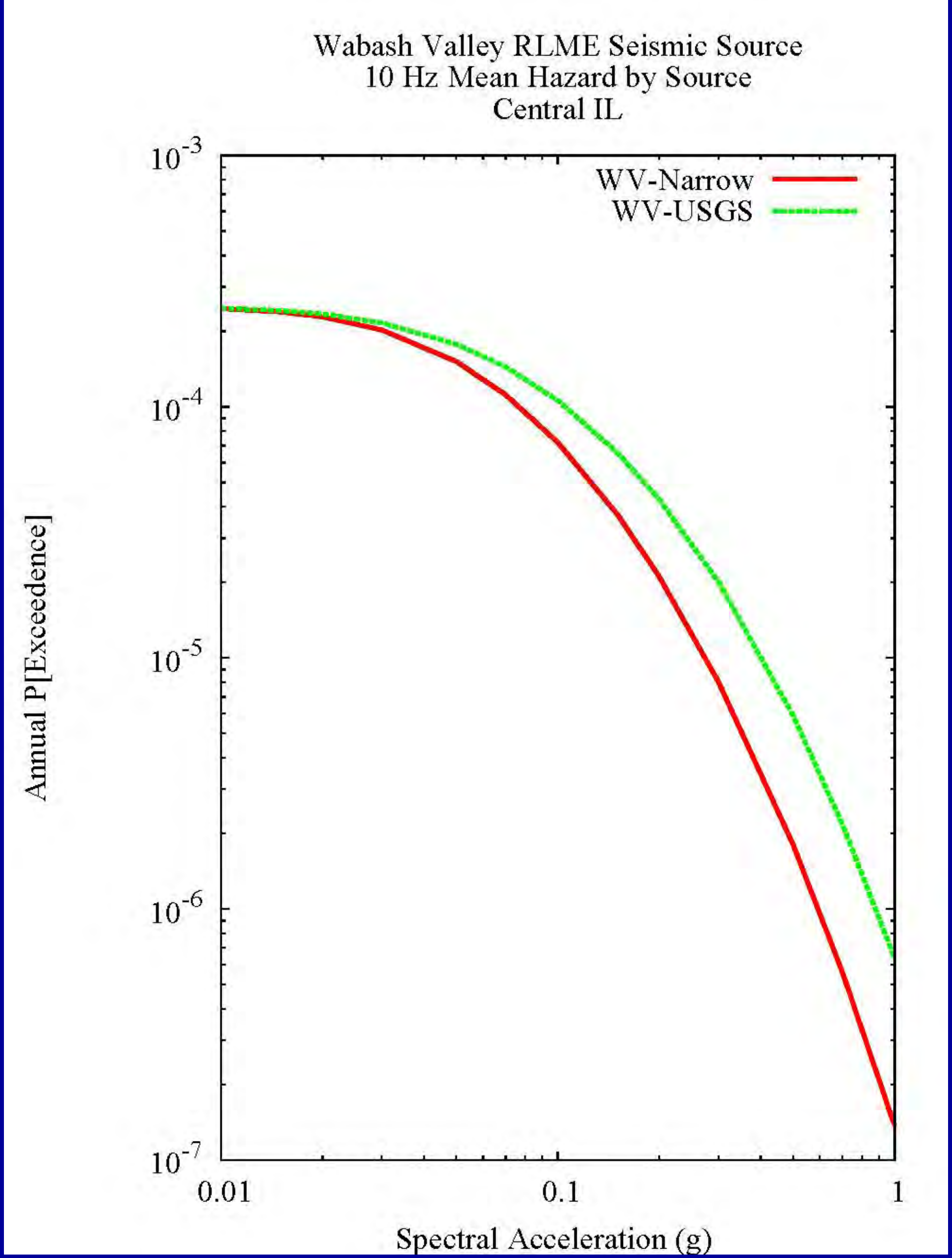
Wabash Valley RLME Seismic Source Location and Test Site: Central IL



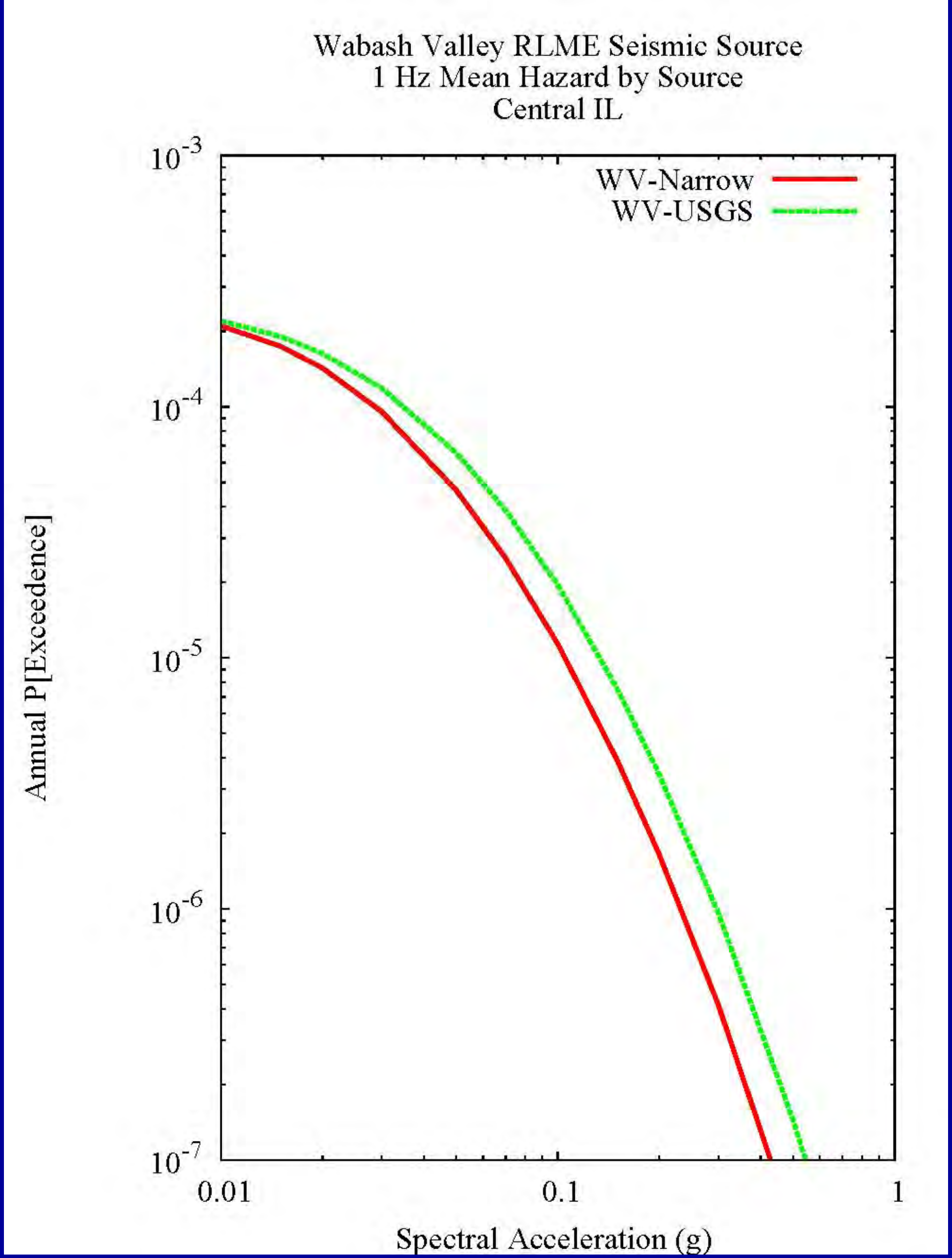
Results for Central IL: PGA, Geometry



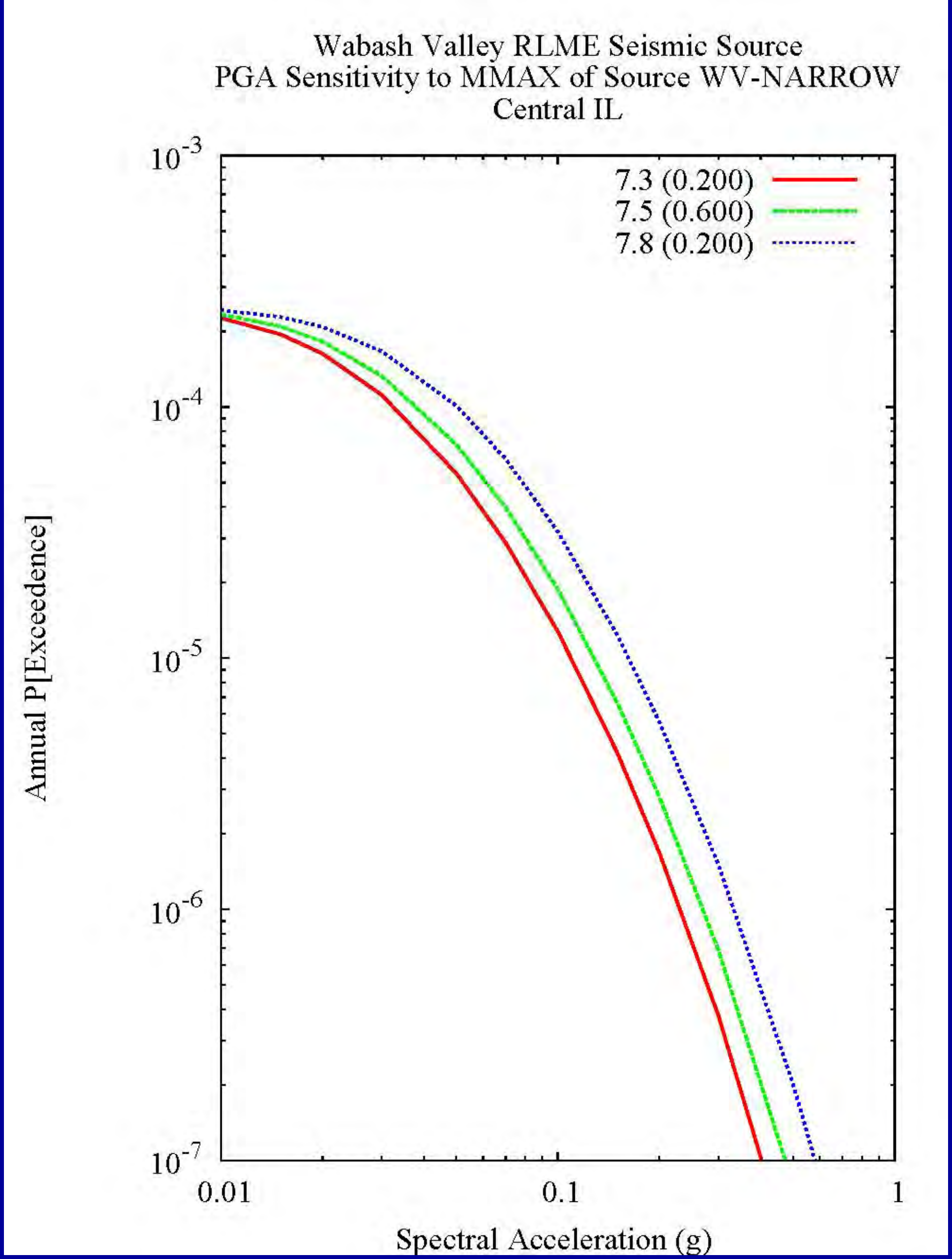
Results for Central IL: 10 Hz, Geometry



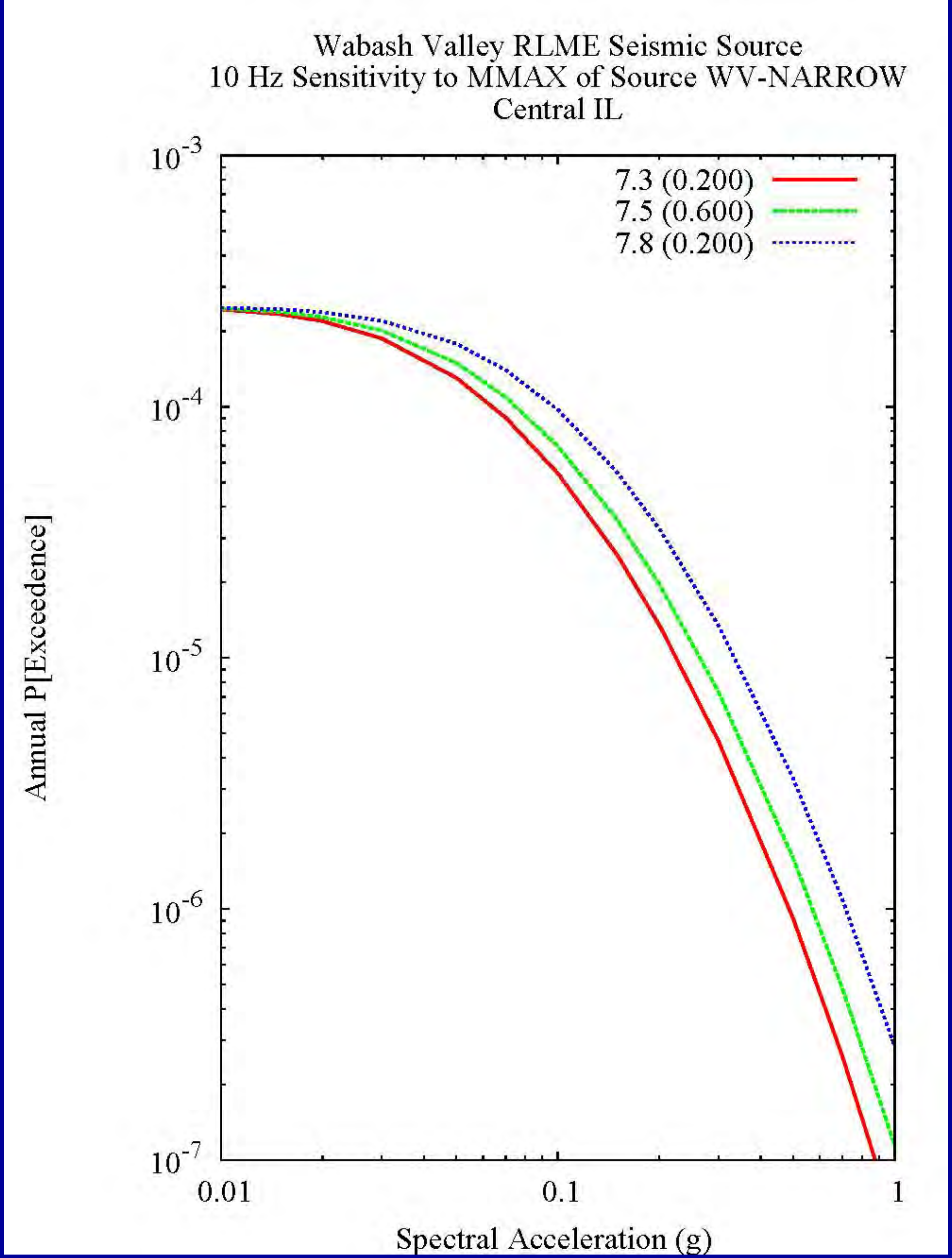
Results for Central IL: 1 Hz, Geometry



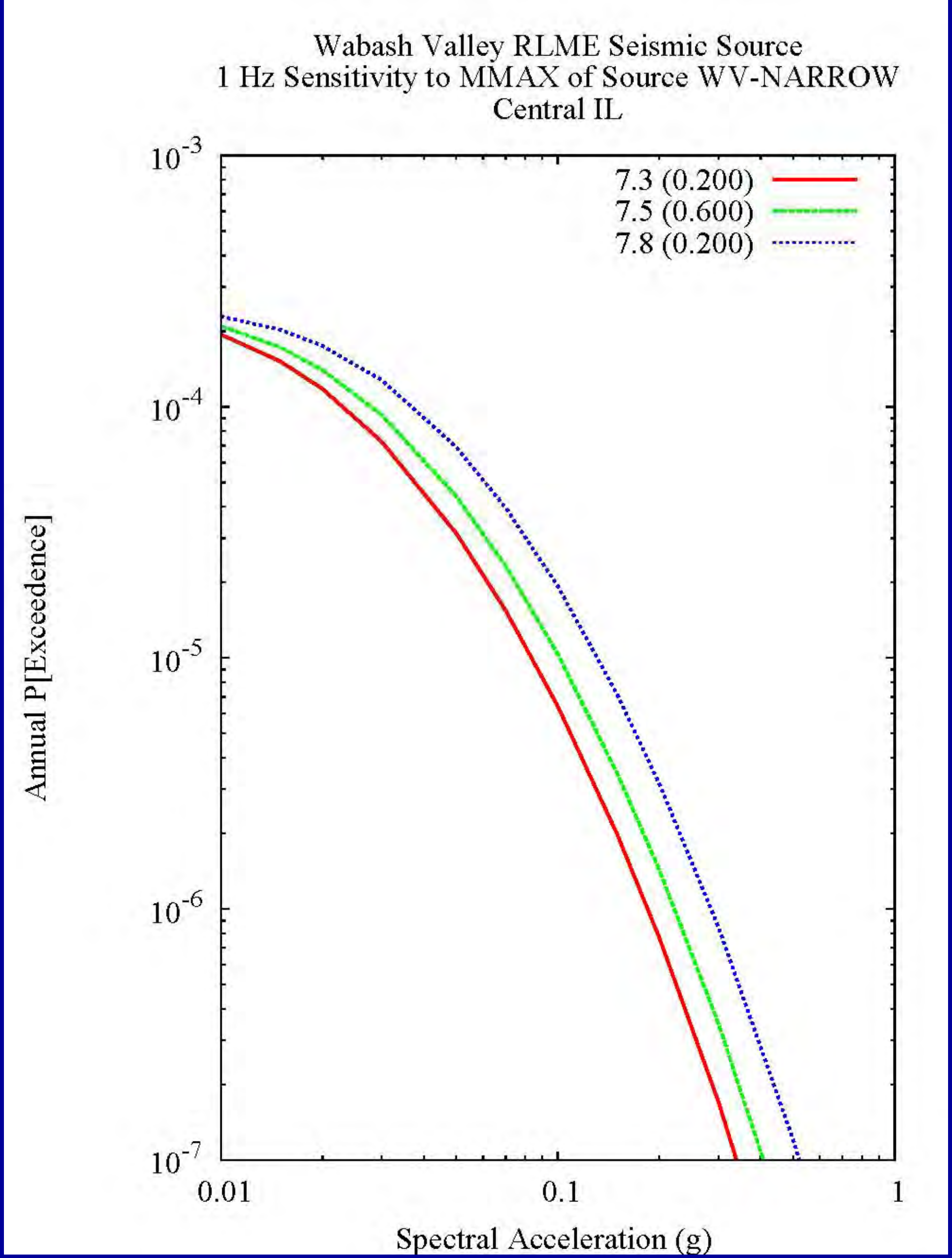
Results for Central IL : PGA, Mmax



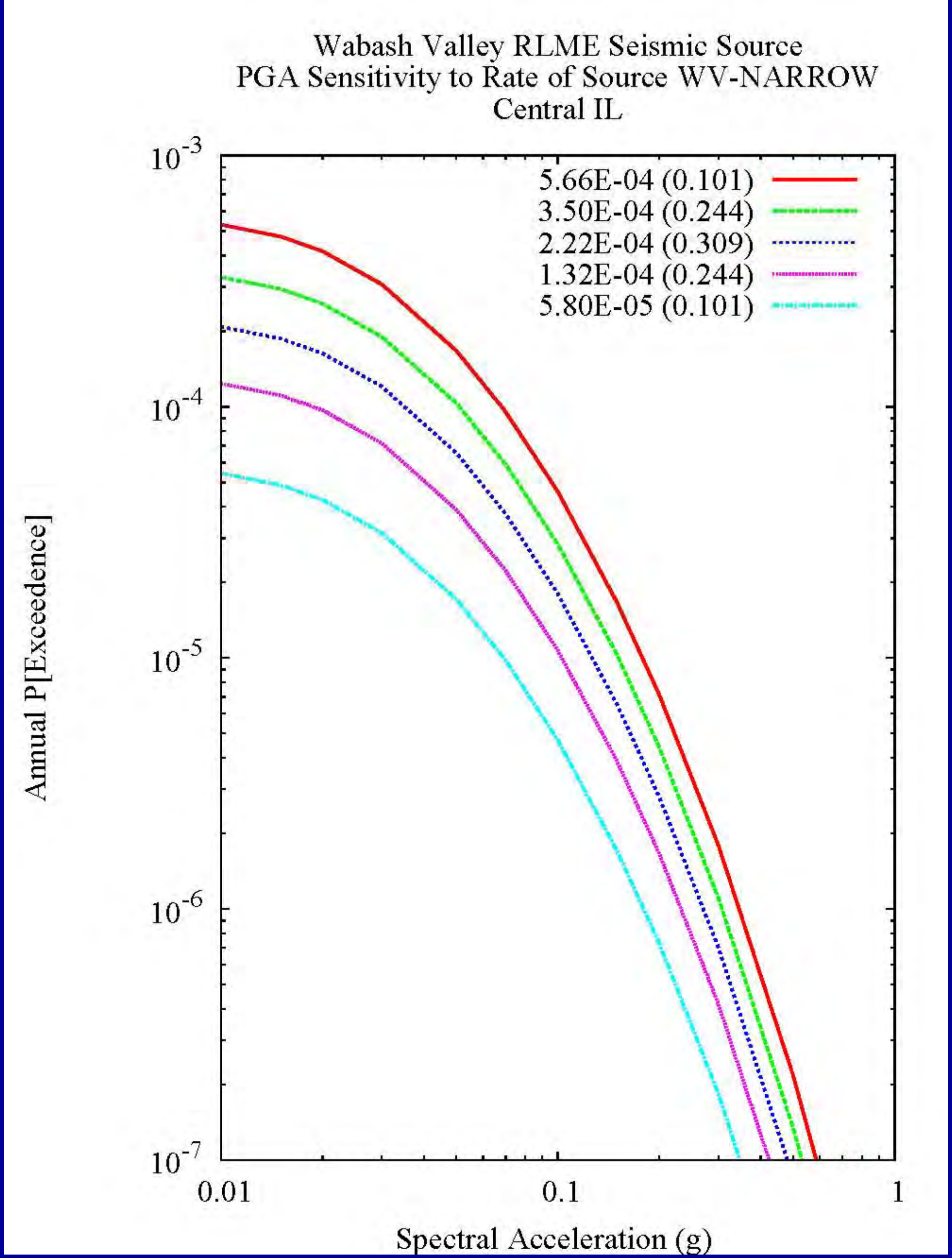
Results for Central IL : 10 Hz, Mmax



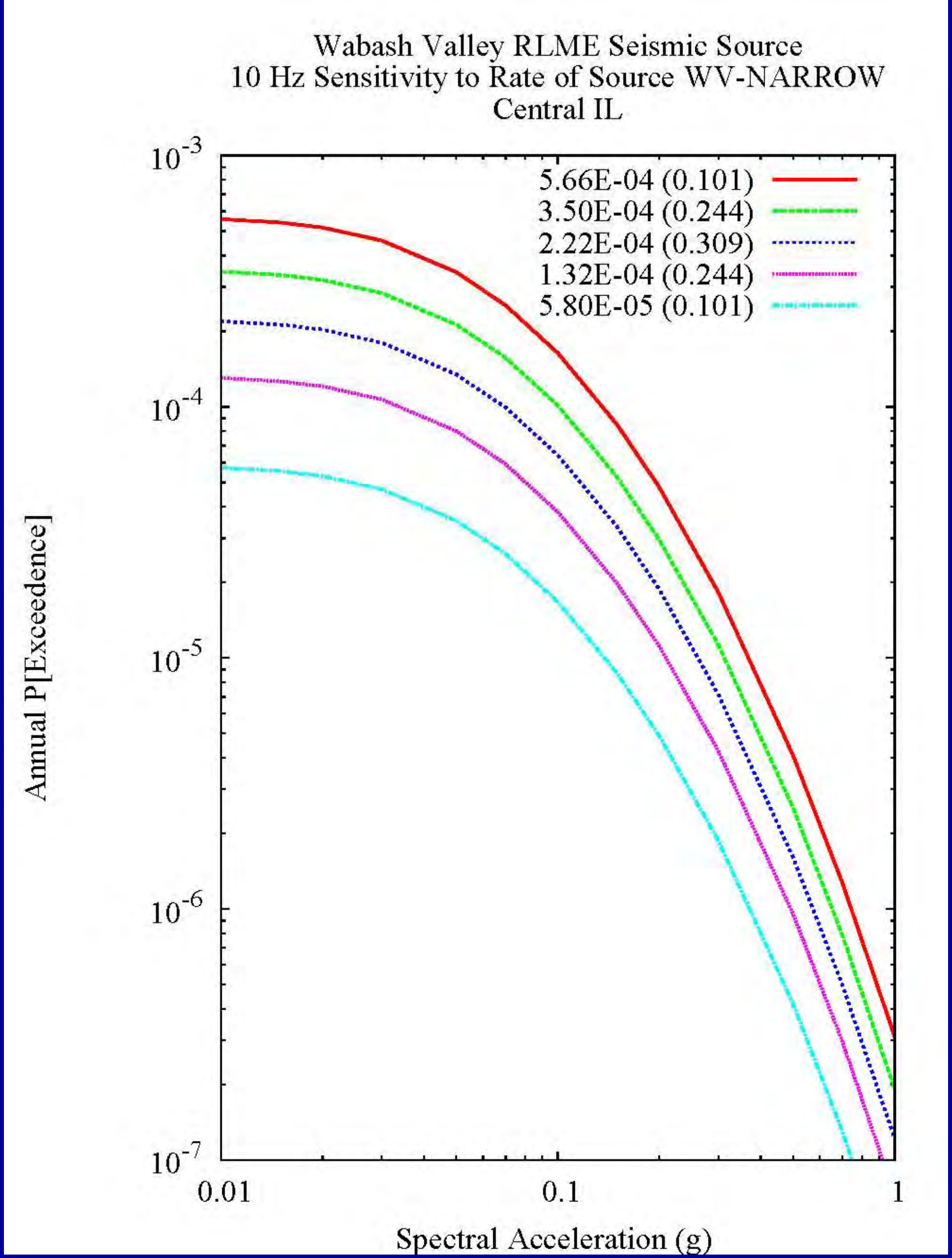
Results for Central IL : 1 Hz, Mmax



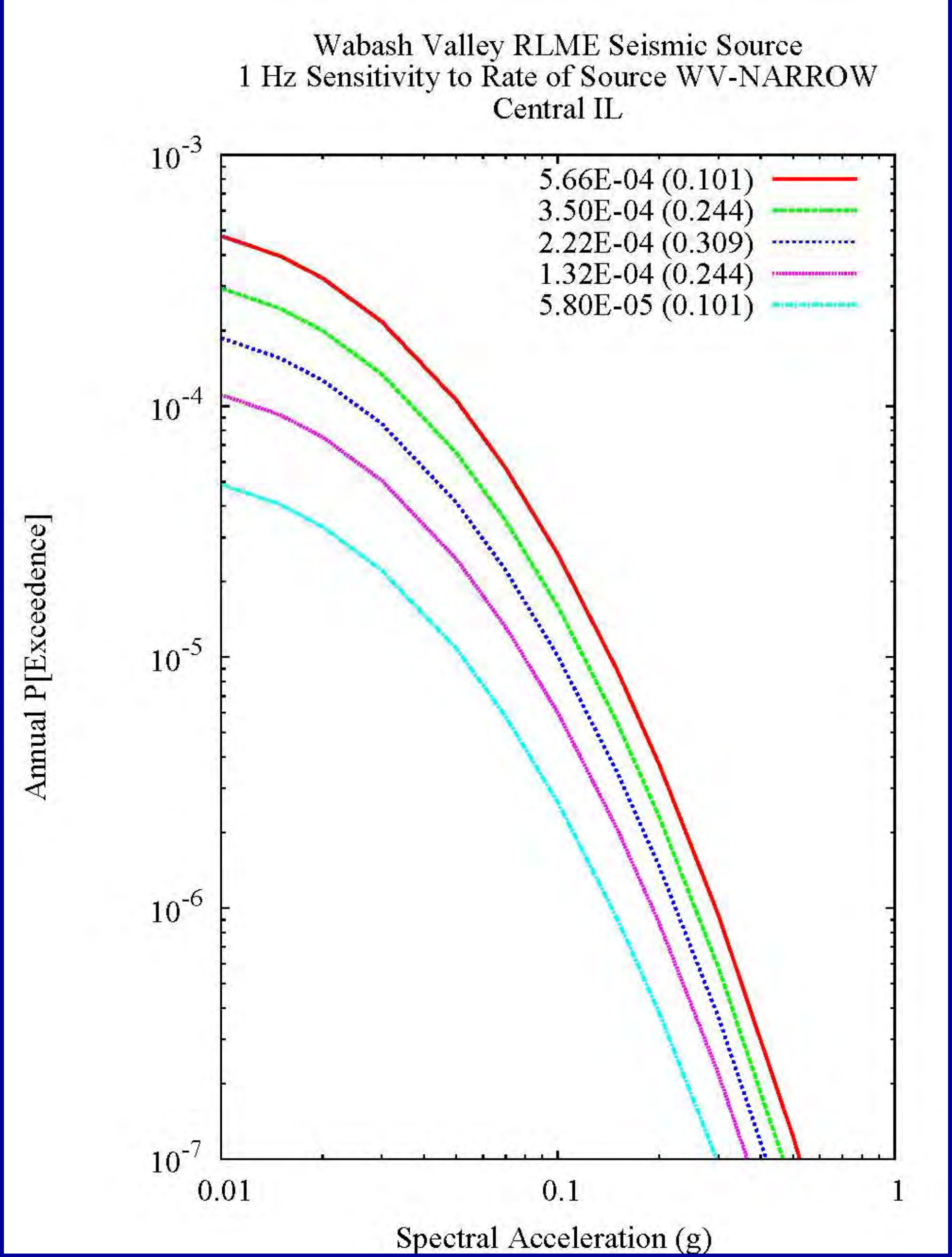
Results for Central IL : PGA, Rate



Results for Central IL : 10 Hz, Rate



Results for Central IL : 1 Hz, Rate



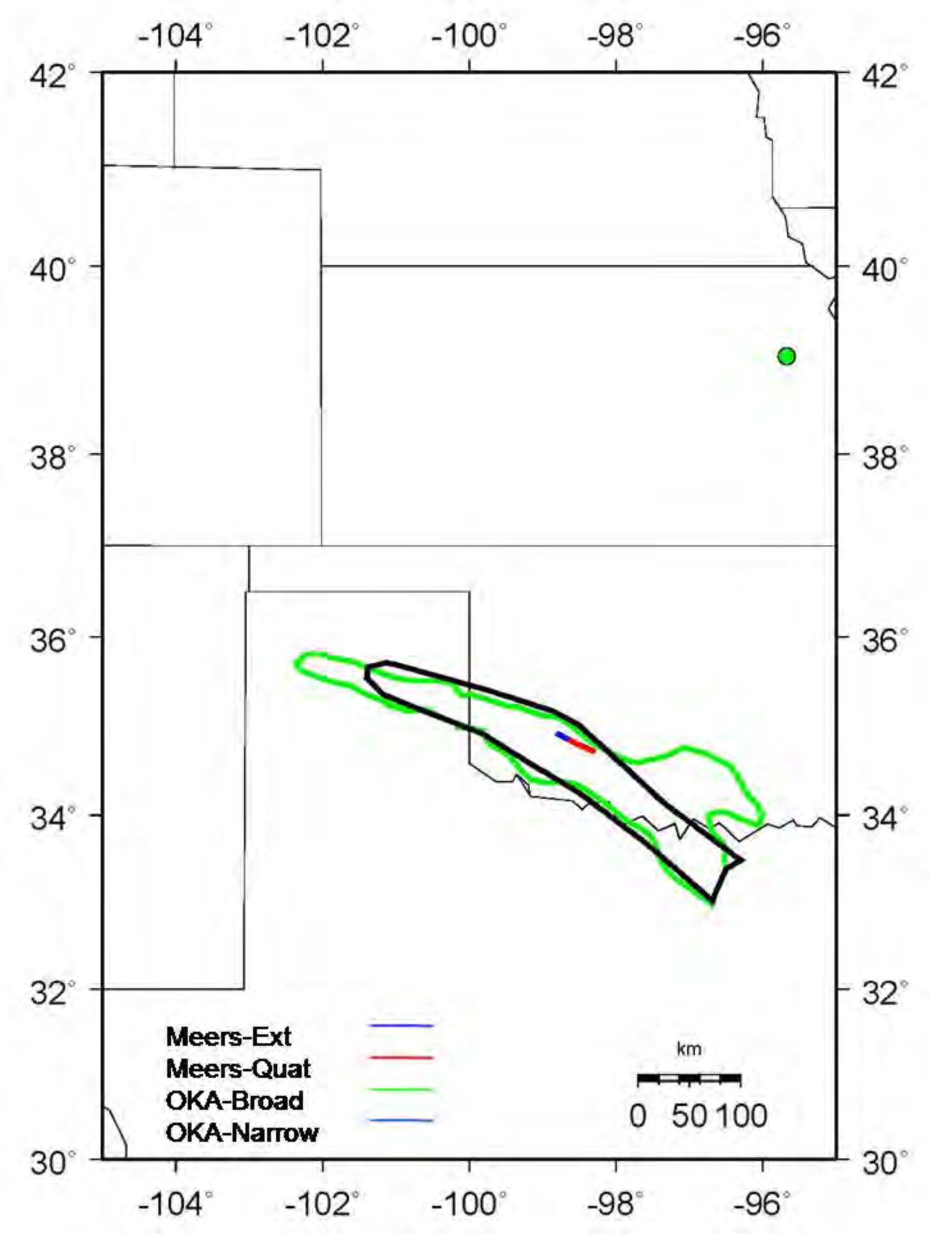
RLME Seismic Source Sensitivity Studies

Allison Shumway
William Lettis & Associates, Inc.
Workshop #3
August 25-26, 2009

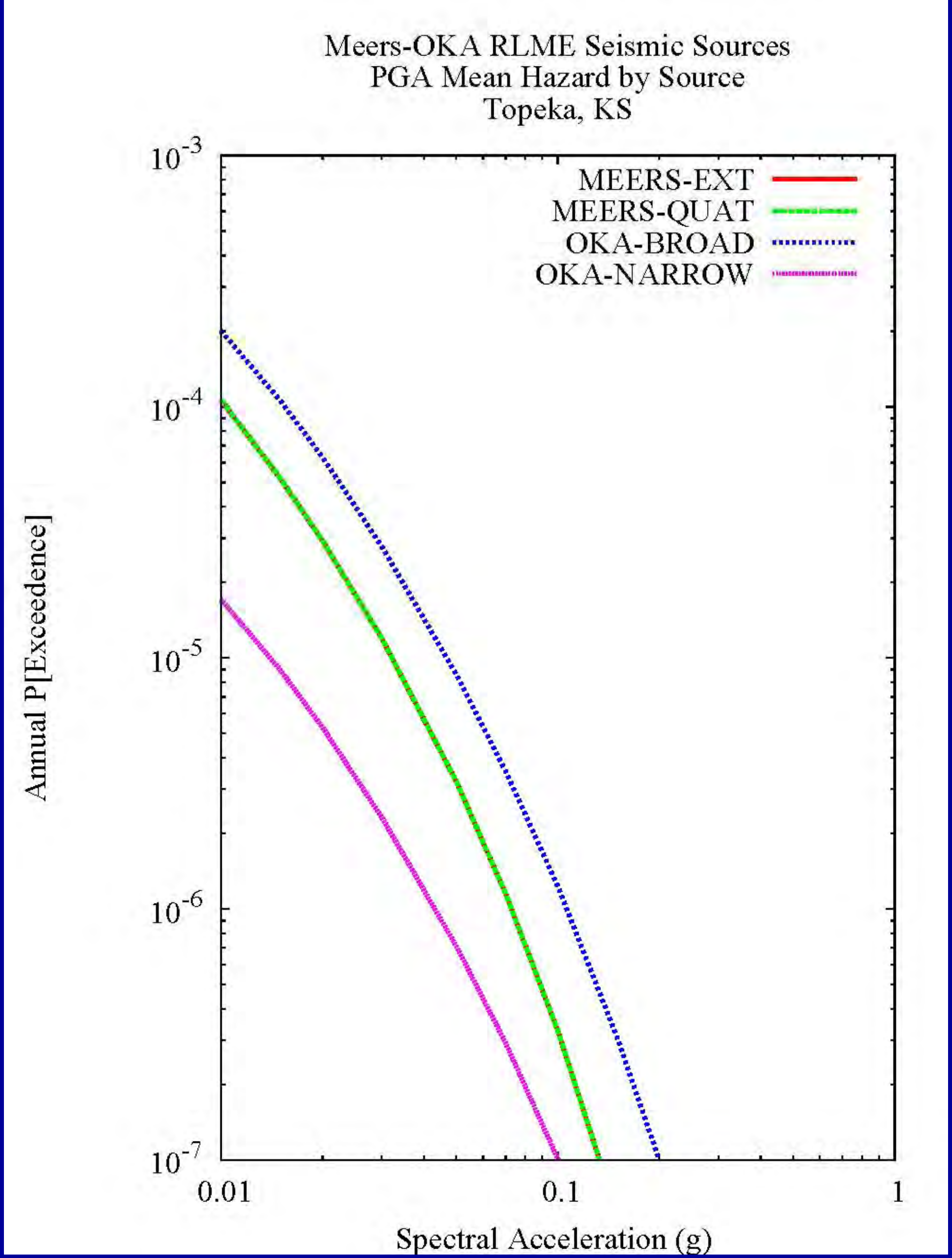
Meers and OK Aulacogen RLME Seismic Sources

- Sensitivity studies: geometry, rate, and Mmax
- Sources: Meers-Quat (0.9 wt) (and Meers-Ext (0.1 wt)) and OKA-B (0.9 wt) (and OKA-C (0.1 wt))
- Frequencies: 1 Hz, 10 Hz, and PGA
- Site : Topeka, KS

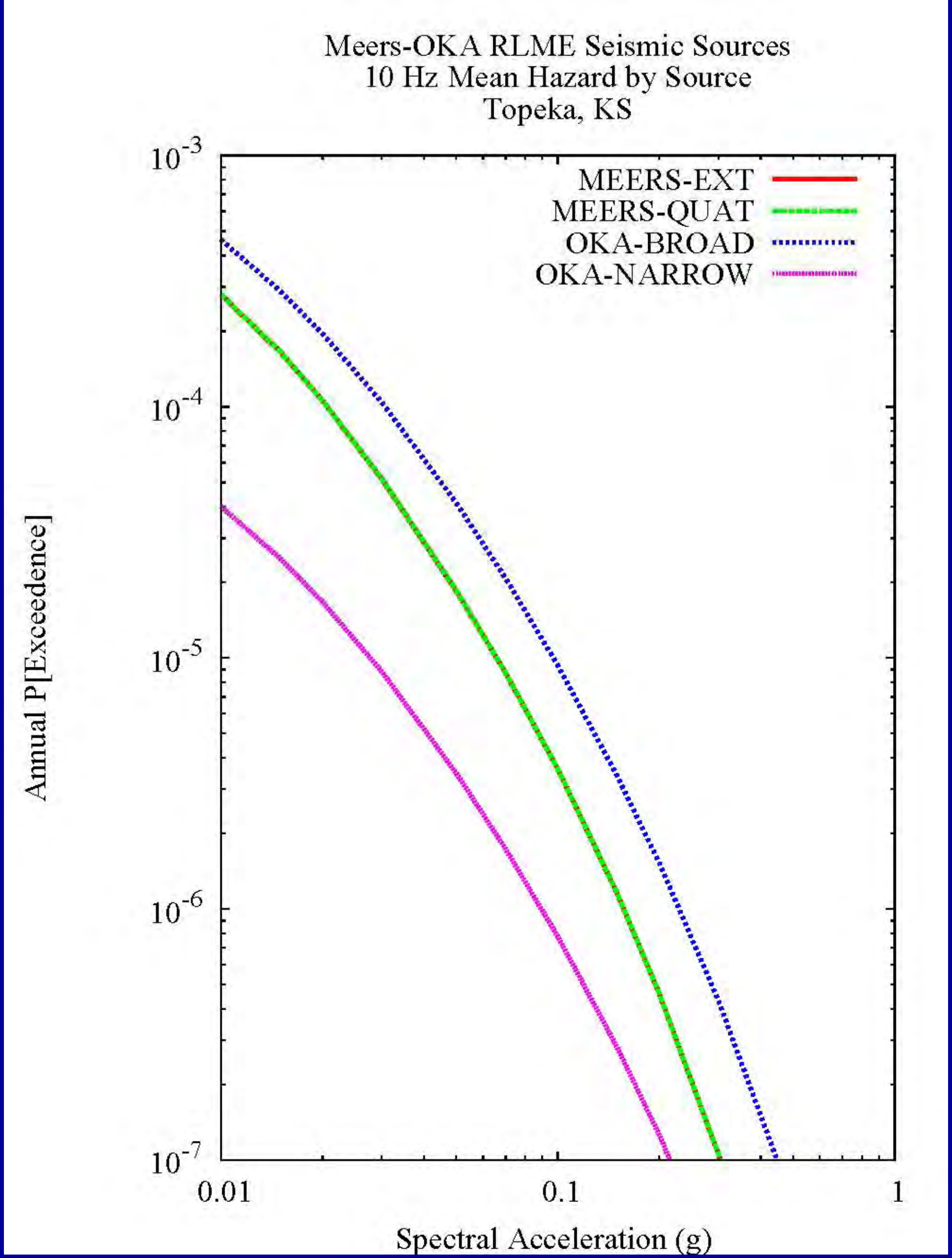
Meers-OKA RLME Seismic Source Location and Test Site: Topeka, KS



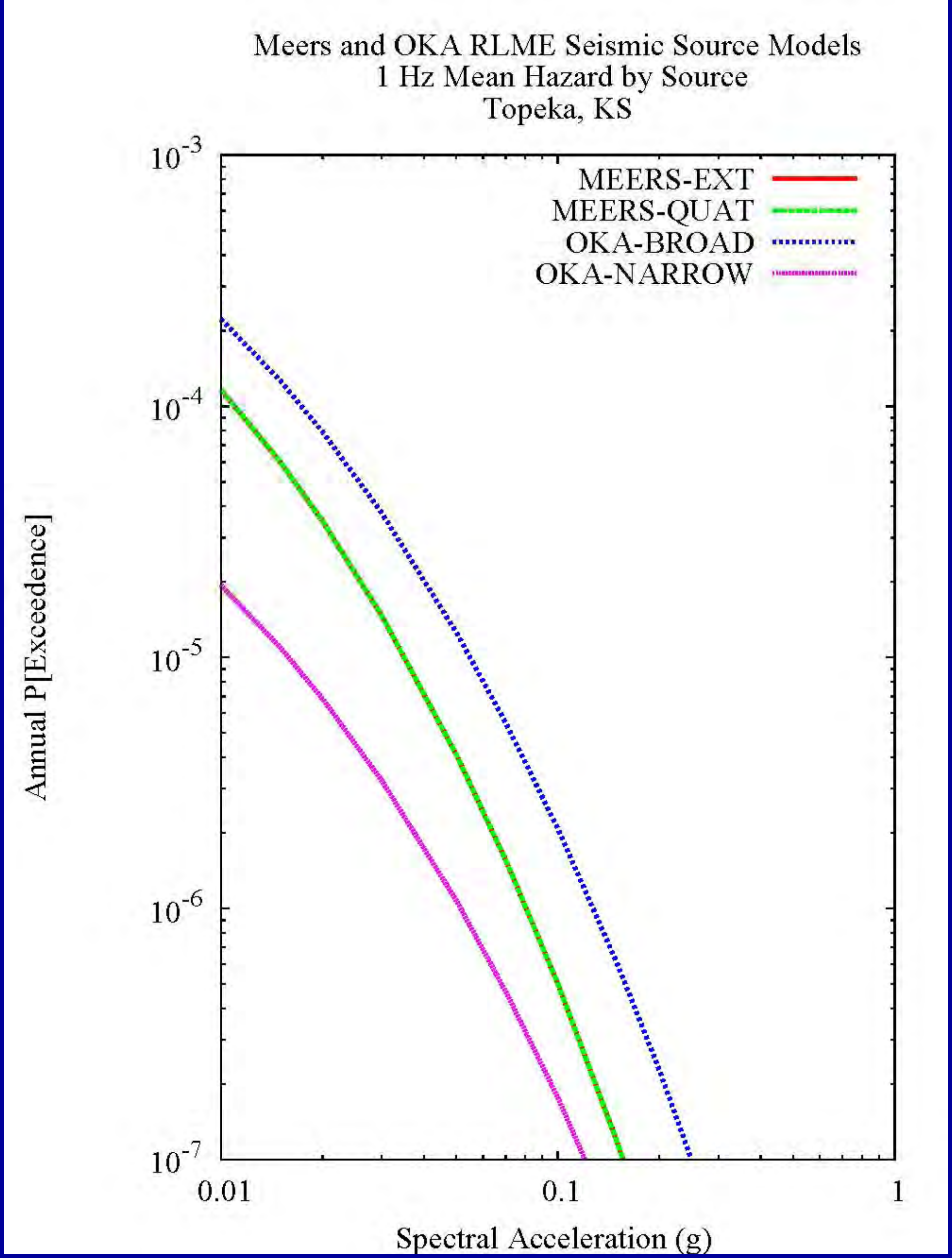
Results for Topeka, KS: Meers-Quat, PGA, Geometry



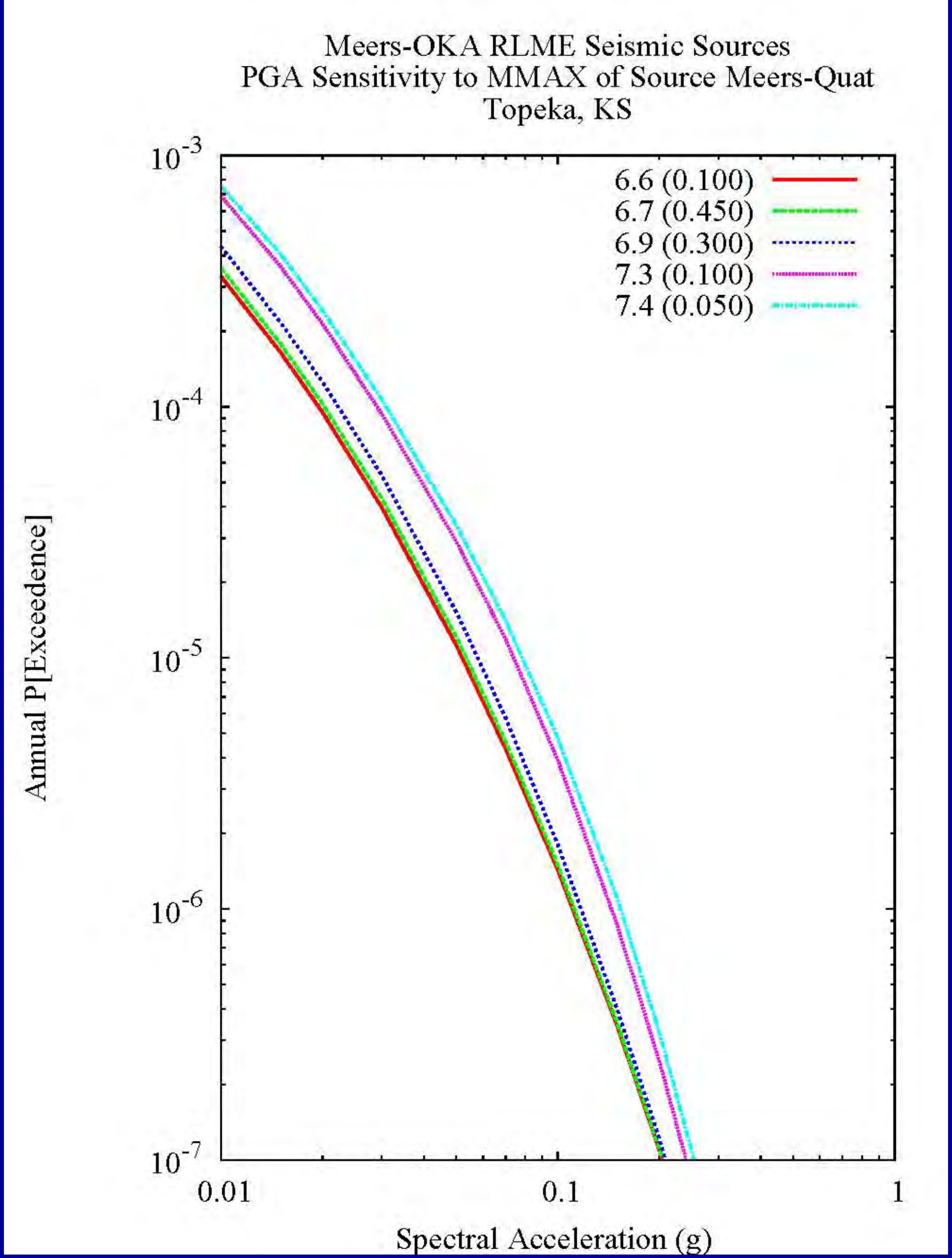
Results for Topeka, KS: Meers-Quat, 10 Hz, Geometry



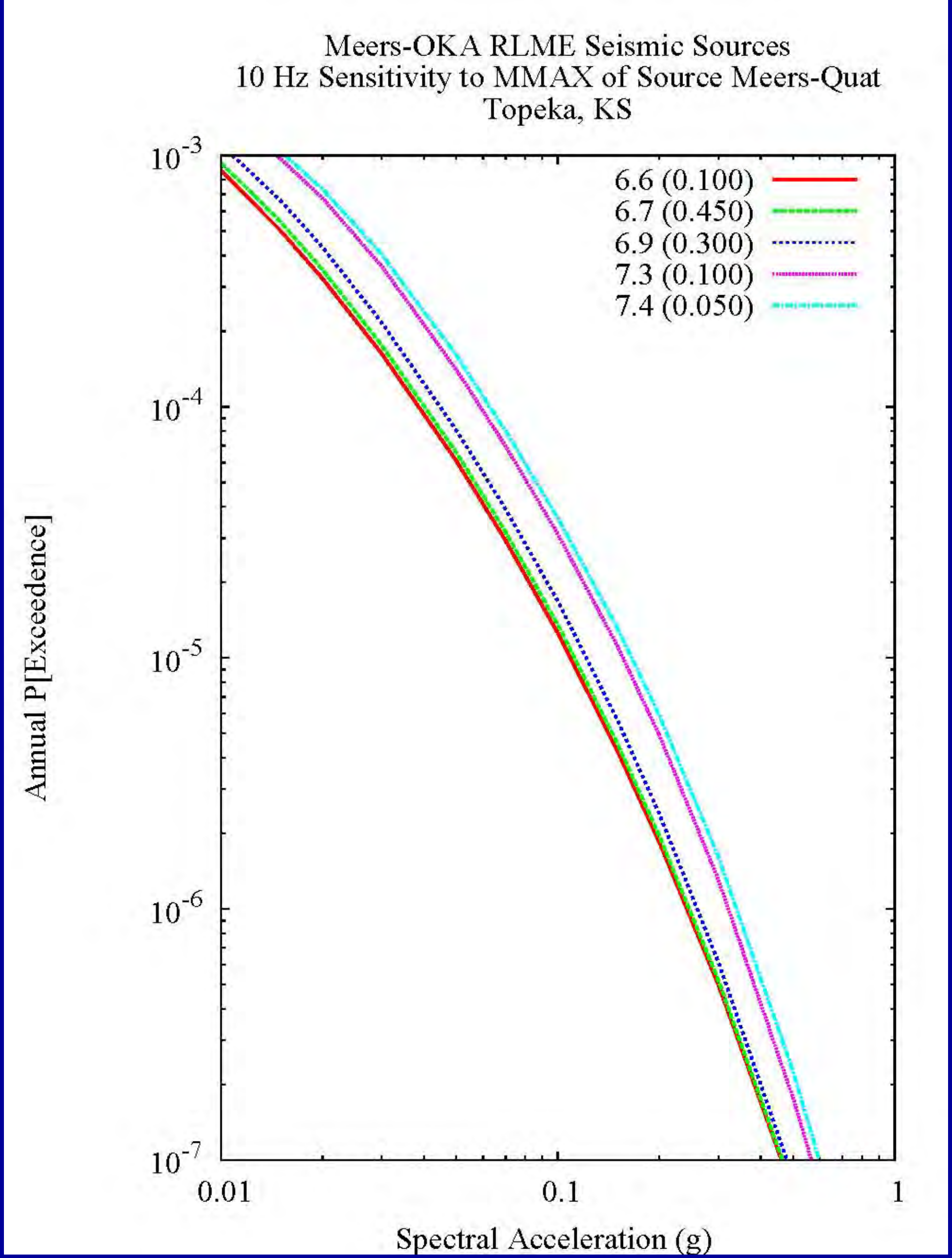
Results for Topeka, KS: Meers-Quat, 1 Hz, Geometry



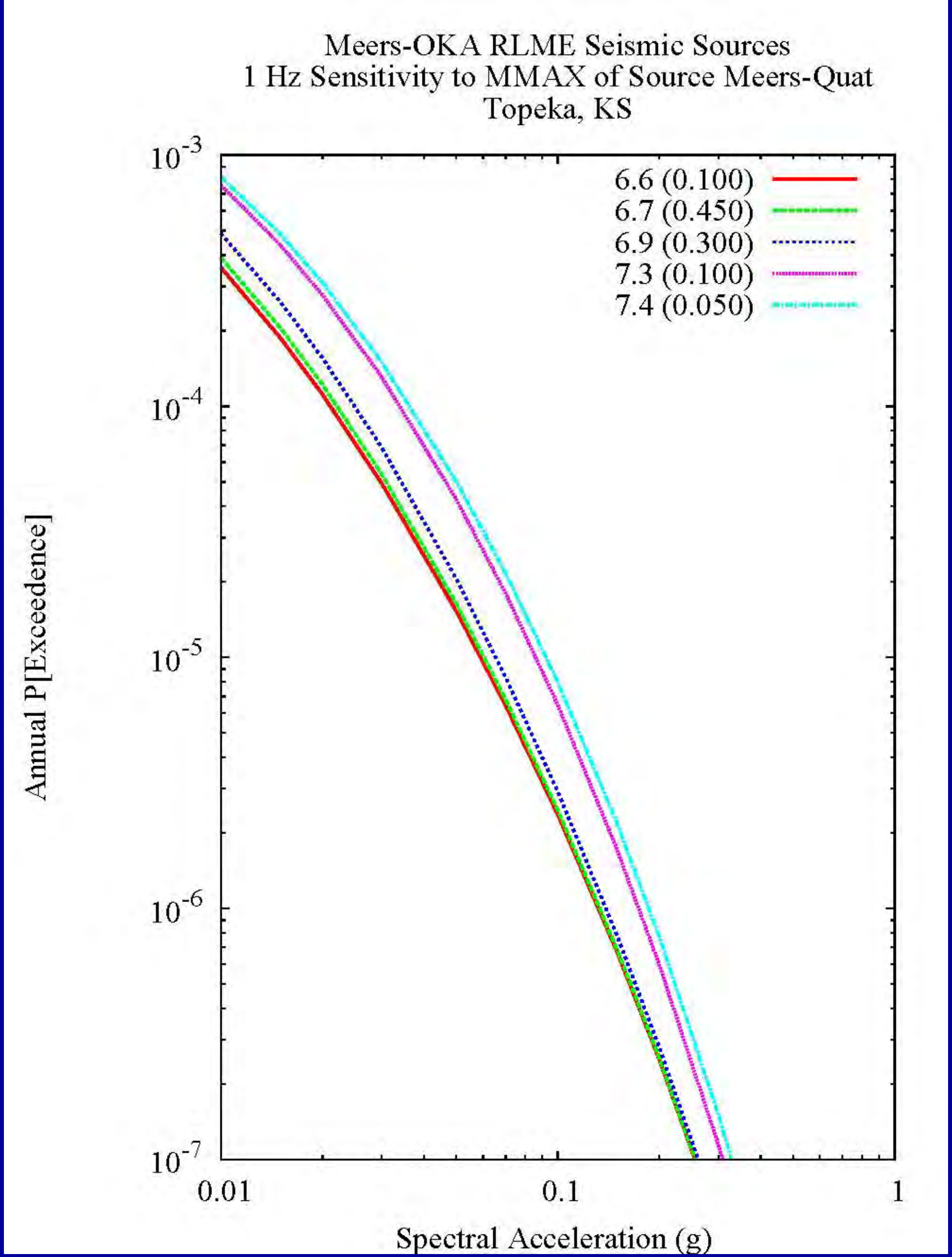
Results for Topeka, KS : Meers-Quat, PGA, Mmax



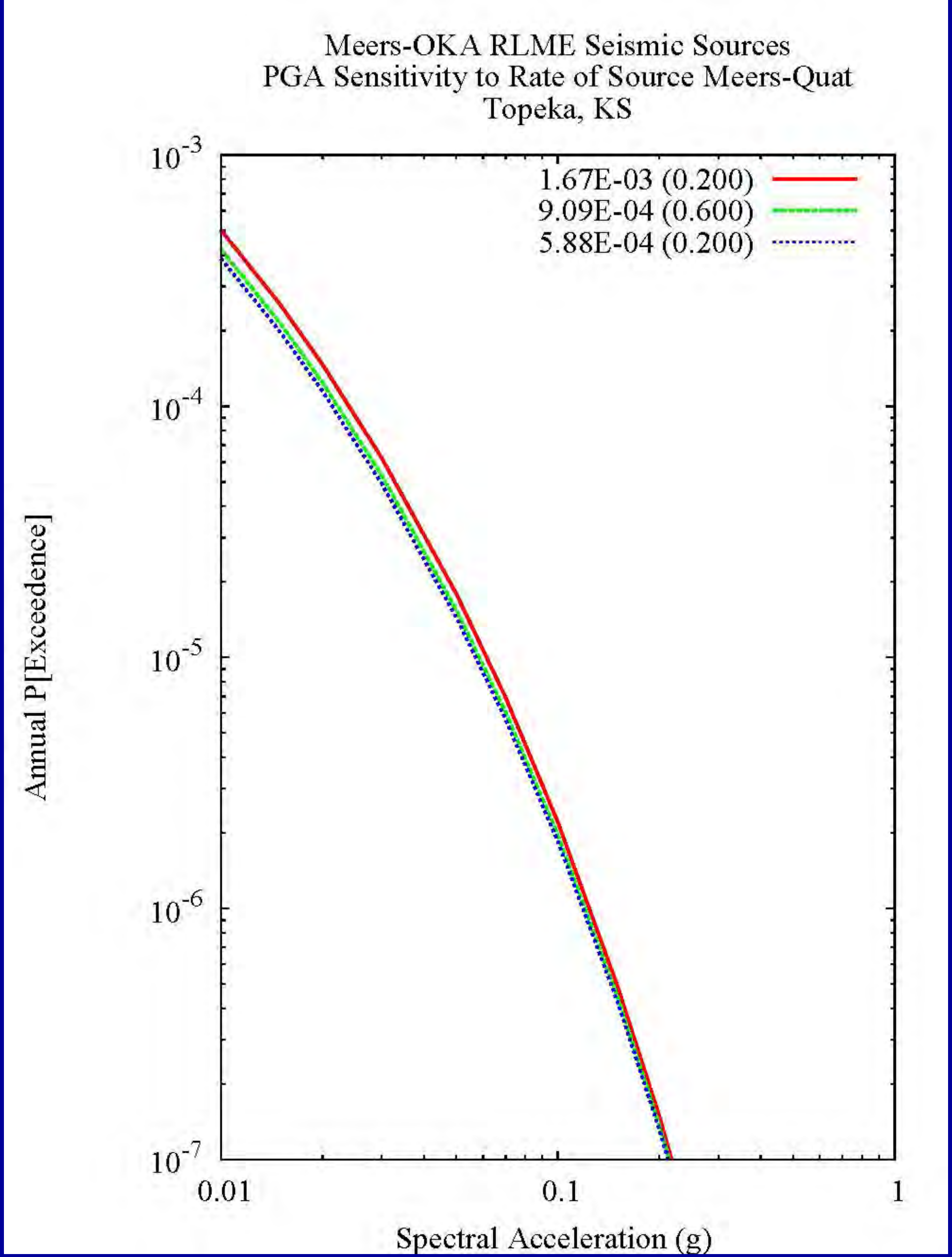
Results for Topeka, KS : Meers-Quat, 10 Hz, Mmax



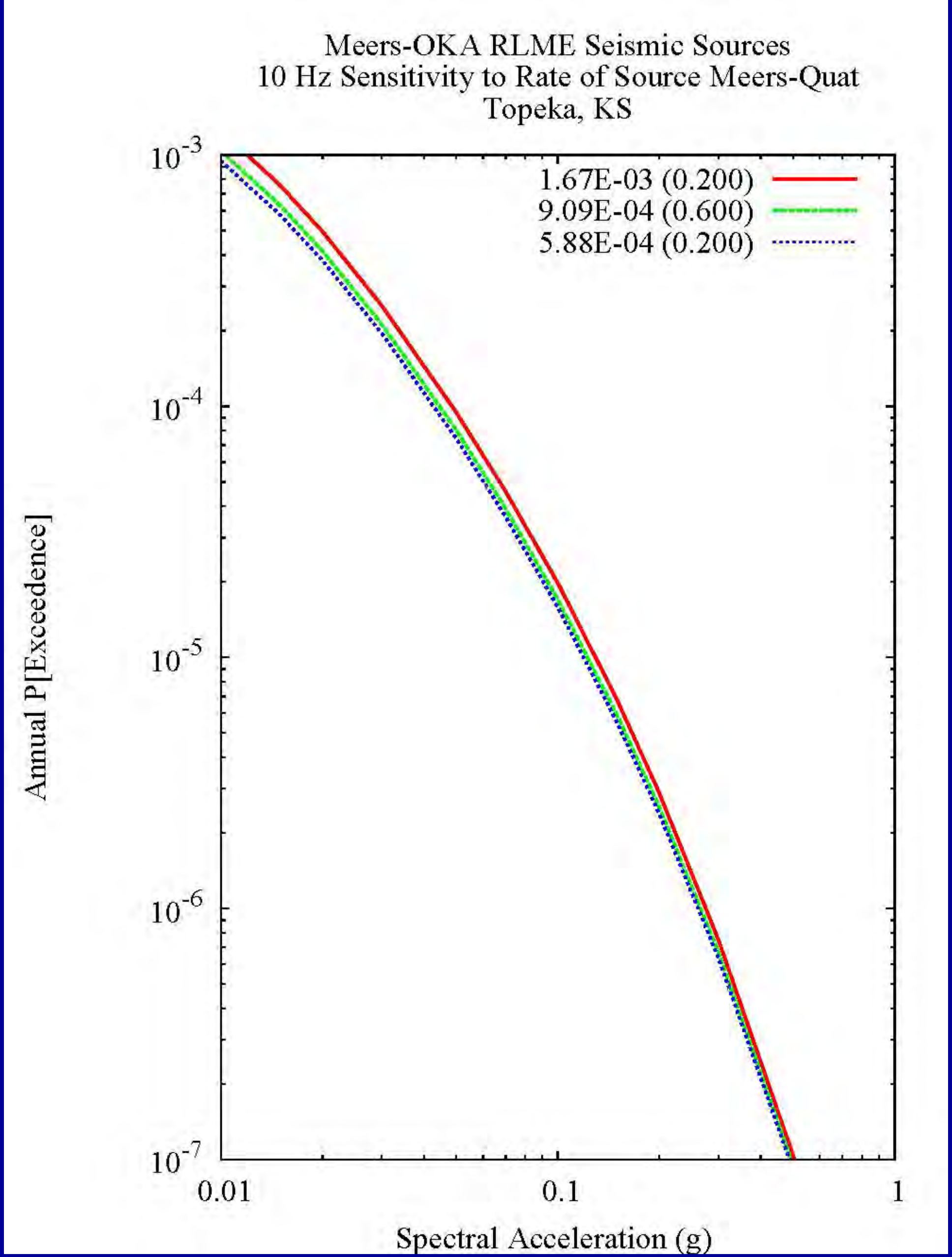
Results for Topeka, KS : Meers-Quat, 1 Hz, Mmax



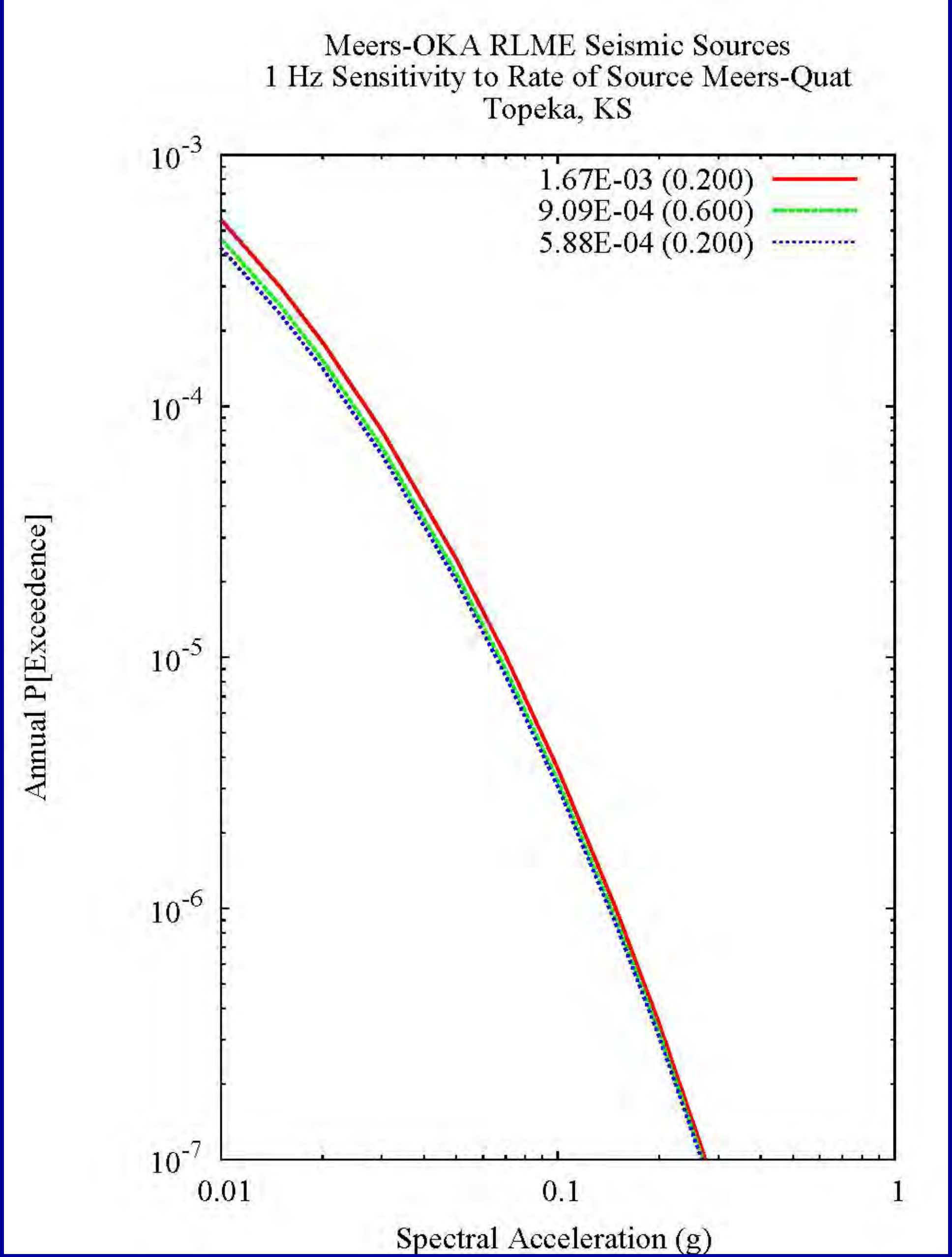
Results for Topeka, KS : Meers-Quat, PGA, Rate



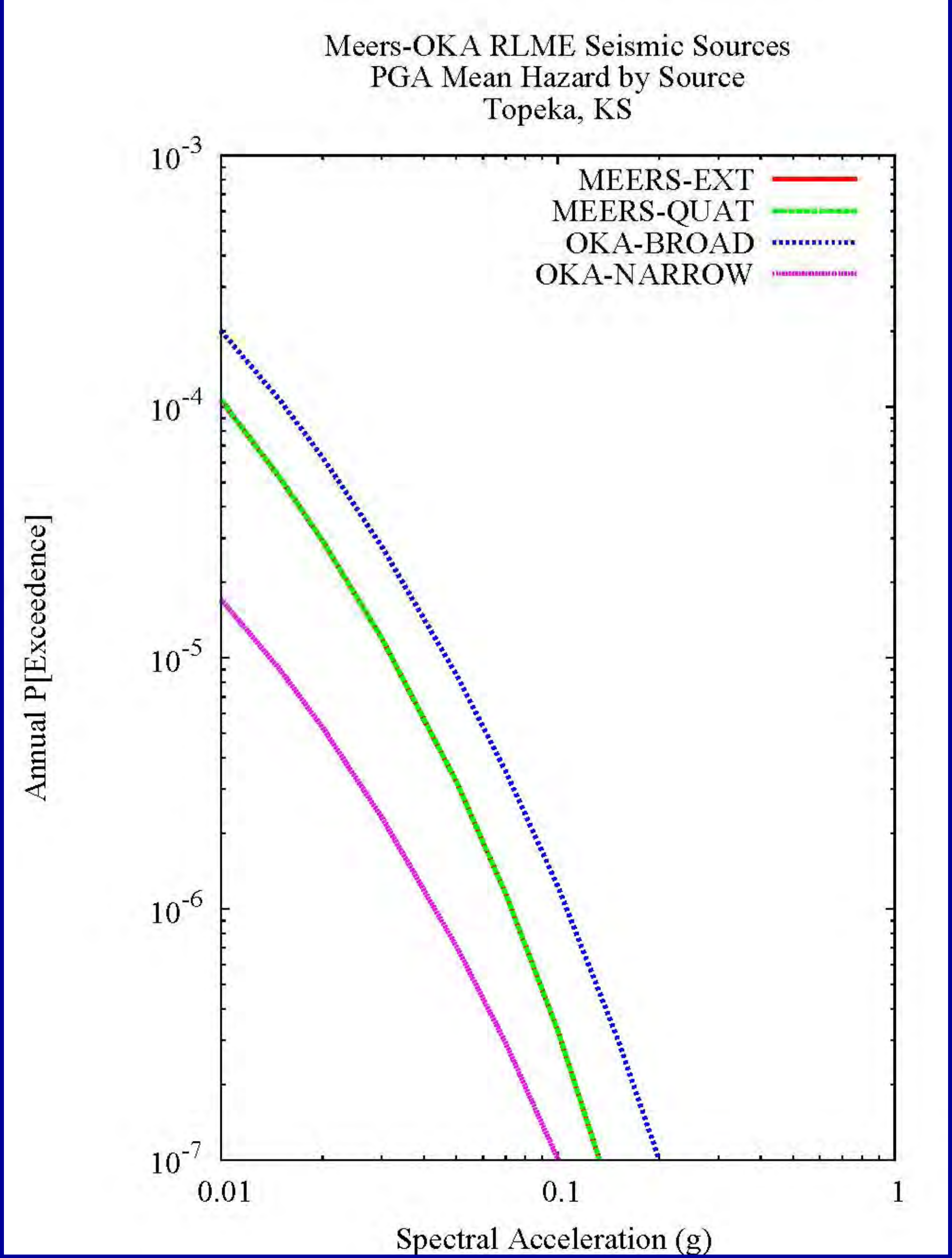
Results for Topeka, KS : Meers-Quat, 10 Hz, Rate



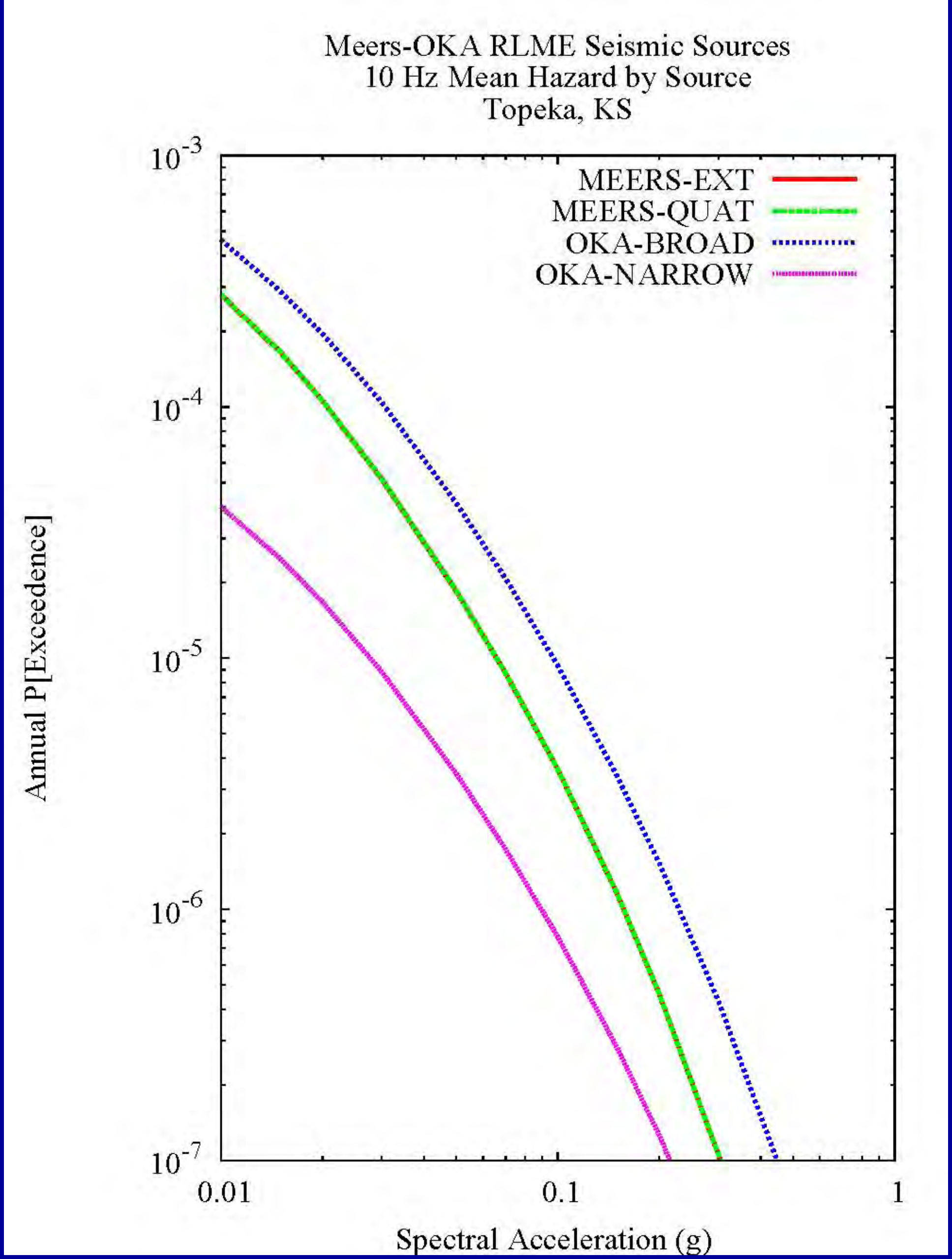
Results for Topeka, KS : Meers-Quat, 1 Hz, Rate



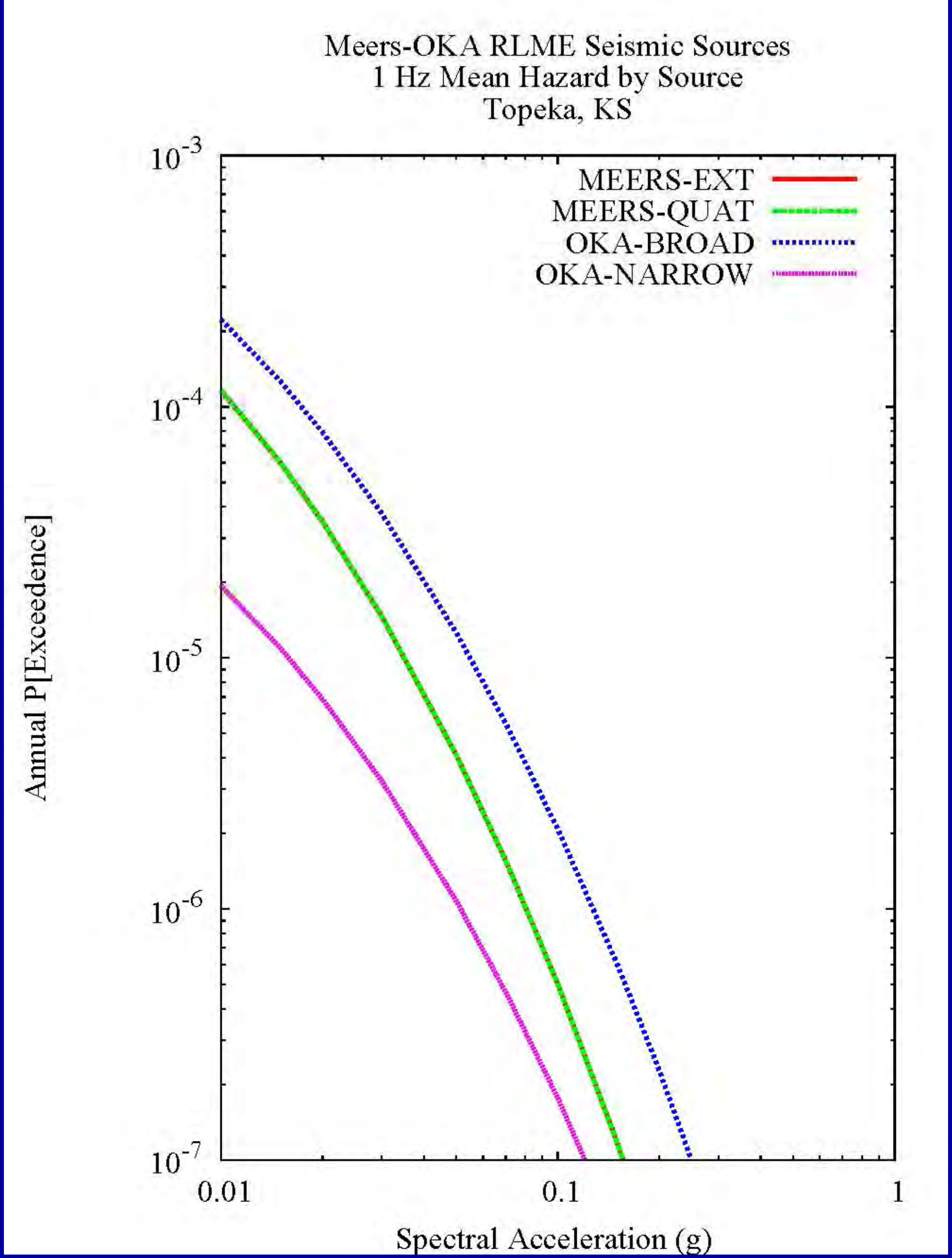
Results for Topeka, KS: OKA-B, PGA, Geometry



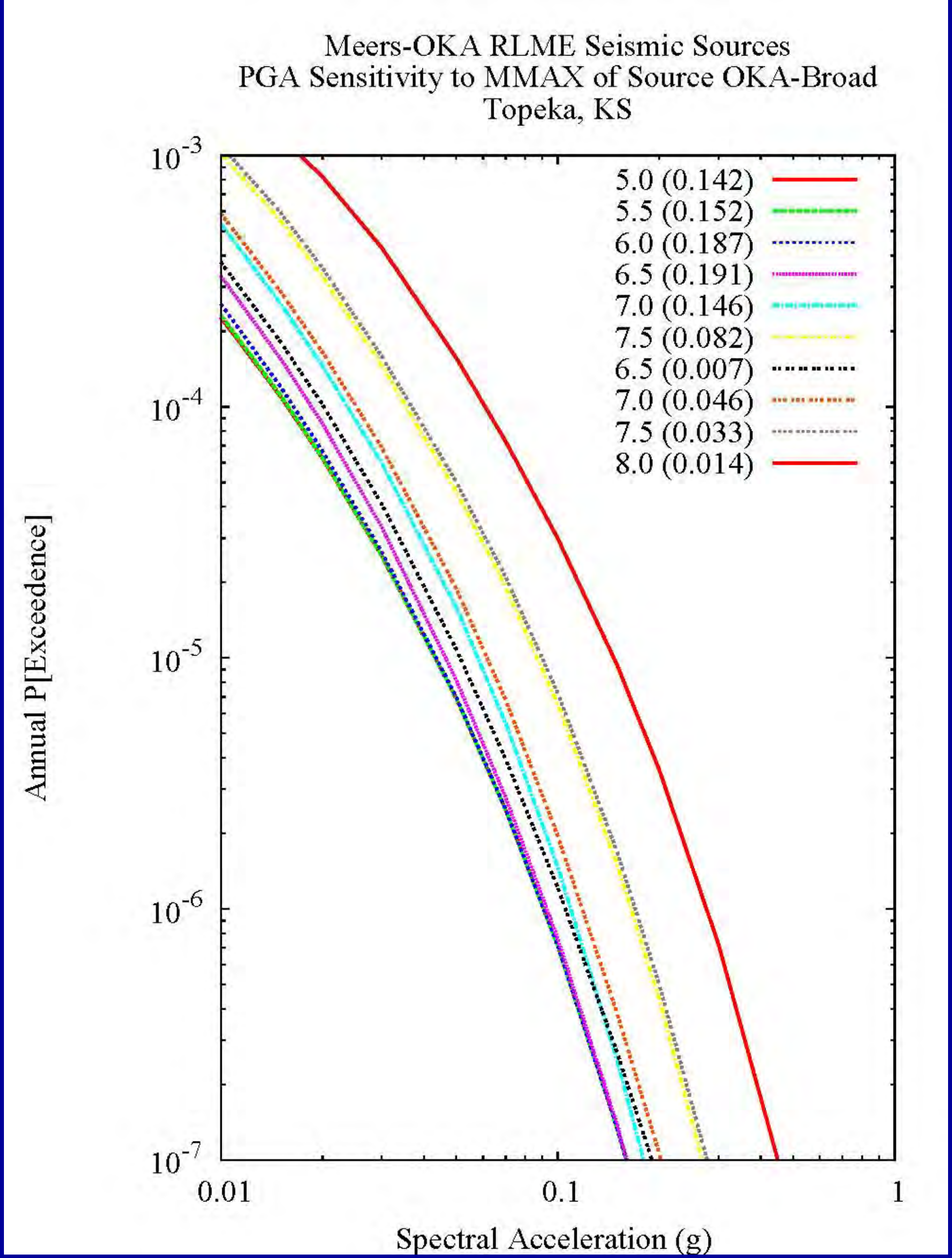
Results for Topeka, KS: OKA-B, 10 Hz, Geometry



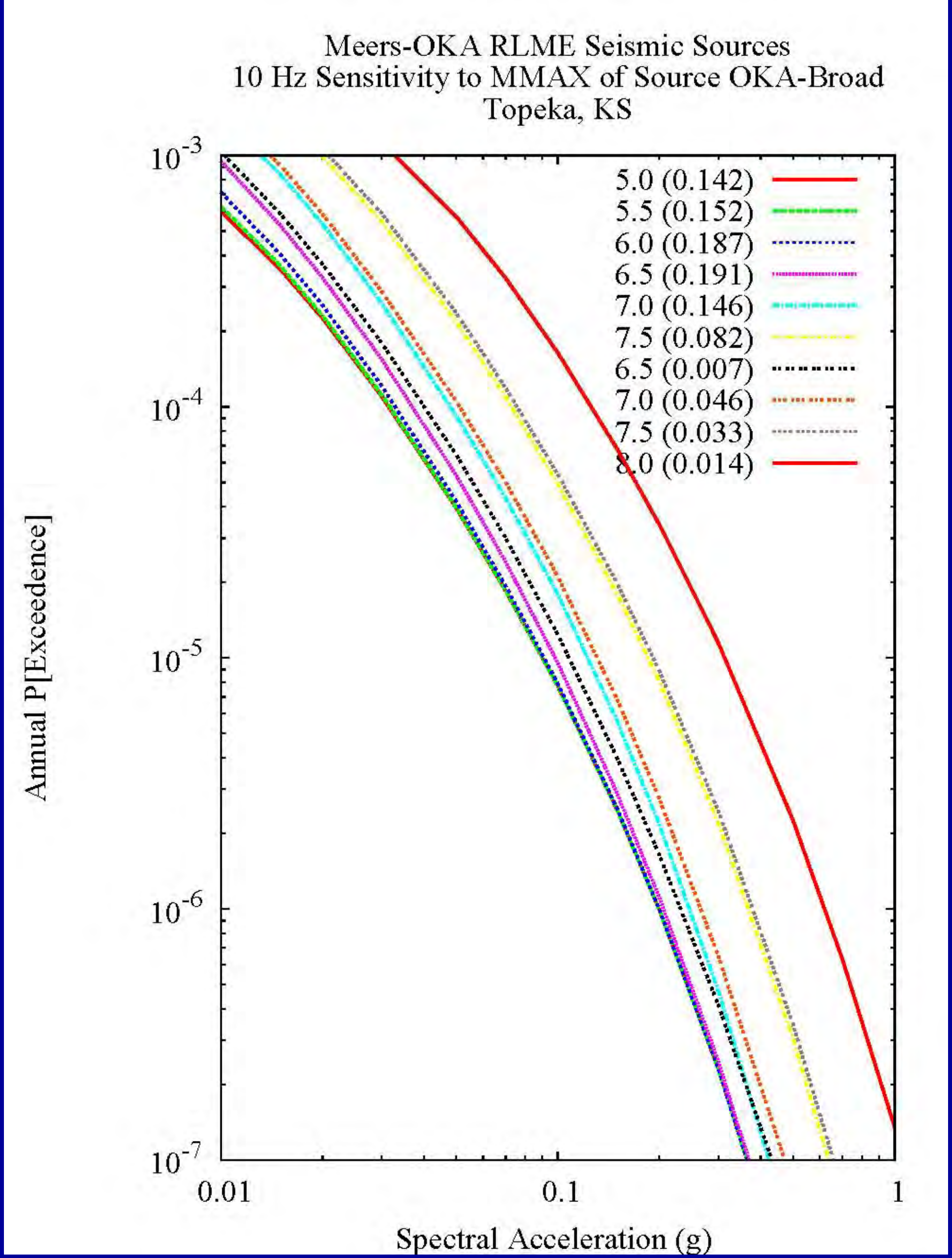
Results for Topeka, KS: OKA-B, 1 Hz, Geometry



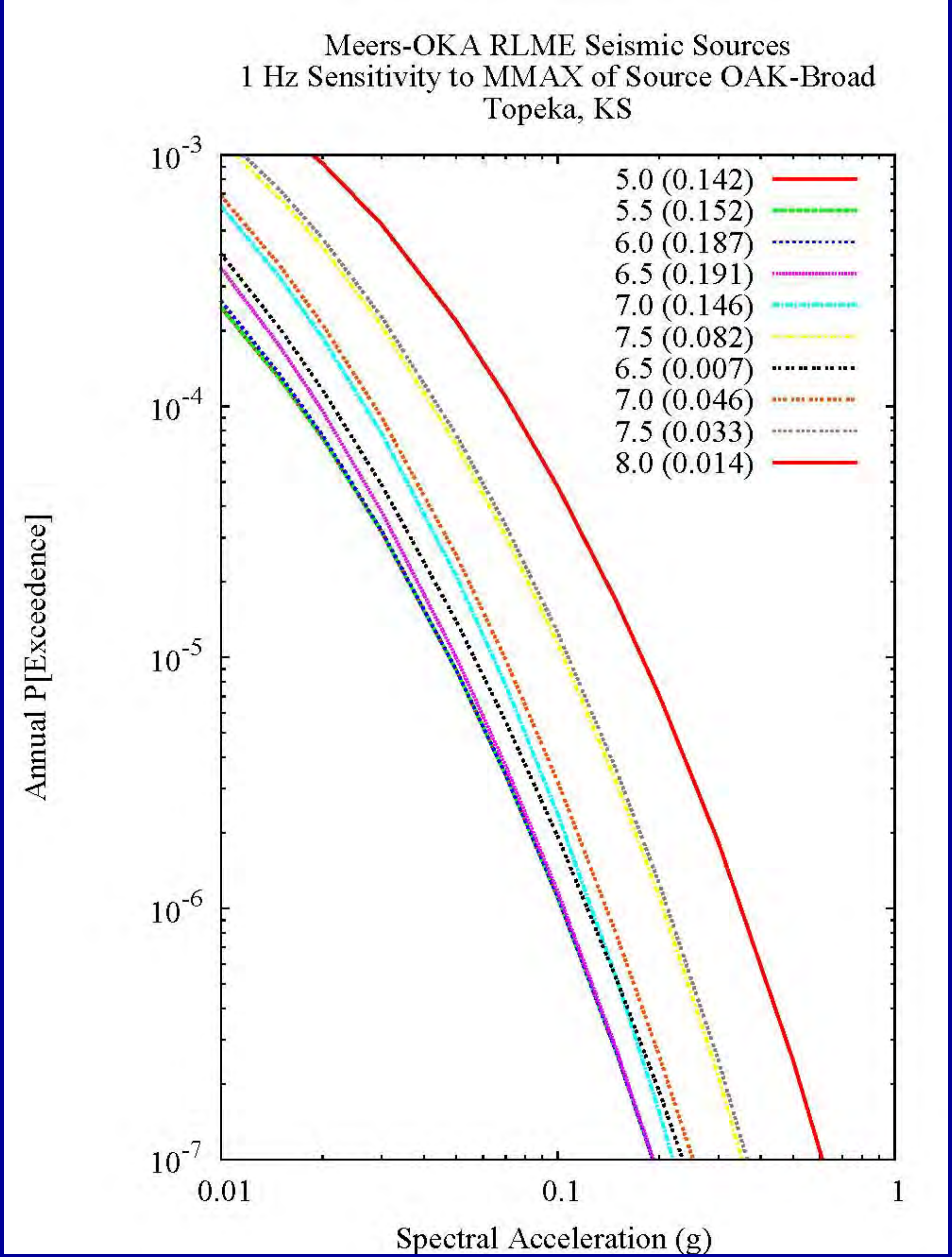
Results for Topeka, KS : OKA-B, PGA, Mmax



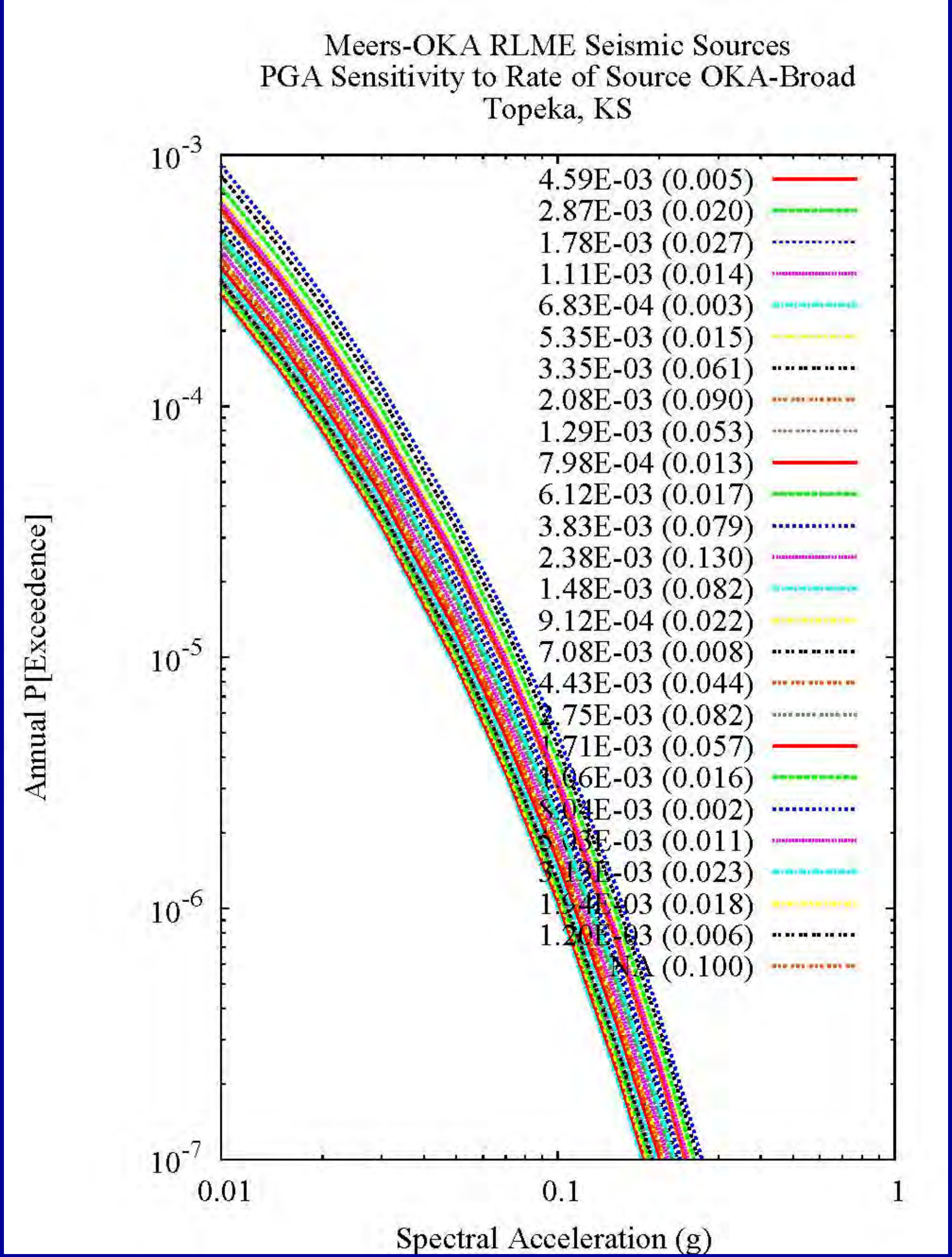
Results for Topeka, KS : OKA-B, 10 Hz, Mmax



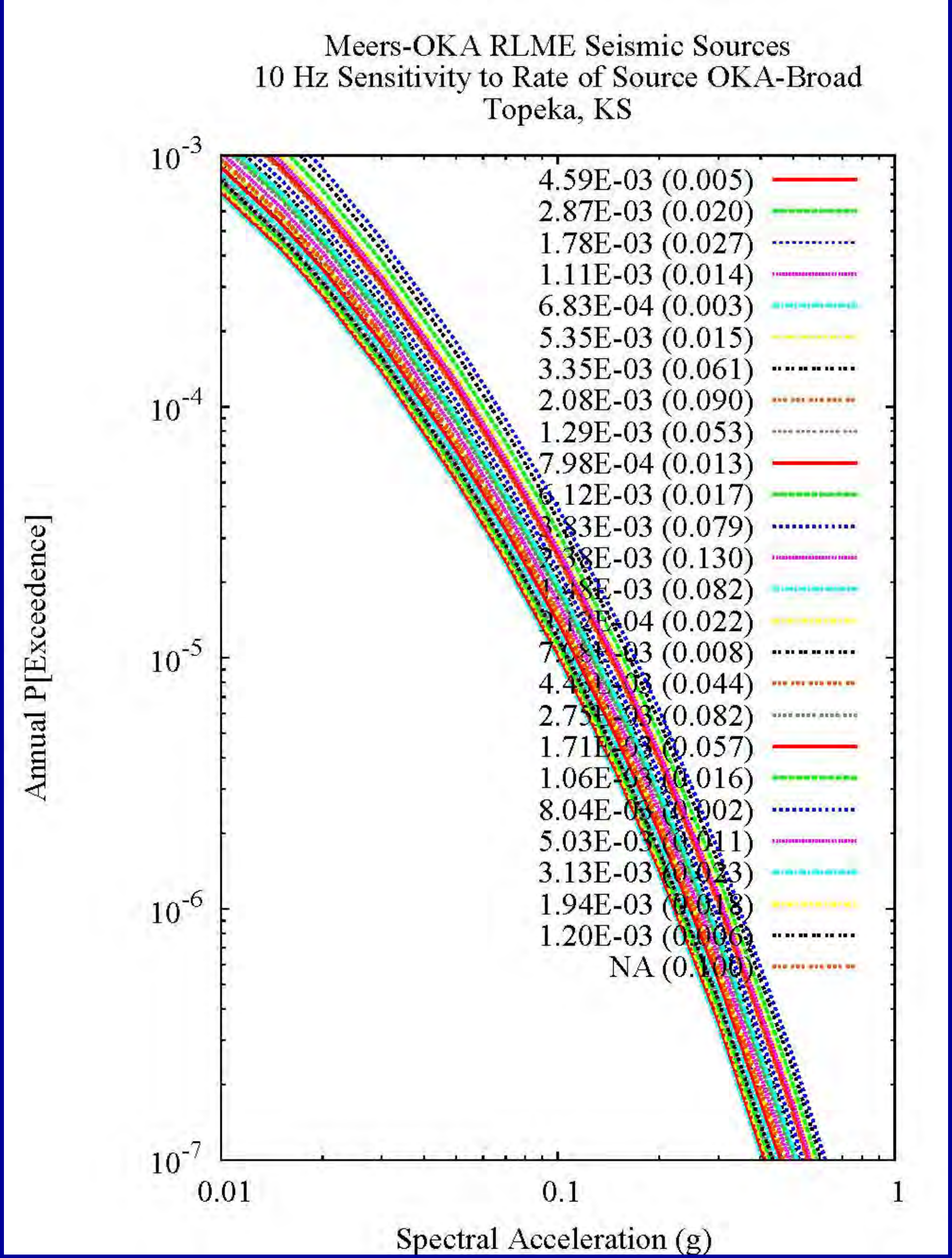
Results for Topeka, KS : OKA-B, 1 Hz, Mmax



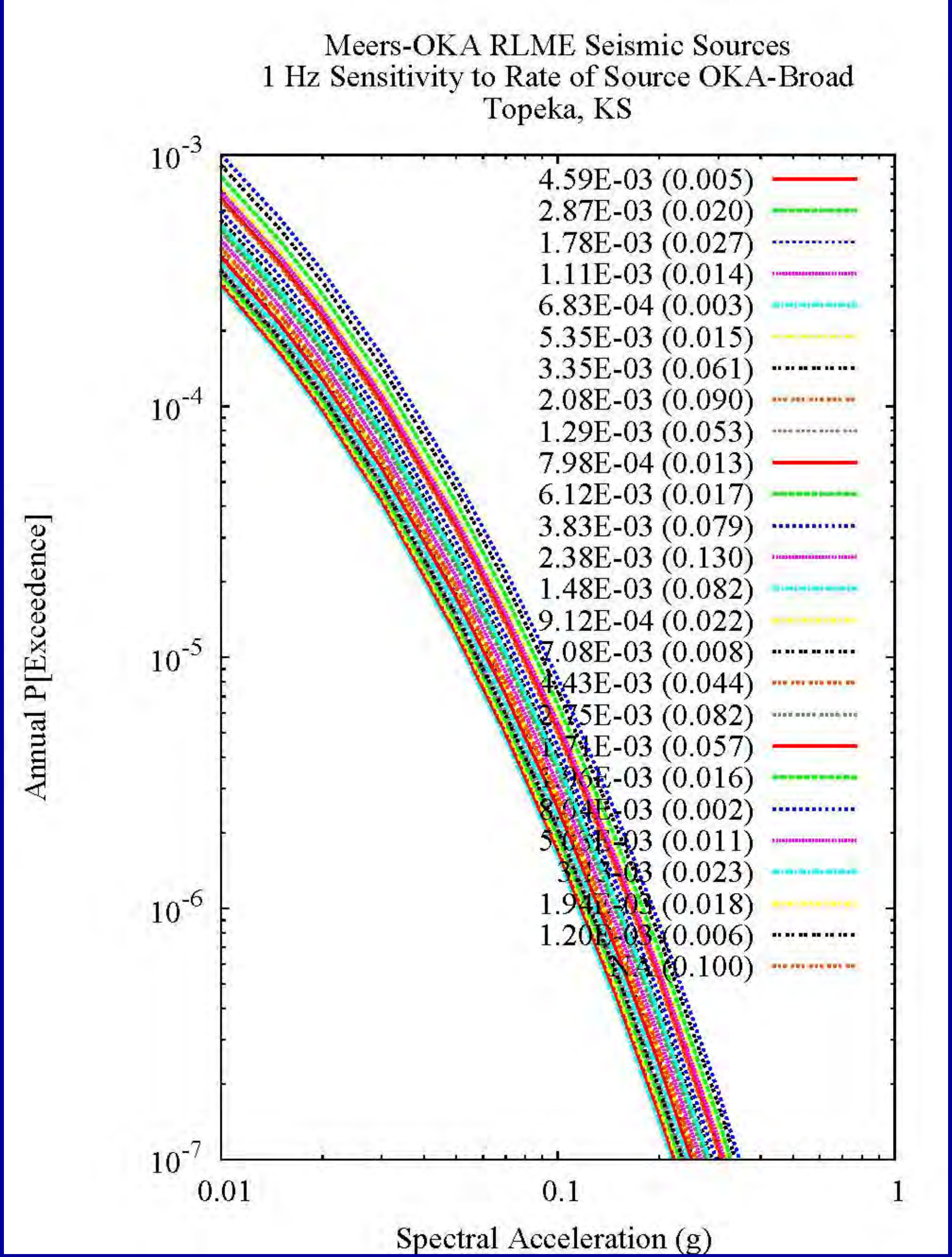
Results for Topeka, KS : OKA-B, PGA, Rate



Results for Topeka, KS : OKA-B, 10 Hz, Rate



Results for Topeka, KS : OKA-B, 1 Hz, Rate



RLME Seismic Source Sensitivity Studies

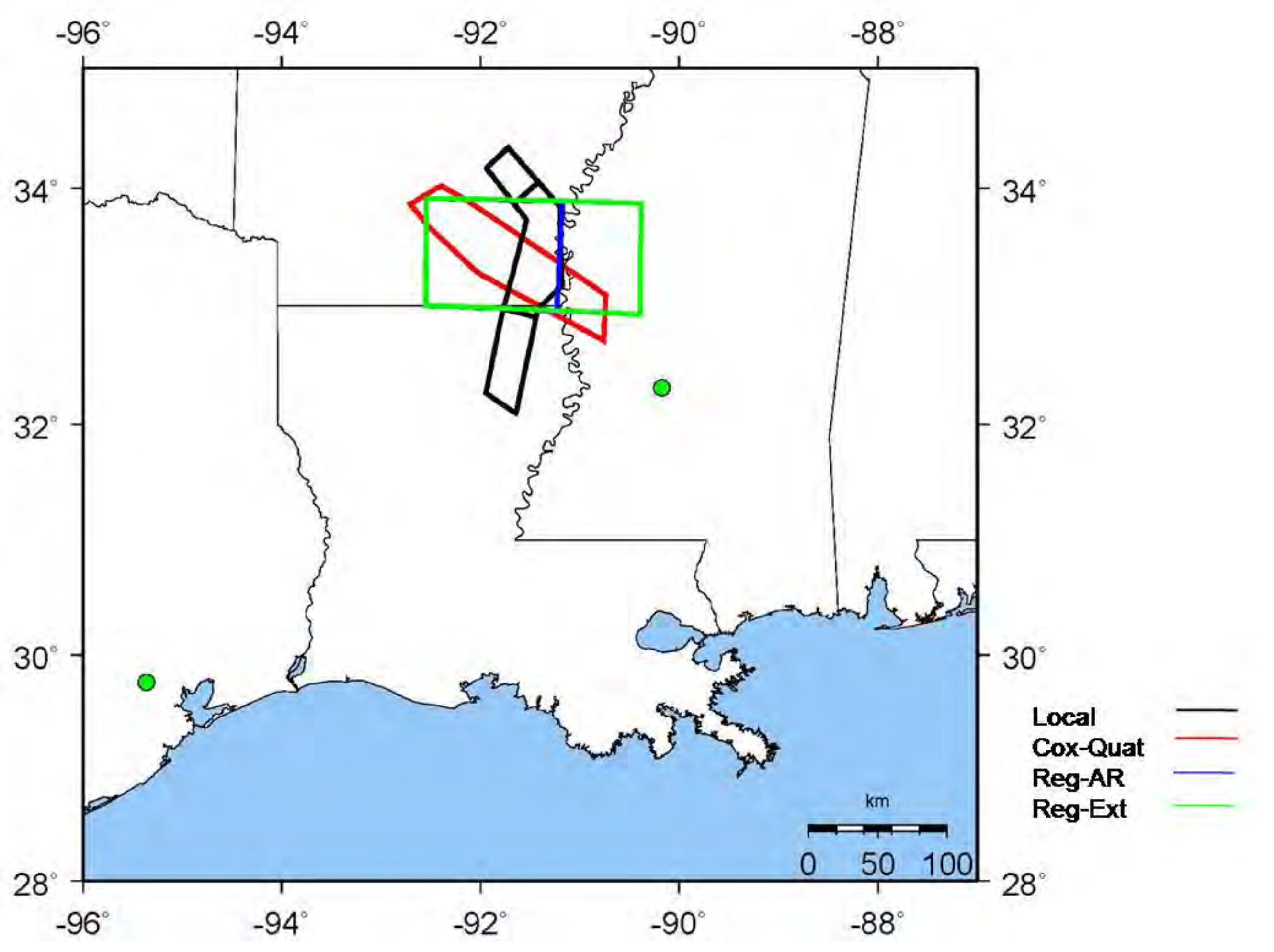
Allison Shumway
William Lettis & Associates, Inc.

Workshop #3
August 25-26, 2009

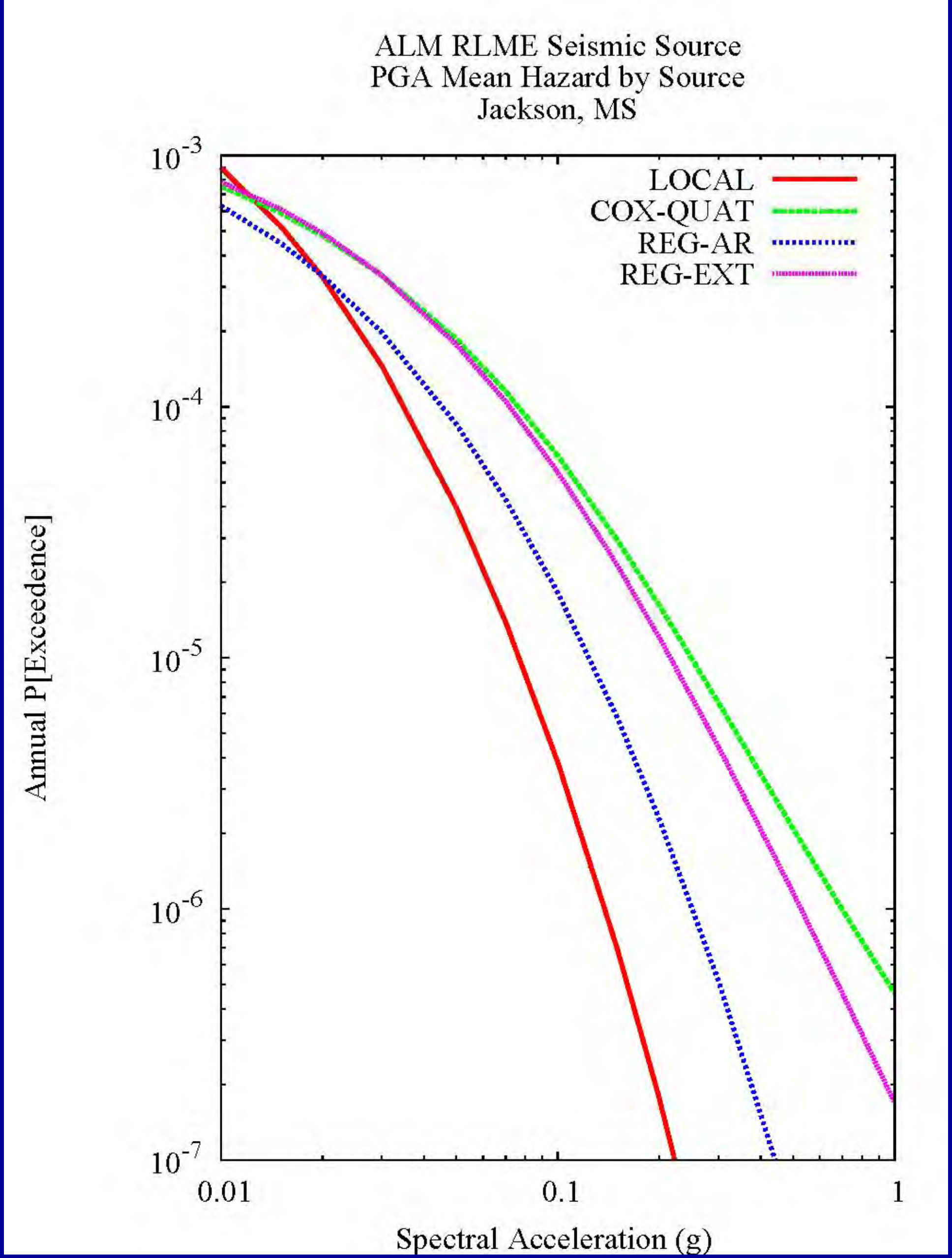
ALM RLME Seismic Source

- Sensitivity studies: geometry, rate, and Mmax
- Sources: Cox-Quat (highest weighted source)
- Special Case: Fault Rupture Sensitivity: Leaky vs. Strict
- Frequencies: PGA, 10 Hz, and 1 Hz
- Site 1: Jackson, MS
- Site 2: Houston, TX

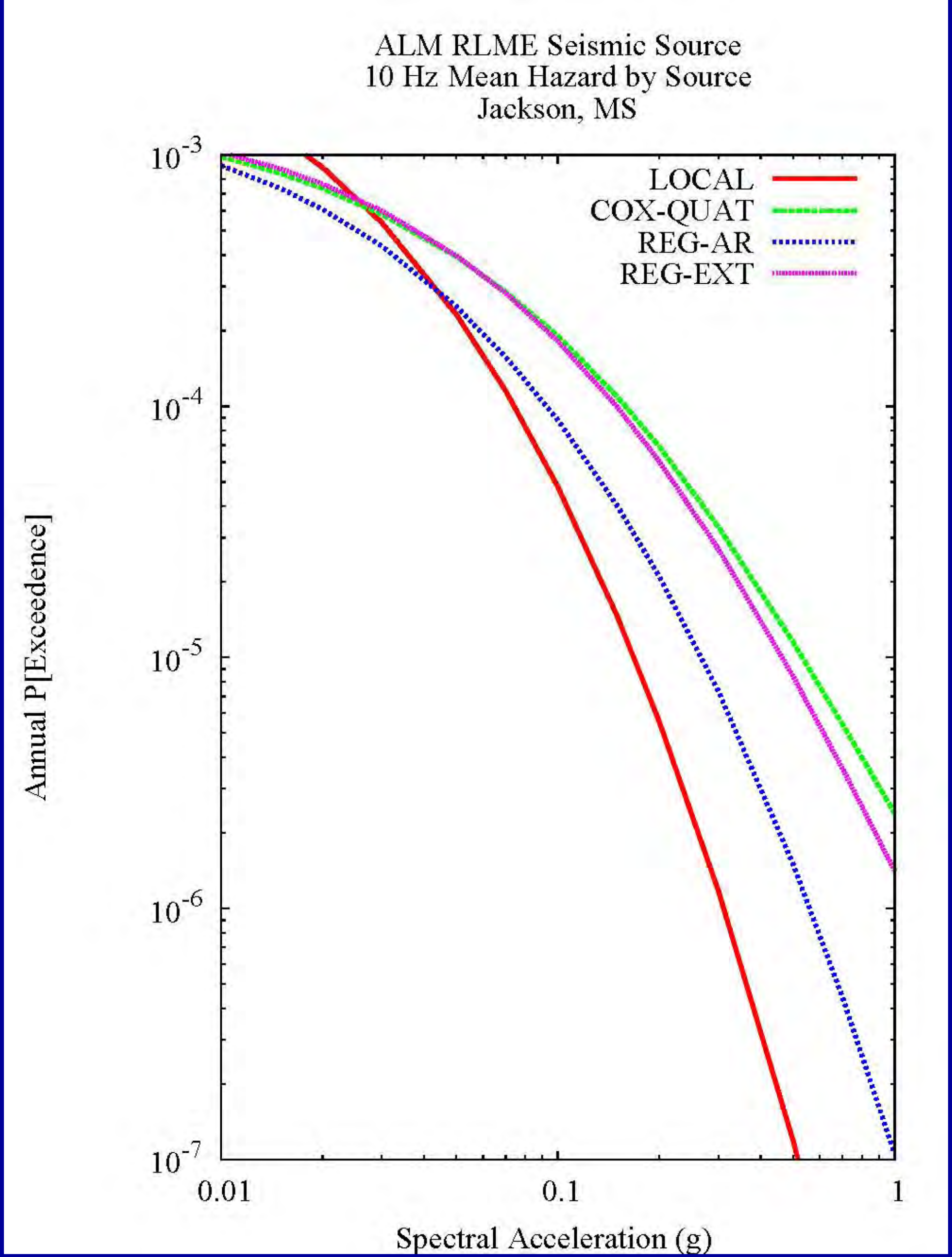
ALM RLME Seismic Source Location and Test Site Locations: Jackson, MS and Houston, TX



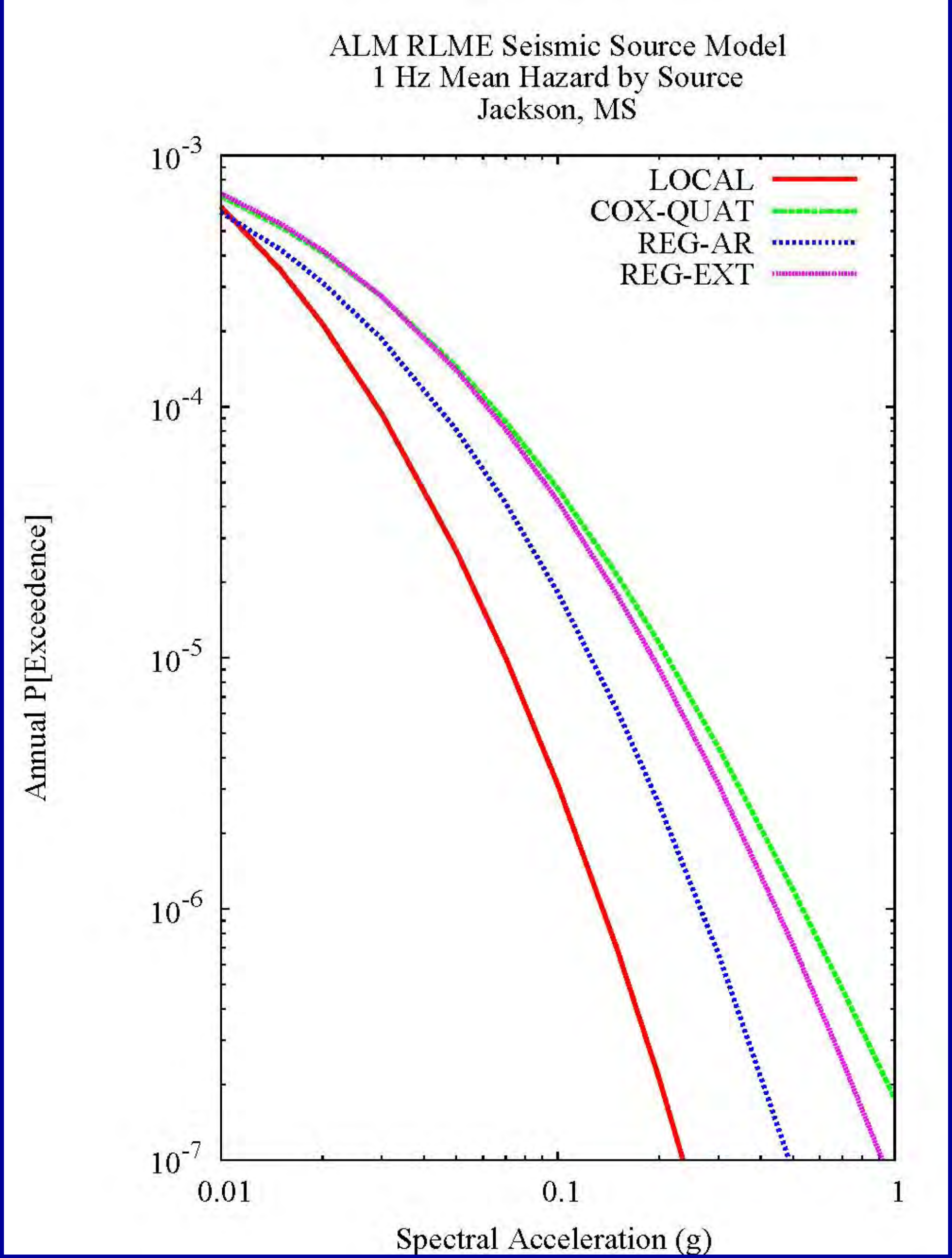
Results for Jackson, MS: Leaky, PGA, Geometry



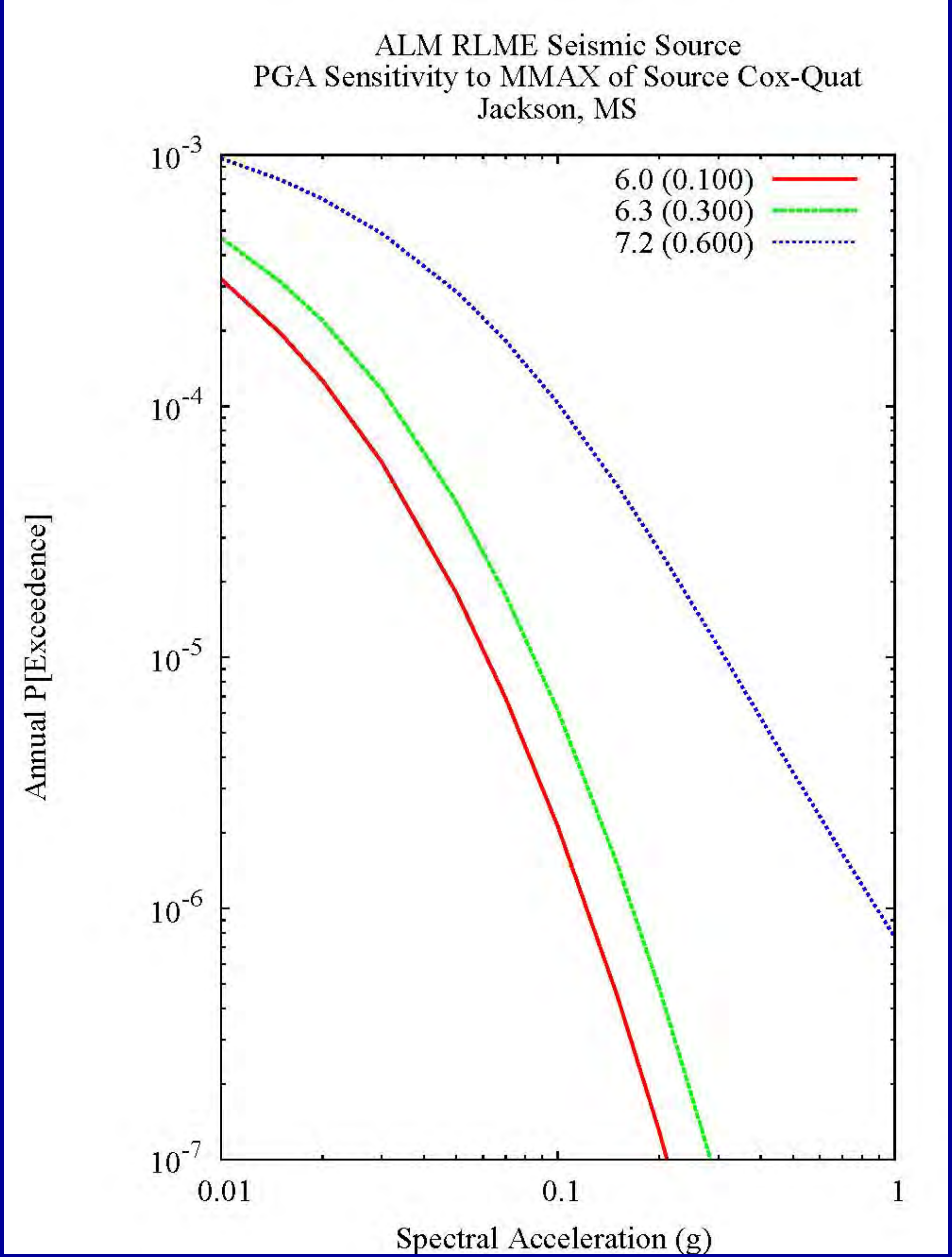
Results for Jackson, MS: Leaky, 10 Hz, Geometry



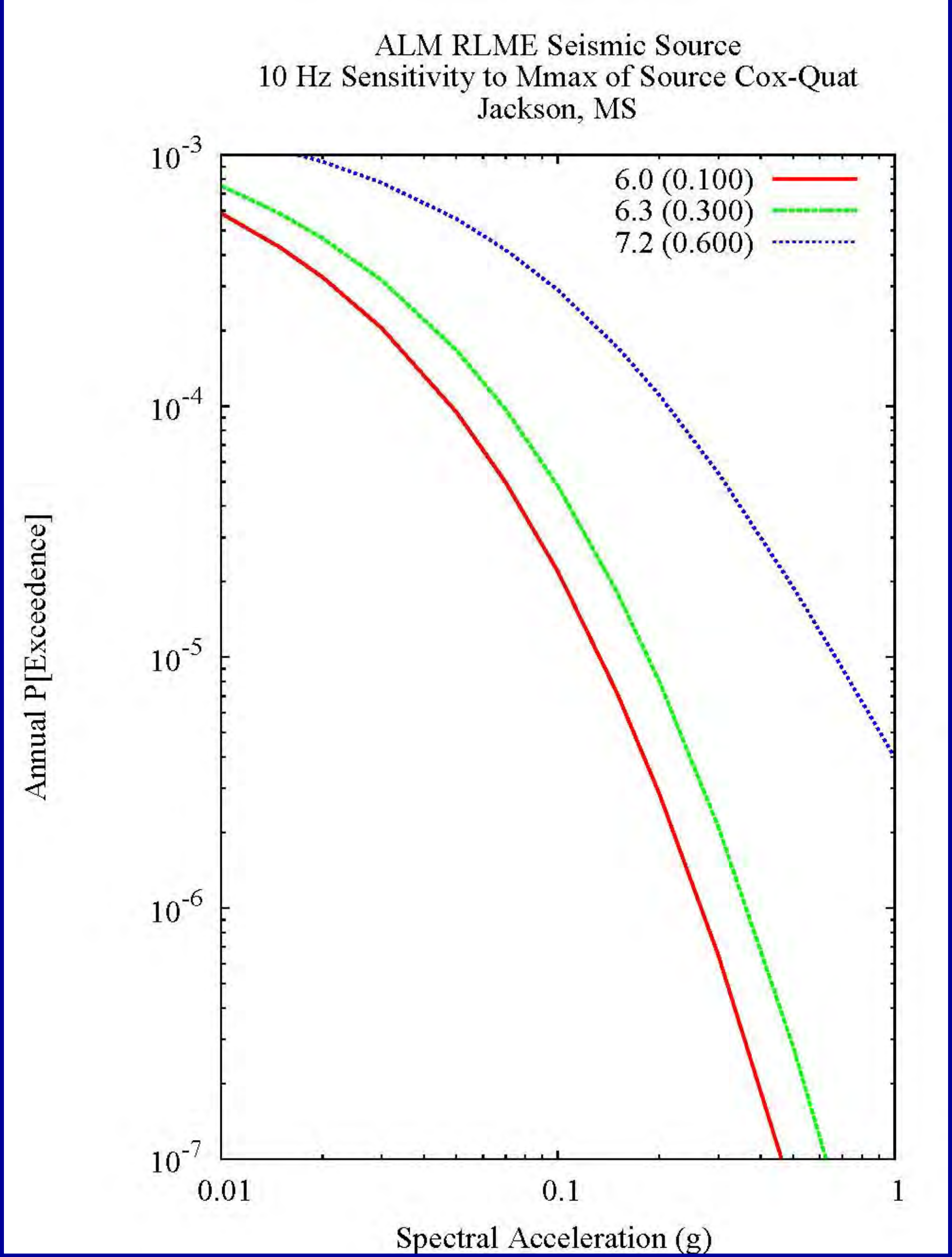
Results for Jackson, MS: Leaky, 1 Hz, Geometry



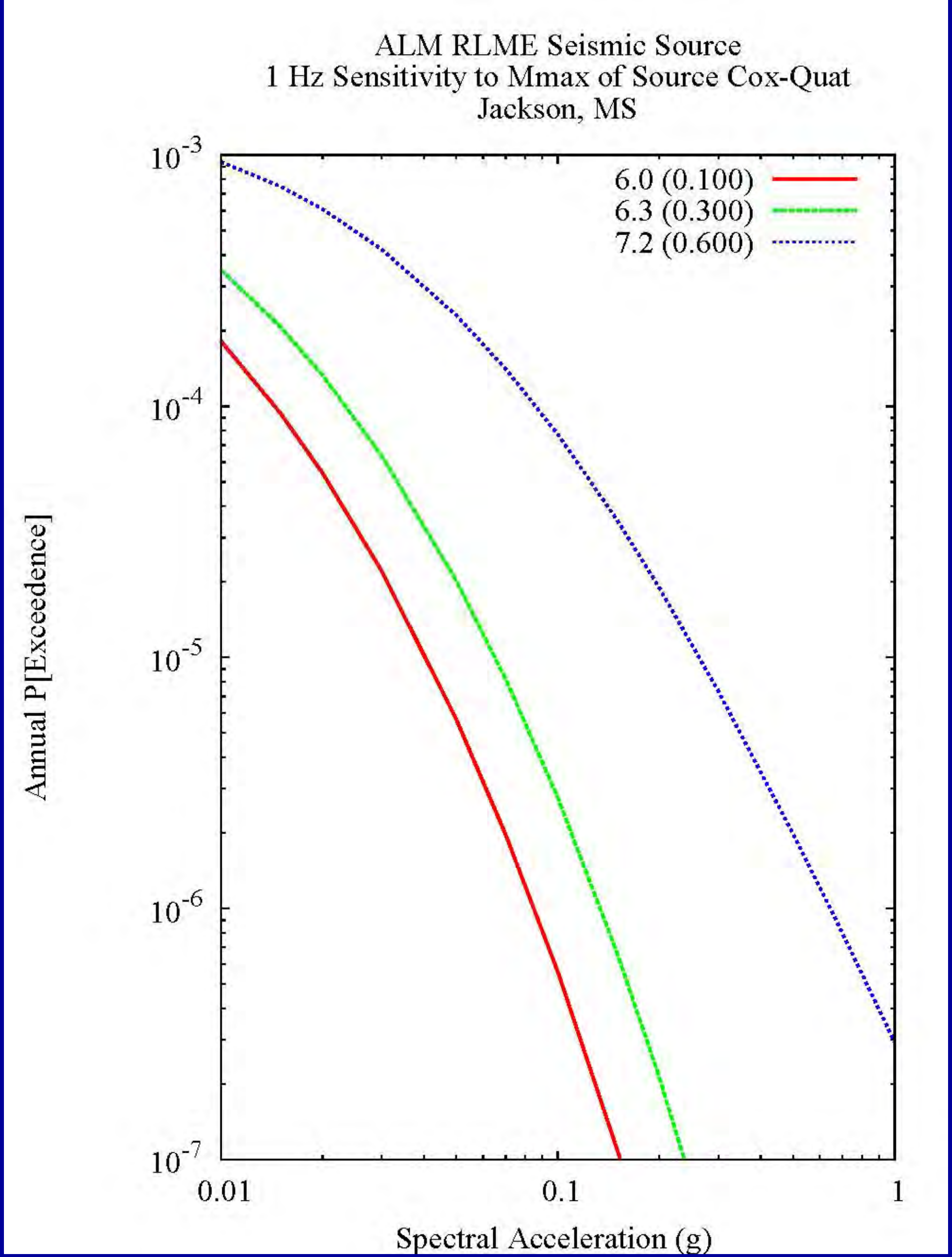
Results for Jackson, MS : Leaky, Cox-Quat Source, PGA, Mmax



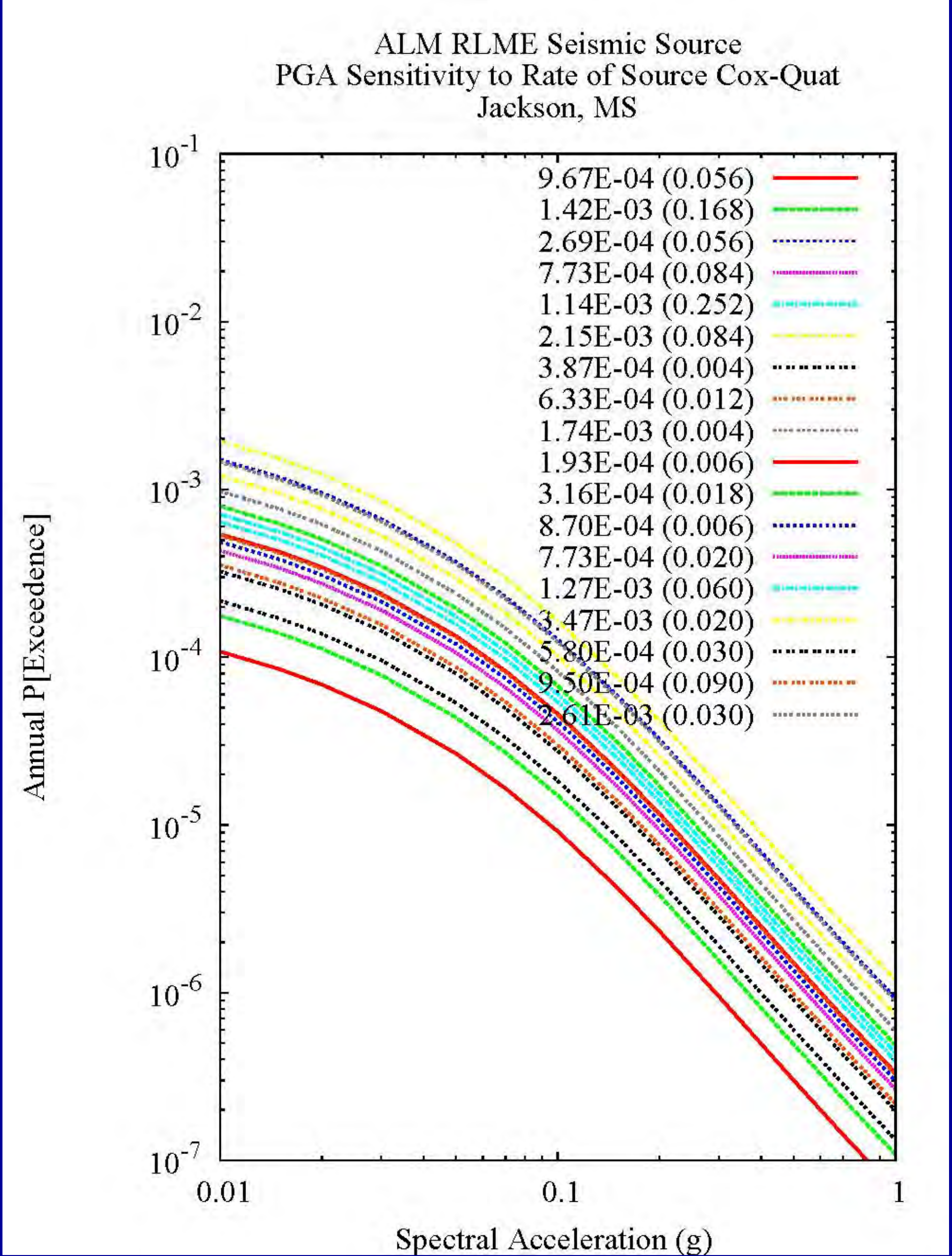
Results for Jackson, MS : Leaky, Cox-Quat Source,10 Hz, Mmax



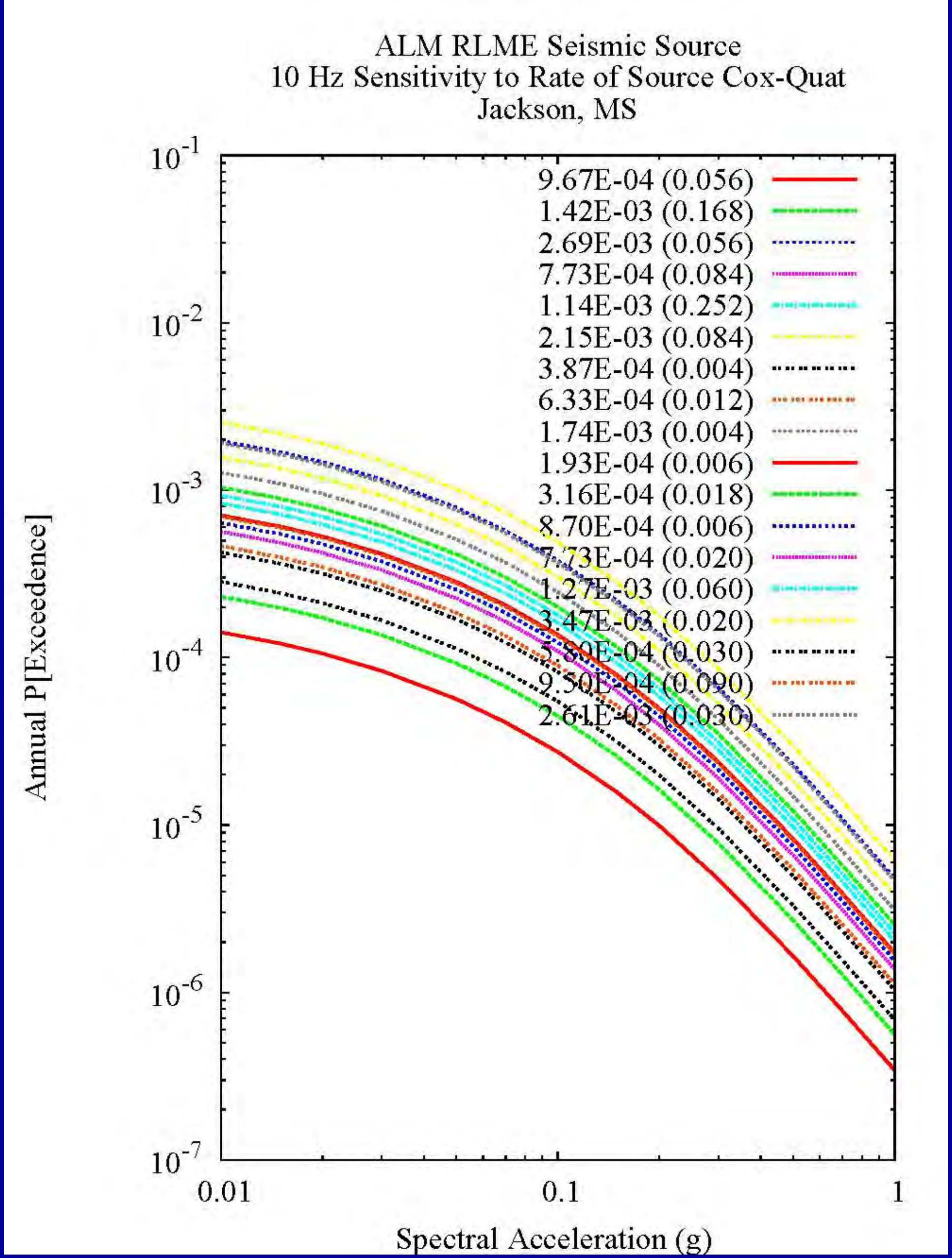
Results for Jackson, MS : Leaky, Cox-Quat Source, 1 Hz, Mmax



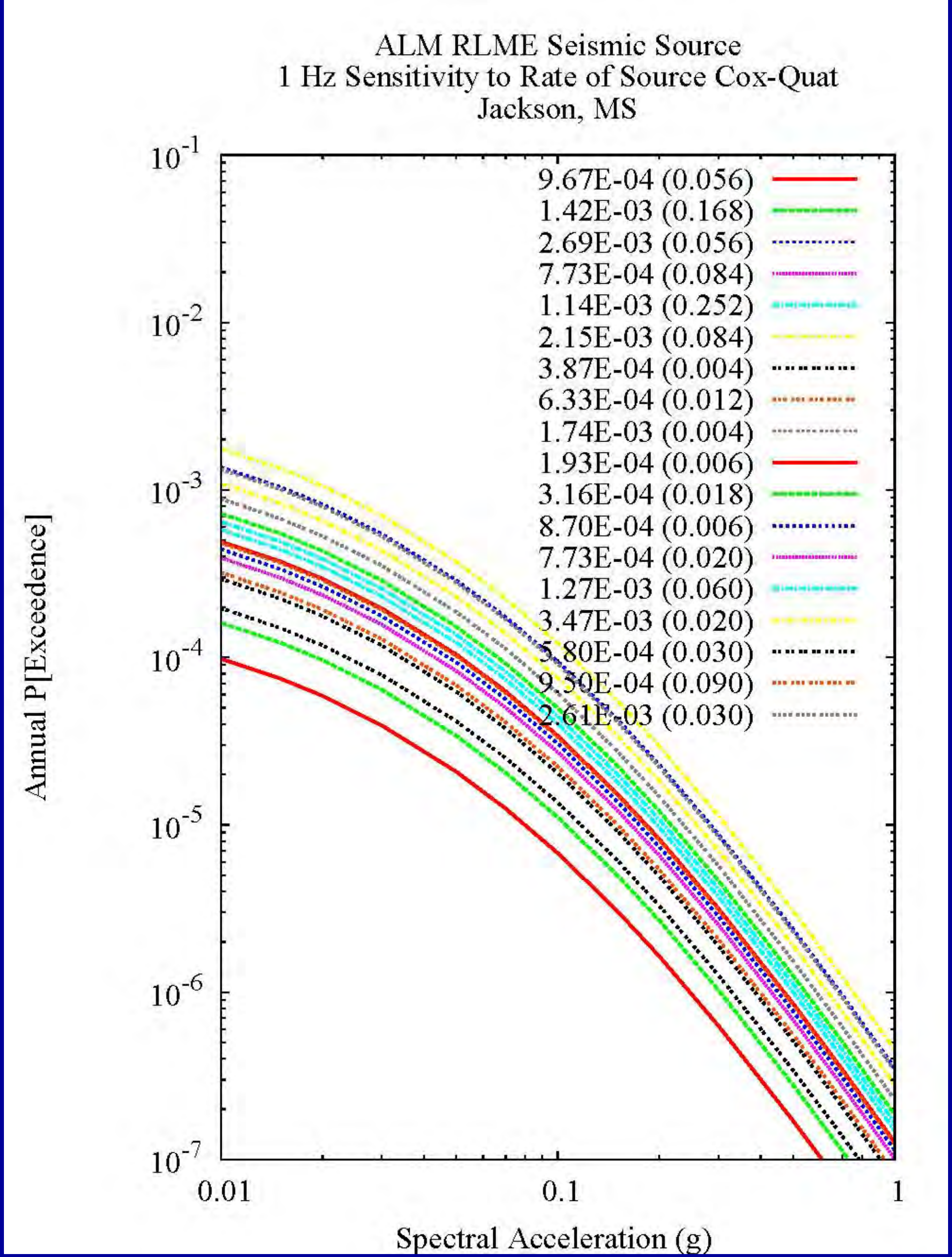
Results for Jackson, MS : Leaky, Cox-Quat Source, PGA, Rate



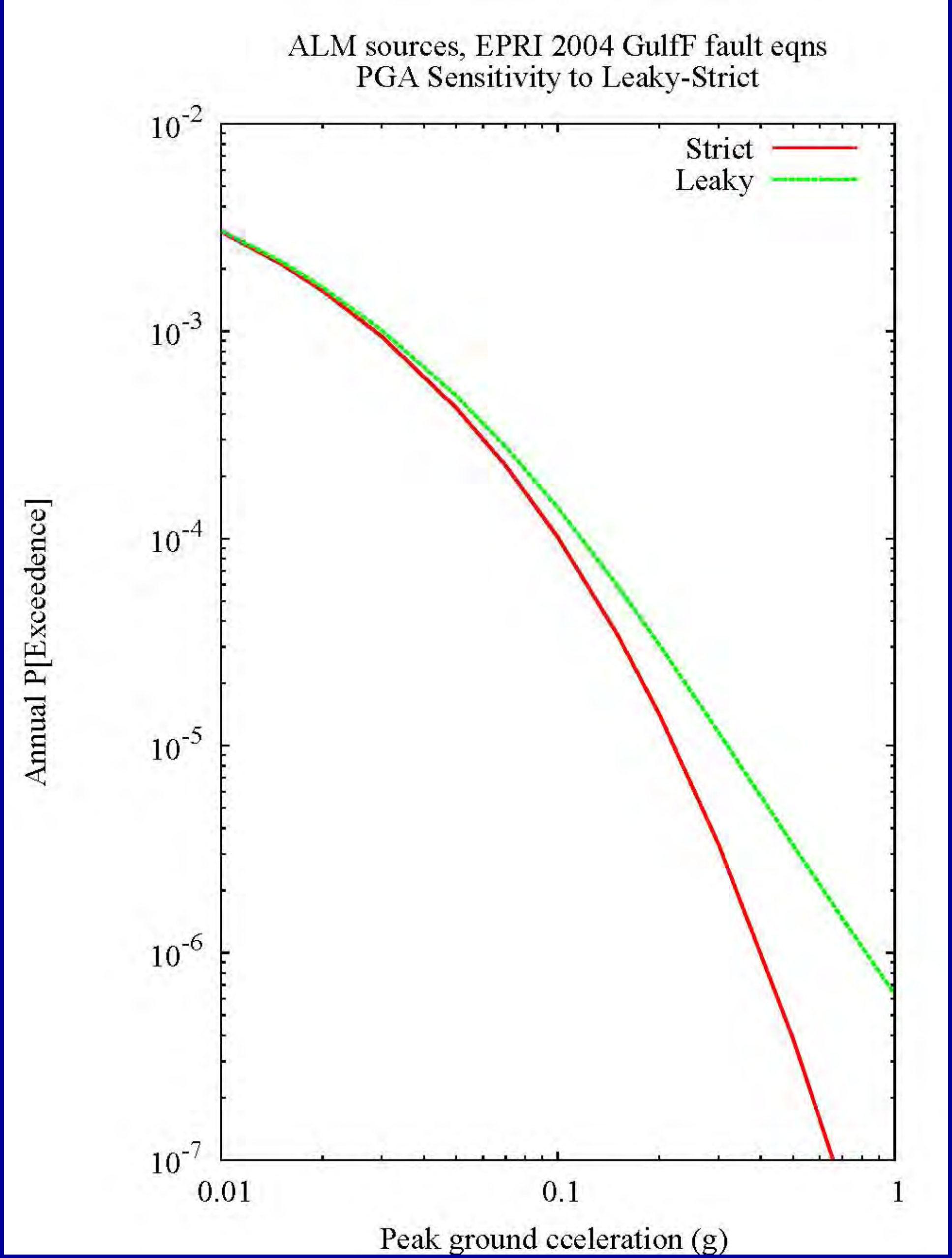
Results for Jackson, MS : Leaky, Cox-Quat Source, 10 Hz, Rate



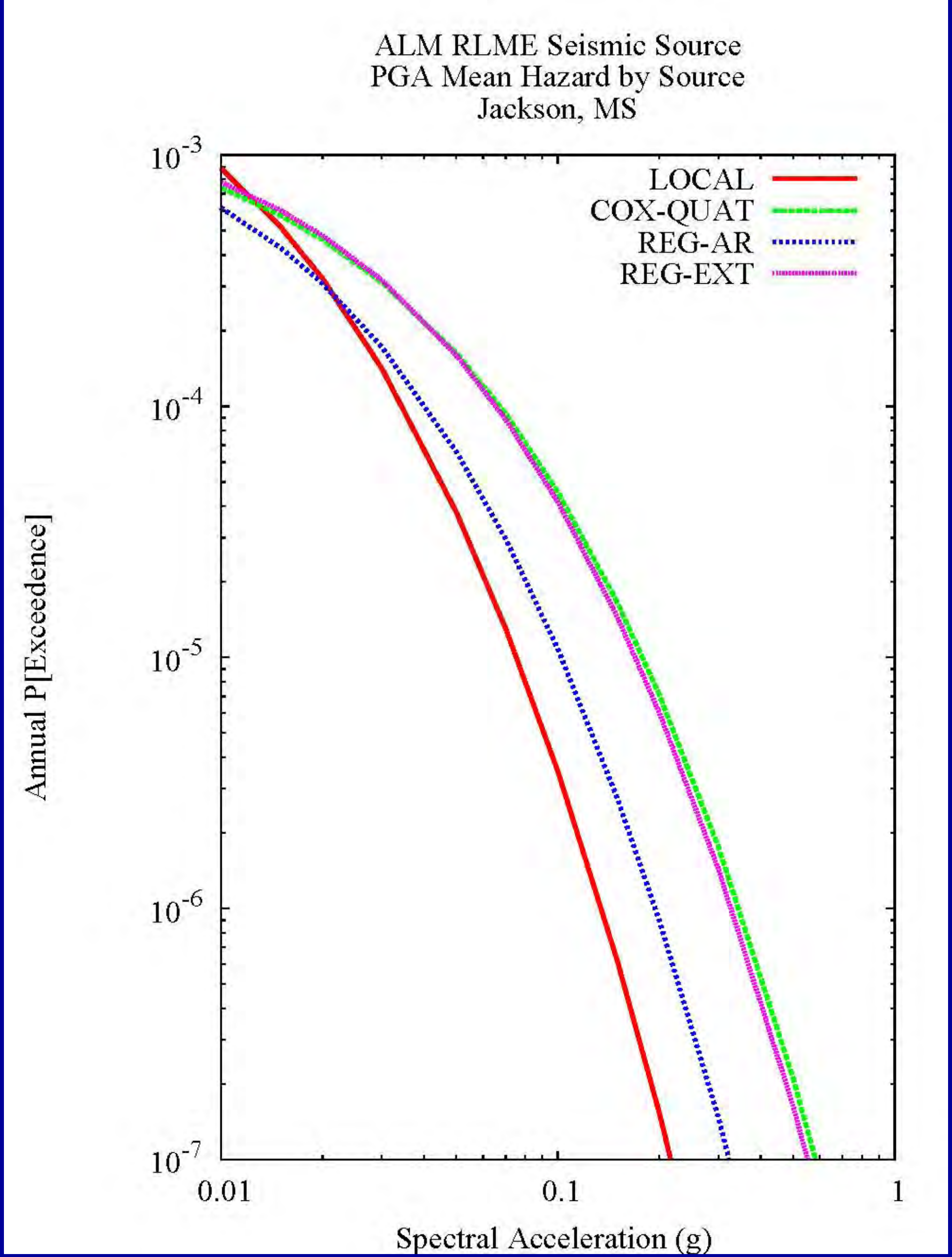
Results for Jackson, MS : Leaky, Cox-Quat Source, 1 Hz, Rate



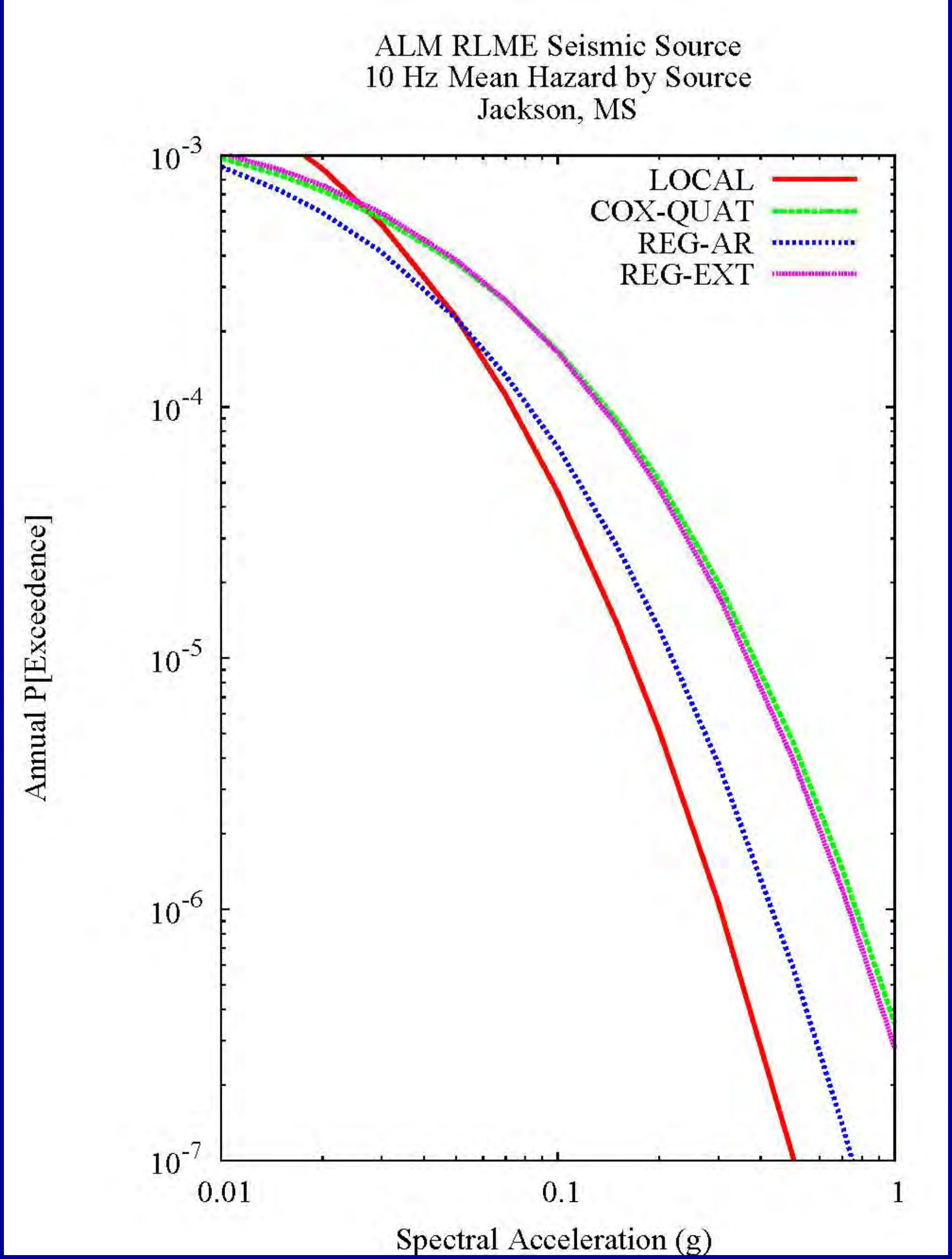
Results for Jackson, MS : Leaky VS. Strict Comparison at PGA



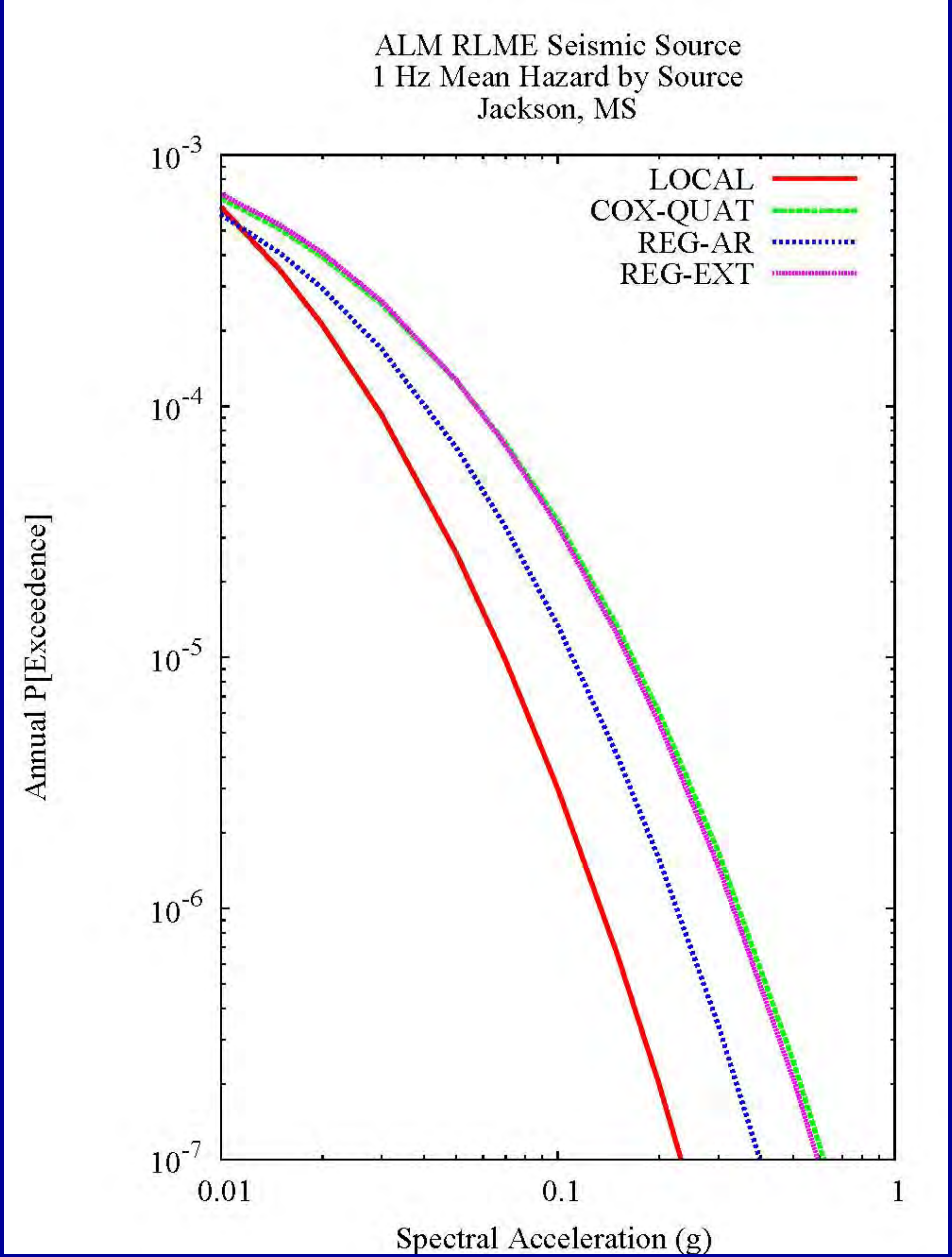
Results for Jackson, MS: Strict, PGA, Geometry



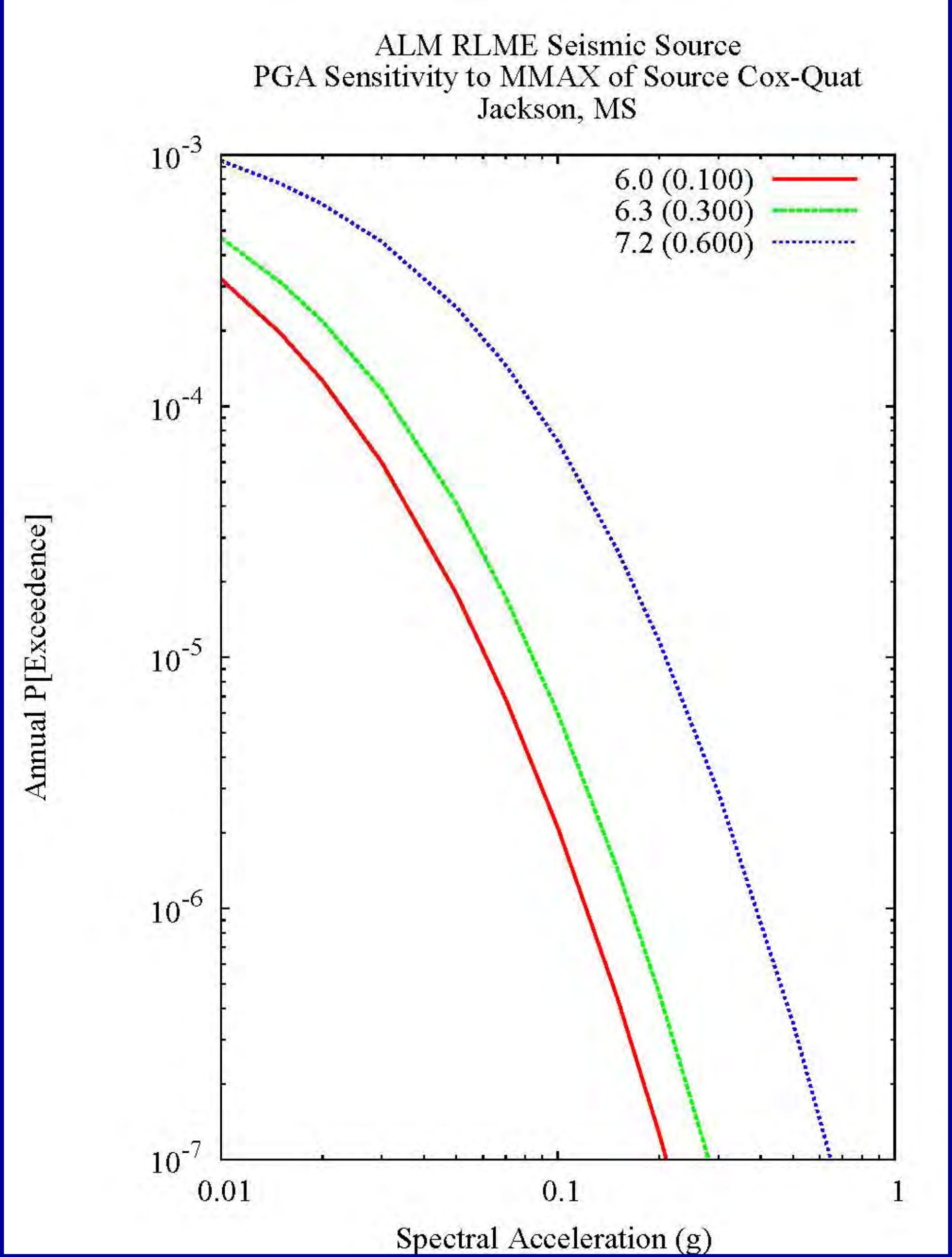
Results for Jackson, MS: Strict, 10 Hz, Geometry



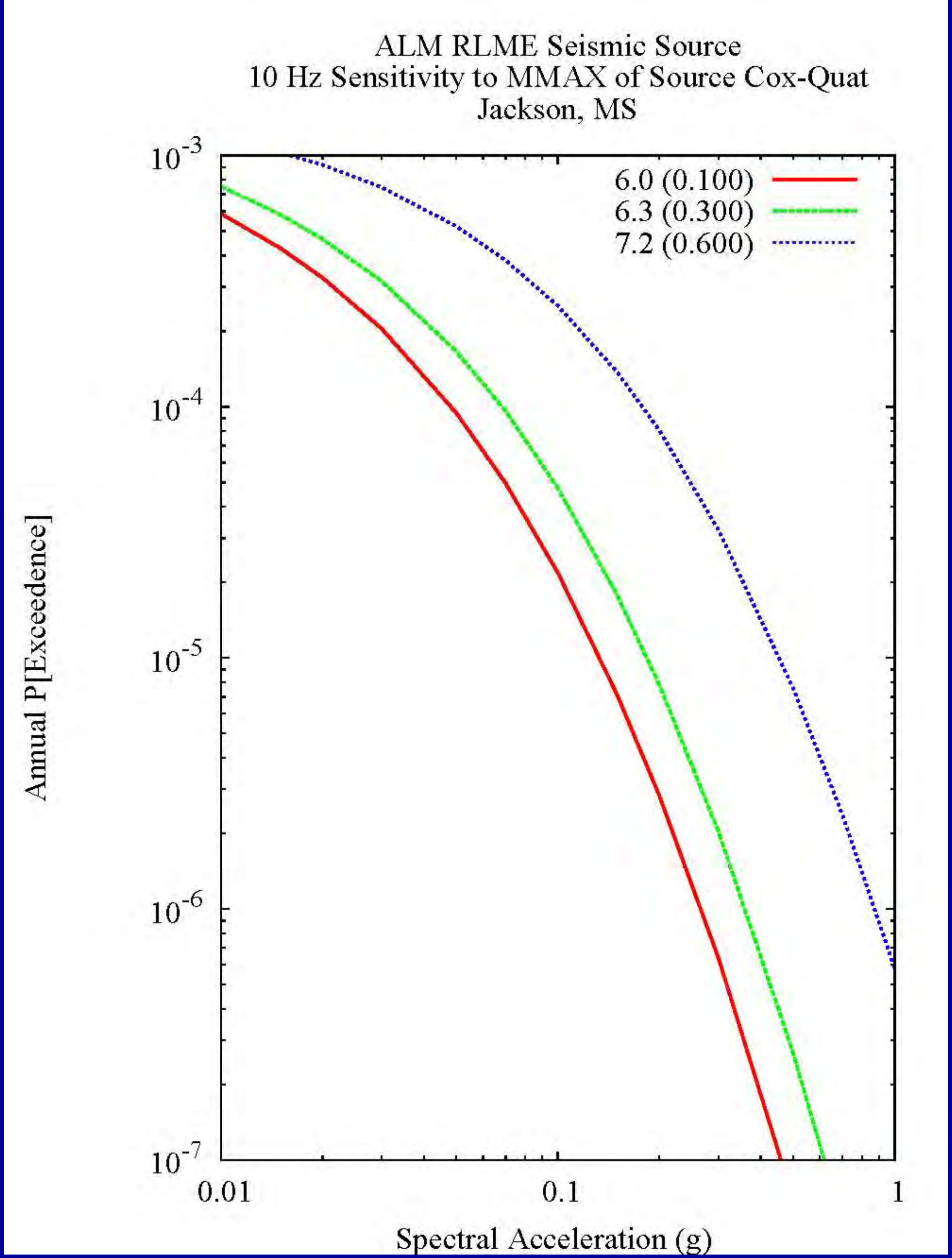
Results for Jackson, MS: Strict, 1 Hz, Geometry



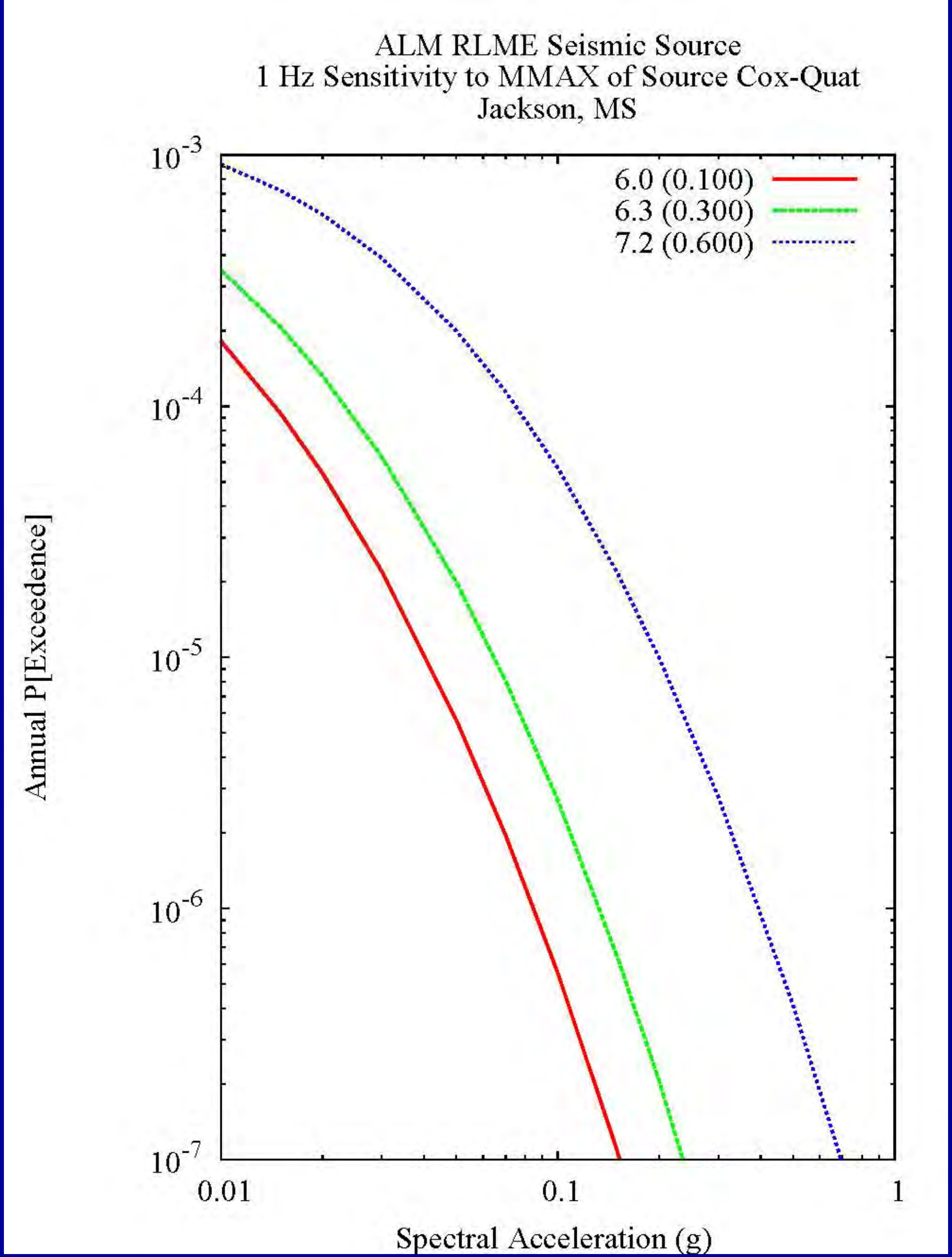
Results for Jackson, MS : Strict, Cox-Quat Source, PGA, Mmax



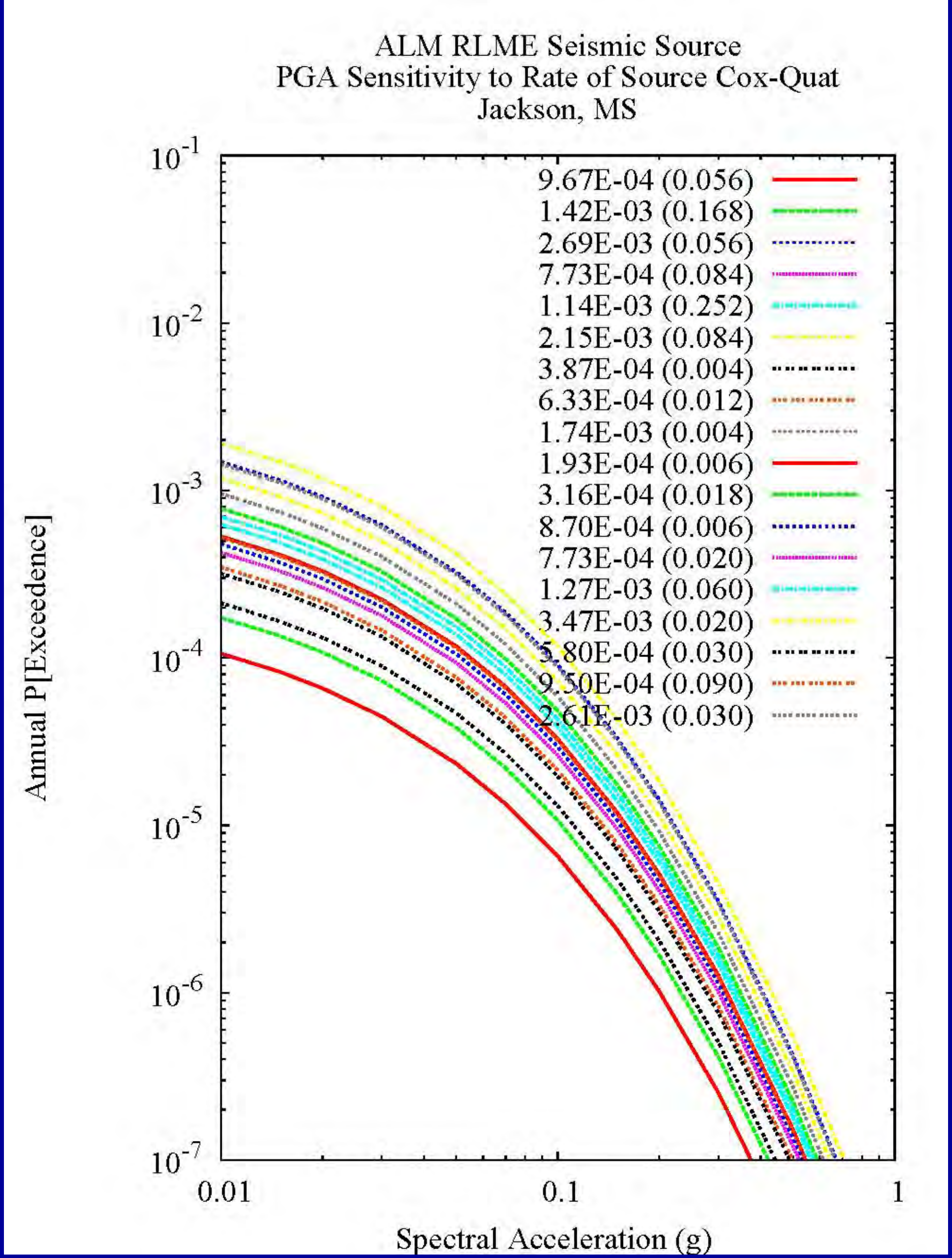
Results for Jackson, MS : Strict, Cox-Quat Source,10 Hz, Mmax



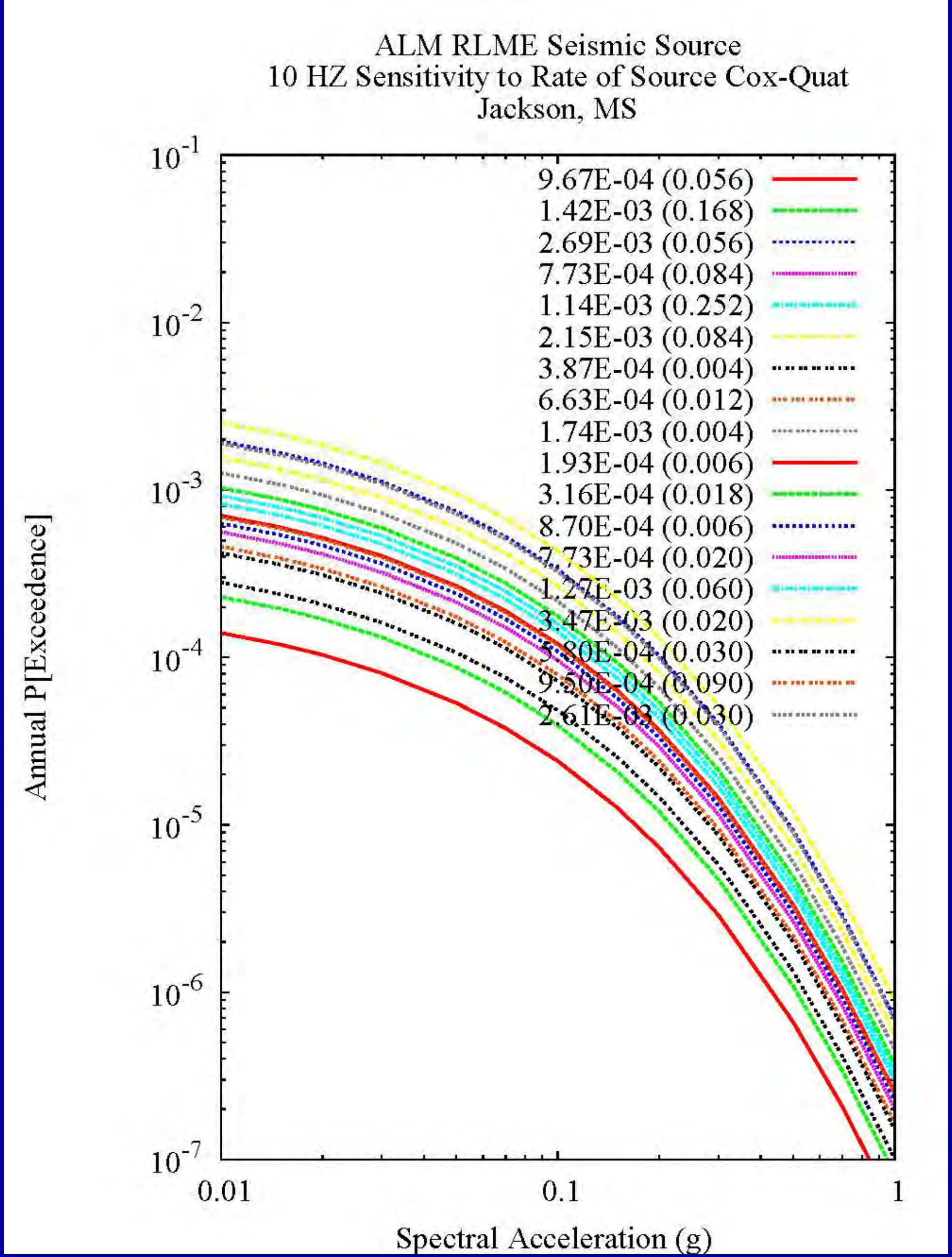
Results for Jackson, MS : Strict, Cox-Quat Source, 1 Hz, Mmax



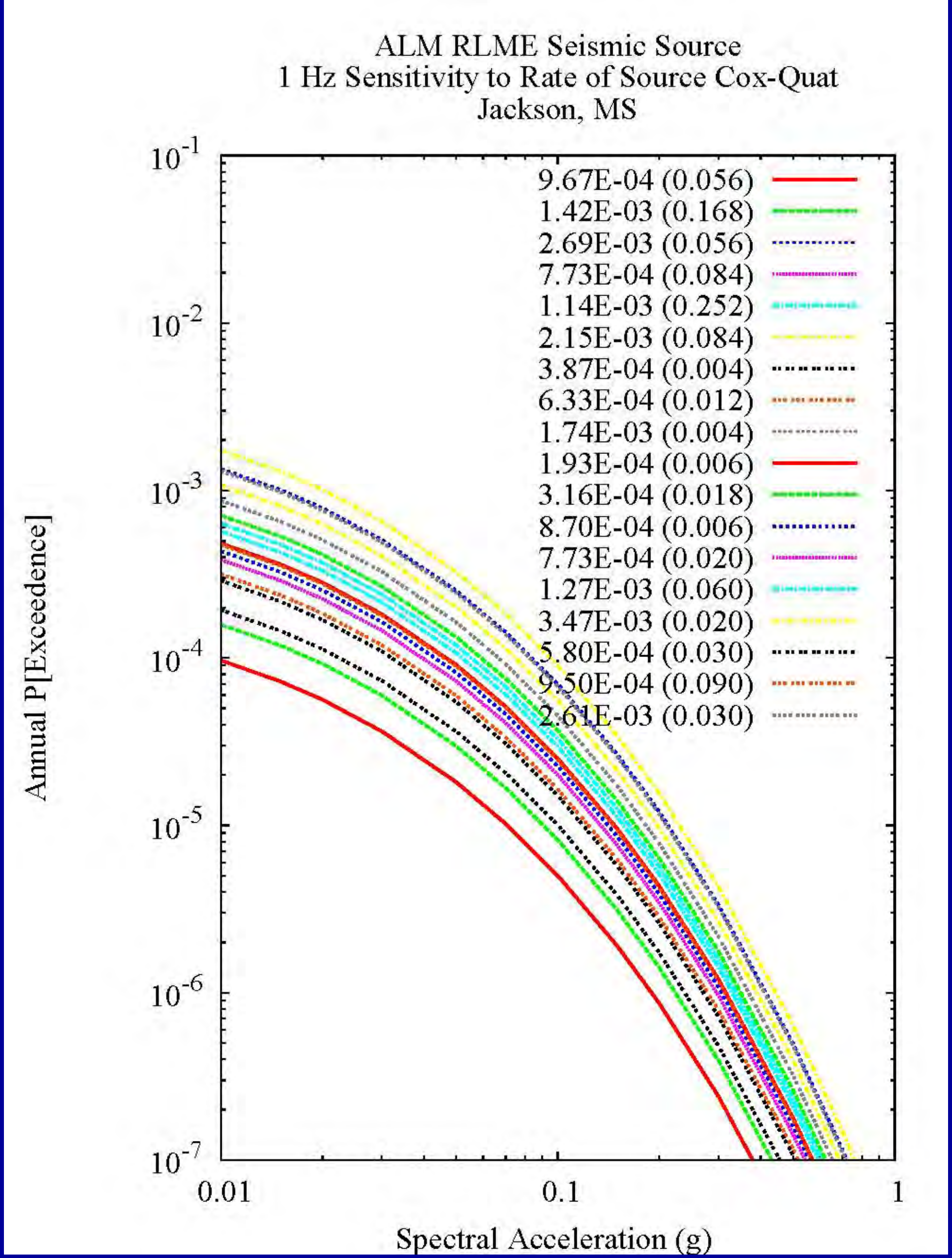
Results for Jackson, MS : Strict, Cox-Quat Source, PGA, Rate



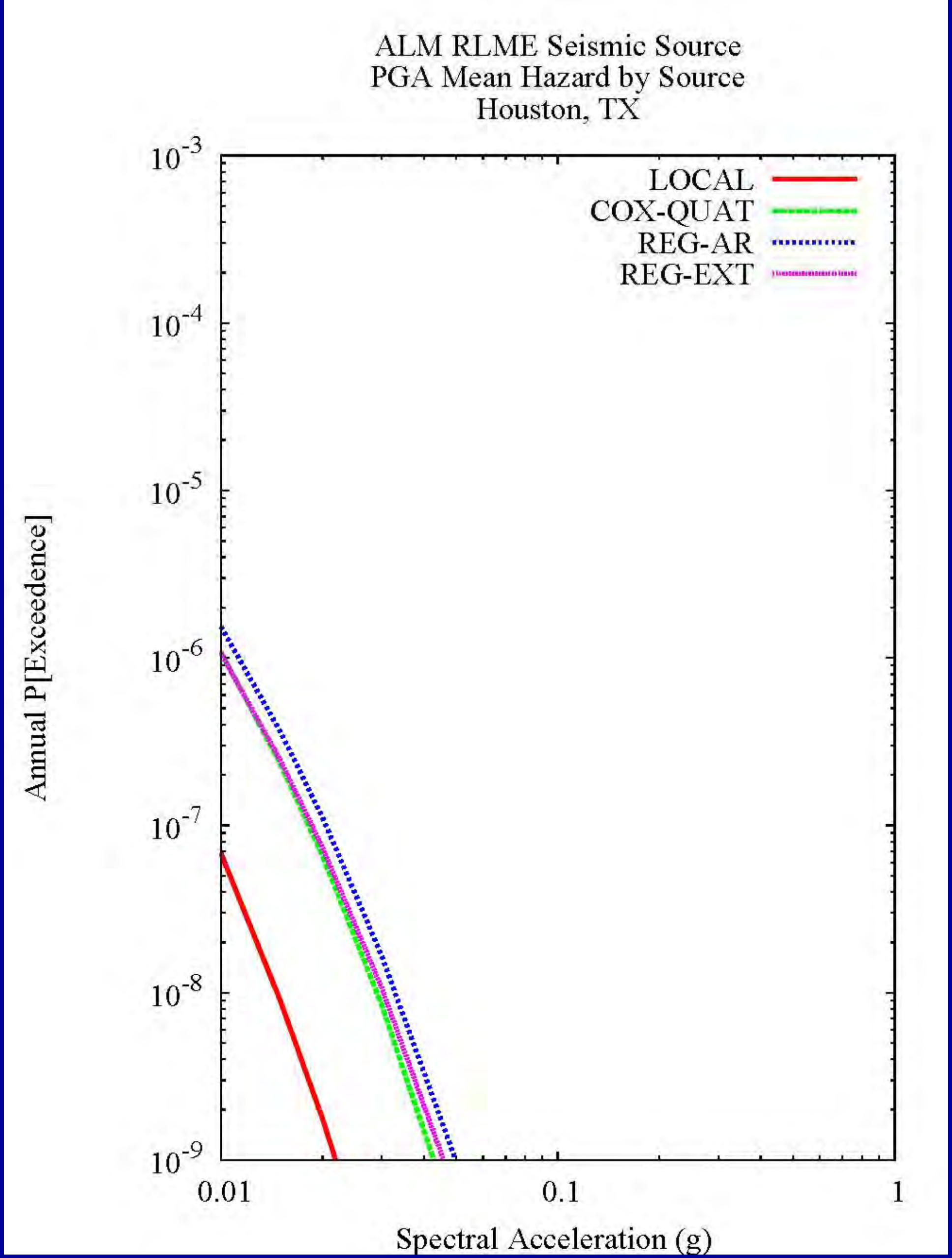
Results for Jackson, MS : Strict, Cox-Quat Source, 10 Hz, Rate



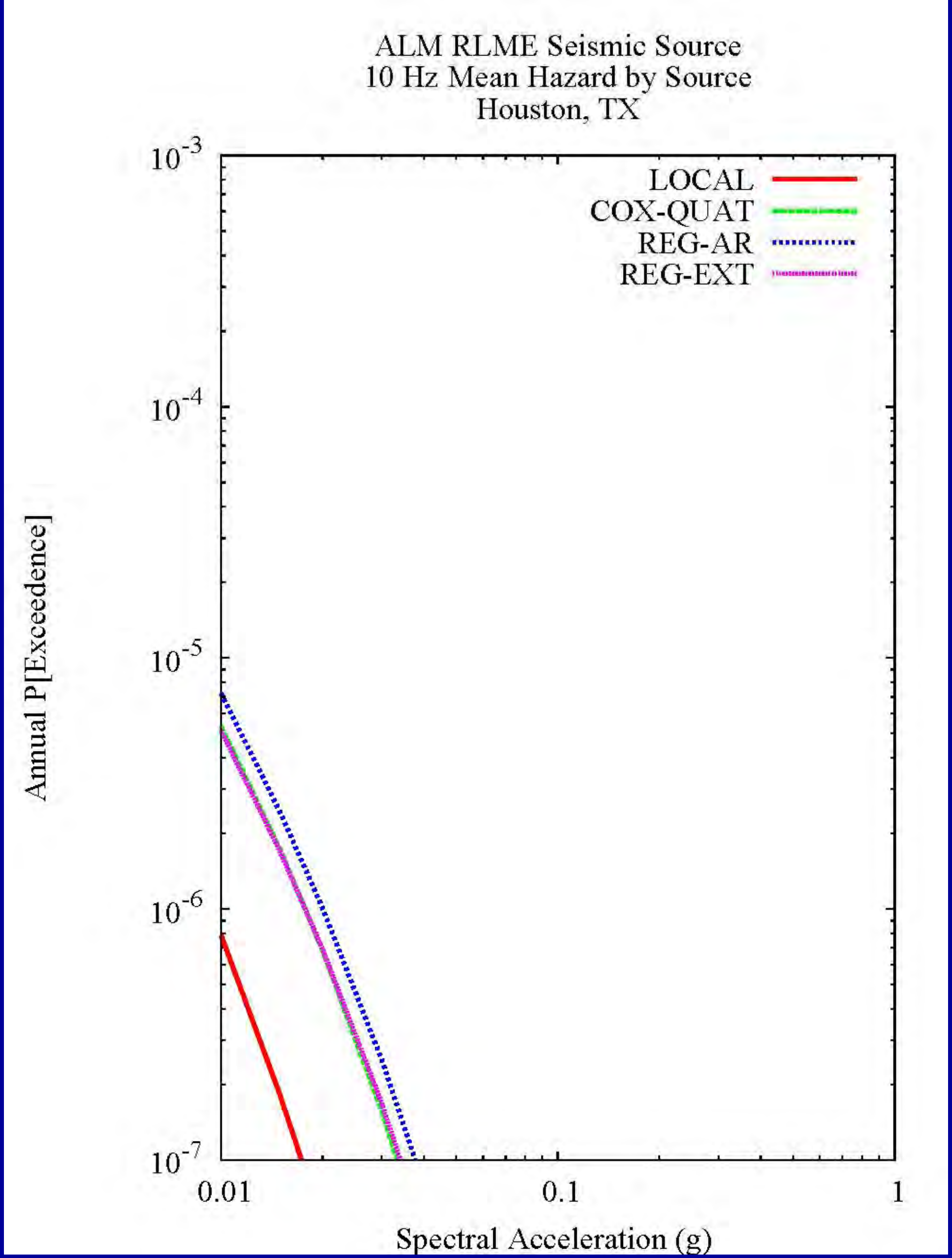
Results for Jackson, MS : Strict, Cox-Quat Source, 1 Hz, Rate



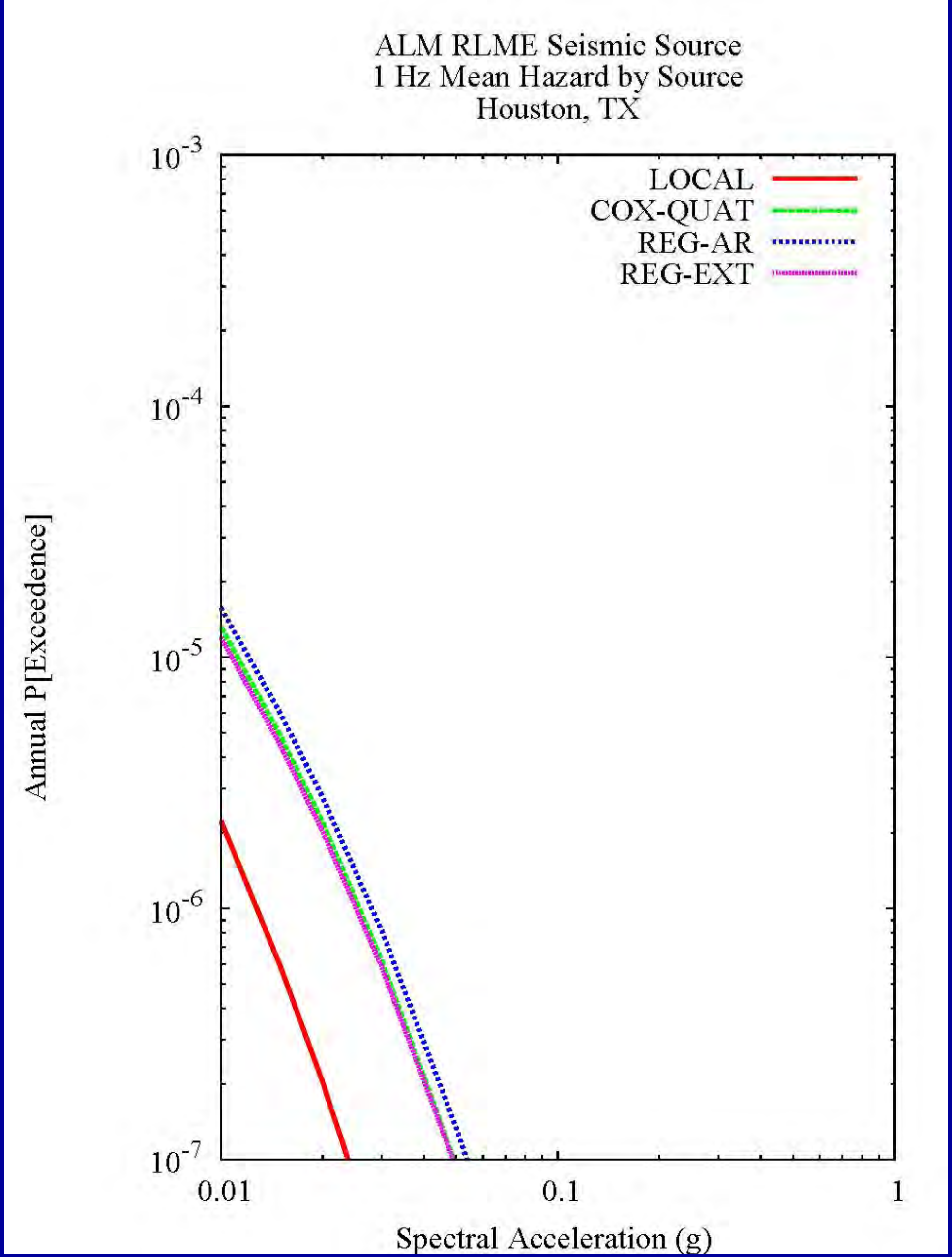
Results for Houston, TX: Leaky, PGA, Geometry



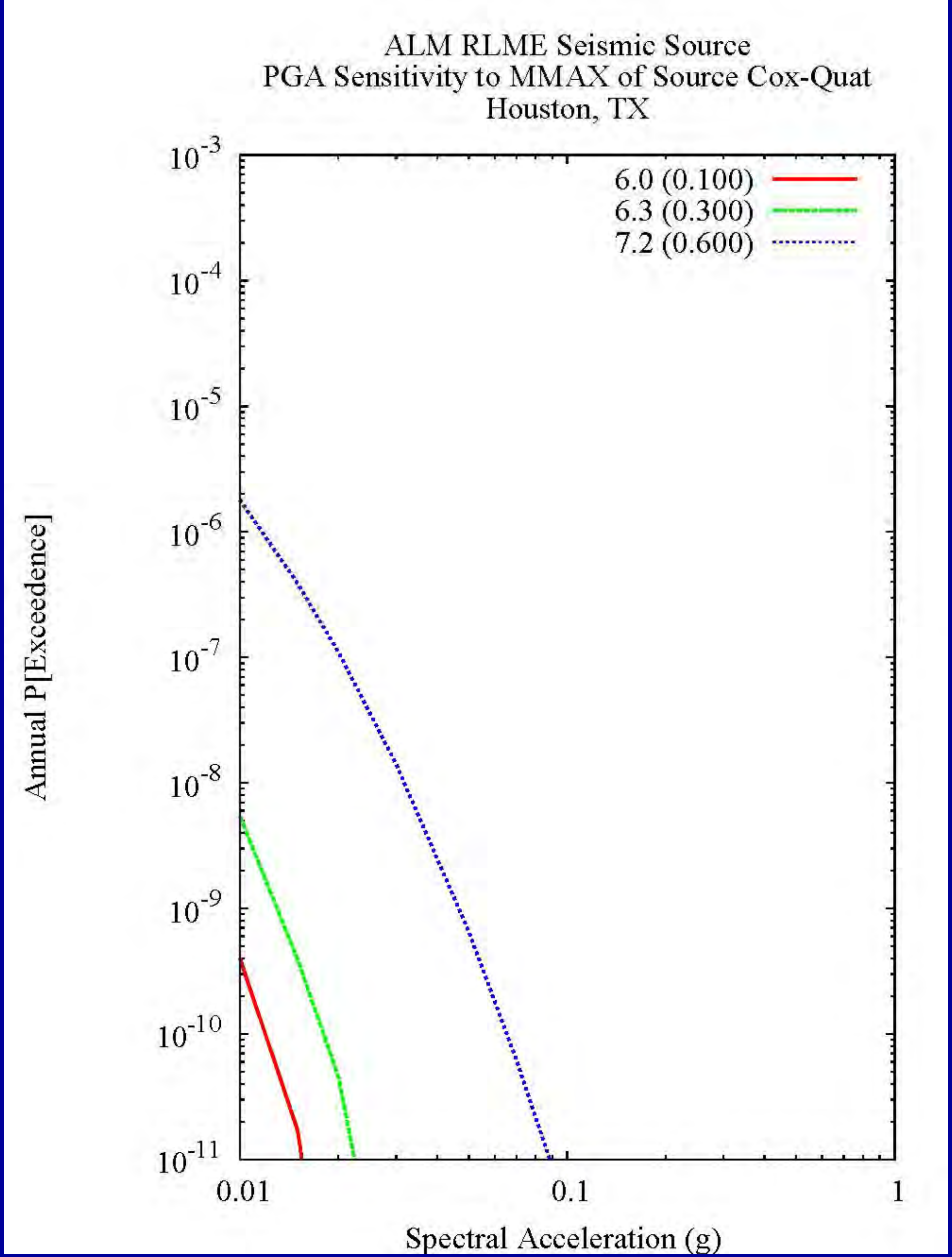
Results for Houston, TX: Leaky, 10 Hz, Geometry



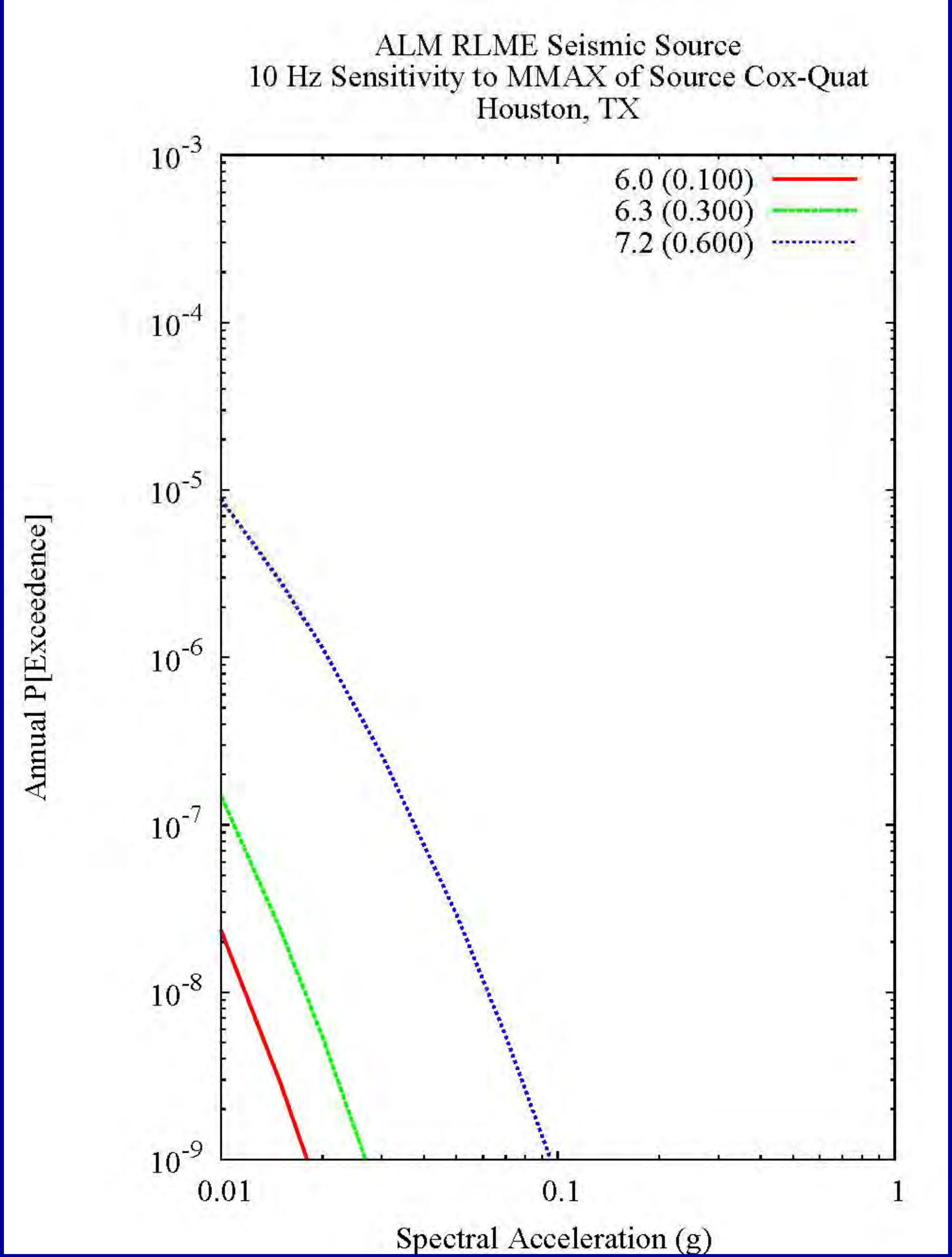
Results for Houston, TX: Leaky, 1 Hz, Geometry



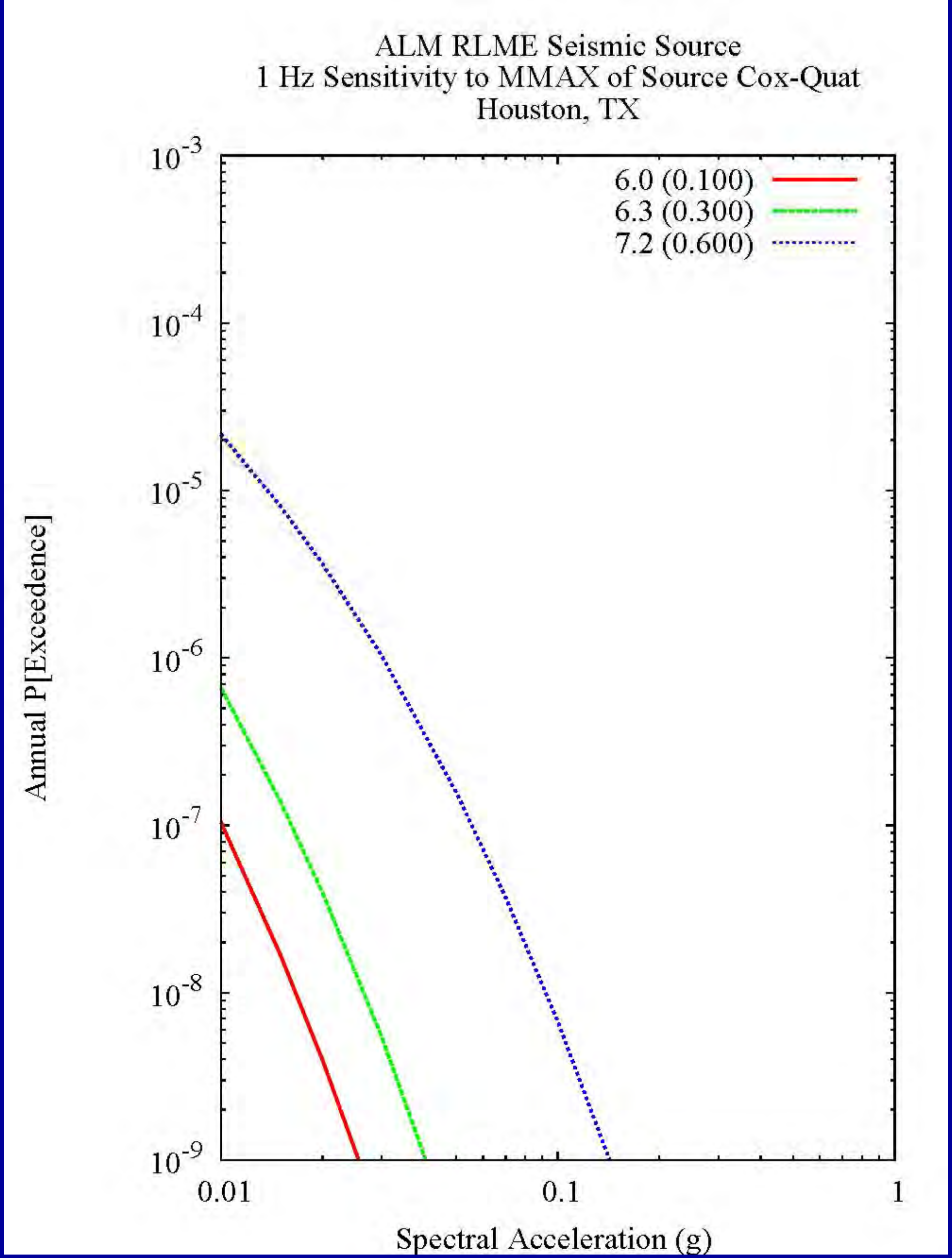
Results for Houston, TX : Leaky, Cox-Quat Source, PGA, Mmax



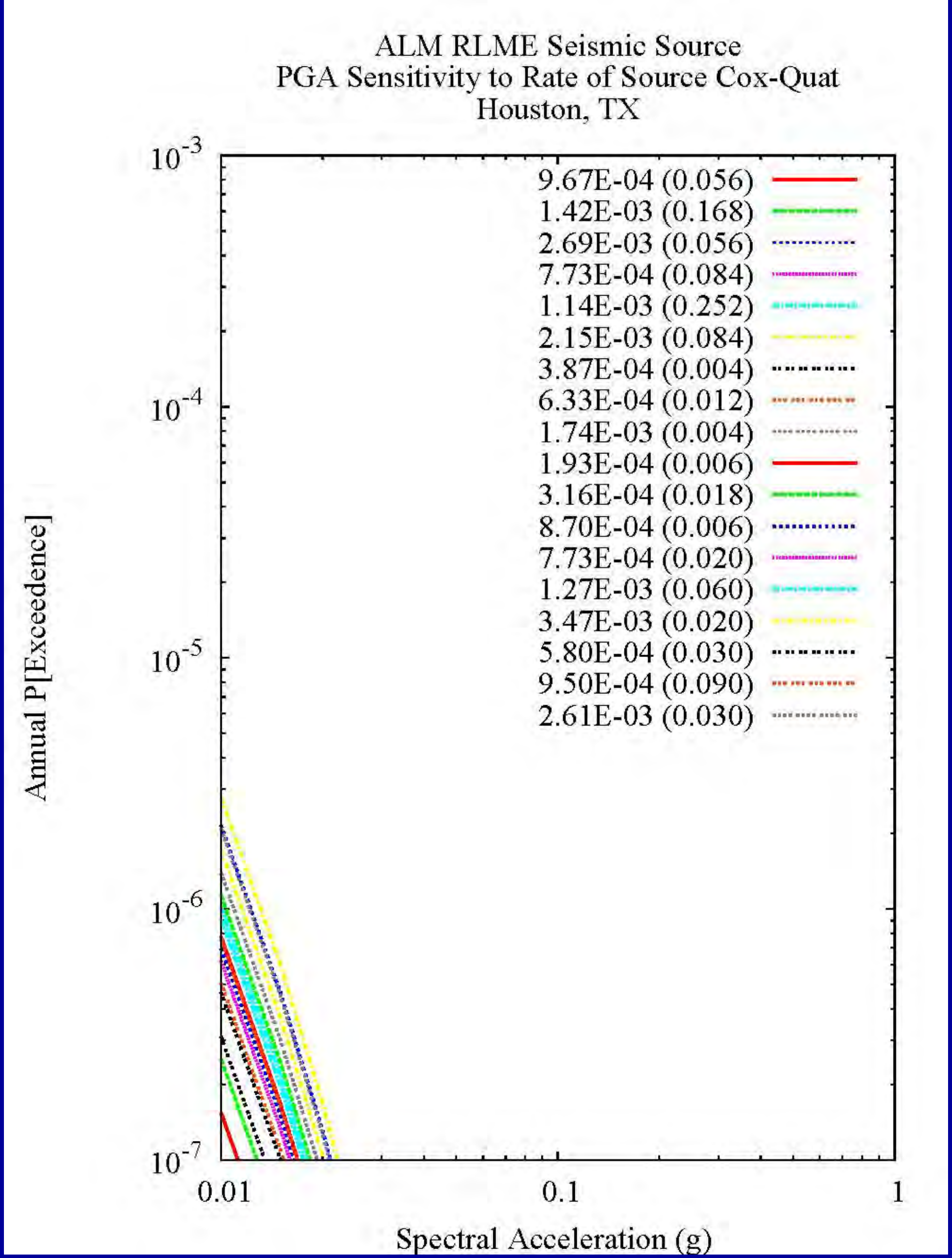
Results for Houston, TX : Leaky, Cox-Quat Source,10 Hz, Mmax



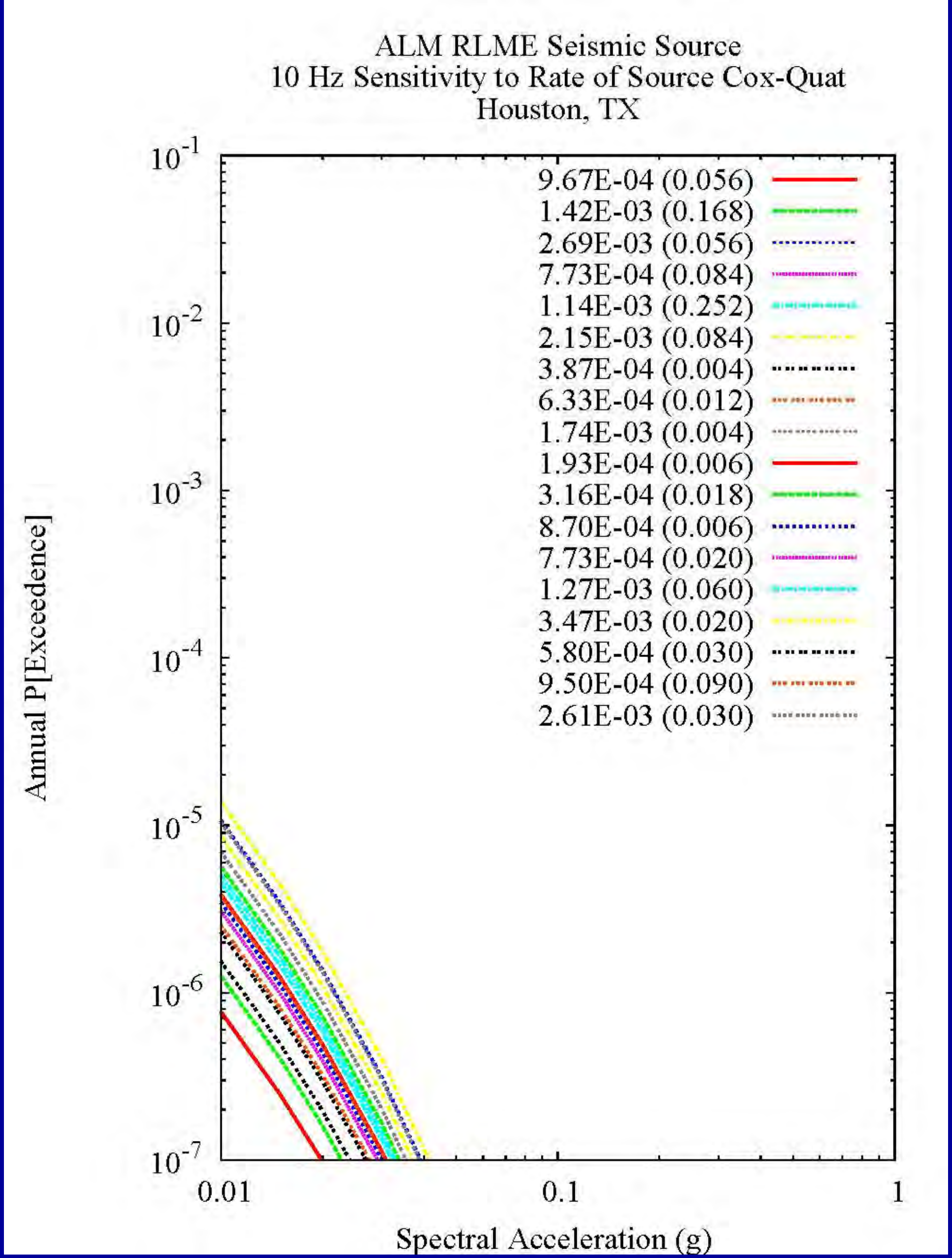
Results for Houston, TX : Leaky, Cox-Quat Source, 1 Hz, Mmax



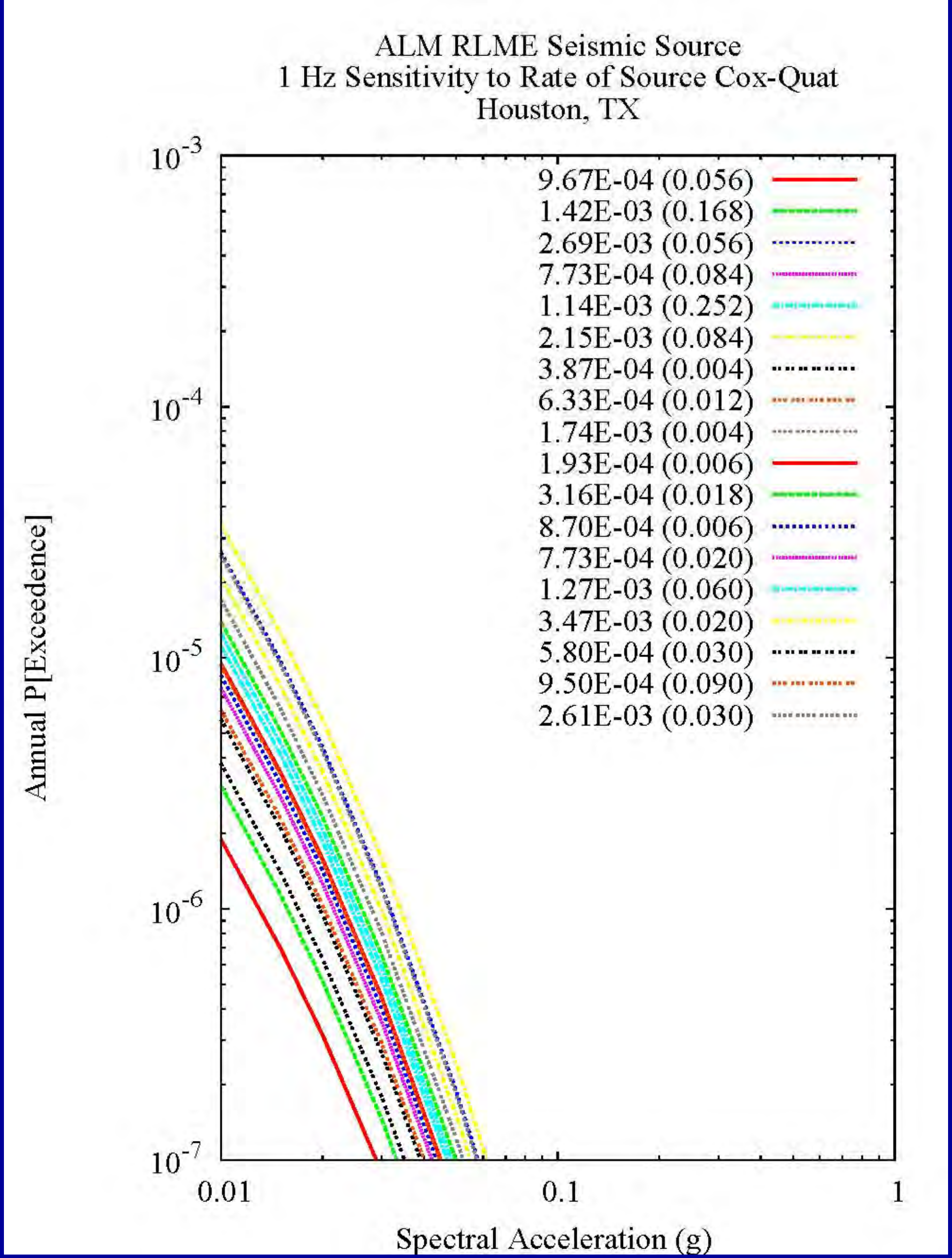
Results for Houston, TX : Leaky, Cox-Quat Source, PGA, Rate



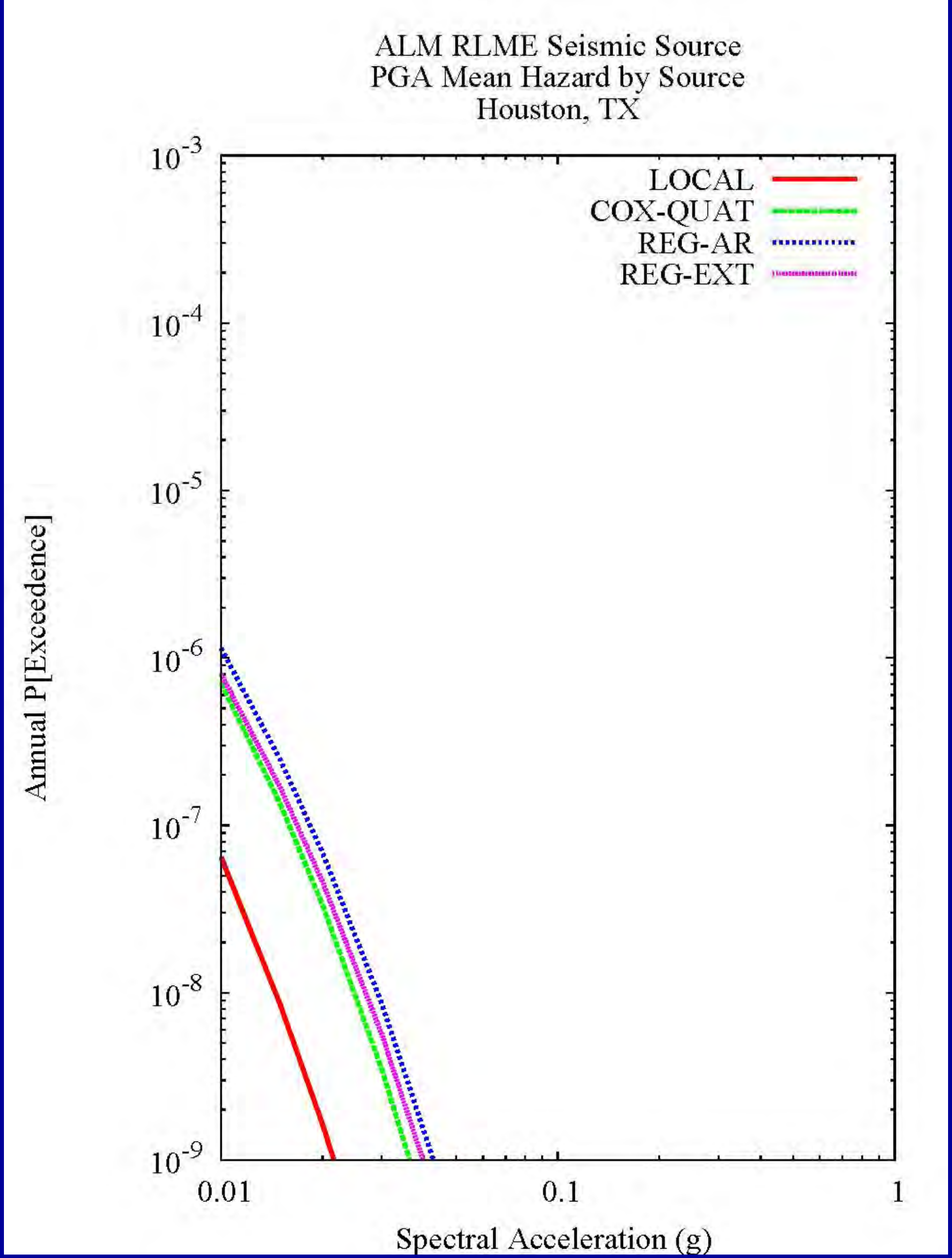
Results for Houston, TX : Leaky, Cox-Quat Source, 10 Hz, Rate



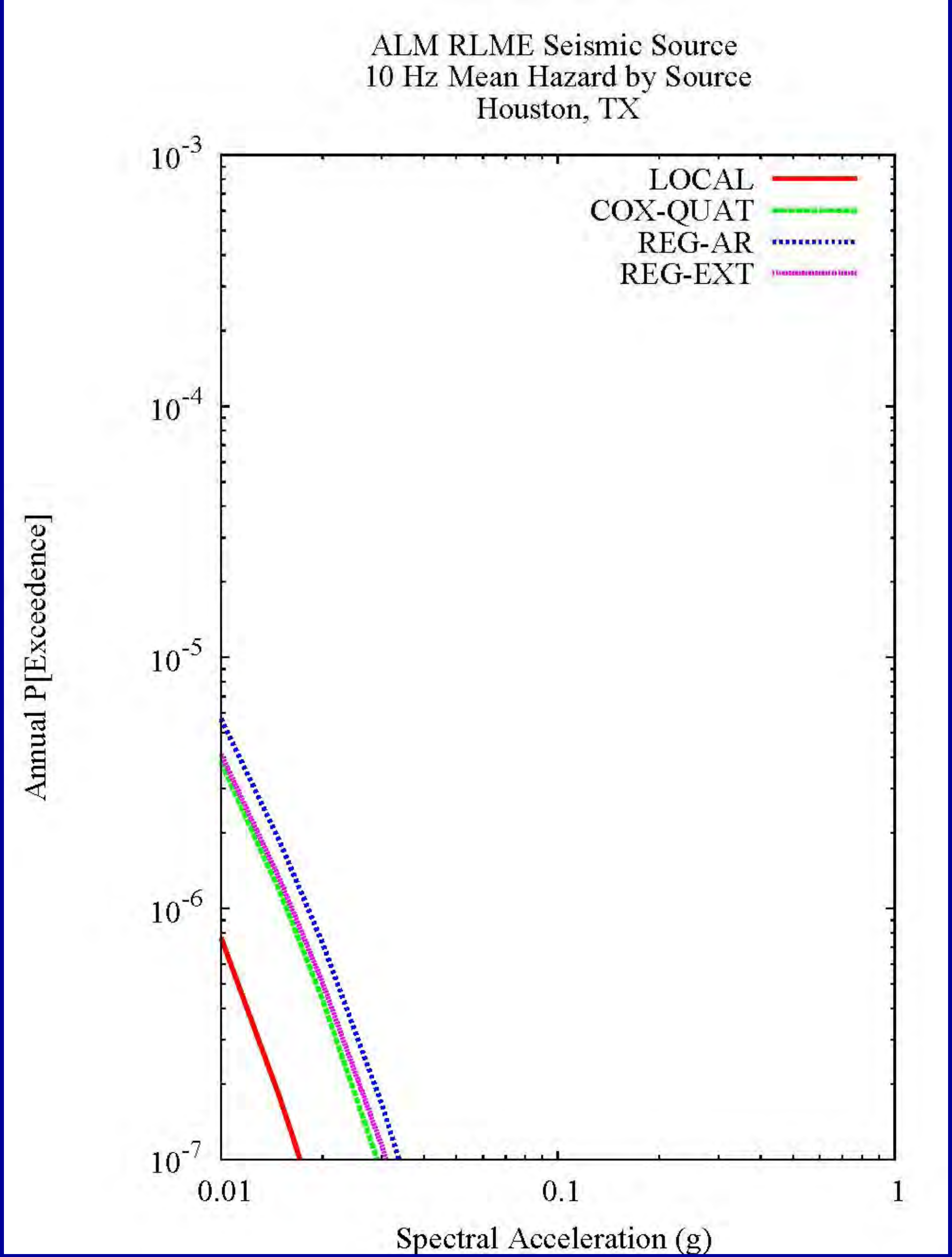
Results for Houston, TX : Leaky, Cox-Quat Source, 1 Hz, Rate



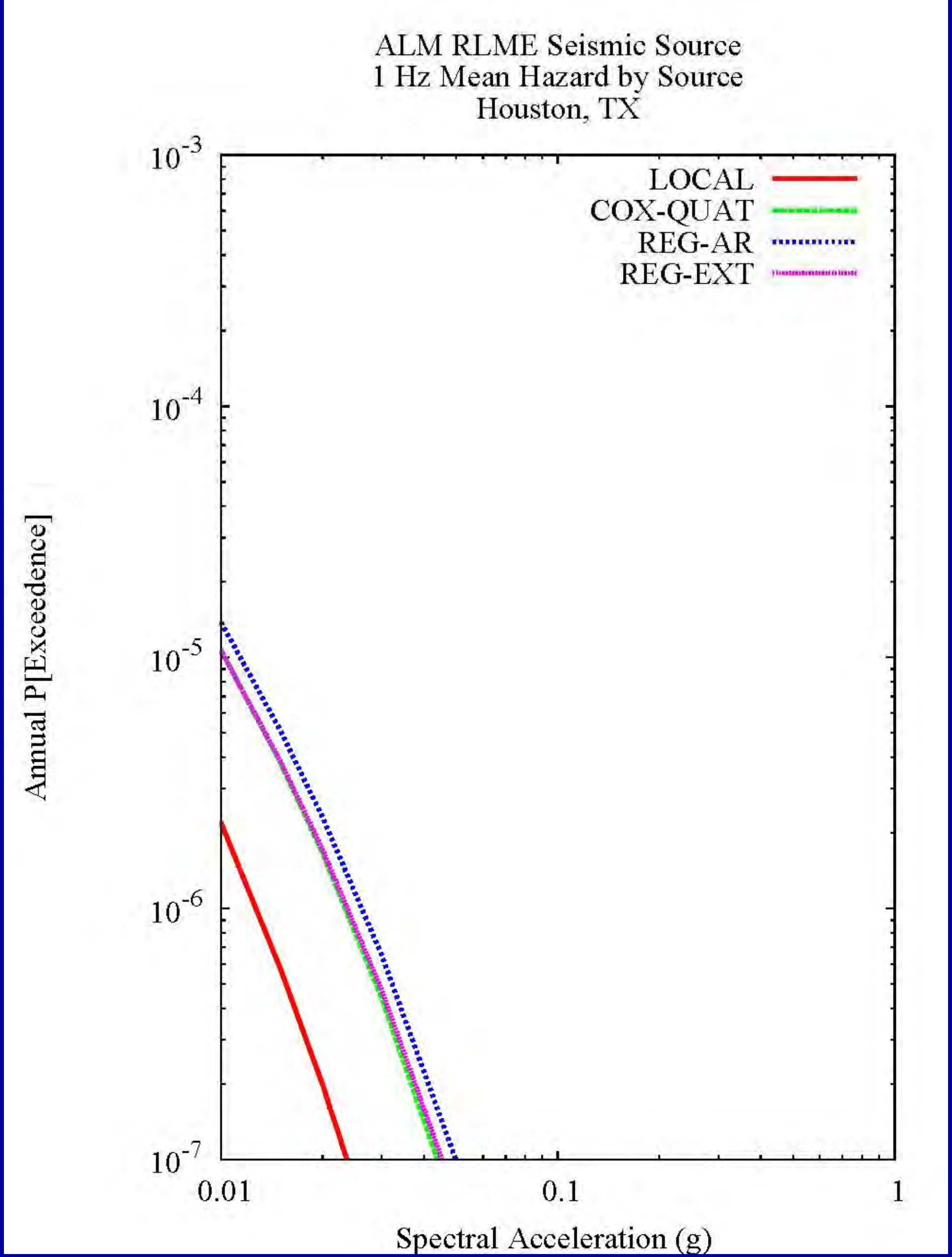
Results for Houston, TX: Strict, PGA, Geometry



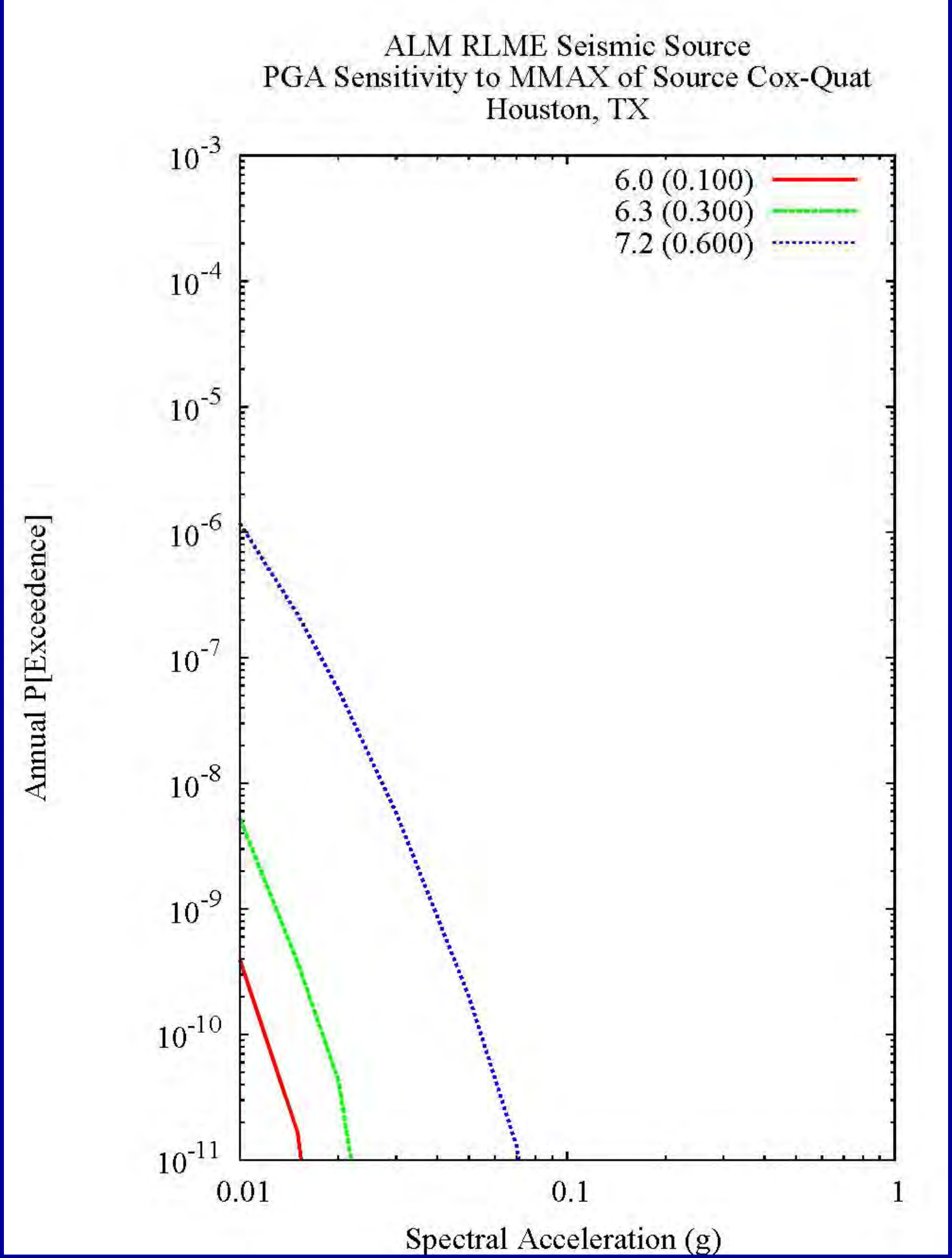
Results for Houston, TX: Strict, 10 Hz, Geometry



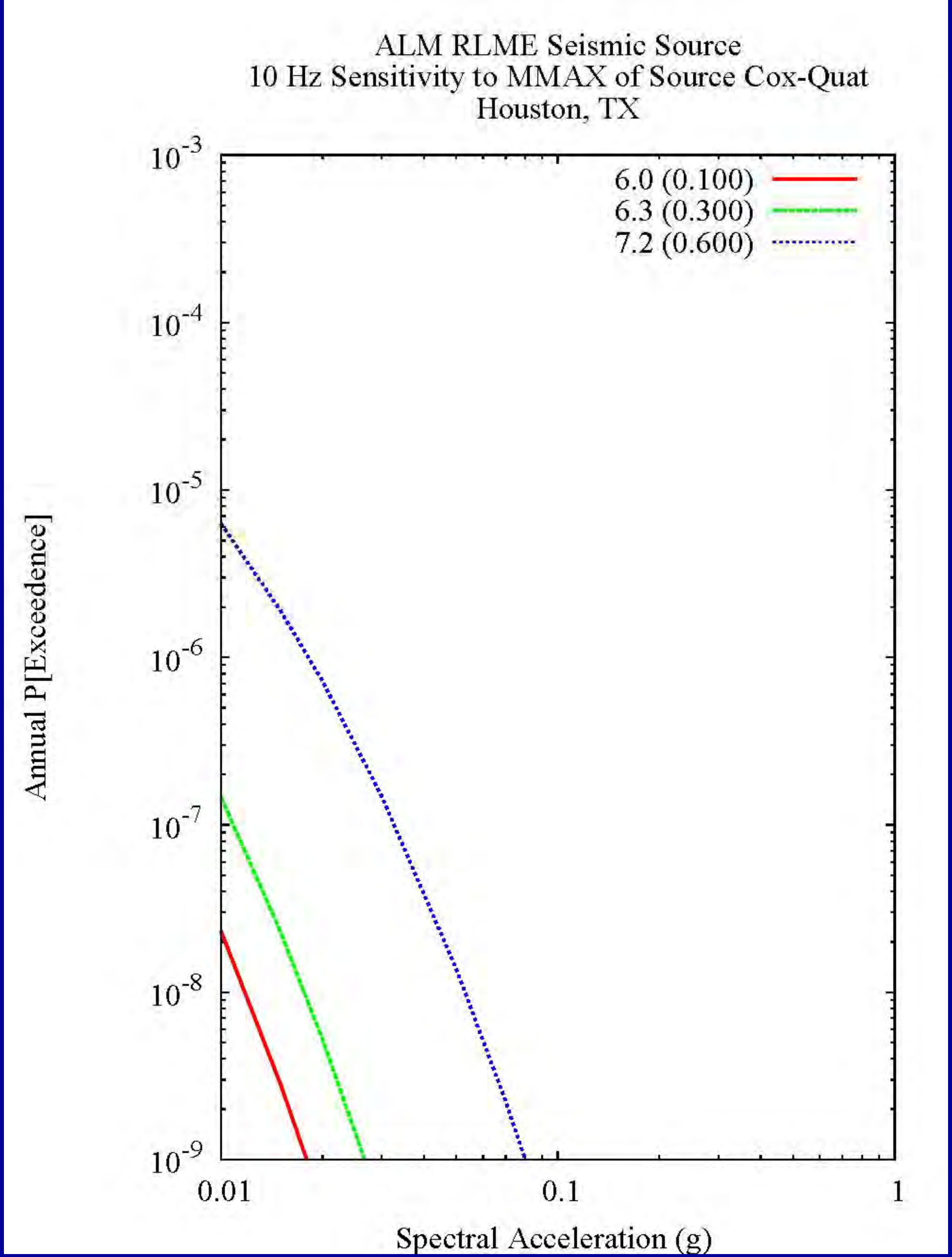
Results for Houston, TX: Strict, 1 Hz, Geometry



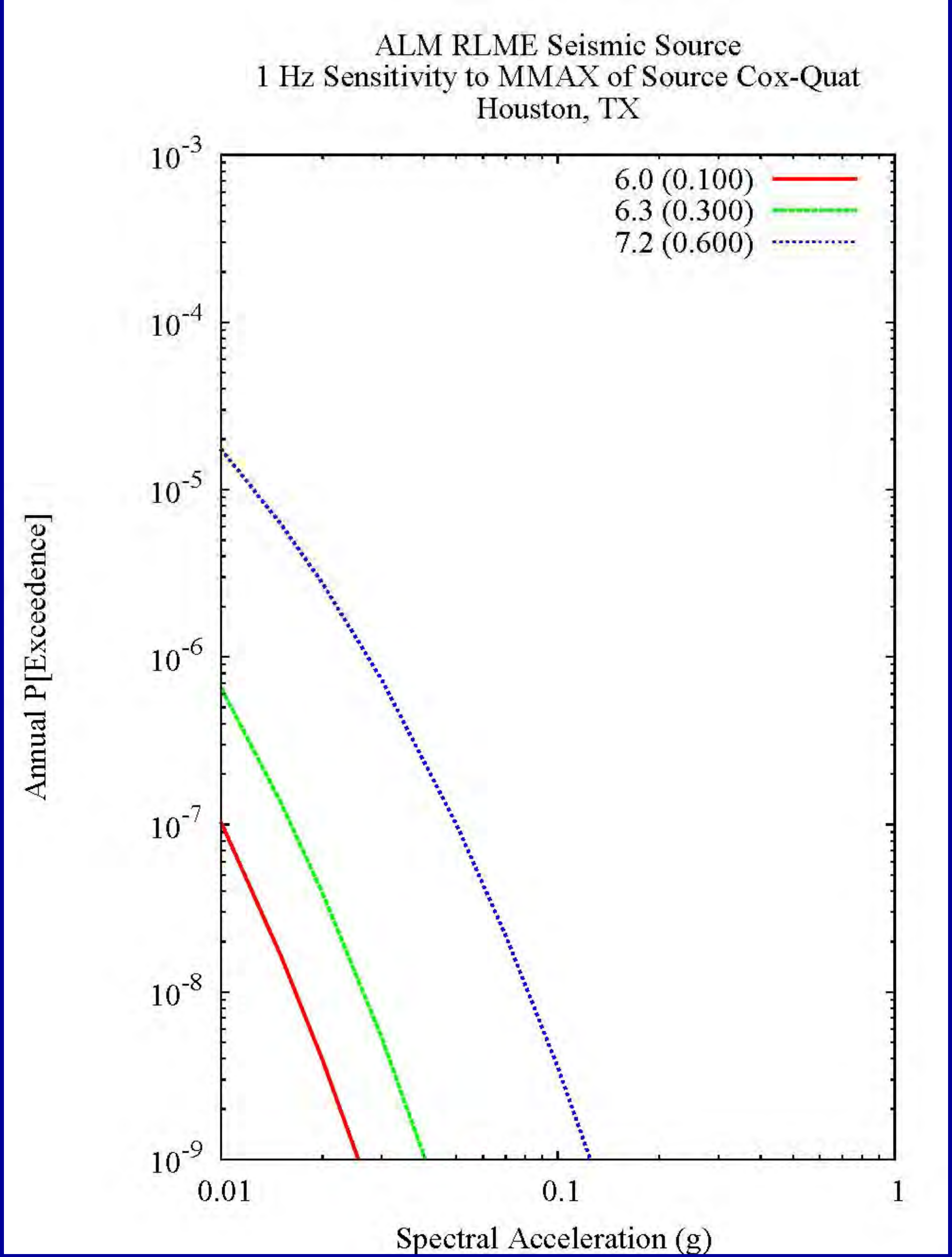
Results for Houston, TX : Strict, Cox-Quat Source, PGA, Mmax



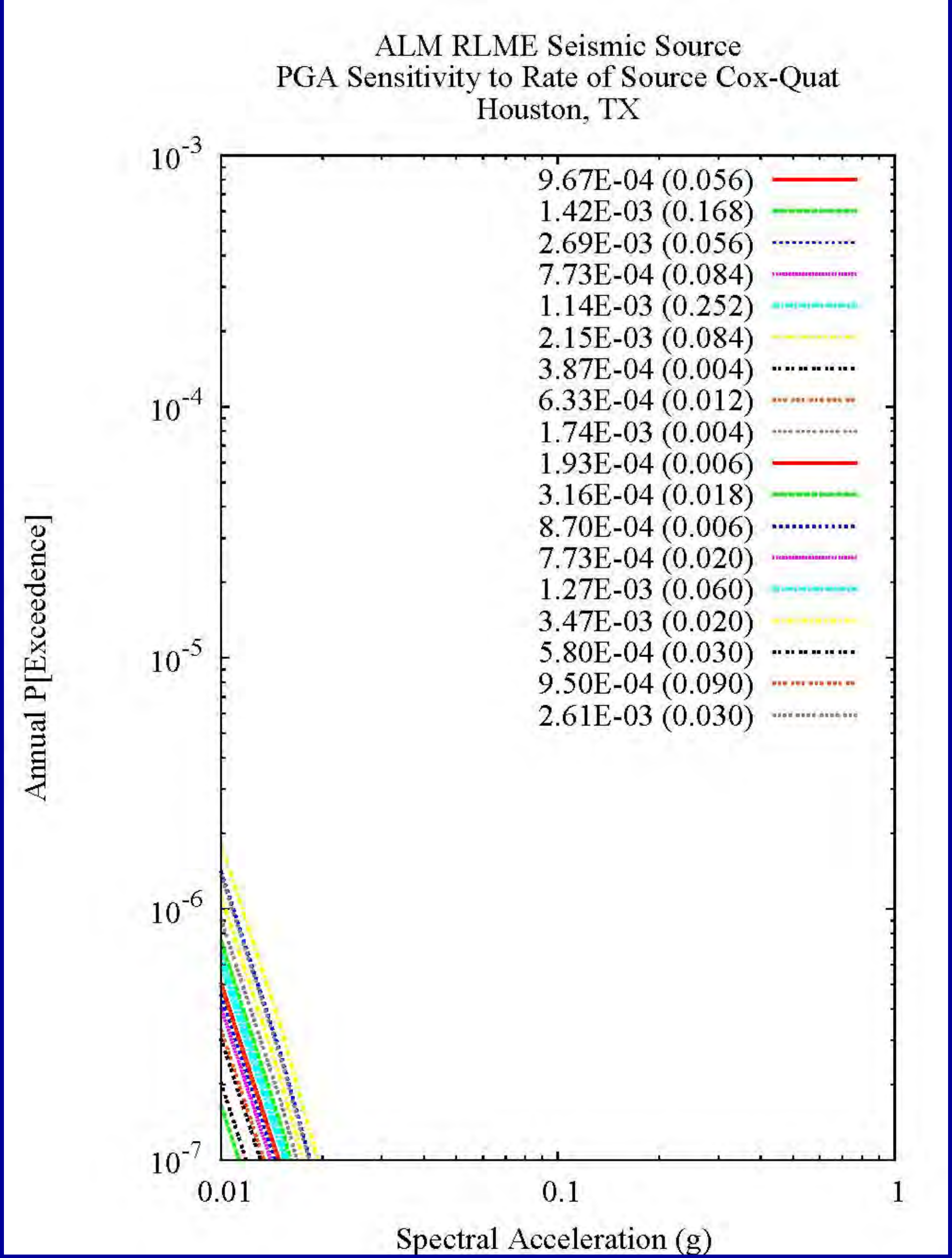
Results for Houston, TX : Strict, Cox-Quat Source,10 Hz, Mmax



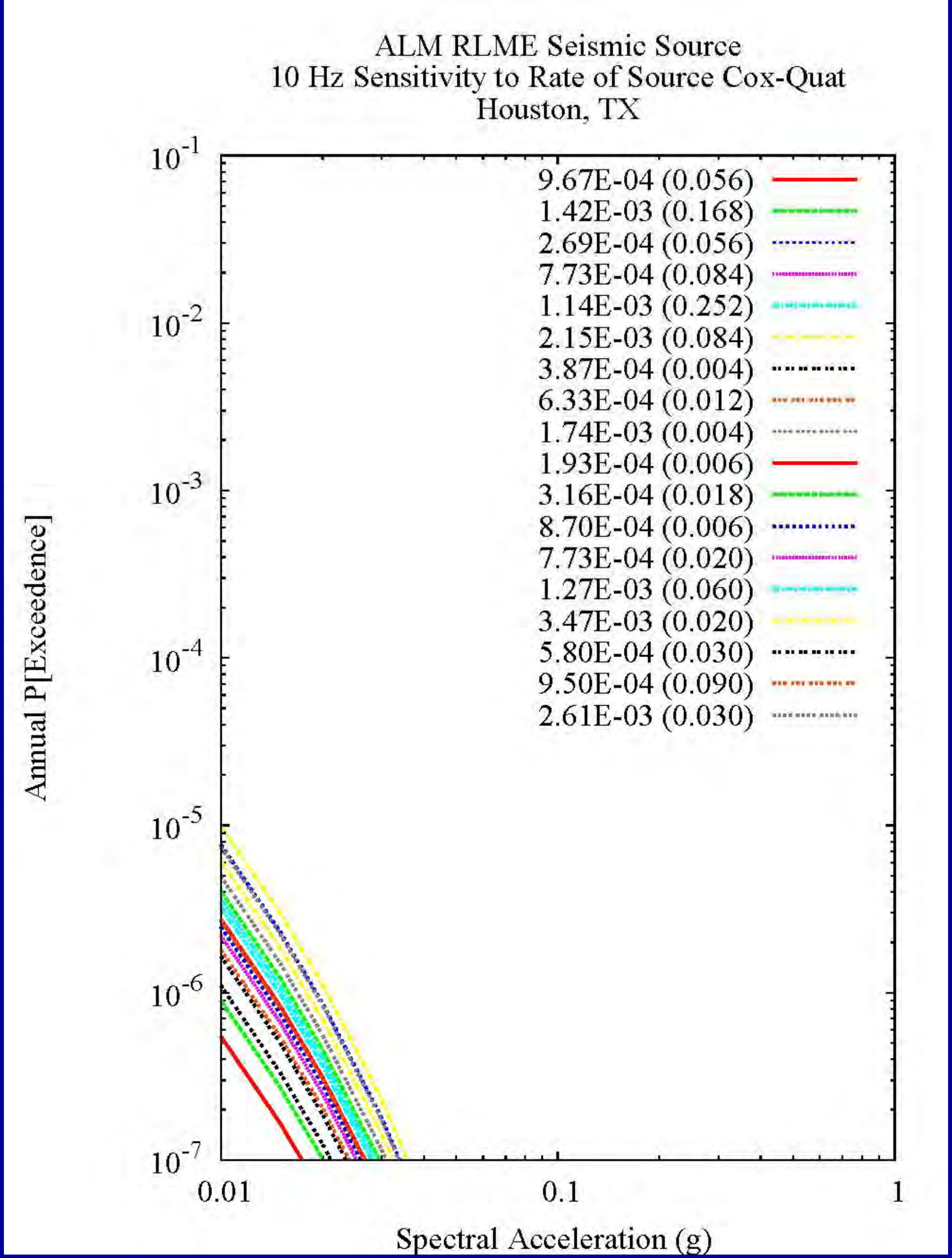
Results for Houston, TX : Strict, Cox-Quat Source, 1 Hz, Mmax



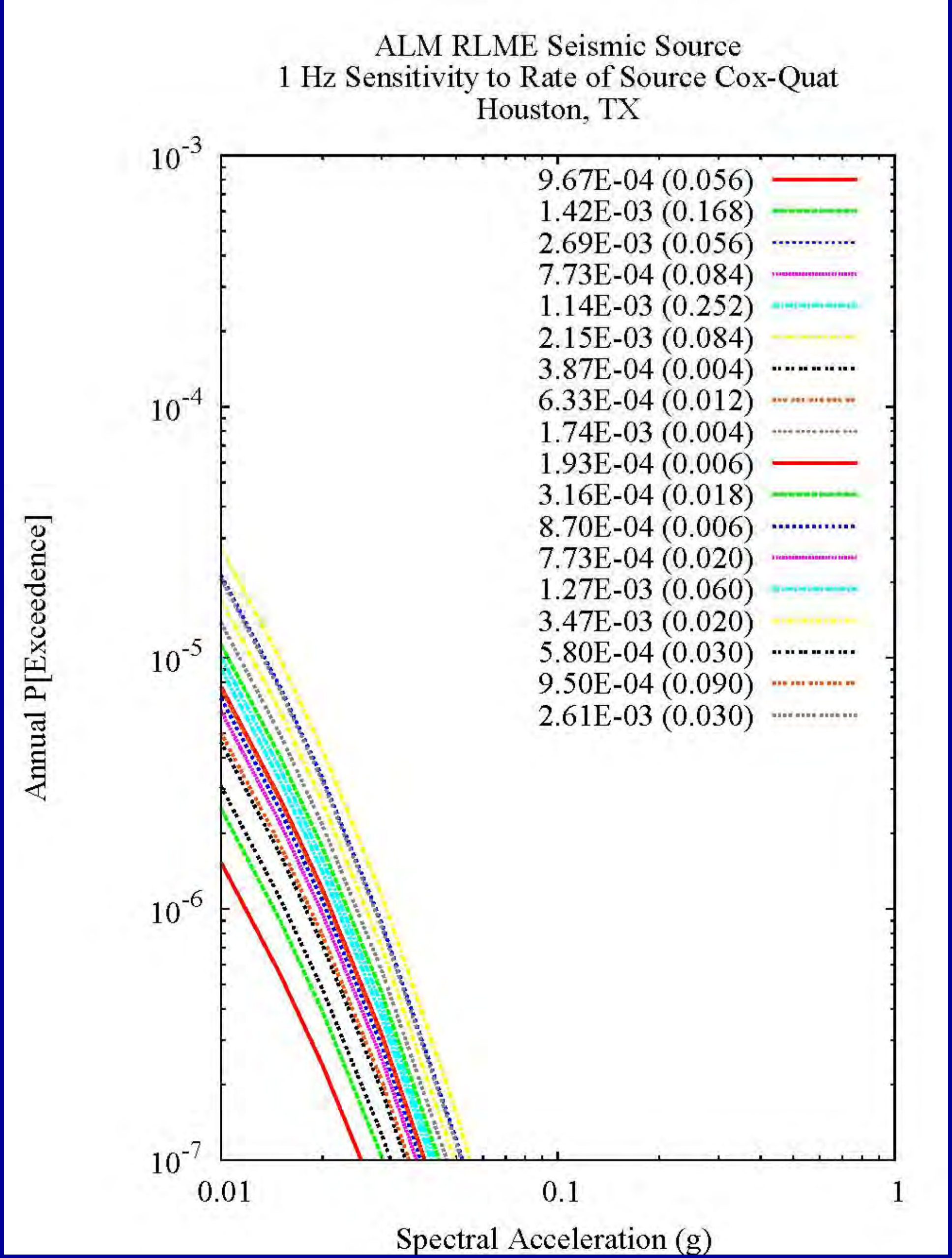
Results for Houston, TX : Strict, Cox-Quat Source, PGA, Rate



Results for Houston, TX : Strict, Cox-Quat Source, 10 Hz, Rate



Results for Houston, TX : Strict, Cox-Quat Source, 1 Hz, Rate



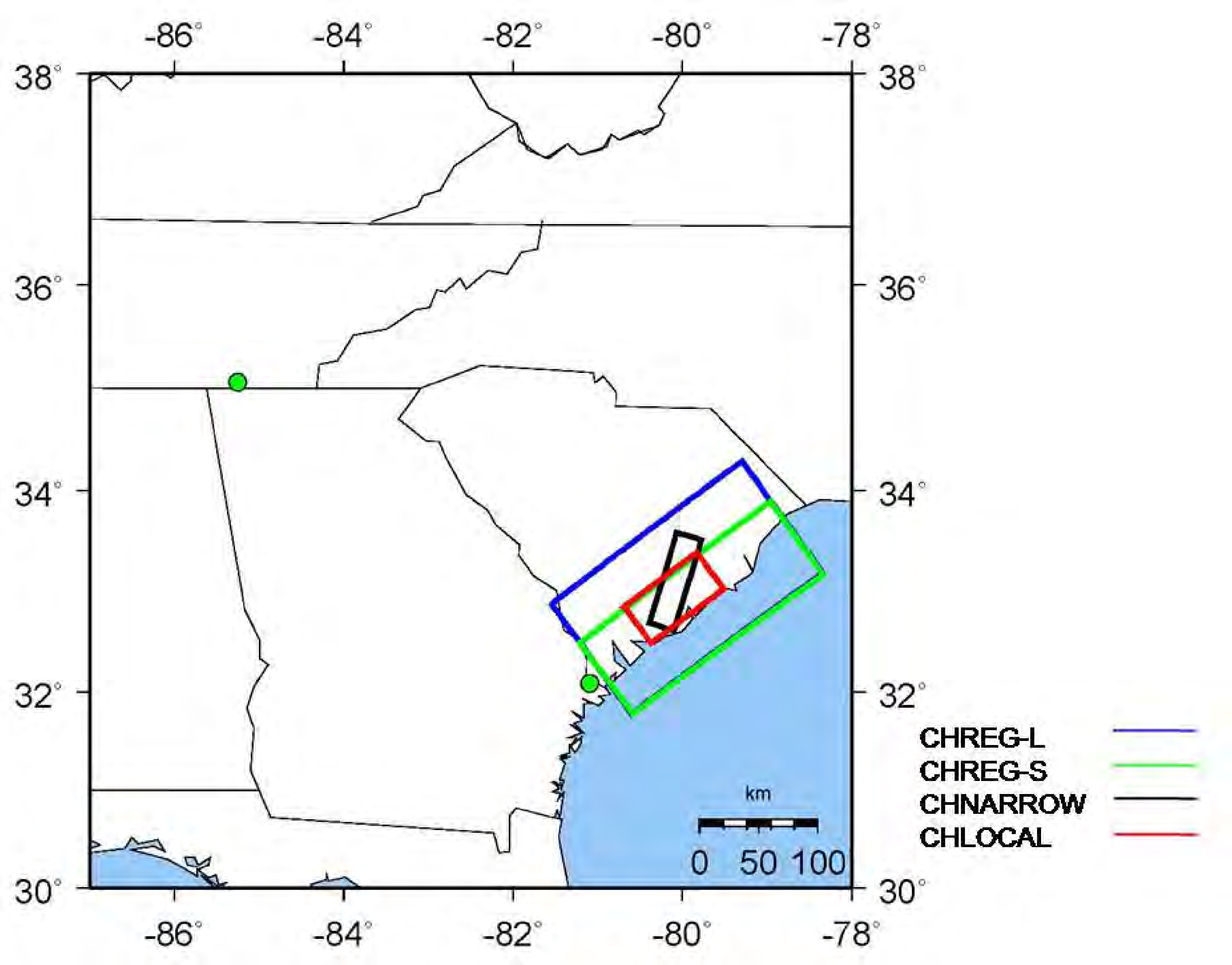
RLME Seismic Source Sensitivity Studies

Allison Shumway
William Lettis & Associates, Inc.
Workshop #3
August 25-26, 2009

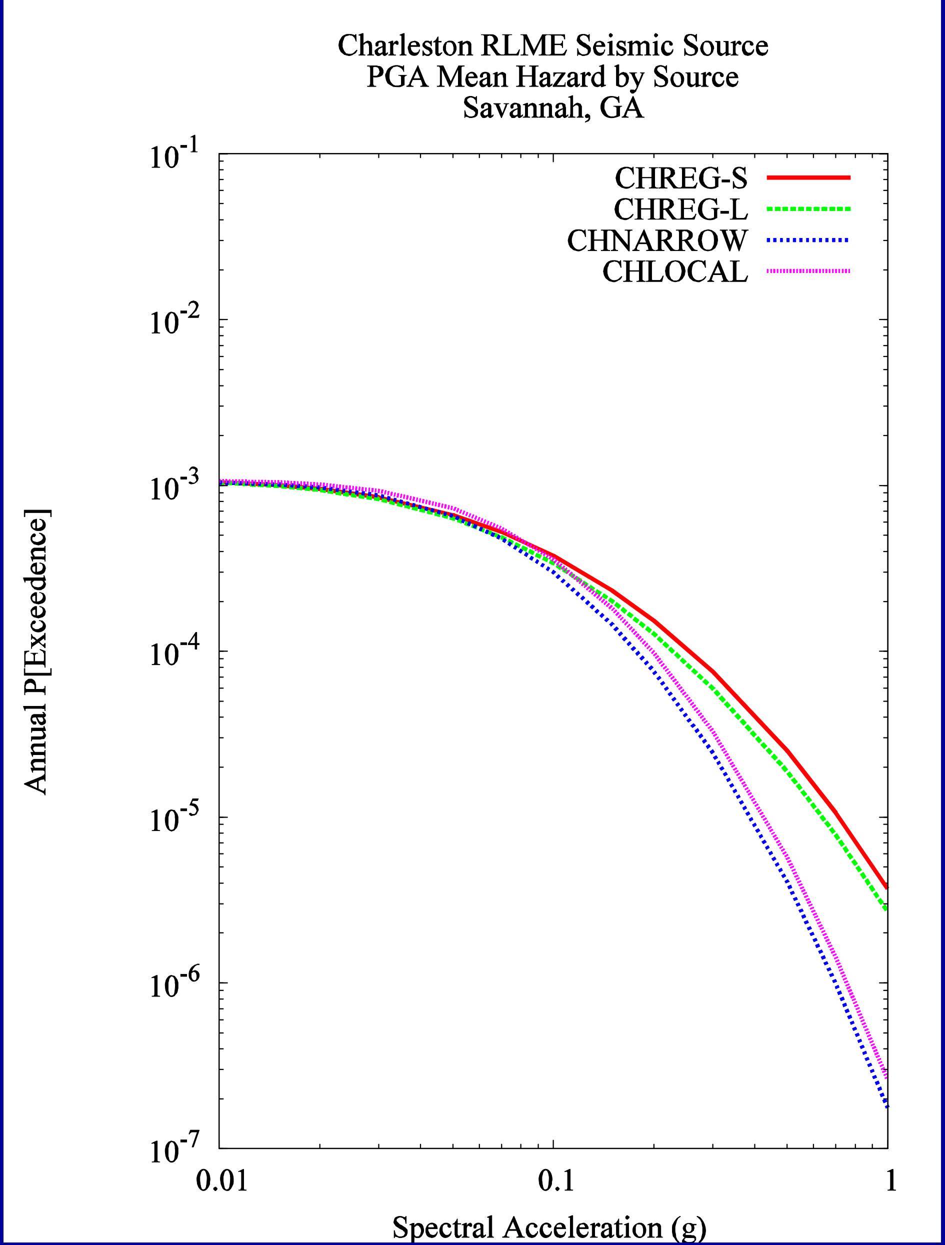
Charleston RLME Seismic Source

- Sensitivity studies: geometry, rate, and Mmax
- Sources: Local (highest weighted source)
- Frequencies: PGA, 10 Hz, and 1 Hz
- Site 1: Savannah, GA
- Site 2: Chattanooga, TN

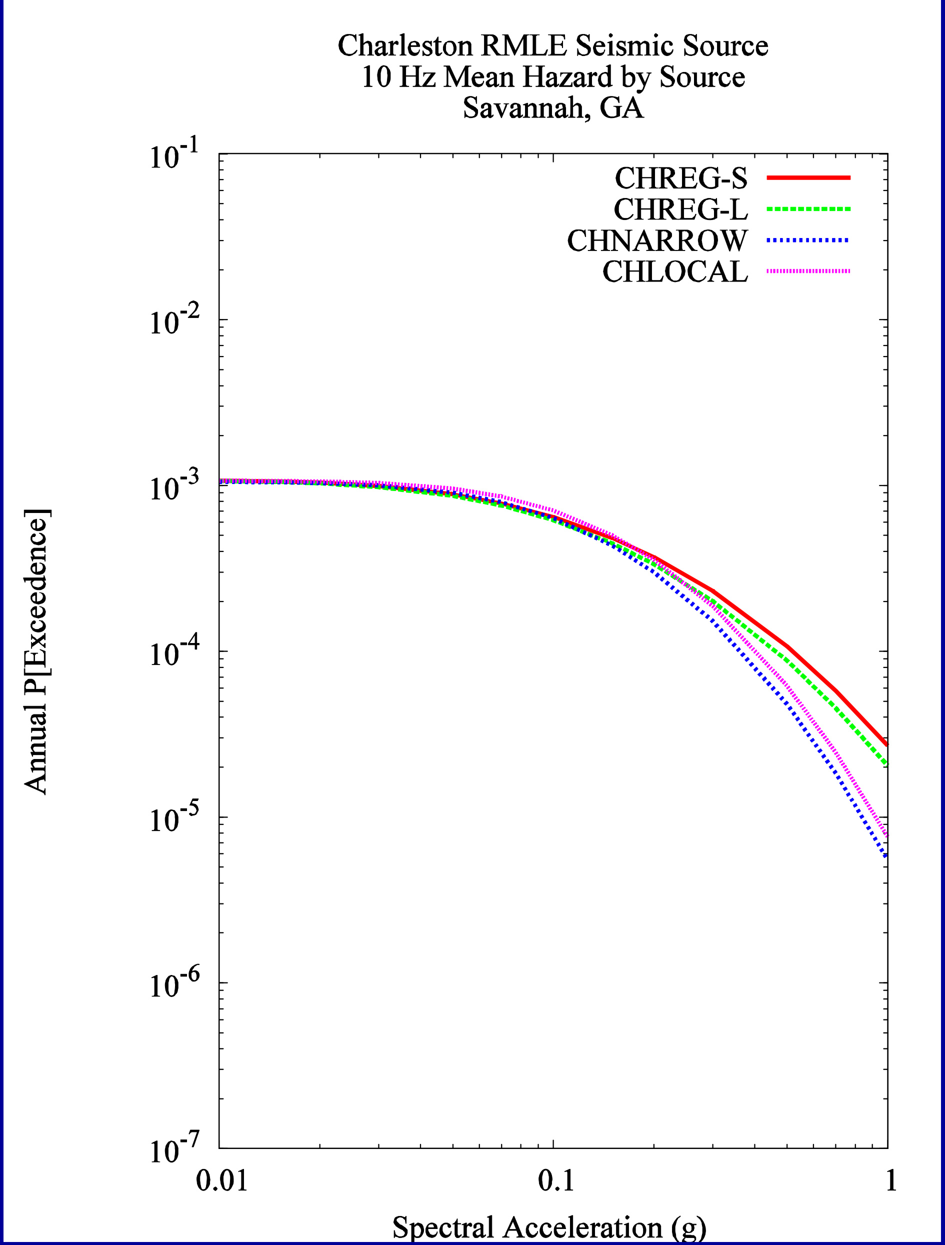
Charleston RLME Source Location and Test Site Locations: Savannah, GA and Chattanooga, TN



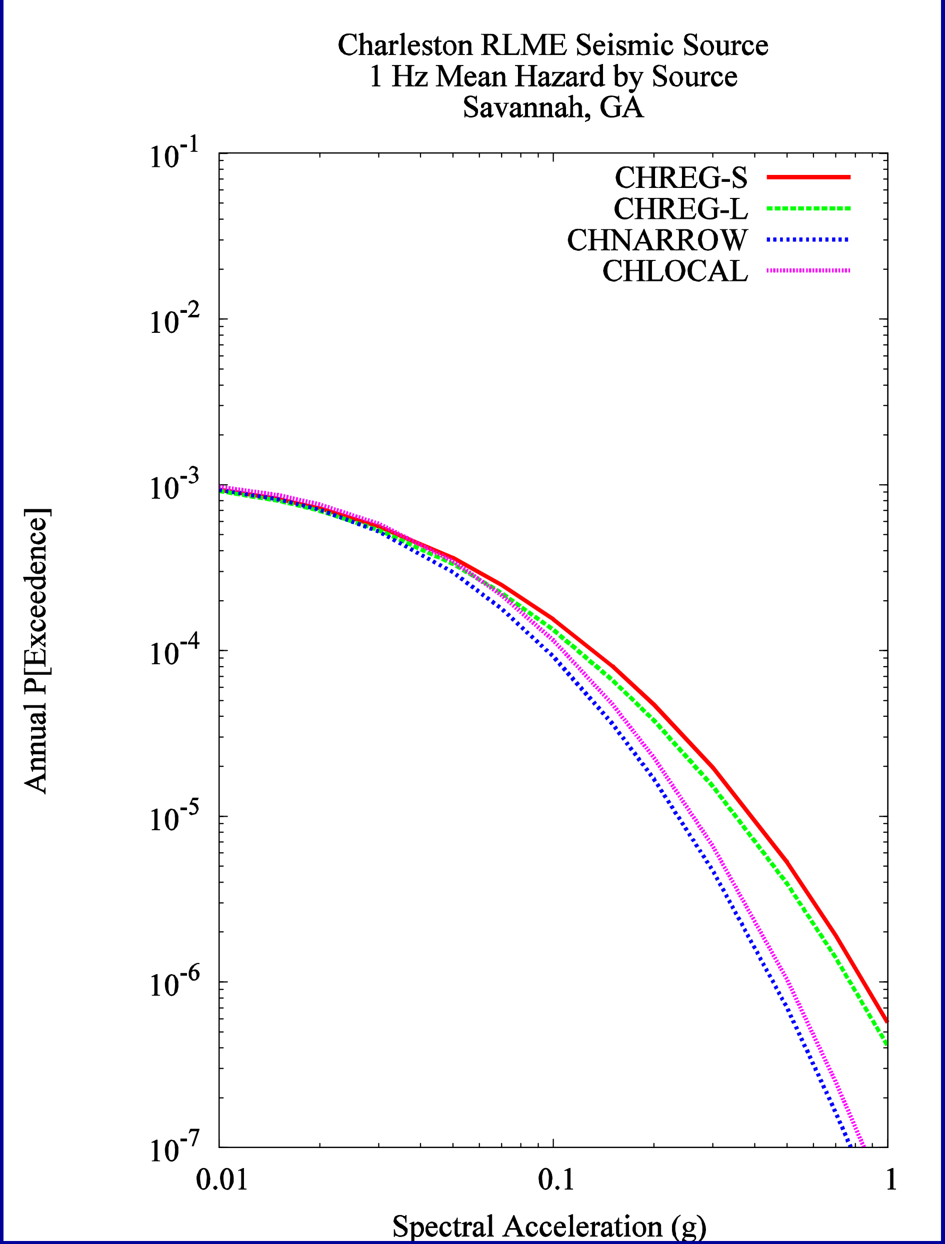
Results for Savannah, GA: PGA, Geometry



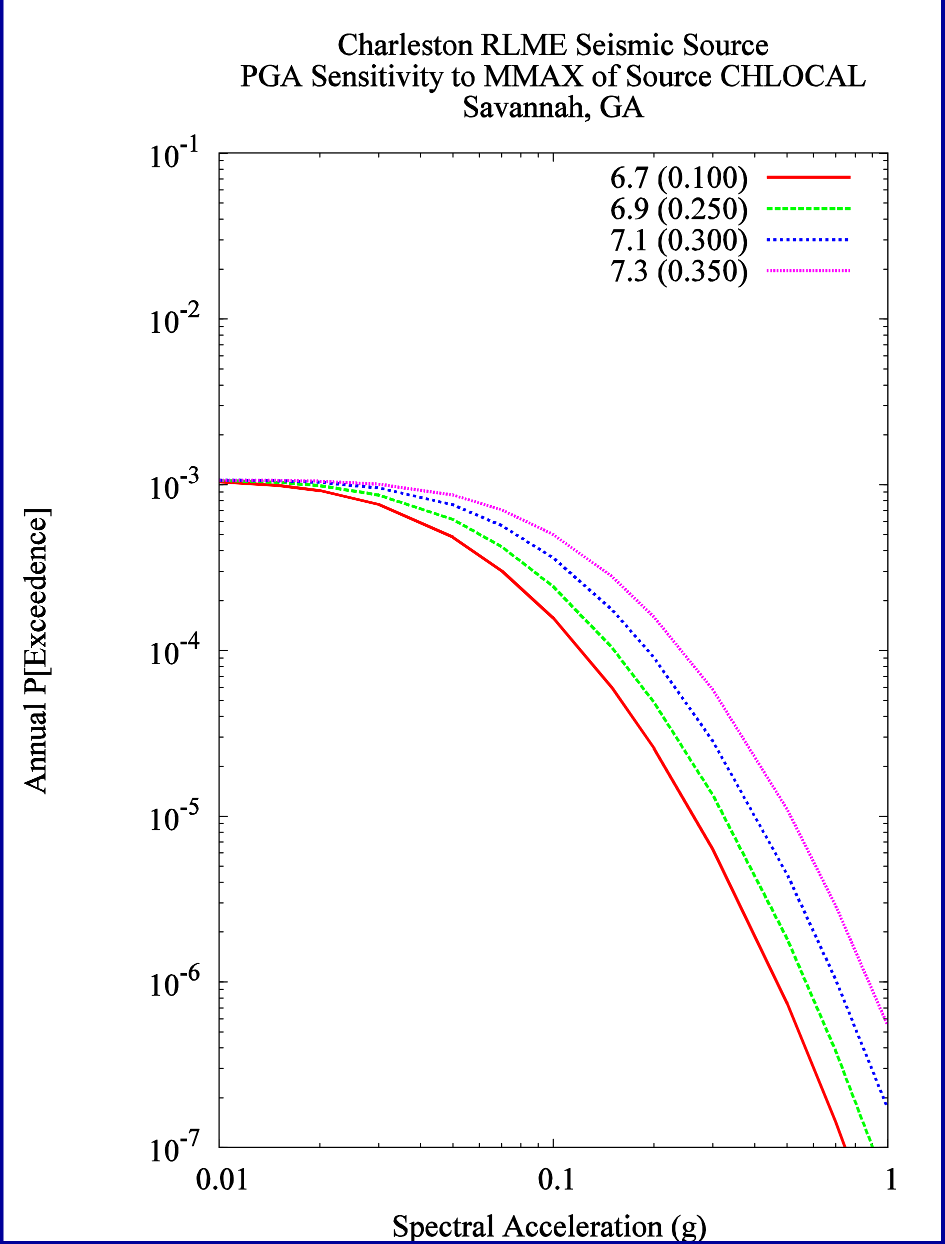
Results for Savannah, GA: 10 Hz, Geometry



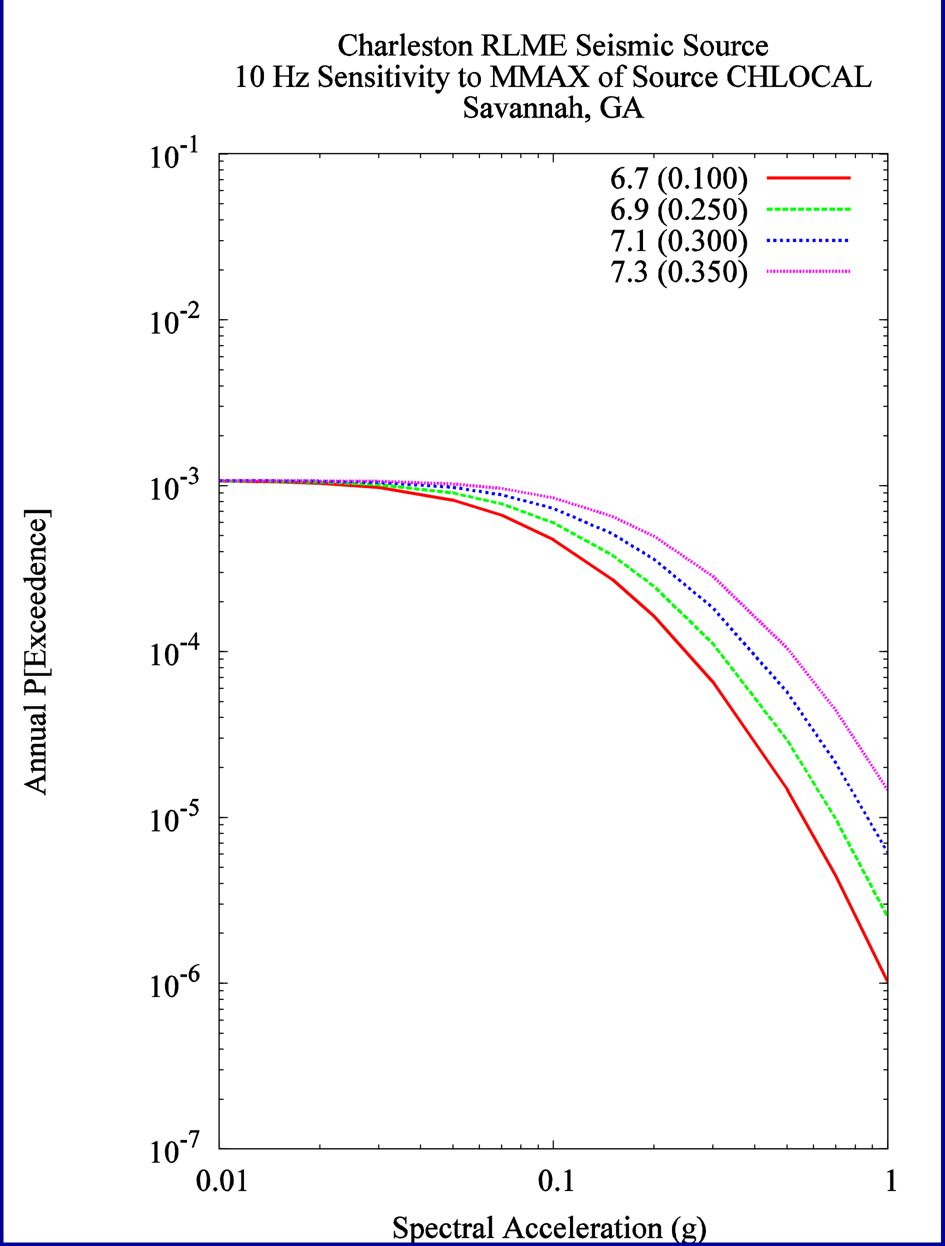
Results for Savannah, GA: 1 Hz, Geometry



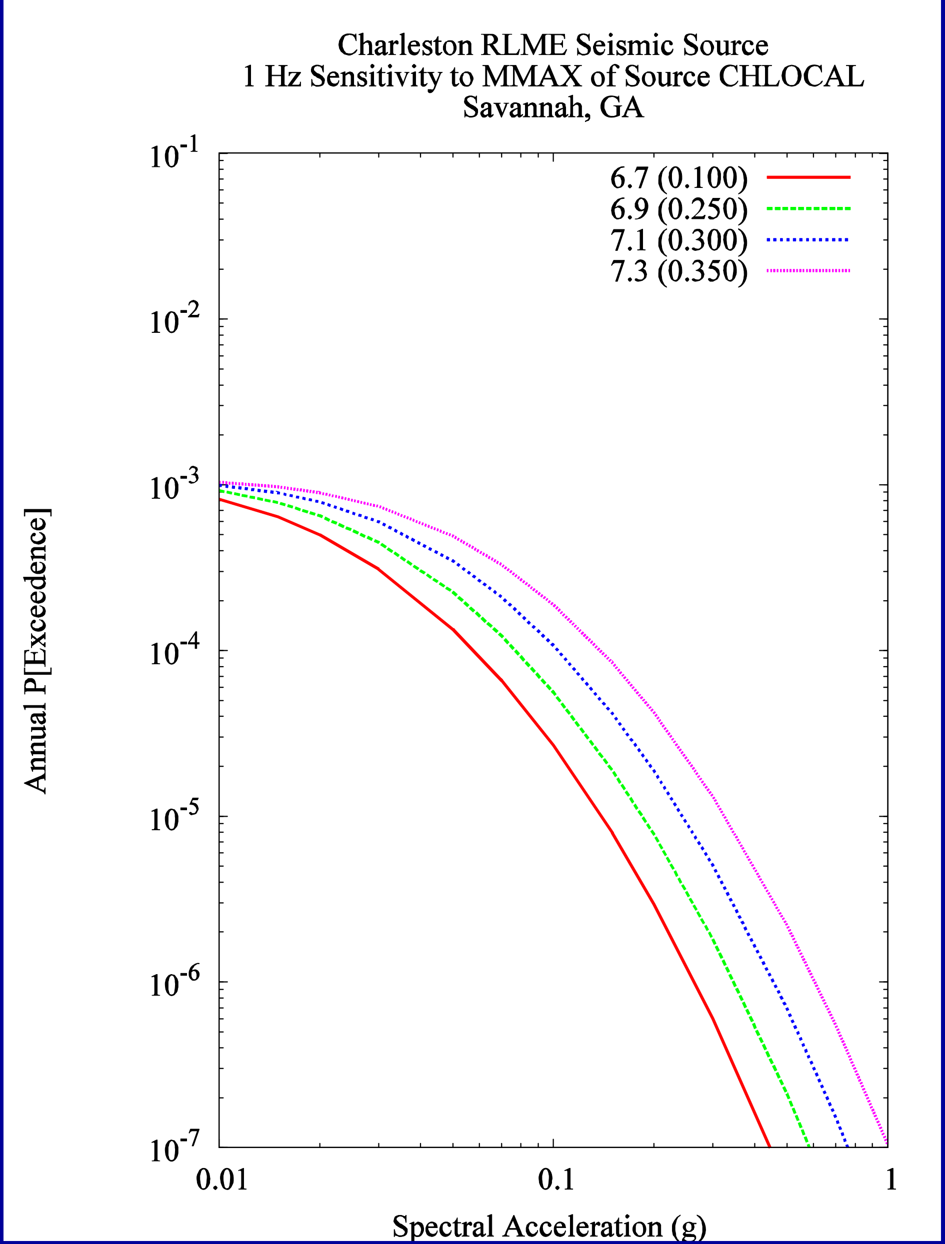
Results for Savannah, GA : Local Source, PGA, Mmax



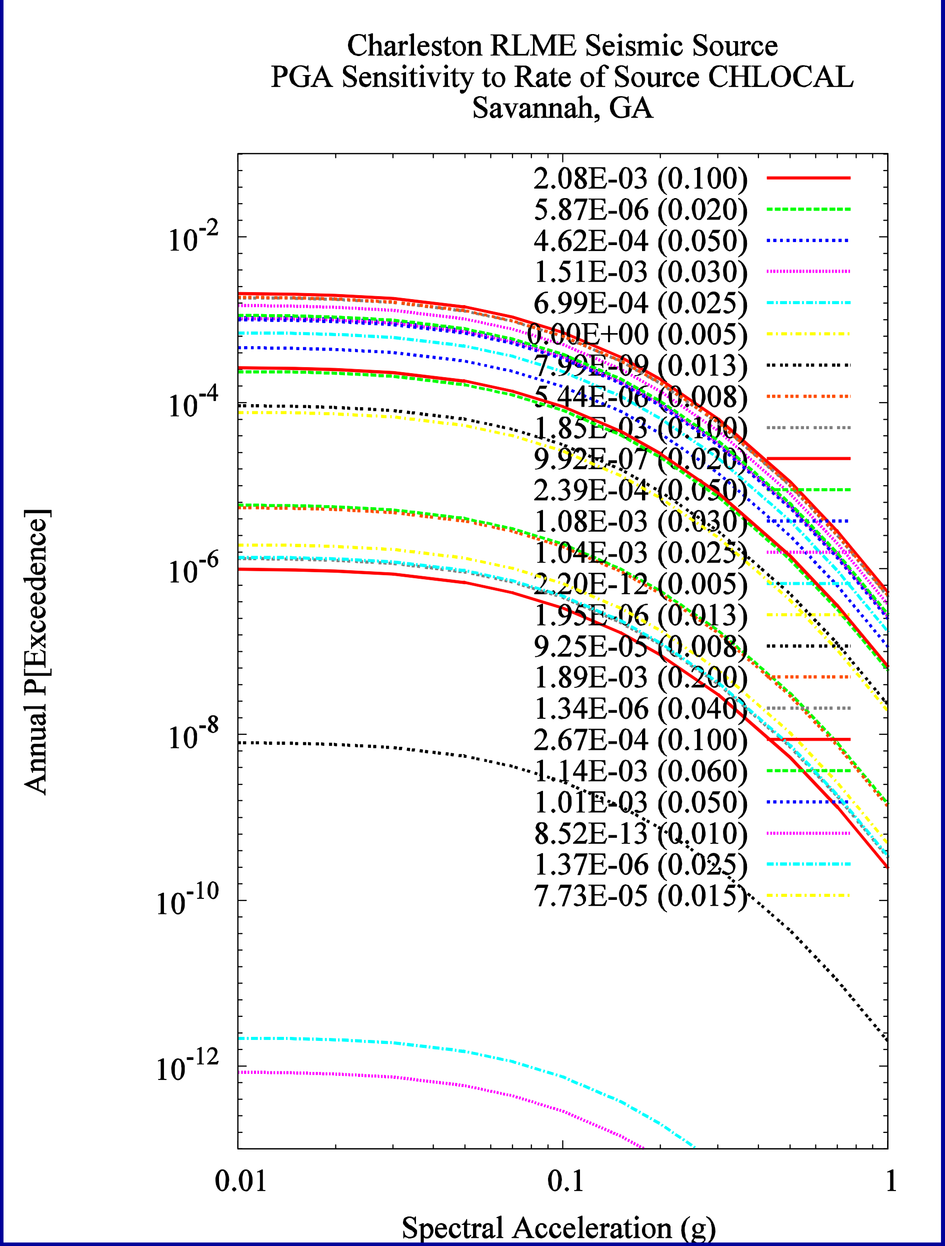
Results for Savannah, GA : Local Source,10 Hz, Mmax



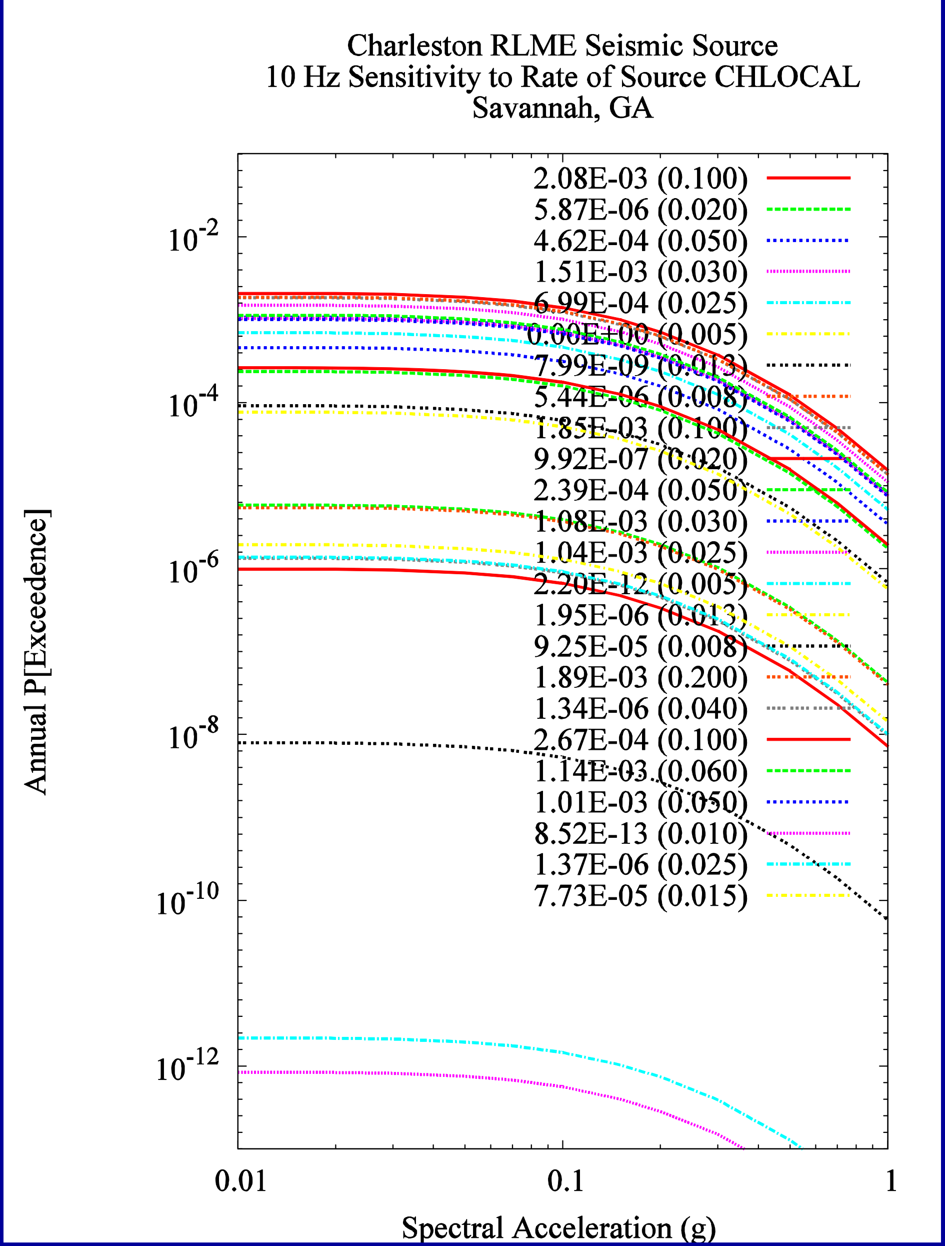
Results for Savannah, GA : Local Source, 1 Hz, Mmax



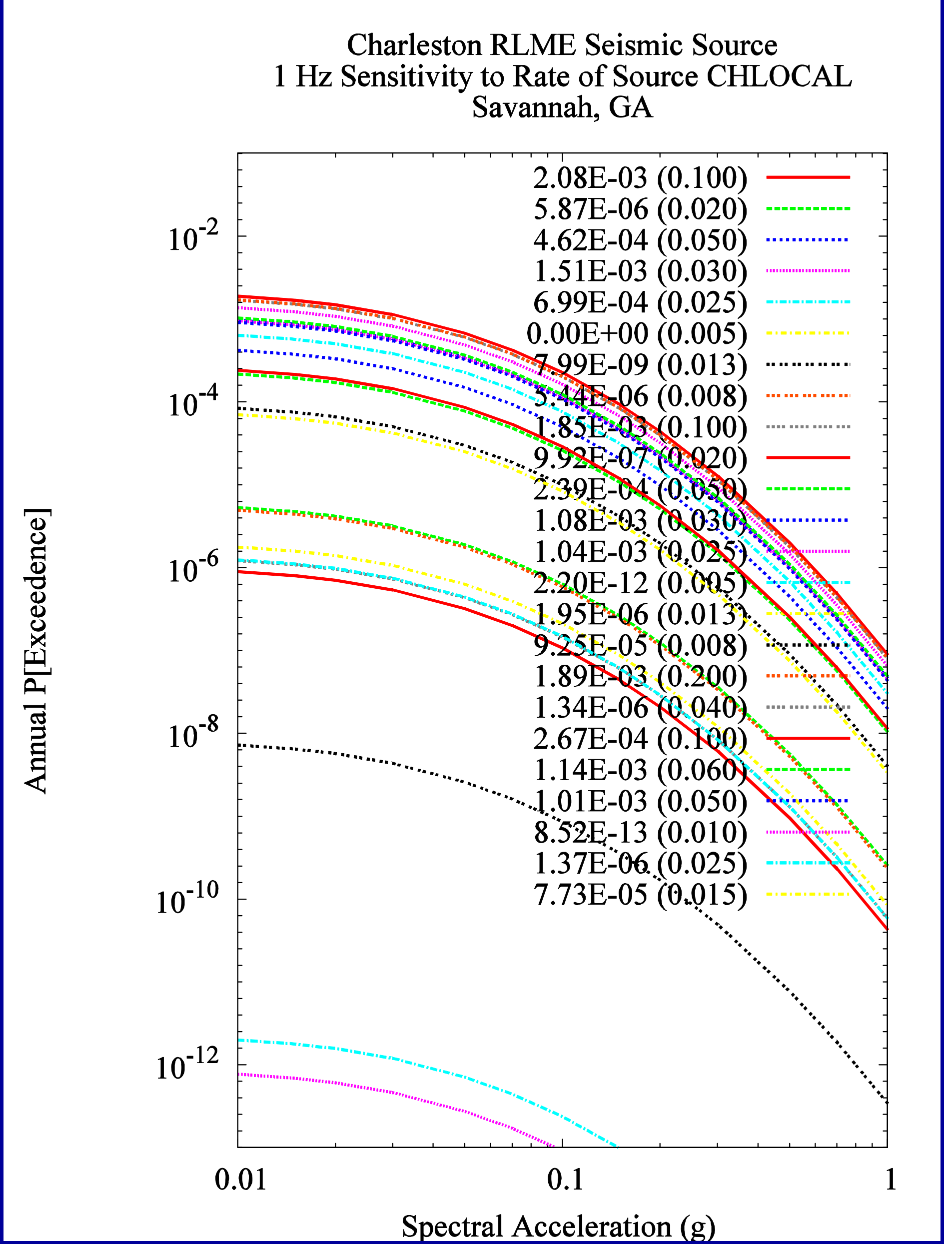
Results for Savannah, GA : Local Source, PGA, Rate



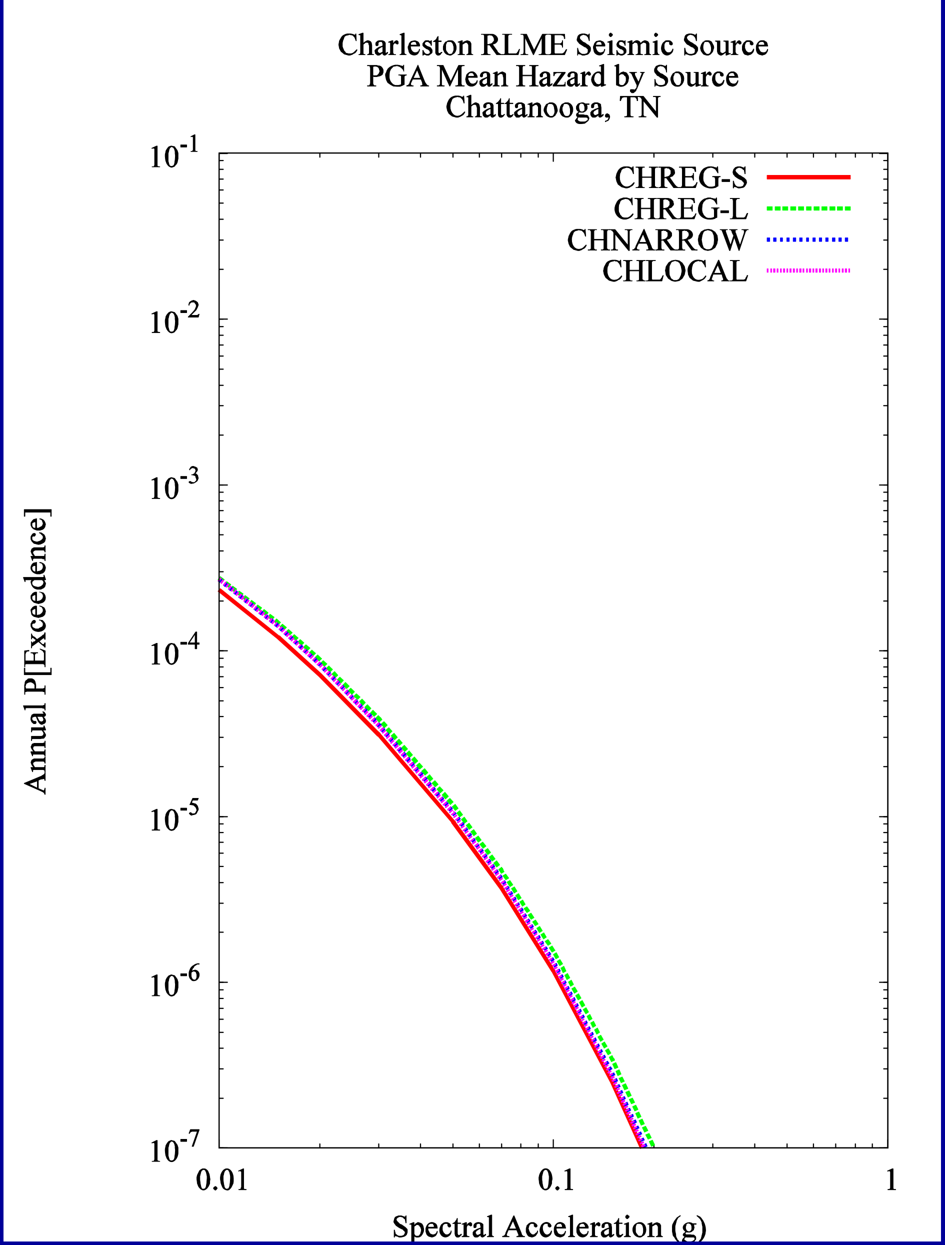
Results for Savannah, GA : Local Source, 10 Hz, Rate



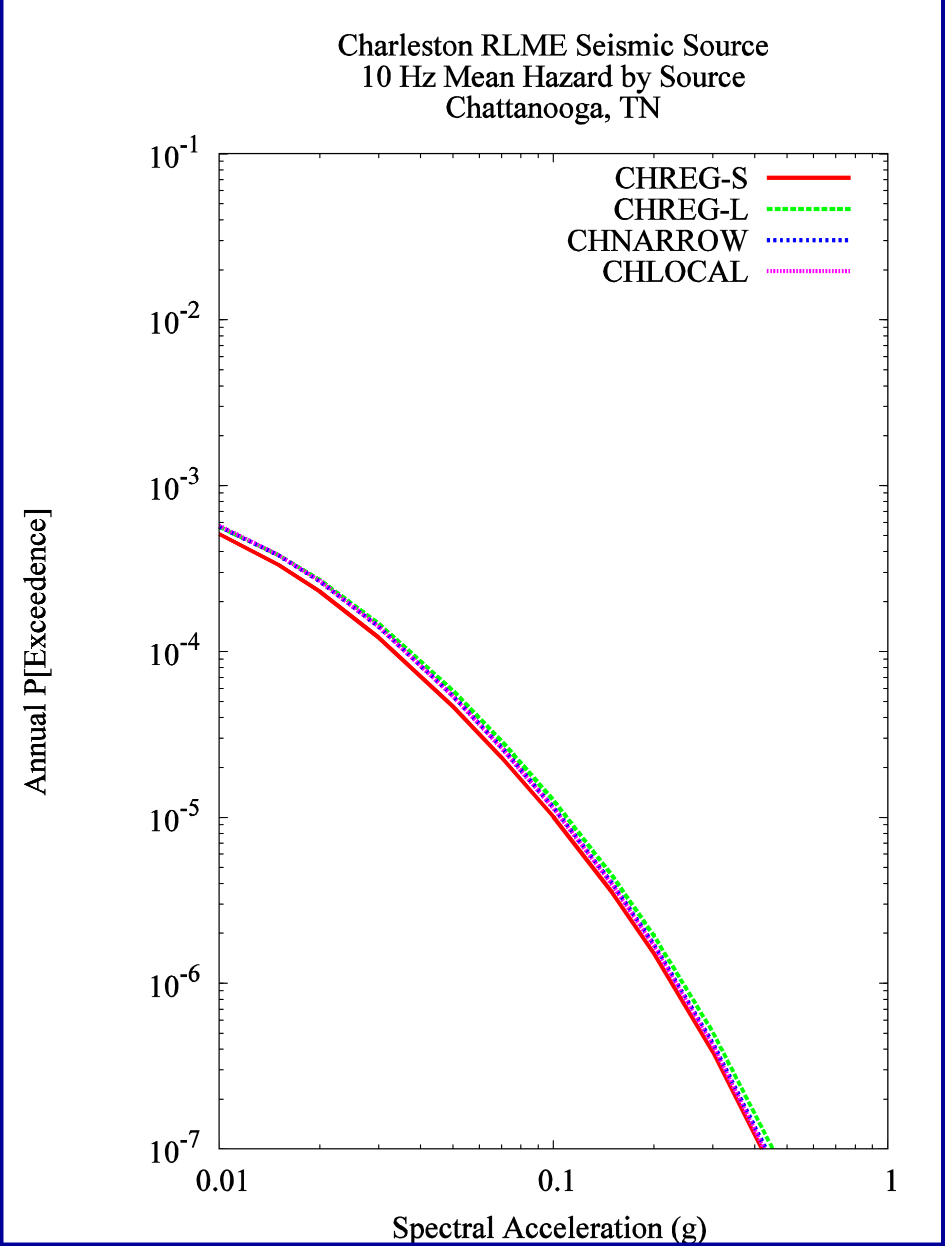
Results for Savannah, GA : Local Source, 1 Hz, Rate



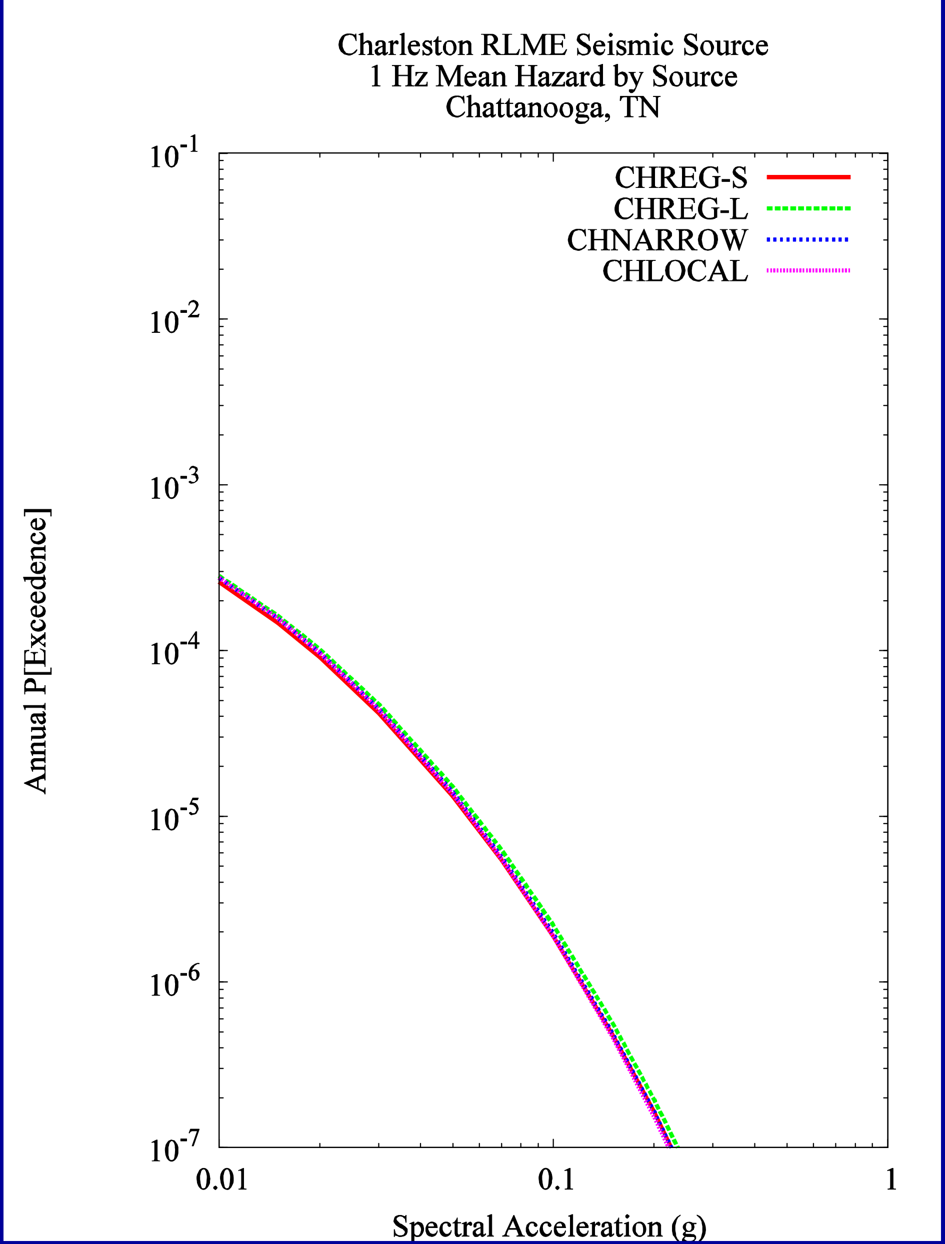
Results for Chattanooga, TN: PGA, Geometry



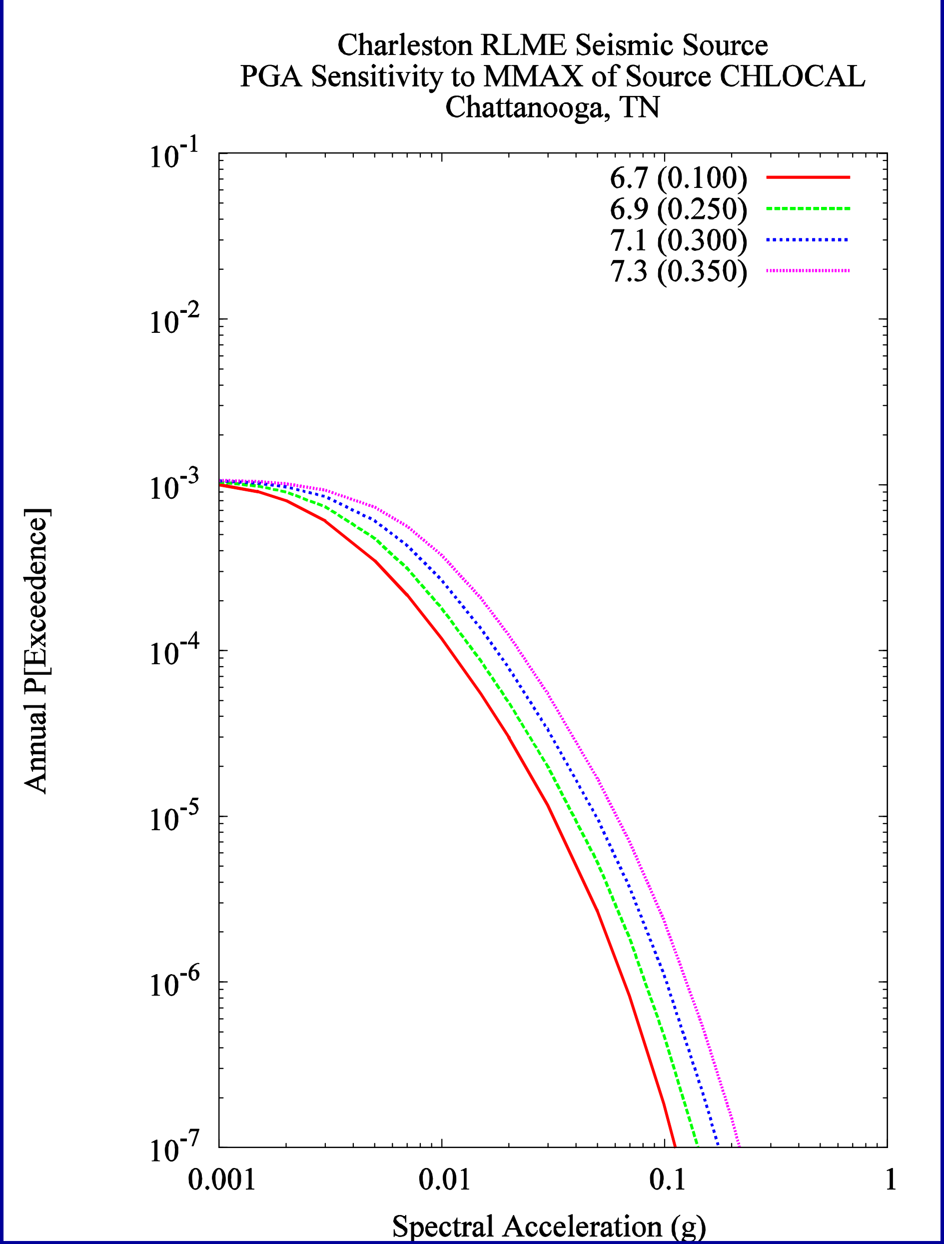
Results for Chattanooga, TN: 10 Hz, Geometry



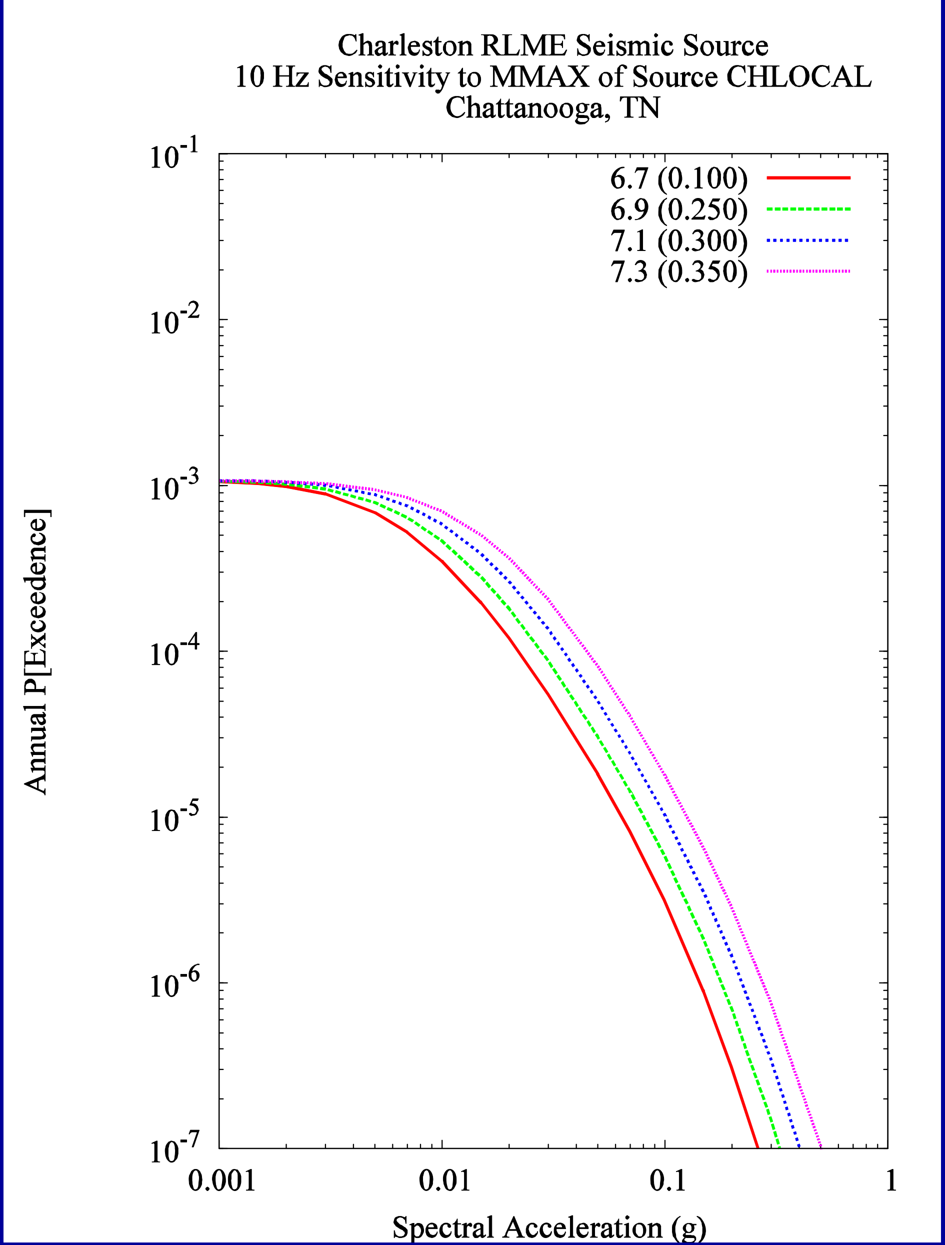
Results for Chattanooga, TN: 1 Hz, Geometry



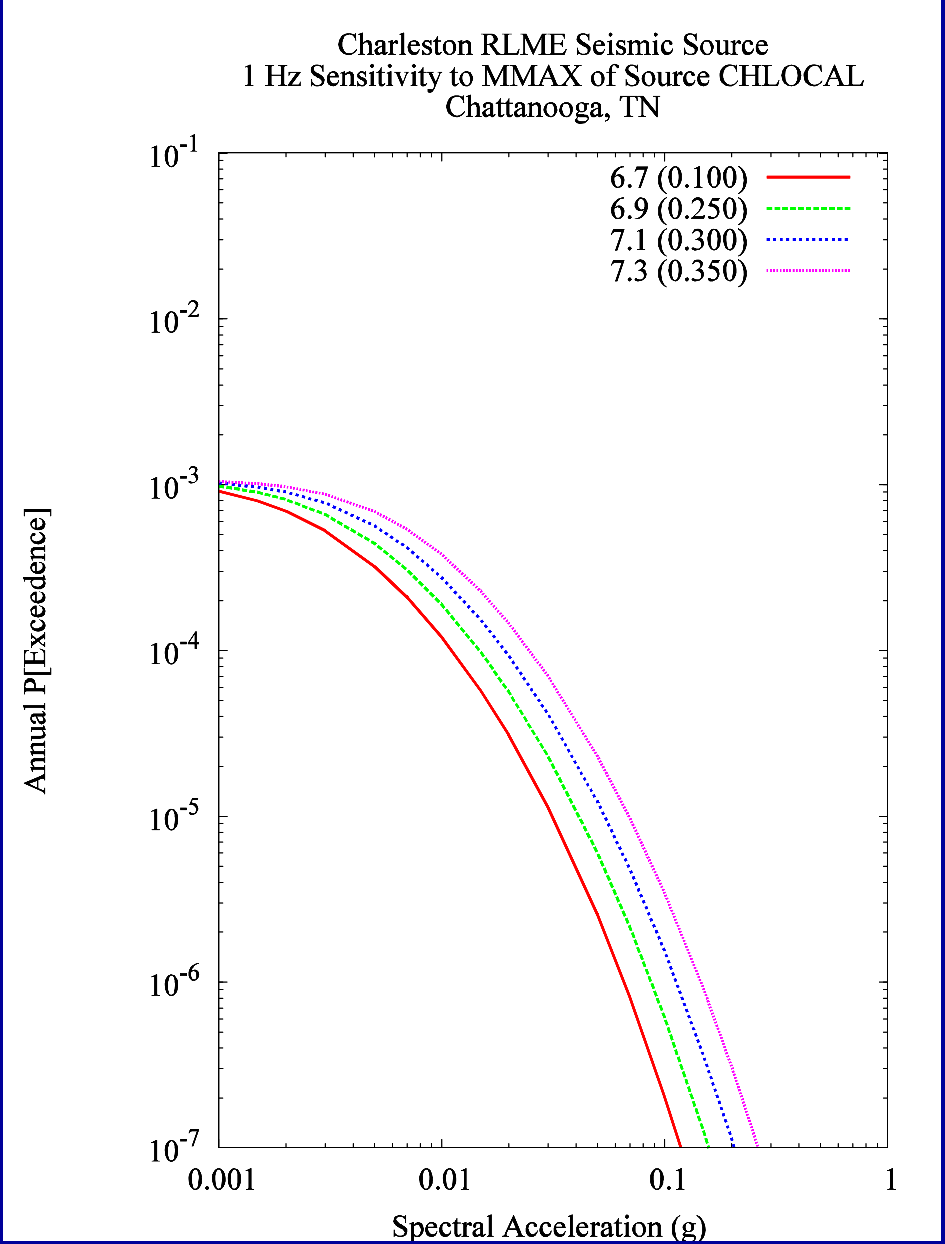
Results for Chattanooga, TN : Local Source, PGA, Mmax



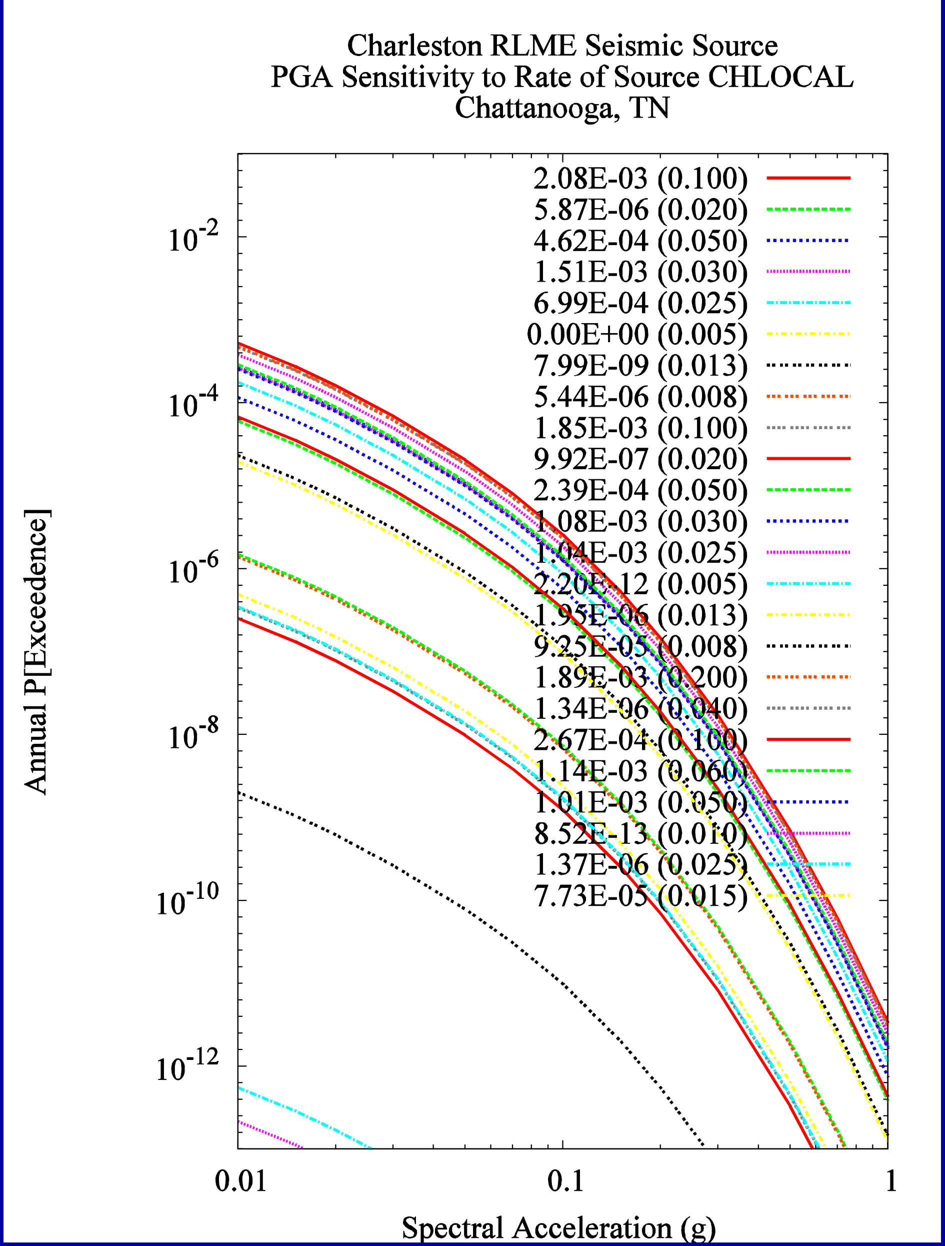
Results for Chattanooga, TN : Local Source,10 Hz, Mmax



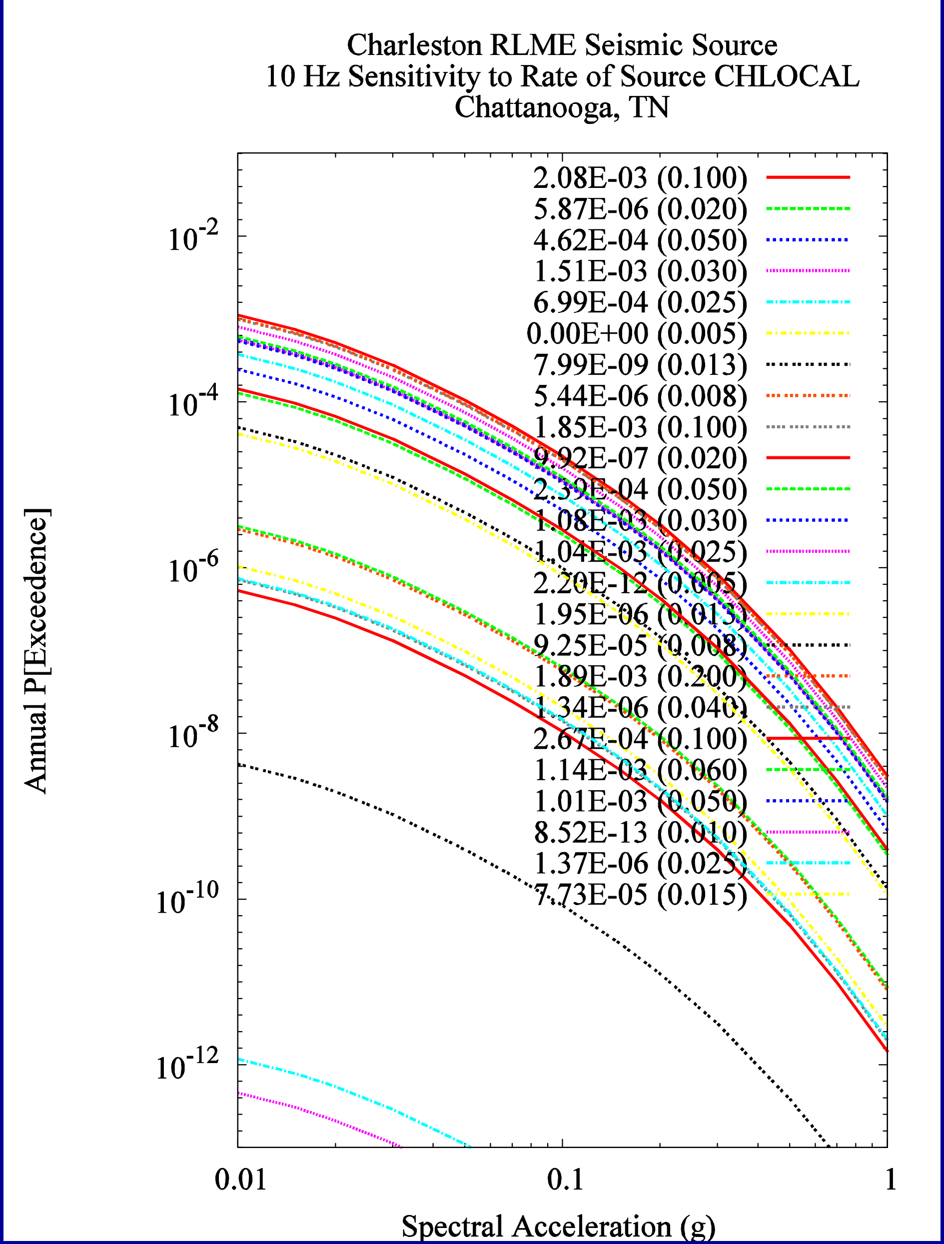
Results for Chattanooga, TN : Local Source, 1 Hz, Mmax



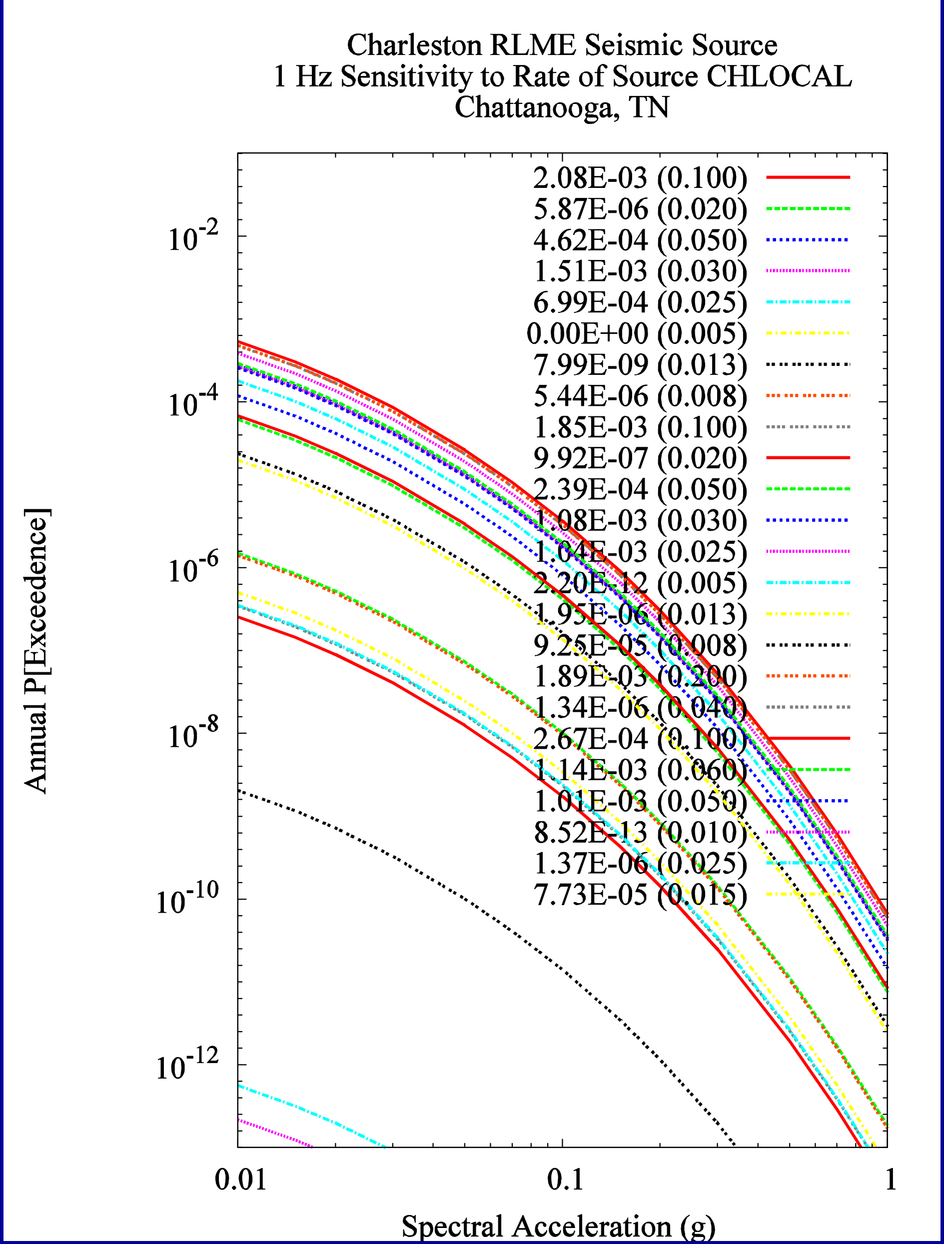
Results for Chattanooga, TN : Local Source, PGA, Rate



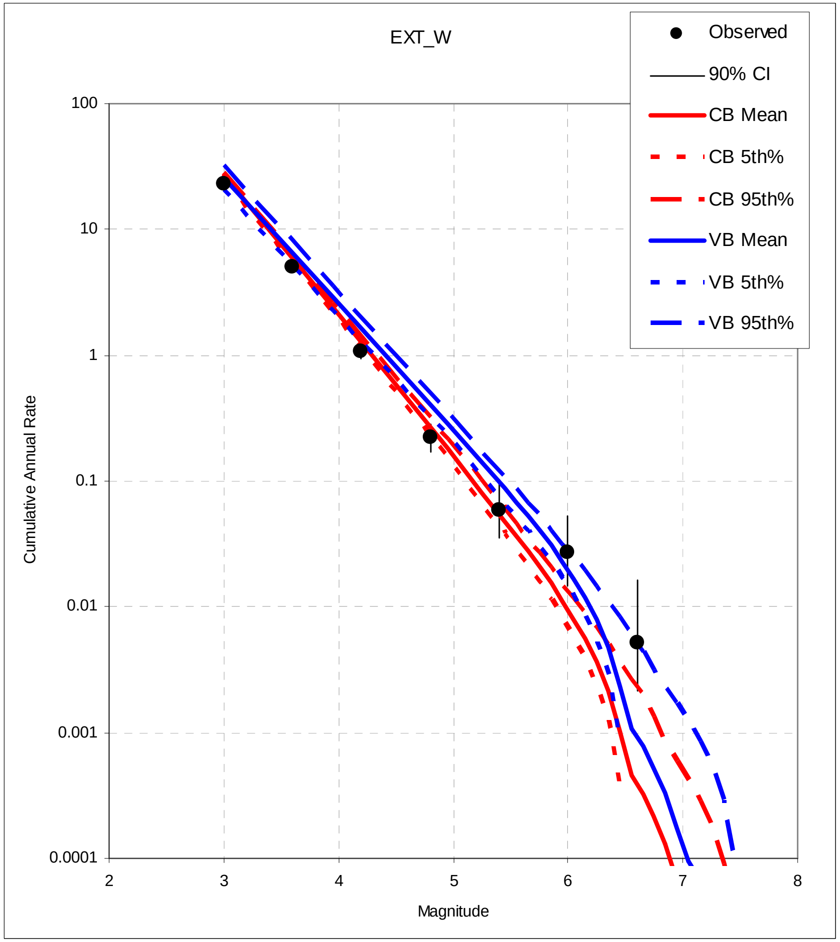
Results for Chattanooga, TN : Local Source, 10 Hz, Rate

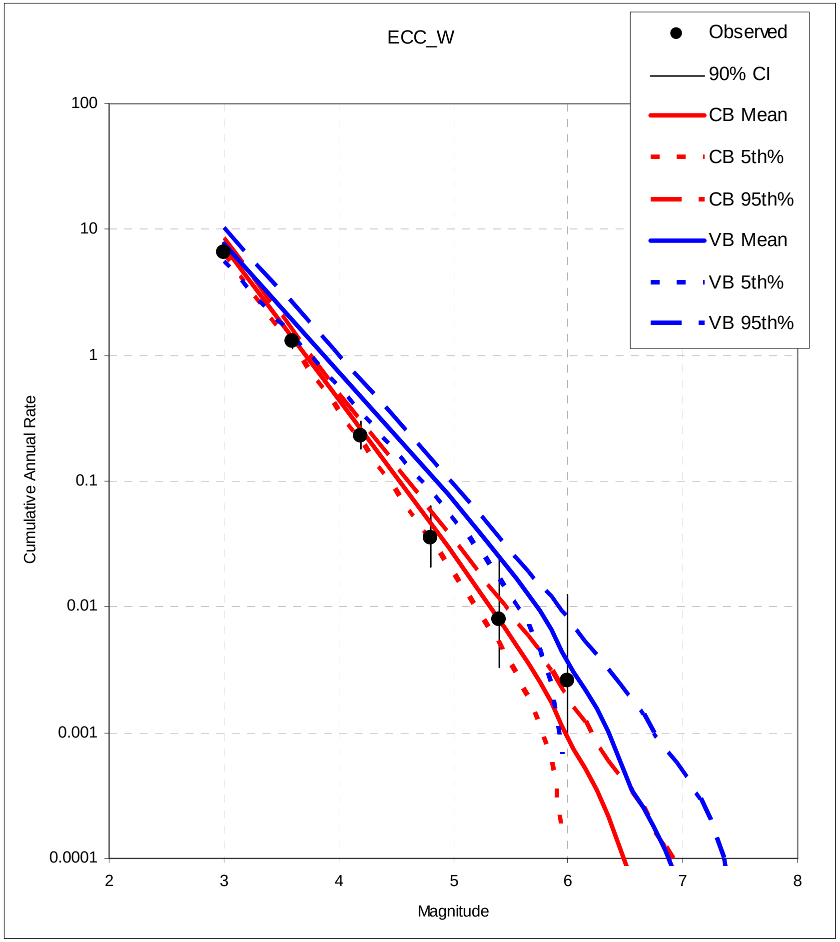


Results for Chattanooga, TN : Local Source, 1 Hz, Rate

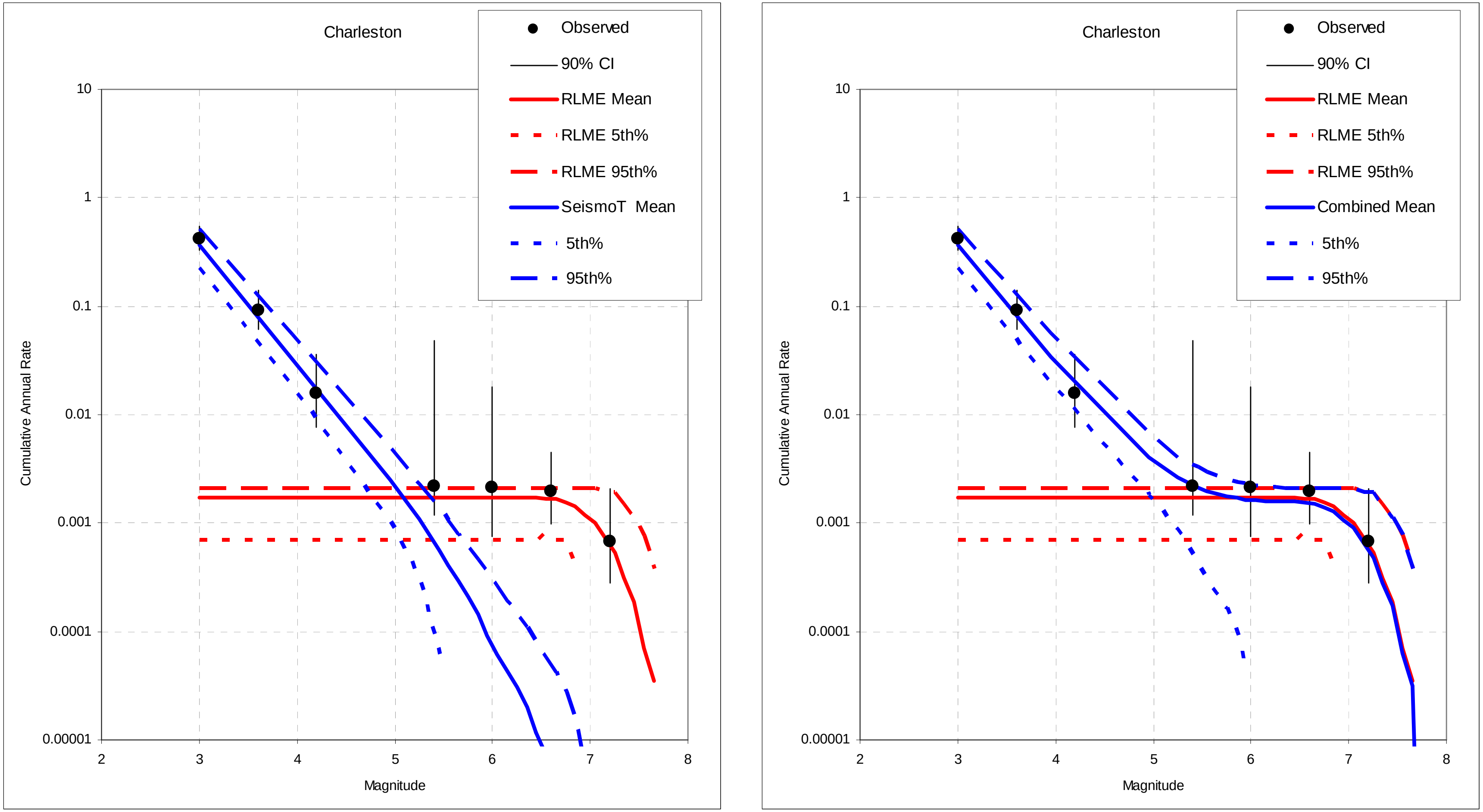


Regional Seismicity Comparisons



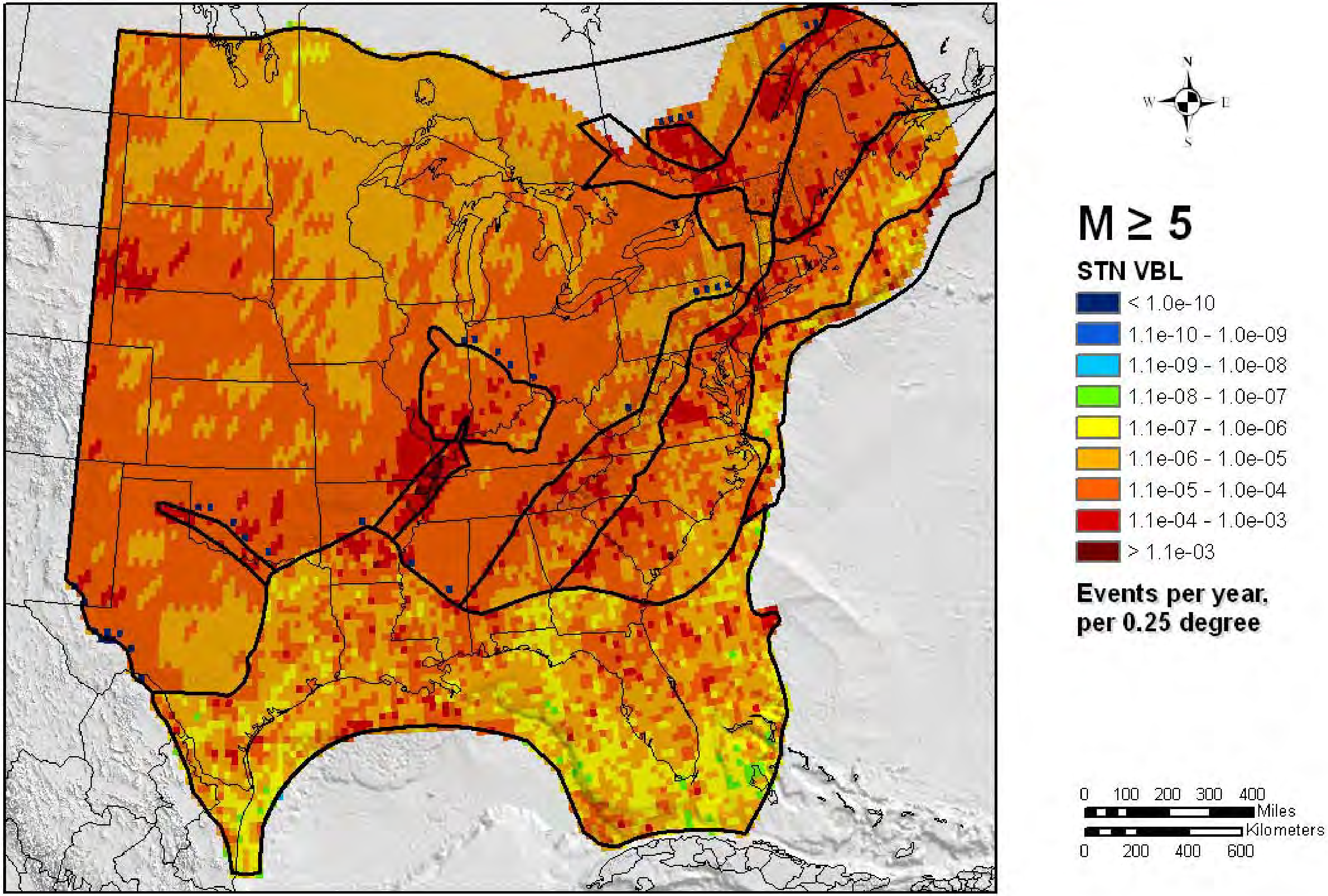


Seismicity Fits at Charleston



St Lawrence

Spatial Density Model of Historical Seismicity



M ≥ 5

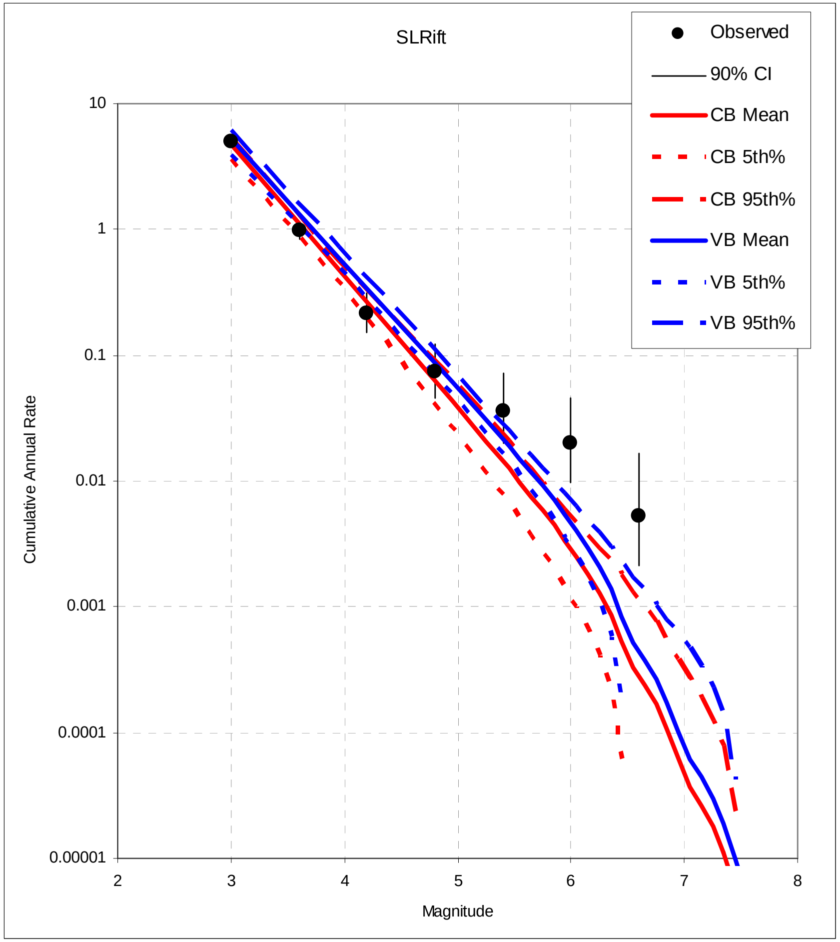
STN VBL

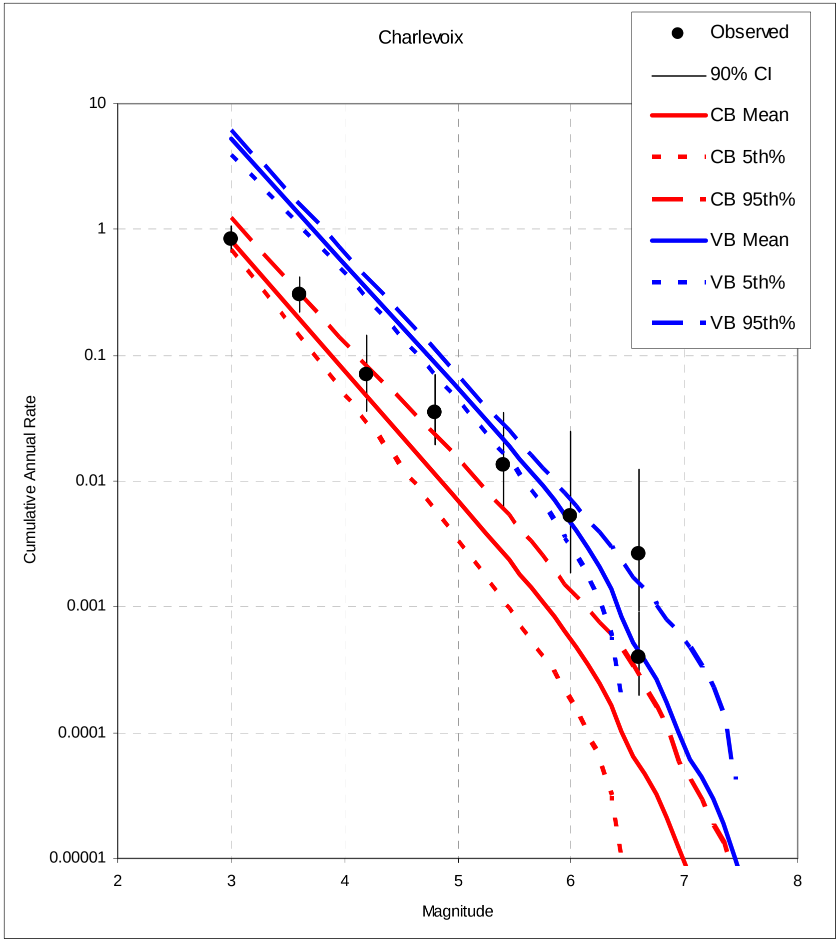
- 🟦 < 1.0e-10
- 🟦 1.1e-10 - 1.0e-09
- 🟦 1.1e-09 - 1.0e-08
- 🟩 1.1e-08 - 1.0e-07
- 🟨 1.1e-07 - 1.0e-06
- 🟧 1.1e-06 - 1.0e-05
- 🟧 1.1e-05 - 1.0e-04
- 🟥 1.1e-04 - 1.0e-03
- 🟫 > 1.1e-03

Events per year, per 0.25 degree

AMEC Geomatrix

St Lawrence and Charlevoix





TI Lead’s Conclusions from Feedback Discussion on August 25

- Large impact on predicted rate density of alternative interpretations of the position of the extended/non-extended boundary
- Large impact on predicted rate density of seismotectonic zone boundaries (i.e., step-function at boundary)
  - Present for both kernel smoothing and variable a and b smoothing approaches
  - Zonation introduces step boundaries and brings into focus the assessment of Mmax, if want zone by zone differences

TI Lead’s Conclusions from Feedback Discussion on August 25(cont’d)

- RLME Sources
  - Post-2000 SSC models are similar in treatment of NMSZ earthquake recurrence and lead to comparable mean hazard
  - Within-cluster recurrence is very important; don’t know the significance of the “in-cluster” versus “out of cluster” models
  - At NMSZ, renewal model gives lower hazard given the elapsed time has been short relative to average recurrence interval
  - Strong sensitivity to characteristic magnitudes at all RLMEs
  - At NMSZ
    - Rupture scenarios are not very important
    - No strong sensitivity to rupture length models; at these magnitudes get entire lengths rupturing
  - As move out of immediate proximity to RLME, the background or regional seismotectonic zones are important and contribute more then RLME source
    - At Central Illinois host zone is high relative to NM RLME sources
    - At Topeka, background sources dominate the hazard

TI Lead's Conclusions from Feedback Discussion on August 25(cont'd)

RLME Sources (continued)

- Cheraw fault
  - Mmax is fairly important at low AFEs, but likely the host source dominates at the Topeka site
  - Recurrence is most important
  - New data suggests may be longer is unlikely to be important
- Wabash Valley RLME
  - Geometry is not too important
  - Rate is most important
  - Paleoseismic recurrence predicts somewhat higher than the observed (?)
- OK Aulocogen/Meers
  - Geometry appears to be an important issue; need to check this for errors
  - Have only run the in-cluster so far, so not clear whether in-cluster versus out of cluster is an important issue for the Meers fault
  - Aulocogen: Floating Meers-type event model appears to be important
  - The background Mmax within the aulocogen (without the Meers) is potentially important
- ALM RLME Seismic Source
  - Testing randomly oriented ruptures that are allowed or not to extend beyond the boundary:Low sensitivity to leaky vs. strict
  - High sensitivity to source boundaries
  - High sensitivity to rates

Sensitivity Results for CEUS Source Zones

Presentation by
Gabriel R. Toro, Risk Engineering, Inc

EPRI CEUS Seismic Source Characterization
Workshop III

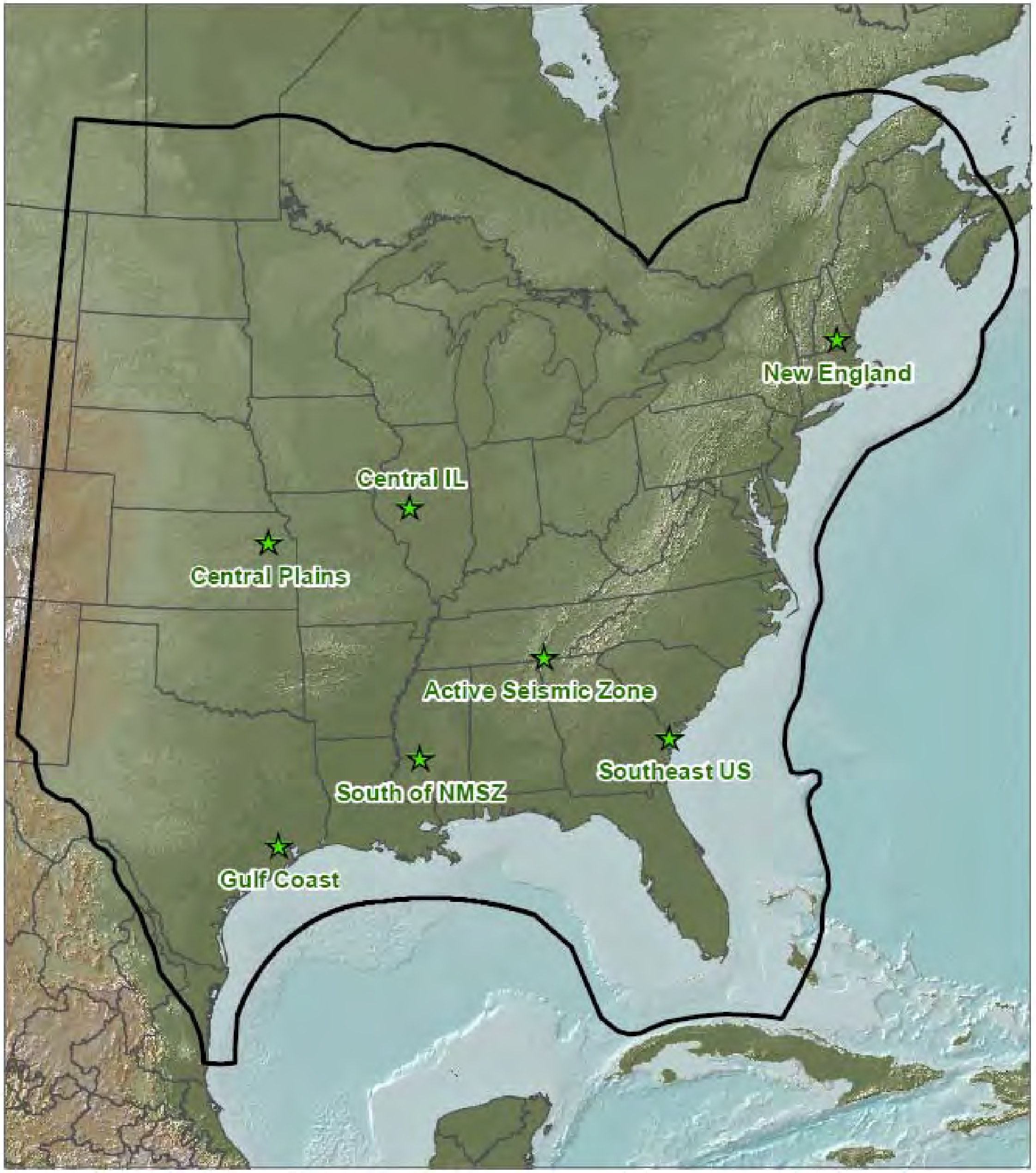
Palo Alto, CA; August 25-26, 2009
(rev. 9/4/09: additional sensitivities for Chattanooga, IRM source)

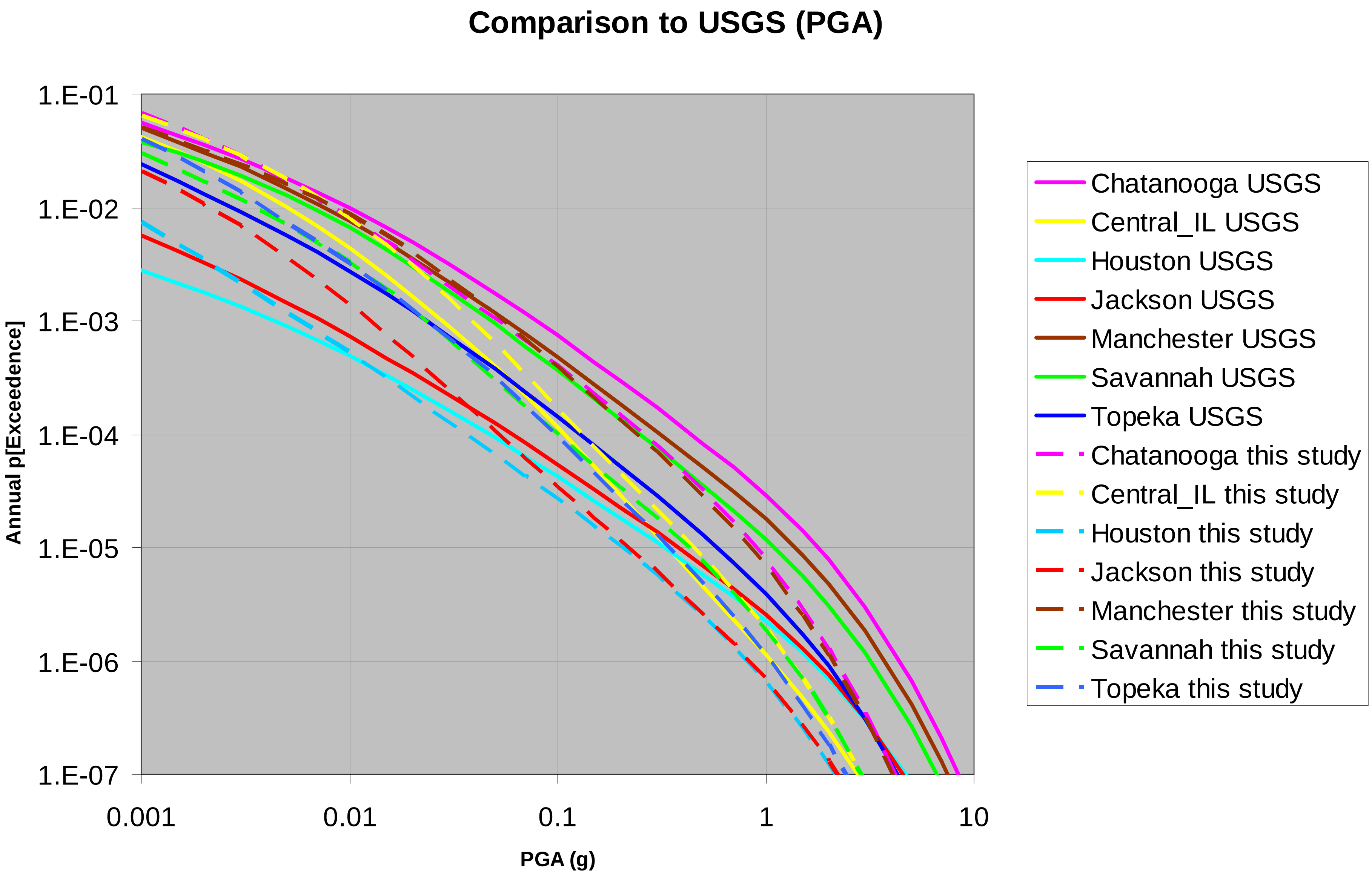
Outline

- Comparison to results using USGS zonations
- Sensitivities for each site
  - Sensitivities for PGA
  - Sensitivities for 1 Hz
  - Summary of sensitivities
- Overall summary

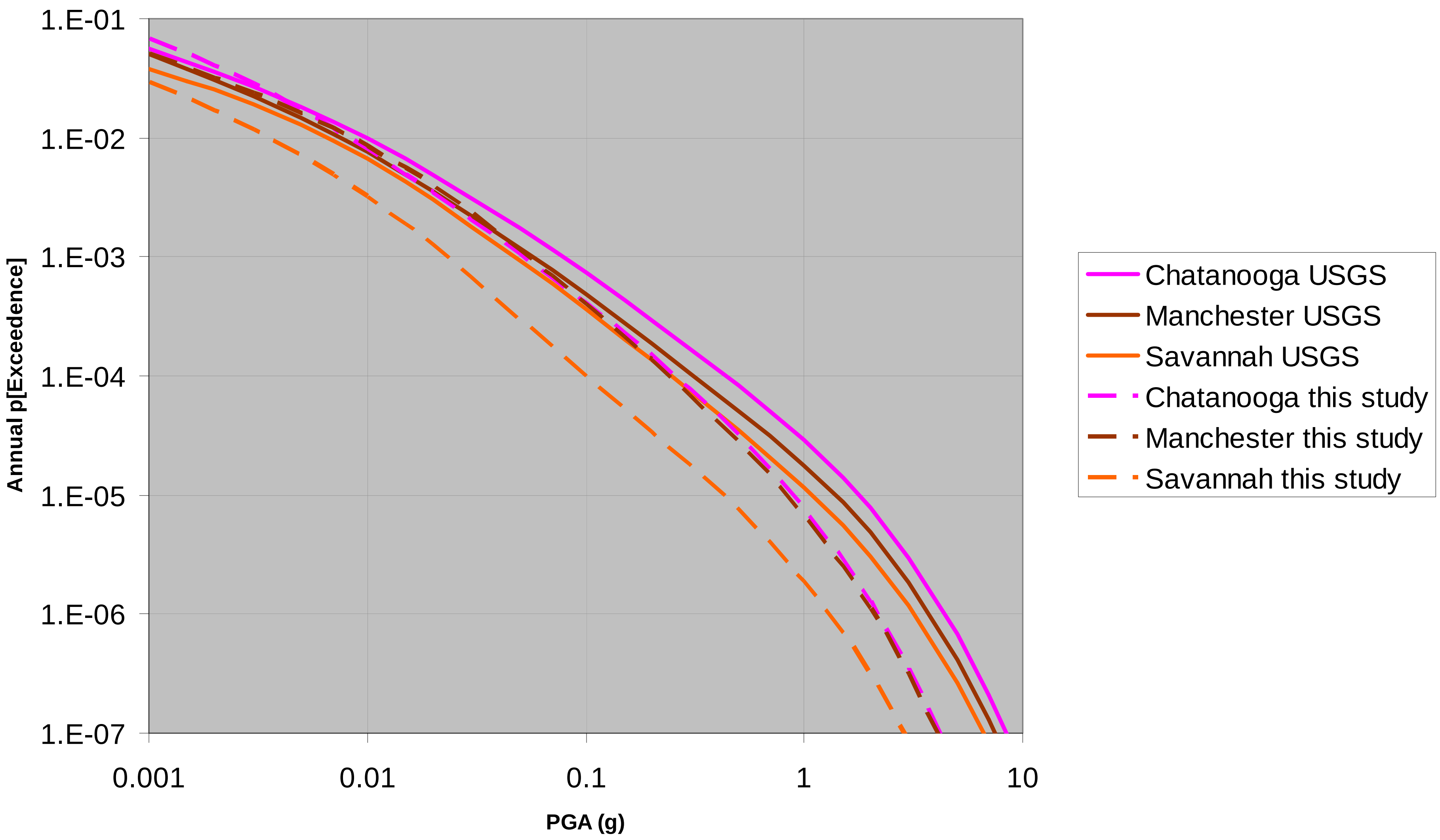
William Lettis & Associates, Inc.

RISK ENGINEERING


New England
Central IL
Central Plains
Active Seismic Zone
South of NMSZ
Southeast US
Gulf Coast


Comparison to USGS (PGA)
Annual p[Exceedence]
1.E-01
1.E-02
1.E-03
1.E-04
1.E-05
1.E-06
1.E-07
0.001
0.01
0.1
1
10
PGA (g)
Chatanooga USGS
Central_IL USGS
Houston USGS
Jackson USGS
Manchester USGS
Savannah USGS
Topeka USGS
Chatanooga this study
Central_IL this study
Houston this study
Jackson this study
Manchester this study
Savannah this study
Topeka this study

Comparison to USGS (PGA)



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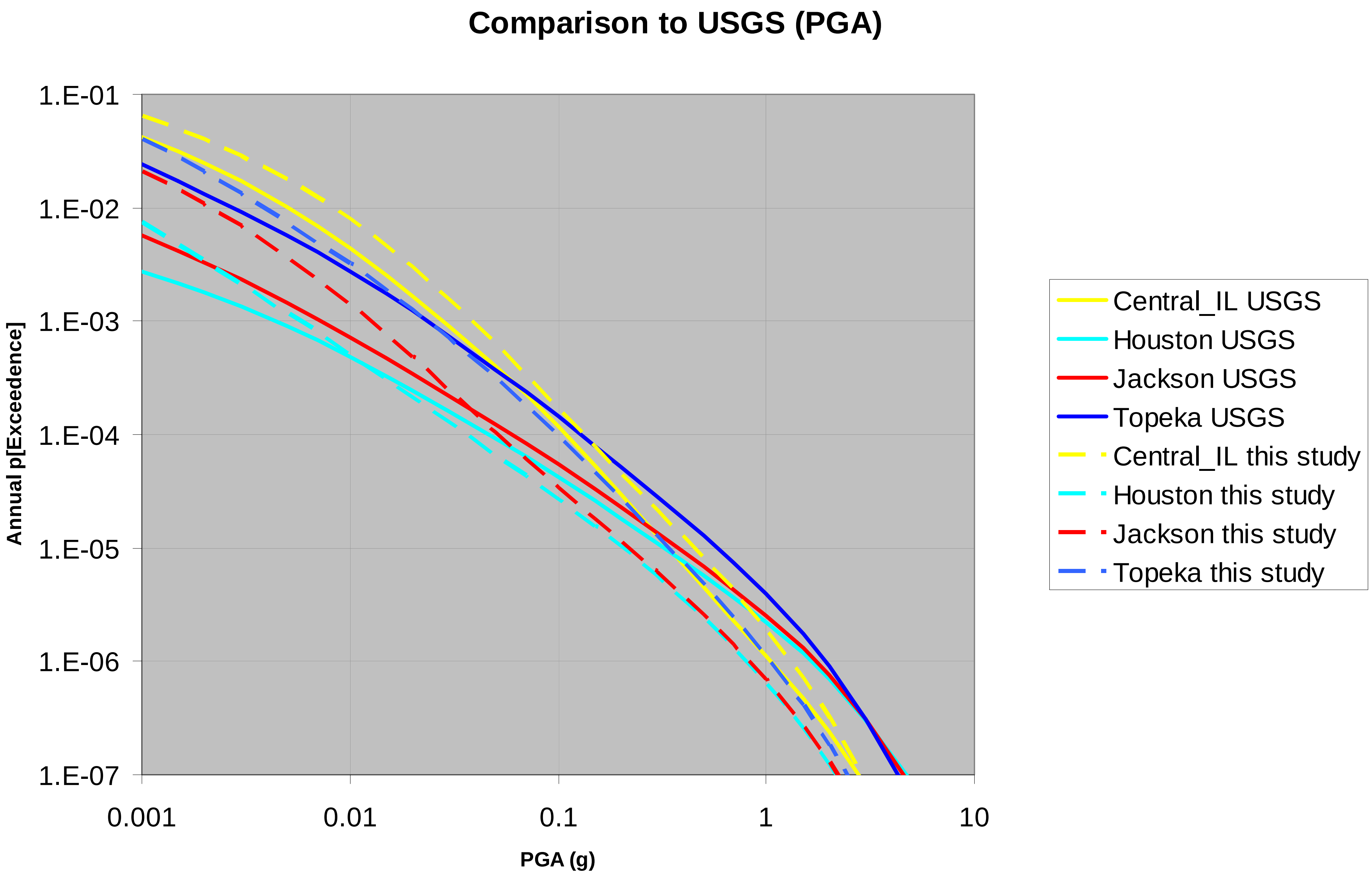
RISK ENGINEERING



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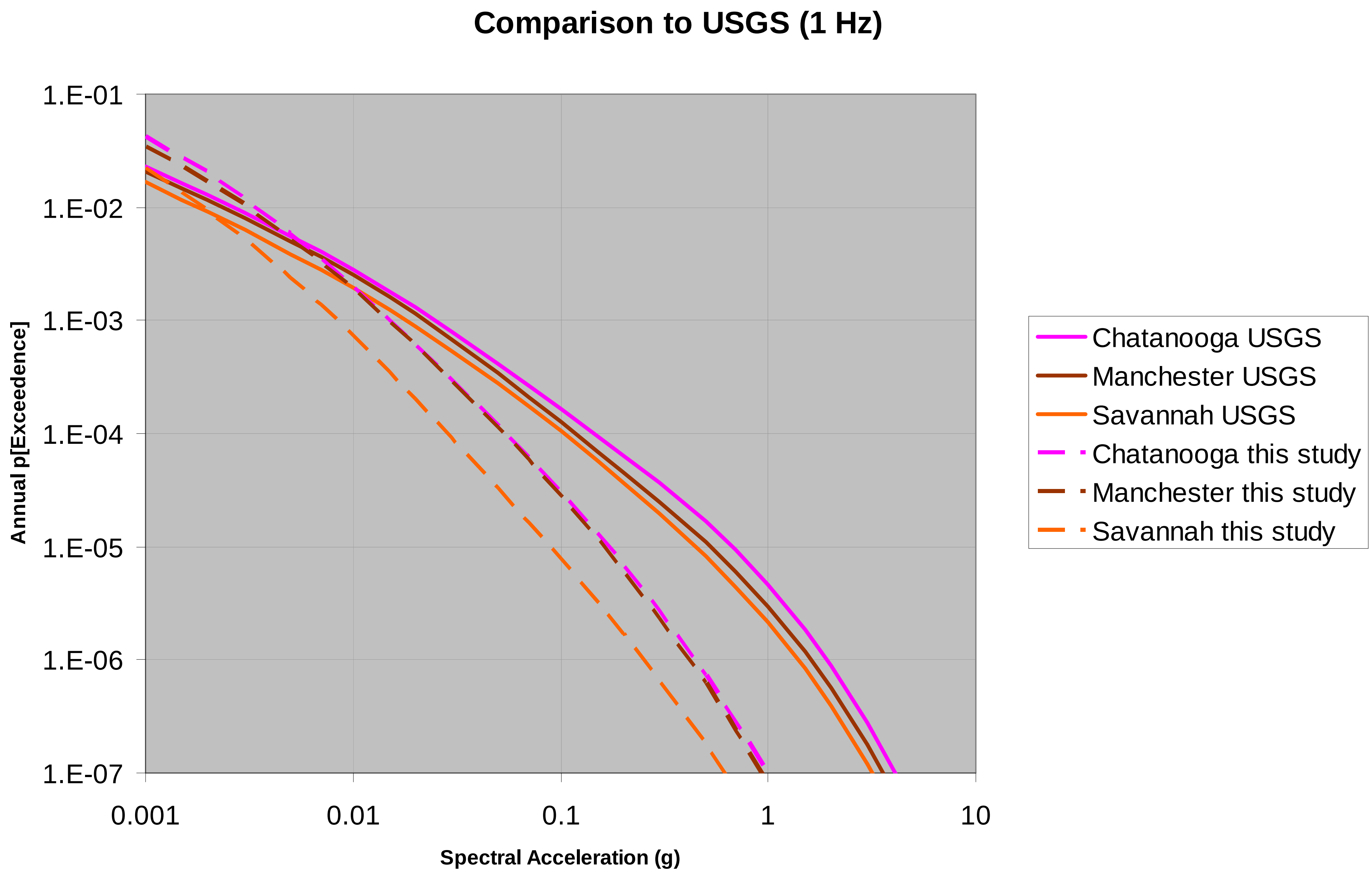
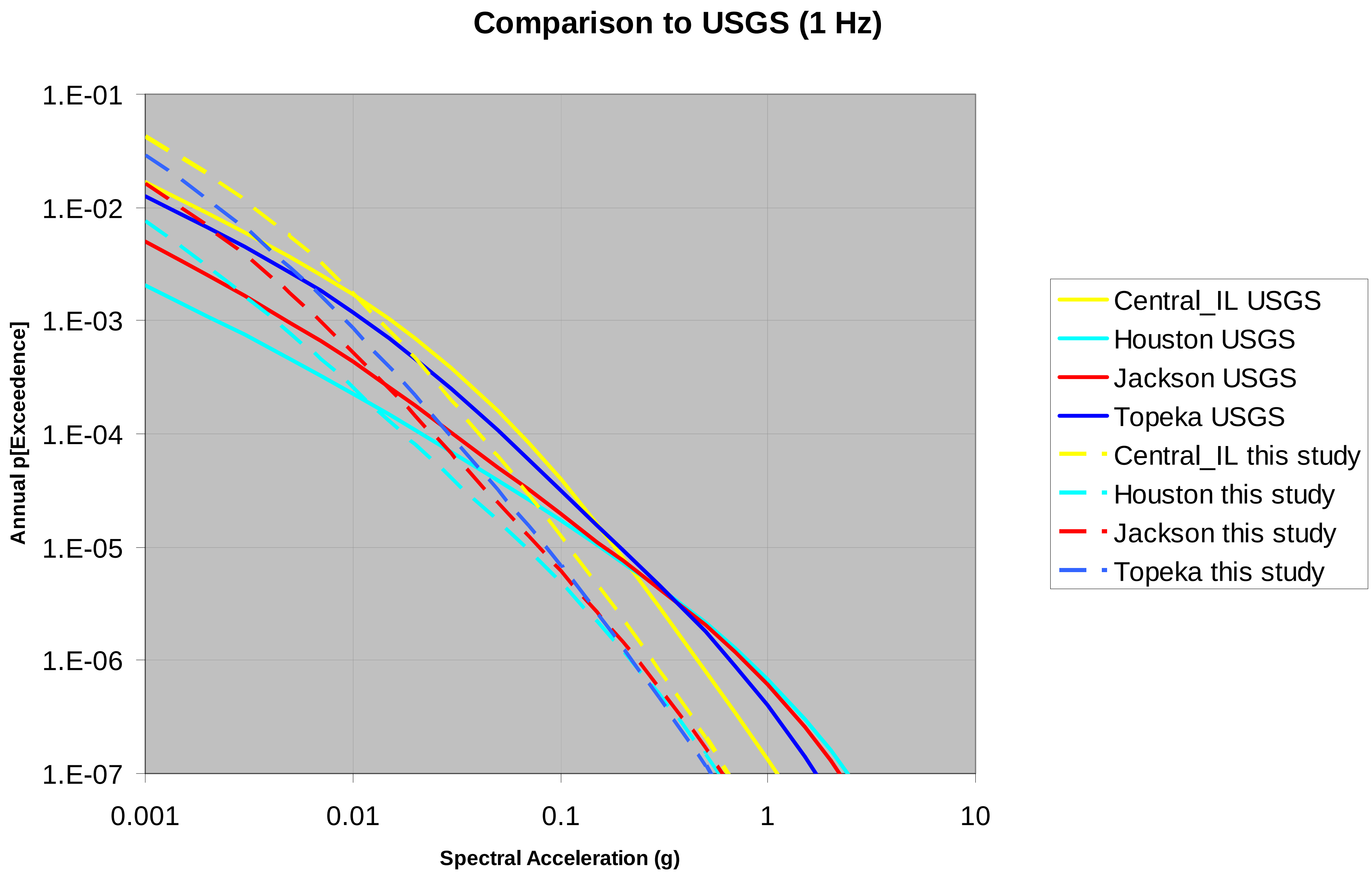
RISK ENGINEERING


Comparison to USGS (1 Hz)
Annual p[Exceedence]
1.E-01
1.E-02
1.E-03
1.E-04
1.E-05
1.E-06
1.E-07
0.001
0.01
0.1
1
10
Spectral Acceleration (g)
Chatanooga USGS
Manchester USGS
Savannah USGS
Chatanooga this study
Manchester this study
Savannah this study


Comparison to USGS (1 Hz)
Annual p[Exceedence]
1.E-01
1.E-02
1.E-03
1.E-04
1.E-05
1.E-06
1.E-07
0.001
0.01
0.1
1
10
Spectral Acceleration (g)
Central_IL USGS
Houston USGS
Jackson USGS
Topeka USGS
Central_IL this study
Houston this study
Jackson this study
Topeka this study

SE US Site: Savannah, GA

- Dominant sources
- Mean & fractile hazard curves (not including ground-motion uncertainty)
- Sensitivity to branches of master logic-tree
- Sensitivity to source characteristics (Mmax, recurrence)

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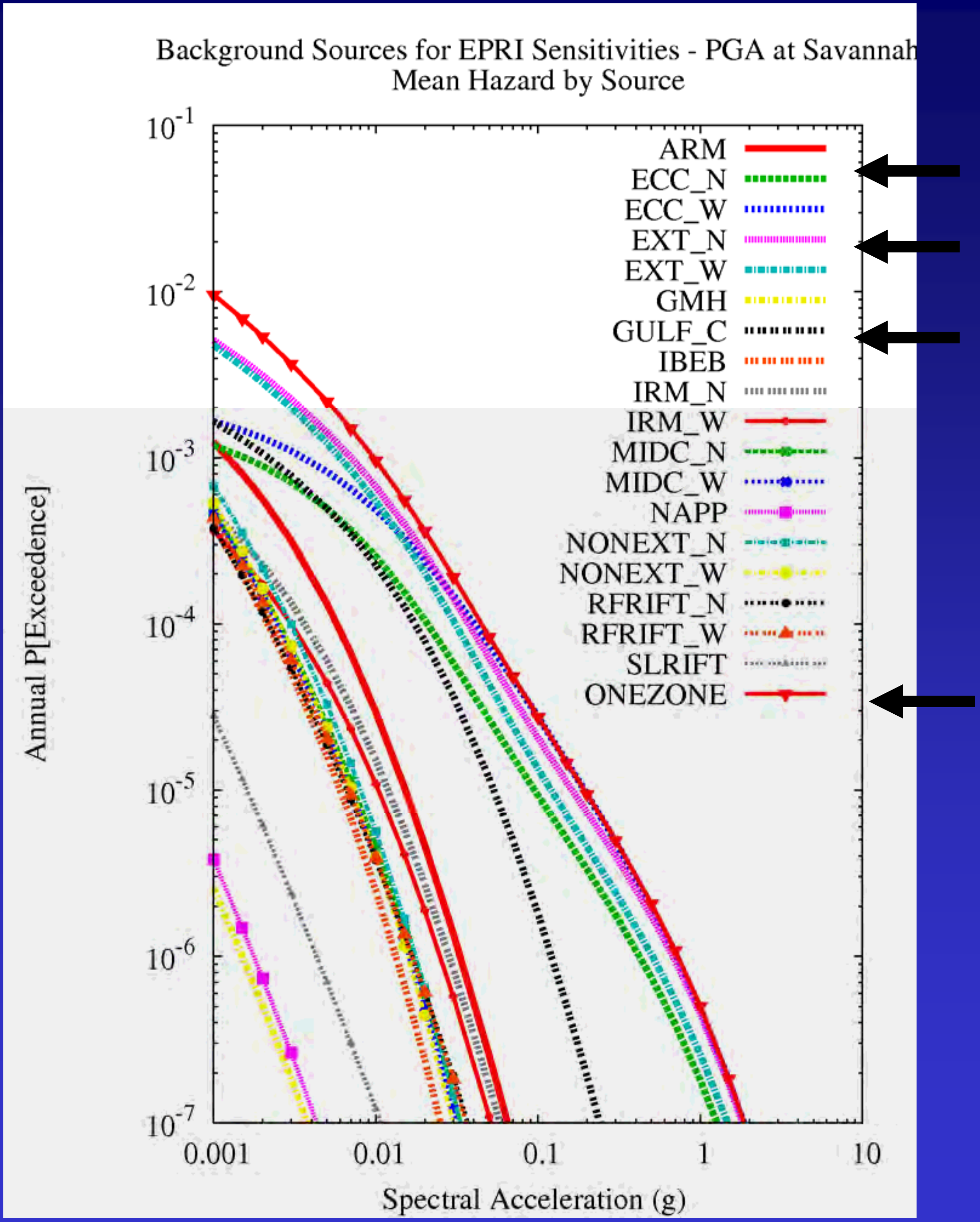
RISK ENGINEERING



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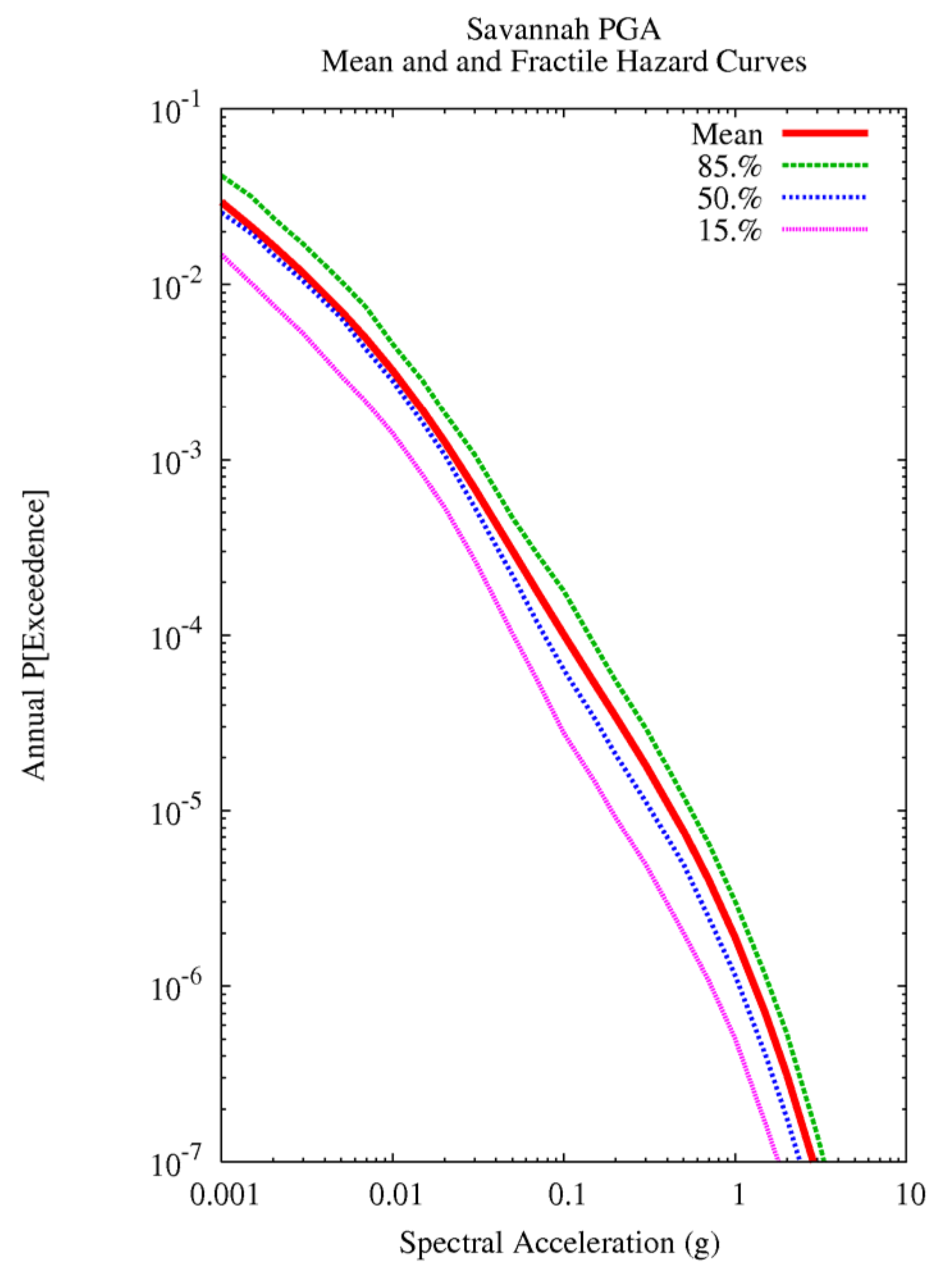
G. Toro - Backgrounds, August 25-26, 2009, slide 10

RISK ENGINEERING



Does not Include uncertainty in ground motion

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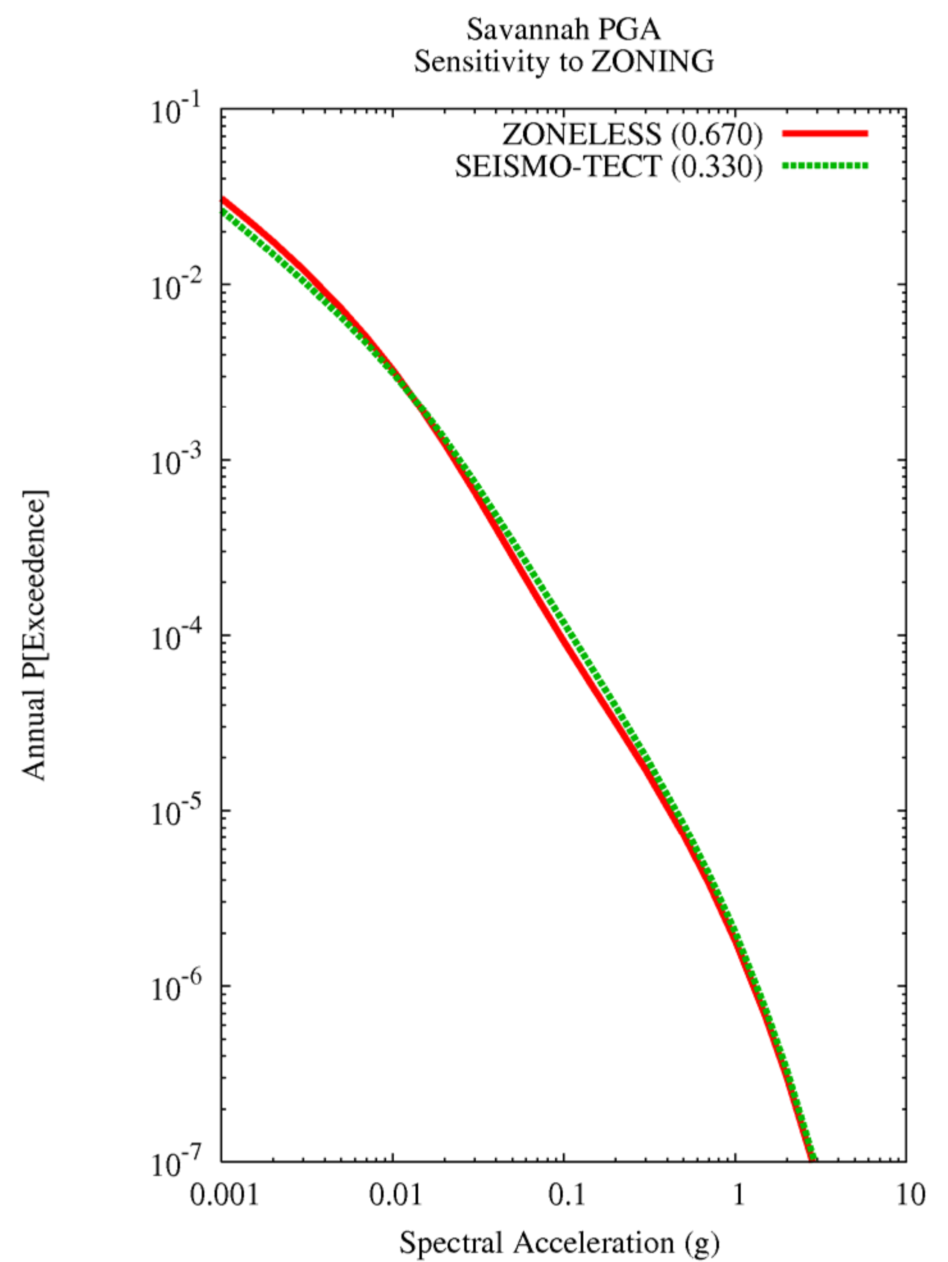
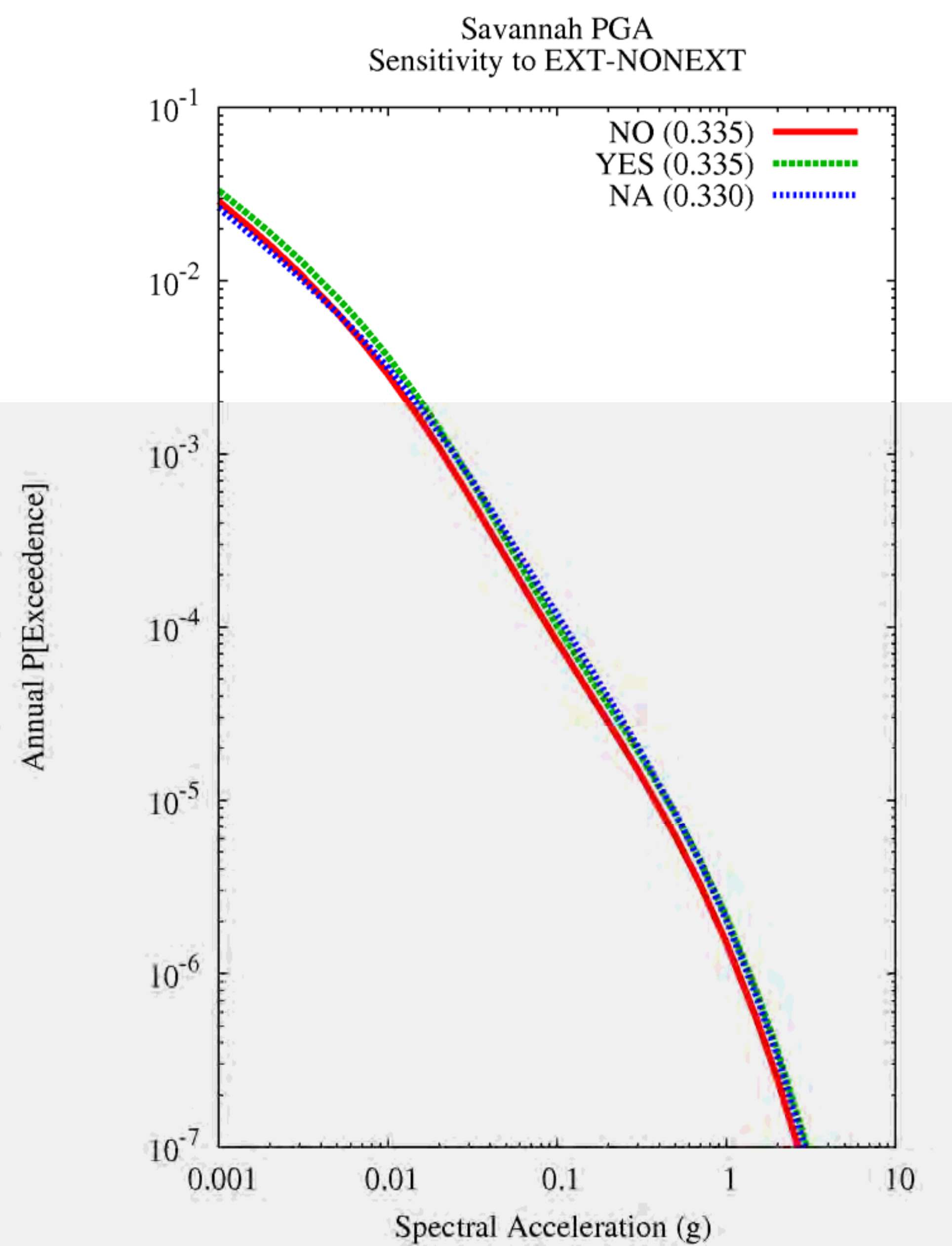
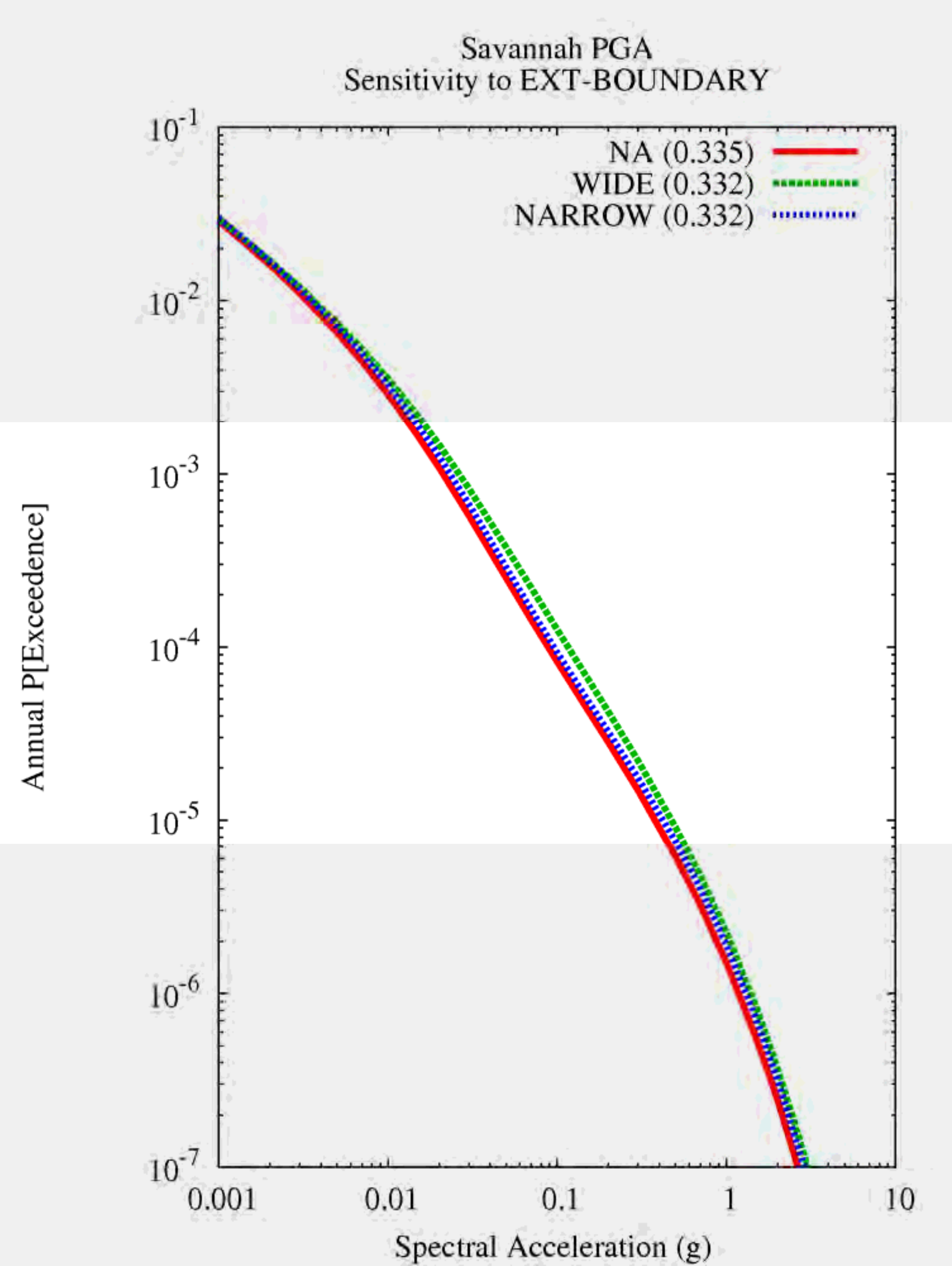
RISK ENGINEERING


Savannah PGA
Sensitivity to ZONING
ZONELESS (0.670)
SEISMO-TECT (0.330)
Annual P[Exceedence]
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
0.001
0.01
0.1
1
10
Spectral Acceleration (g)


Savannah PGA
Sensitivity to EXT-NONEXT
NO (0.335)
YES (0.335)
NA (0.330)
Annual P[Exceedence]
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
0.001
0.01
0.1
1
10
Spectral Acceleration (g)



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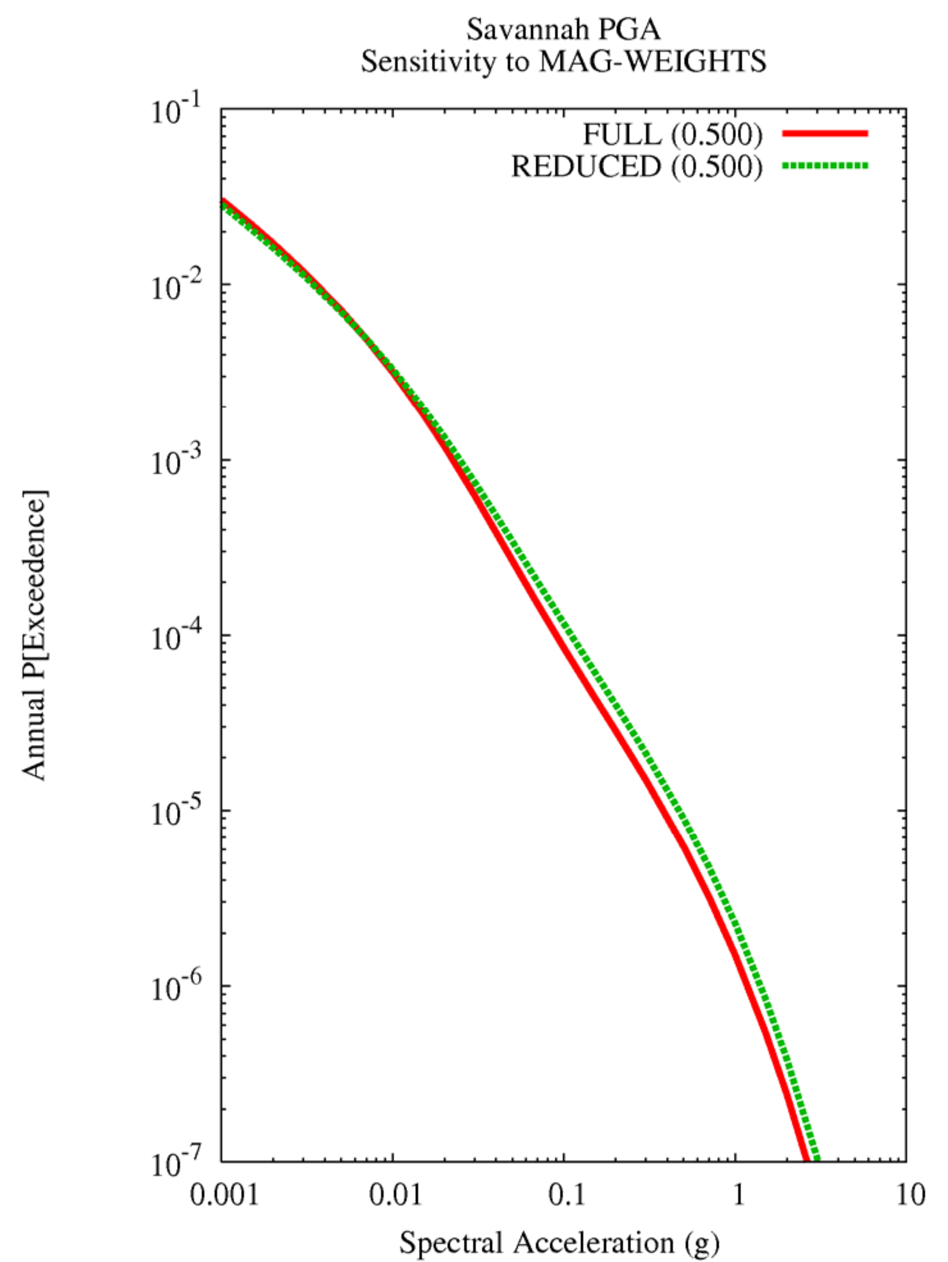

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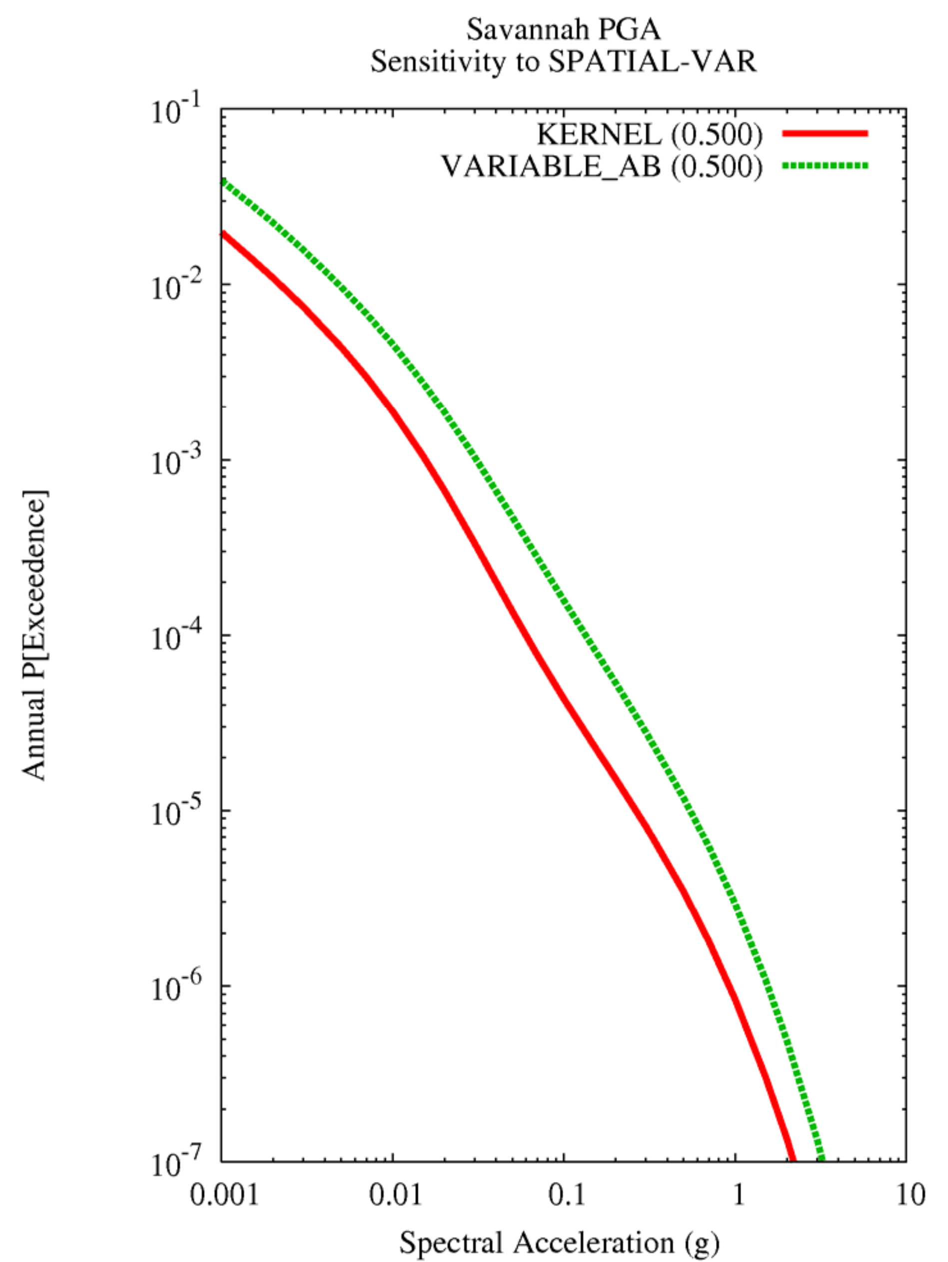
RISK ENGINEERING



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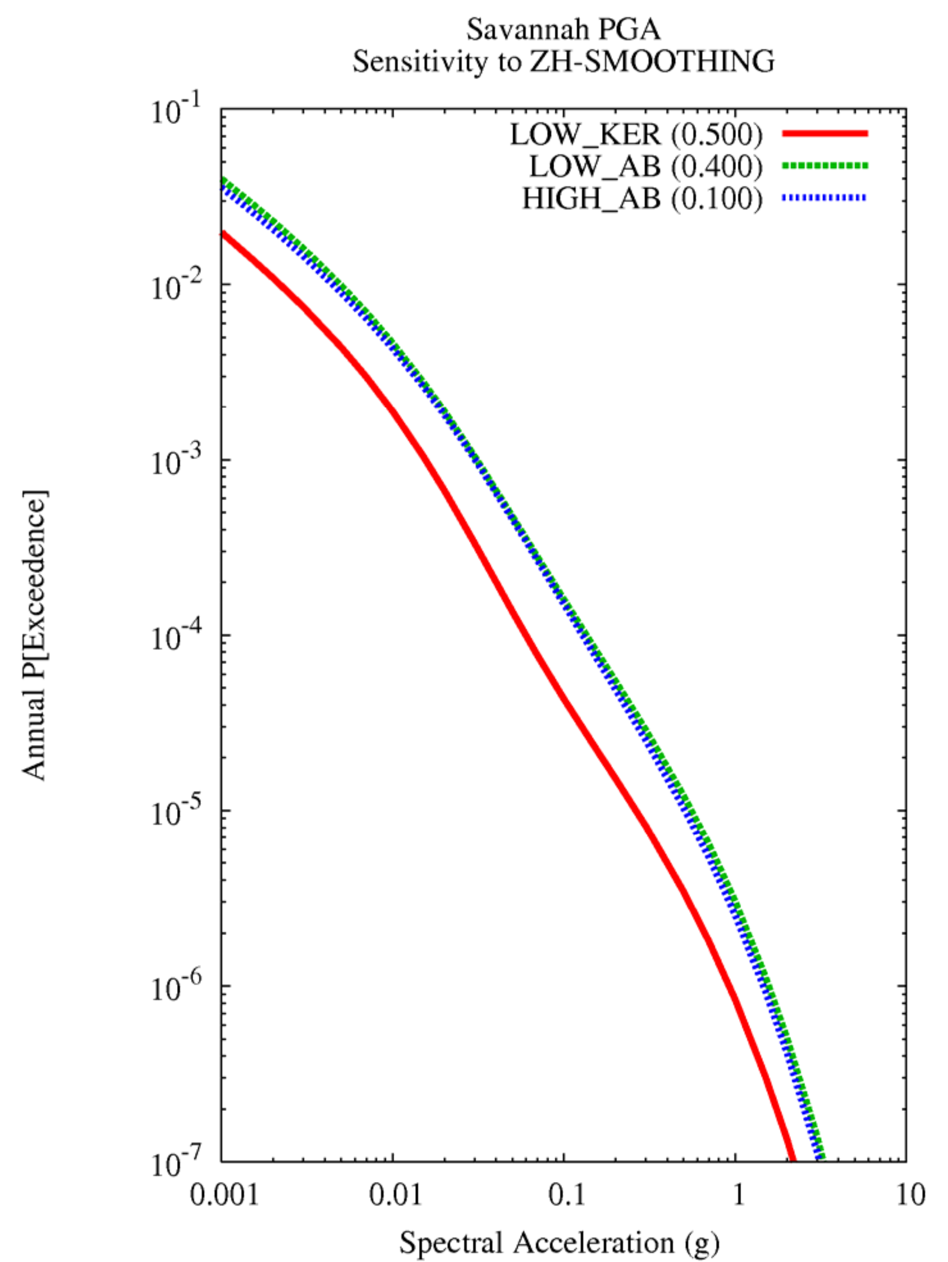
RISK ENGINEERING

Smoothing in zoneless-hybrid approach



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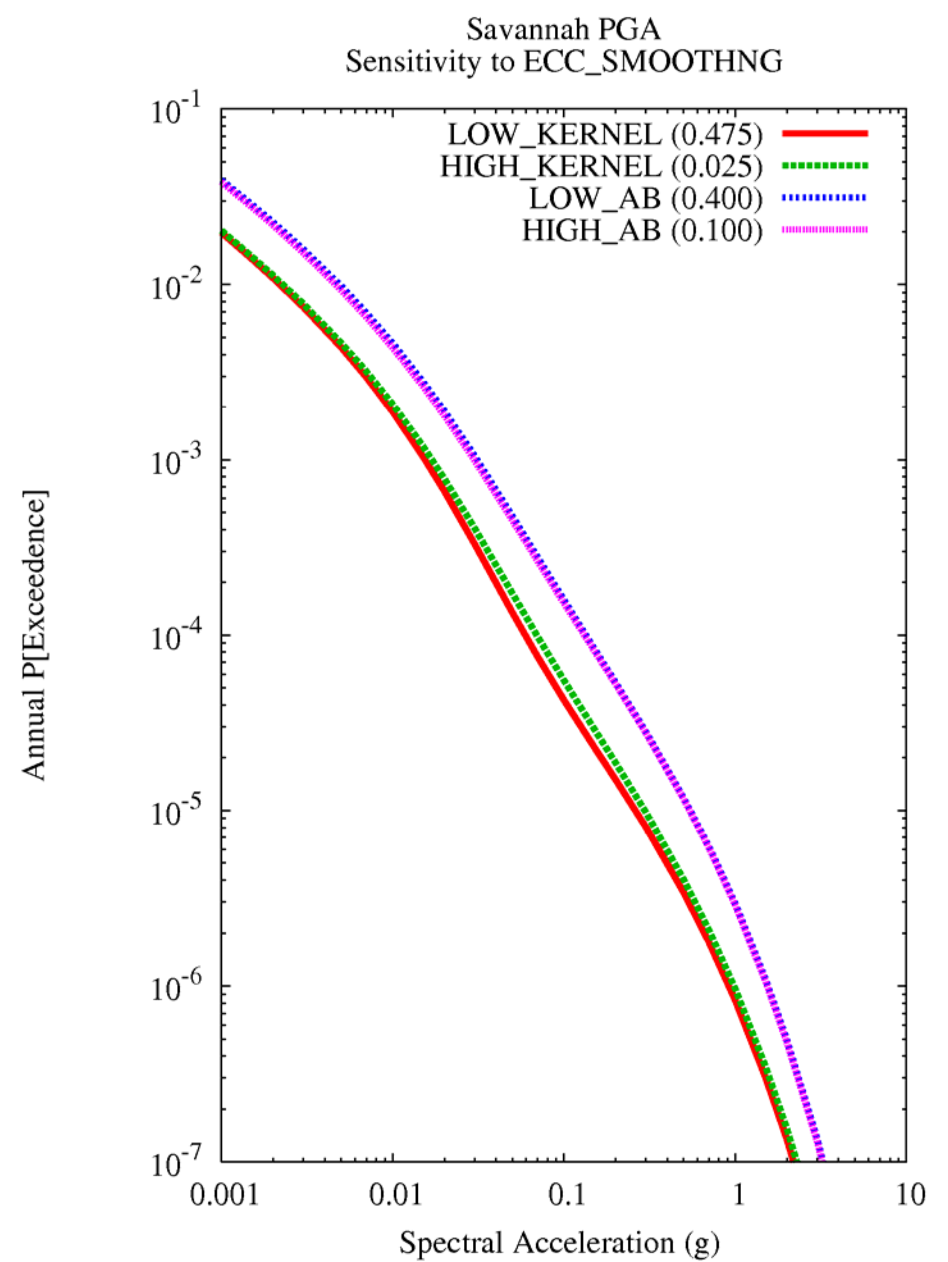
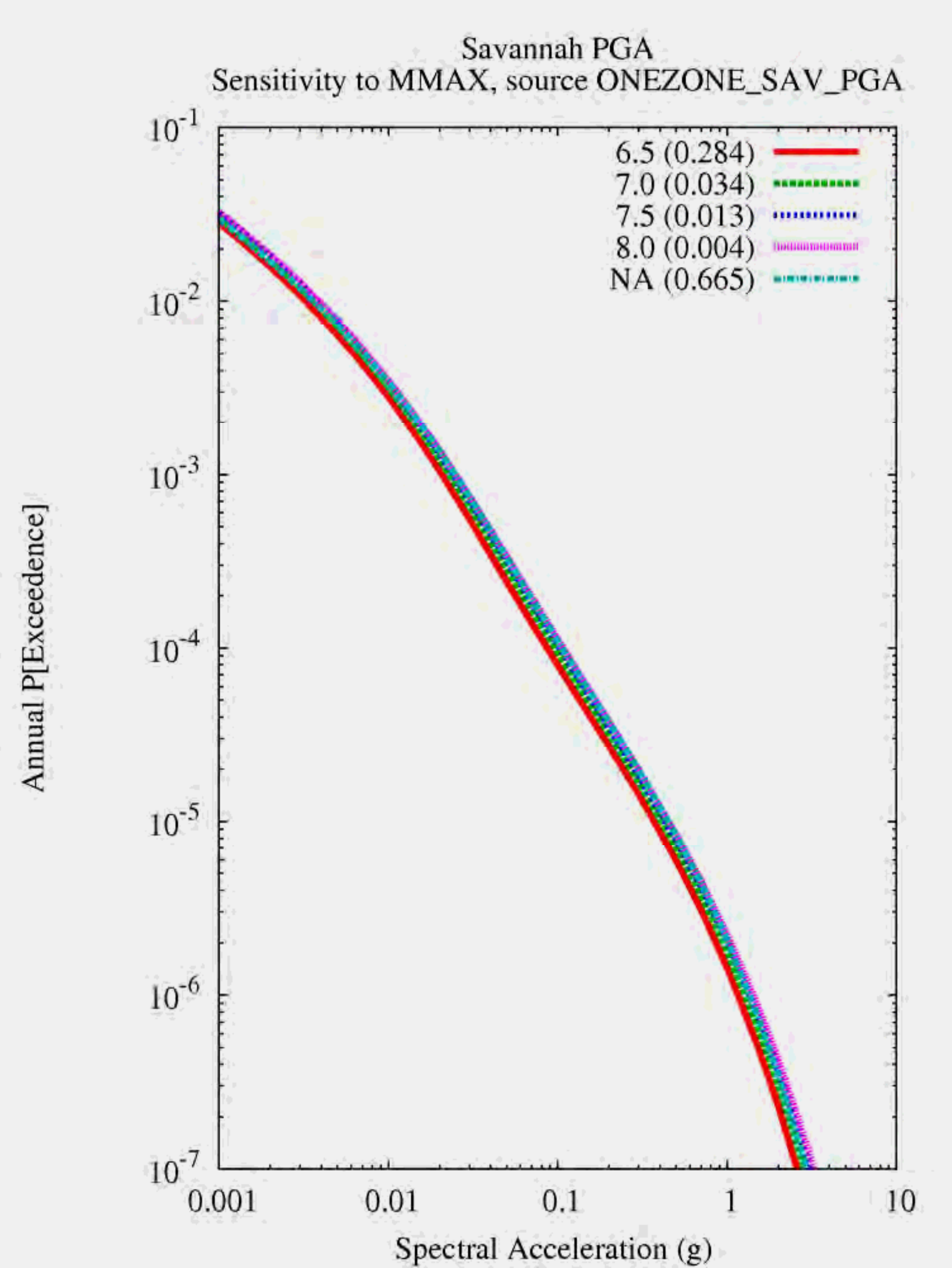
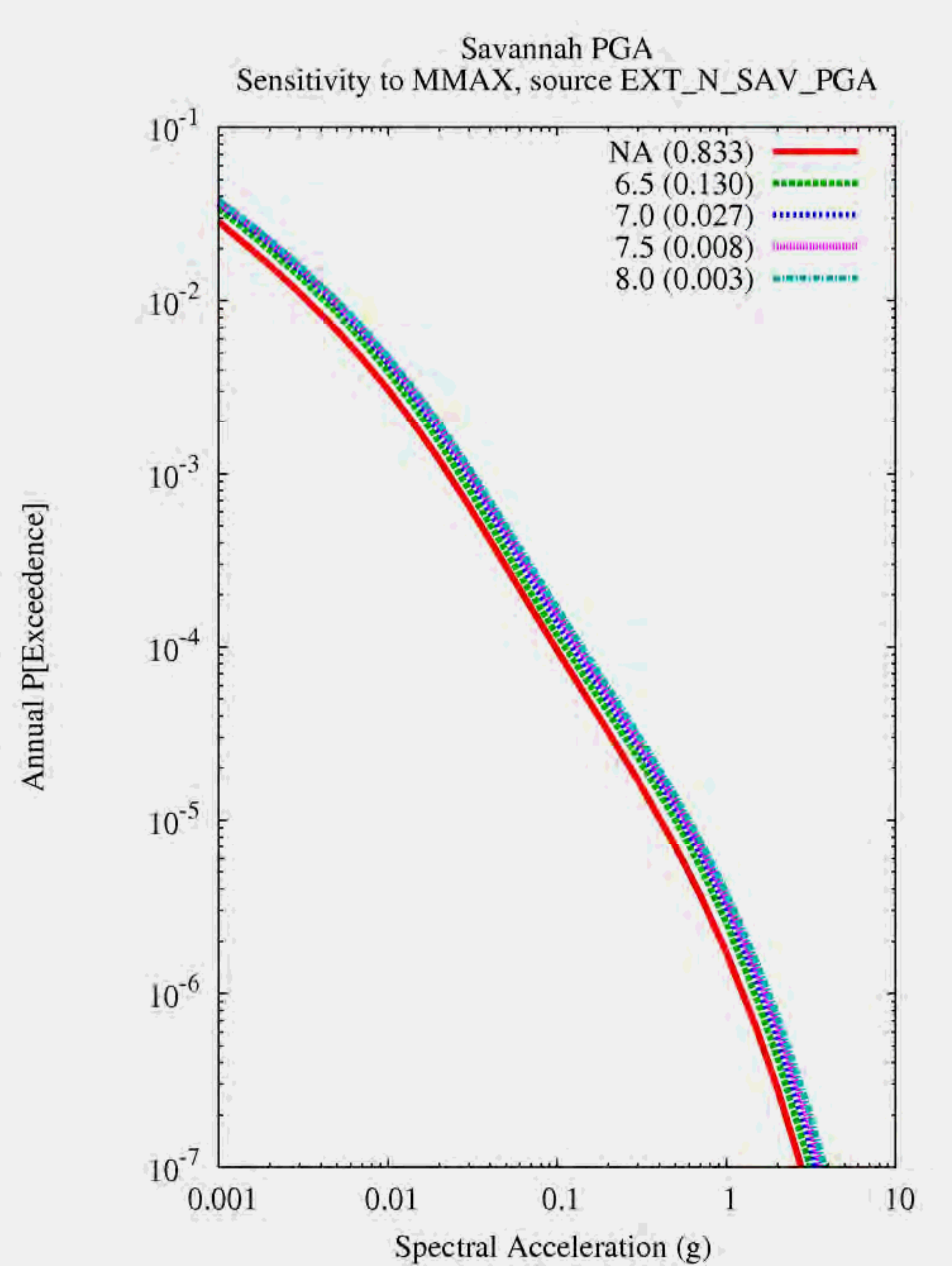
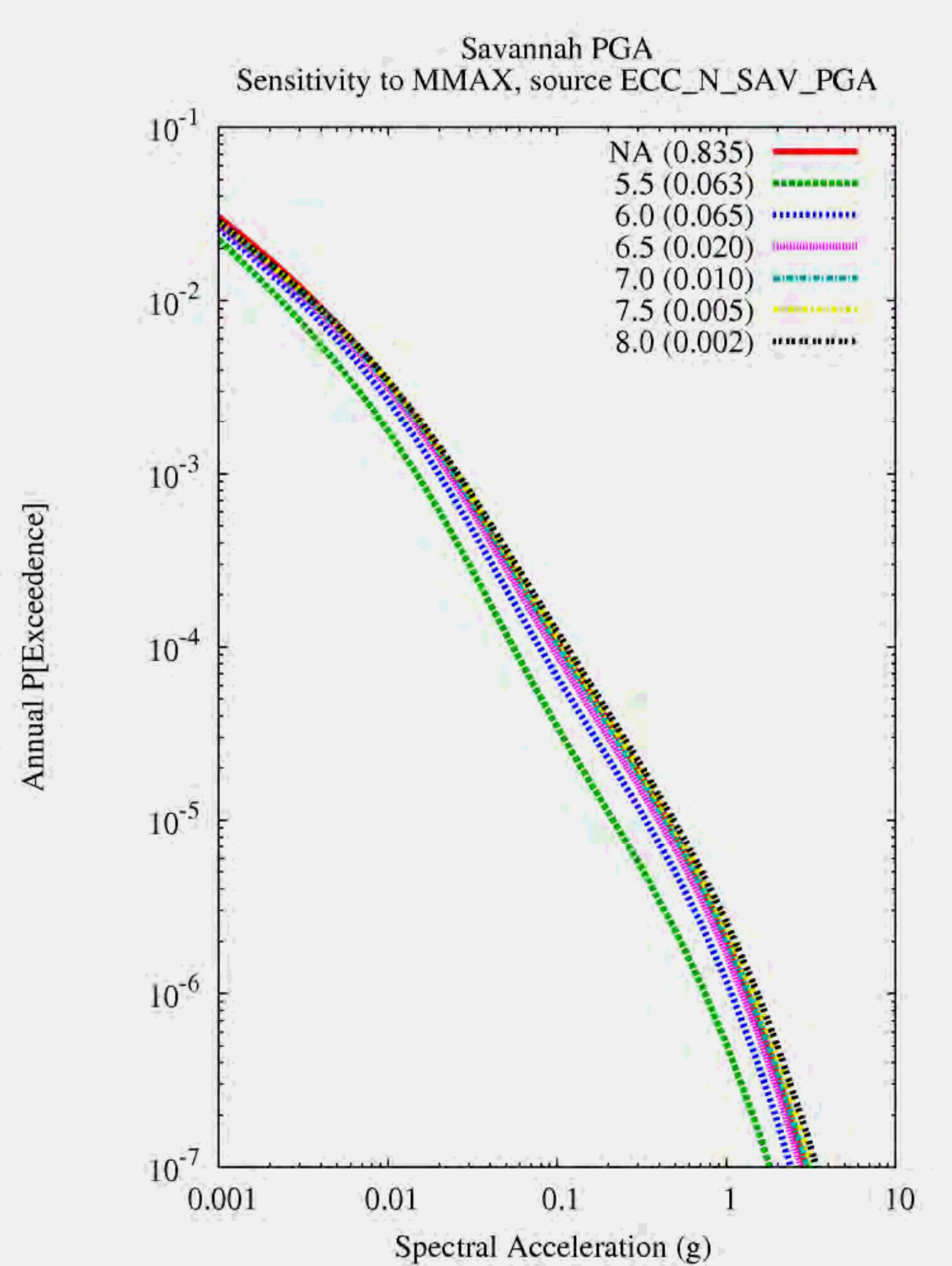
Smoothing in Extended Continental Crust (ECC)

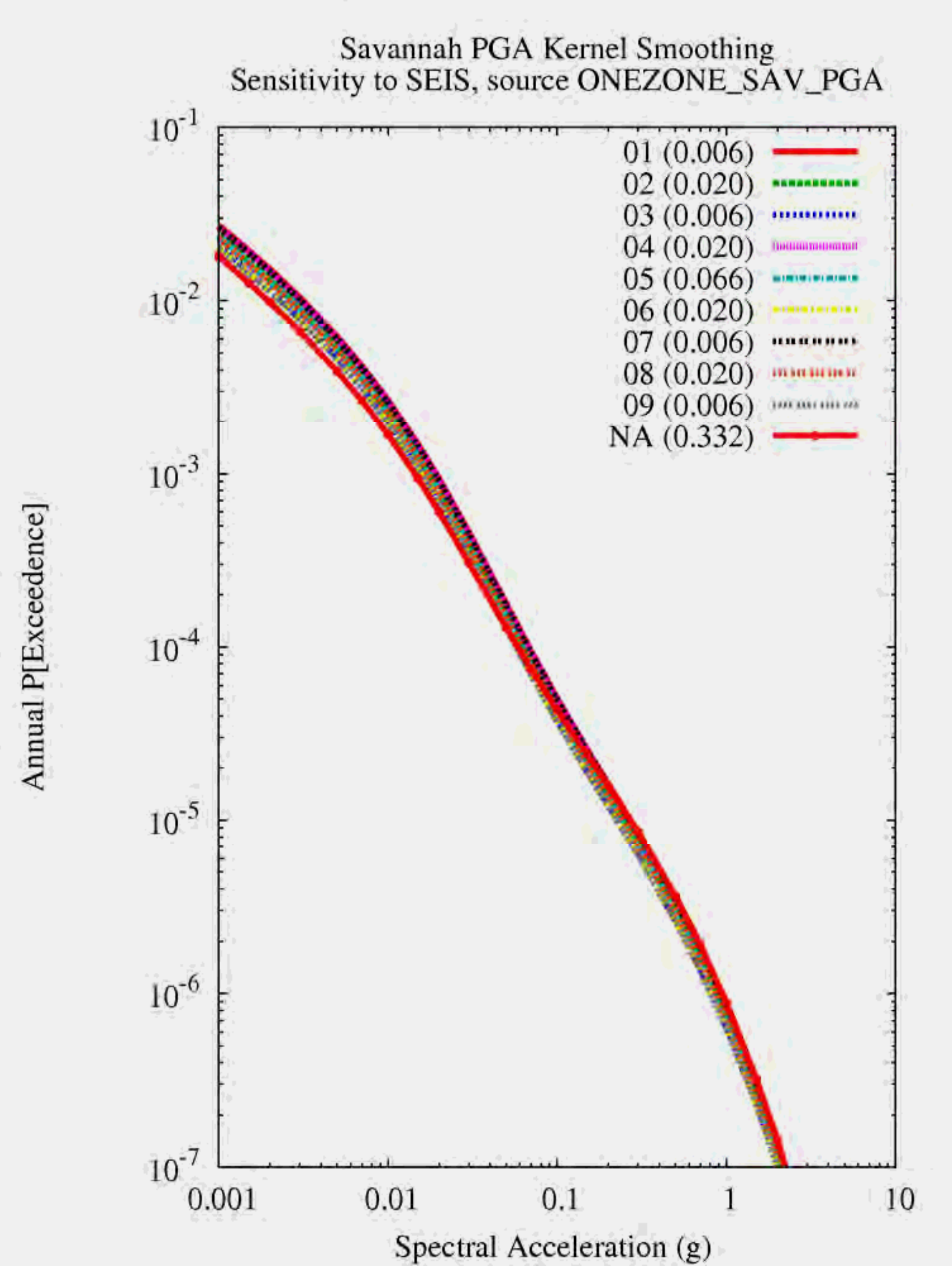


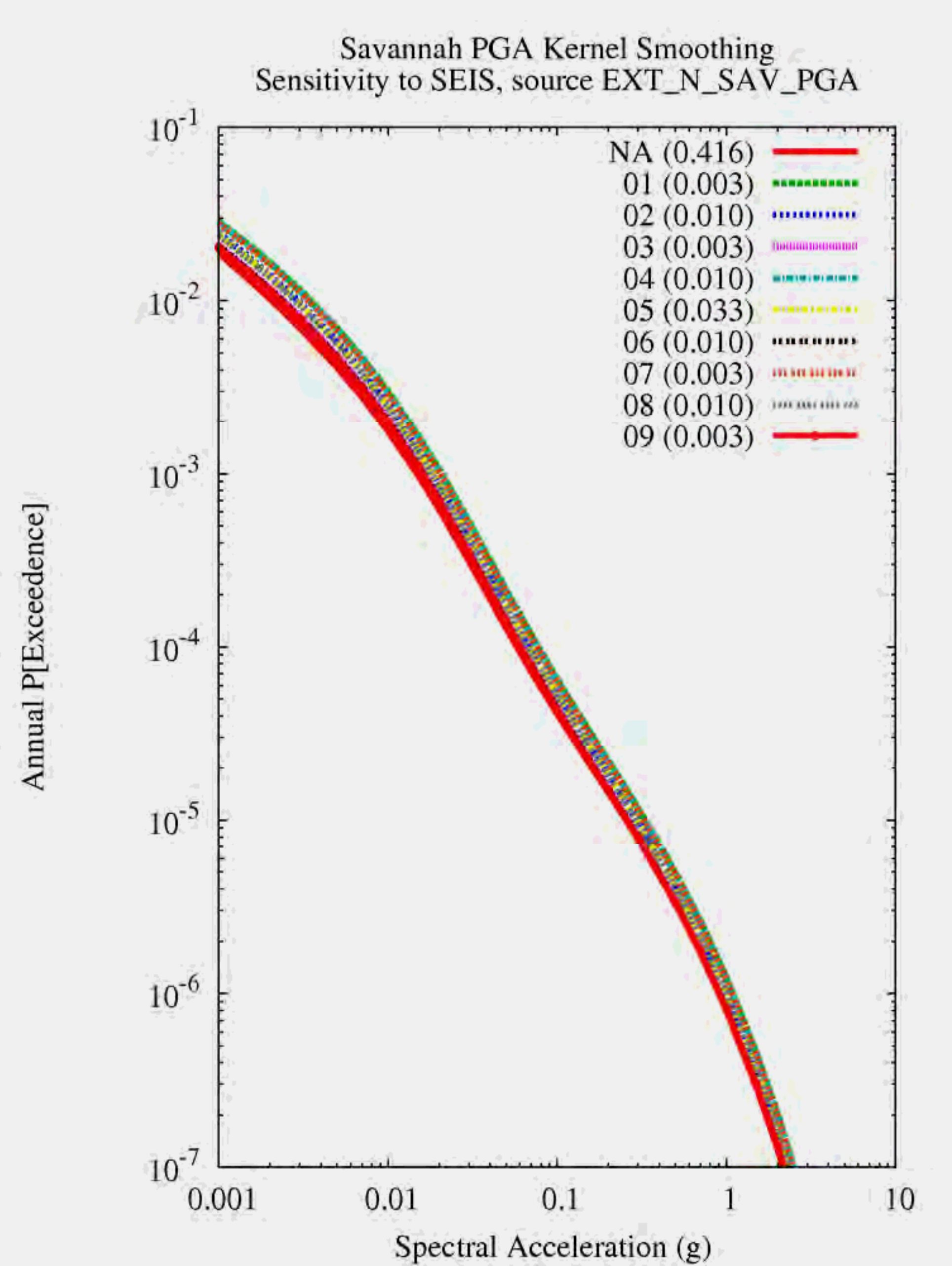

Savannah PGA
Sensitivity to MMAX, source ONEZONE_SAV_PGA
6.5 (0.284)
7.0 (0.034)
7.5 (0.013)
8.0 (0.004)
NA (0.665)
Annual P[Exceedence]
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
0.001
0.01
0.1
1
10
Spectral Acceleration (g)


Savannah PGA
Sensitivity to MMAX, source EXT_N_SAV_PGA
NA (0.833)
6.5 (0.130)
7.0 (0.027)
7.5 (0.008)
8.0 (0.003)
Annual P[Exceedence]
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
0.001
0.01
0.1
1
10
Spectral Acceleration (g)



ECC:
Extended
Continental
Crust


Savannah PGA Kernel Smoothing
Sensitivity to SEIS, source ONEZONE_SAV_PGA
Annual P[Exceedence]
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
0.001
0.01
0.1
1
10
Spectral Acceleration (g)
01 (0.006)
02 (0.020)
03 (0.006)
04 (0.020)
05 (0.066)
06 (0.020)
07 (0.006)
08 (0.020)
09 (0.006)
NA (0.332)



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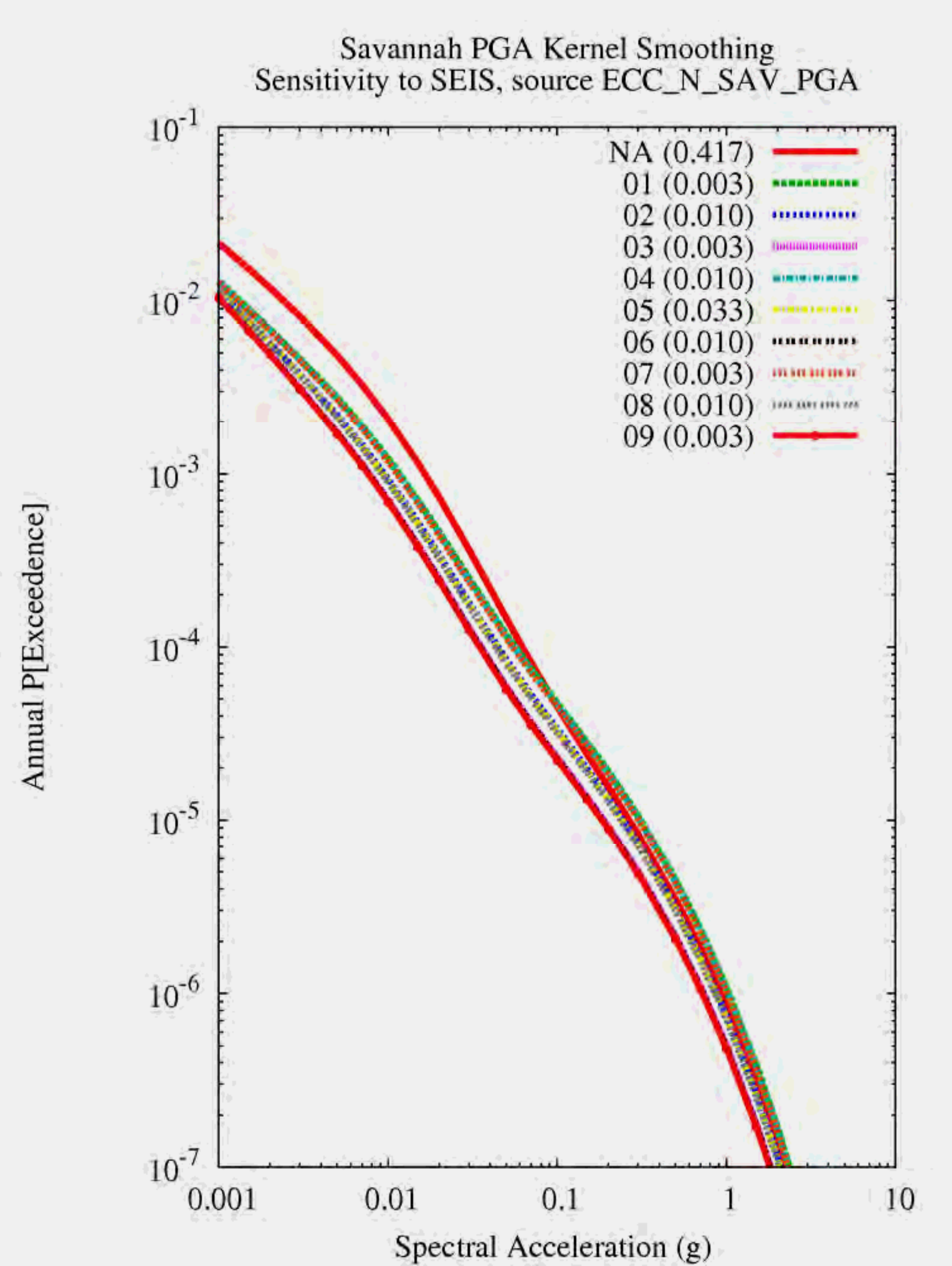
RISK ENGINEERING



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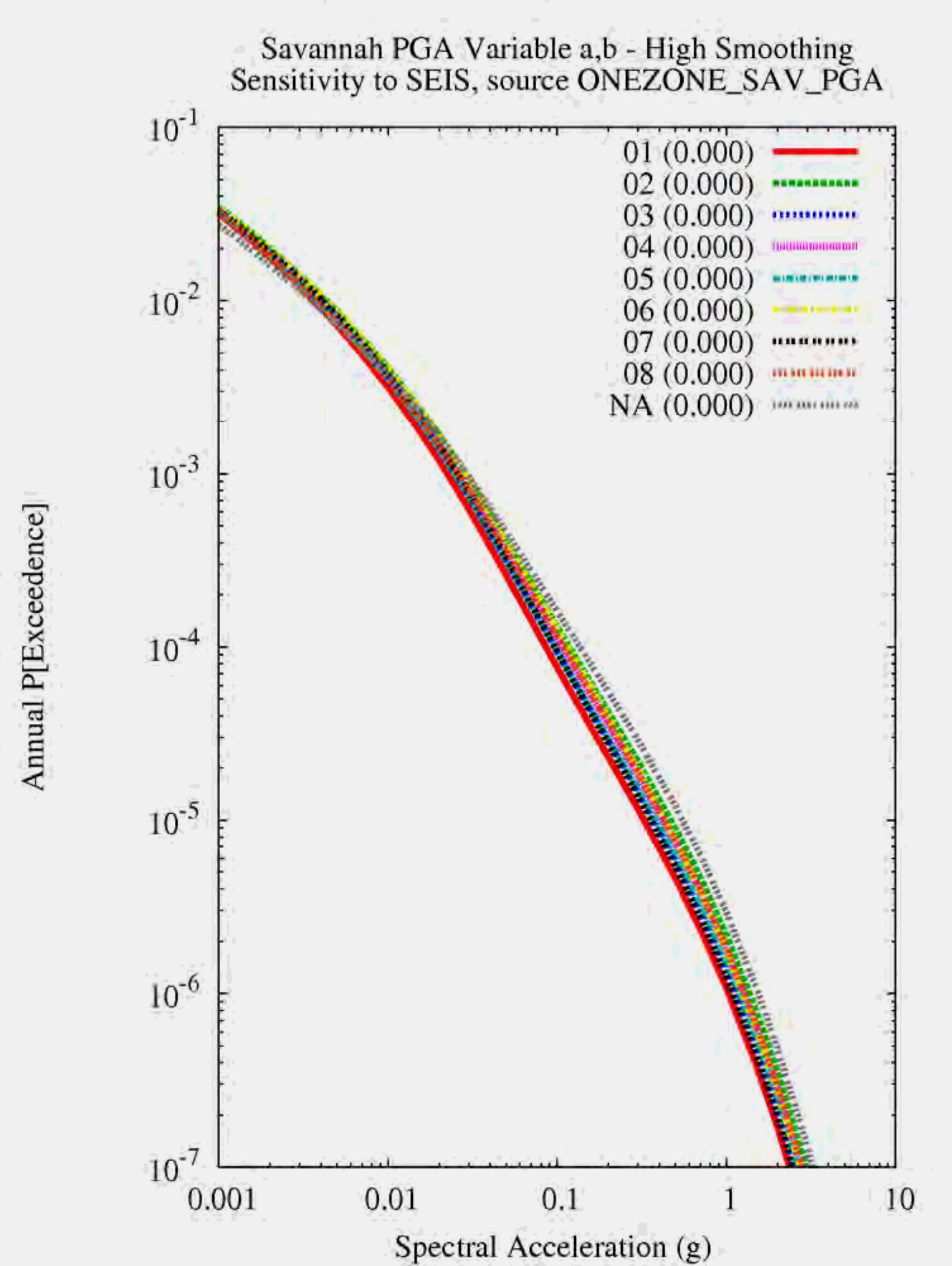
RISK ENGINEERING



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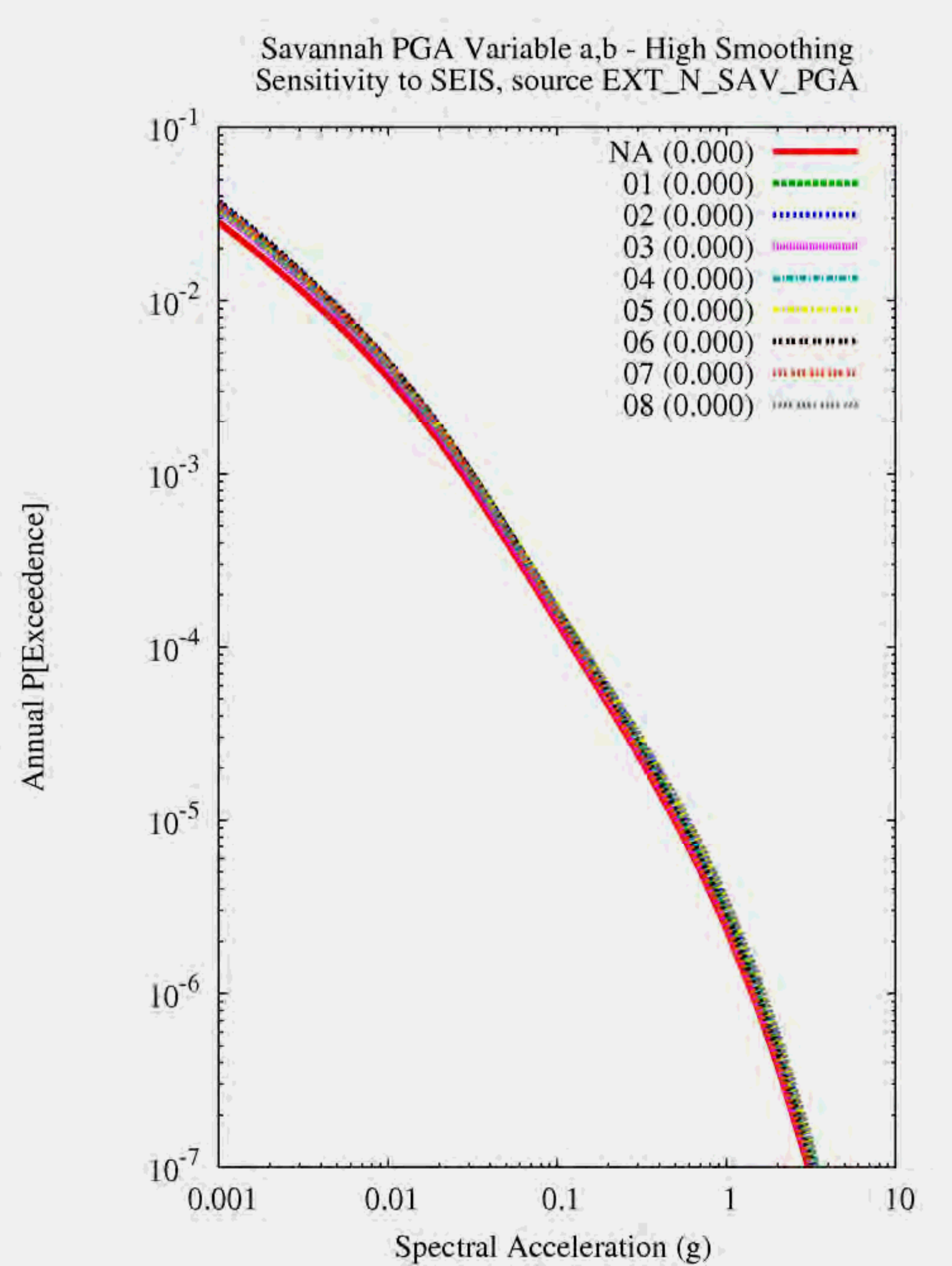
RISK ENGINEERING



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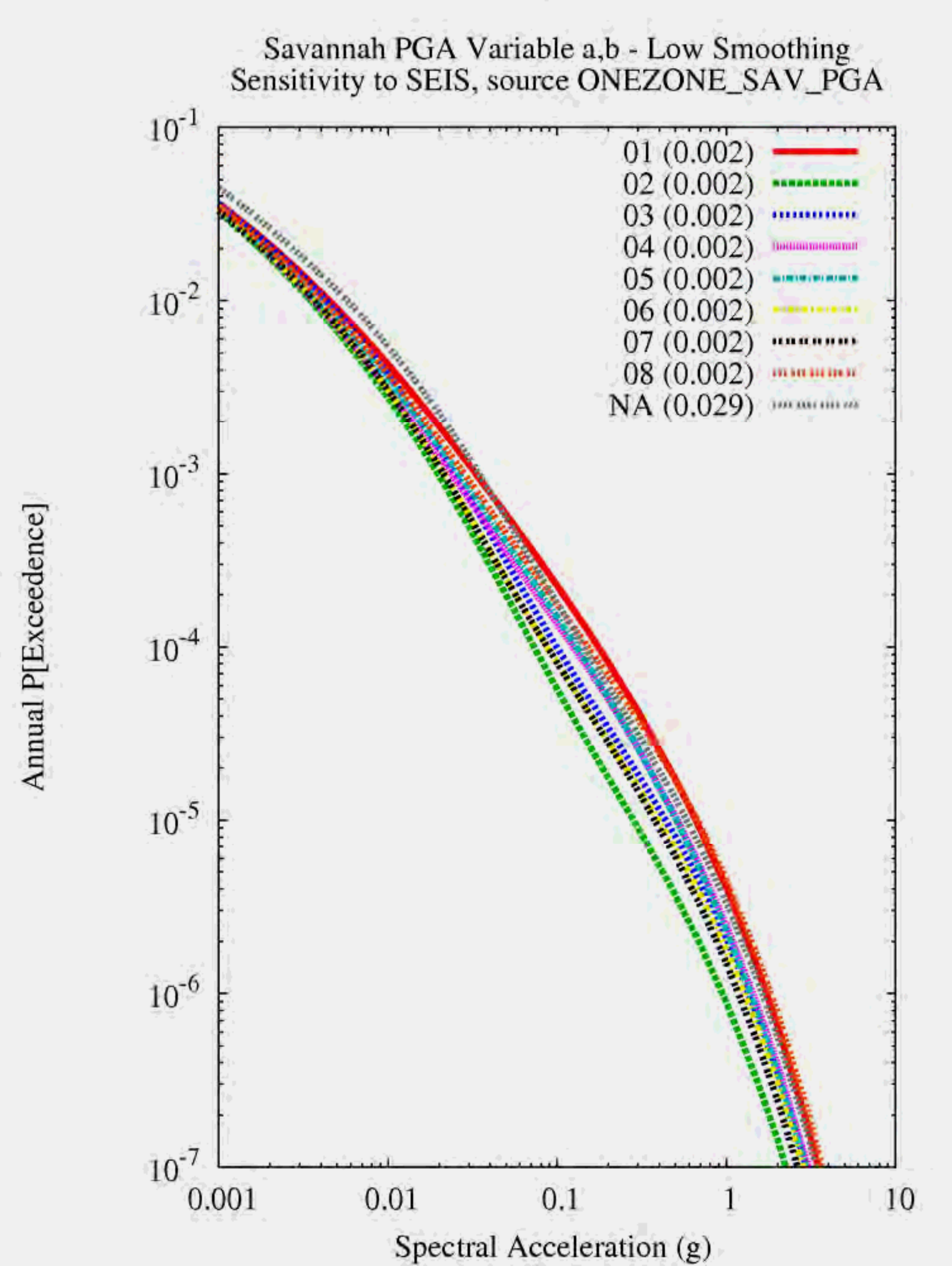
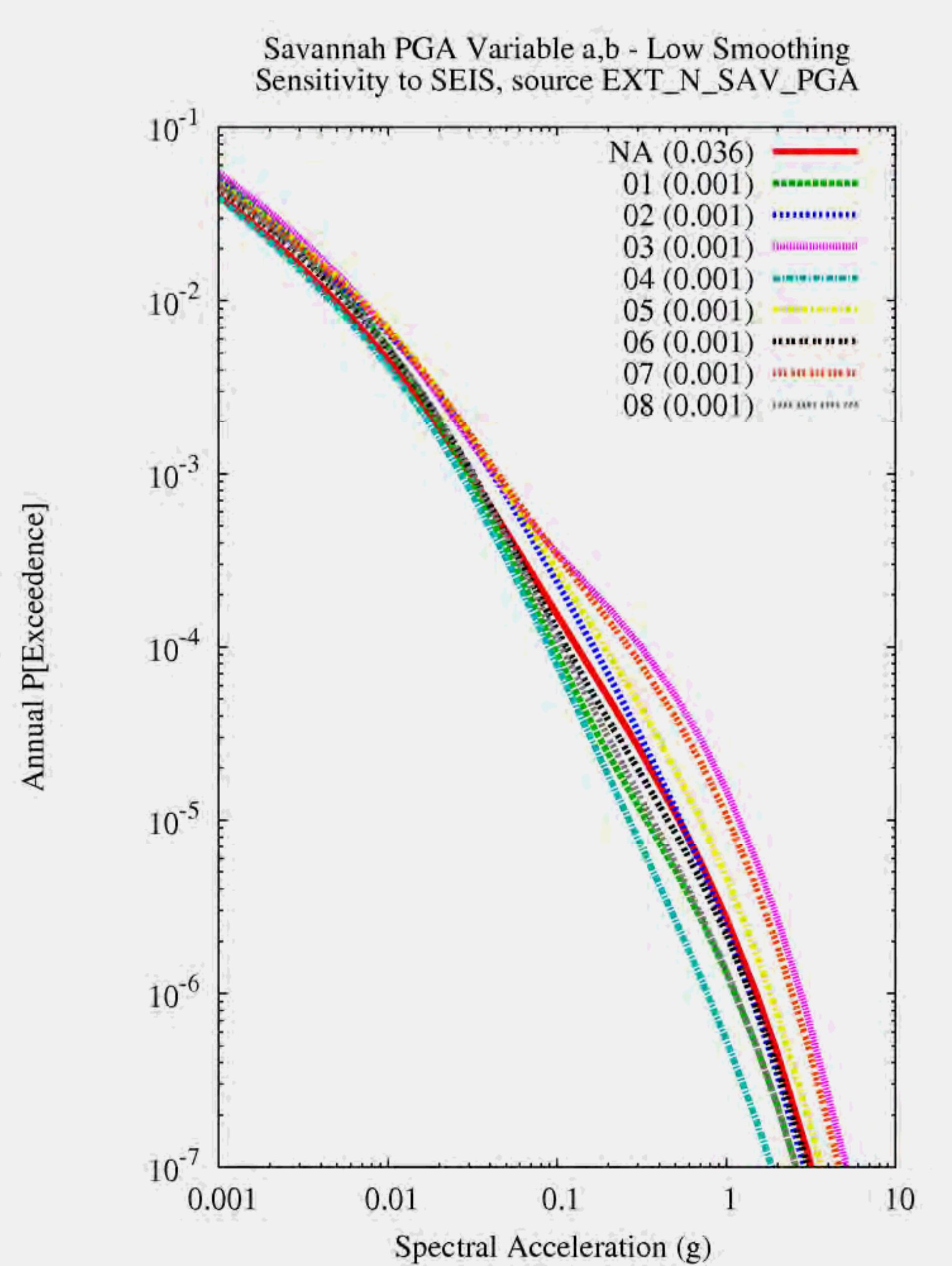
RISK ENGINEERING


Savannah PGA Variable a,b - Low Smoothing
Sensitivity to SEIS, source ONEZONE_SAV_PGA
Annual P[Exceedence]
Spectral Acceleration (g)
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
0.001
0.01
0.1
1
10
01 (0.002)
02 (0.002)
03 (0.002)
04 (0.002)
05 (0.002)
06 (0.002)
07 (0.002)
08 (0.002)
NA (0.029)



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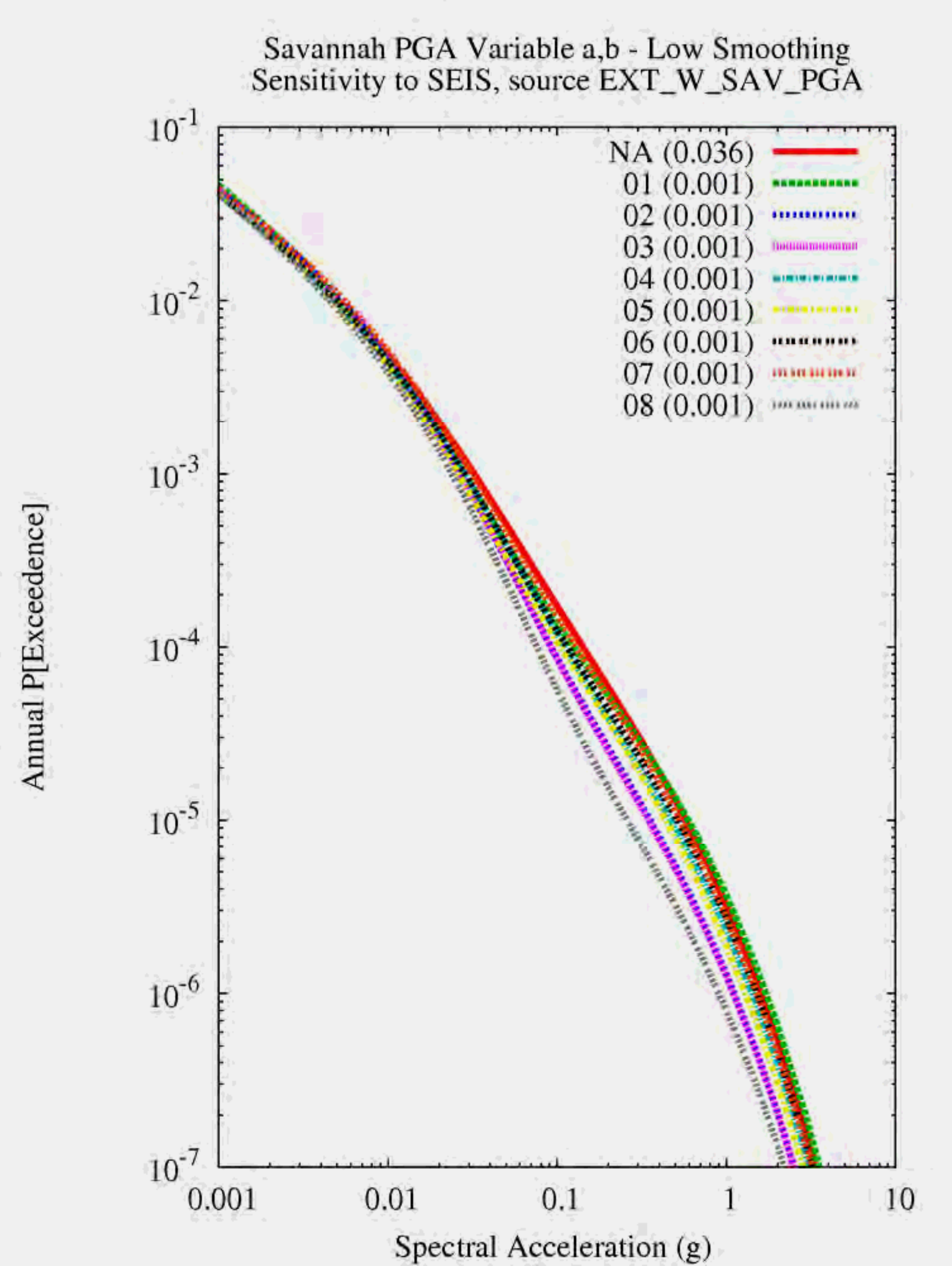
RISK ENGINEERING



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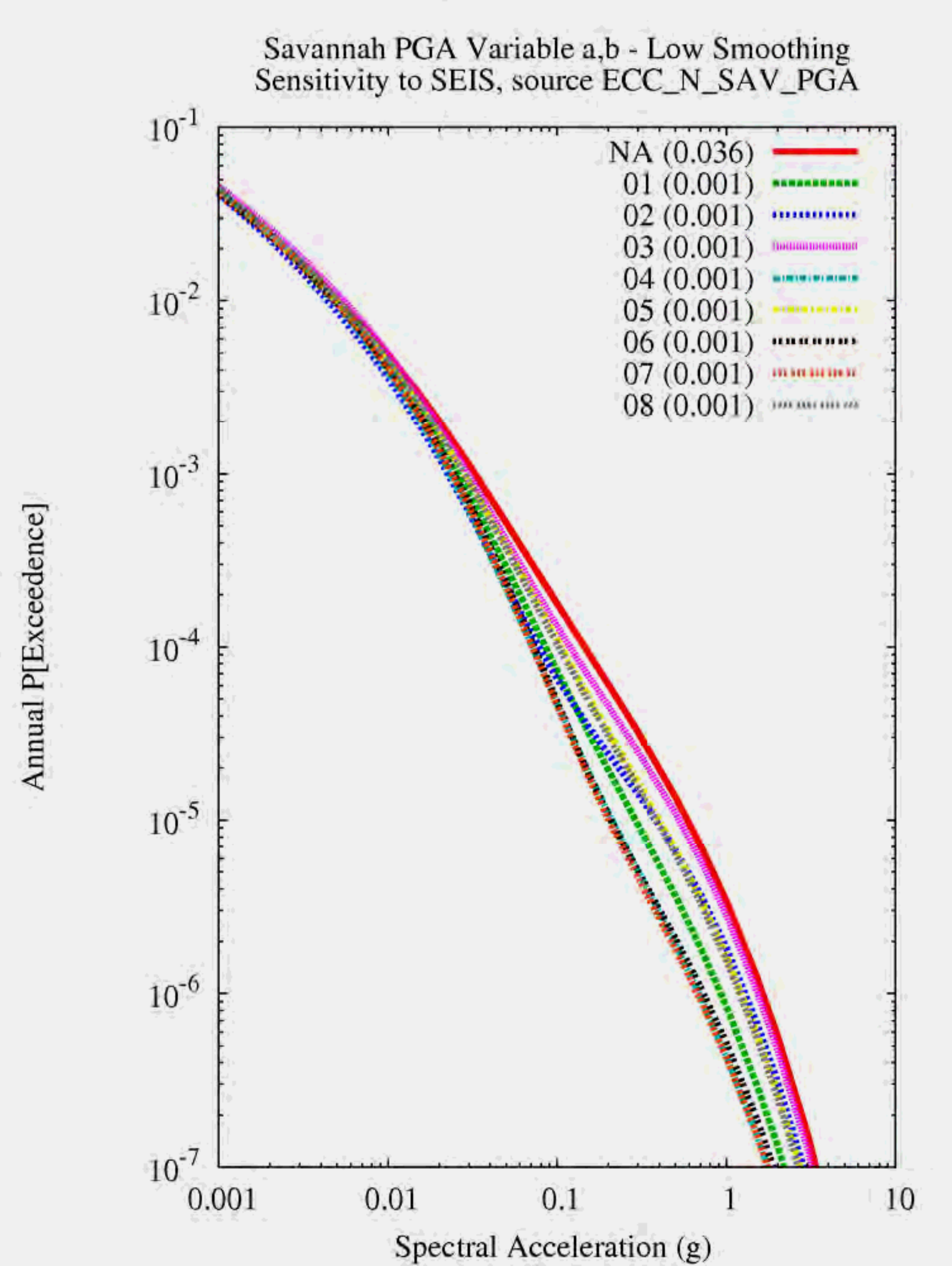
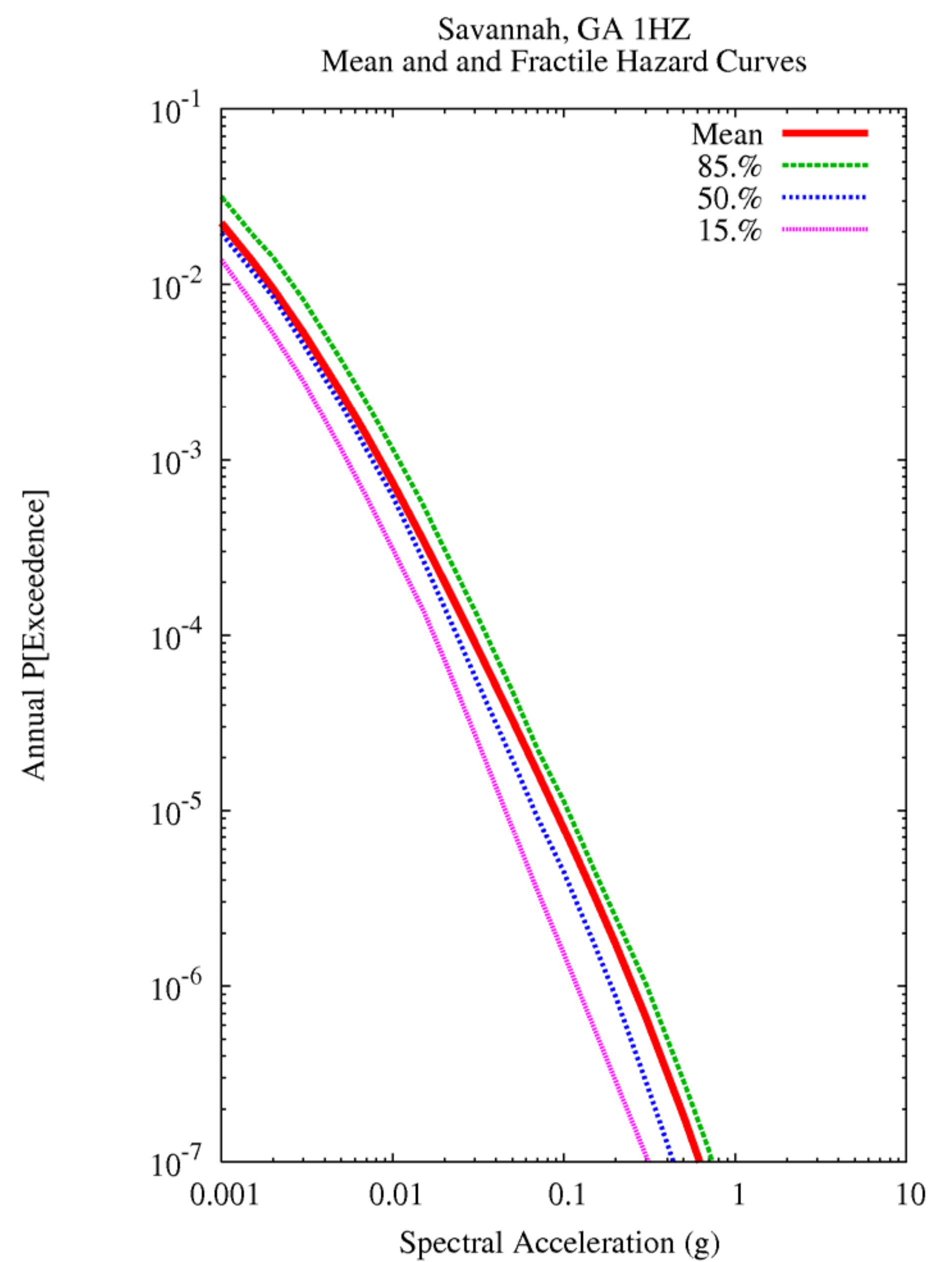
RISK ENGINEERING


Savannah PGA Variable a,b - Low Smoothing
Sensitivity to SEIS, source ECC_N_SAV_PGA
NA (0.036)
01 (0.001)
02 (0.001)
03 (0.001)
04 (0.001)
05 (0.001)
06 (0.001)
07 (0.001)
08 (0.001)
Annual P[Exceedence]
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
0.001
0.01
0.1
1
10
Spectral Acceleration (g)

Savannah 1 Hz results



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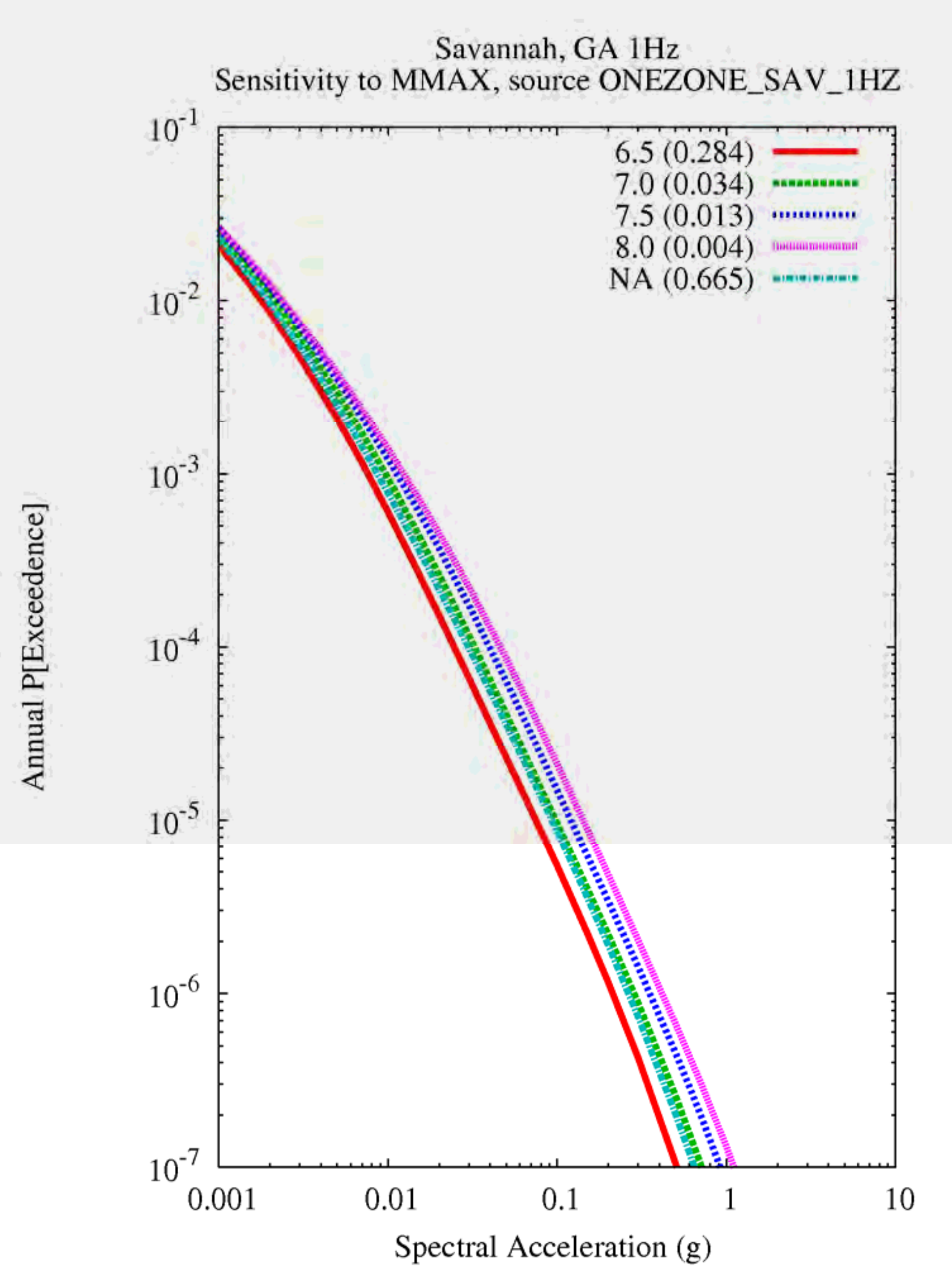
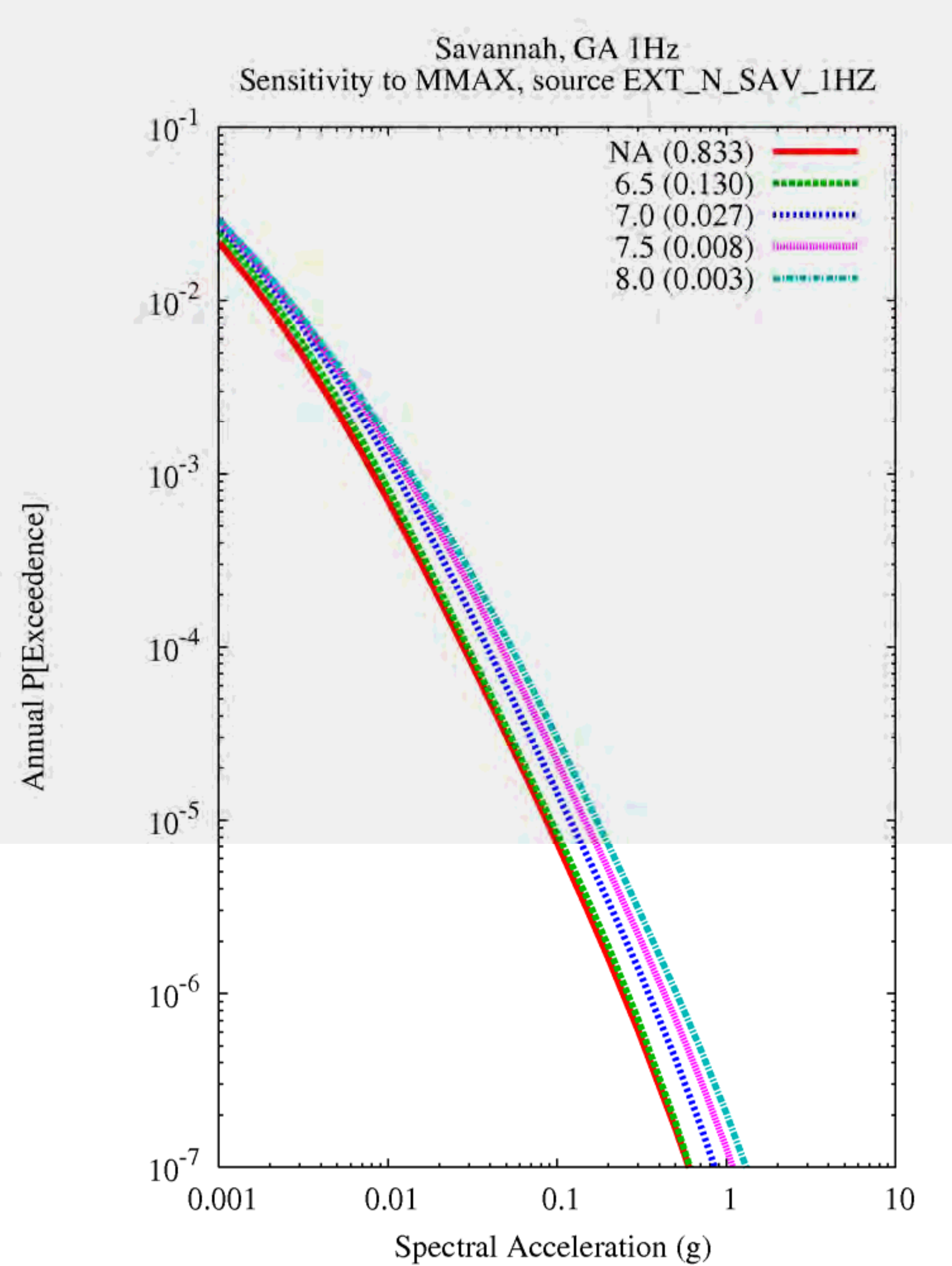
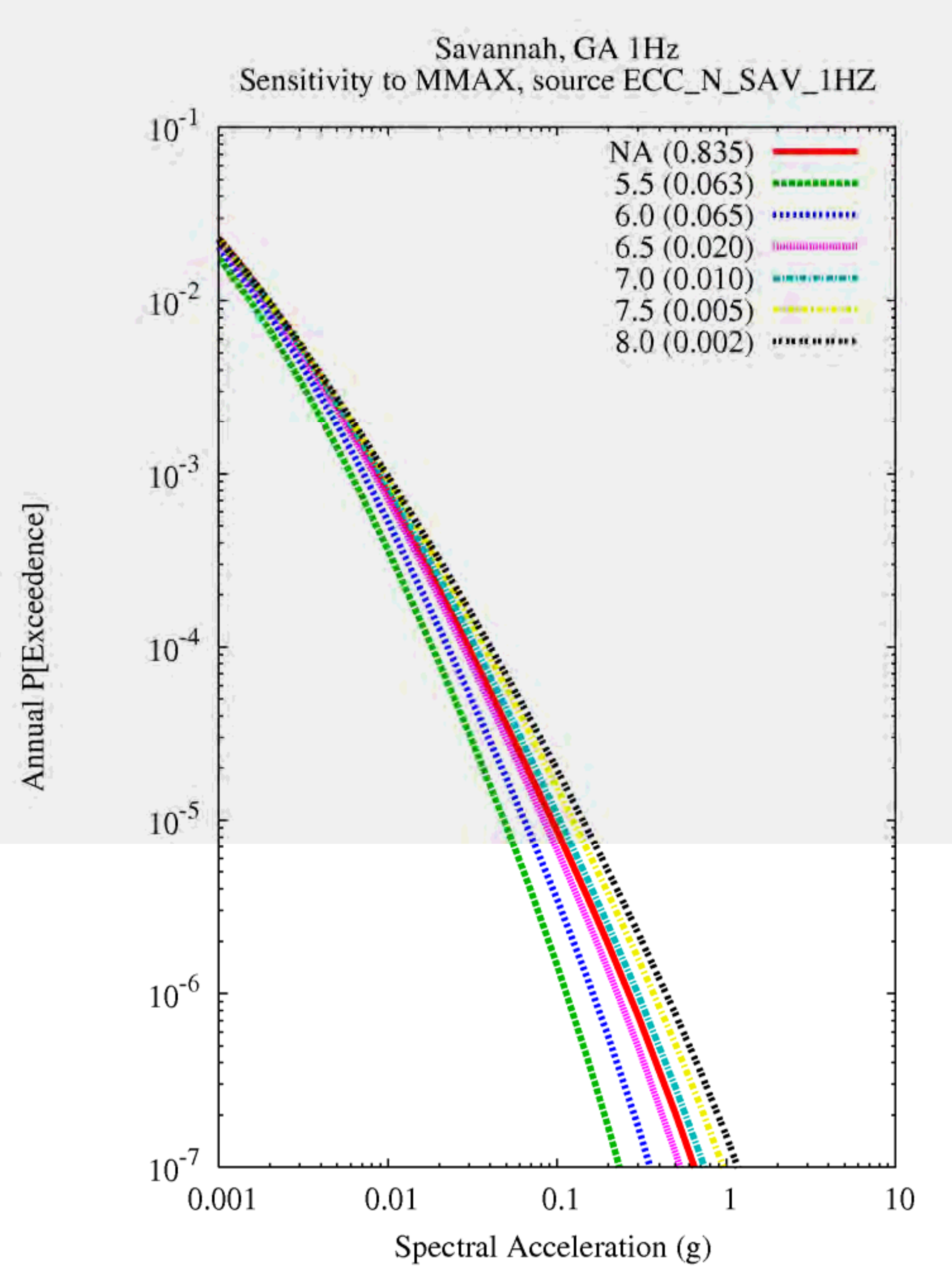
RISK ENGINEERING


Savannah, GA 1Hz
Sensitivity to MMAX, source ONEZONE_SAV_1HZ
Annual P[Exceedence]
Spectral Acceleration (g)
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
0.001
0.01
0.1
1
10
6.5 (0.284)
7.0 (0.034)
7.5 (0.013)
8.0 (0.004)
NA (0.665)


Savannah, GA 1Hz
Sensitivity to MMAX, source EXT_N_SAV_1HZ
NA (0.833)
6.5 (0.130)
7.0 (0.027)
7.5 (0.008)
8.0 (0.003)
Annual P[Exceedence]
10-1
10-2
10-3
10-4
10-5
10-6
10-7
0.001
0.01
0.1
1
10
Spectral Acceleration (g)



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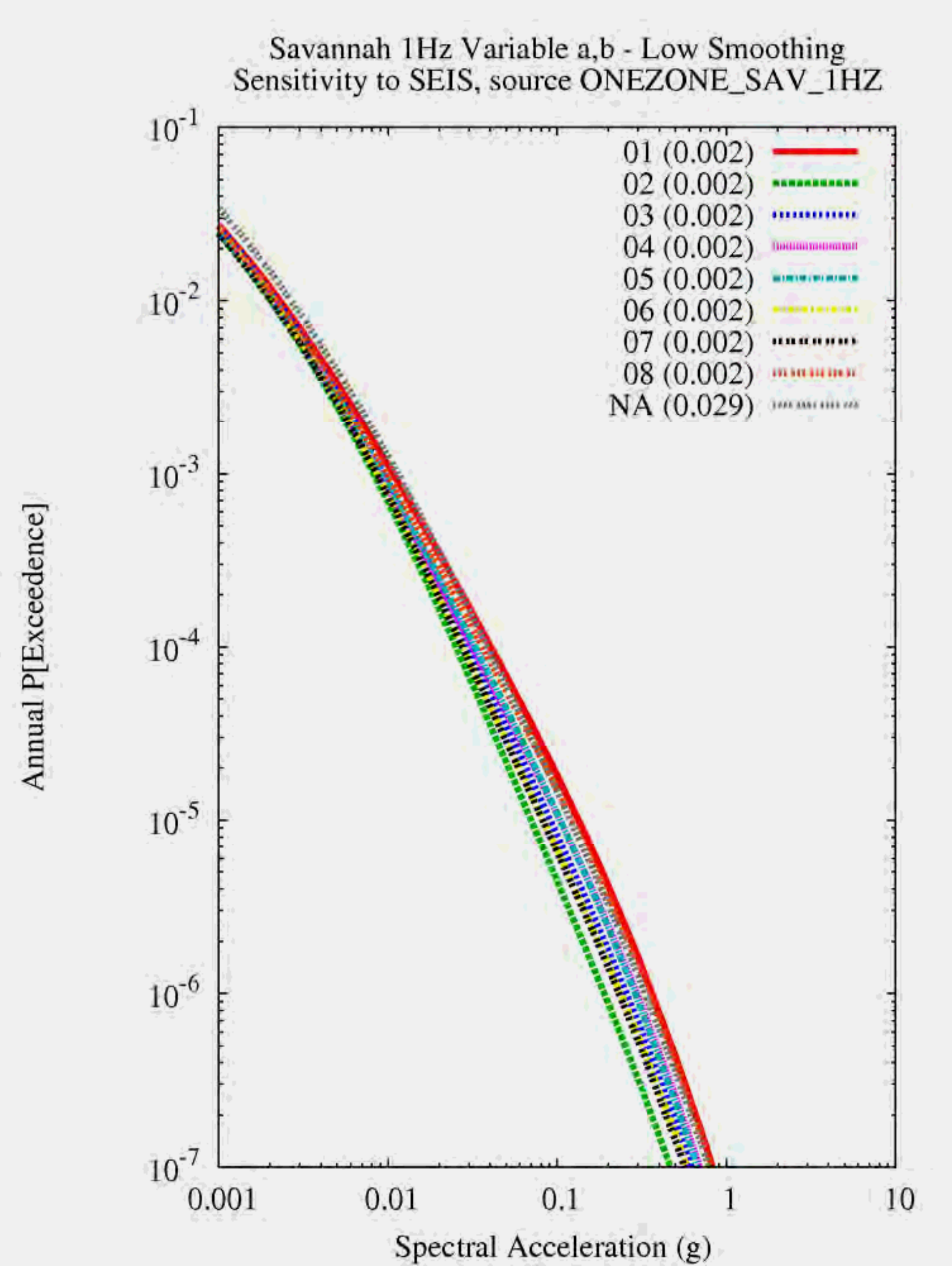

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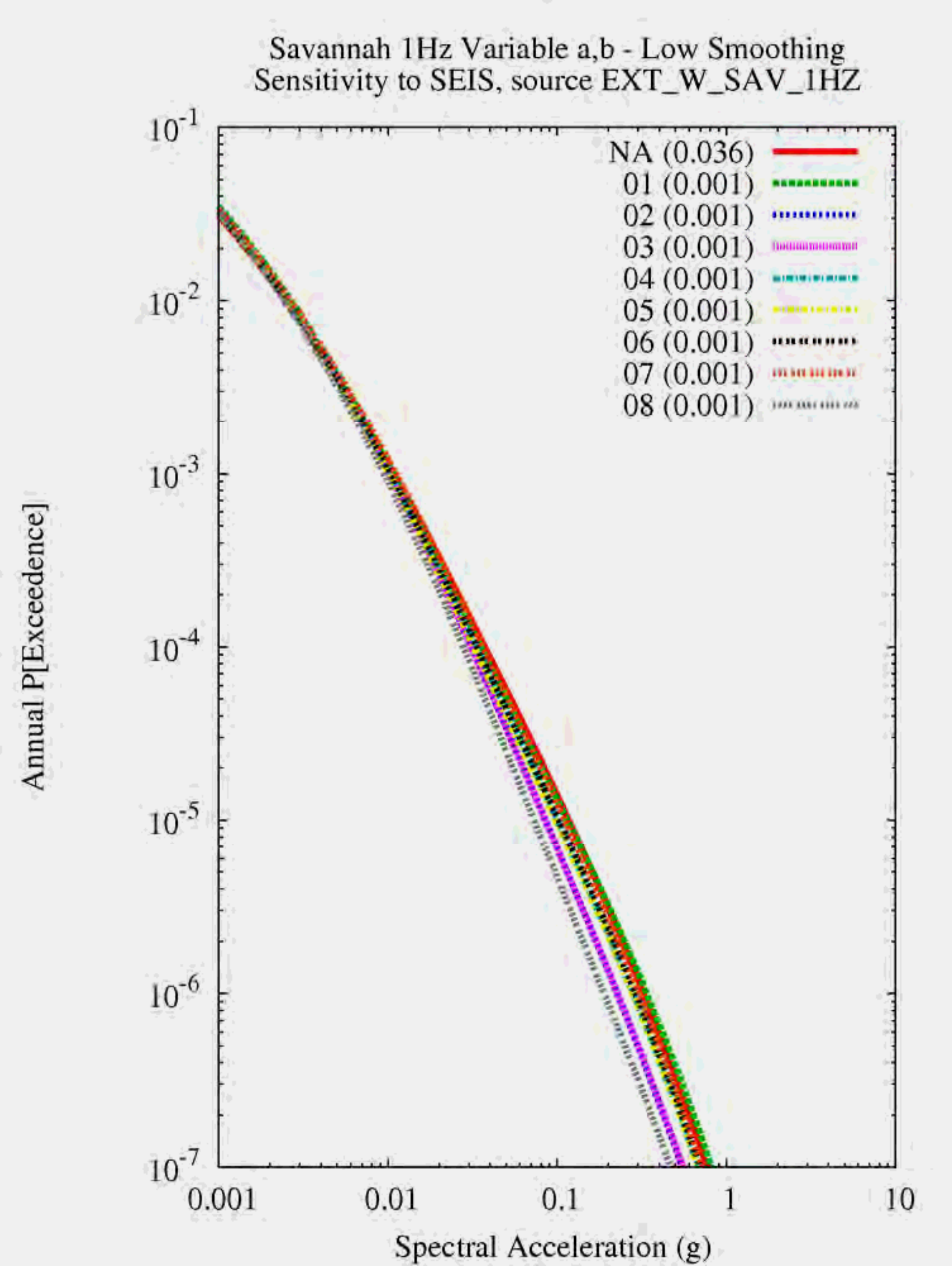
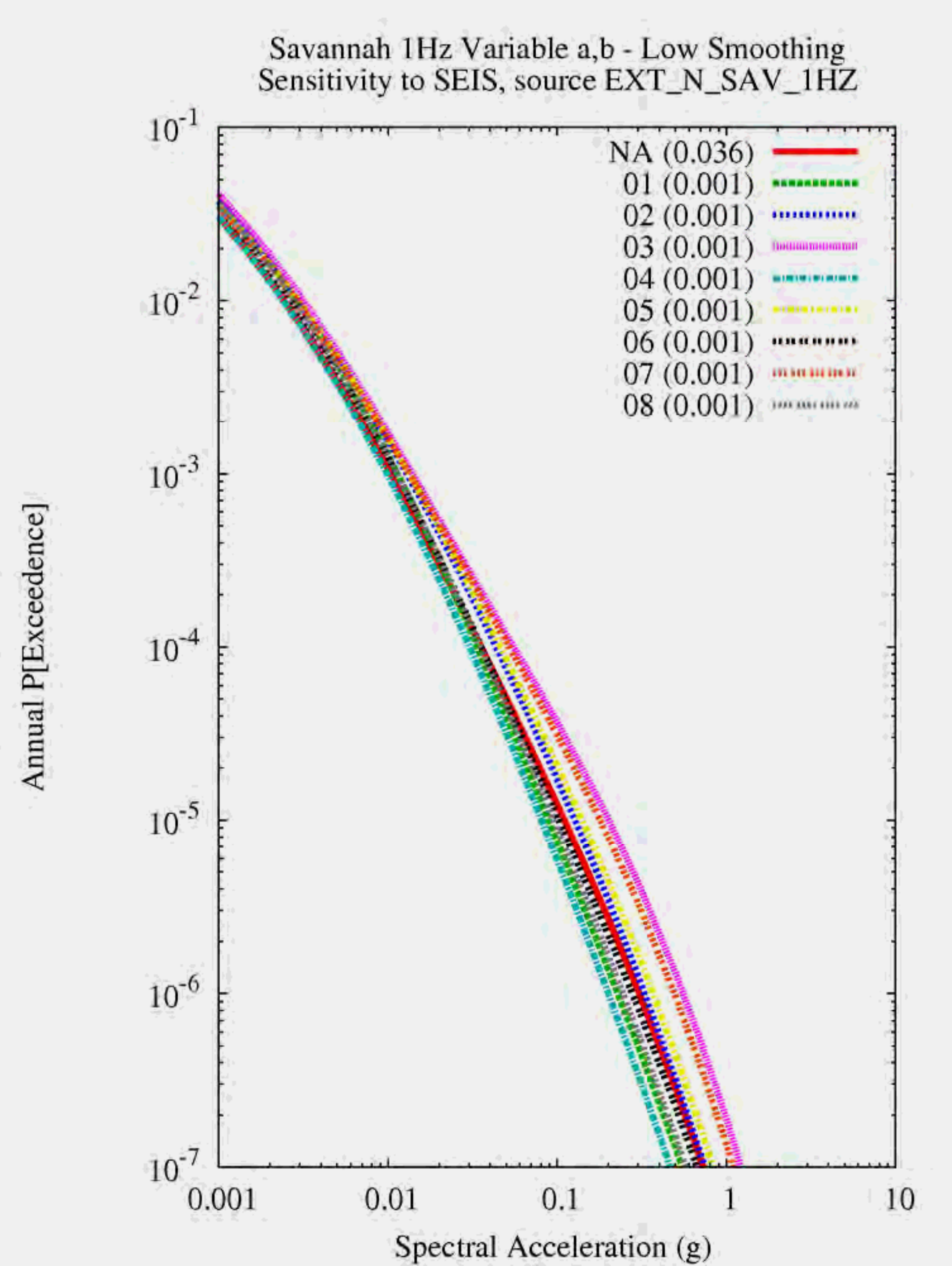
RISK ENGINEERING


Savannah 1Hz Variable a,b - Low Smoothing
Sensitivity to SEIS, source EXT_W_SAV_1HZ
NA (0.036)
01 (0.001)
02 (0.001)
03 (0.001)
04 (0.001)
05 (0.001)
06 (0.001)
07 (0.001)
08 (0.001)
Annual P[Exceedence]
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
0.001
0.01
0.1
1
10
Spectral Acceleration (g)



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Summary for SE US Site (Savannah)

- Major sensitivities
  - Choice of smoothing approach
    - Kernel with constant b vs.
    - Penalized likelihood with variable a & b

    (may change)
  - Uncertainty in recurrence (given smoothing approach)
  - Some sensitivity to Mmax (particularly at 1 Hz)

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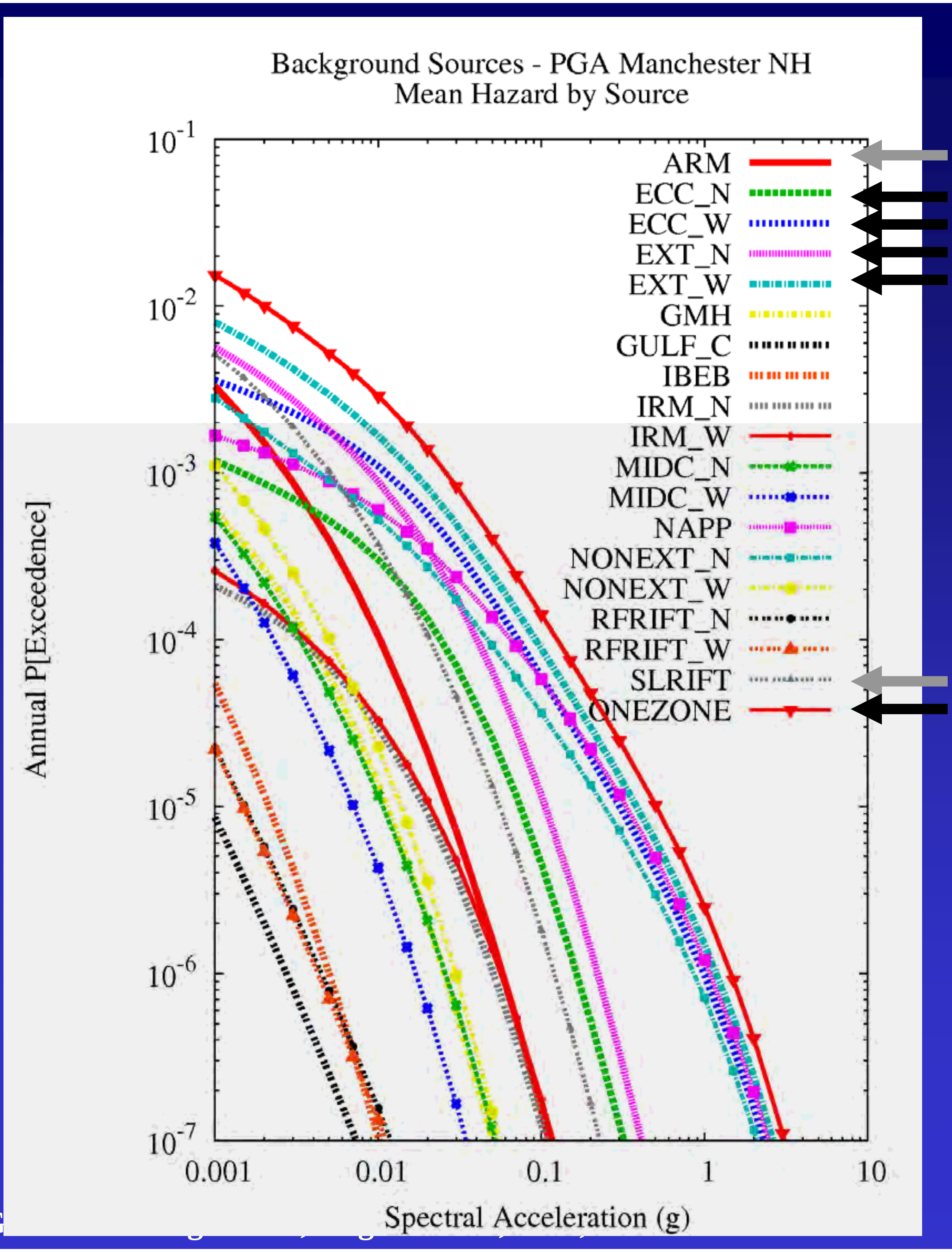
New England Site
(Manchester, NH)



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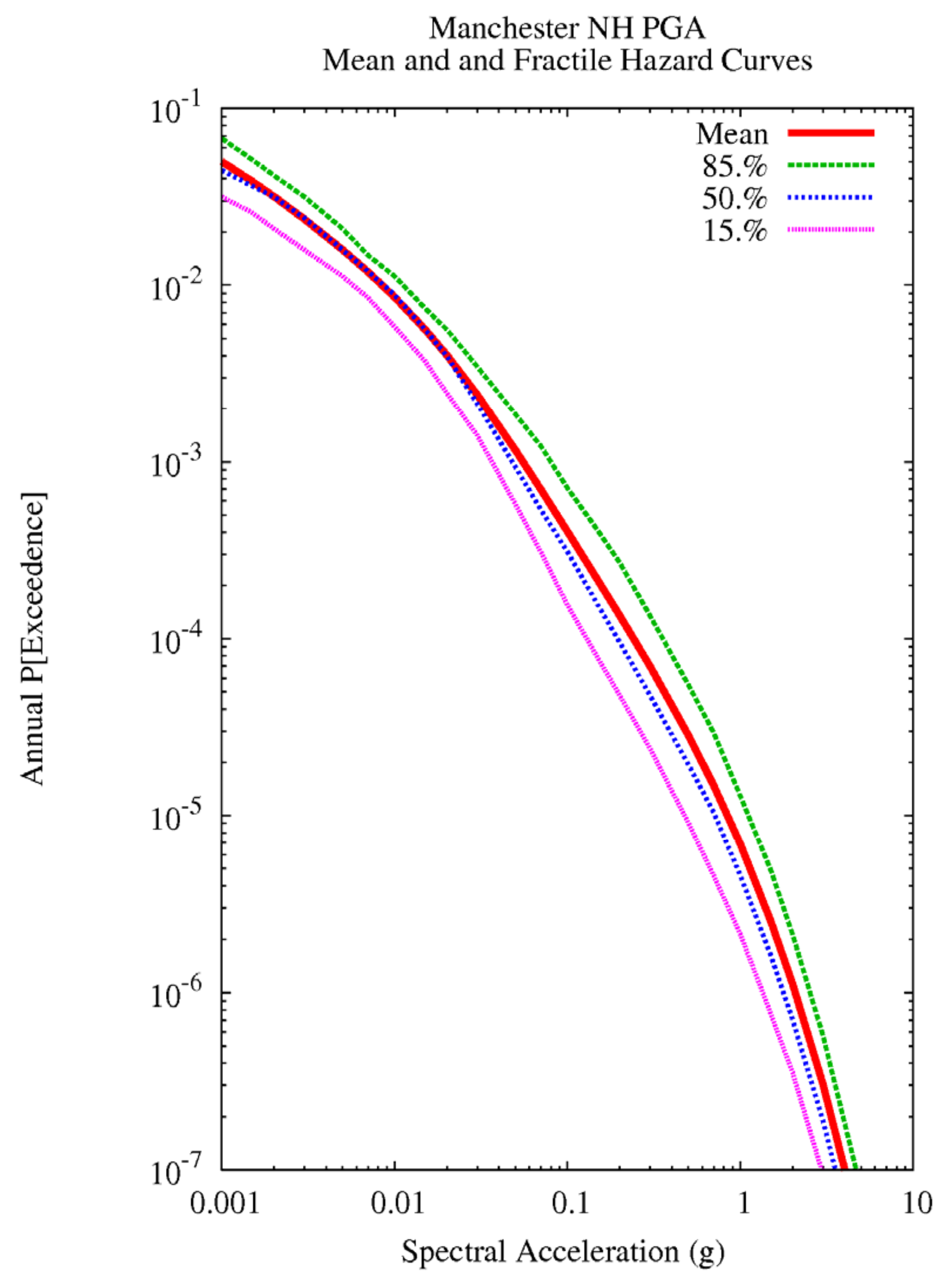
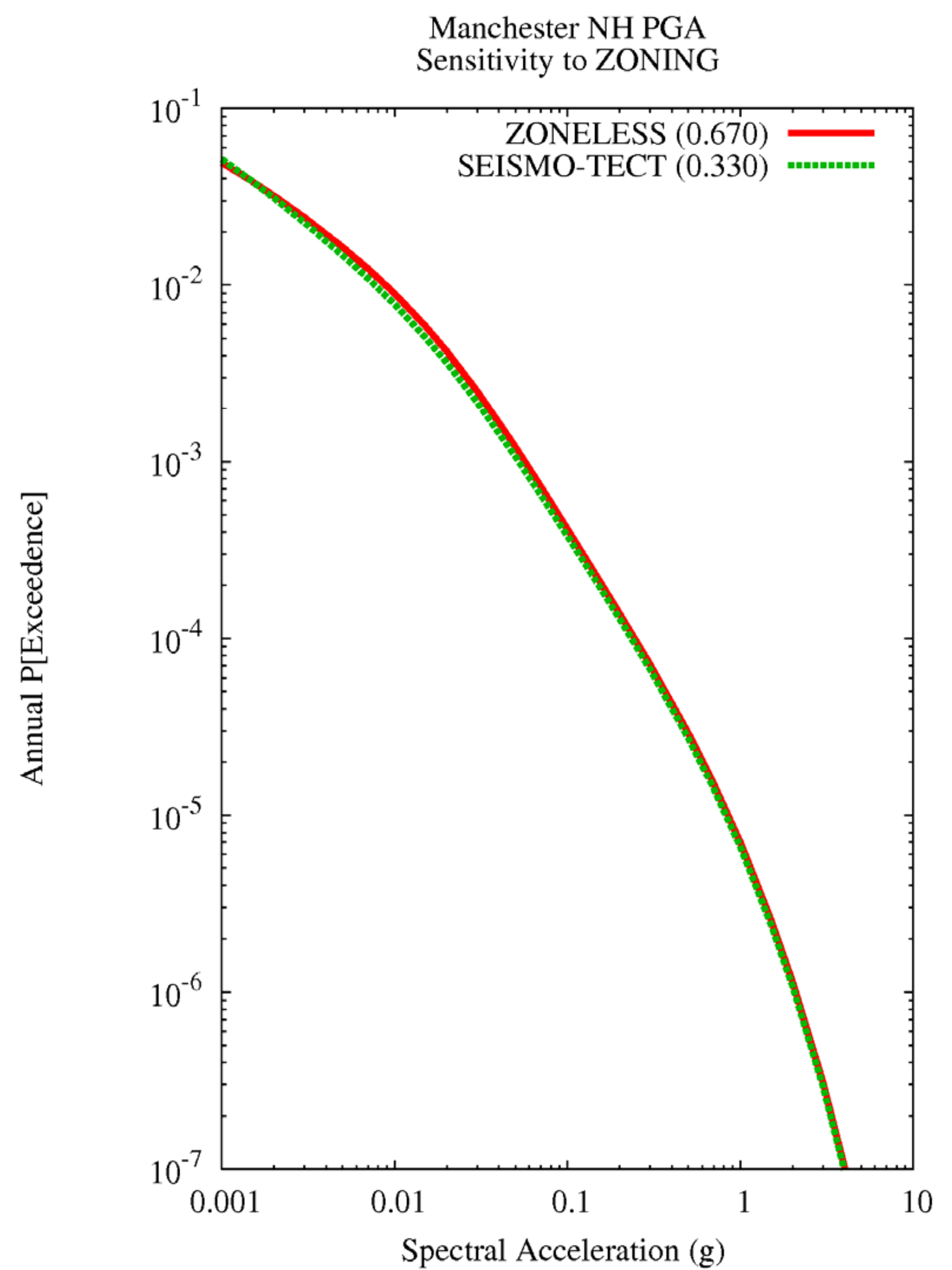

Manchester NH PGA
Mean and and Fractile Hazard Curves
Mean
85.%
50.%
15.%
Annual P[Exceedence]
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
0.001
0.01
0.1
1
10
Spectral Acceleration (g)



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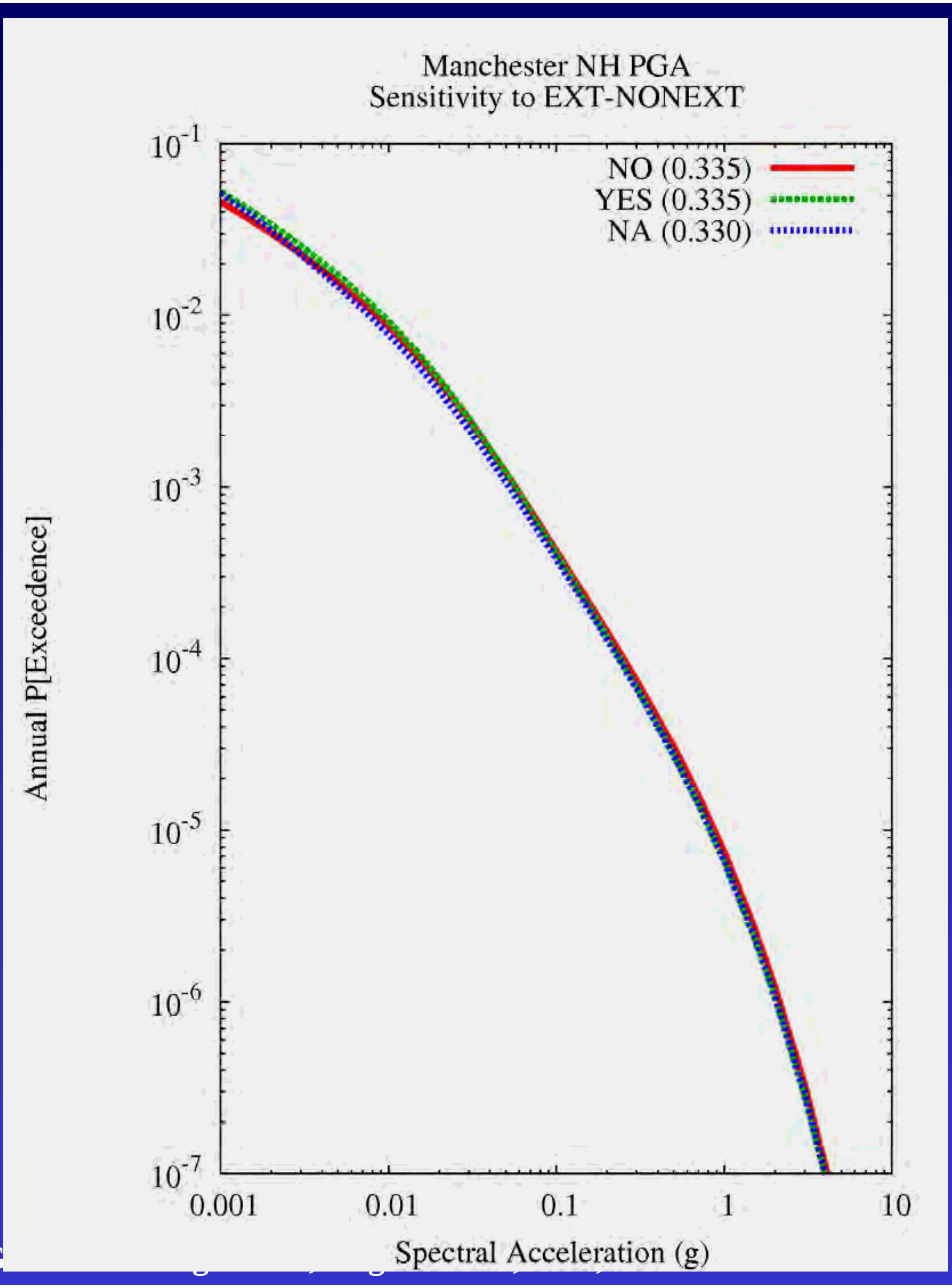
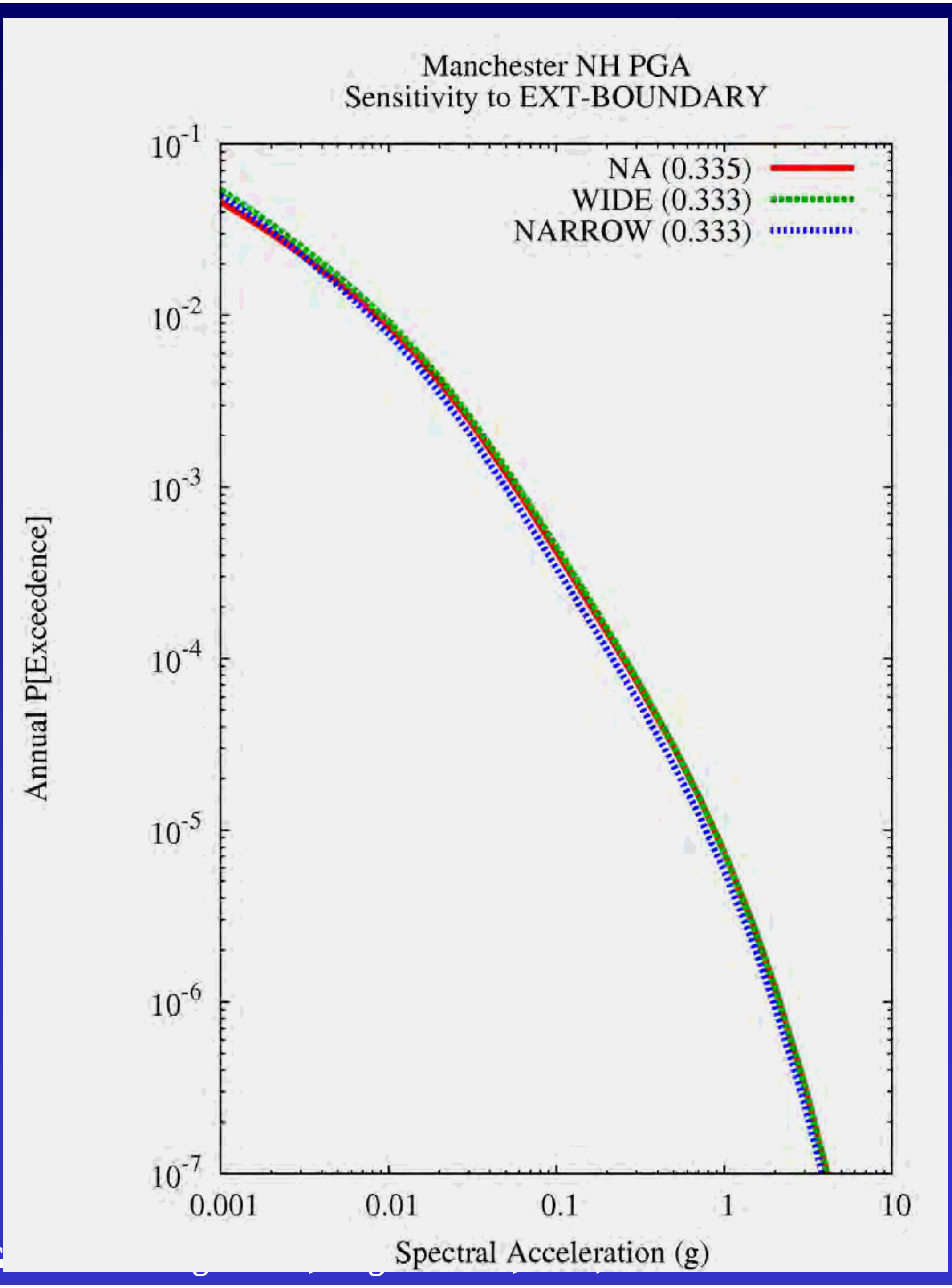
RISK ENGINEERING



William Lettis & Associates, Inc.

RISK ENGINEERING



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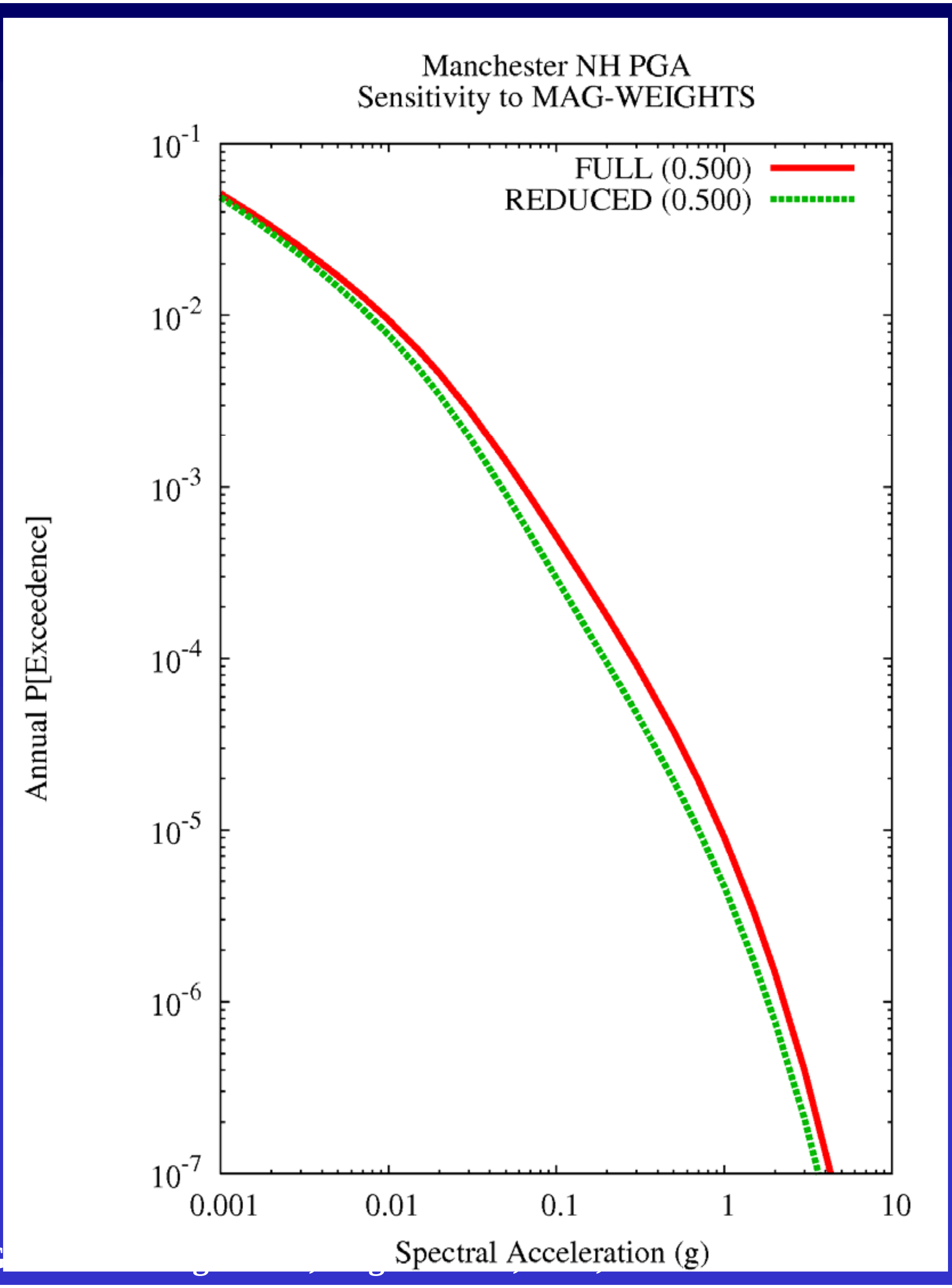
RISK ENGINEERING



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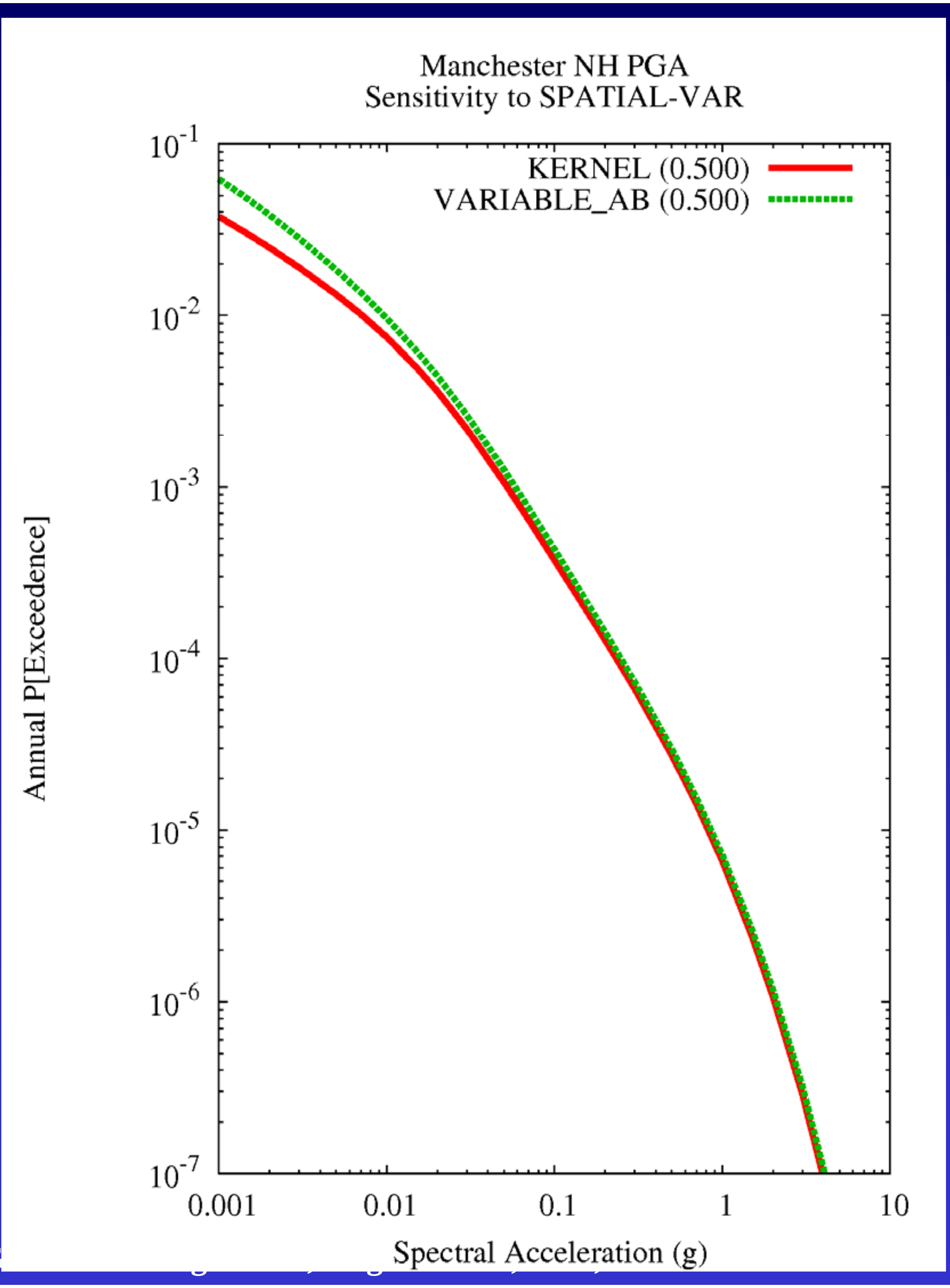
RISK ENGINEERING



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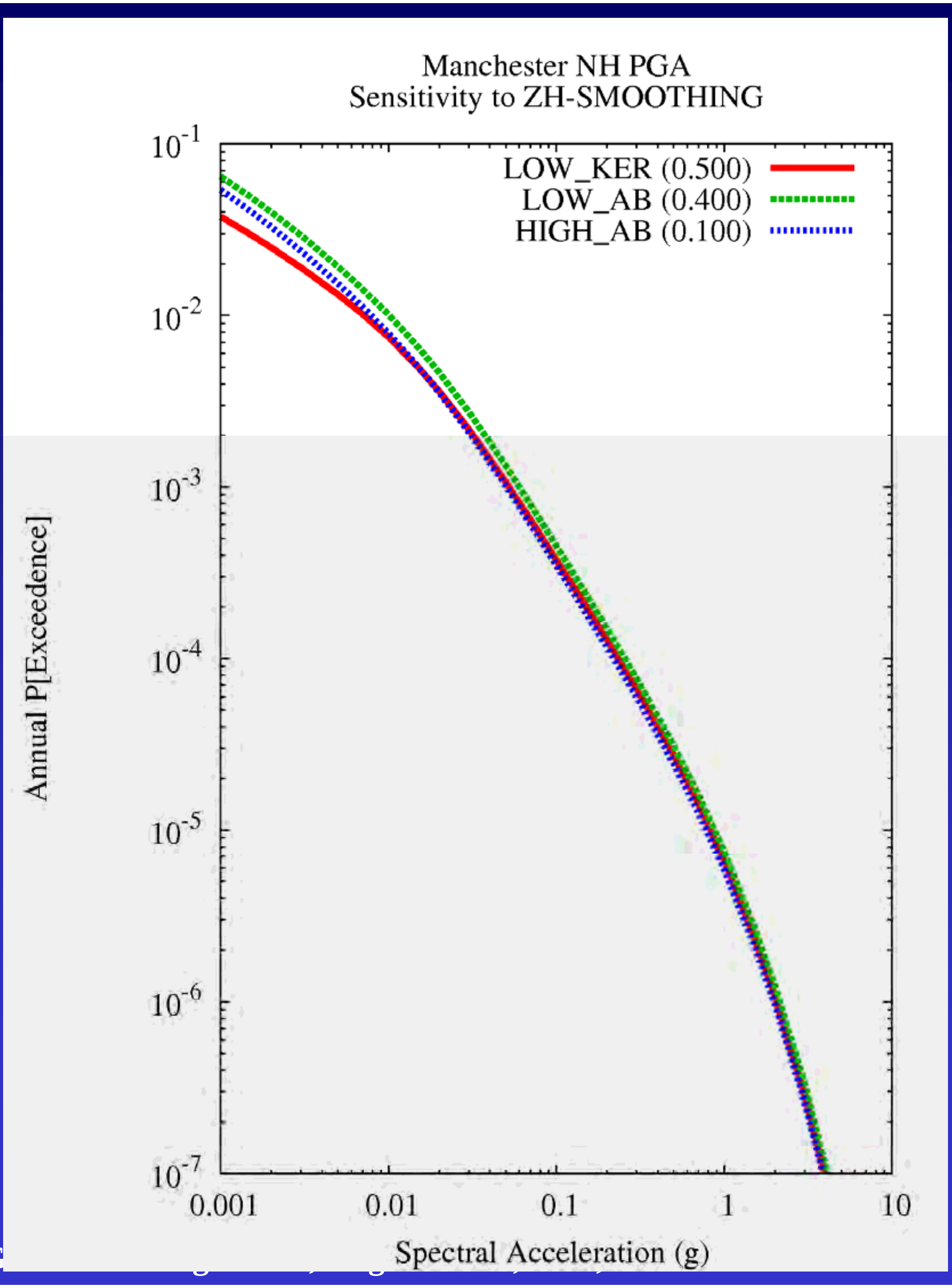

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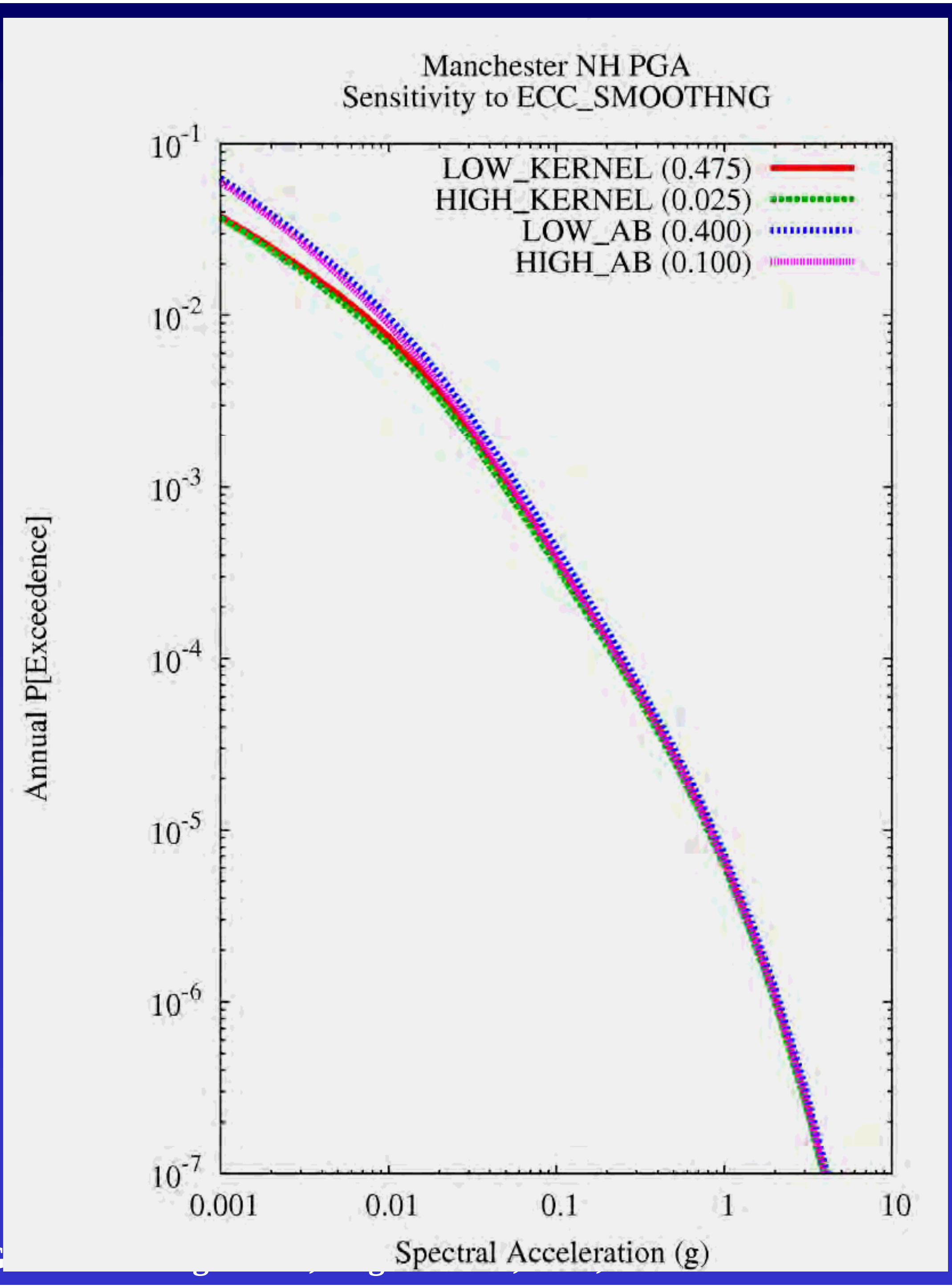

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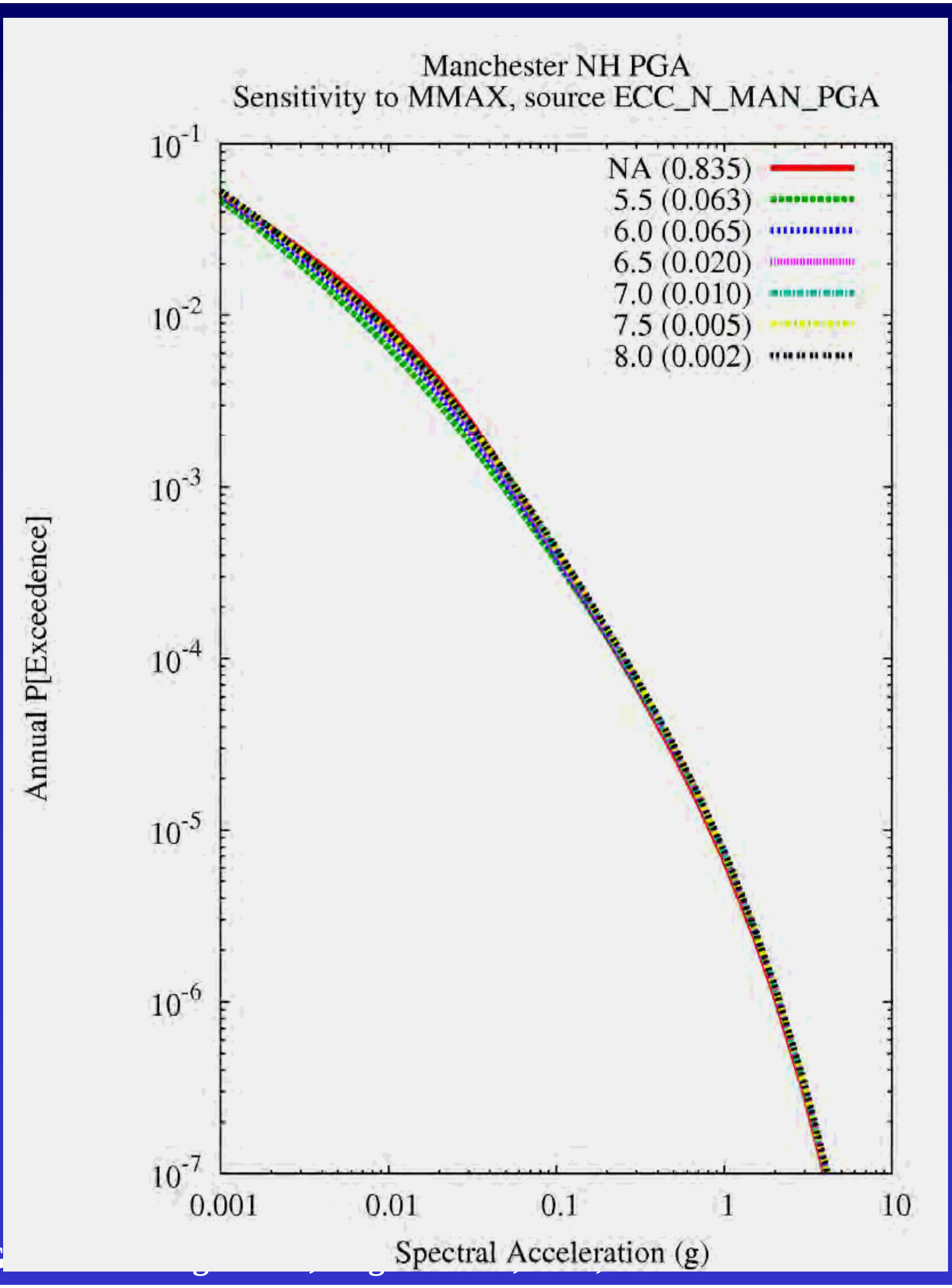
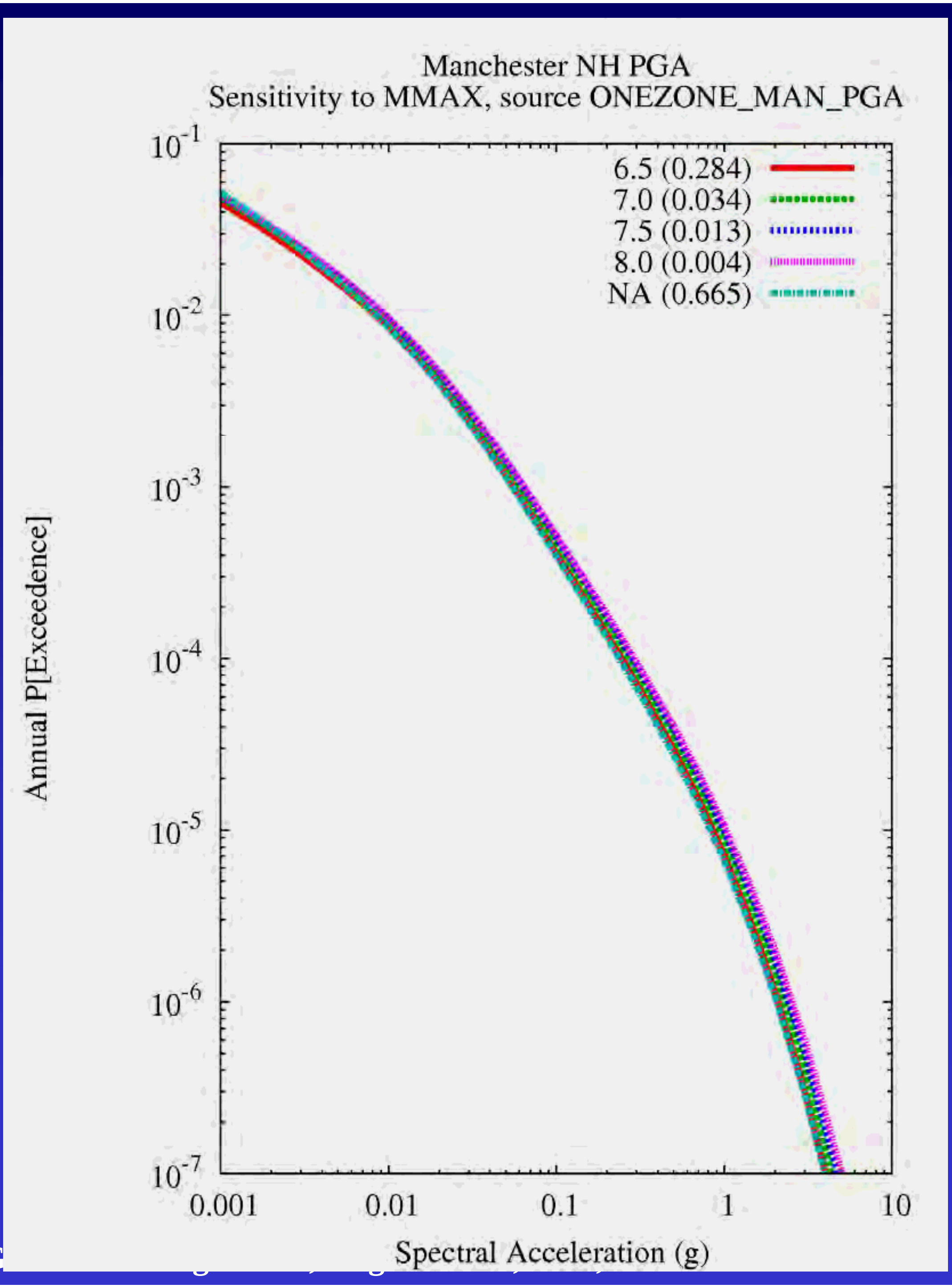

Manchester NH PGA
Sensitivity to MMAX, source ECC_N_MAN_PGA
Annual P[Exceedence]
Spectral Acceleration (g)
10^-1
10^-2
10^-3
10^-4
10^-5
10^-6
10^-7
0.001
0.01
0.1
1
10
NA (0.835)
5.5 (0.063)
6.0 (0.065)
6.5 (0.020)
7.0 (0.010)
7.5 (0.005)
8.0 (0.002)



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RISK
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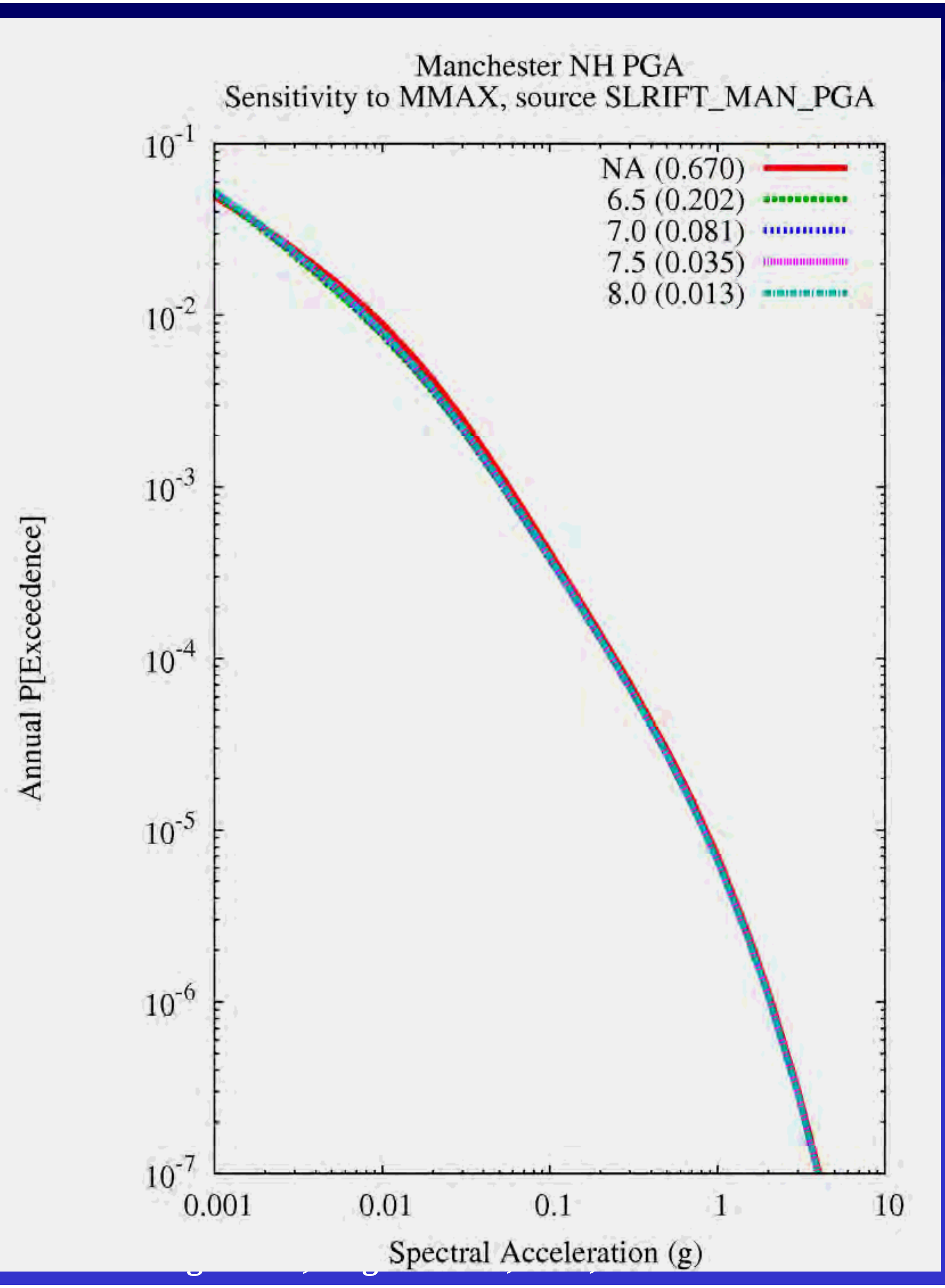
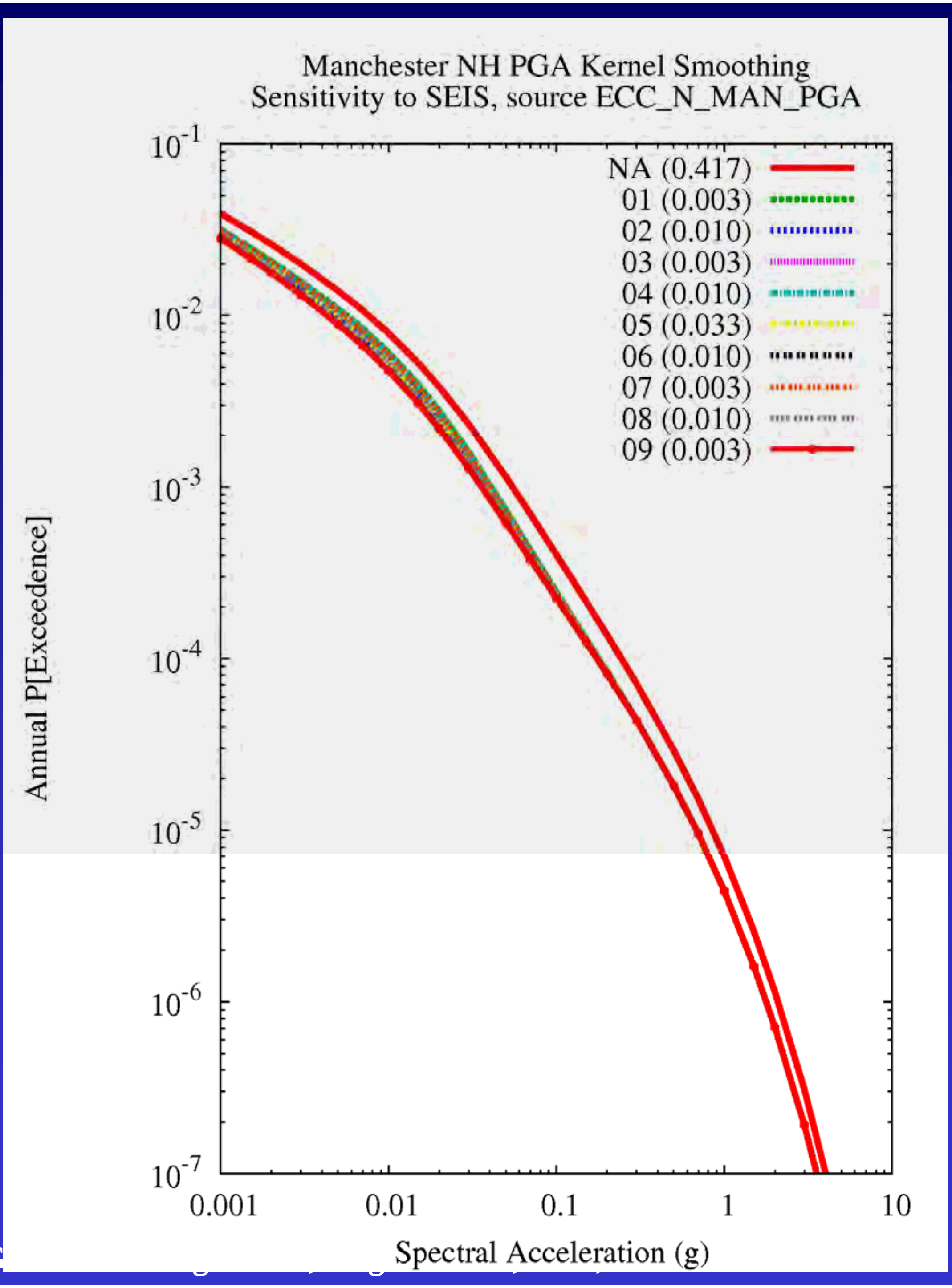
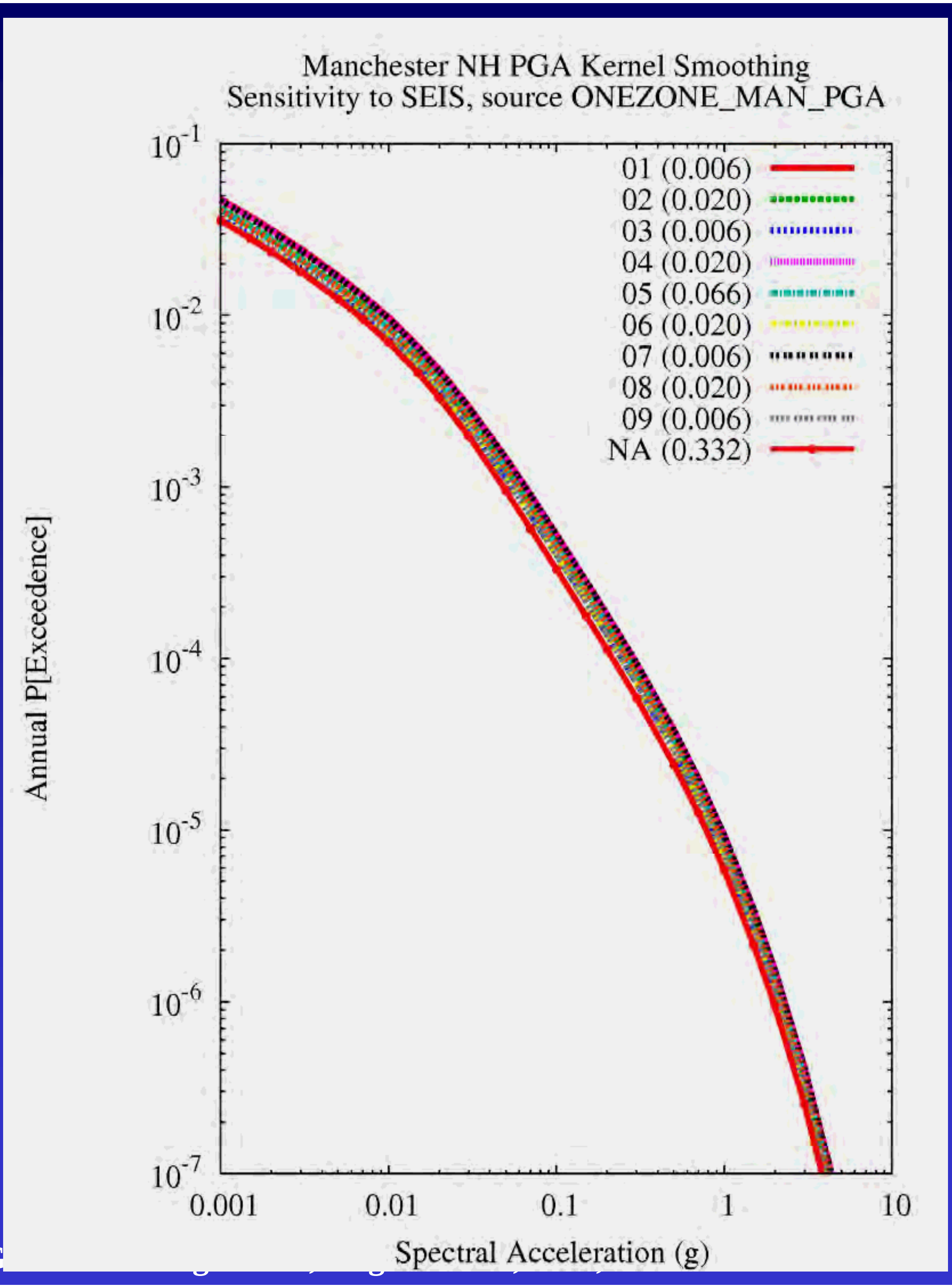


WLA
William Lettis & Associates, Inc.

RISK
ENGINEERING


Manchester NH PGA Kernel Smoothing
Sensitivity to SEIS, source ECC_N_MAN_PGA
Annual P[Exceedence]
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
0.001
0.01
0.1
1
10
Spectral Acceleration (g)
NA (0.417)
01 (0.003)
02 (0.010)
03 (0.003)
04 (0.010)
05 (0.033)
06 (0.010)
07 (0.003)
08 (0.010)
09 (0.003)



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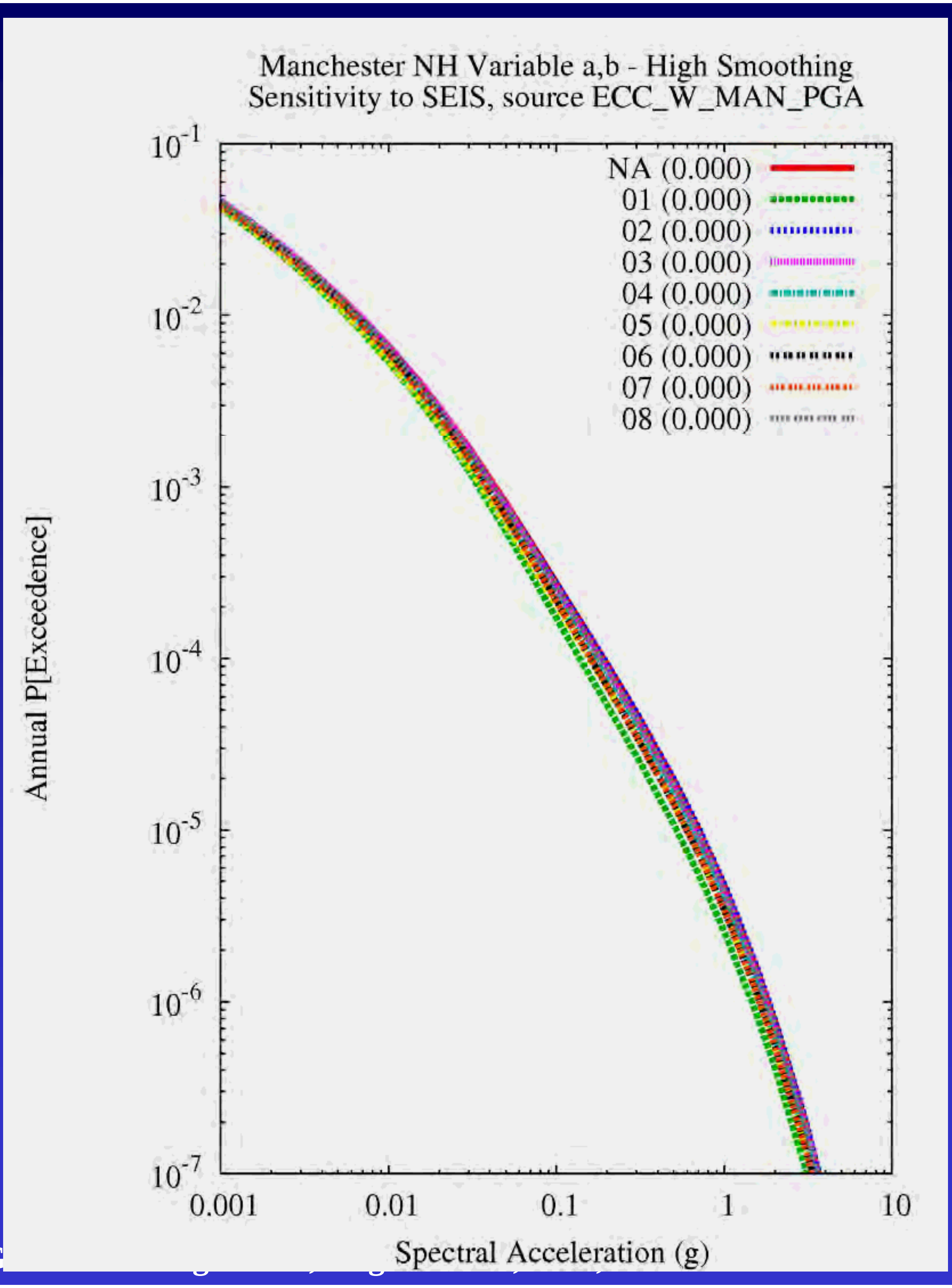
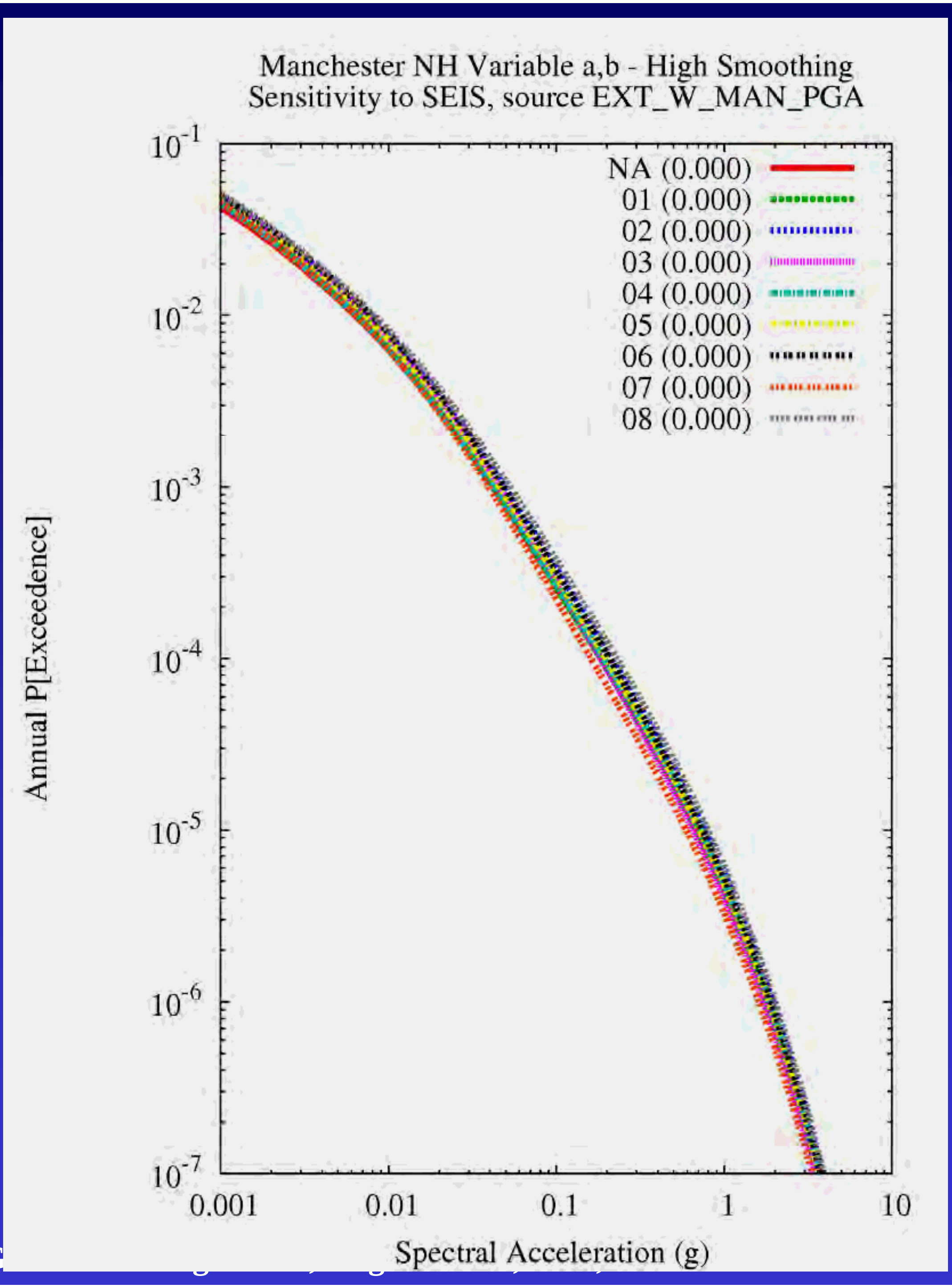
RISK ENGINEERING

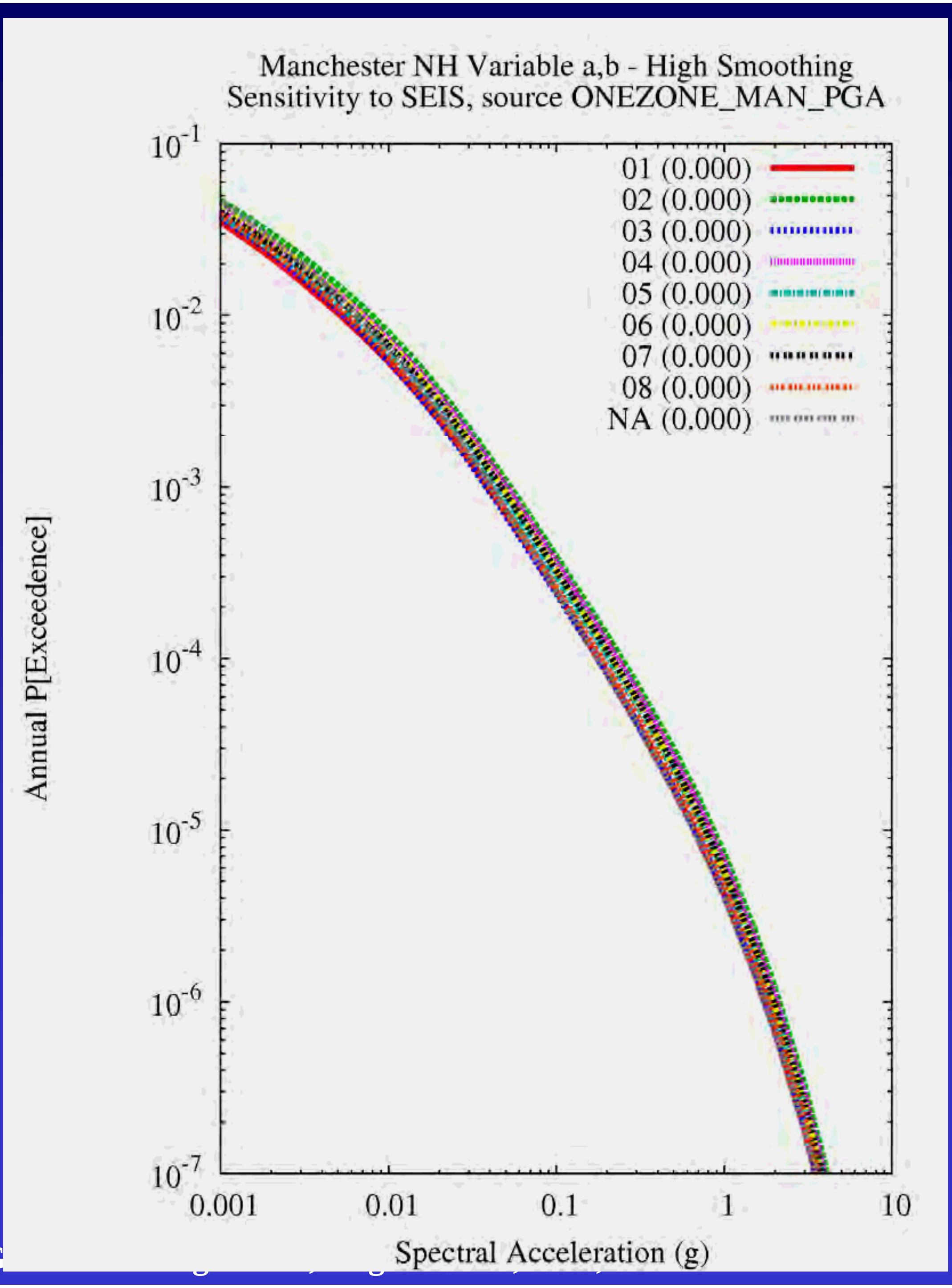


WLA
William Lettis & Associates, Inc.

RISK
ENGINEERING

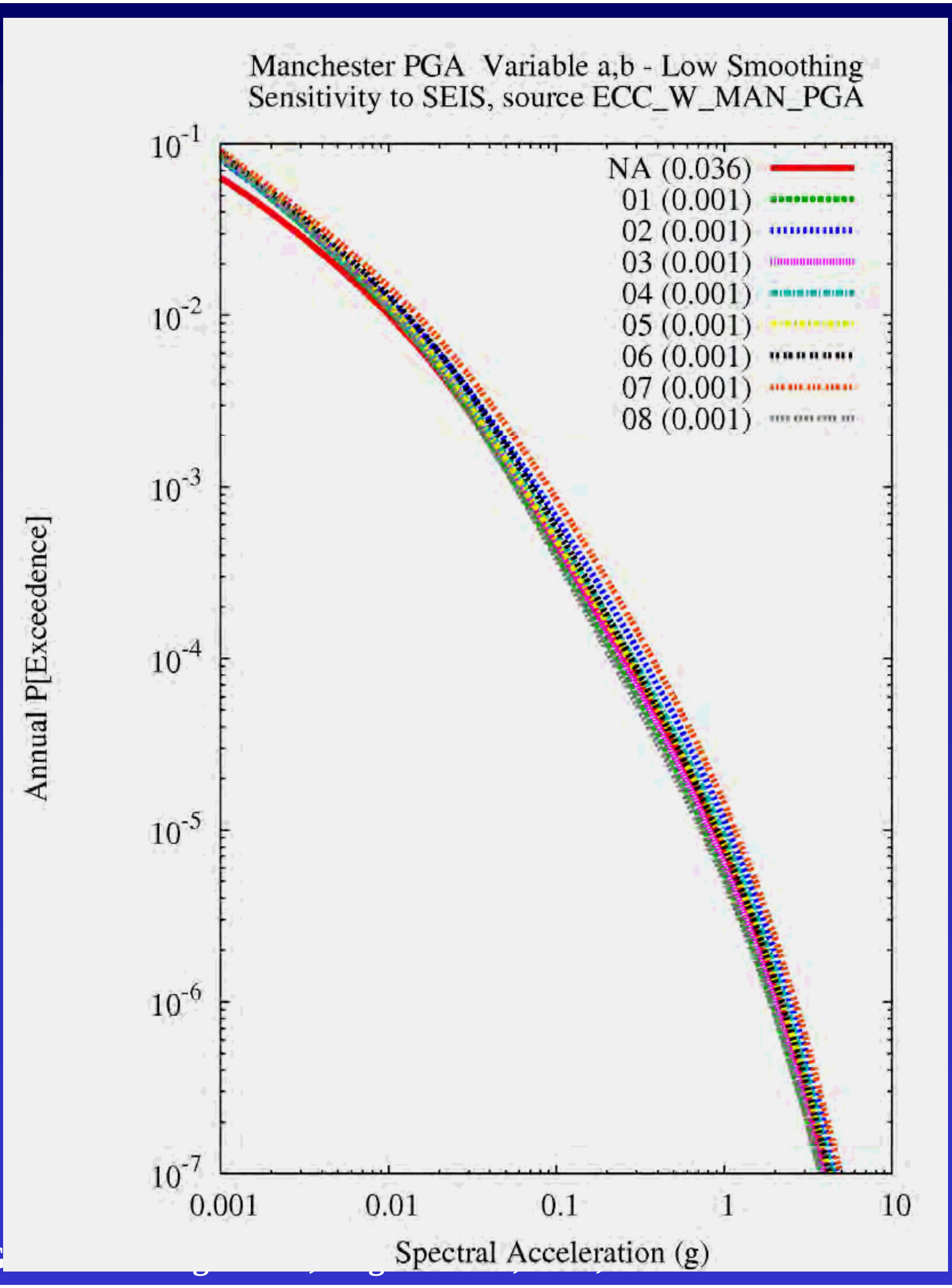


Manchester NH Variable a,b - High Smoothing
Sensitivity to SEIS, source EXT_W_MAN_PGA
Annual P[Exceedence]
Spectral Acceleration (g)
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
0.001
0.01
0.1
1
10
NA (0.000)
01 (0.000)
02 (0.000)
03 (0.000)
04 (0.000)
05 (0.000)
06 (0.000)
07 (0.000)
08 (0.000)



WLA
William Lettis & Associates, Inc.

RISK
ENGINEERING



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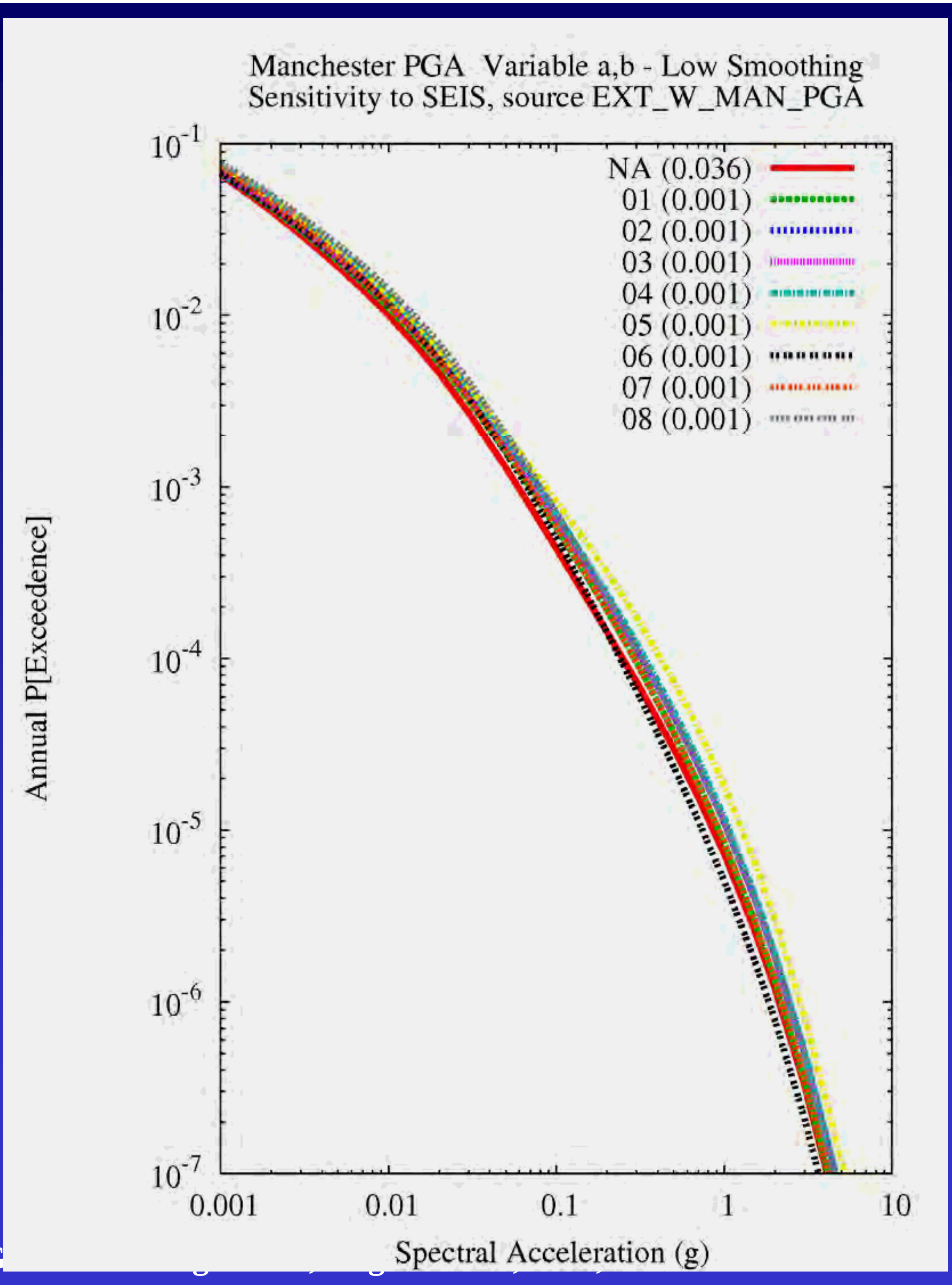
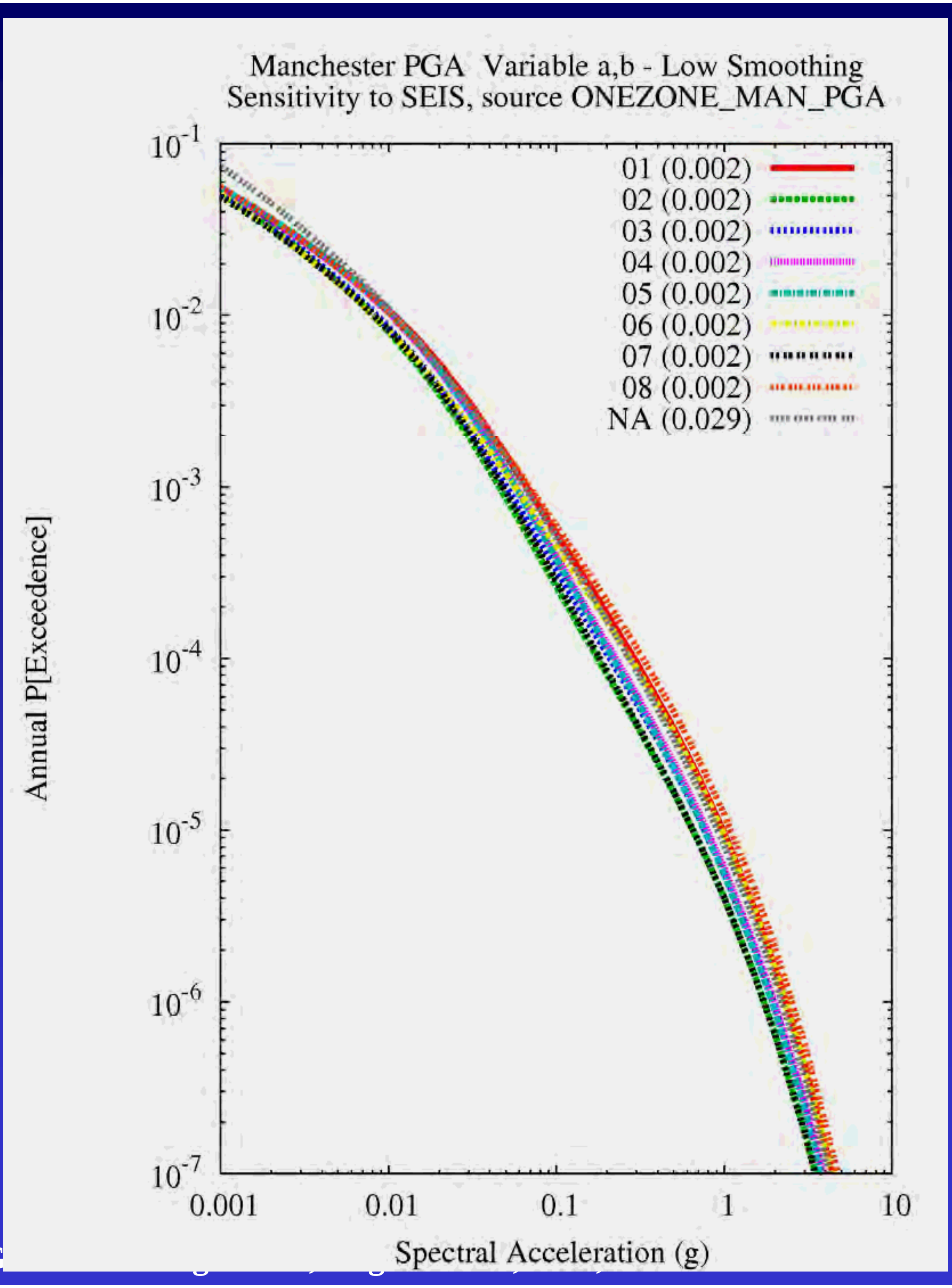


William Lettis & Associates, Inc.

RISK ENGINEERING



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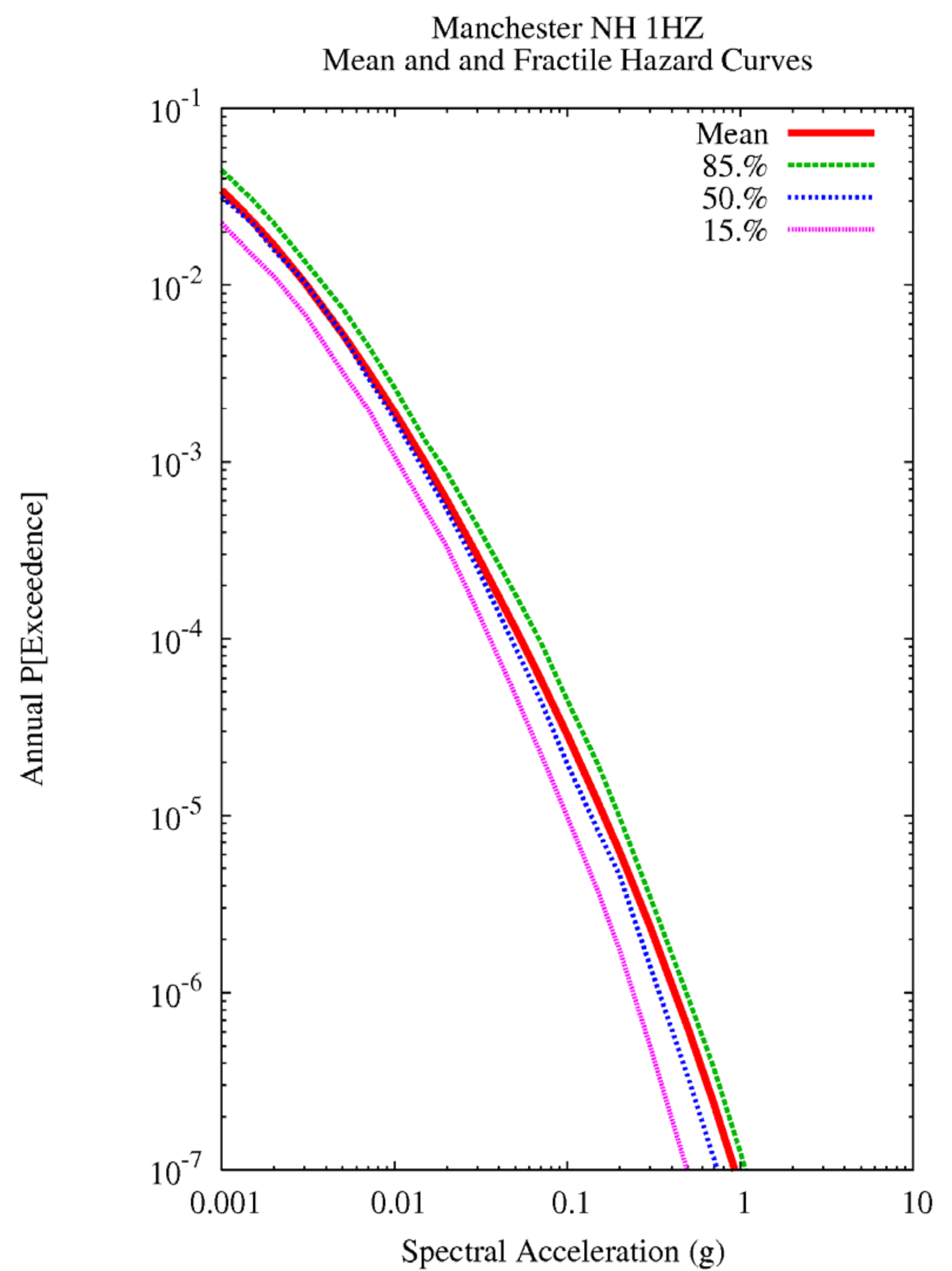
Manchester 1 Hz



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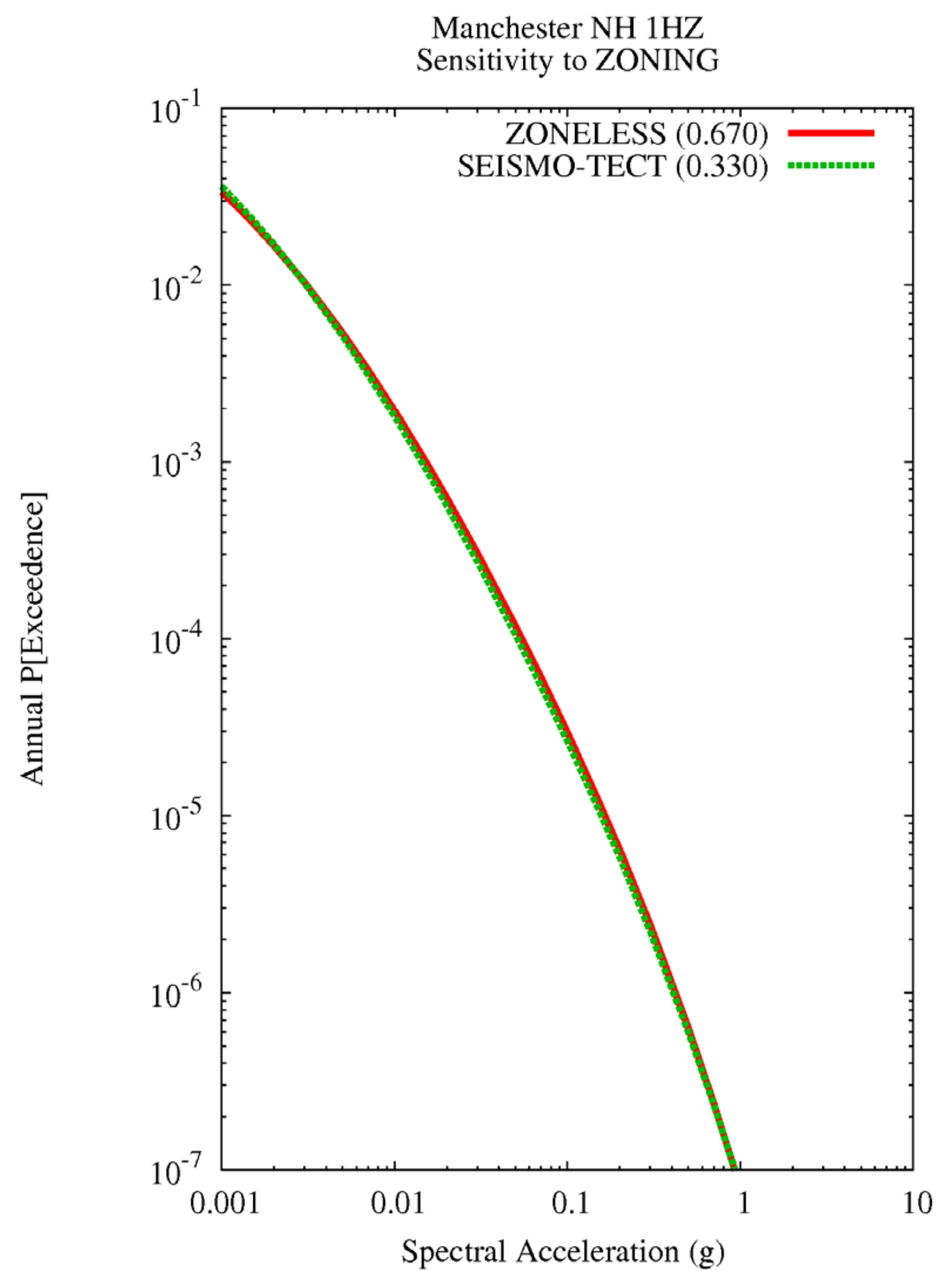

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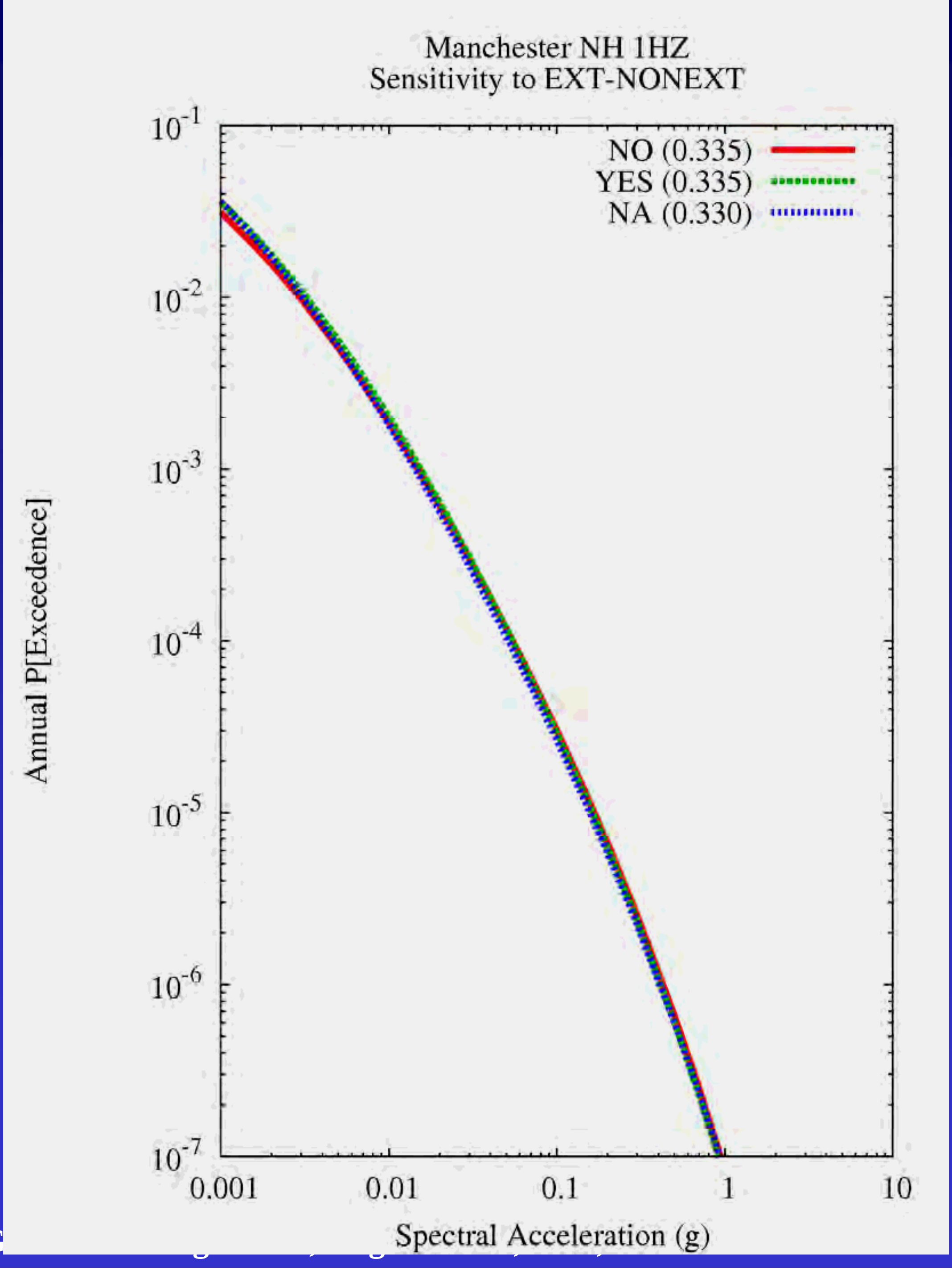

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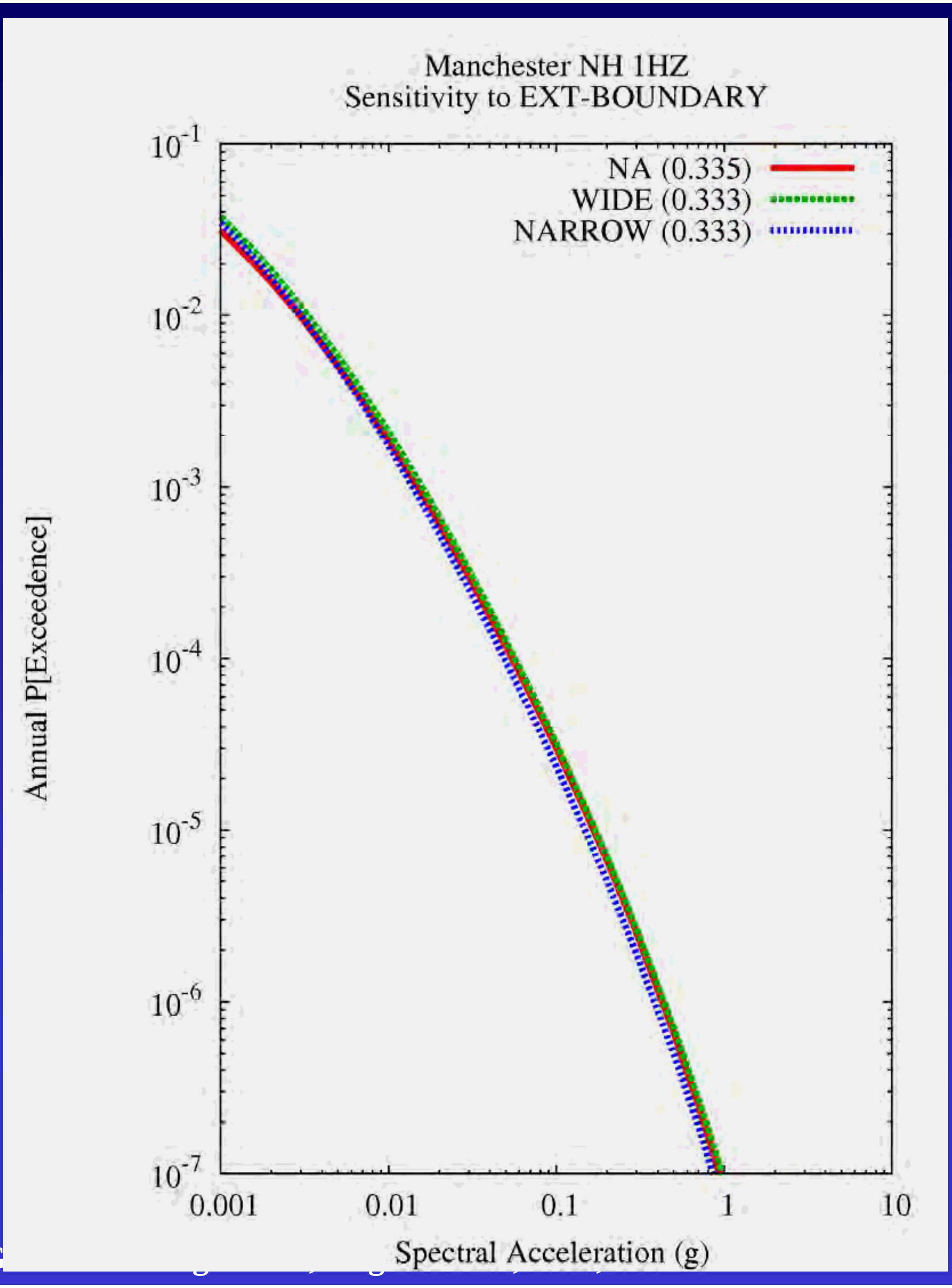
RISK ENGINEERING



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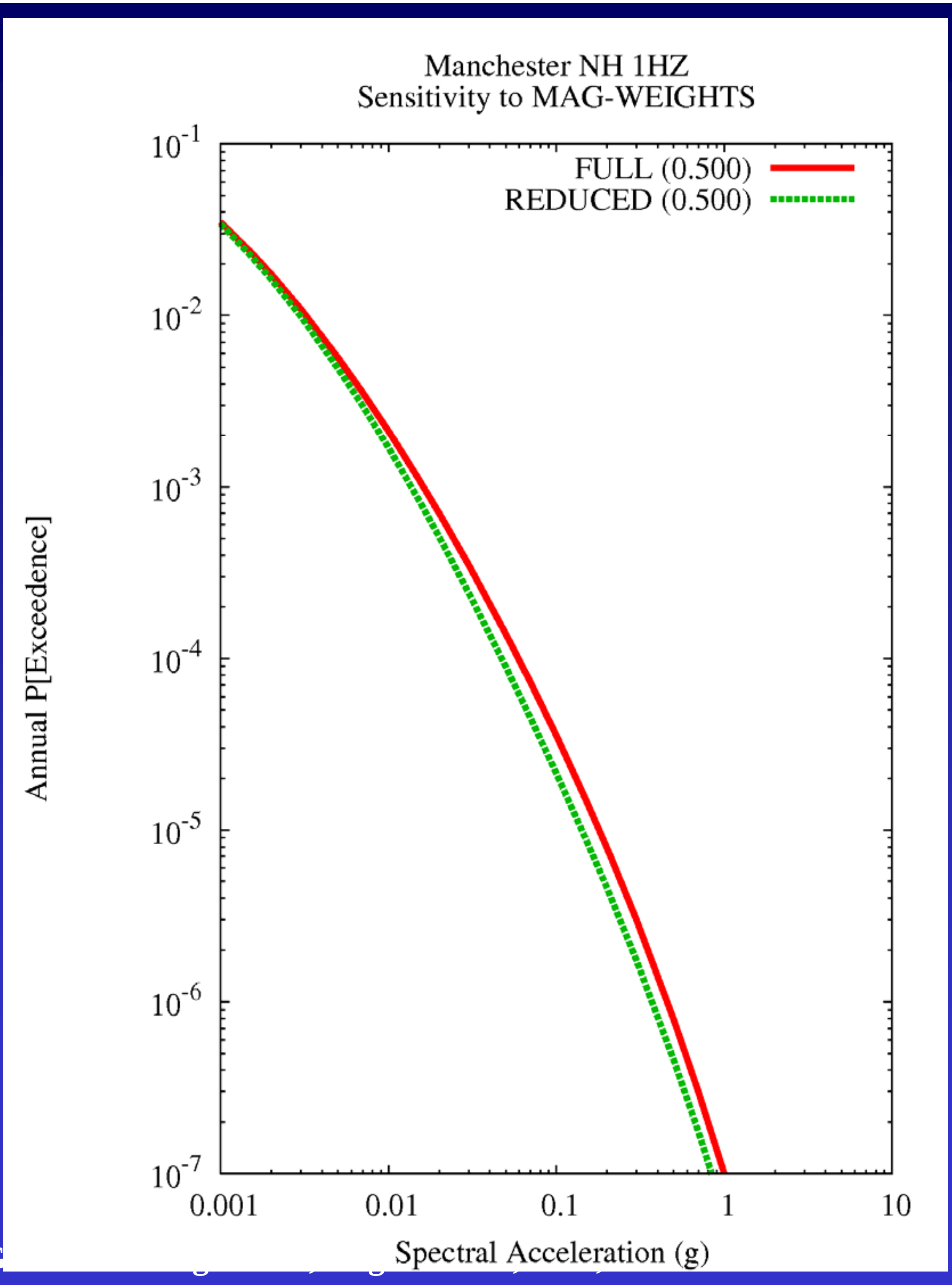
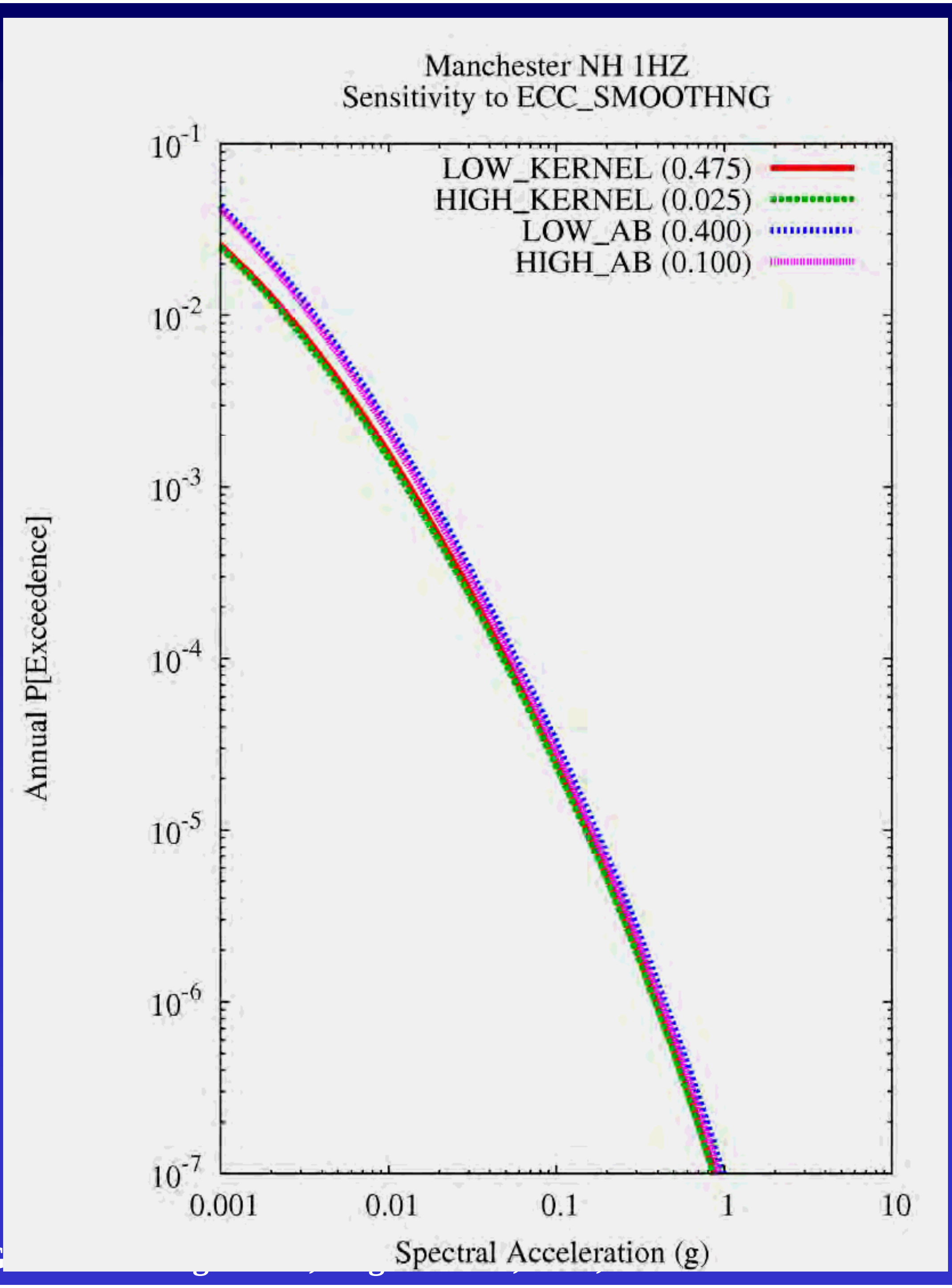
RISK ENGINEERING


Manchester NH 1HZ
Sensitivity to MAG-WEIGHTS
FULL (0.500)
REDUCED (0.500)
Annual P[Exceedence]
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
0.001
0.01
0.1
1
10
Spectral Acceleration (g)



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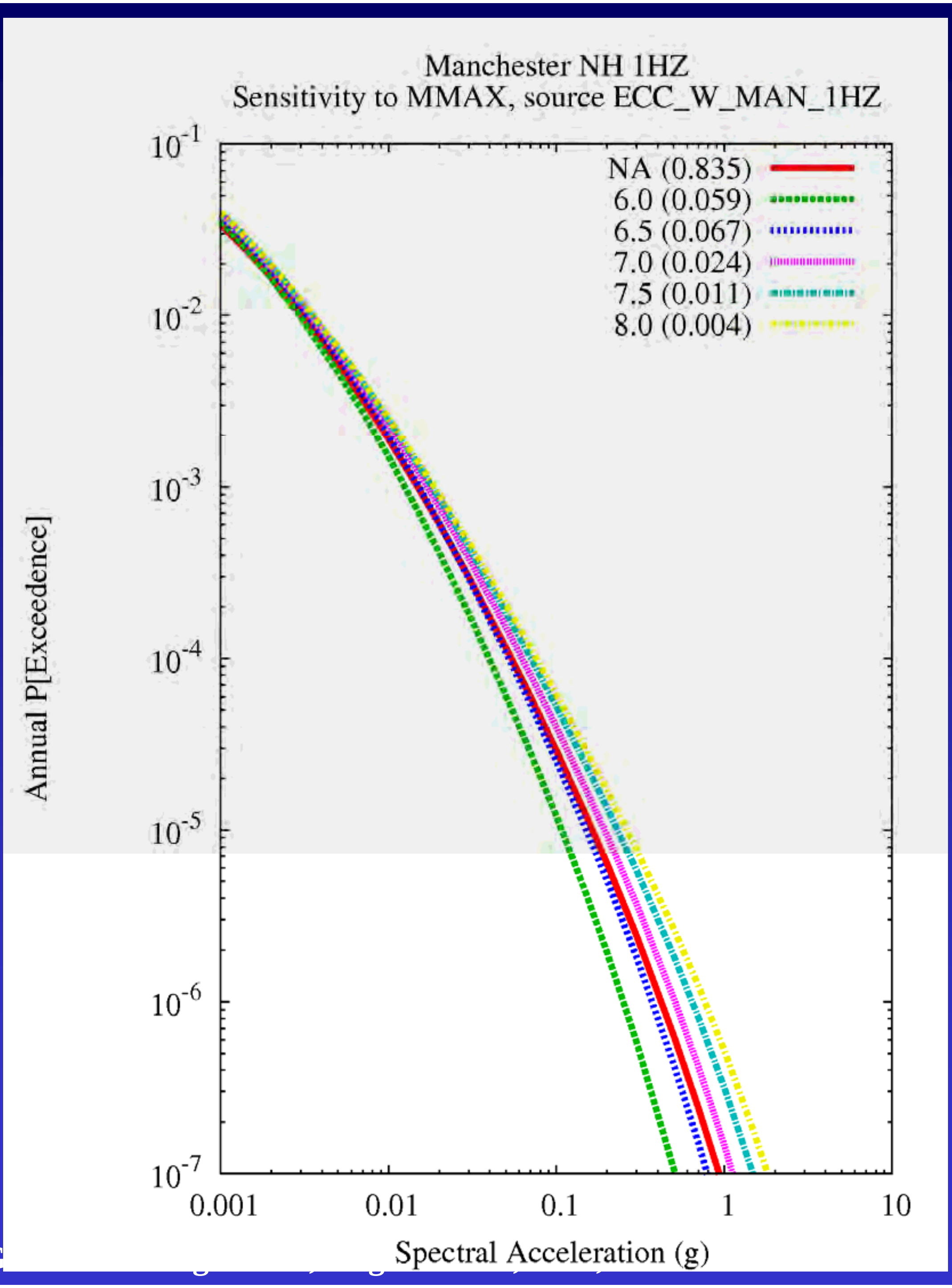
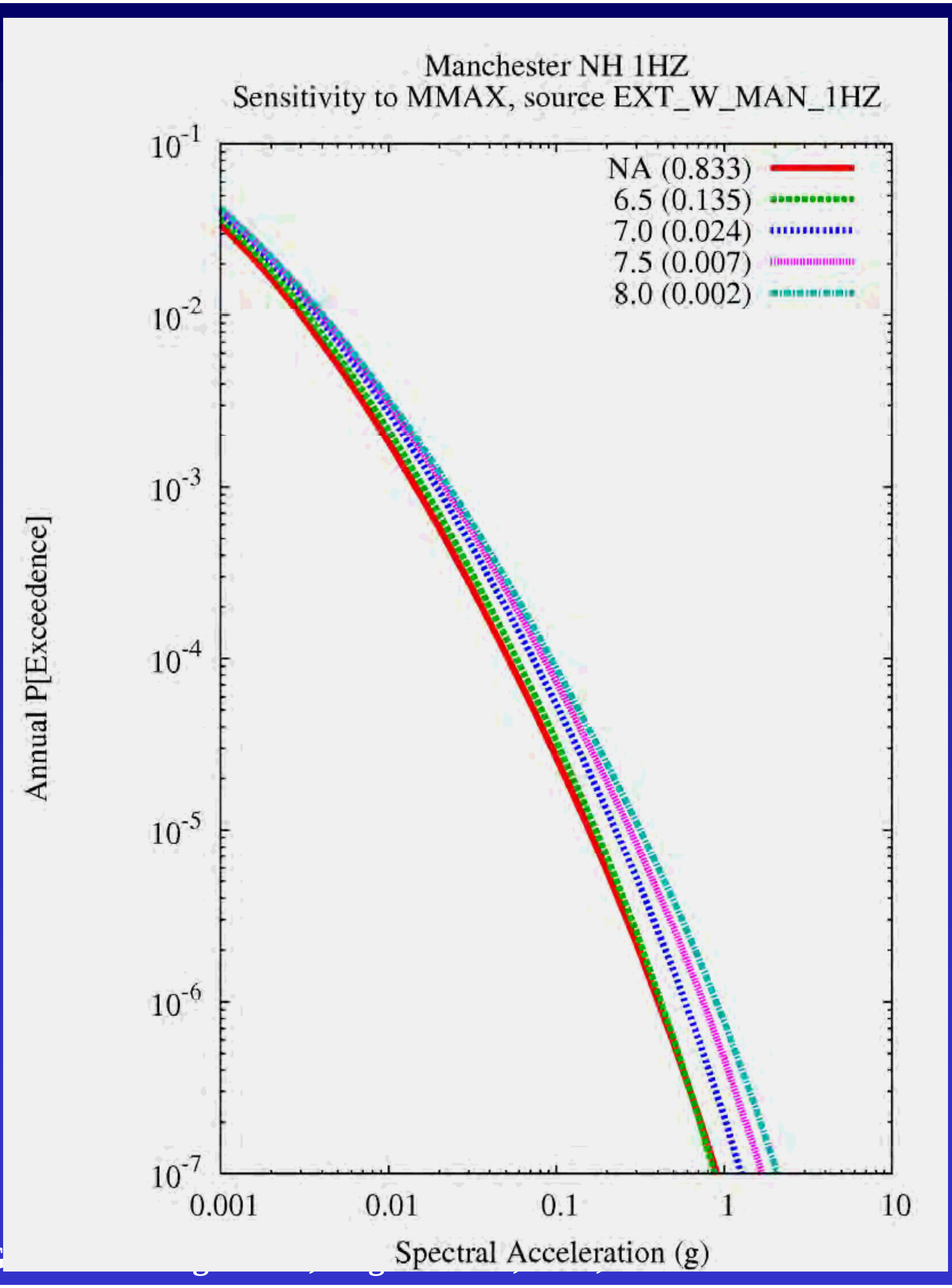
RISK ENGINEERING



WLA William Lettis & Associates, Inc.

RISK ENGINEERING



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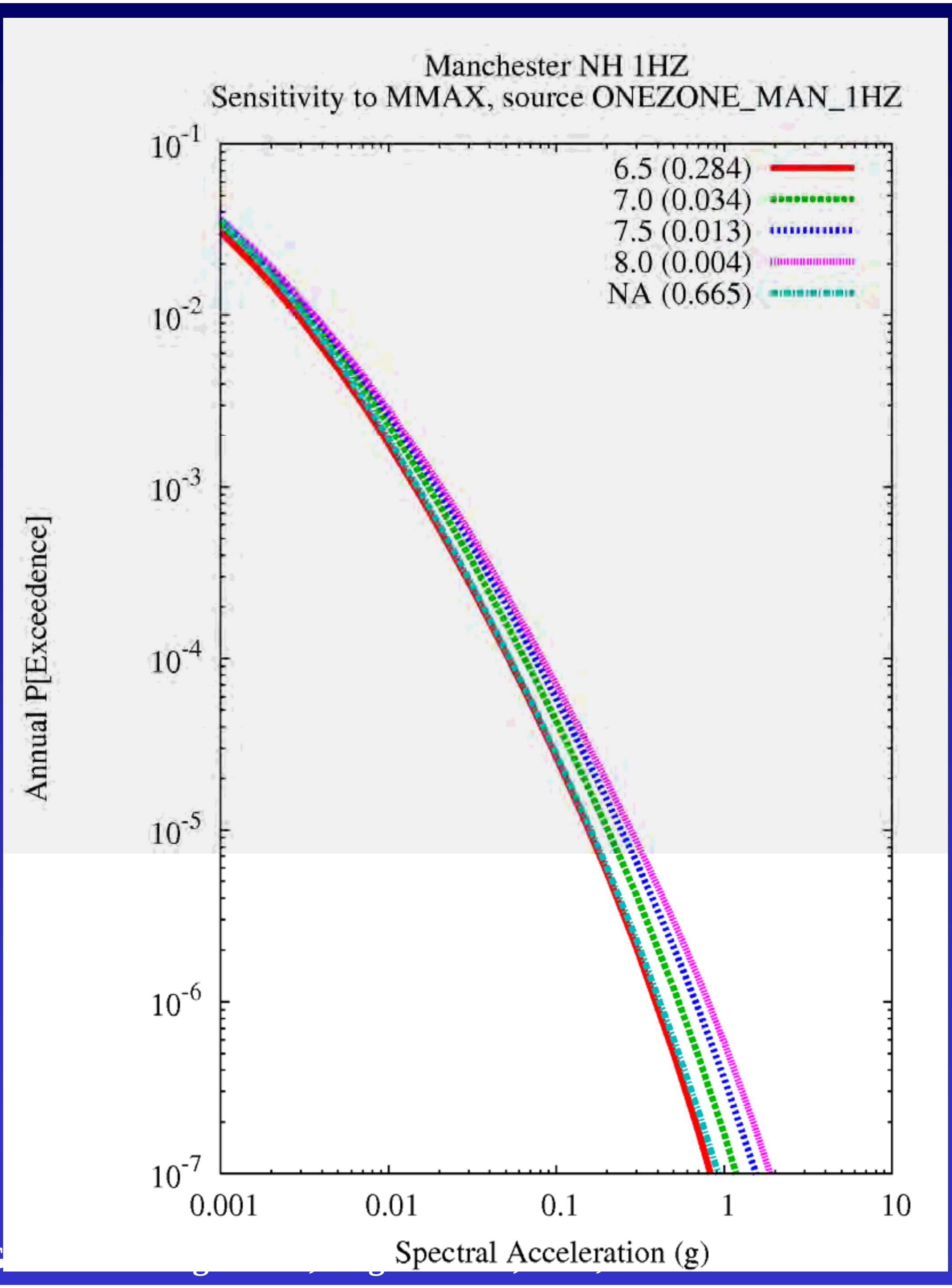
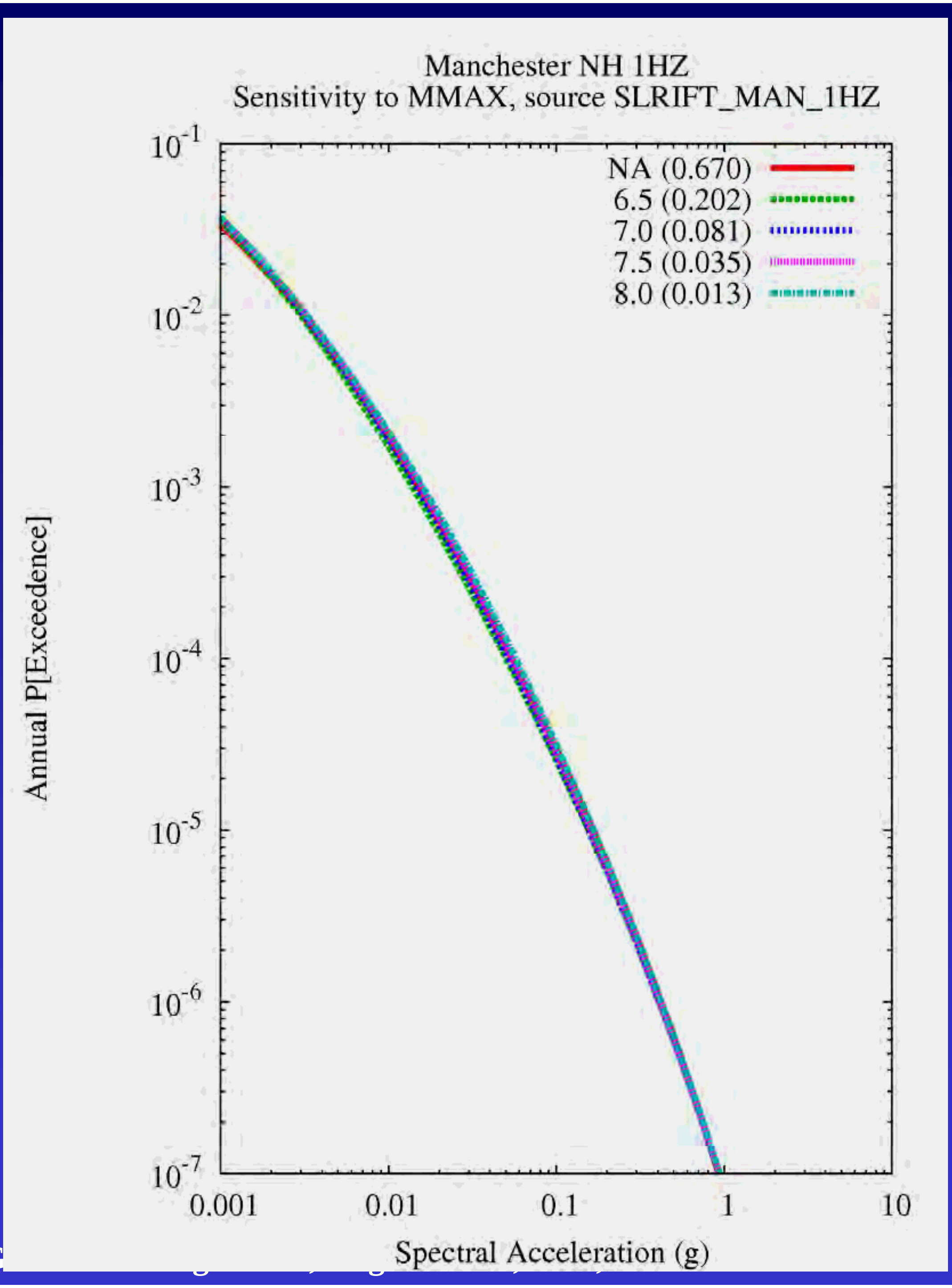
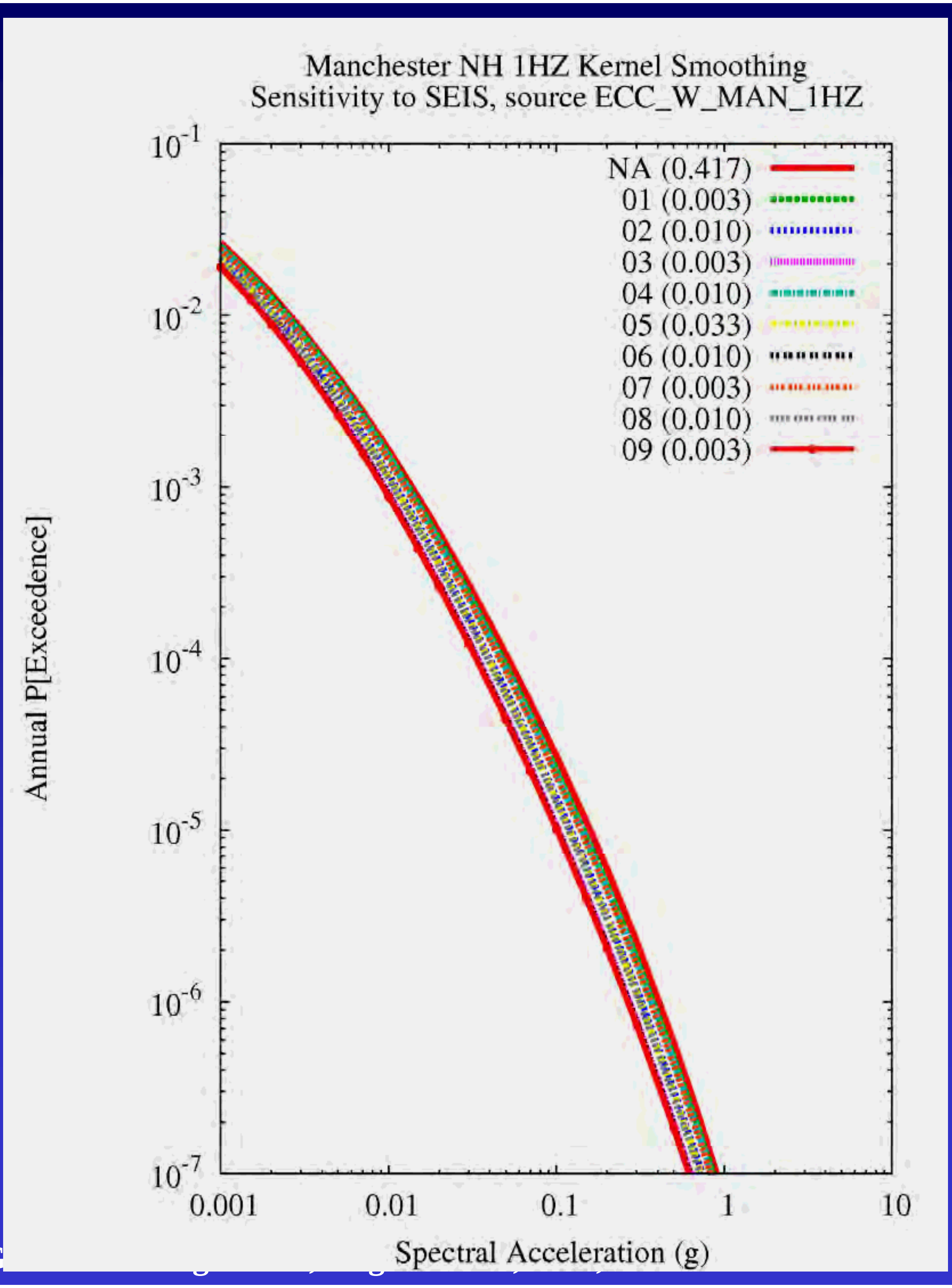


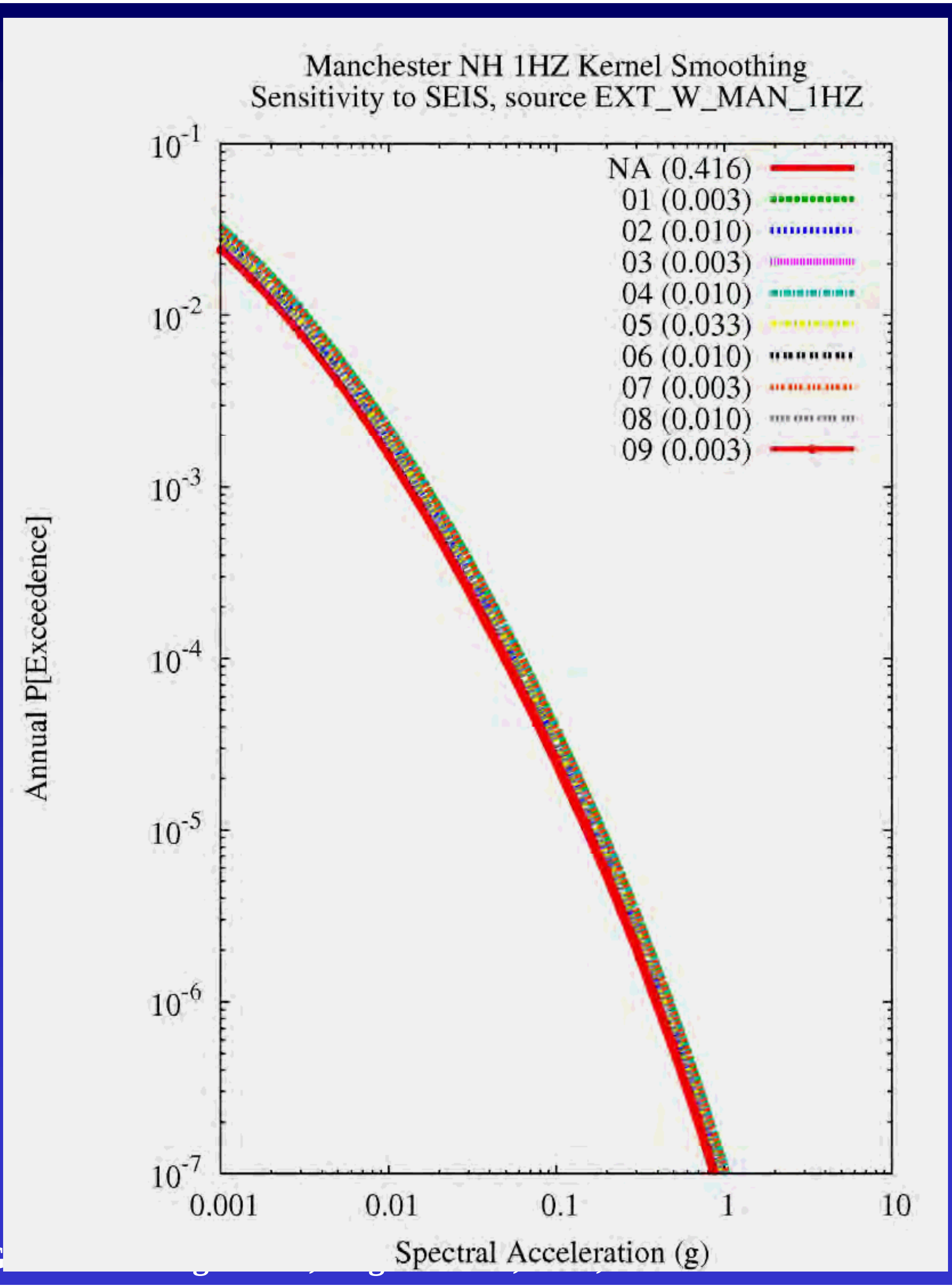
WLA William Lettis & Associates, Inc.

RISK ENGINEERING


Manchester NH 1HZ
Sensitivity to MMAX, source SLRIFT_MAN_1HZ
NA (0.670)
6.5 (0.202)
7.0 (0.081)
7.5 (0.035)
8.0 (0.013)
Annual P[Exceedence]
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
0.001
0.01
0.1
1
10
Spectral Acceleration (g)

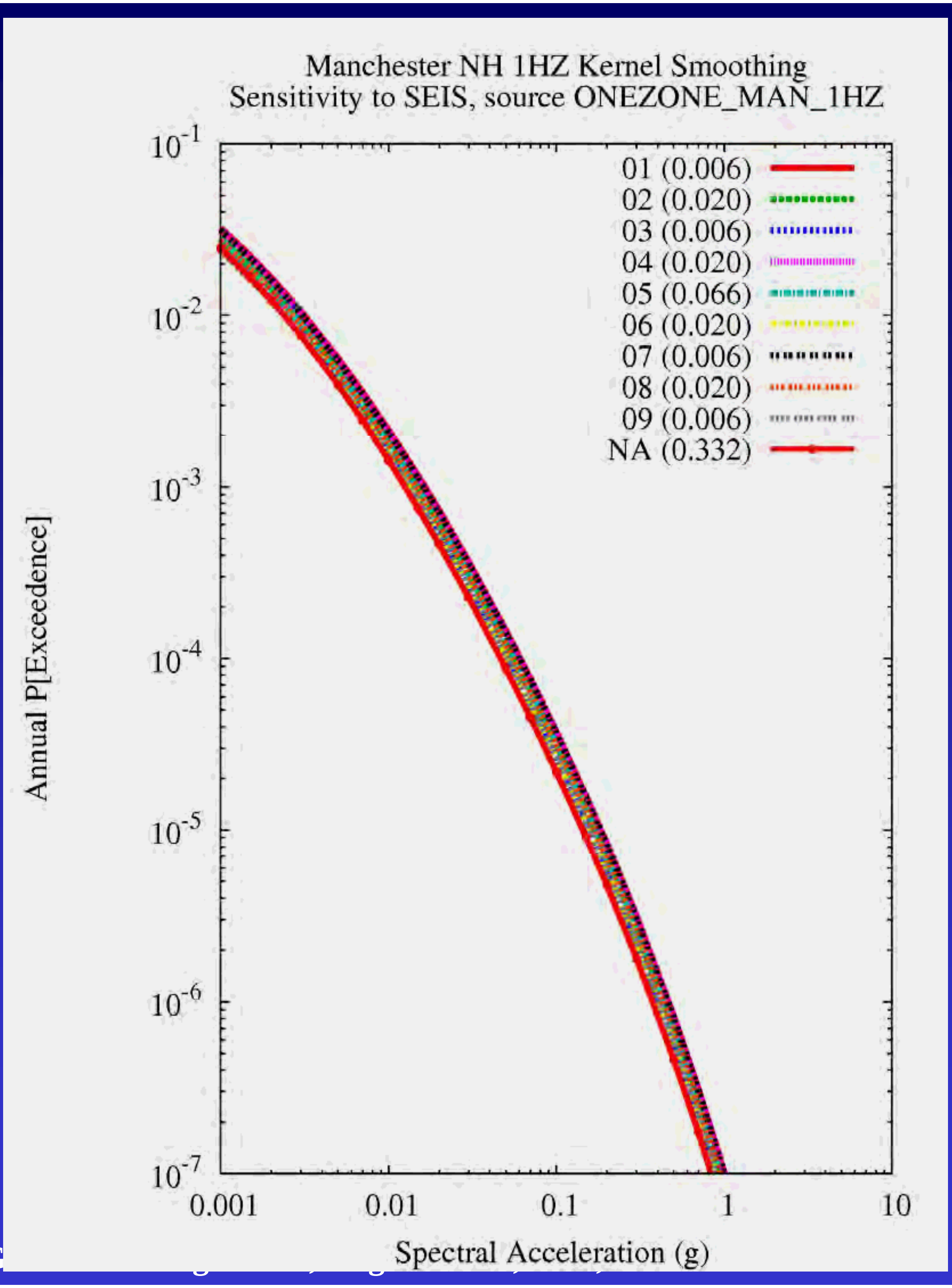


Manchester NH 1HZ Kernel Smoothing
Sensitivity to SEIS, source ECC_W_MAN_1HZ



William Lettis & Associates, Inc.

RISK ENGINEERING



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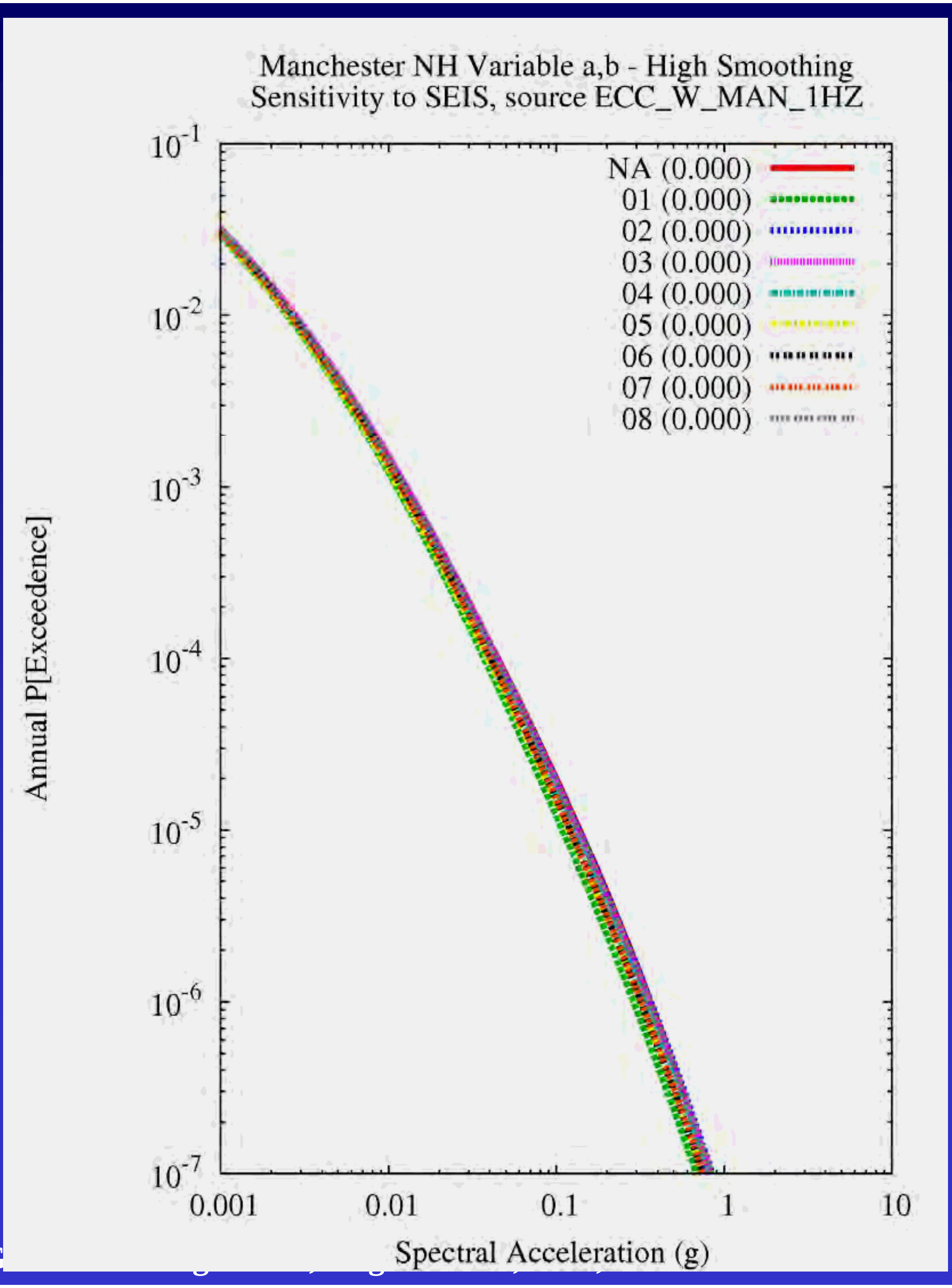
RISK ENGINEERING



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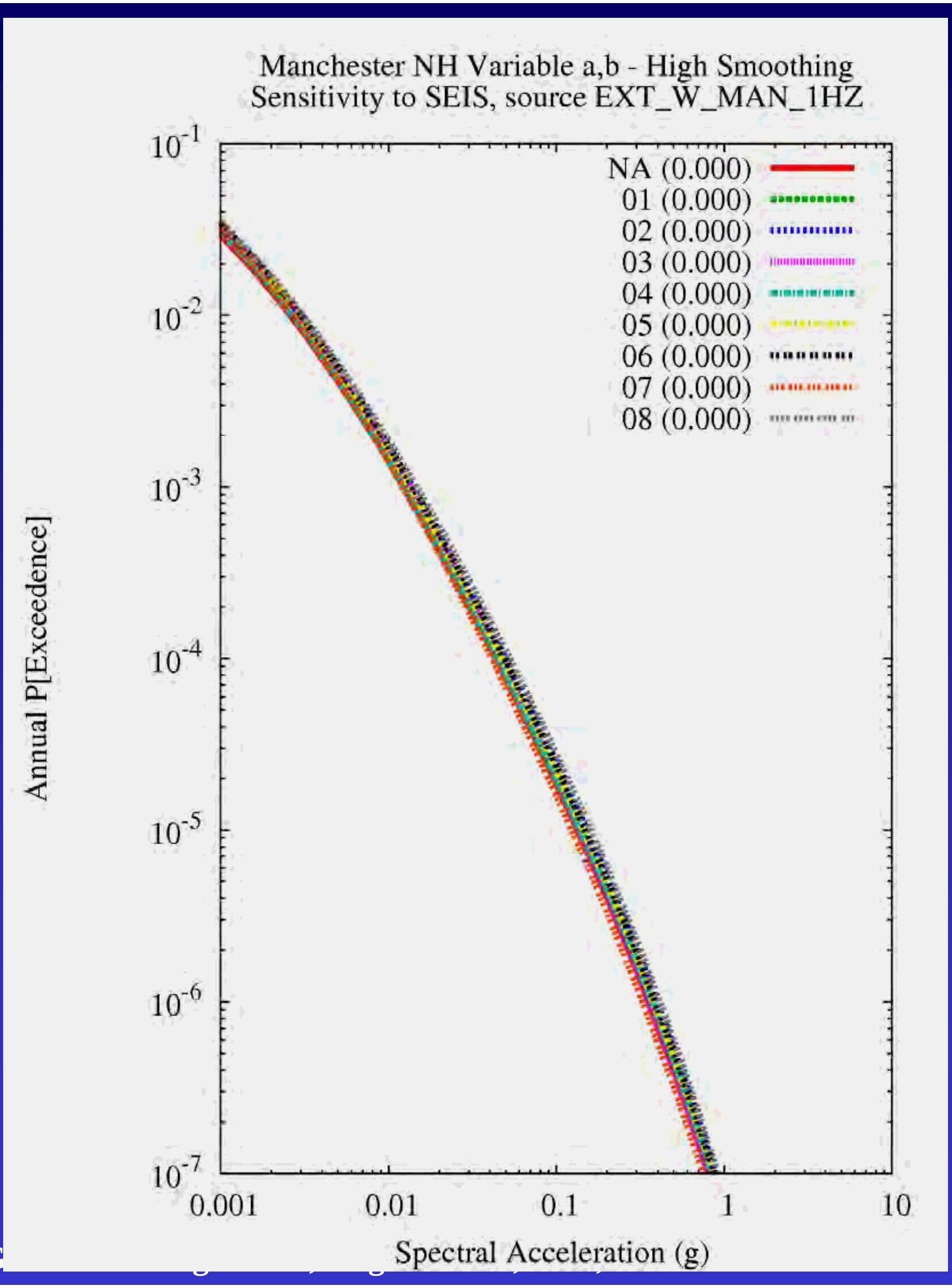
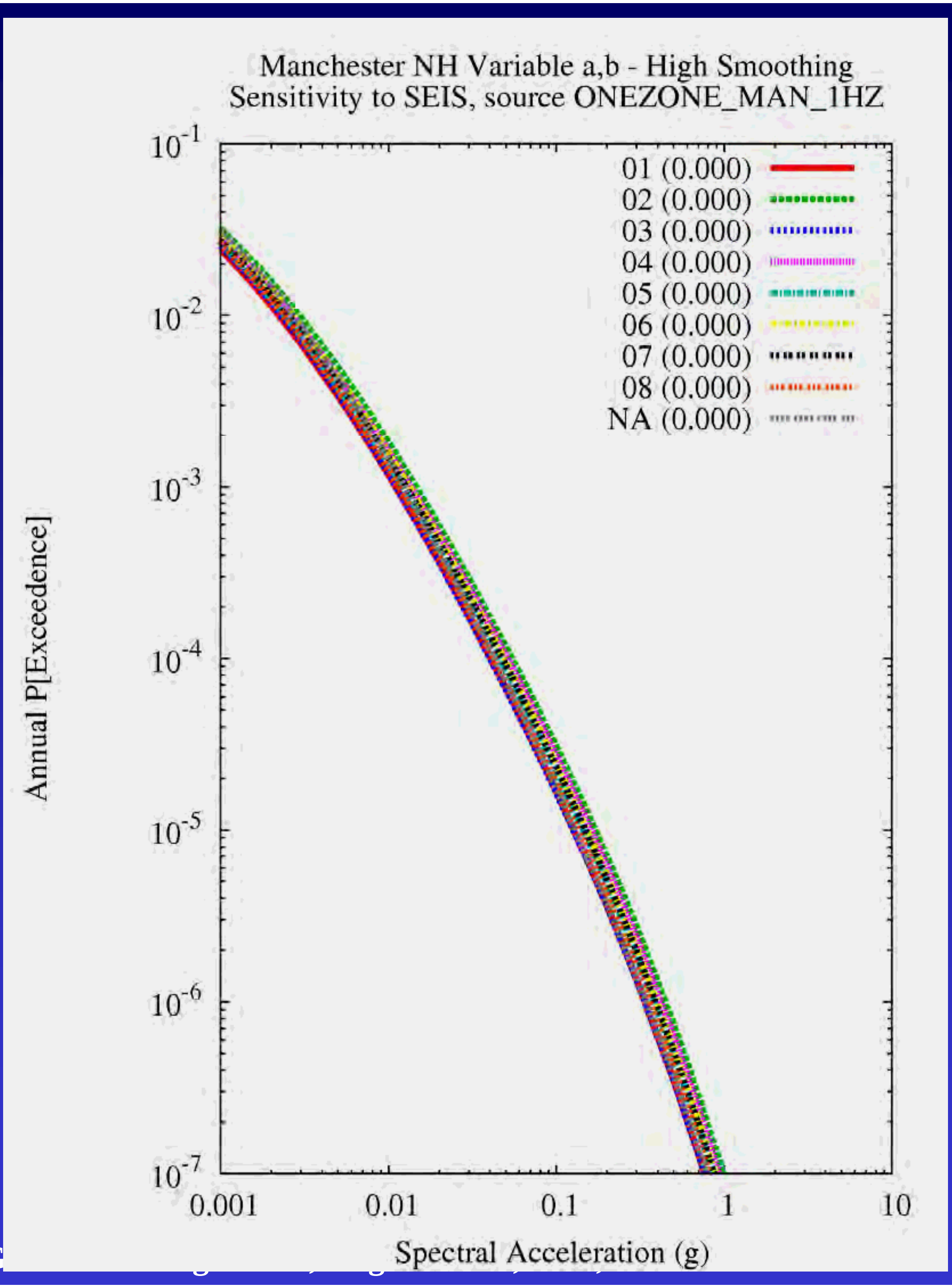
RISK ENGINEERING


Manchester NH Variable a,b - High Smoothing
Sensitivity to SEIS, source EXT_W_MAN_1HZ
NA (0.000)
01 (0.000)
02 (0.000)
03 (0.000)
04 (0.000)
05 (0.000)
06 (0.000)
07 (0.000)
08 (0.000)
Annual P[Exceedence]
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
0.001
0.01
0.1
1
10
Spectral Acceleration (g)



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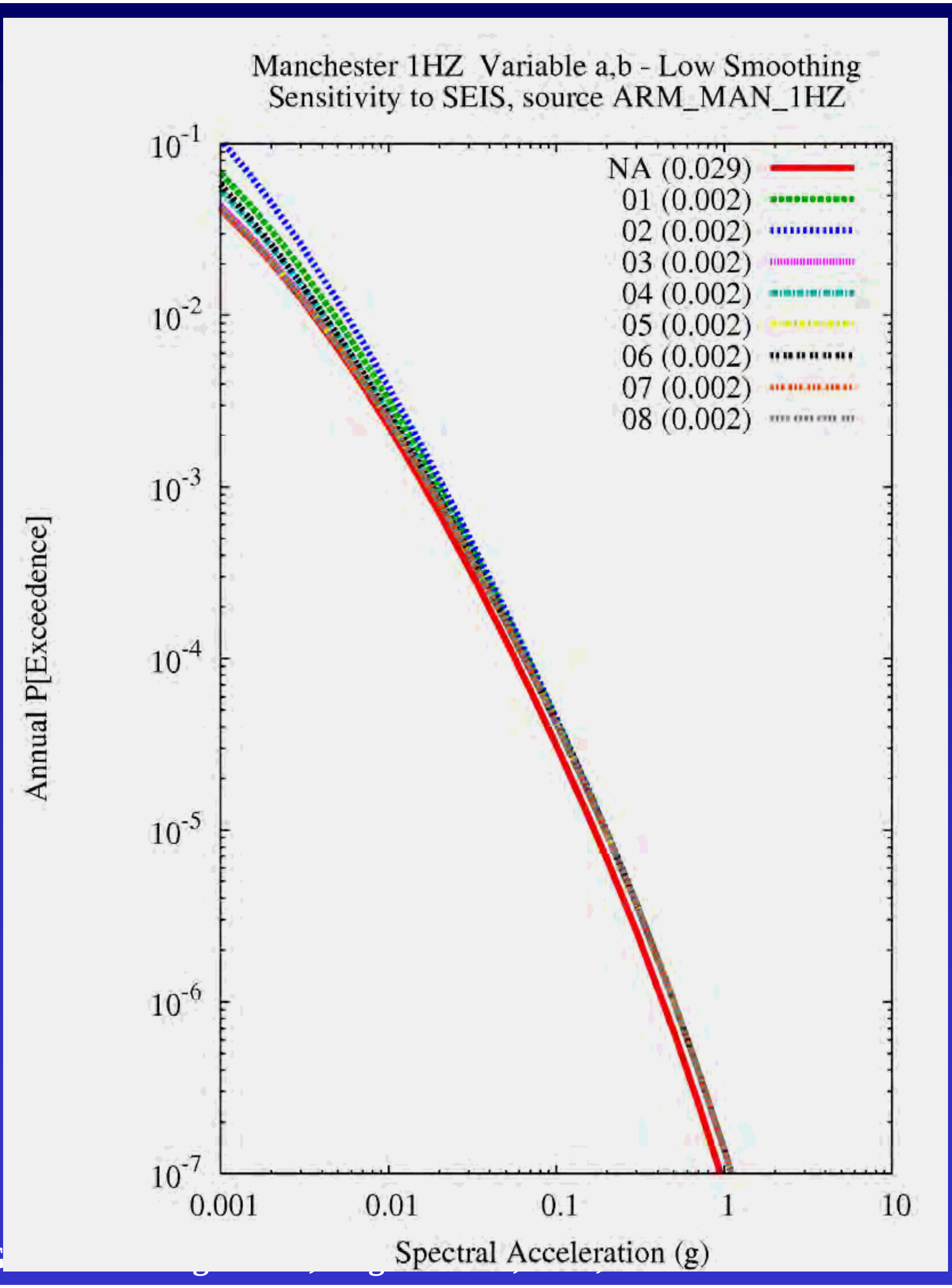

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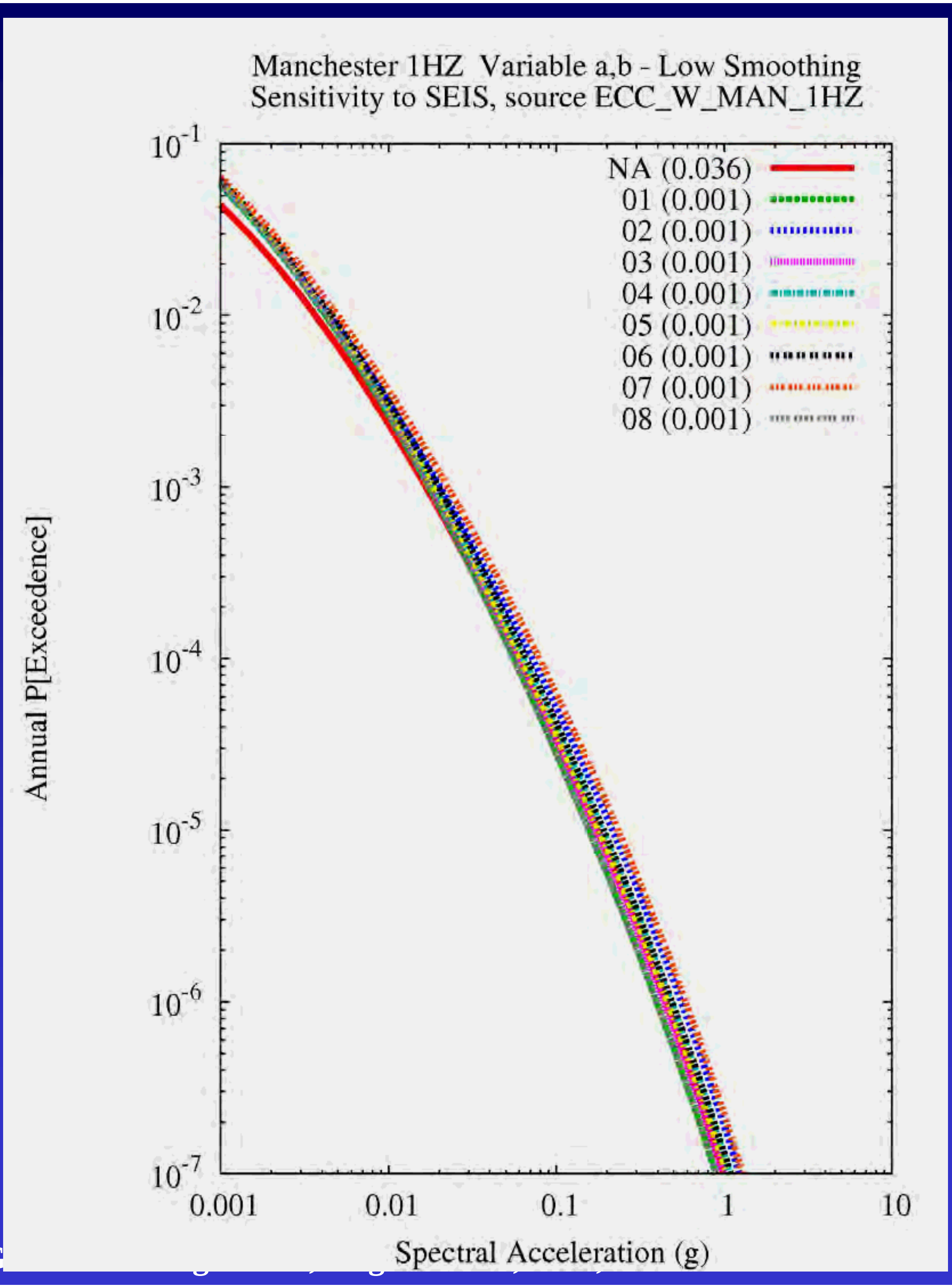
RISK
ENGINEERING



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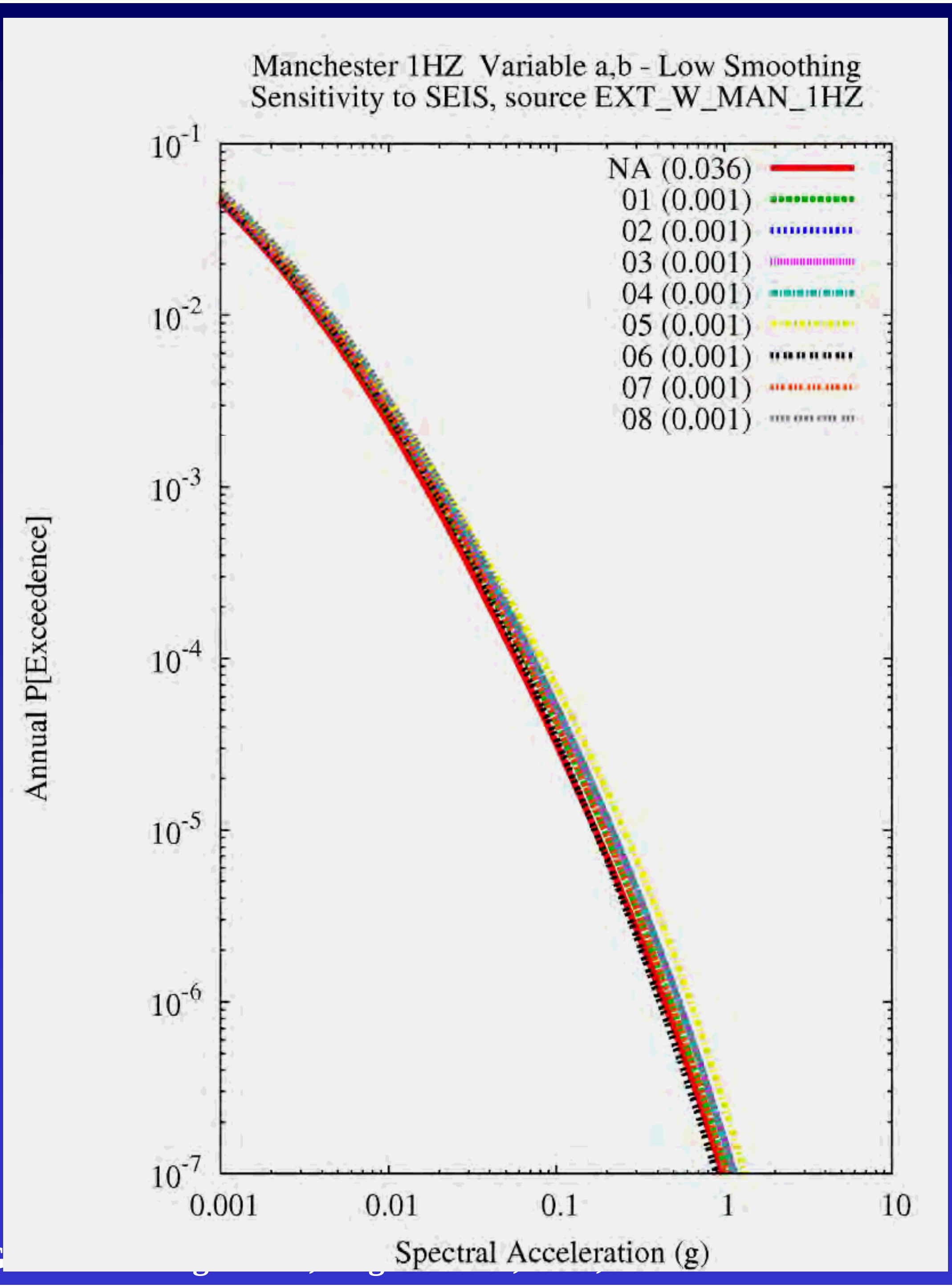
RISK
ENGINEERING



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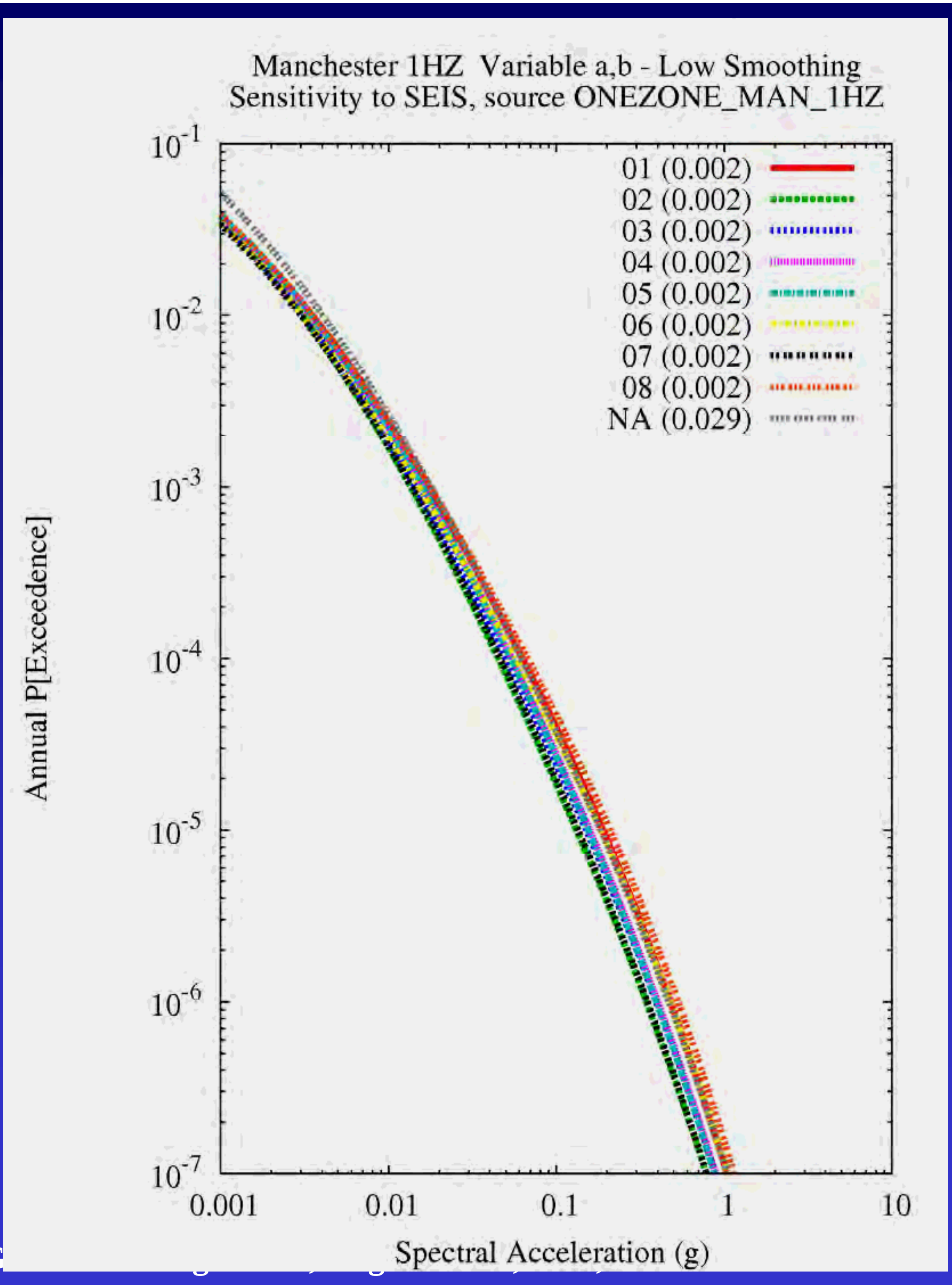
RISK ENGINEERING



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Summary for NE Site

- Major sources of uncertainty
  - – Mmax (for 1 Hz only; moderate)
  - – Recurrence parameters (moderate)

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Central Illinois Site

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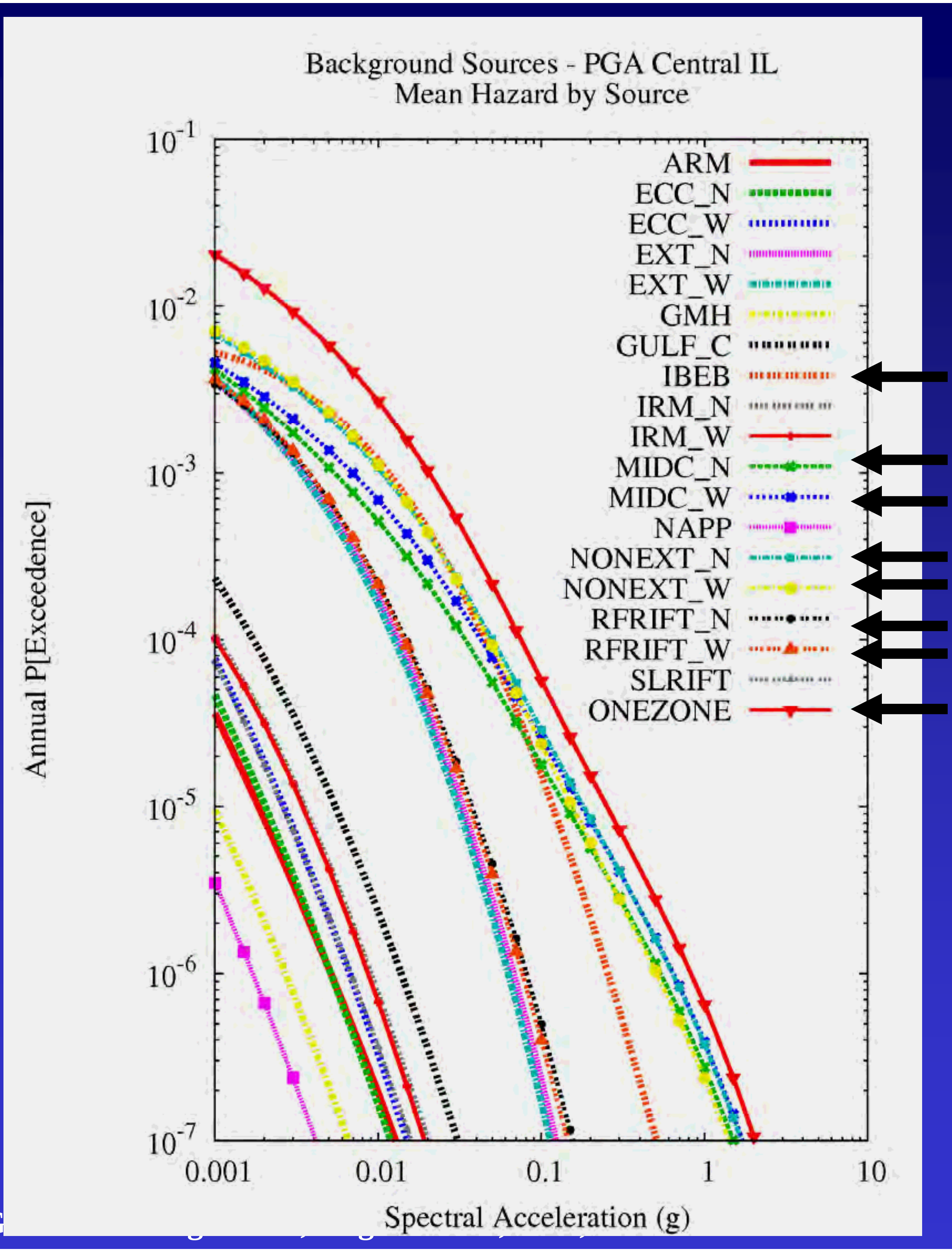

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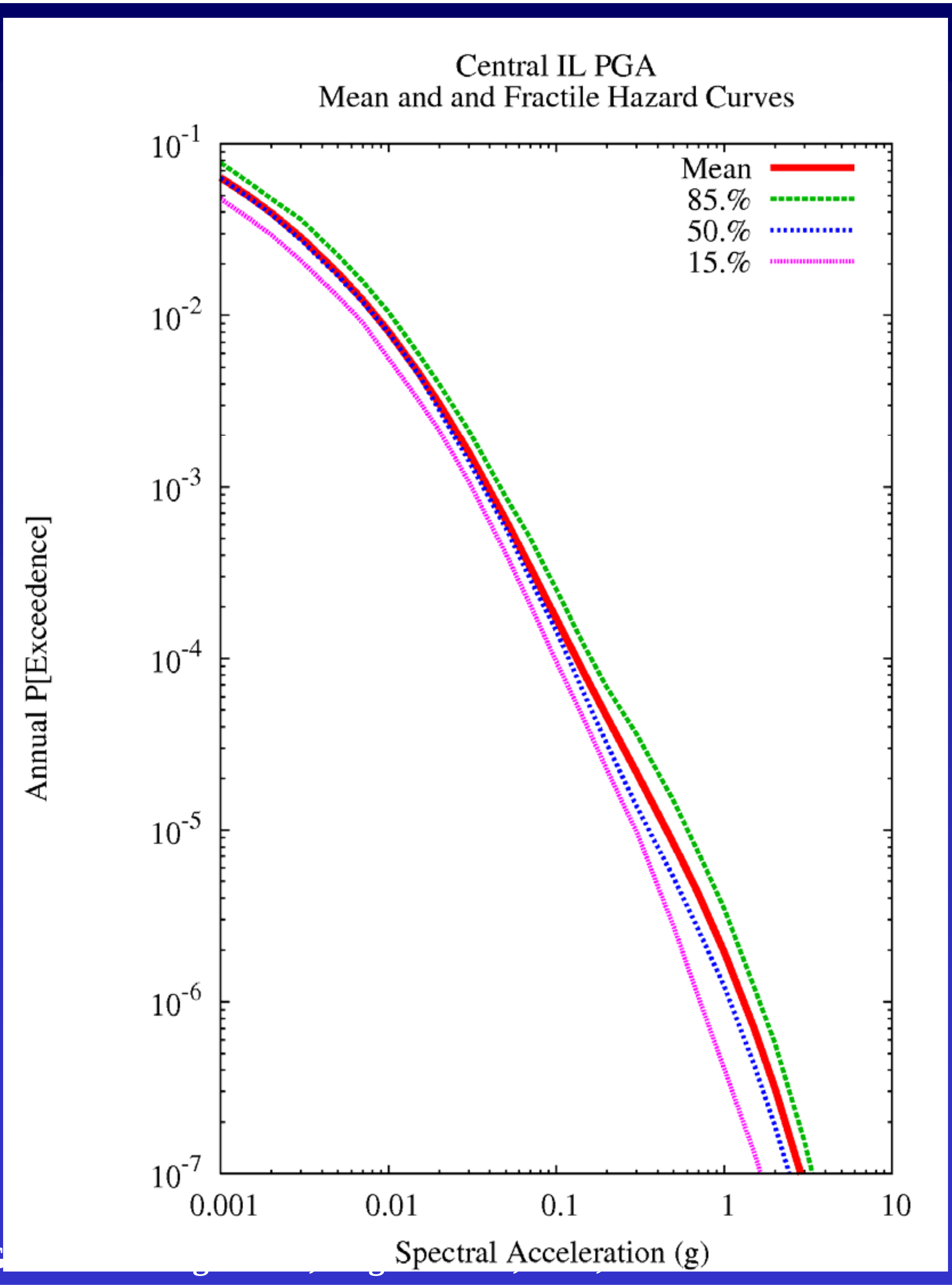
RISK ENGINEERING


Central IL PGA
Mean and and Fractile Hazard Curves

G

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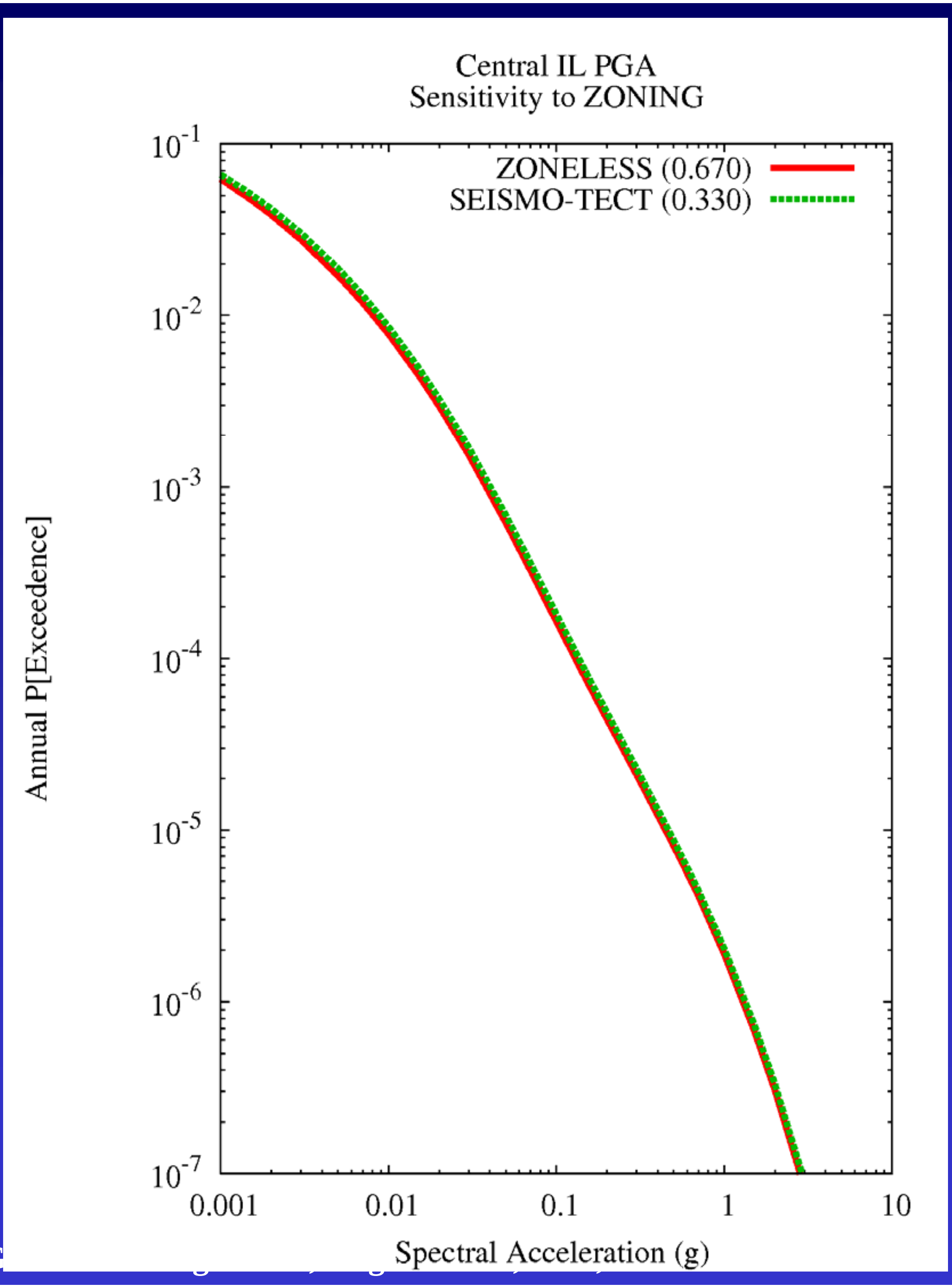
RISK ENGINEERING



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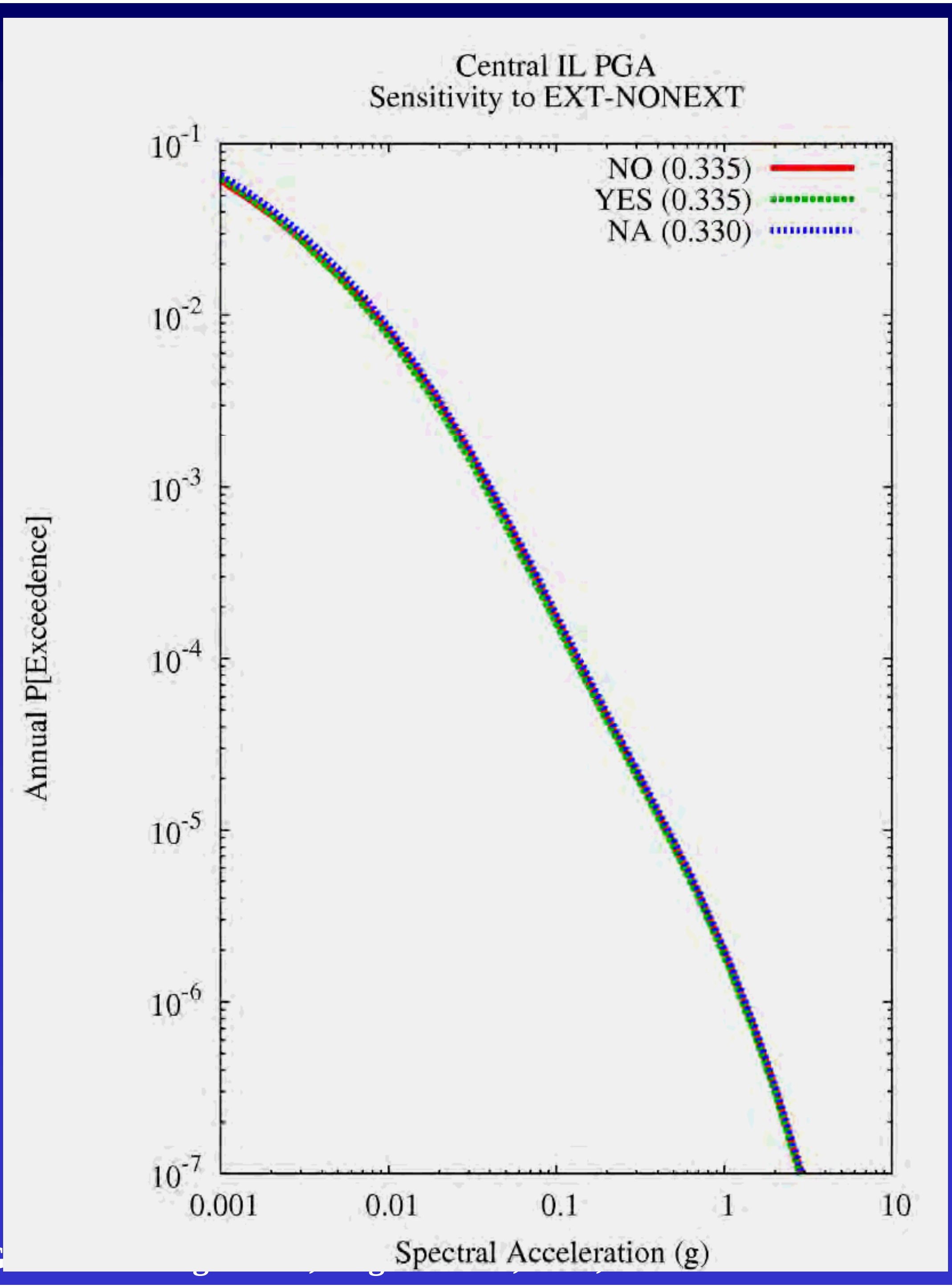

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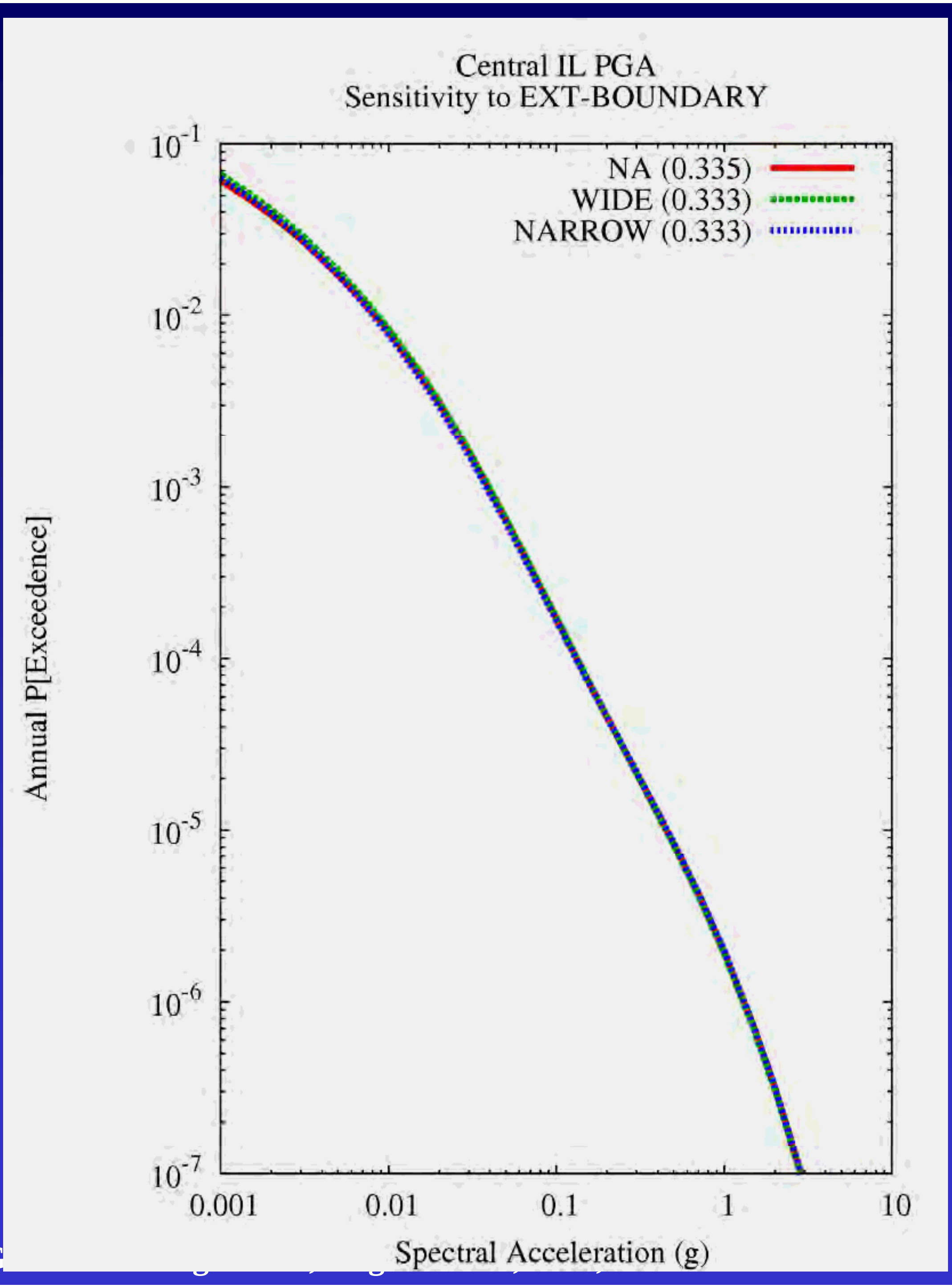
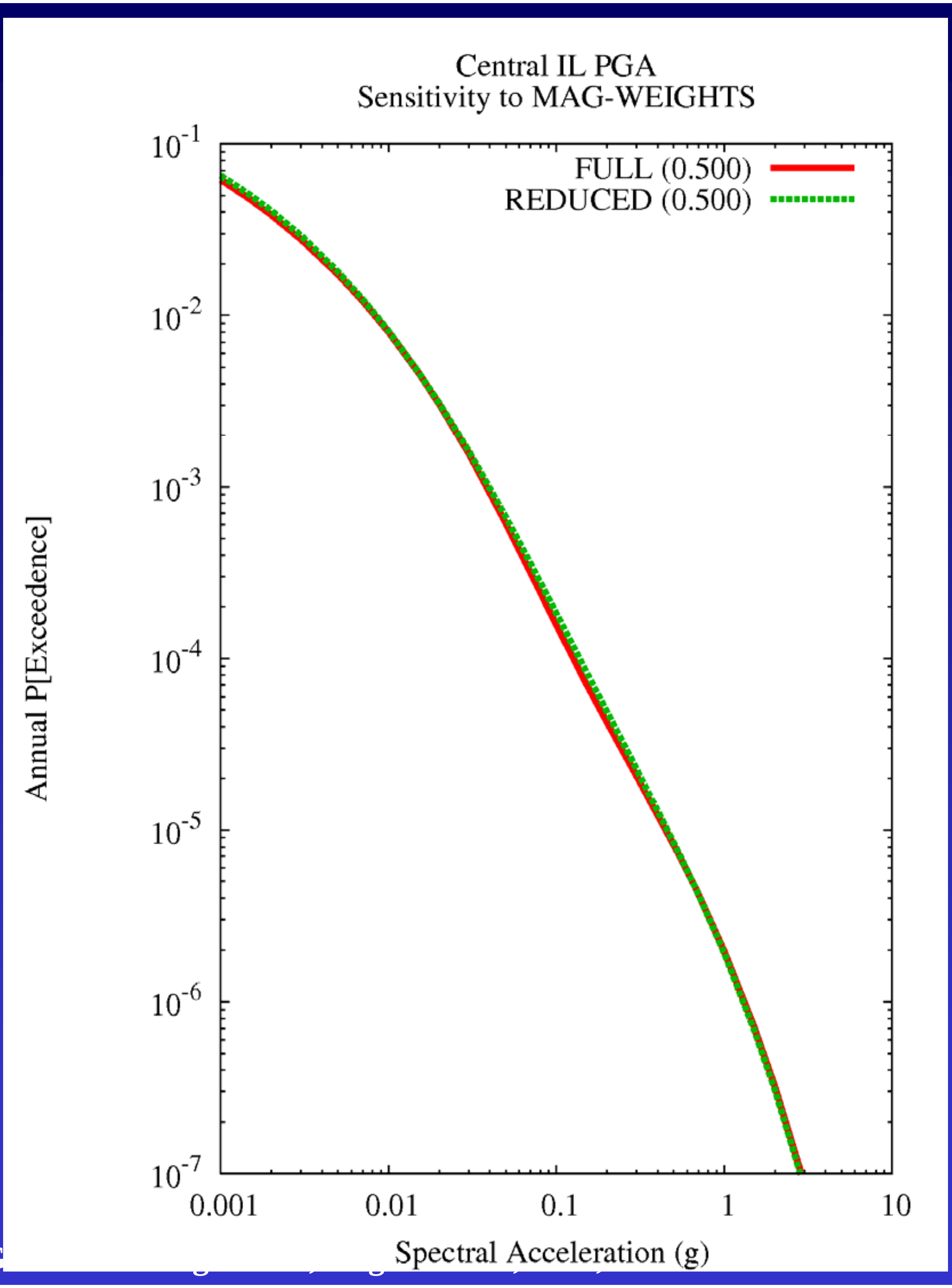
RISK ENGINEERING


Central IL PGA
Sensitivity to EXT-BOUNDARY
NA (0.335)
WIDE (0.333)
NARROW (0.333)
Annual P[Exceedence]
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
0.001
0.01
0.1
1
10
Spectral Acceleration (g)



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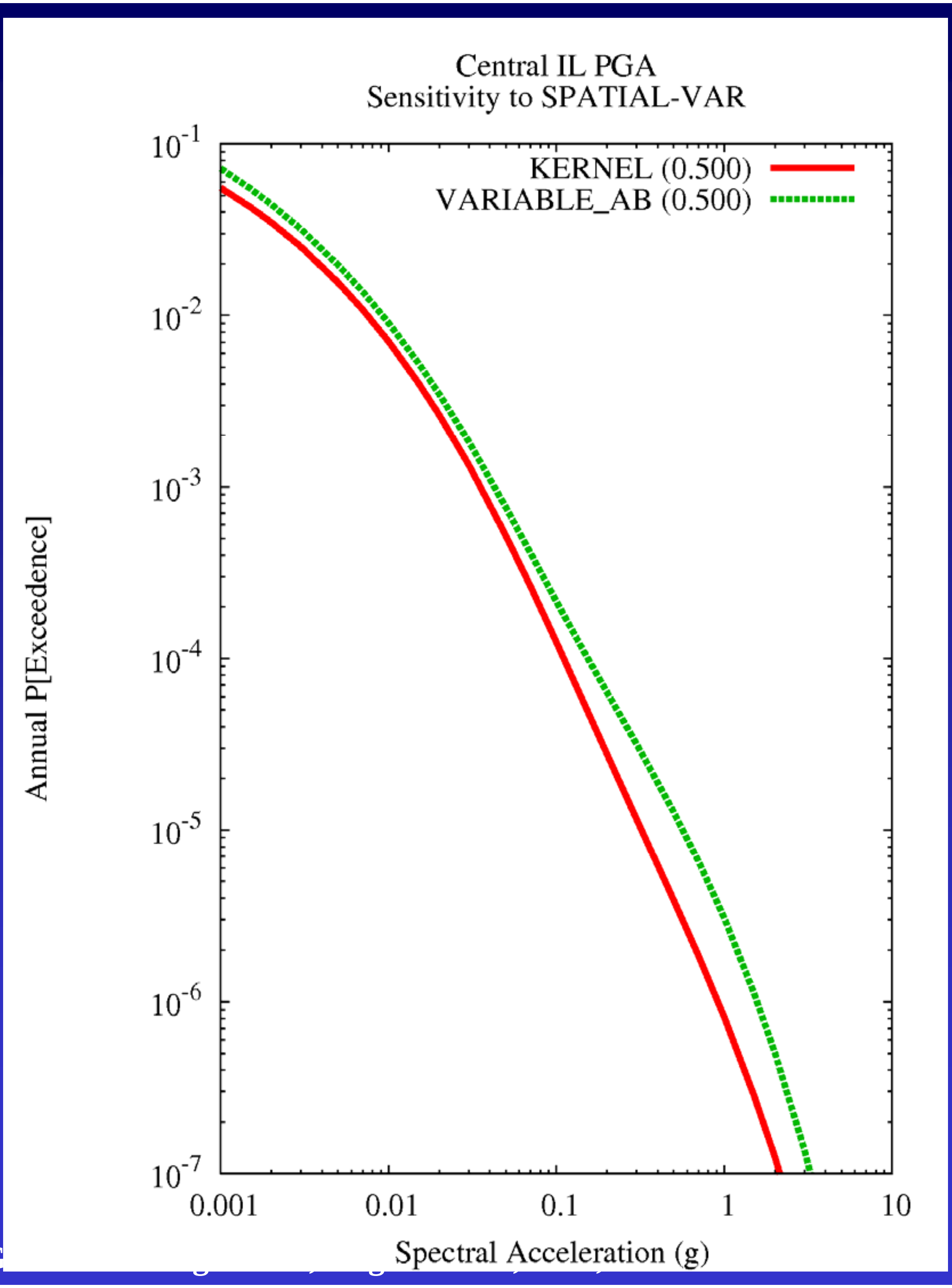
RISK ENGINEERING



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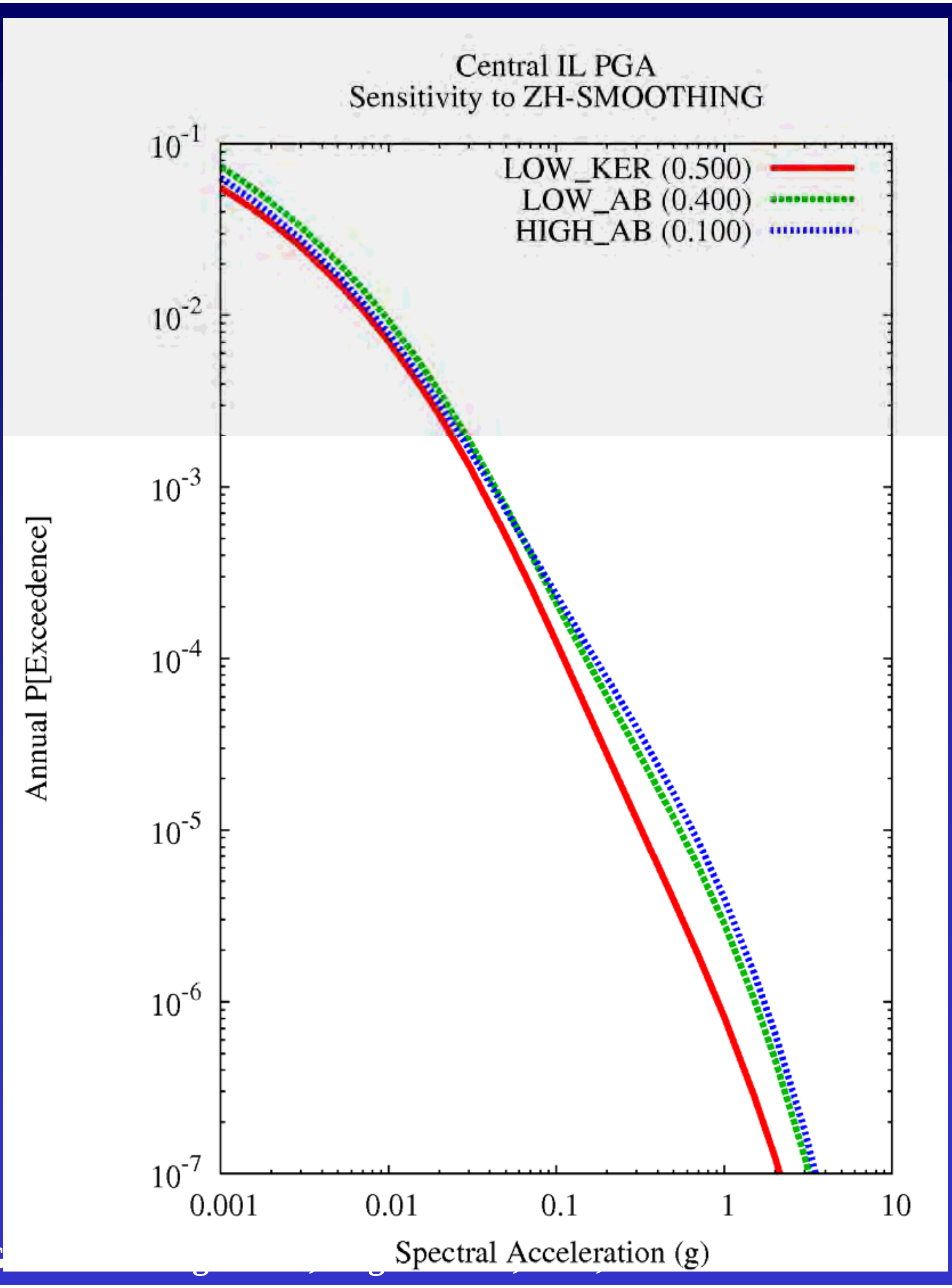
RISK ENGINEERING


Central IL PGA
Sensitivity to ZH-SMOOTHING

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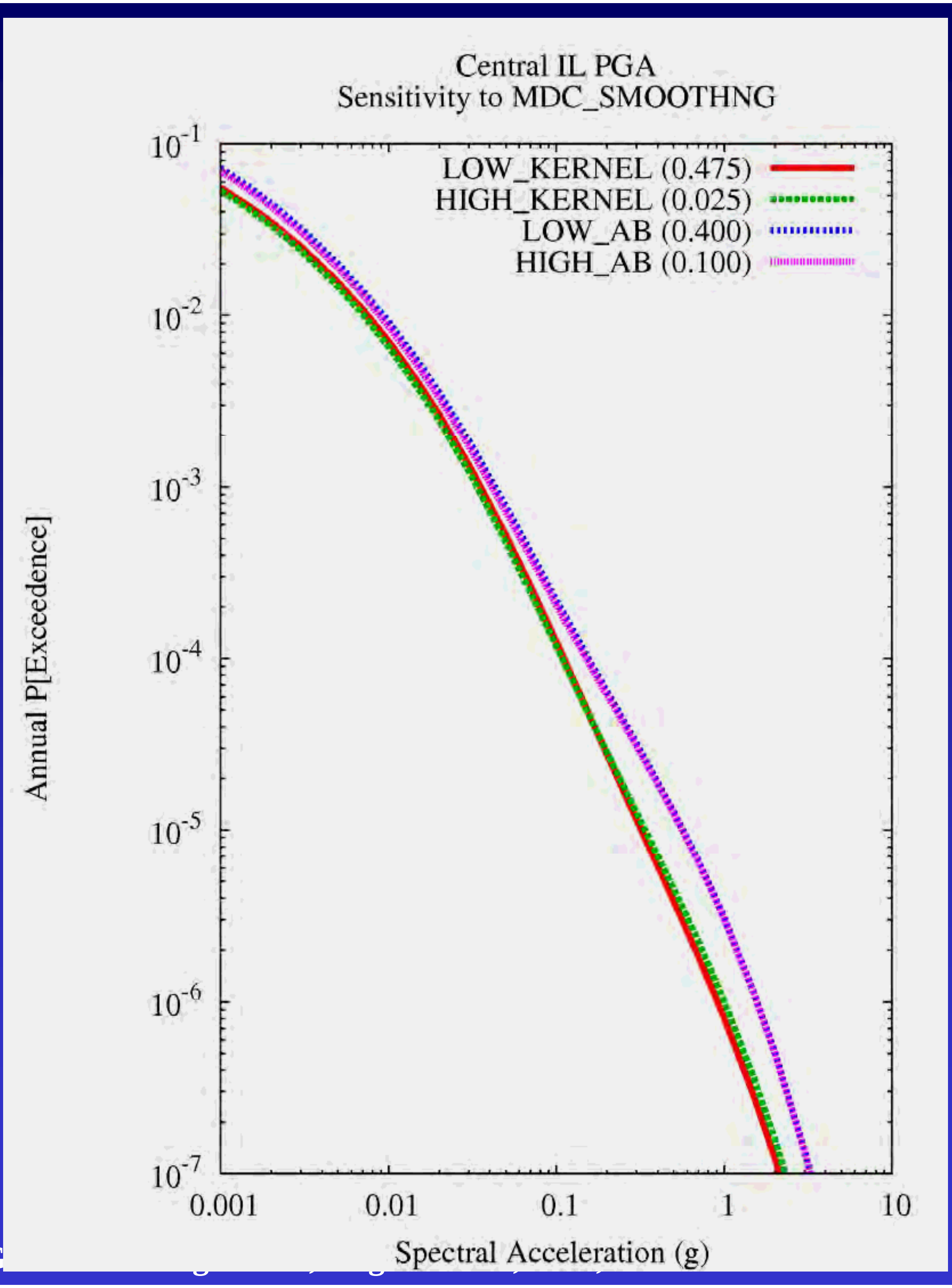
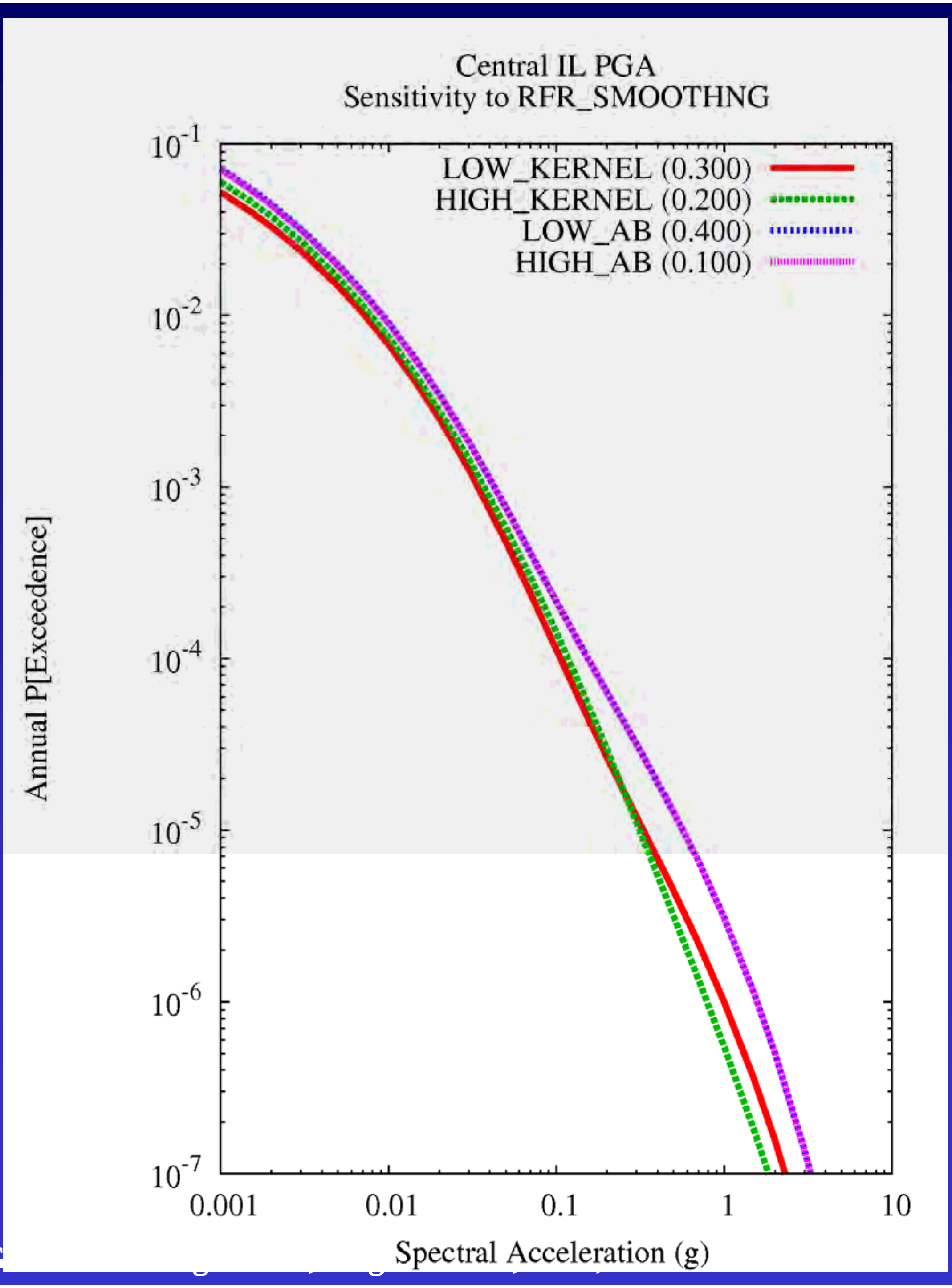
RISK ENGINEERING


Central IL PGA
Sensitivity to MDC_SMOOTHNG
LOW_KERNEL (0.475)
HIGH_KERNEL (0.025)
LOW_AB (0.400)
HIGH_AB (0.100)
Annual P[Exceedence]
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
0.001
0.01
0.1
1
10
Spectral Acceleration (g)



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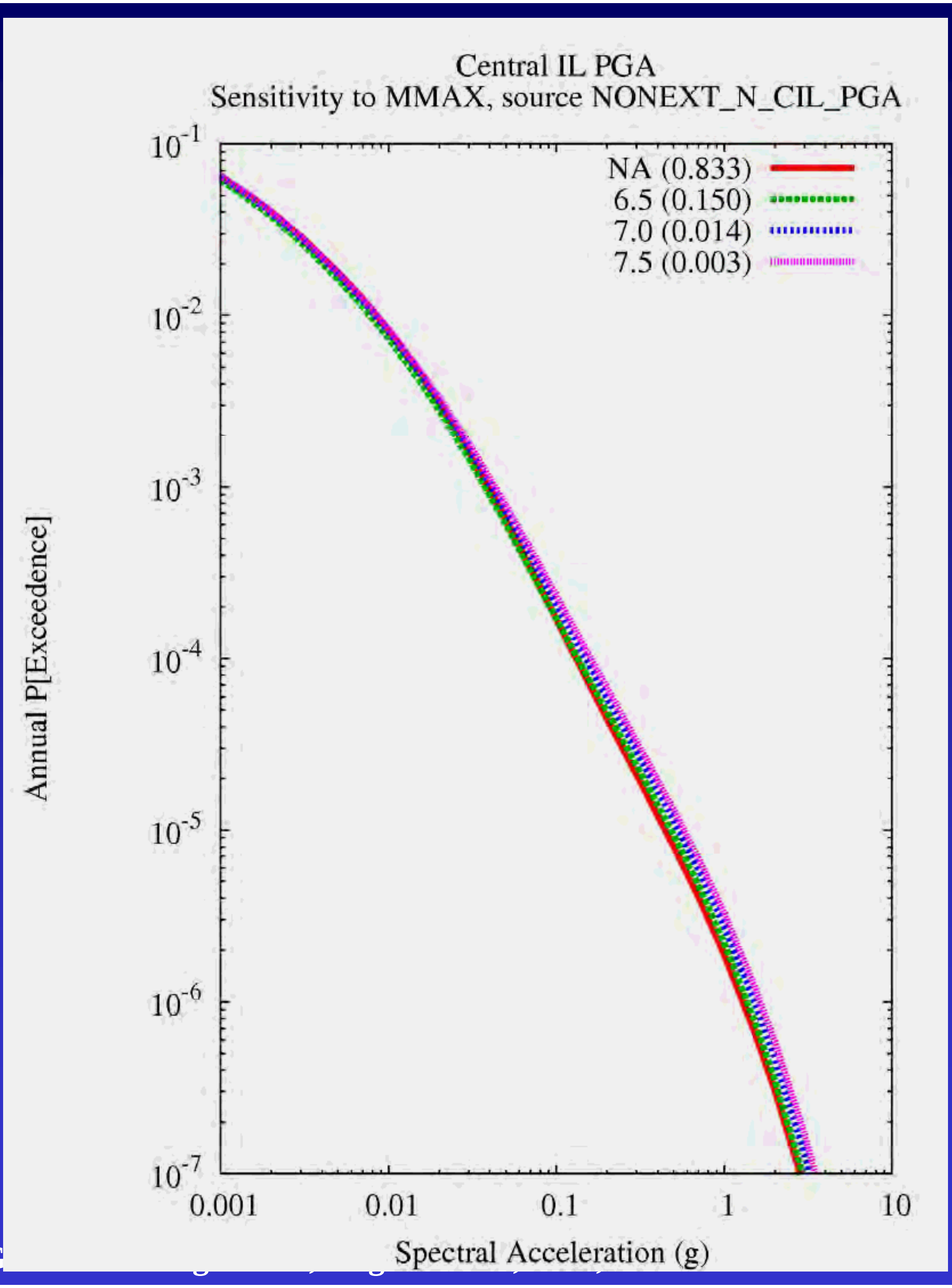

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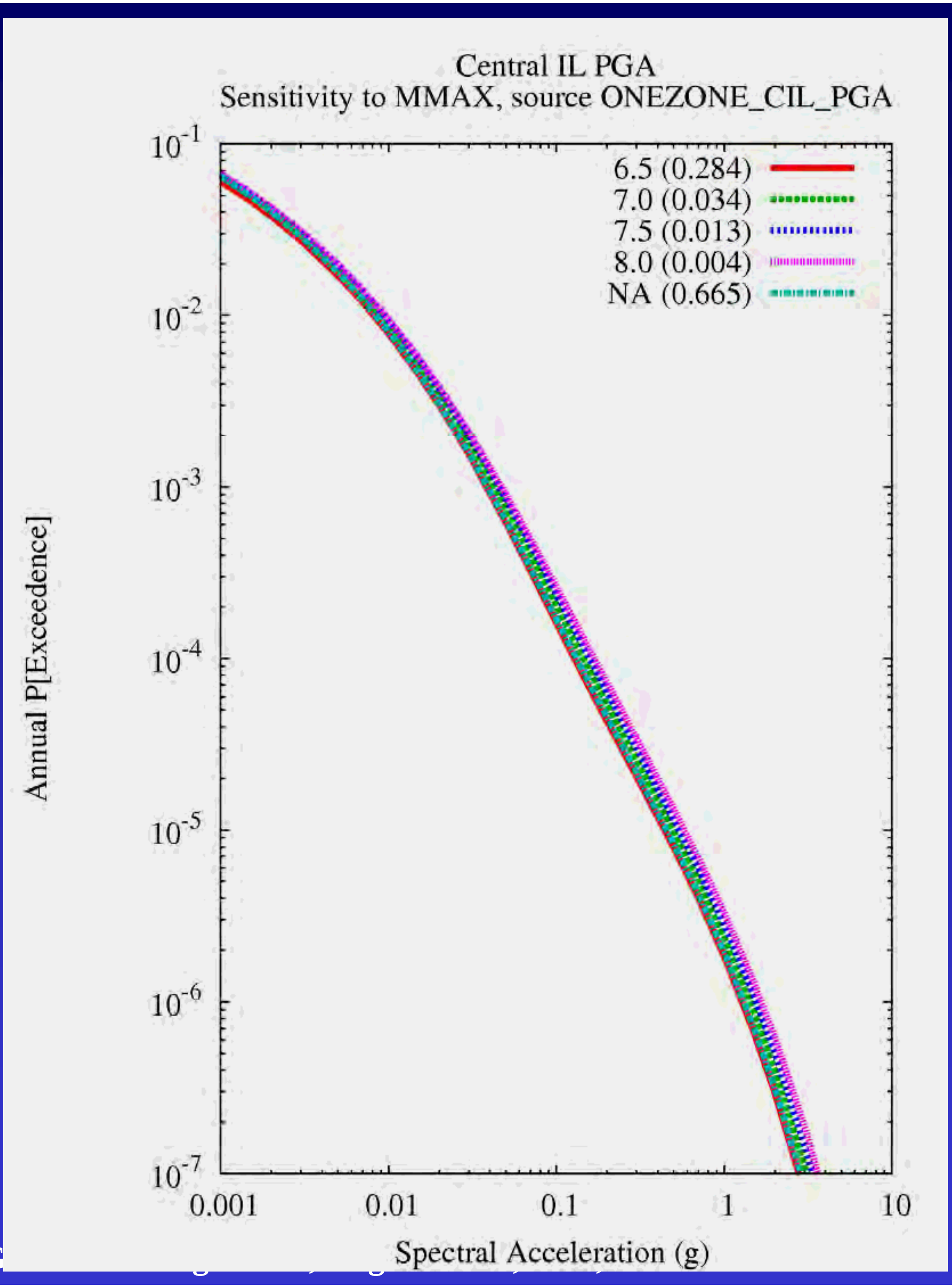
RISK ENGINEERING


Central IL PGA
Sensitivity to MMAX, source ONEZONE_CIL_PGA

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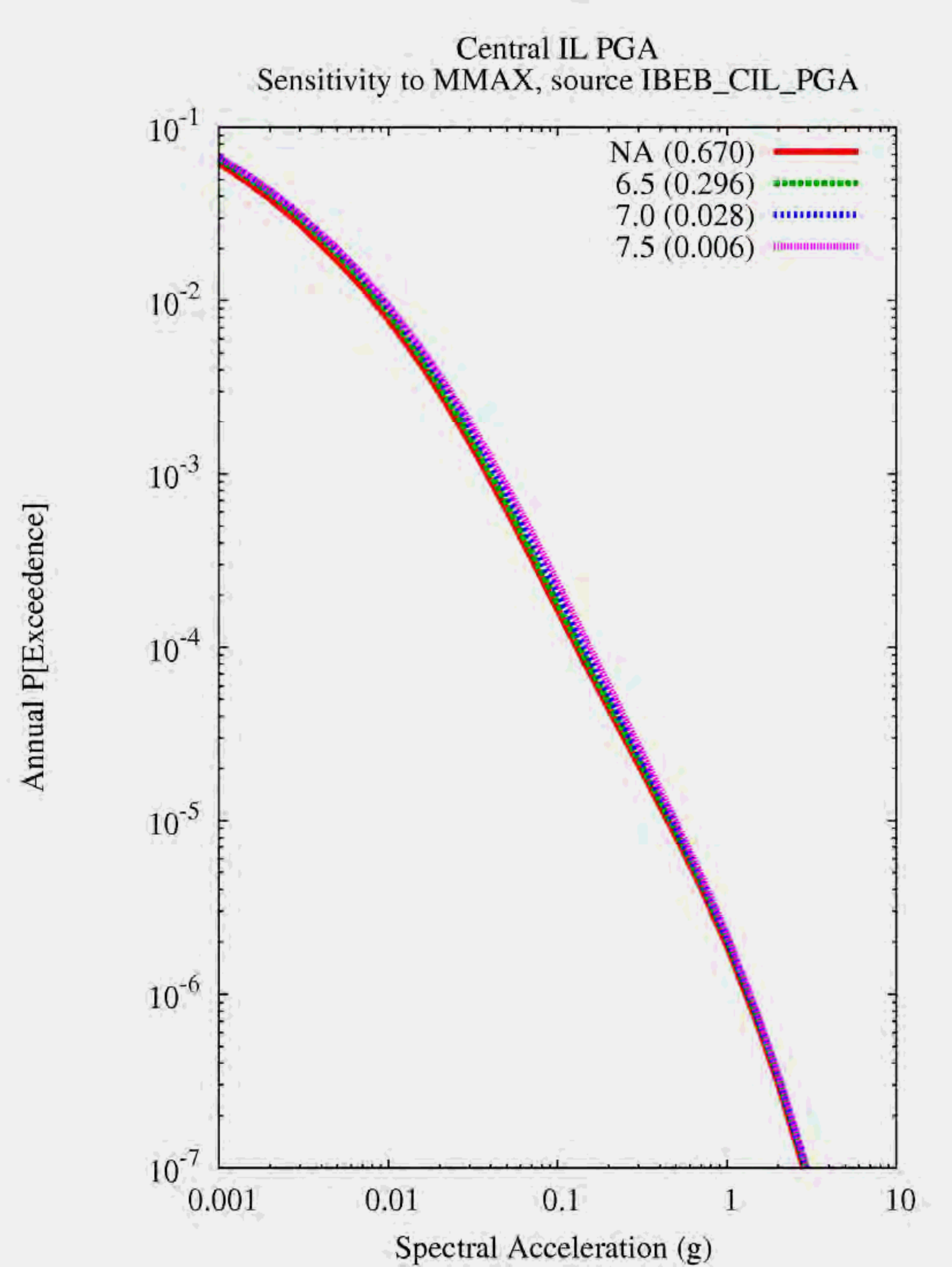

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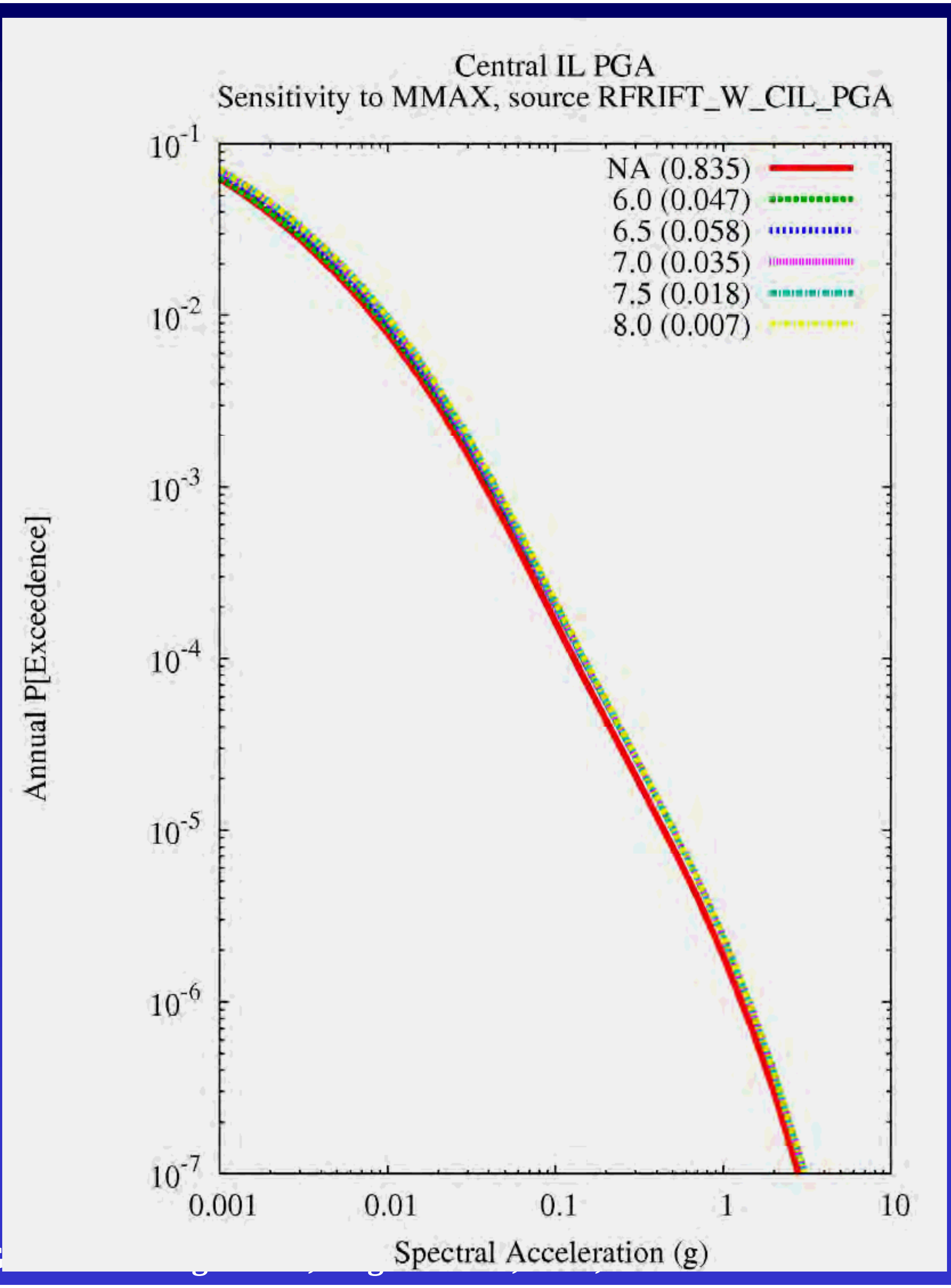
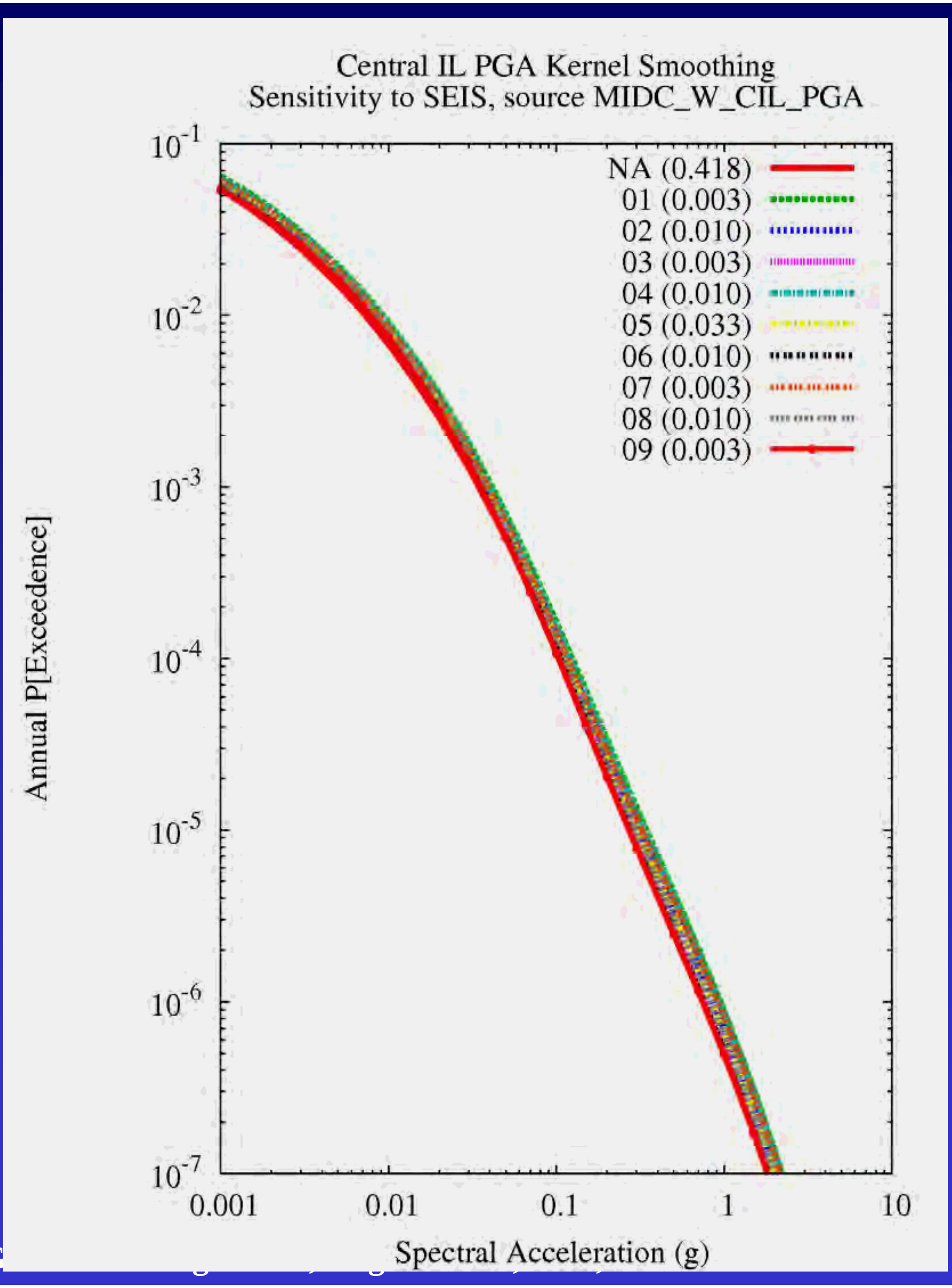
RISK ENGINEERING


Central IL PGA
Sensitivity to MMAX, source RFRIFT_W_CIL_PGA
NA (0.835)
6.0 (0.047)
6.5 (0.058)
7.0 (0.035)
7.5 (0.018)
8.0 (0.007)
Annual P[Exceedence]
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
0.001
0.01
0.1
1
10
Spectral Acceleration (g)



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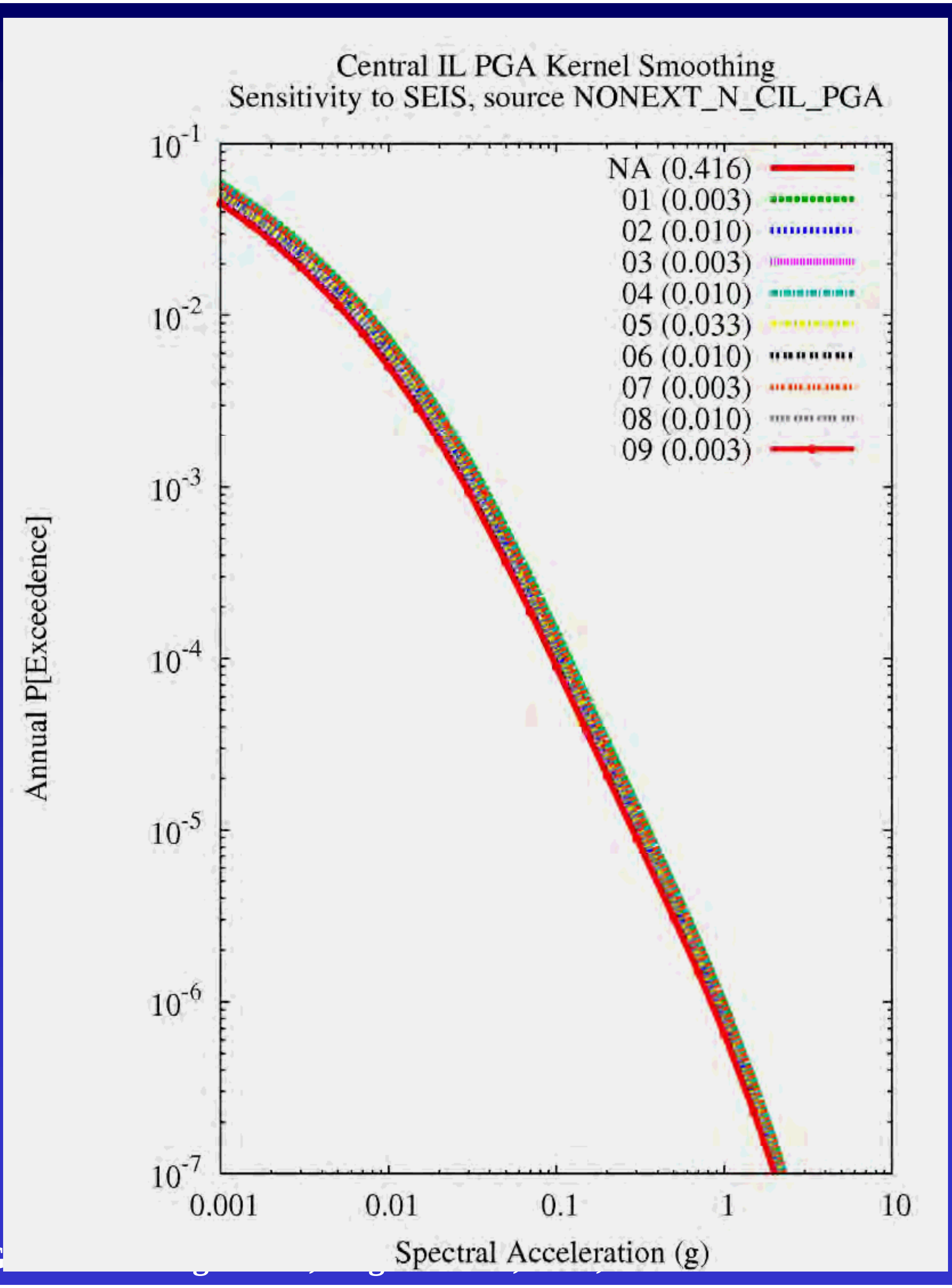
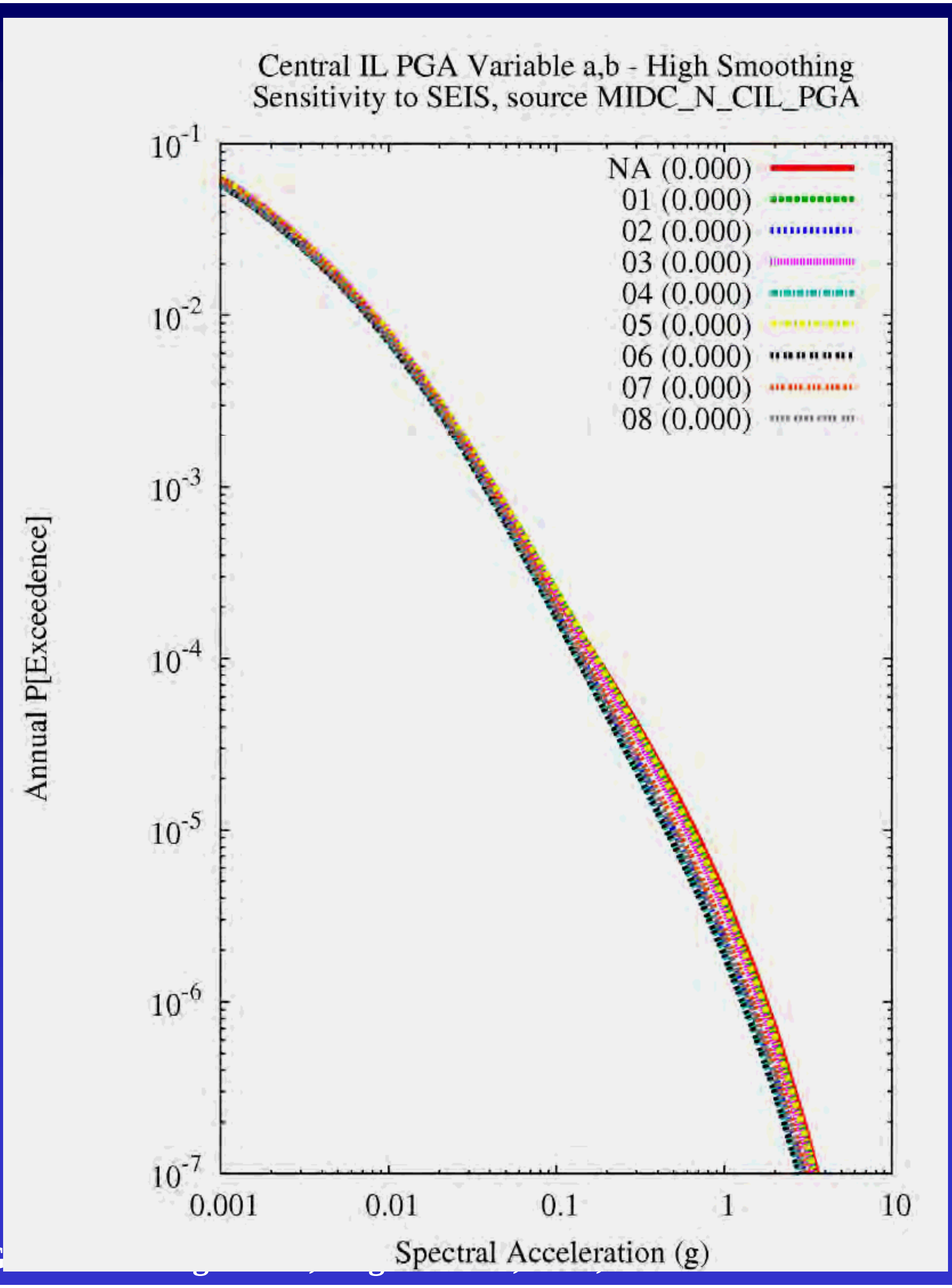
RISK ENGINEERING



William Lettis & Associates, Inc.

RISK ENGINEERING



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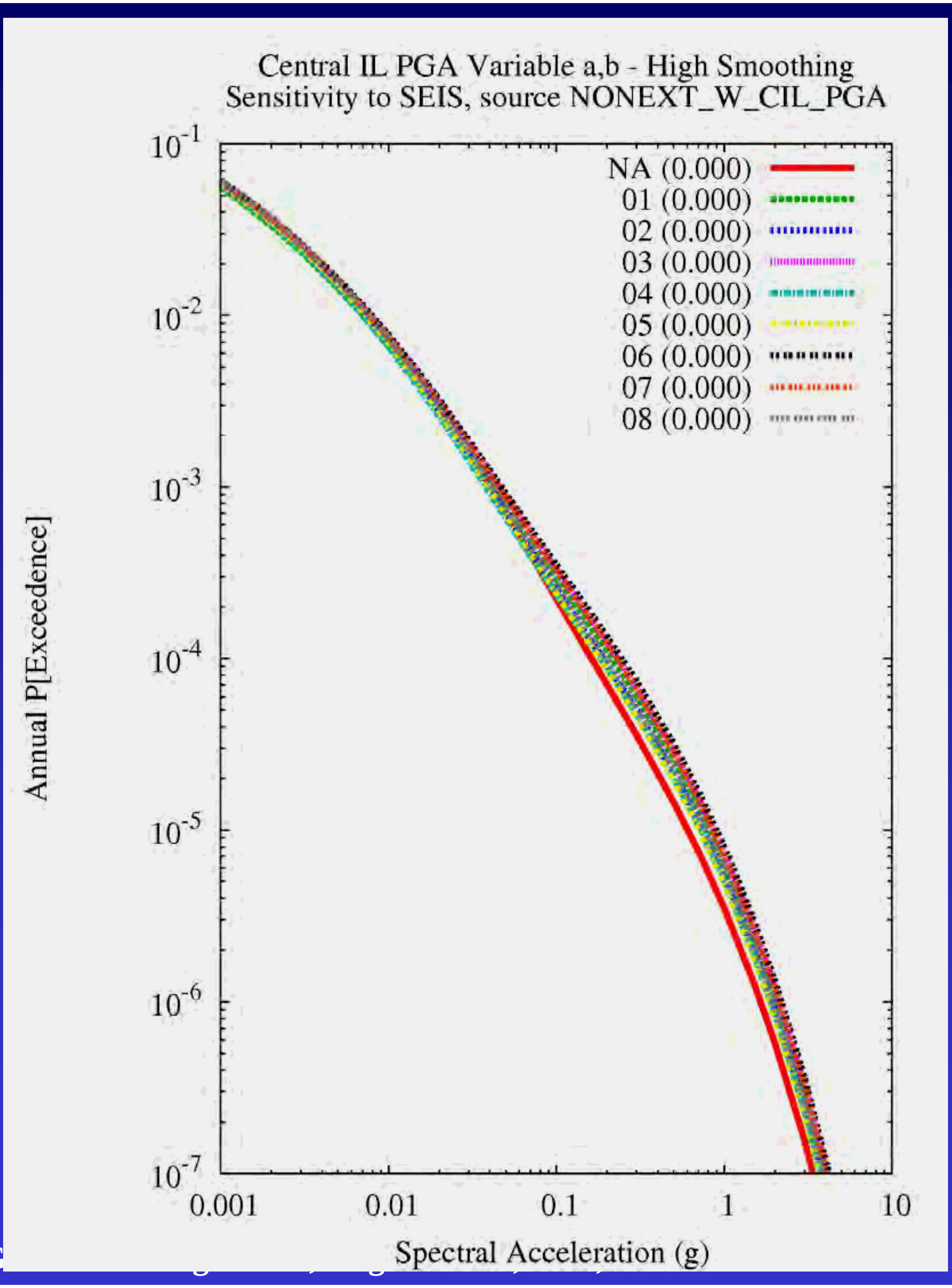
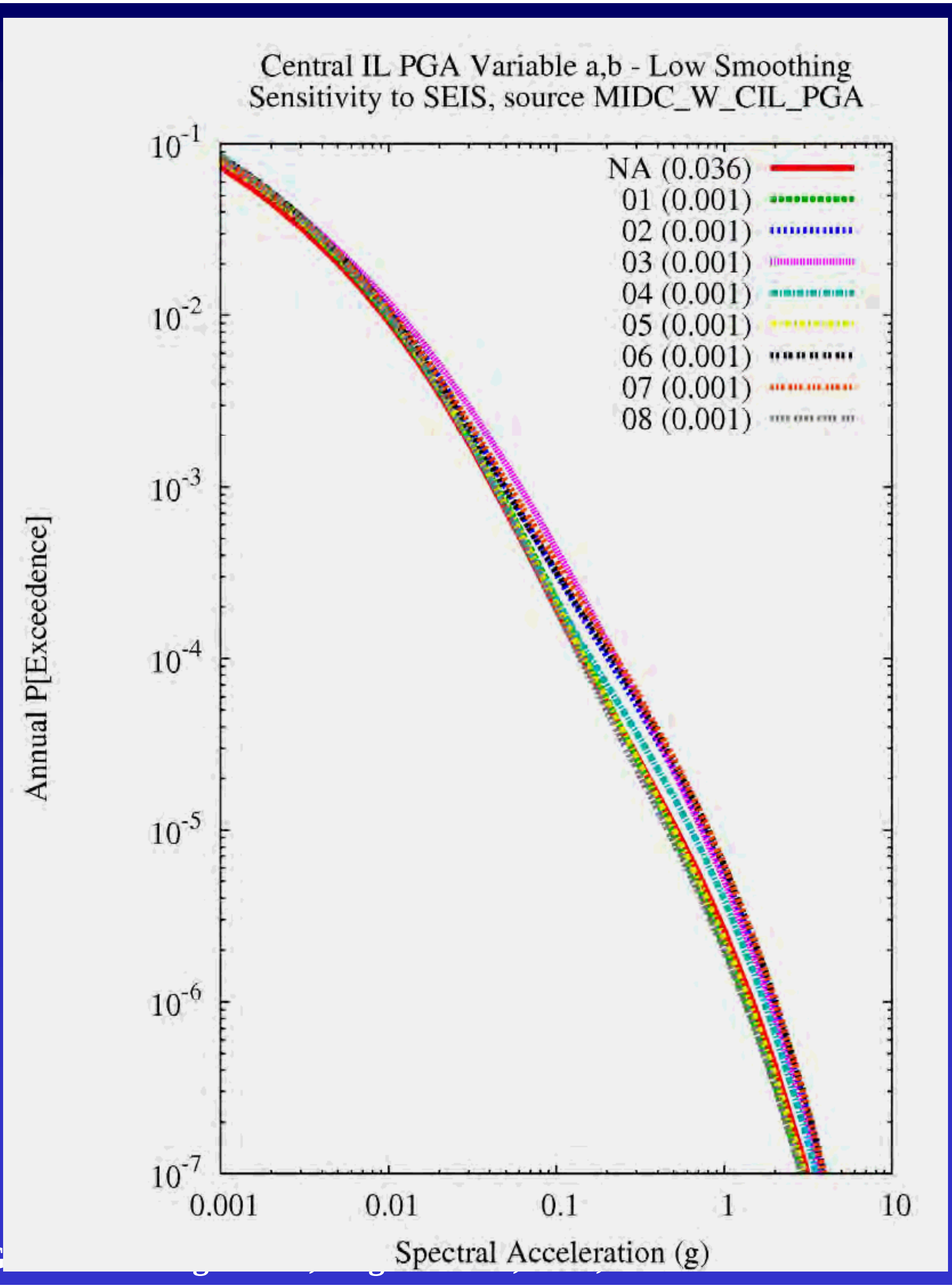
RISK ENGINEERING


Central IL PGA Variable a,b - High Smoothing
Sensitivity to SEIS, source NONEXT_W_CIL_PGA
Annual P[Exceedence]
Spectral Acceleration (g)
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
0.001
0.01
0.1
1
10
NA (0.000)
01 (0.000)
02 (0.000)
03 (0.000)
04 (0.000)
05 (0.000)
06 (0.000)
07 (0.000)
08 (0.000)



Central IL PGA Variable a,b - Low Smoothing
Sensitivity to SEIS, source MIDC_W_CIL_PGA

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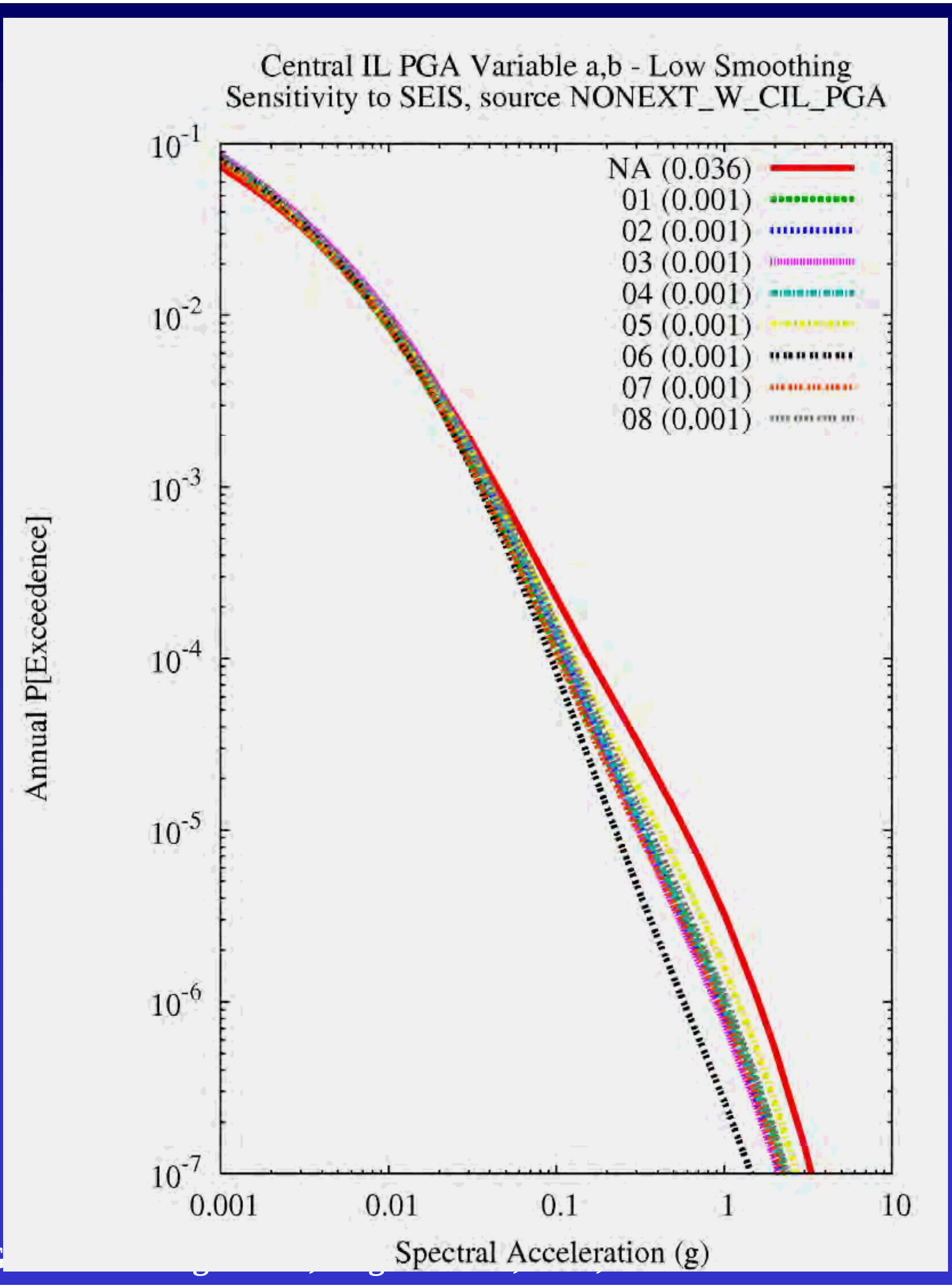
RISK ENGINEERING


Central IL PGA Variable a,b - Low Smoothing
Sensitivity to SEIS, source NONEXT_W_CIL_PGA
NA (0.036)
01 (0.001)
02 (0.001)
03 (0.001)
04 (0.001)
05 (0.001)
06 (0.001)
07 (0.001)
08 (0.001)
Annual P[Exceedence]
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
0.001
0.01
0.1
1
10
Spectral Acceleration (g)

Central IL 1 Hz

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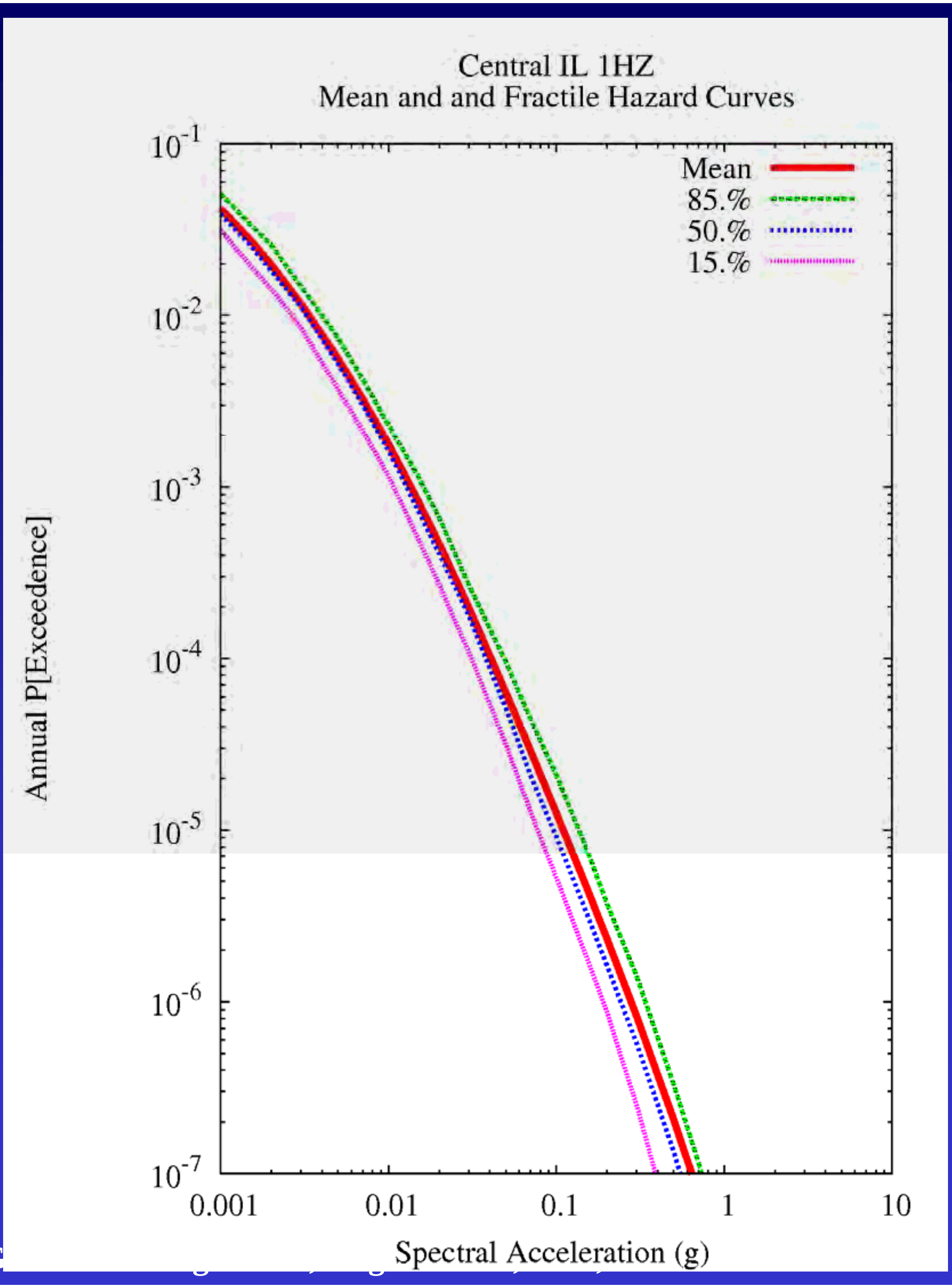
RISK ENGINEERING



Central IL 1HZ
Mean and and Fractile Hazard Curves

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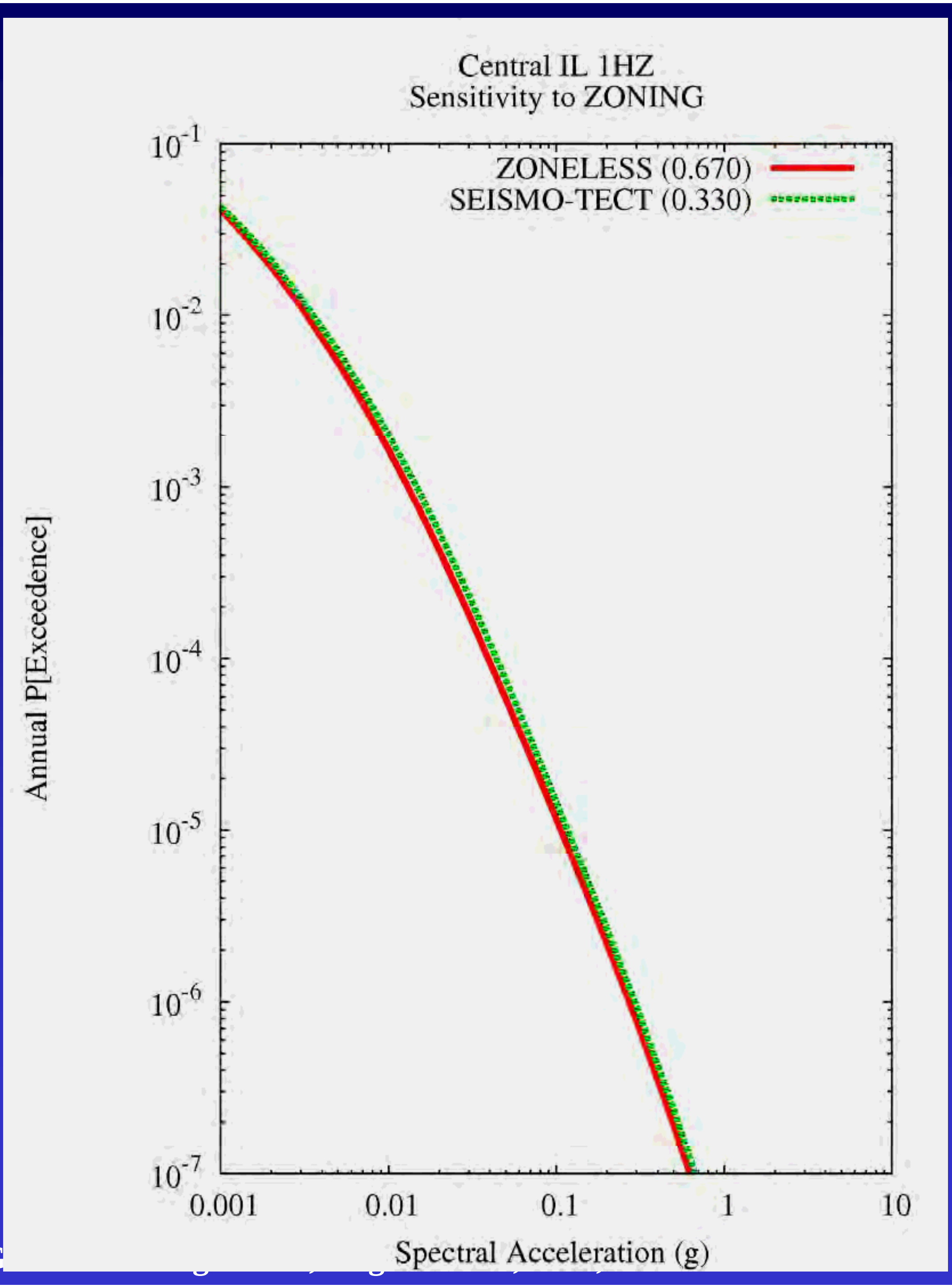
RISK
ENGINEERING



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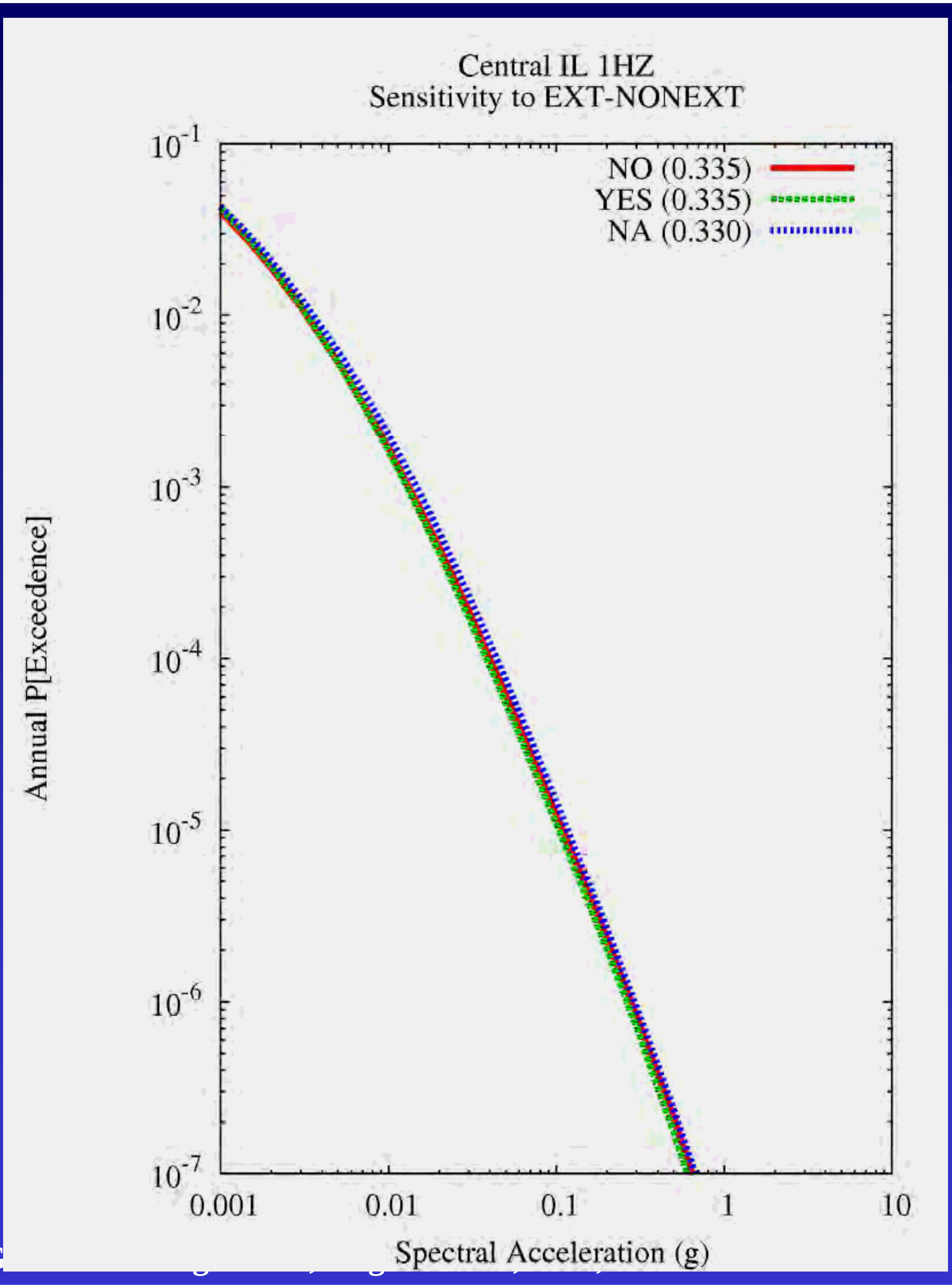
RISK ENGINEERING



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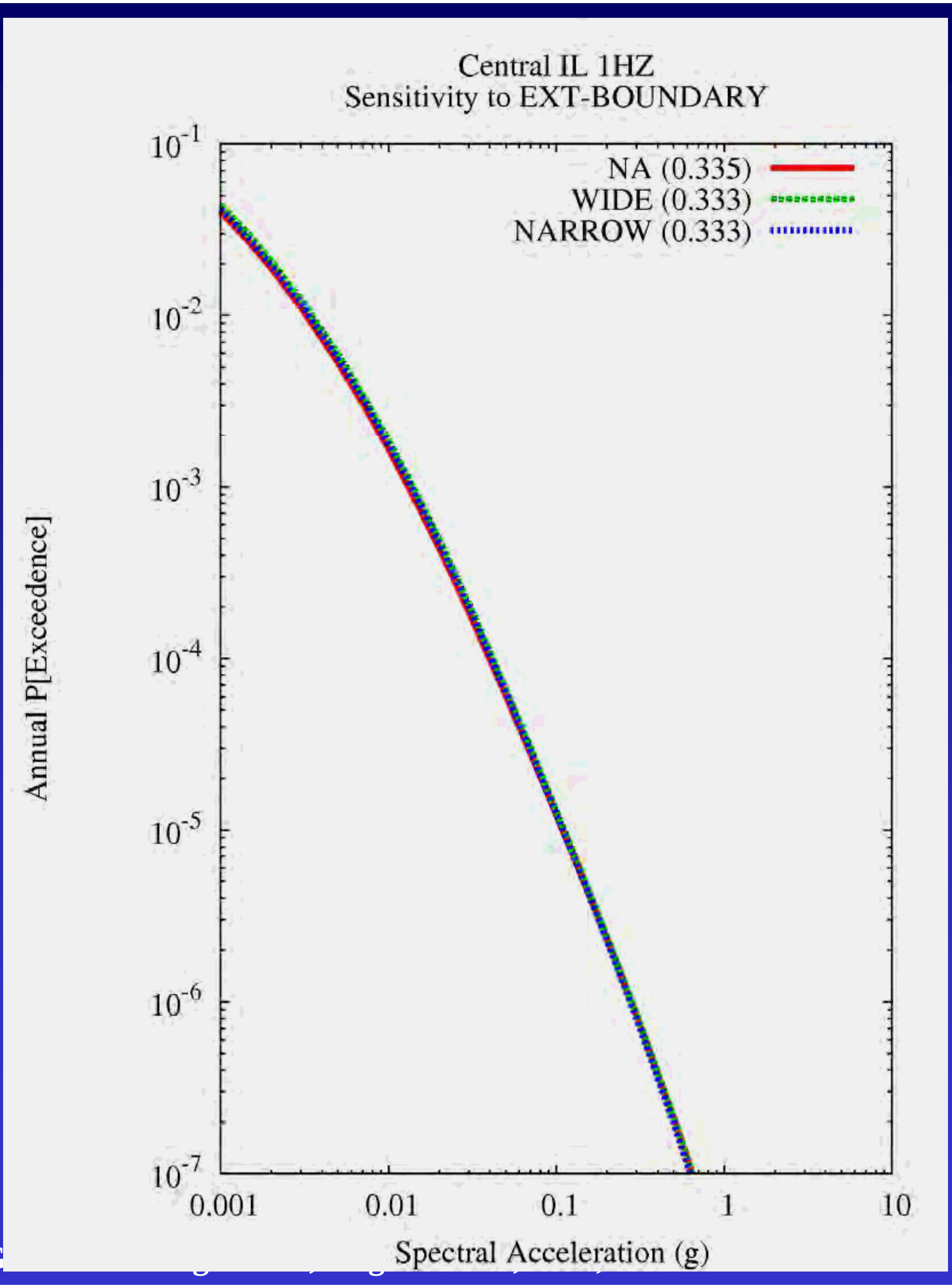
RISK ENGINEERING



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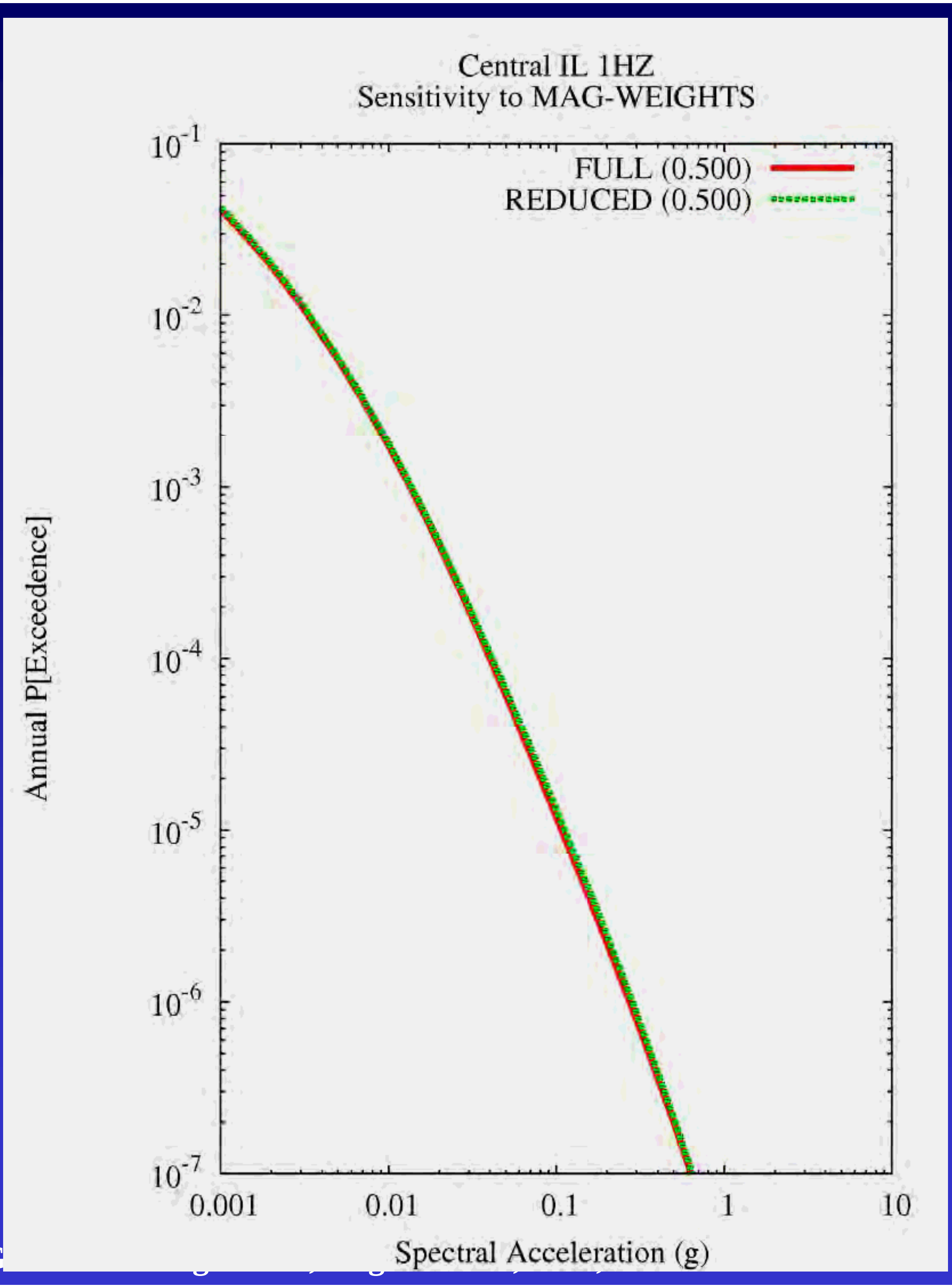
RISK ENGINEERING



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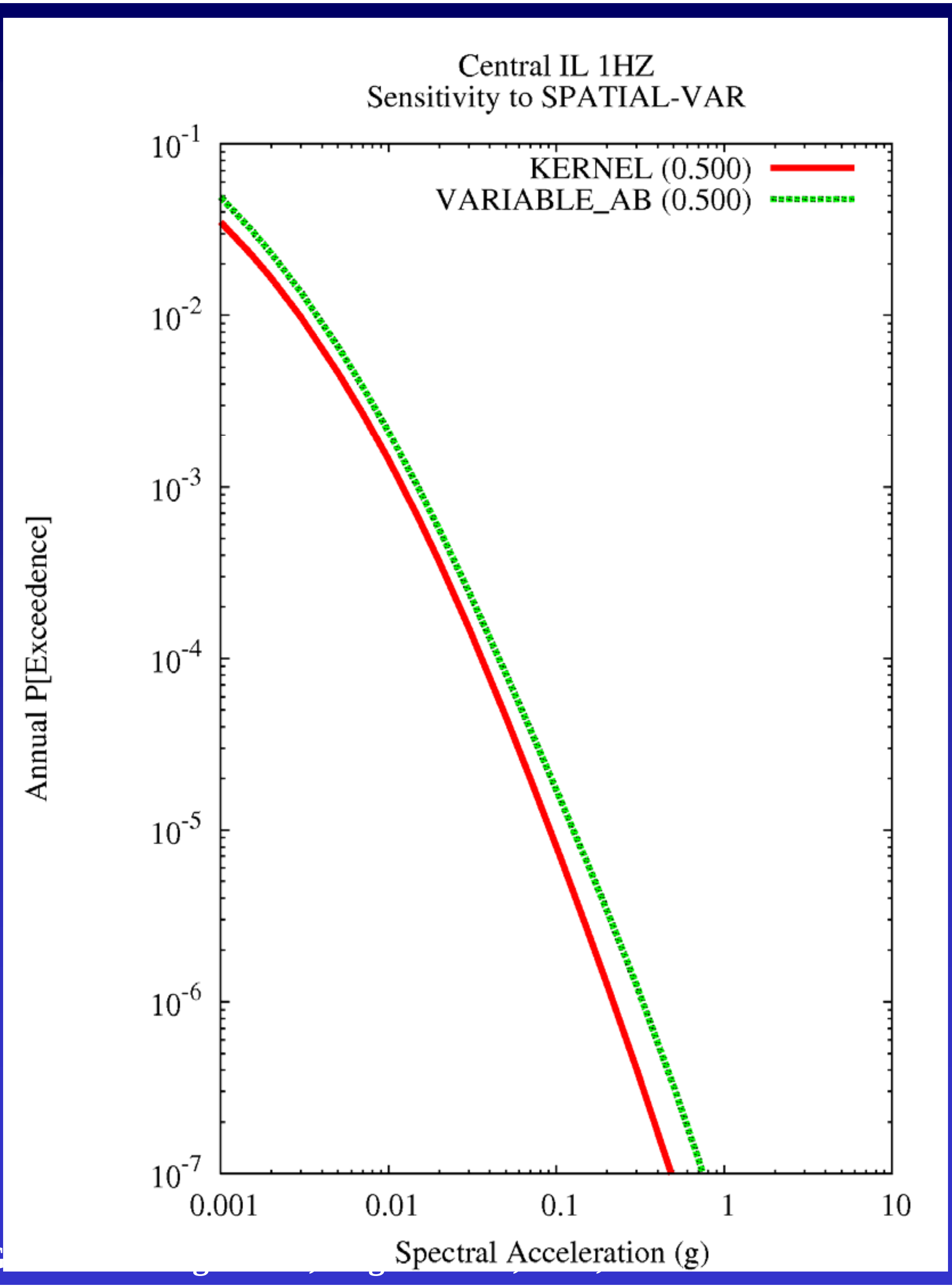
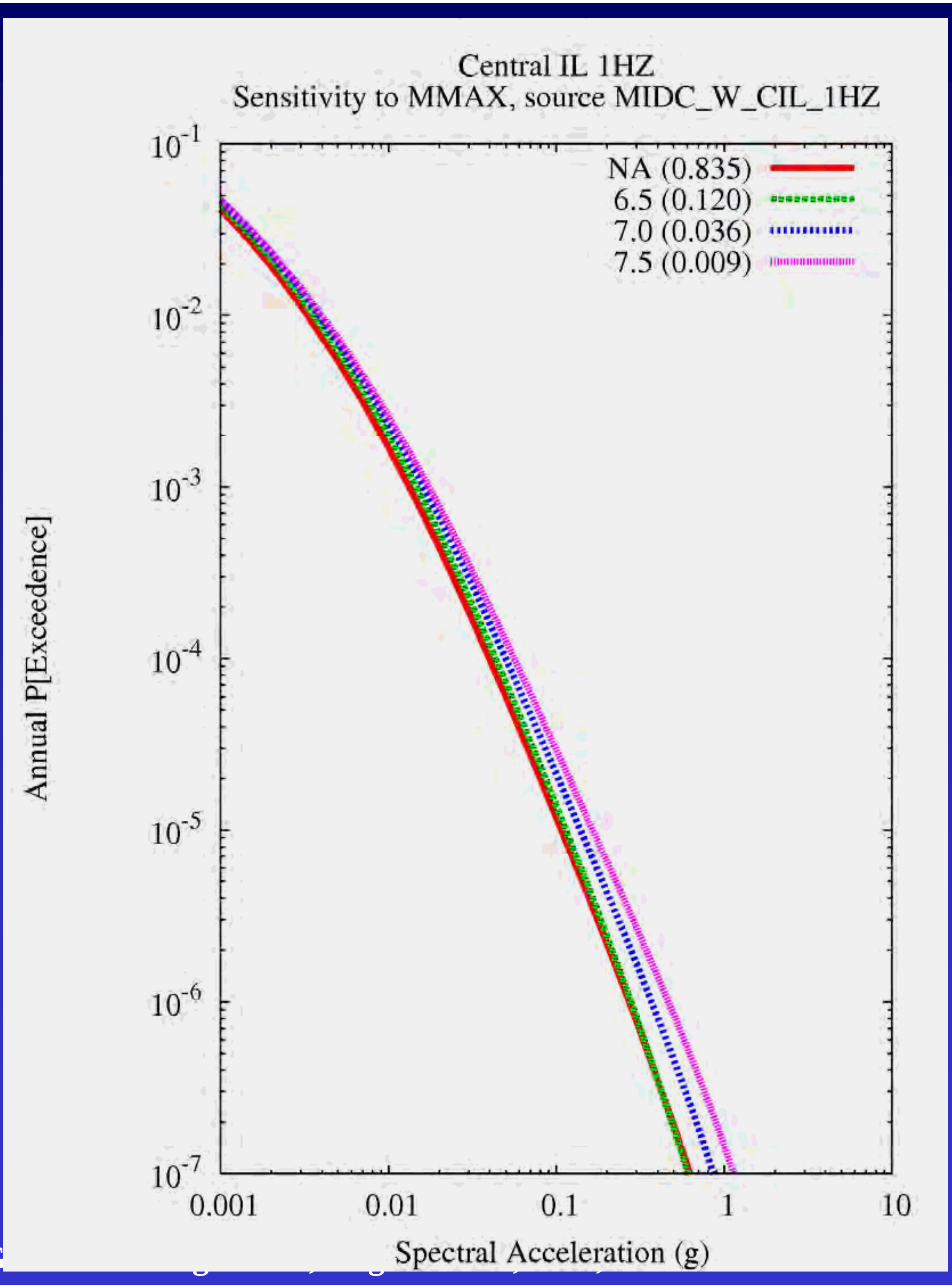

Central IL 1HZ
Sensitivity to SPATIAL-VAR
KERNEL (0.500)
VARIABLE_AB (0.500)
Annual P[Exceedence]
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
0.001
0.01
0.1
1
10
Spectral Acceleration (g)



Central IL 1HZ
Sensitivity to MMAX, source MIDC_W_CIL_1HZ

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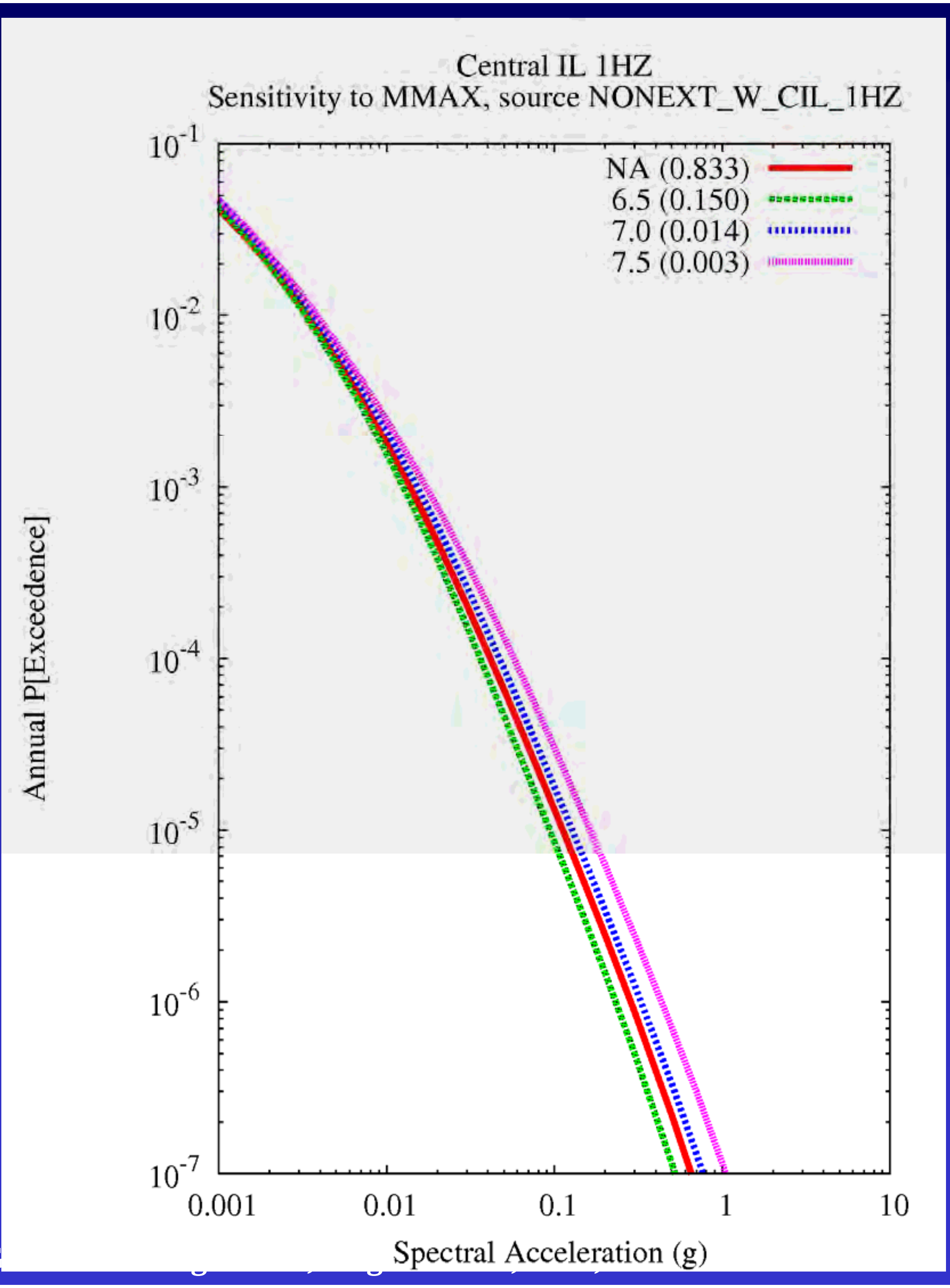
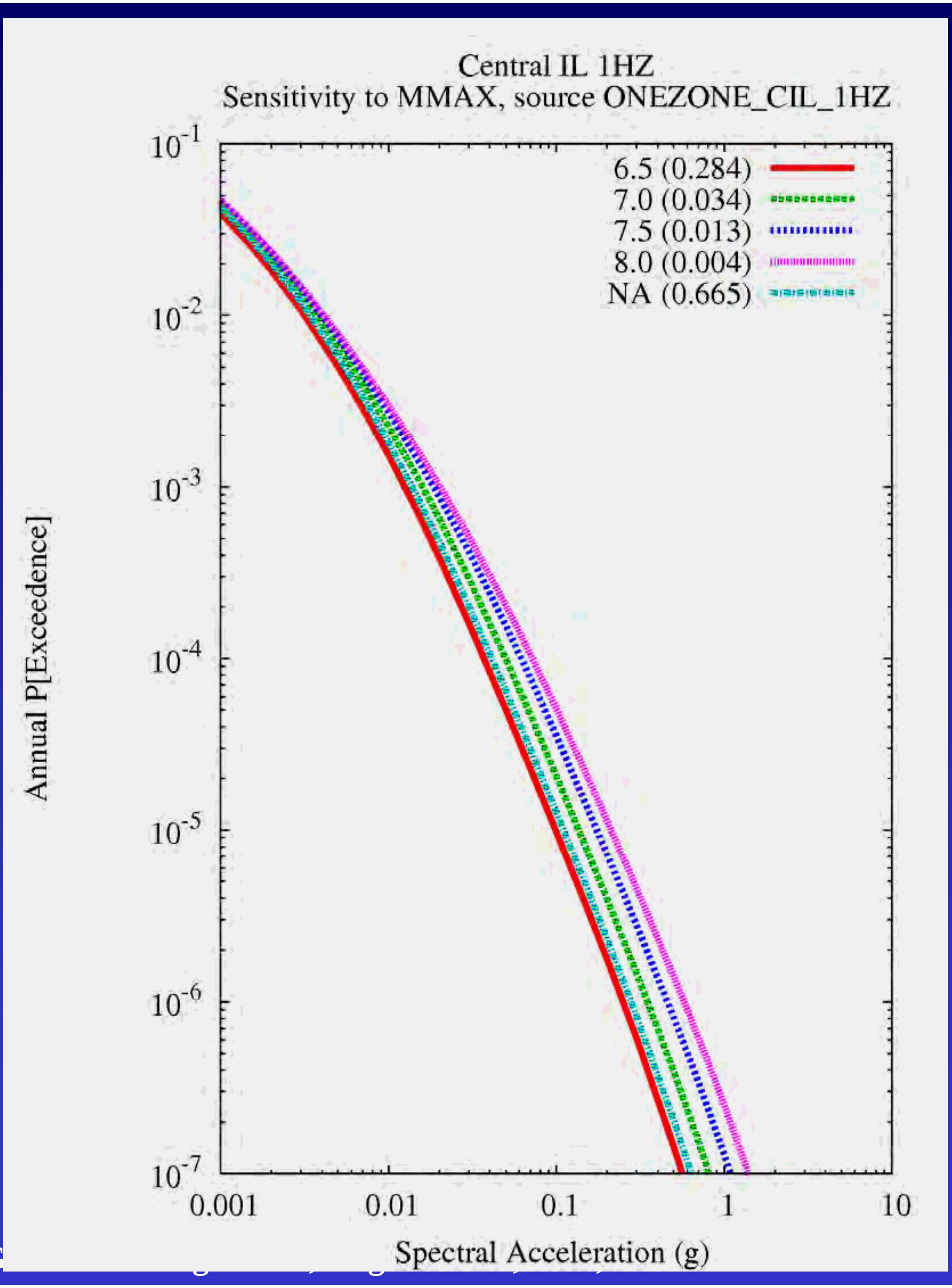
RISK ENGINEERING

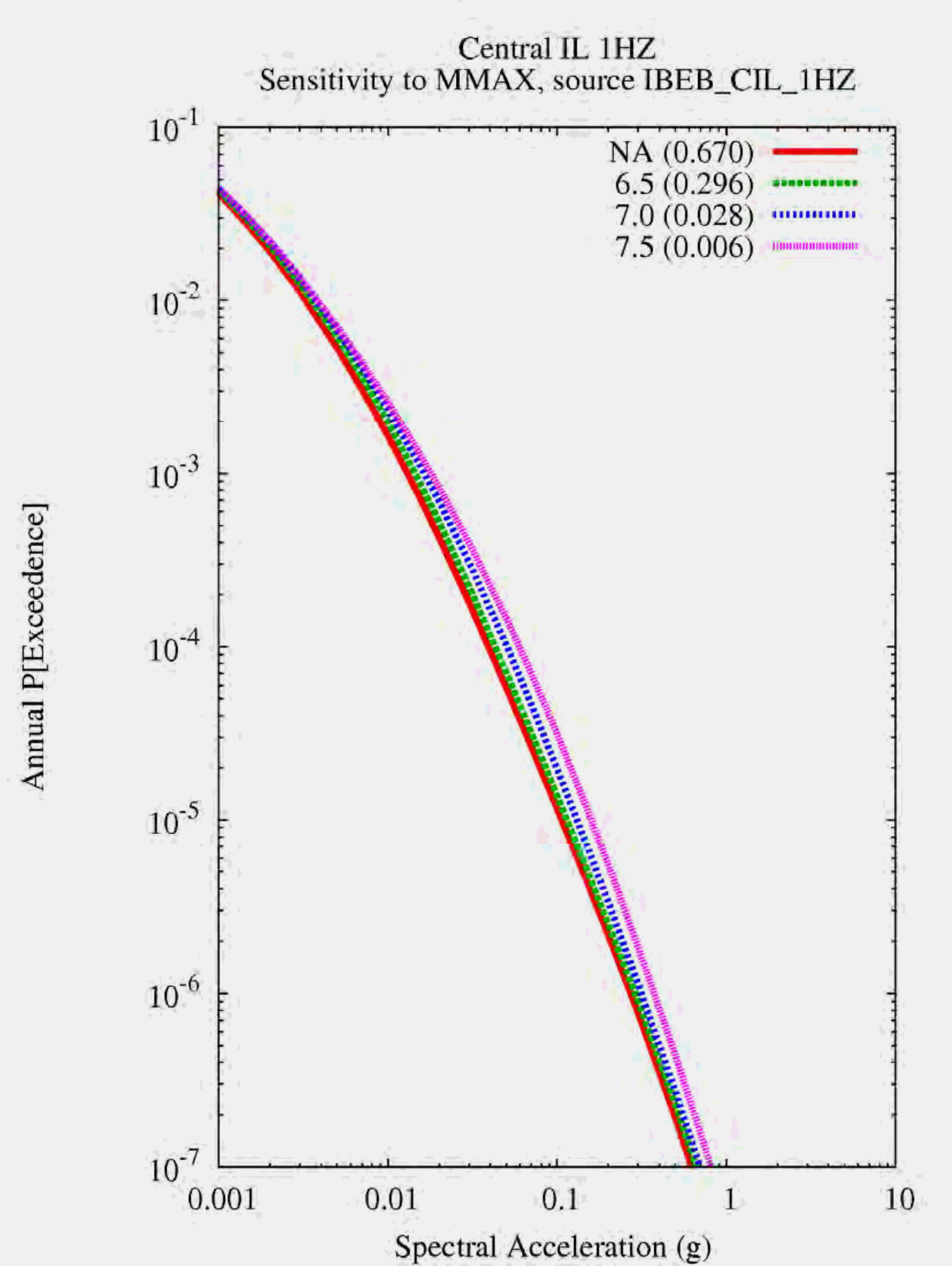


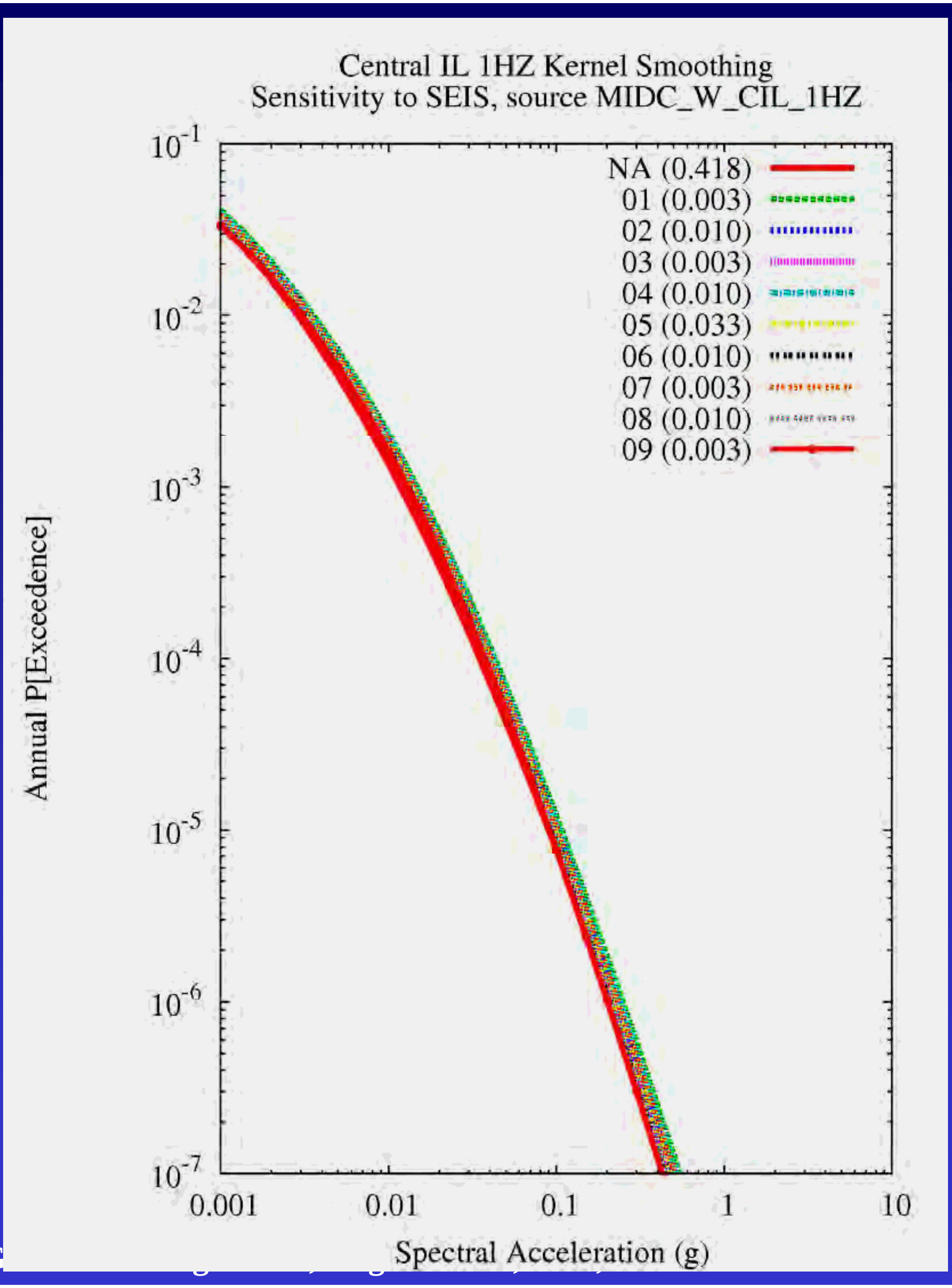
William Lettis & Associates, Inc.

RISK ENGINEERING



William Lettis & Associates, Inc.


Central IL 1HZ
Sensitivity to MMAX, source IBEB_CIL_1HZ
Annual P[Exceedence]
Spectral Acceleration (g)
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
0.001
0.01
0.1
1
10
NA (0.670)
6.5 (0.296)
7.0 (0.028)
7.5 (0.006)



Central IL 1HZ Kernel Smoothing
Sensitivity to SEIS, source MIDC_W_CIL_1HZ

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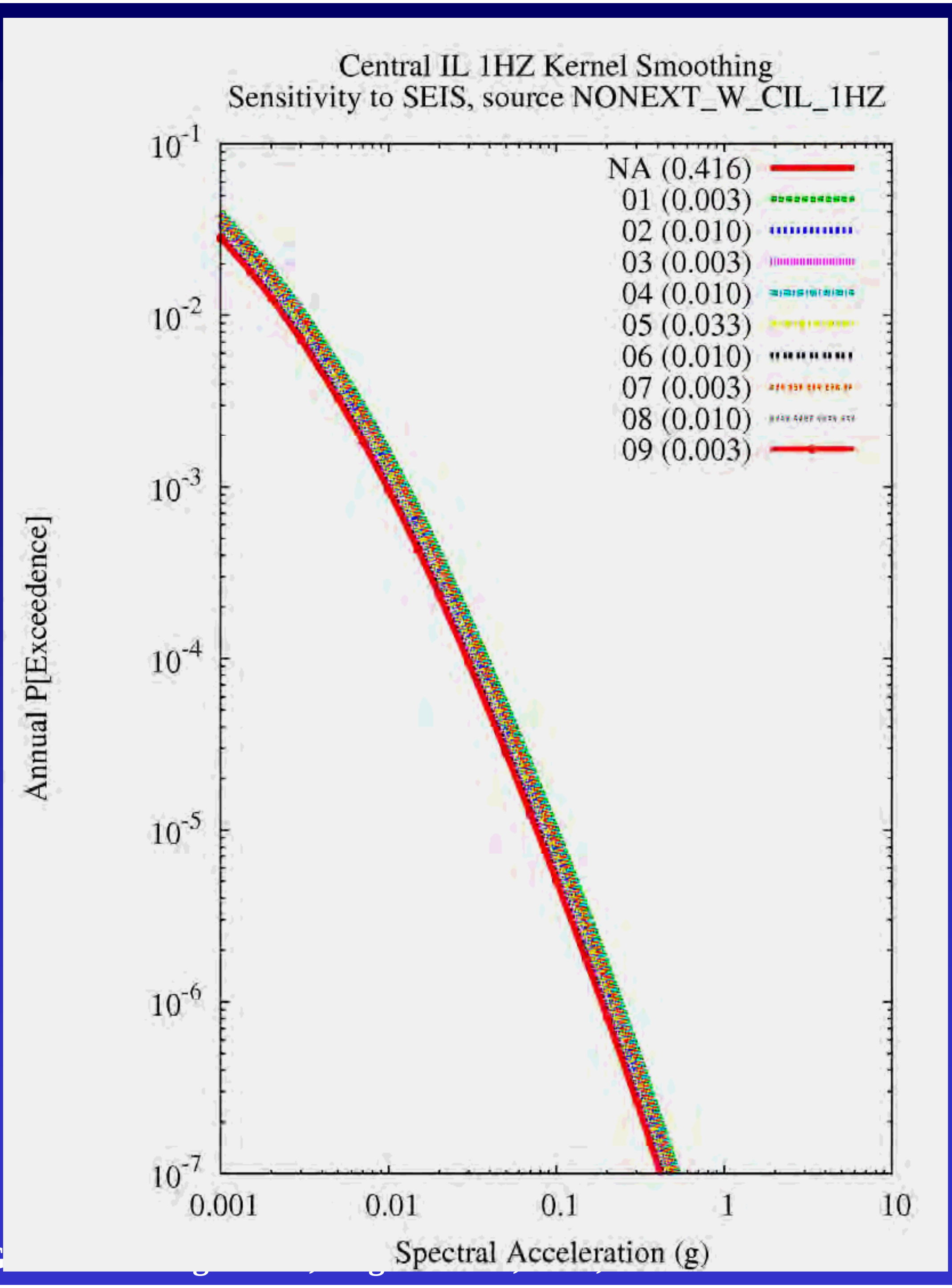
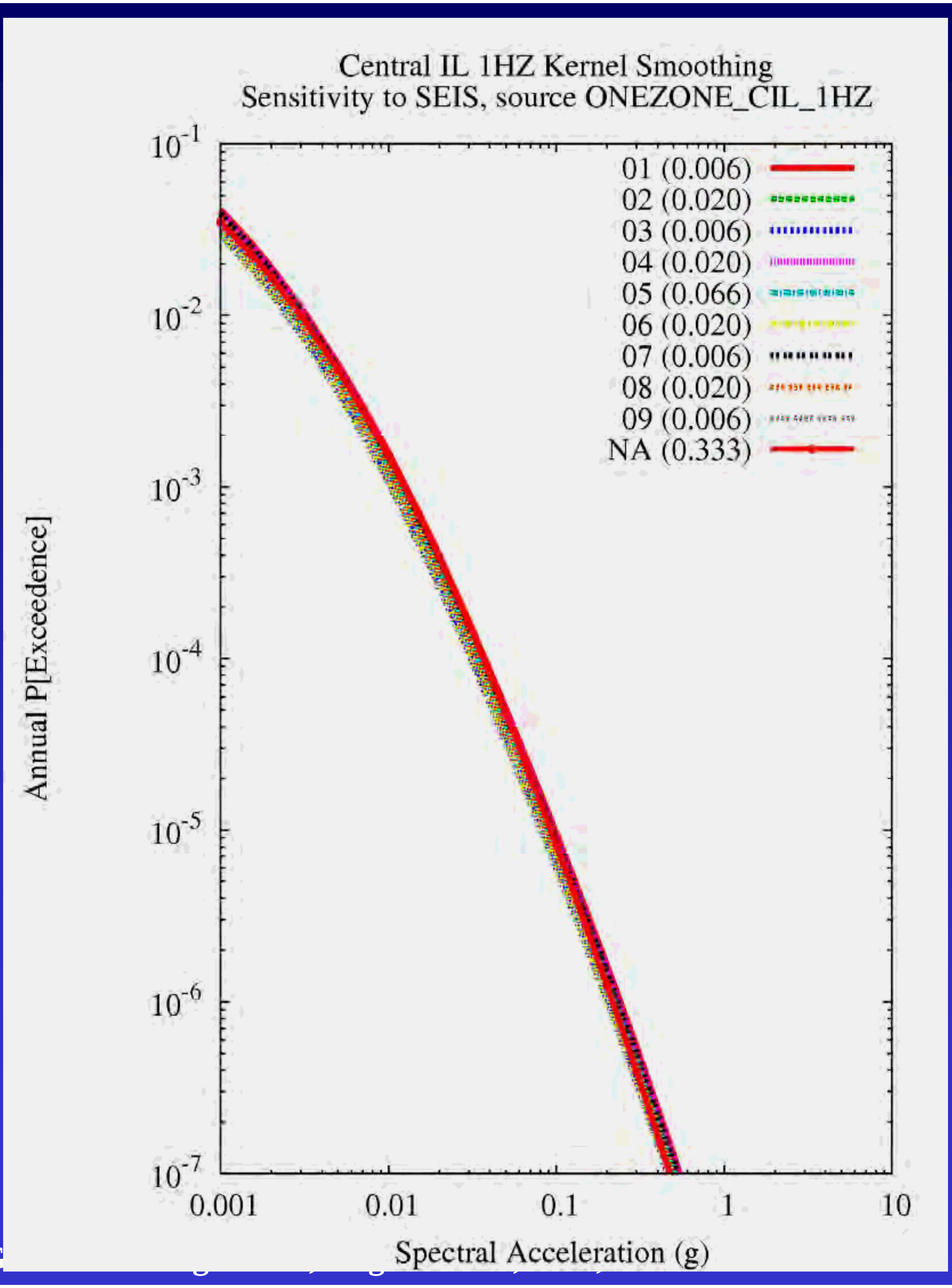

Central IL 1HZ Kernel Smoothing
Sensitivity to SEIS, source NONEXT_W_CIL_1HZ
Annual P[Exceedence]
Spectral Acceleration (g)
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
0.001
0.01
0.1
1
10
NA (0.416)
01 (0.003)
02 (0.010)
03 (0.003)
04 (0.010)
05 (0.033)
06 (0.010)
07 (0.003)
08 (0.010)
09 (0.003)



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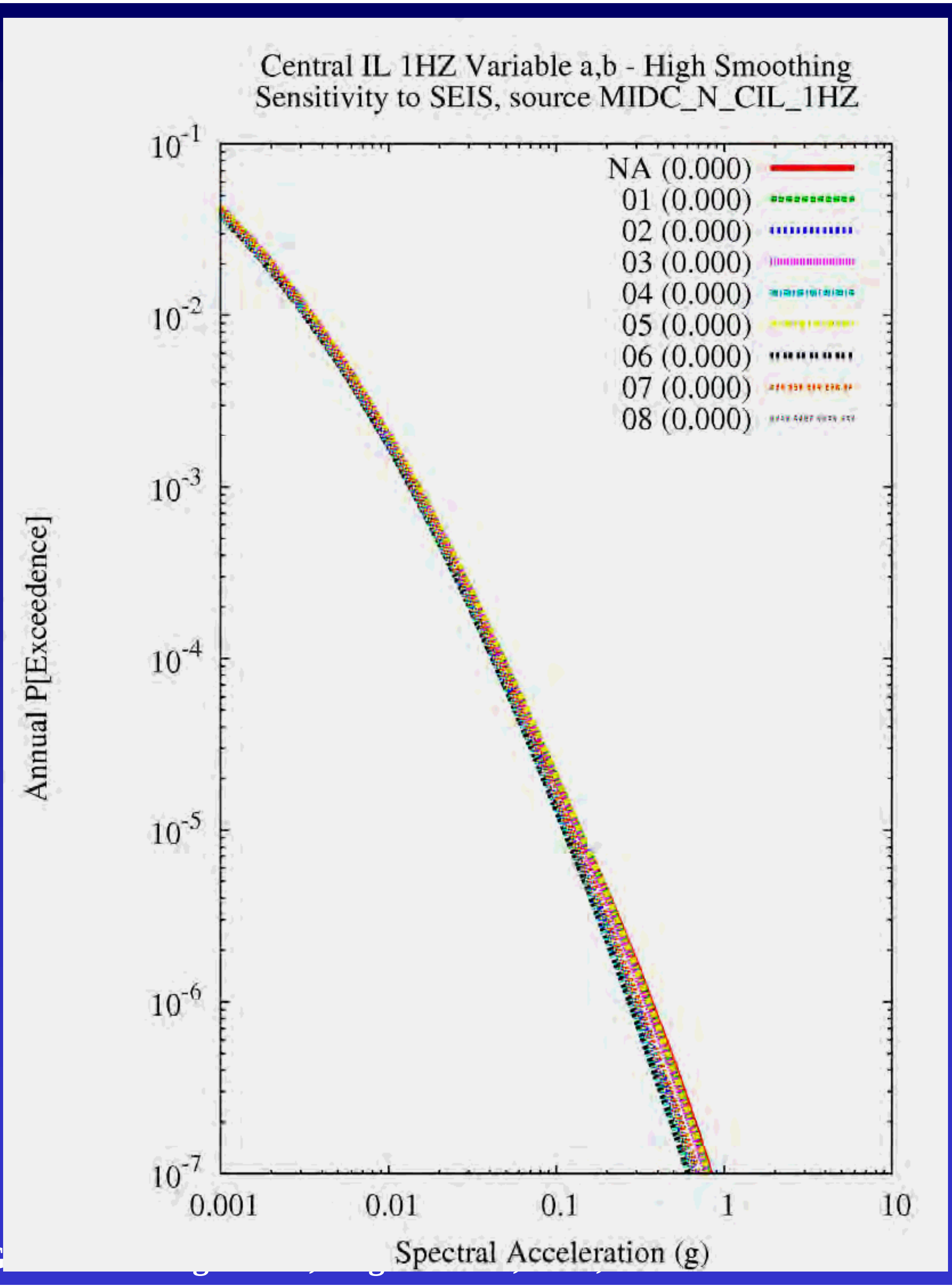
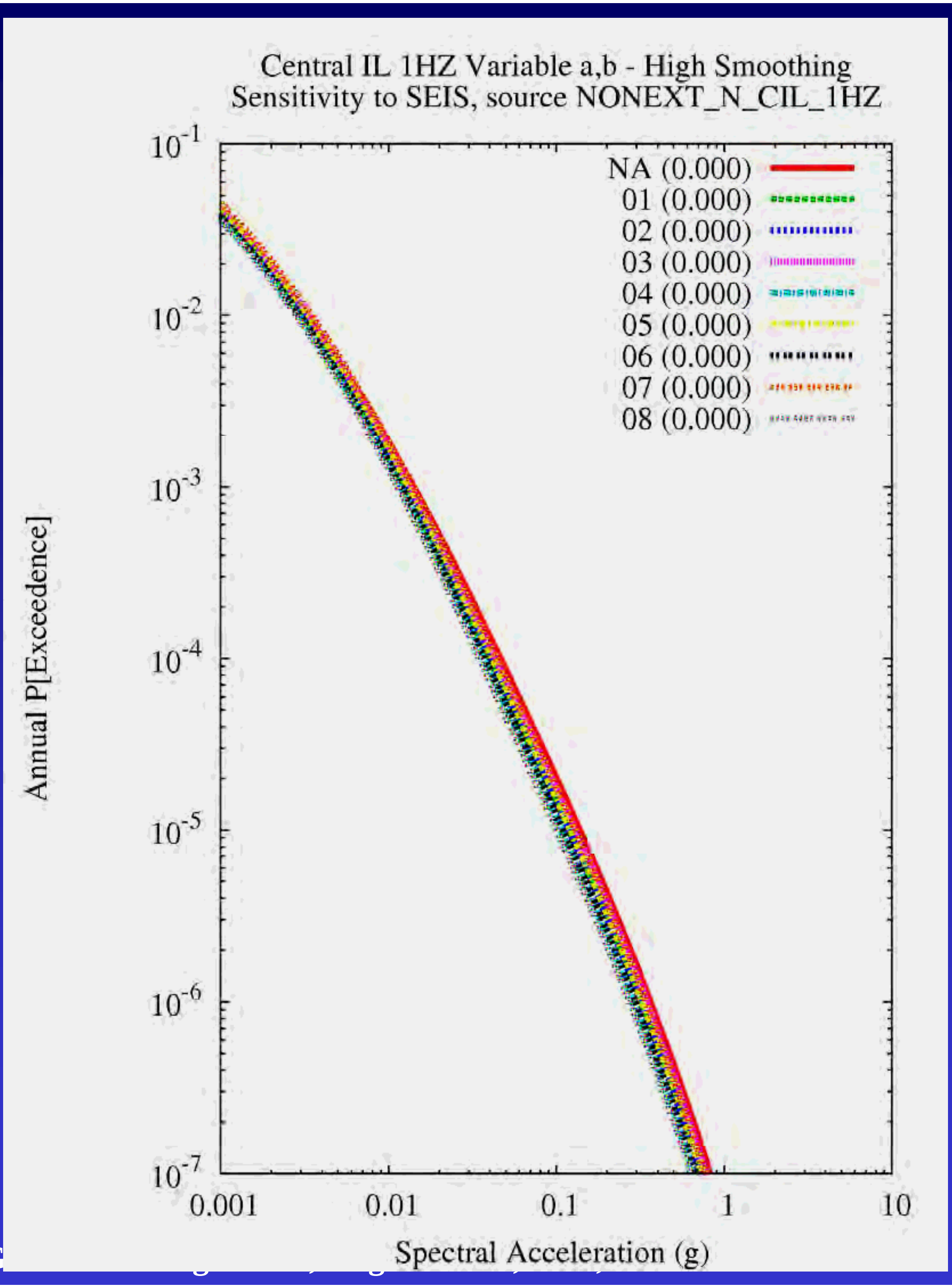


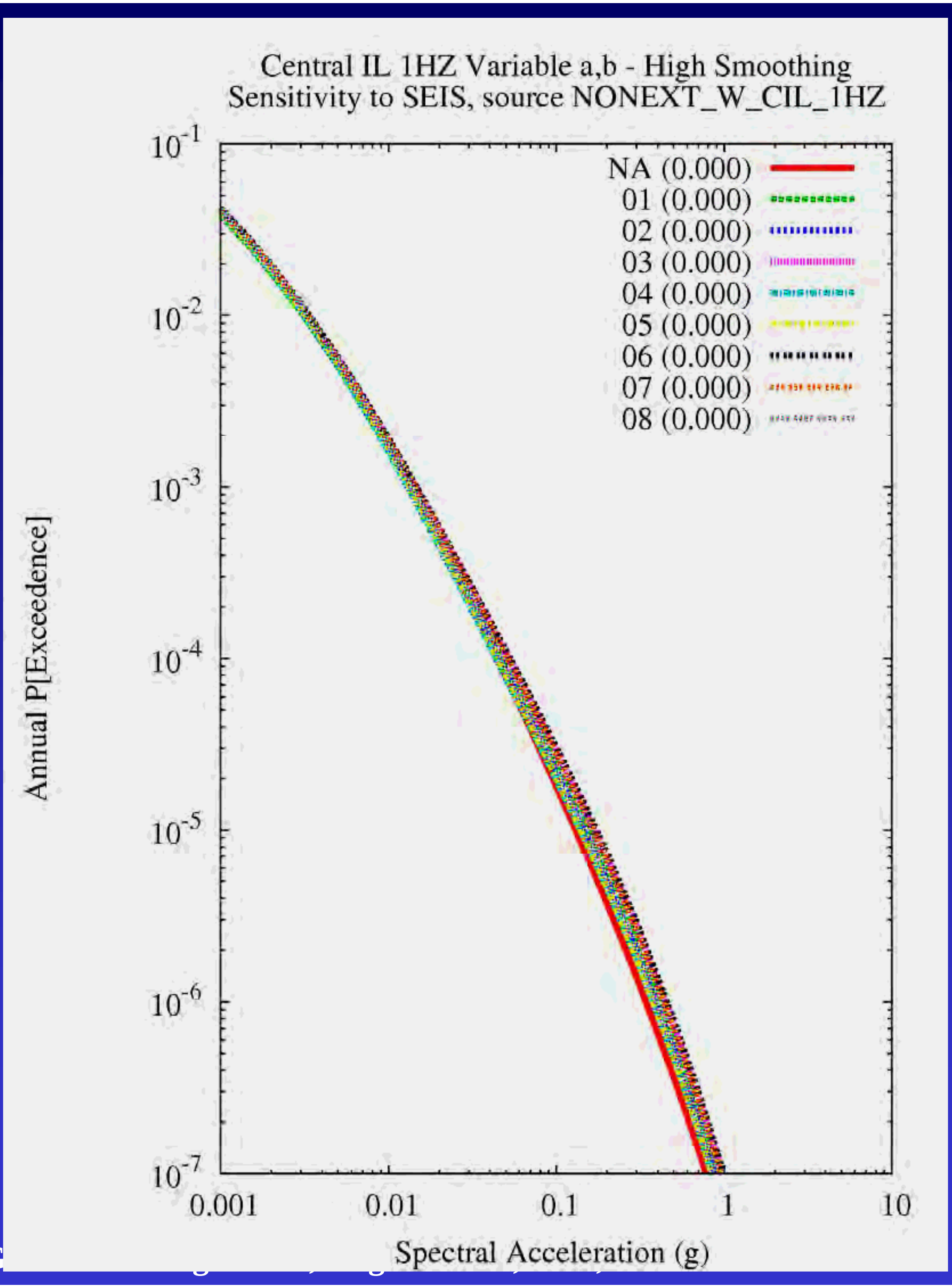
William Lettis & Associates, Inc.

RISK ENGINEERING



William Lettis & Associates, Inc.

RISK ENGINEERING



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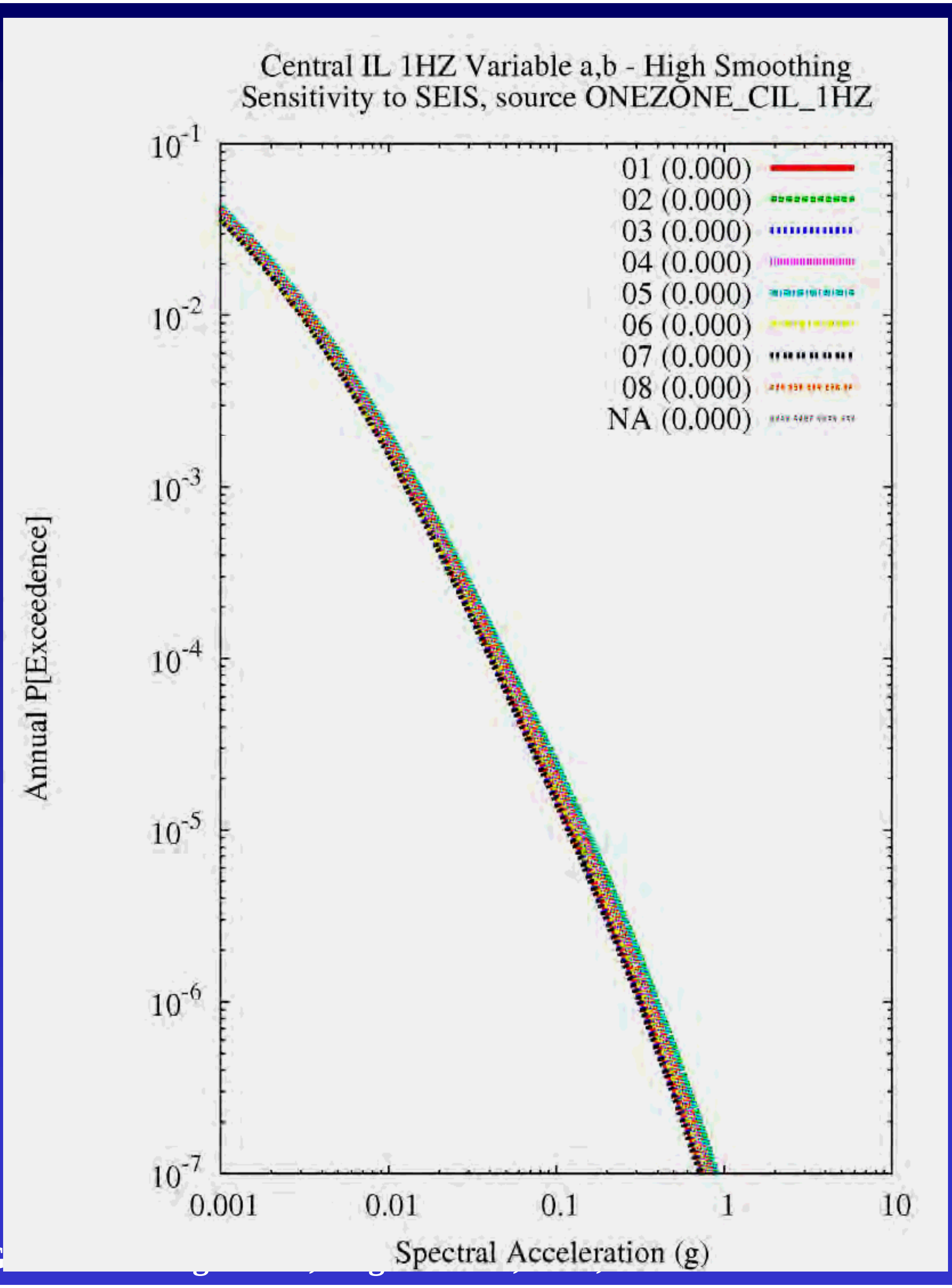
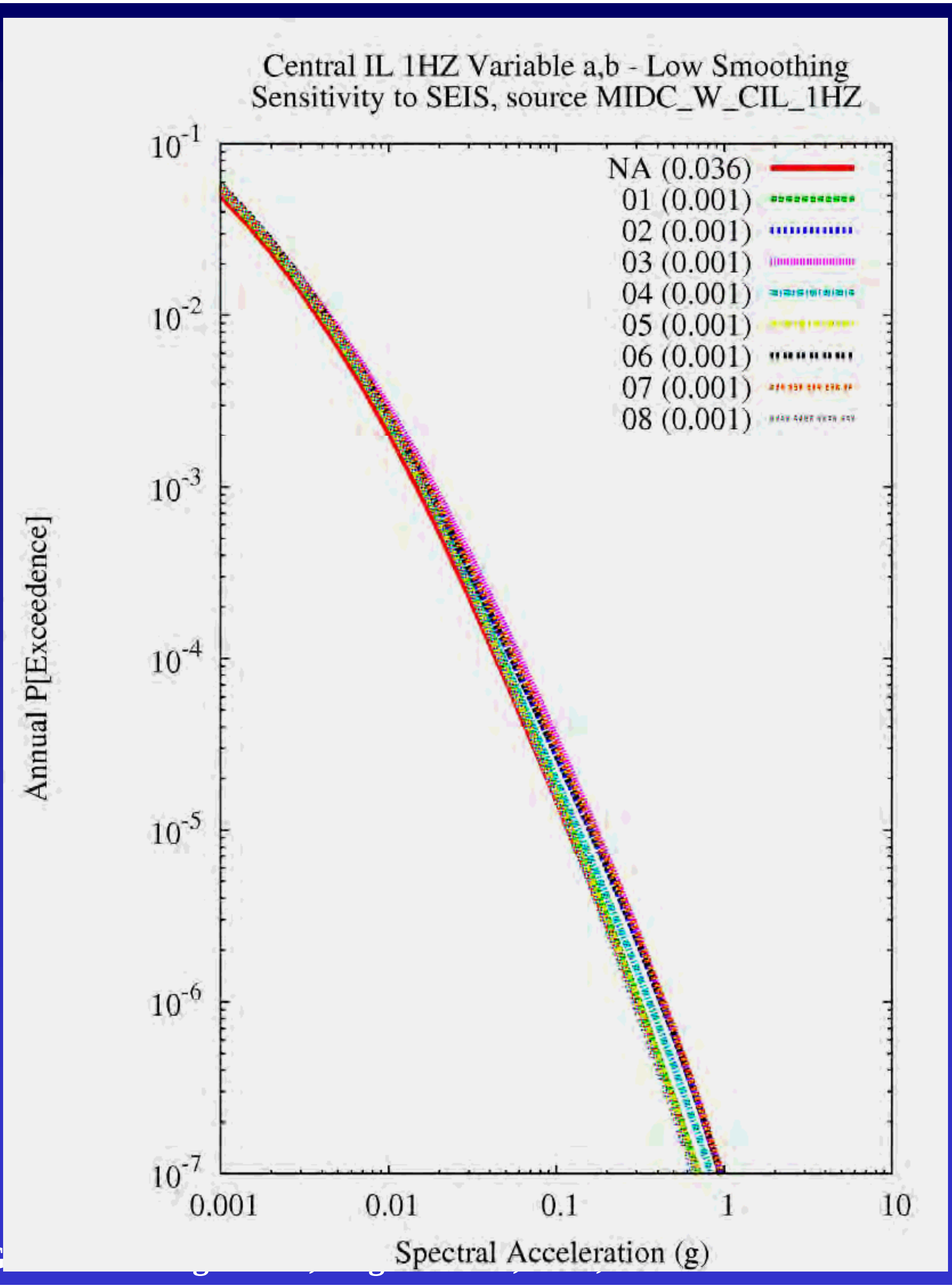


William Lettis & Associates, Inc.

RISK ENGINEERING



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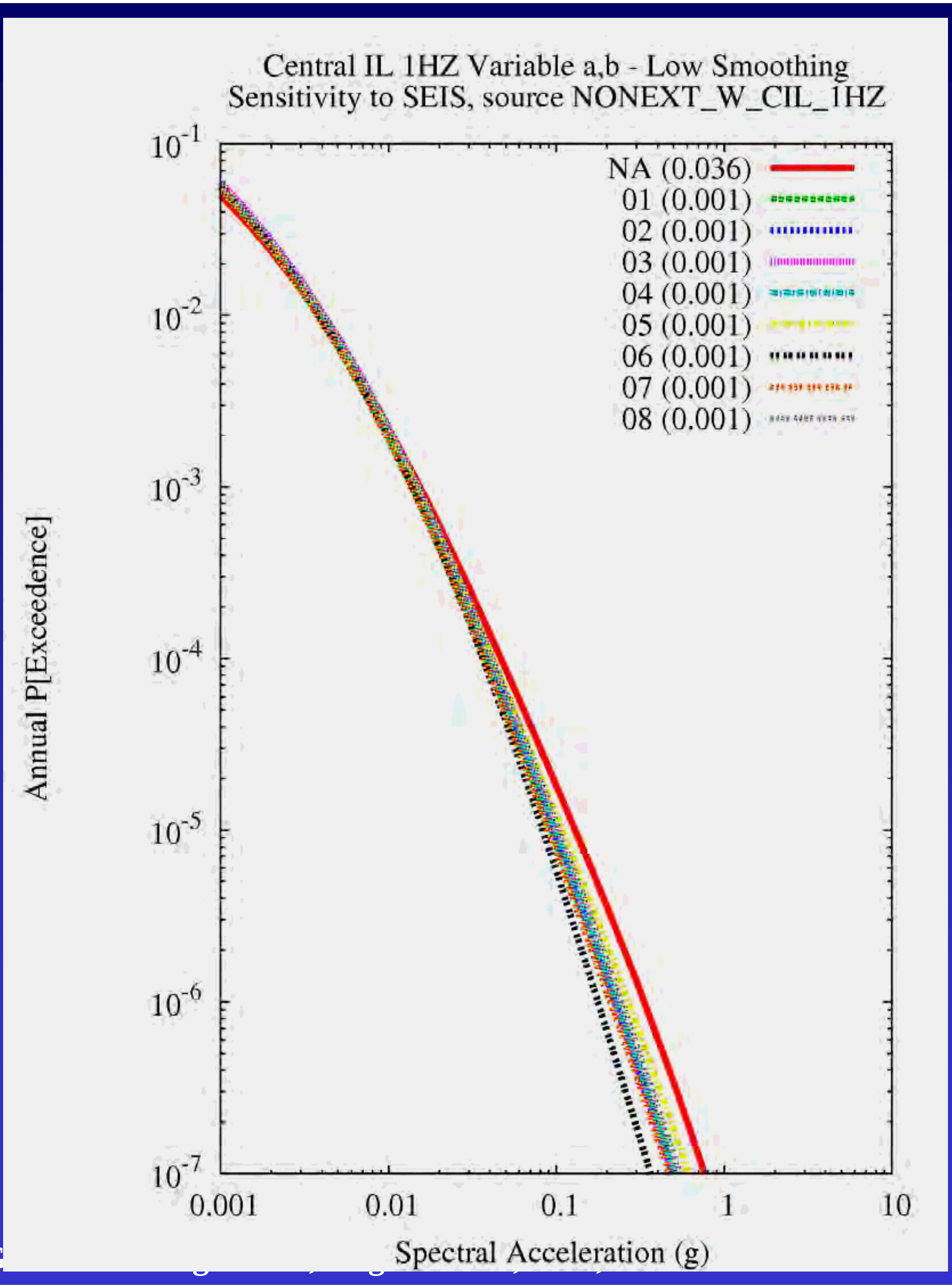

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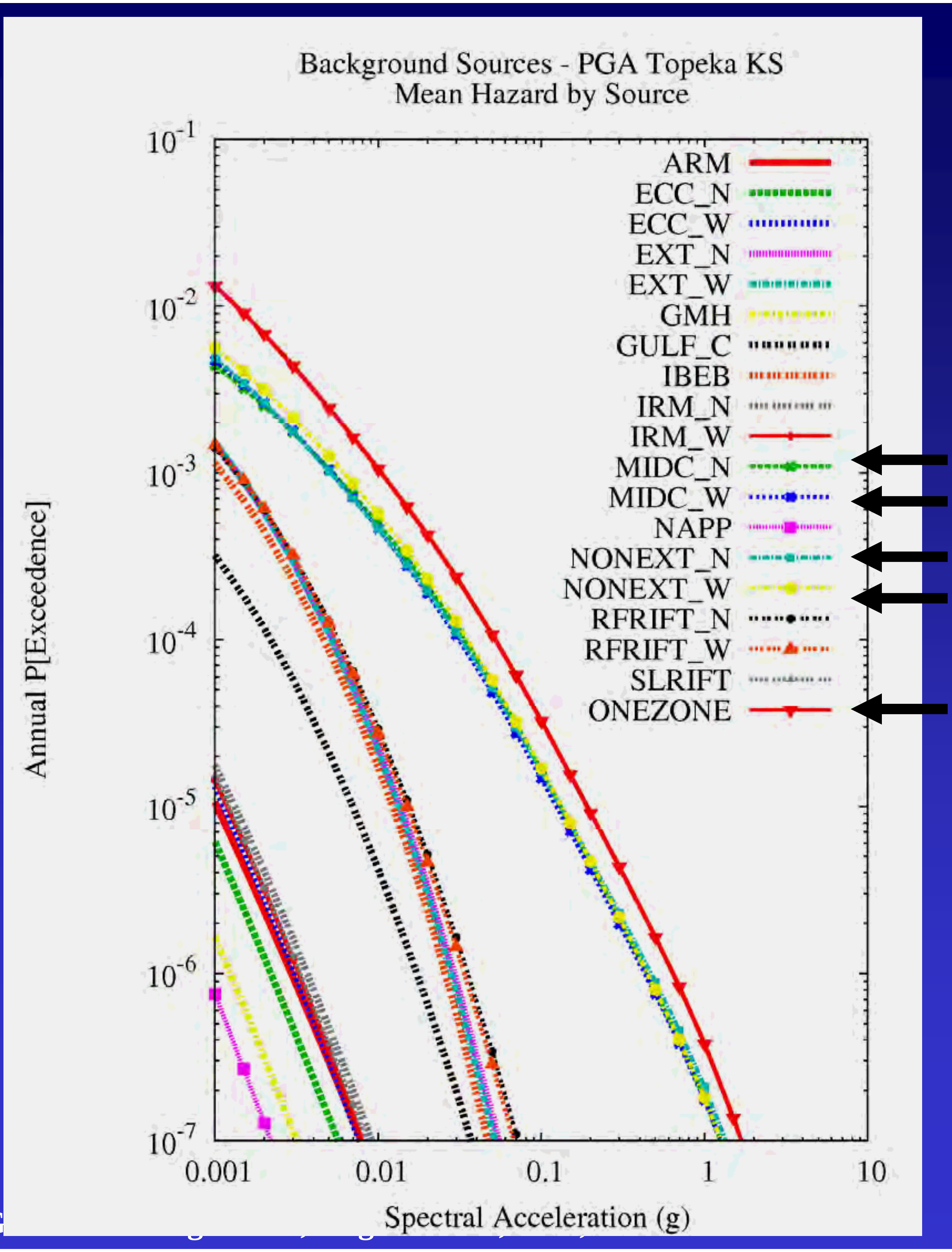
Summary of Sensitivities for Central IL Site

- Major contributors to uncertainty
  - Max. Magnitude (1 Hz only; moderate effect)
  - Smoothing Approach & uncertainty in smoothing (moderate)

Central Plains Site
(Topeka, KS)



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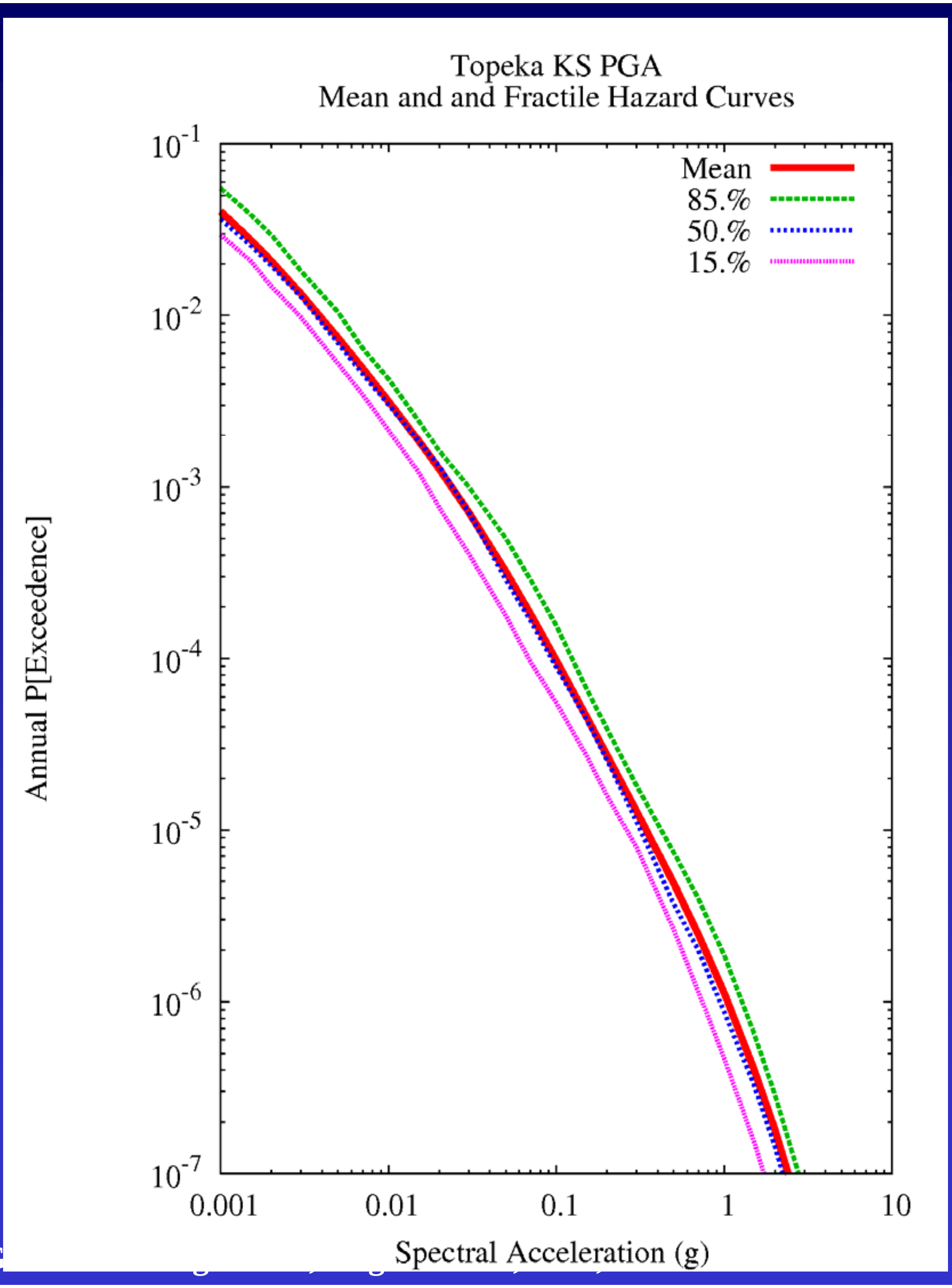
RISK ENGINEERING



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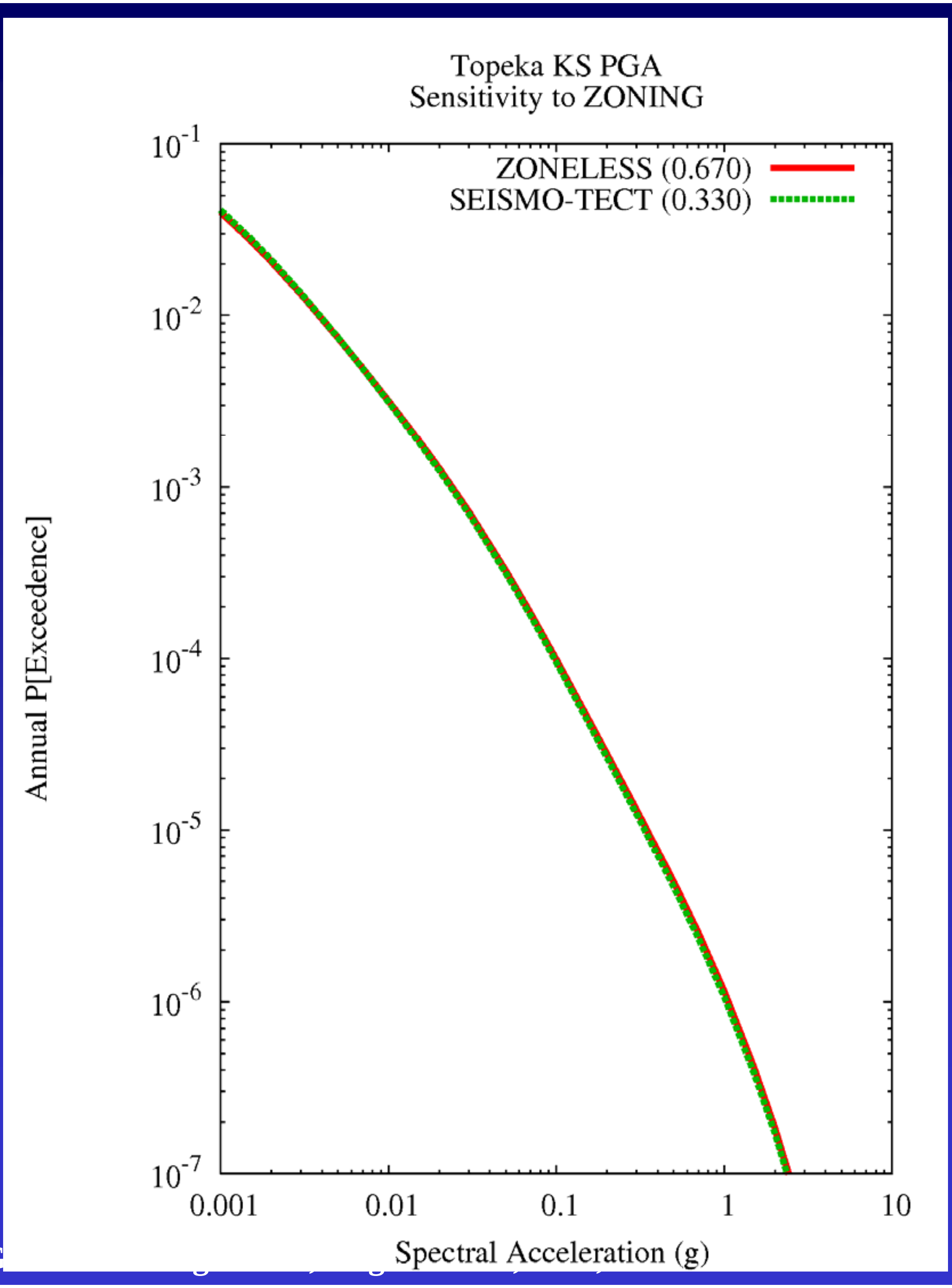

WLA
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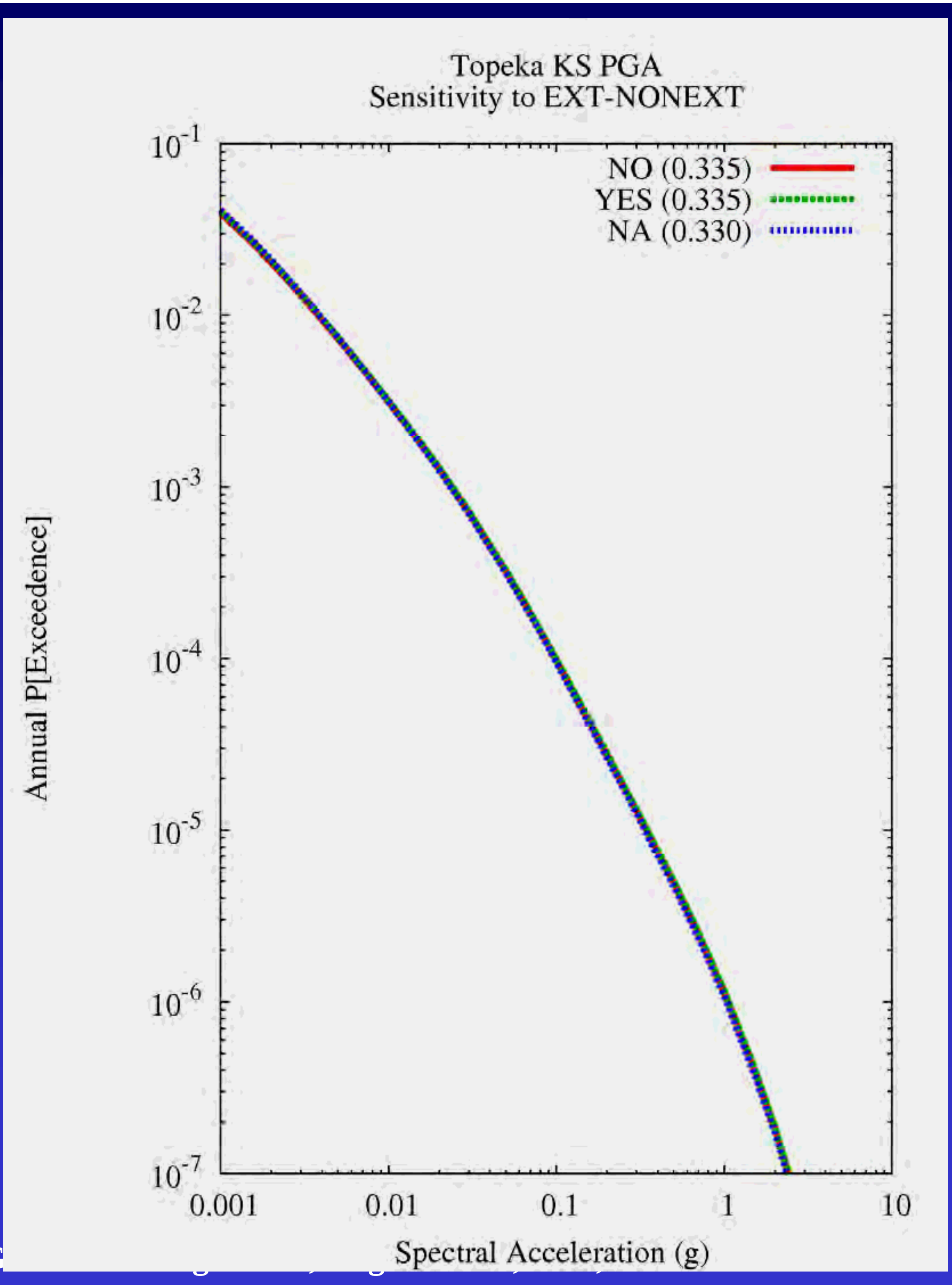
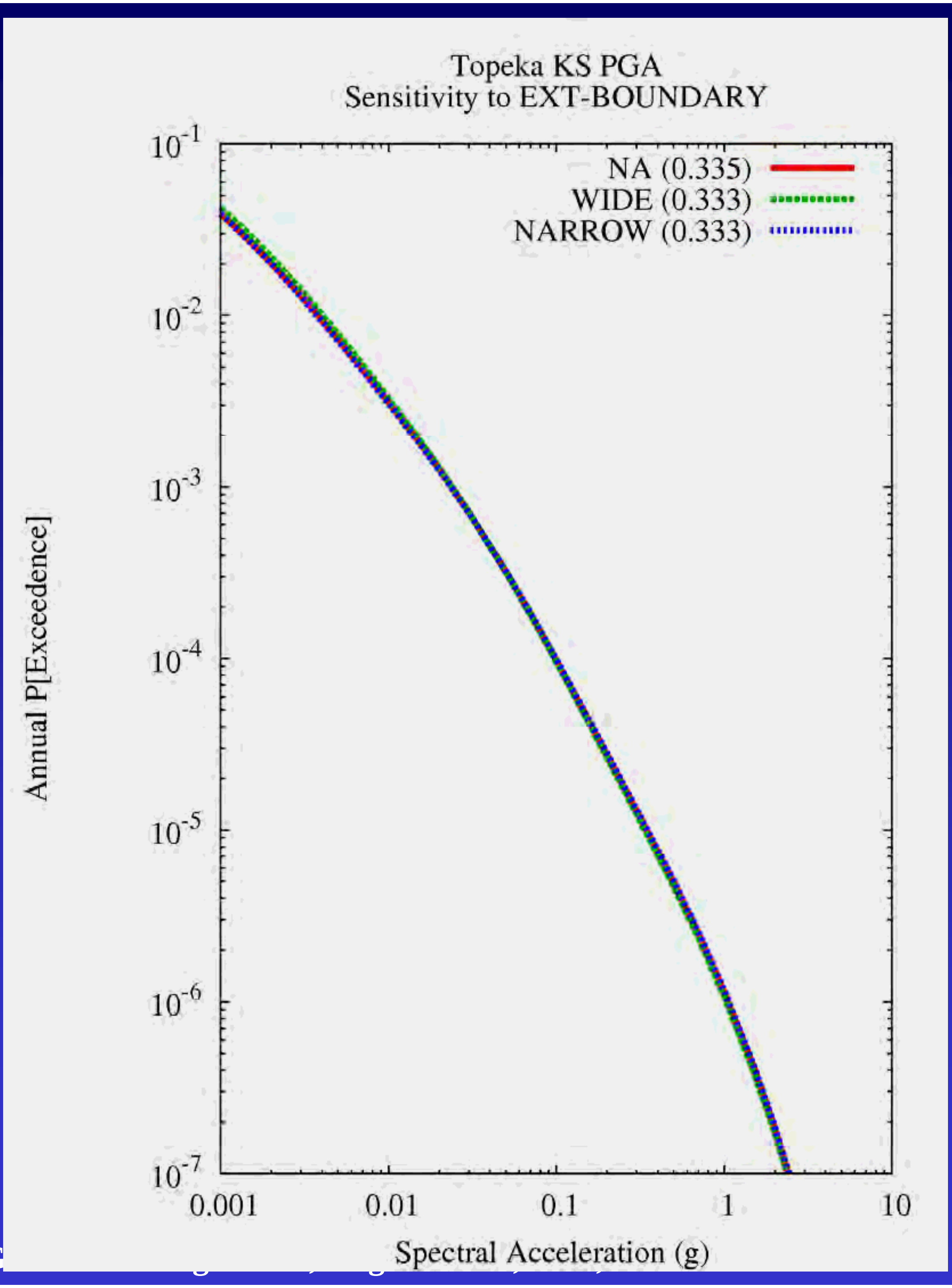
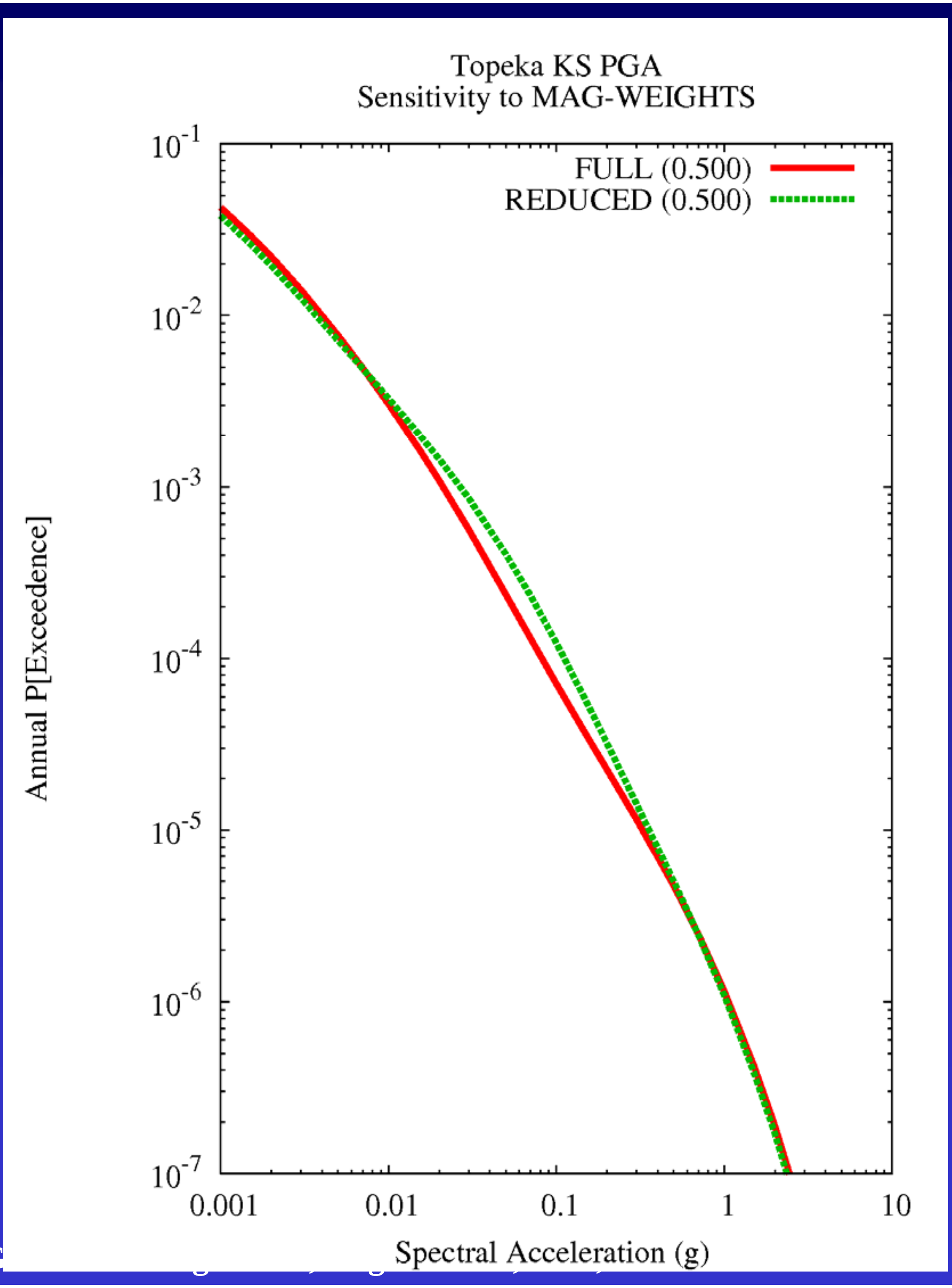


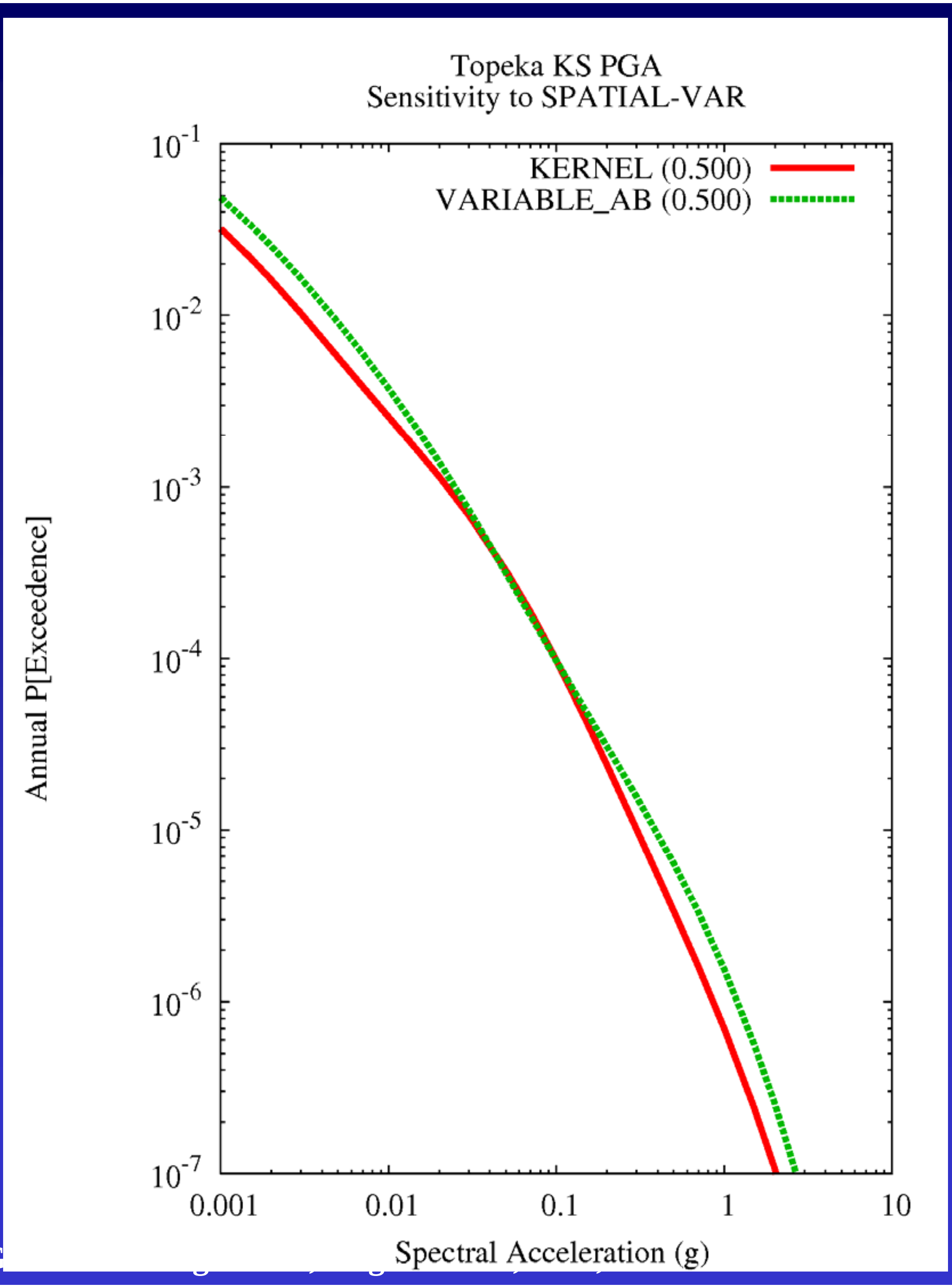
William Lettis & Associates, Inc.

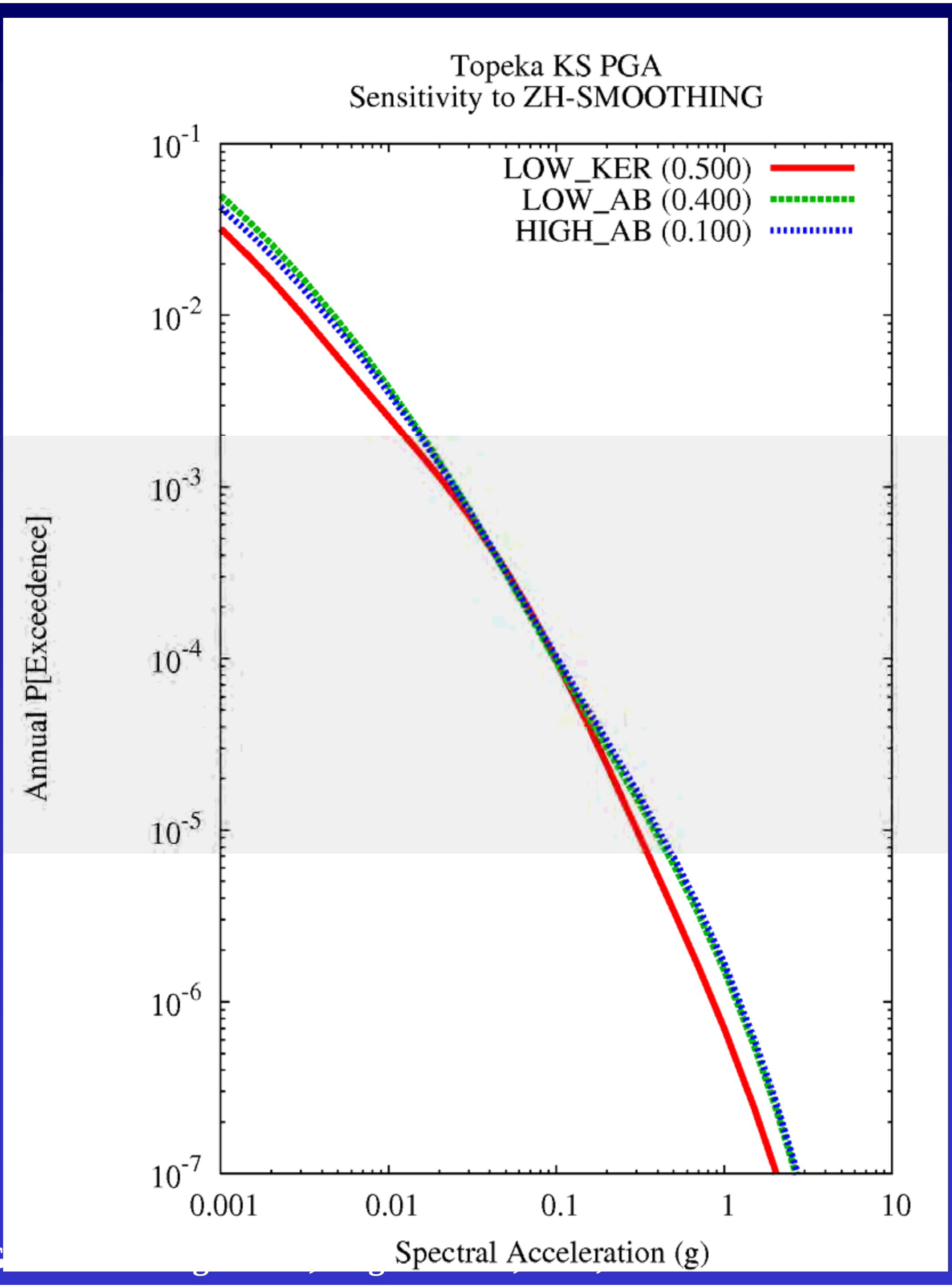

Topeka KS PGA
Sensitivity to EXT-BOUNDARY
NA (0.335)
WIDE (0.333)
NARROW (0.333)
Annual P[Exceedence]
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
0.001
0.01
0.1
1
10
Spectral Acceleration (g)



William Lettis & Associates, Inc.

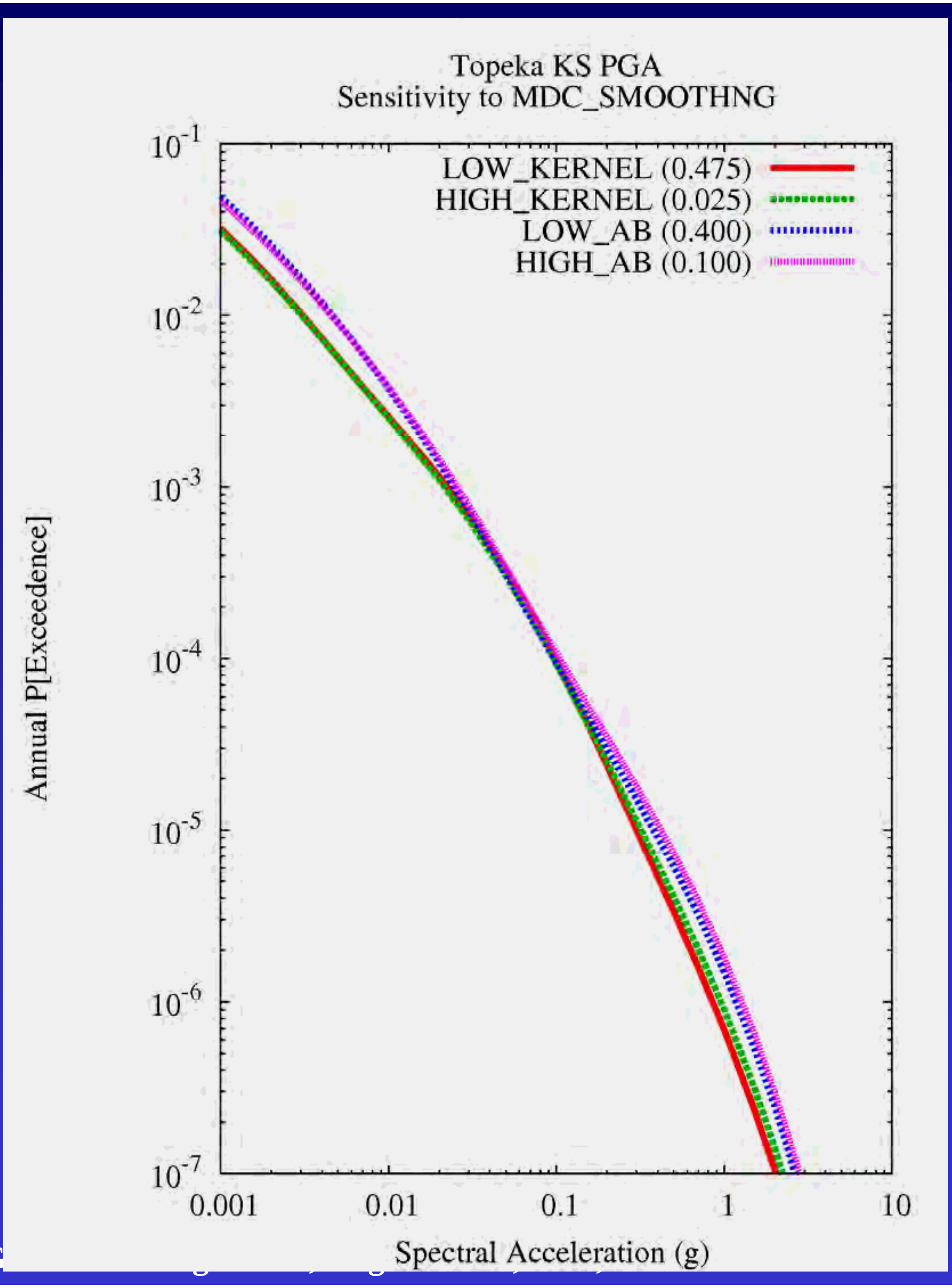
RISK ENGINEERING

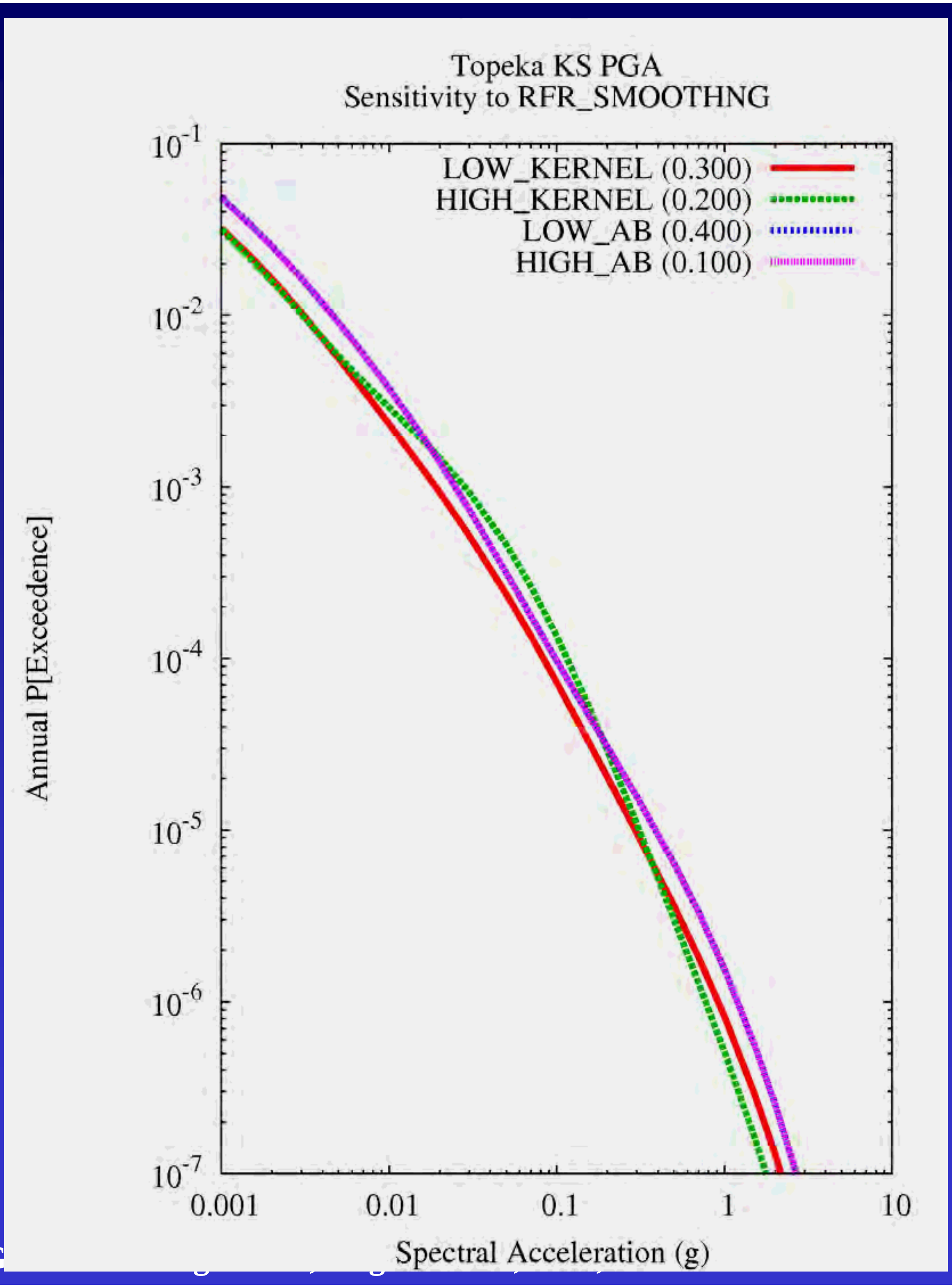

Topeka KS PGA
Sensitivity to SPATIAL-VAR
KERNEL (0.500)
VARIABLE_AB (0.500)
Annual P[Exceedence]
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
0.001
0.01
0.1
1
10
Spectral Acceleration (g)



William Lettis & Associates, Inc.

RISK ENGINEERING


Topeka KS PGA
Sensitivity to MDC_SMOOTHNG
LOW_KERNEL (0.475)
HIGH_KERNEL (0.025)
LOW_AB (0.400)
HIGH_AB (0.100)
Annual P[Exceedence]
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
0.001
0.01
0.1
1
10
Spectral Acceleration (g)



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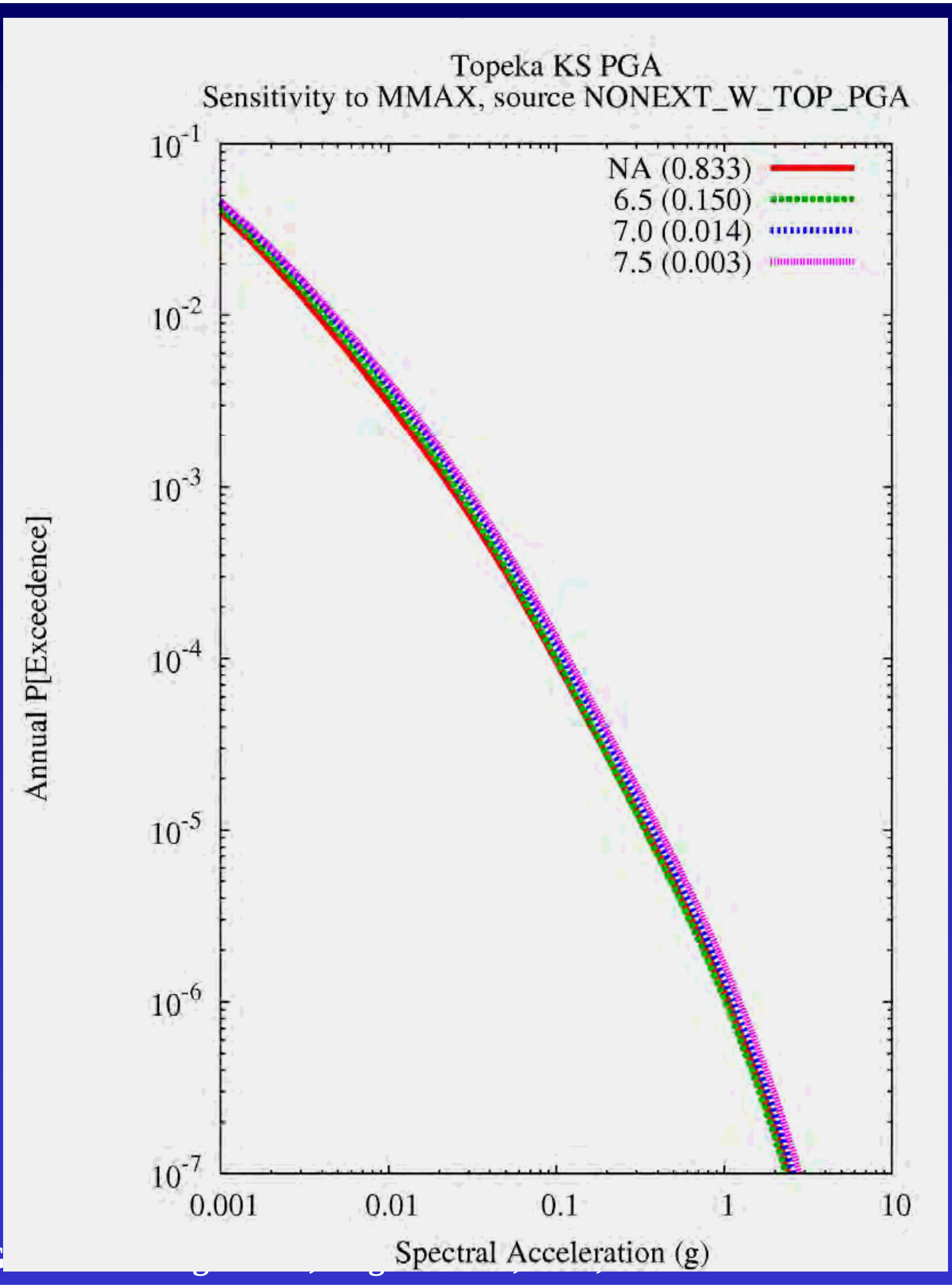
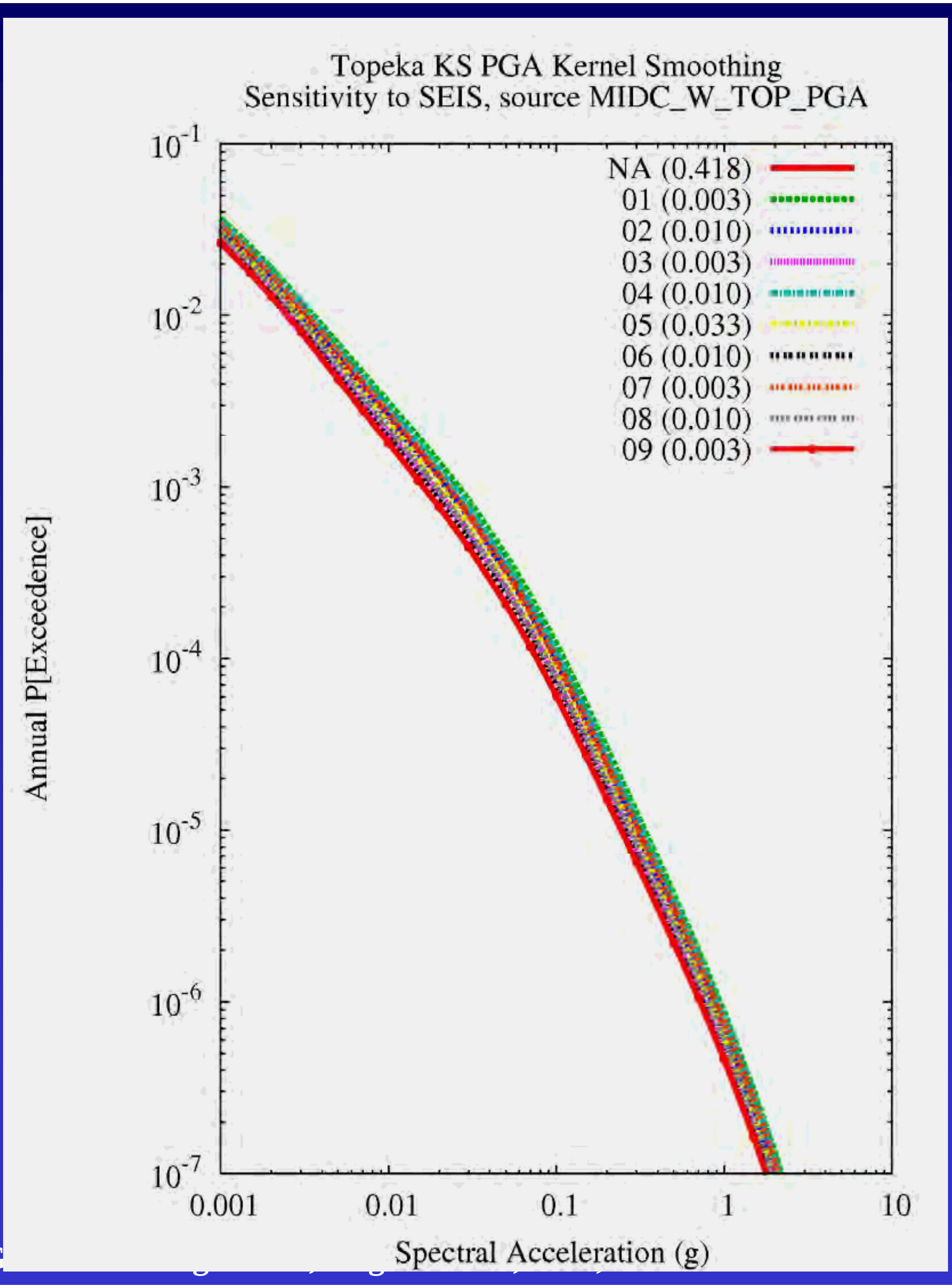
RISK ENGINEERING

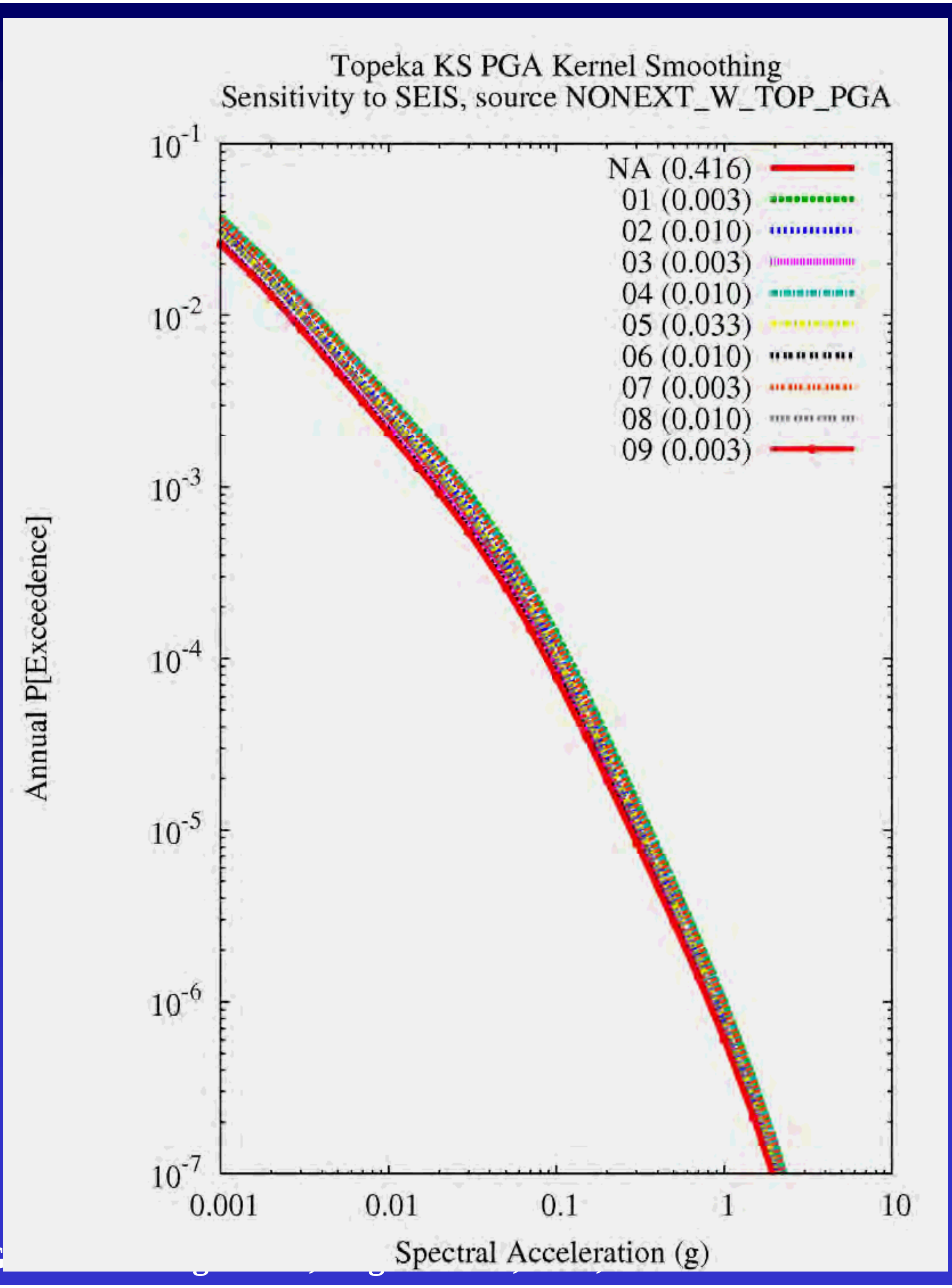


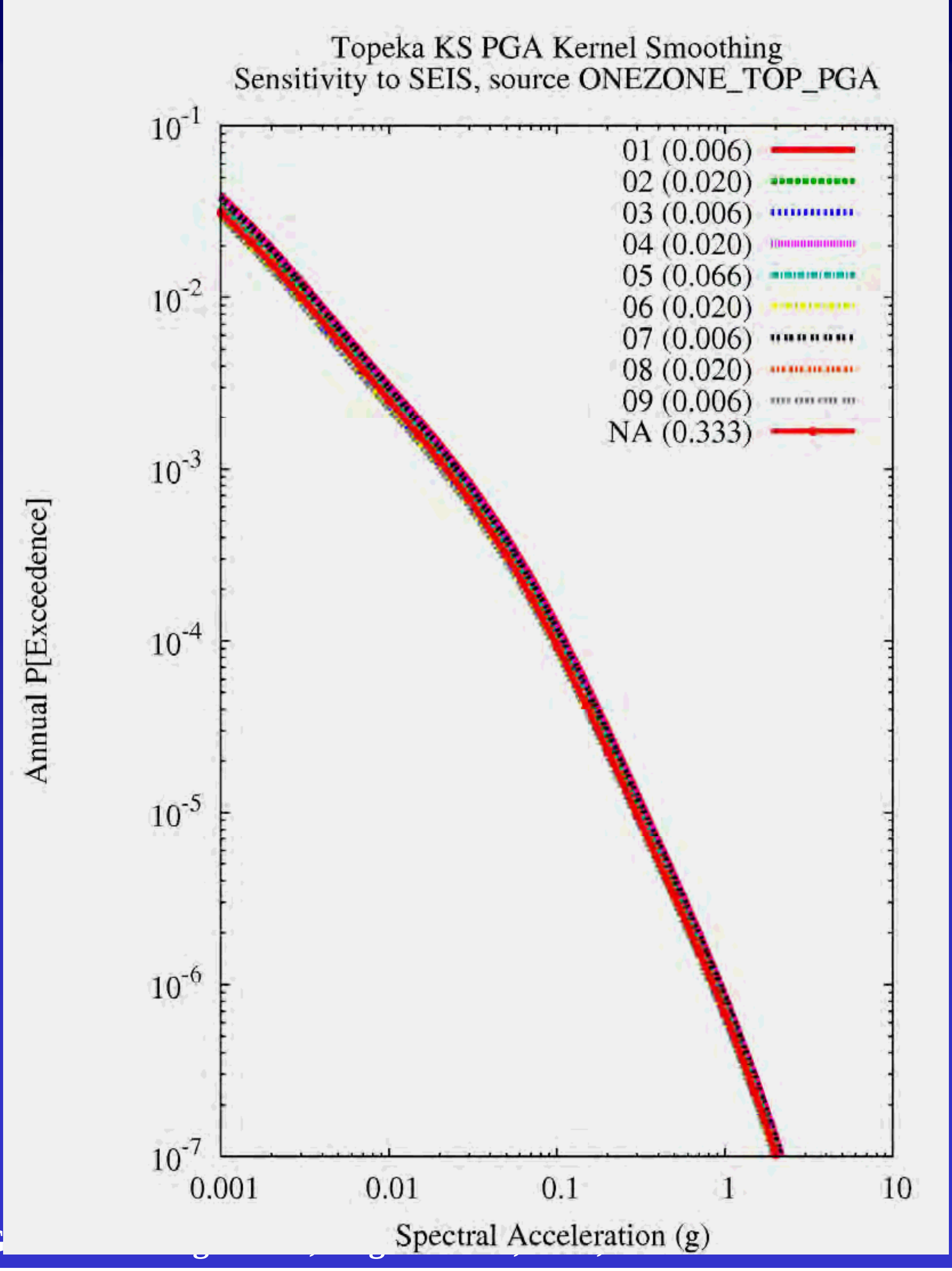
William Lettis & Associates, Inc.



William Lettis & Associates, Inc.

RISK ENGINEERING


Topeka KS PGA Kernel Smoothing
Sensitivity to SEIS, source NONEXT_W_TOP_PGA
Annual P[Exceedence]
Spectral Acceleration (g)
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
0.001
0.01
0.1
1
10
NA (0.416)
01 (0.003)
02 (0.010)
03 (0.003)
04 (0.010)
05 (0.033)
06 (0.010)
07 (0.003)
08 (0.010)
09 (0.003)



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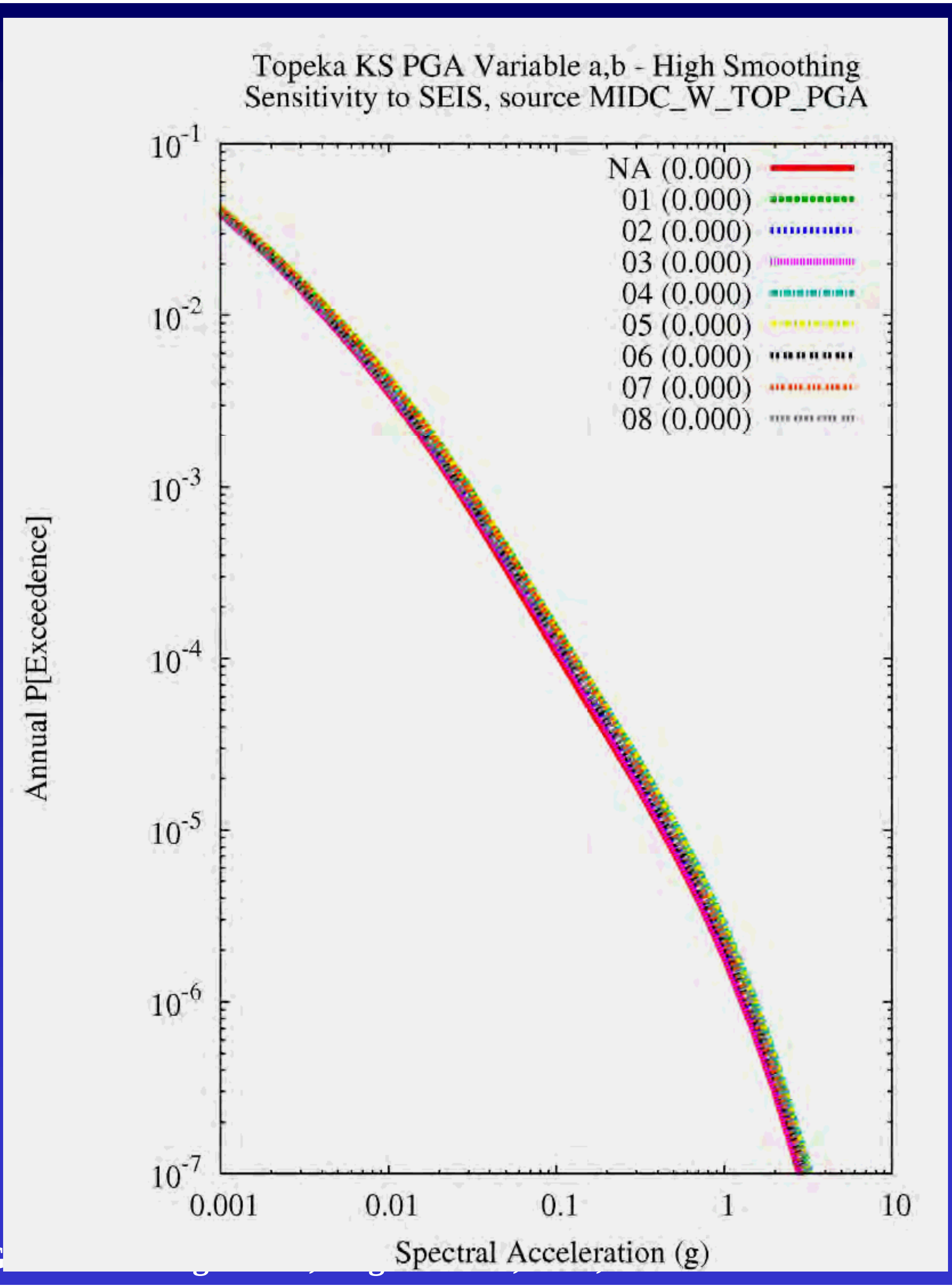
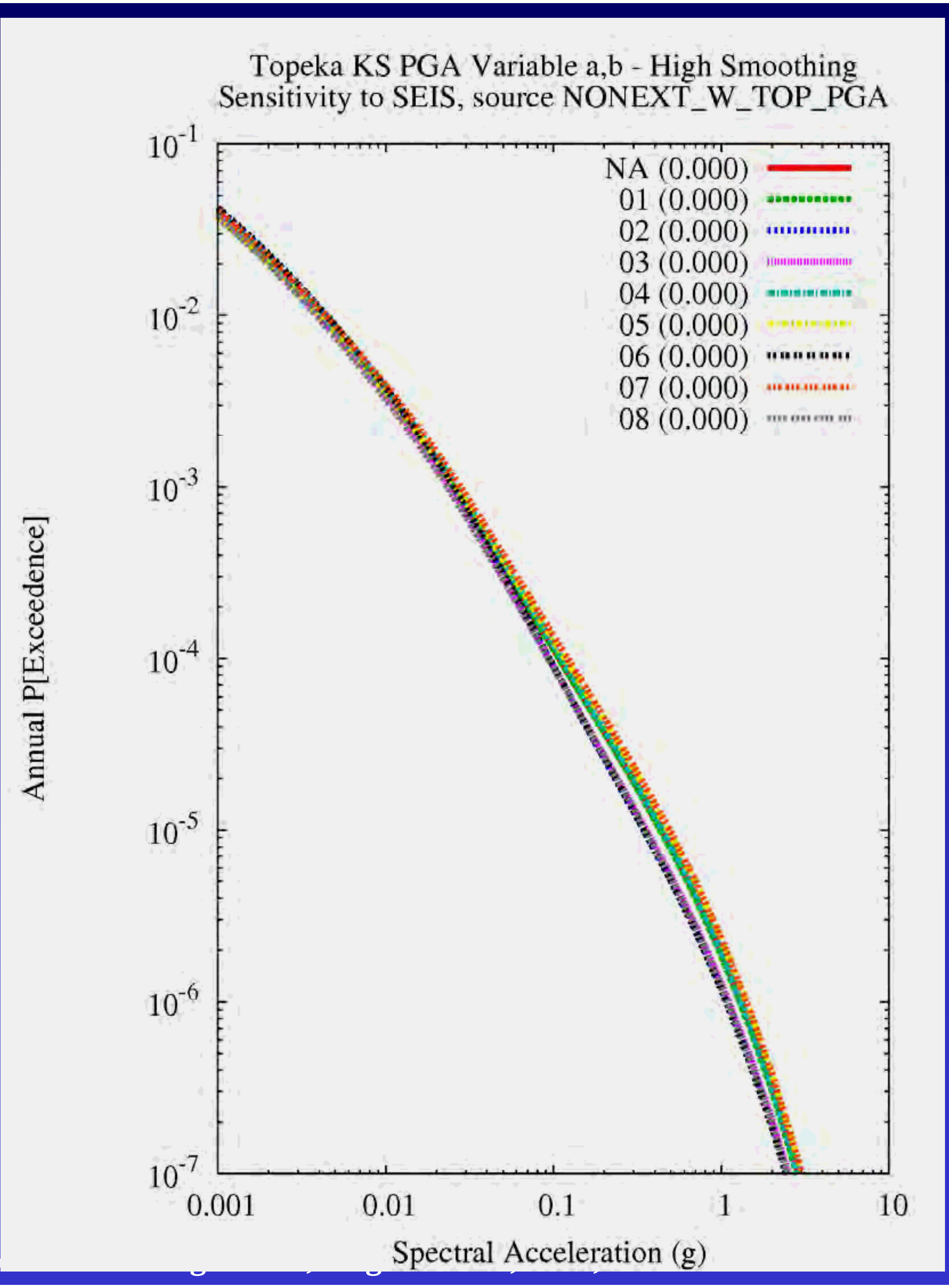
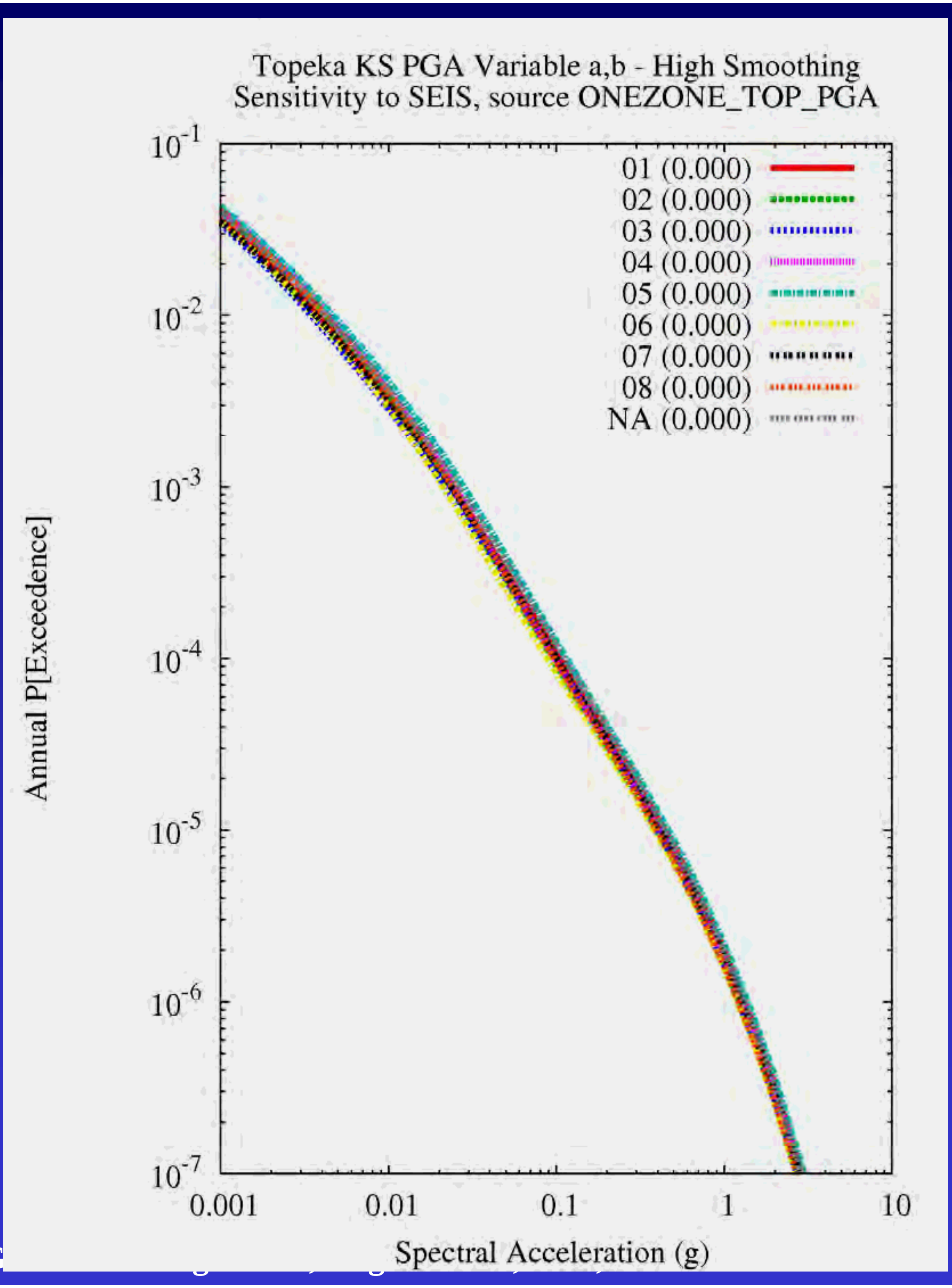


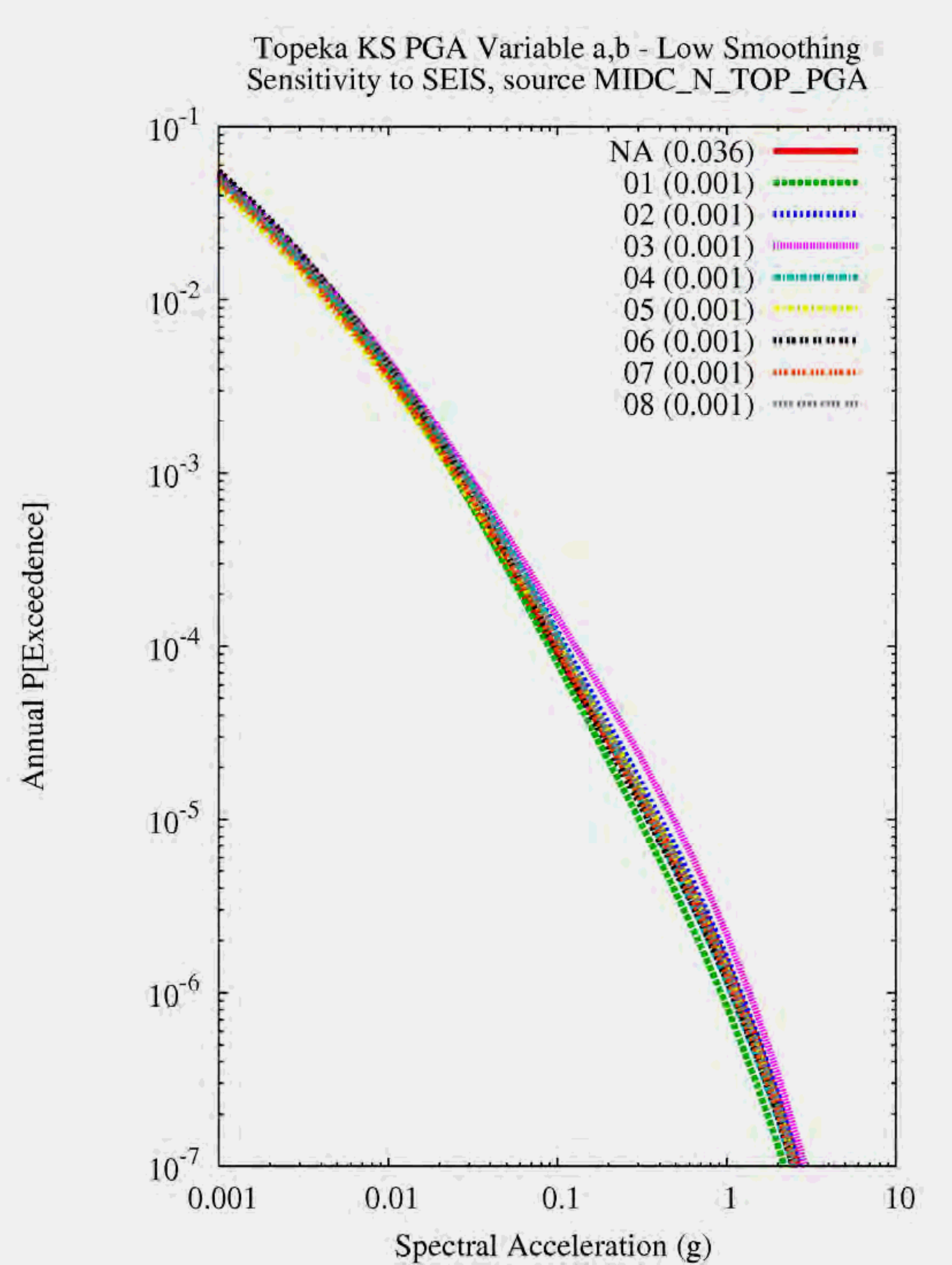
William Lettis & Associates, Inc.

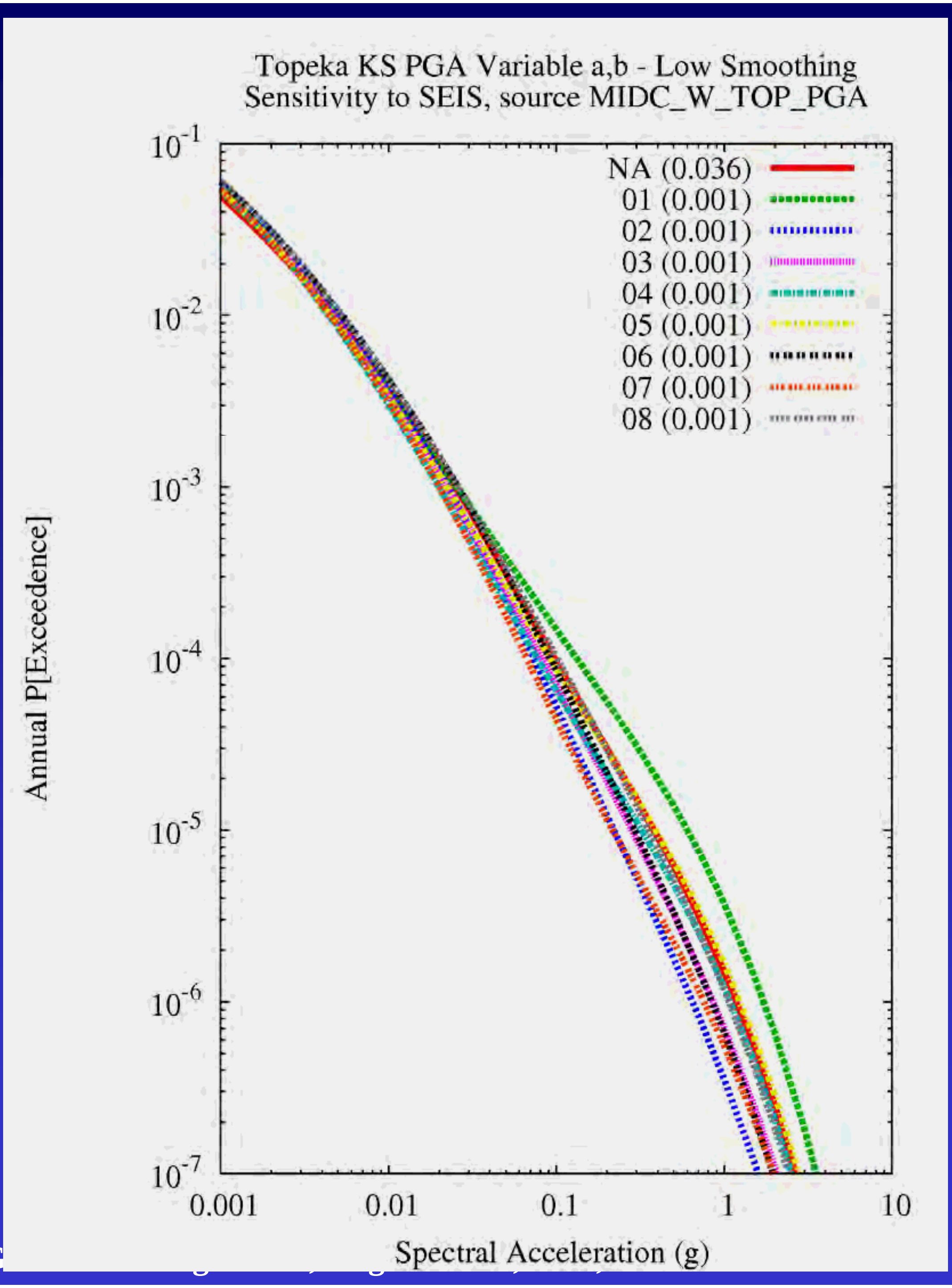

Topeka KS PGA Variable a,b - High Smoothing
Sensitivity to SEIS, source NONEXT_W_TOP_PGA
Annual P[Exceedence]
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
0.001
0.01
0.1
1
10
Spectral Acceleration (g)
NA (0.000)
01 (0.000)
02 (0.000)
03 (0.000)
04 (0.000)
05 (0.000)
06 (0.000)
07 (0.000)
08 (0.000)



William Lettis & Associates, Inc.

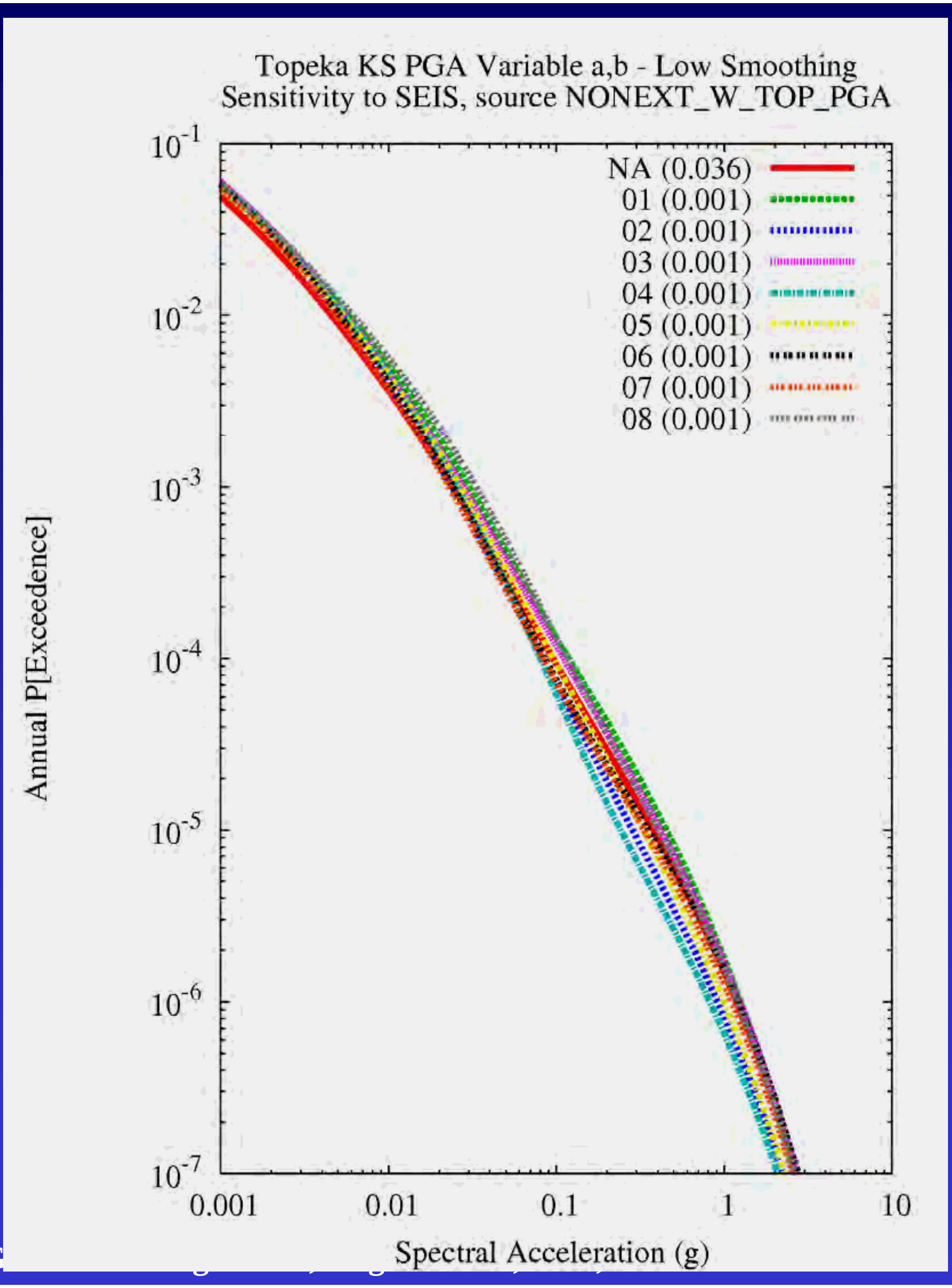
RISK ENGINEERING


Topeka KS PGA Variable a,b - Low Smoothing
Sensitivity to SEIS, source MIDC_N_TOP_PGA
Annual P[Exceedence]
Spectral Acceleration (g)
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
0.001
0.01
0.1
1
10
NA (0.036)
01 (0.001)
02 (0.001)
03 (0.001)
04 (0.001)
05 (0.001)
06 (0.001)
07 (0.001)
08 (0.001)



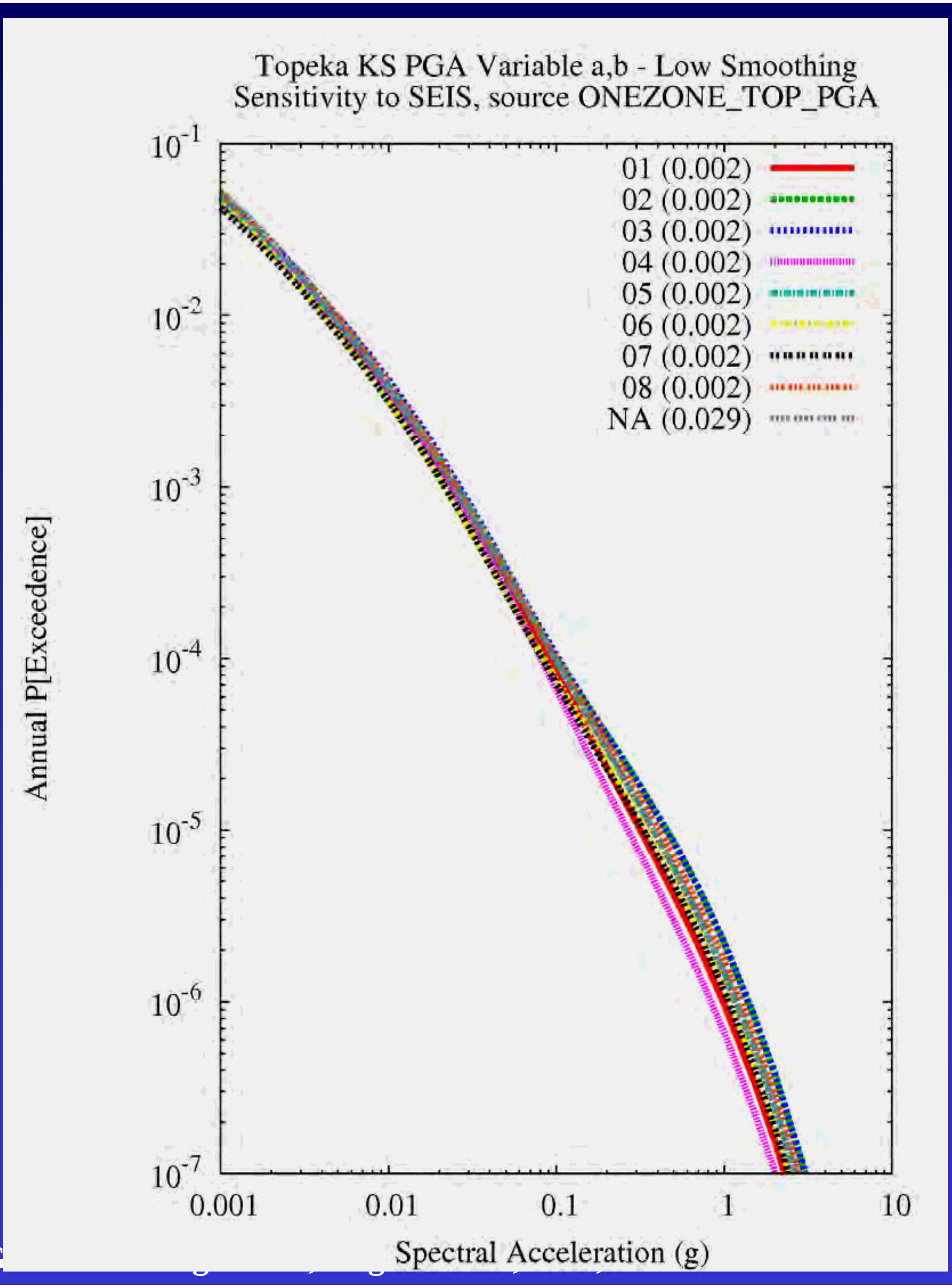
William Lettis & Associates, Inc.

RISK ENGINEERING



William Lettis & Associates, Inc.

RISK ENGINEERING


Topeka KS PGA Variable a,b - Low Smoothing
Sensitivity to SEIS, source ONEZONE_TOP_PGA

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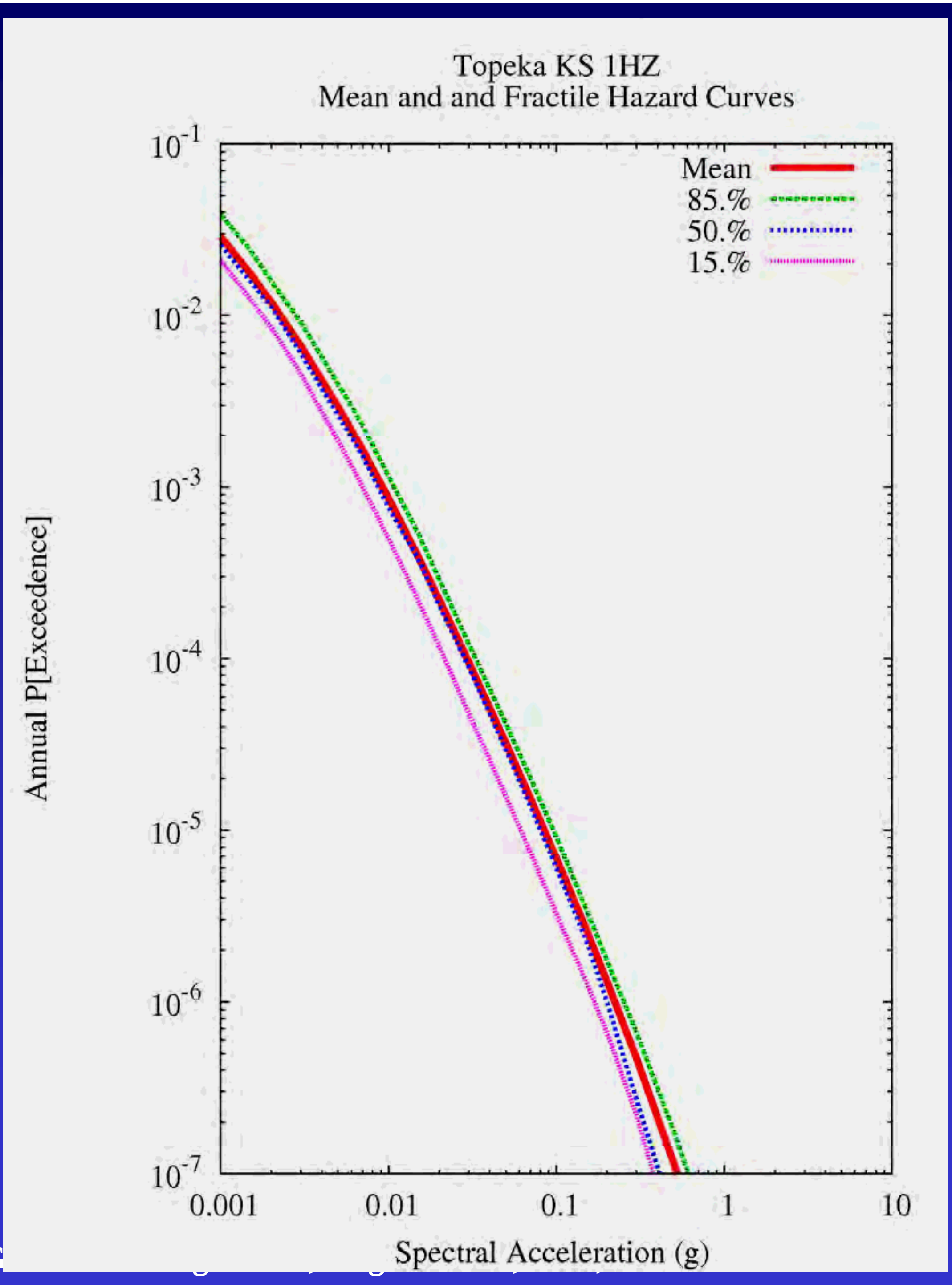
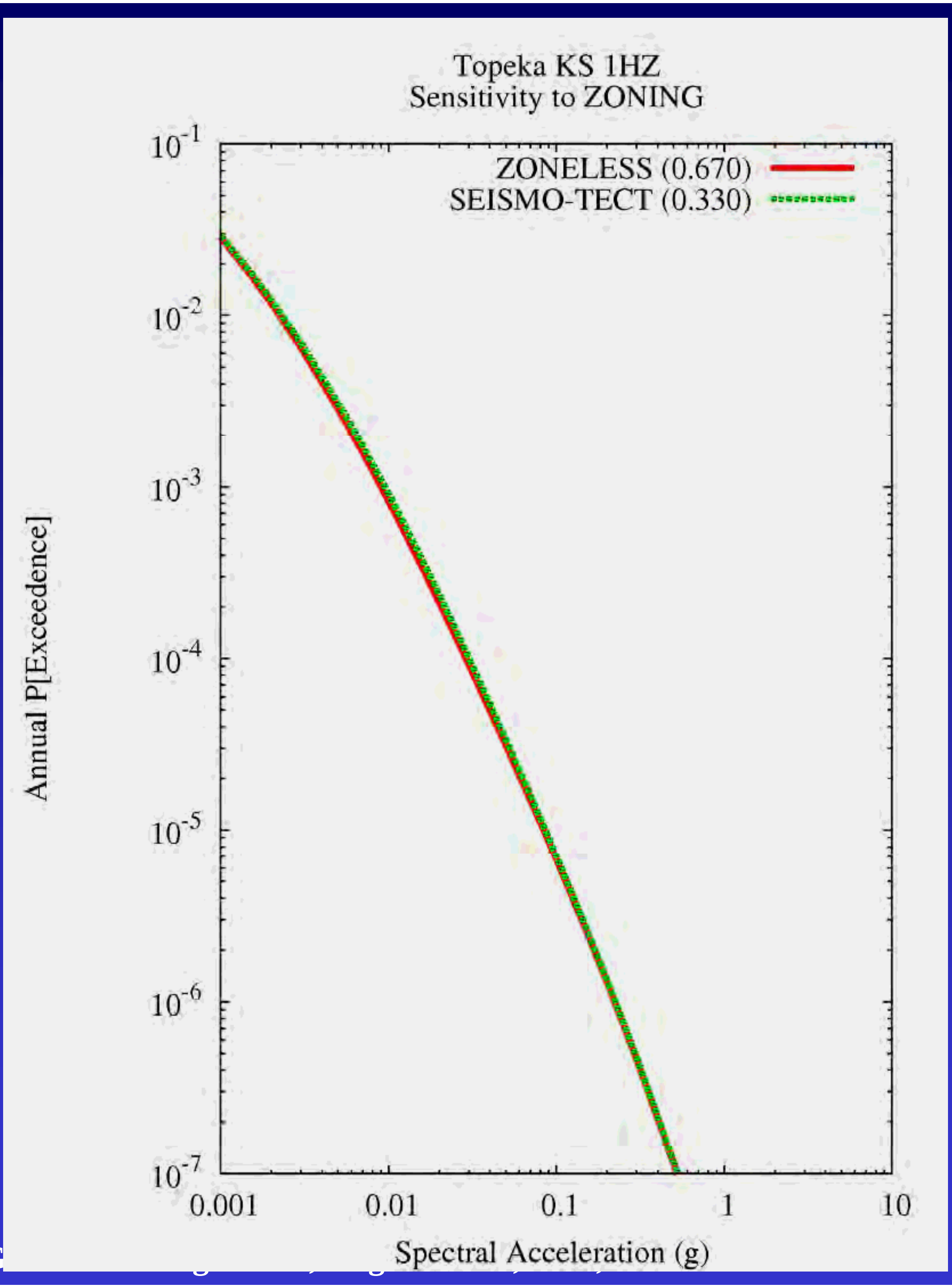
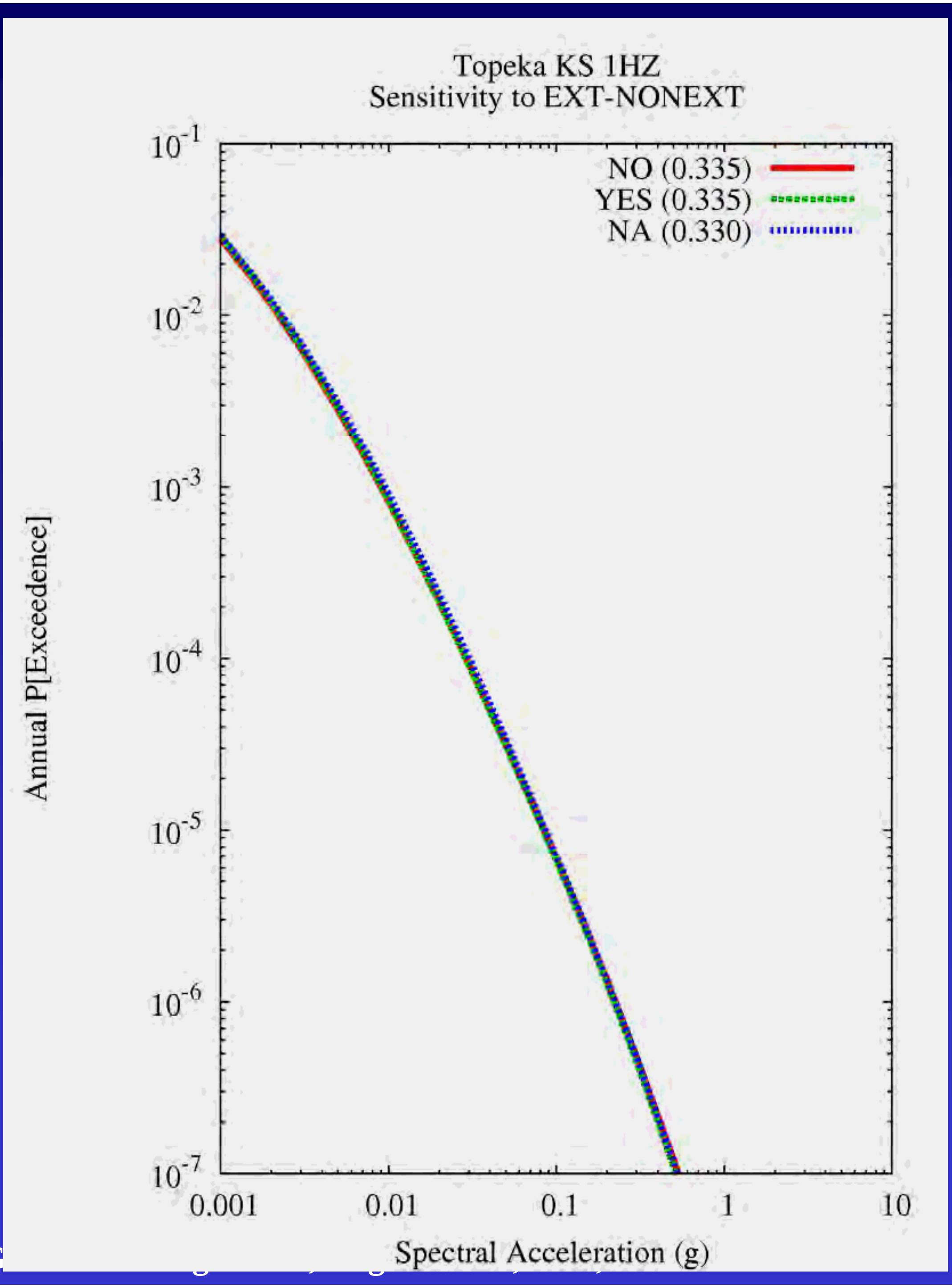
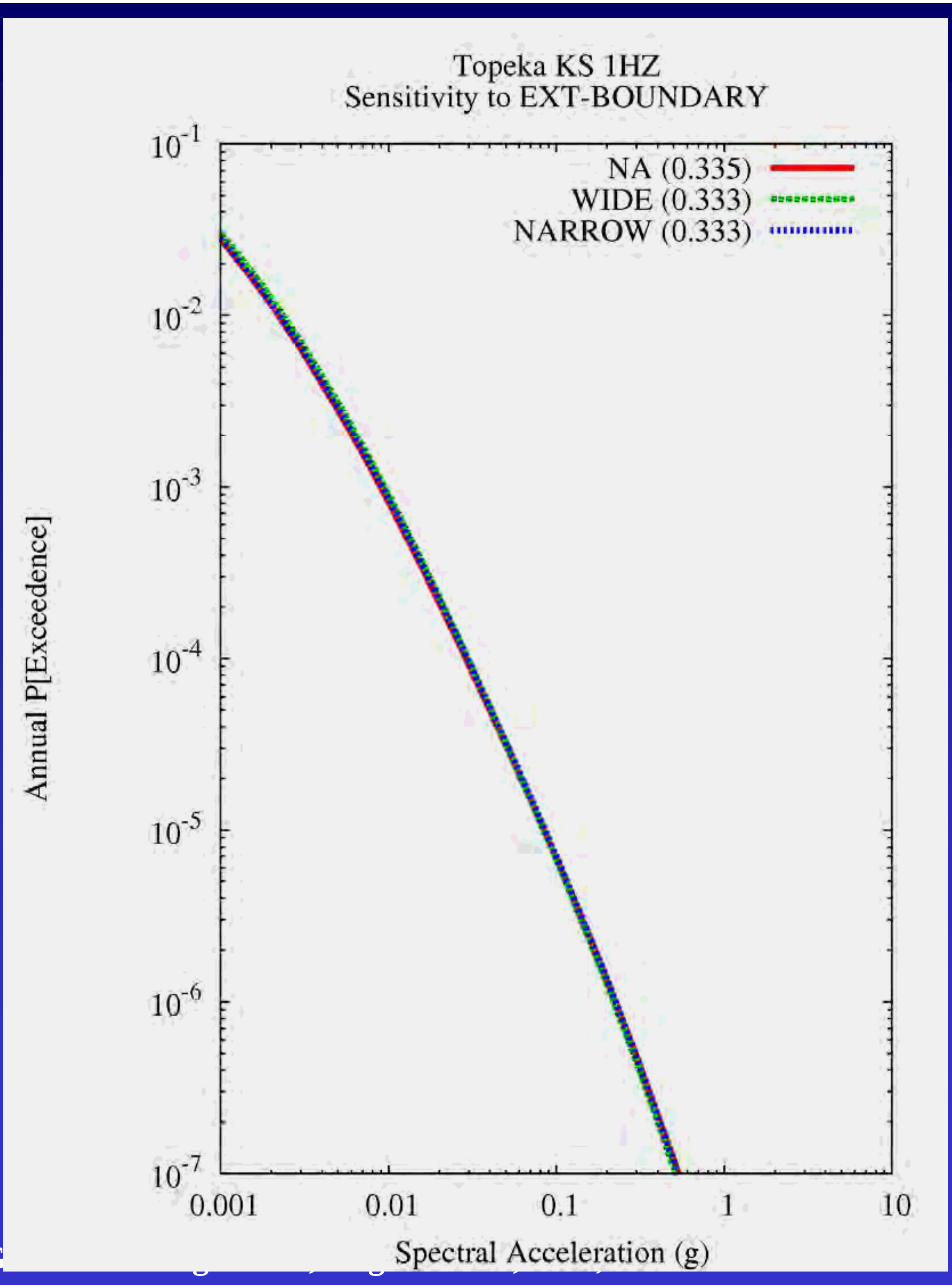

Topeka KS 1HZ
Mean and and Fractile Hazard Curves
Mean
85.%
50.%
15.%
Annual P[Exceedence]
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
0.001
0.01
0.1
1
10
Spectral Acceleration (g)


Topeka KS 1HZ
Sensitivity to ZONING
ZONELESS (0.670)
SEISMO-TECT (0.330)
Annual P[Exceedence]
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
0.001
0.01
0.1
1
10
Spectral Acceleration (g)


Topeka KS 1HZ
Sensitivity to EXT-NONEXT
NO (0.335)
YES (0.335)
NA (0.330)
Annual P[Exceedence]
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
0.001
0.01
0.1
1
10
Spectral Acceleration (g)



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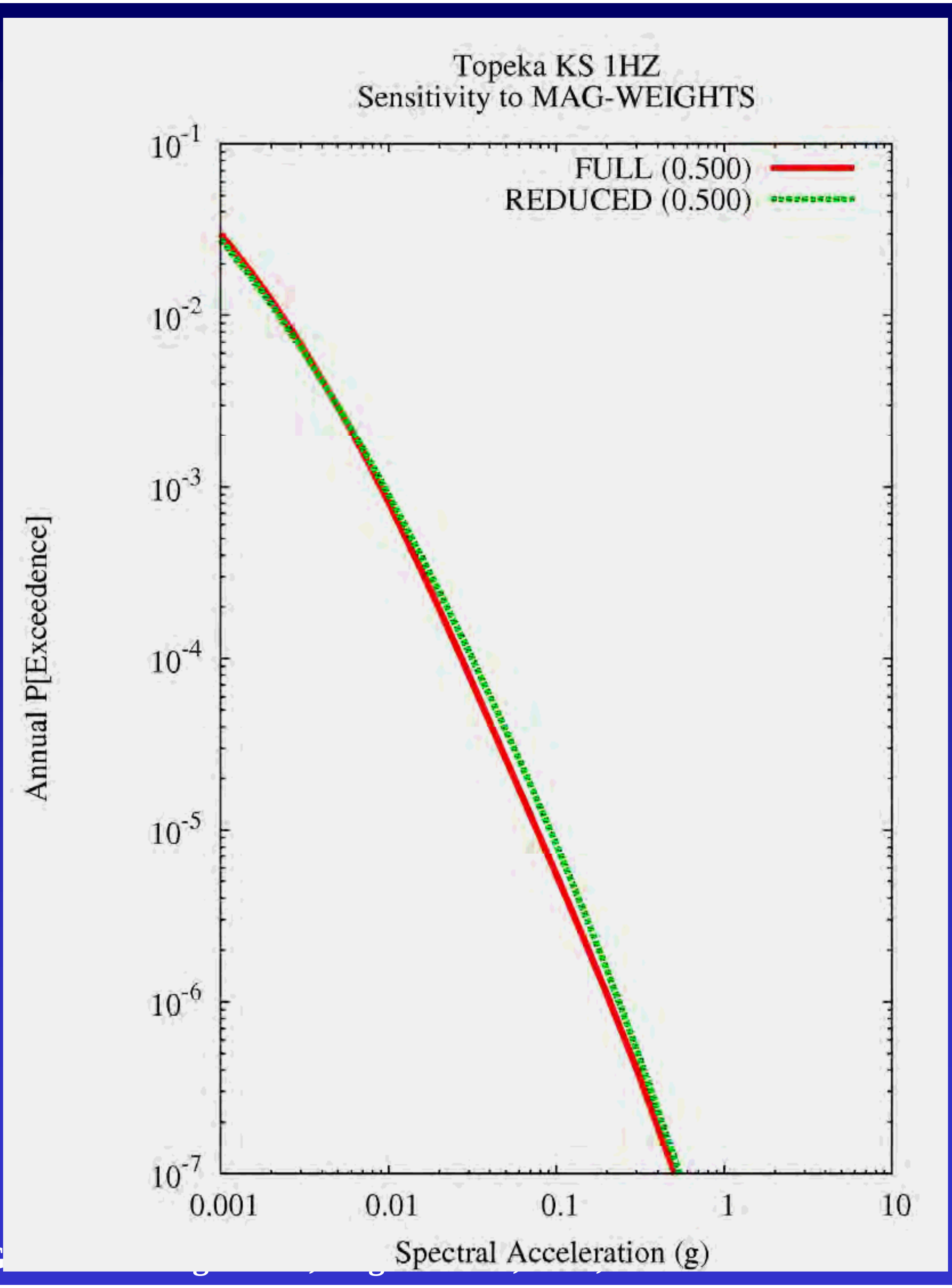
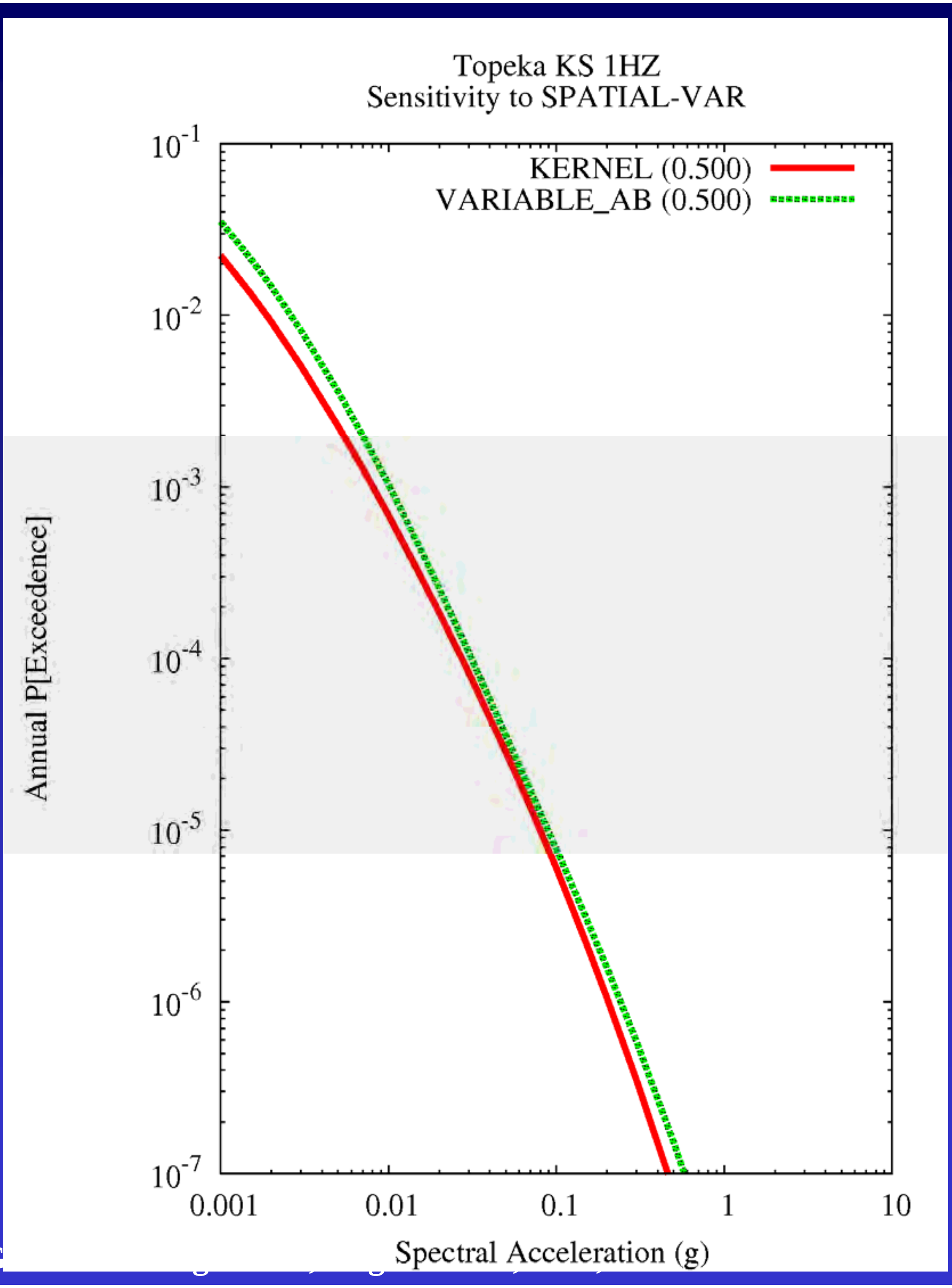

Topeka KS 1HZ
Sensitivity to MAG-WEIGHTS
FULL (0.500)
REDUCED (0.500)
Annual P[Exceedence]
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
0.001
0.01
0.1
1
10
Spectral Acceleration (g)



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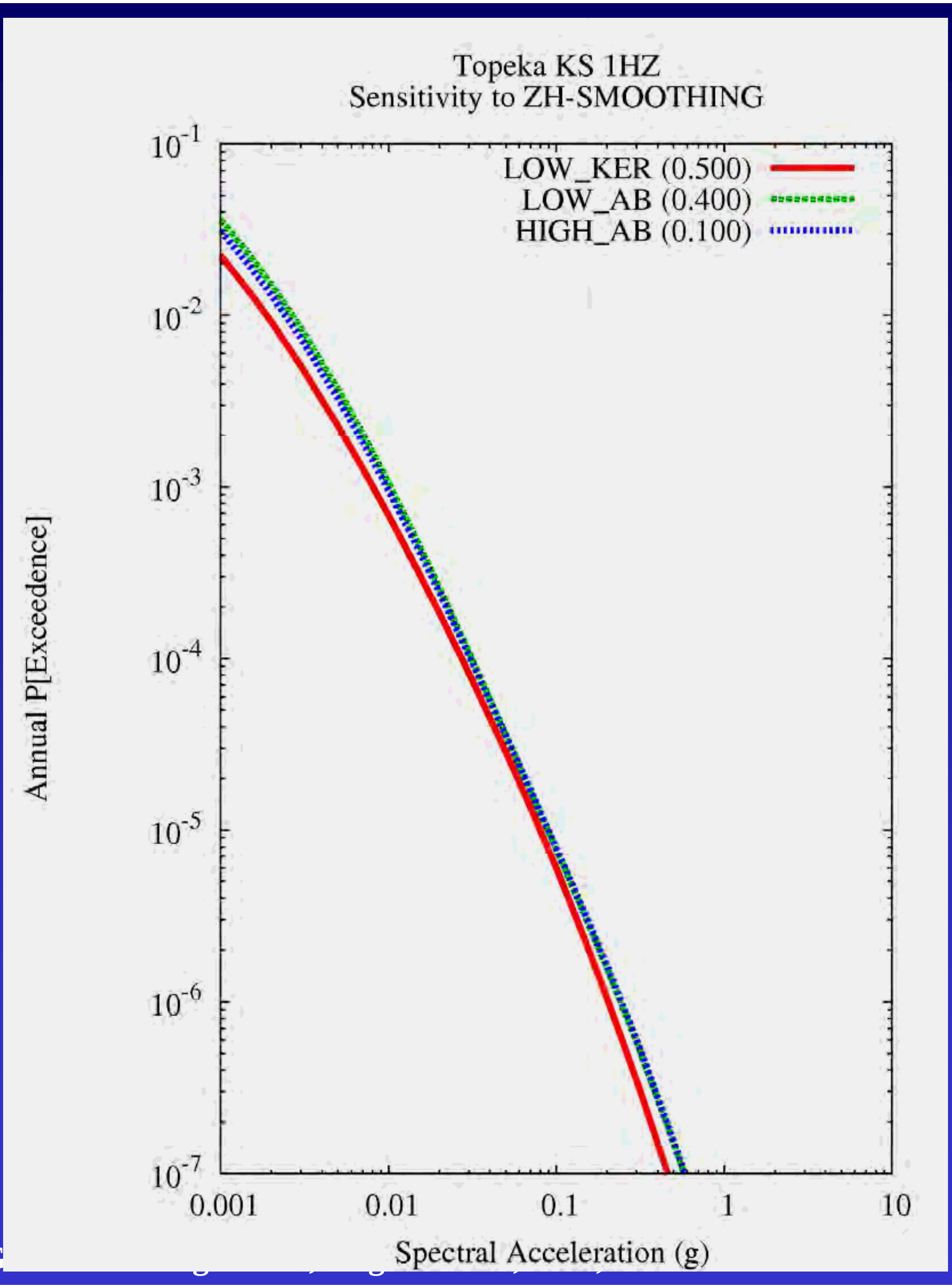

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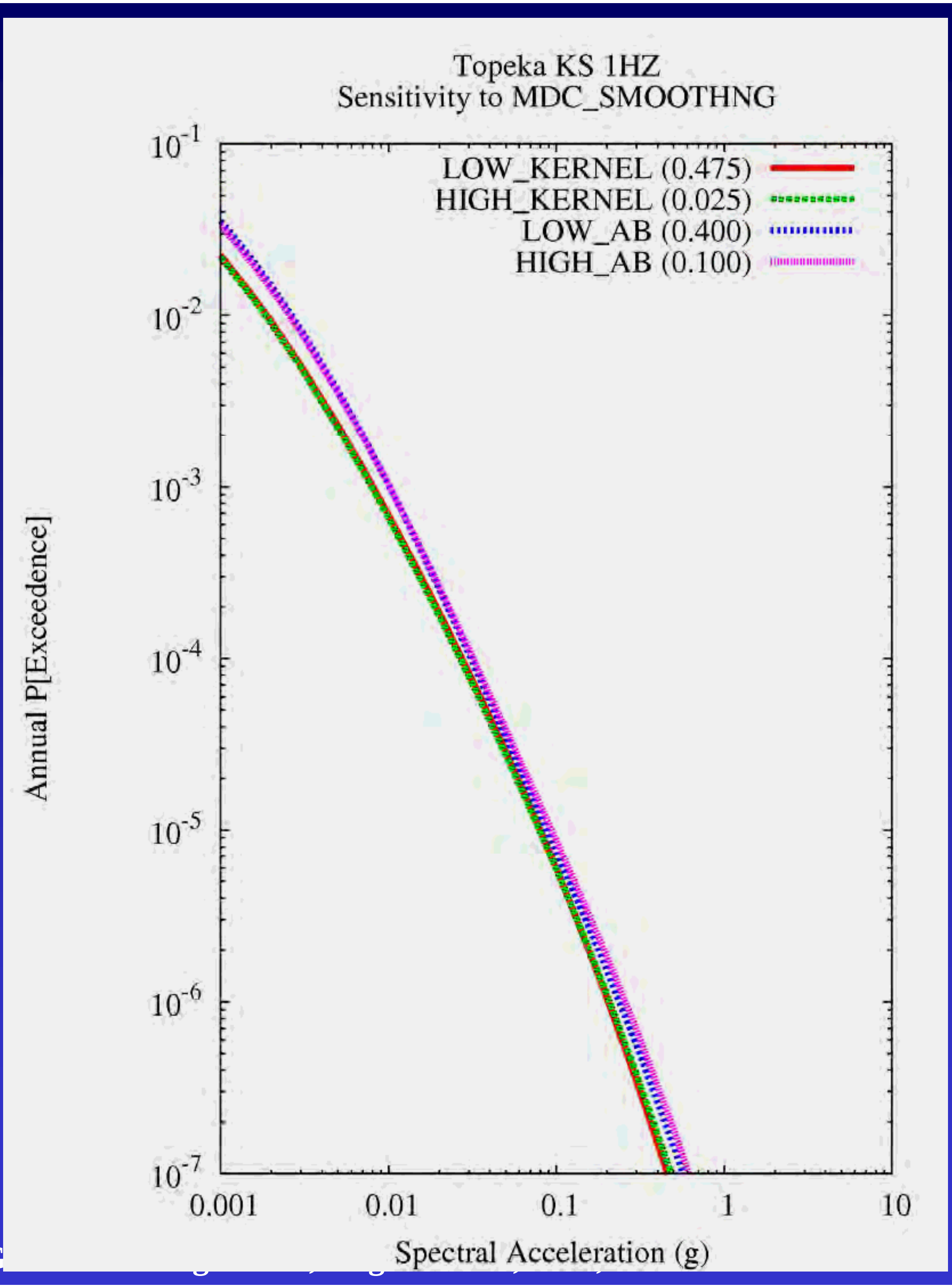
RISK ENGINEERING



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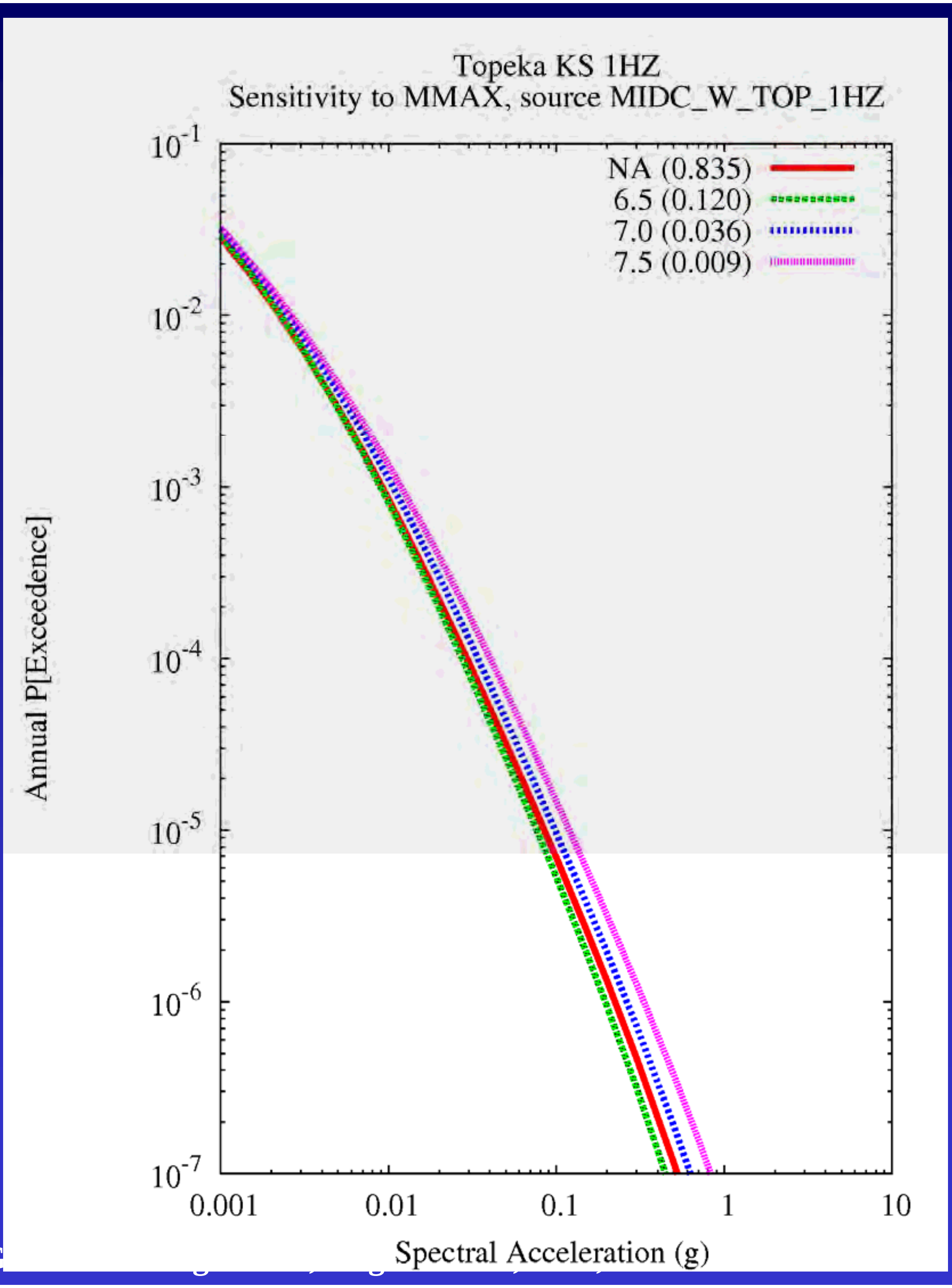
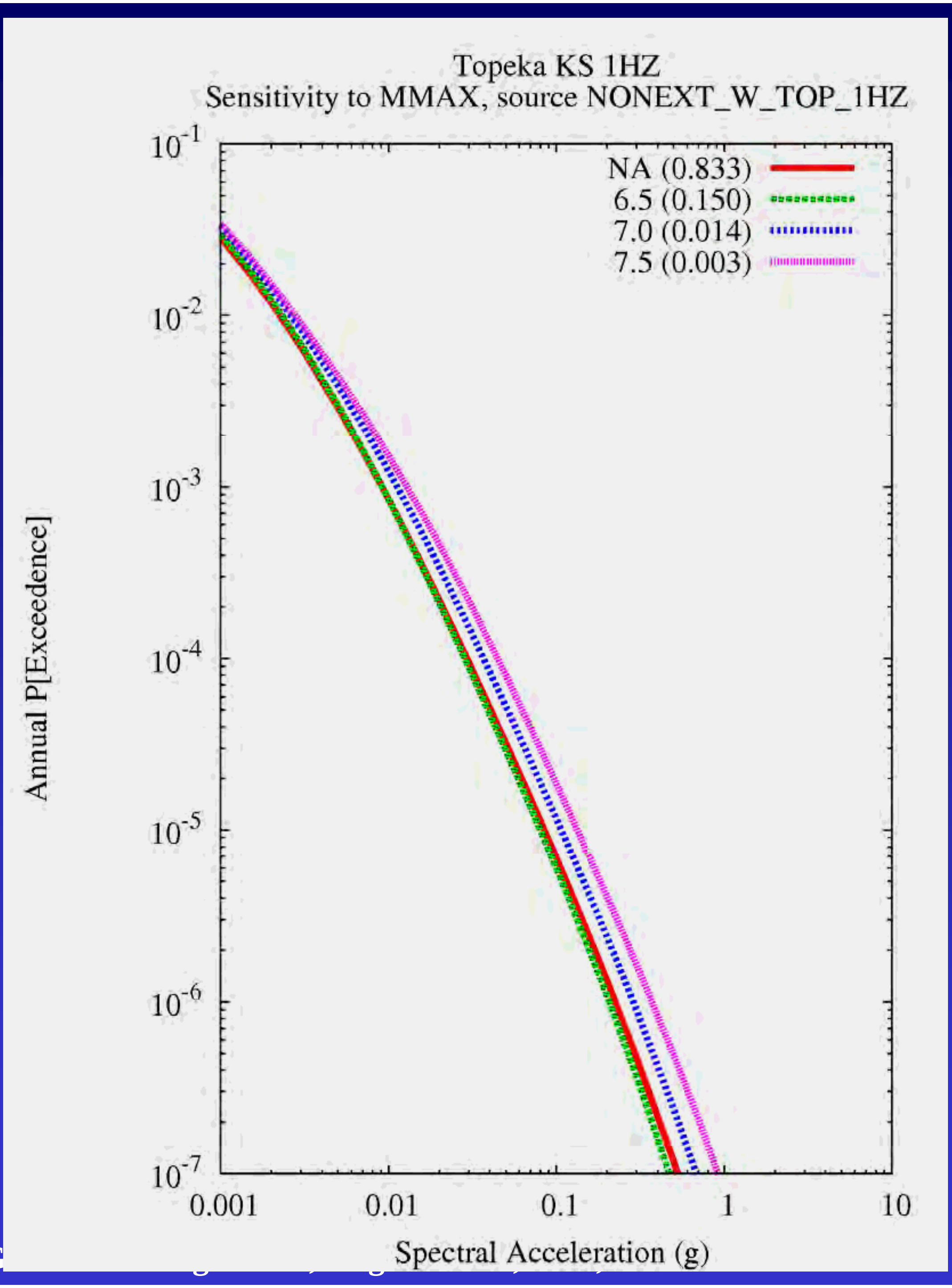
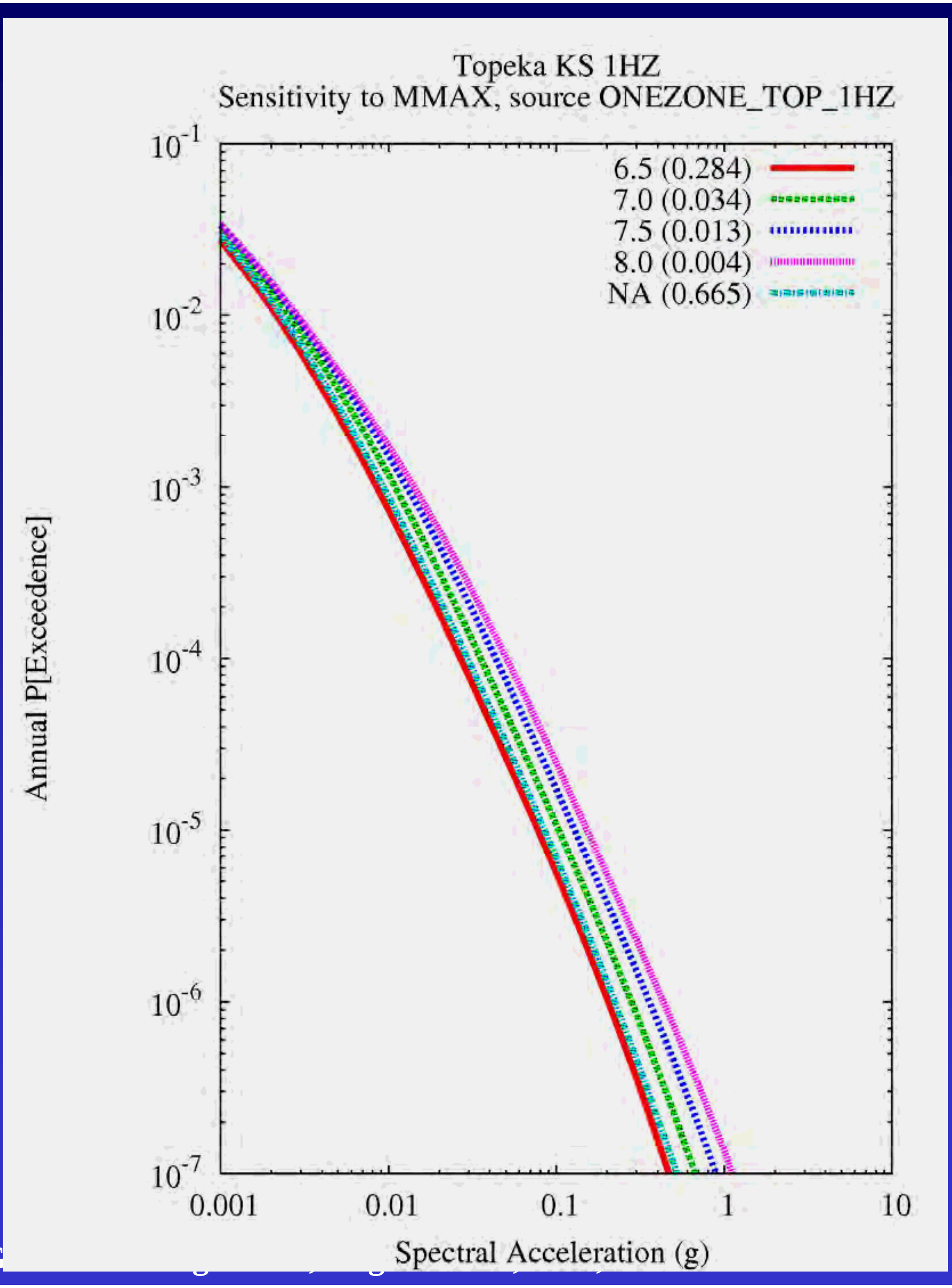
RISK ENGINEERING

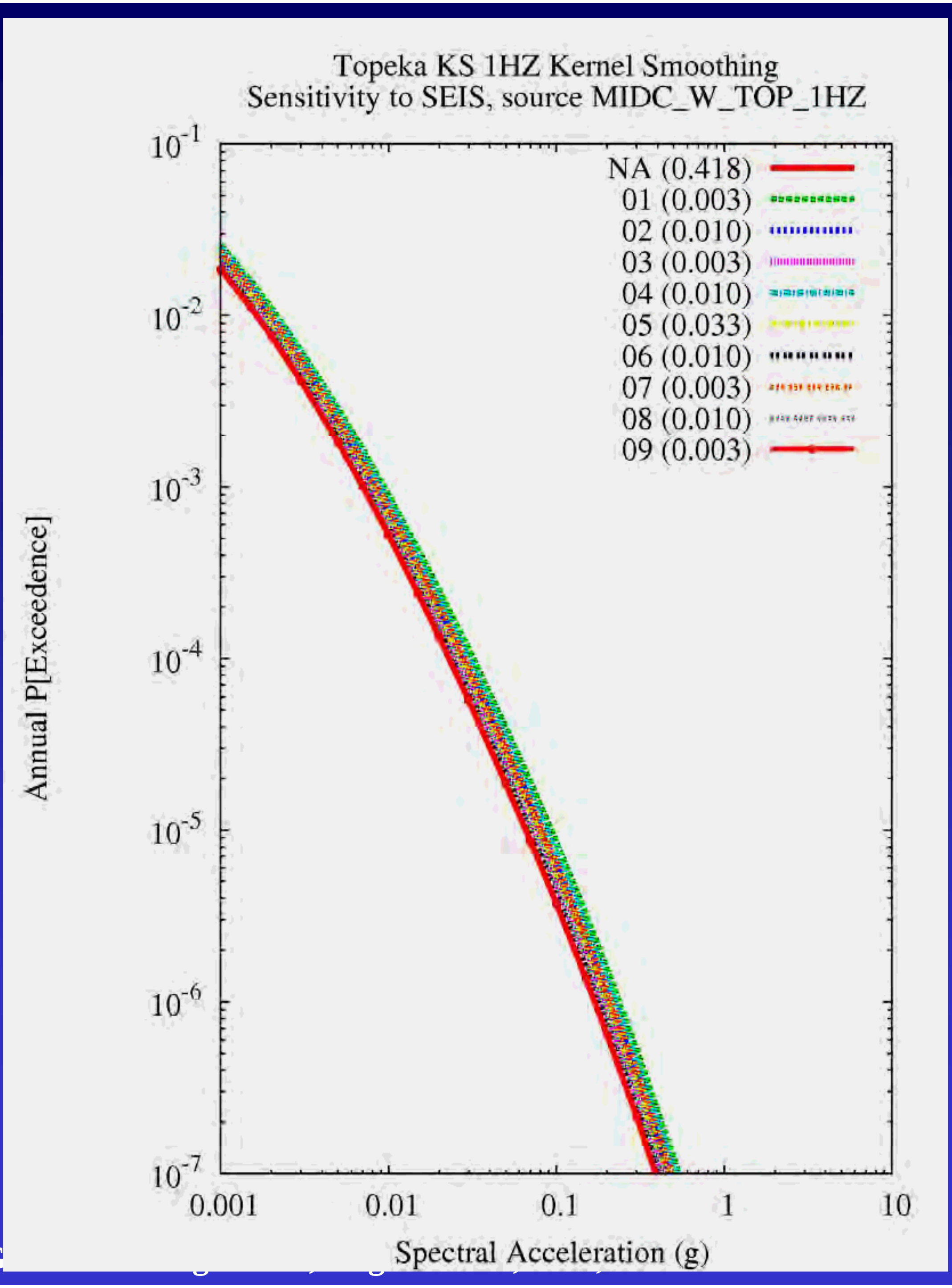

Topeka KS 1HZ
Sensitivity to MMAX, source MIDC_W_TOP_1HZ
NA (0.835)
6.5 (0.120)
7.0 (0.036)
7.5 (0.009)
Annual P[Exceedence]
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
0.001
0.01
0.1
1
10
Spectral Acceleration (g)


Topeka KS 1HZ
Sensitivity to MMAX, source NONEXT_W_TOP_1HZ
NA (0.833)
6.5 (0.150)
7.0 (0.014)
7.5 (0.003)
Annual P[Exceedence]
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
0.001
0.01
0.1
1
10
Spectral Acceleration (g)



William Lettis & Associates, Inc.

RISK ENGINEERING



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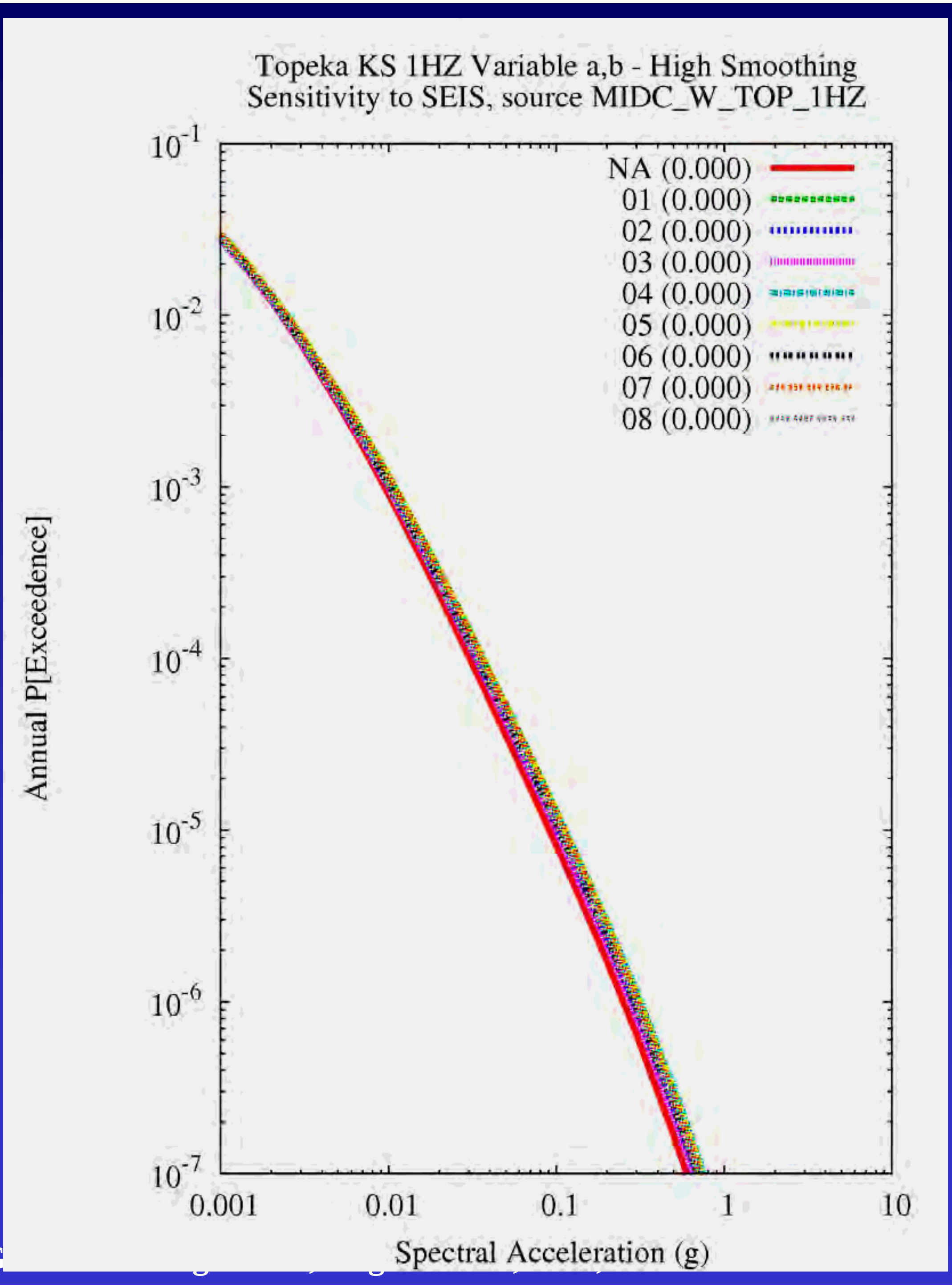
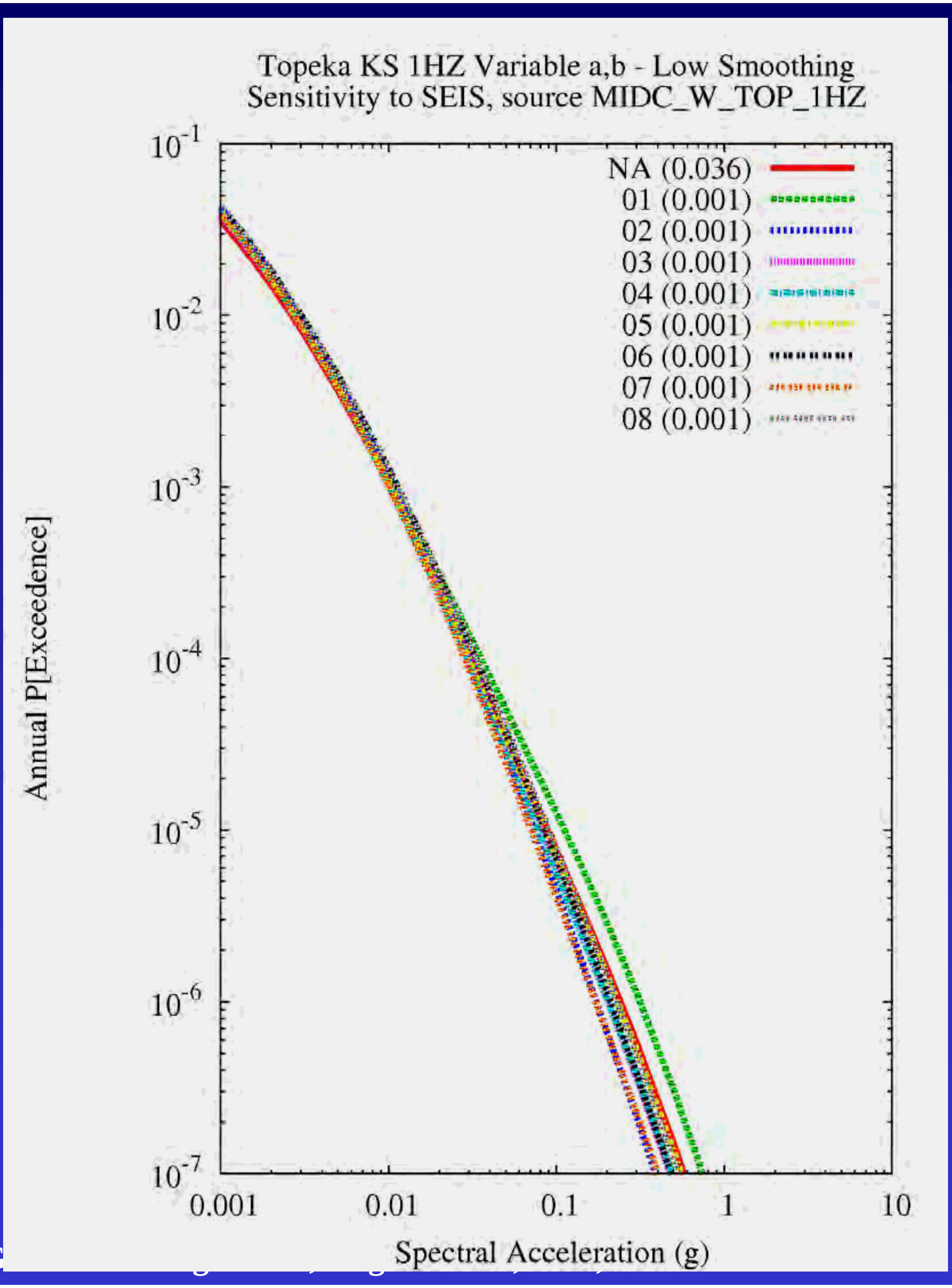


William Lettis & Associates, Inc.

RISK ENGINEERING



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RISK ENGINEERING

Summary of Results for Great Plains Site

- Major contributors to uncertainty
  - Max. Magnitude (1 Hz only; moderate effect)
  - Smoothing Approach & uncertainty in smoothing (moderate)

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South of NMSZ site
(Jackson, MS)

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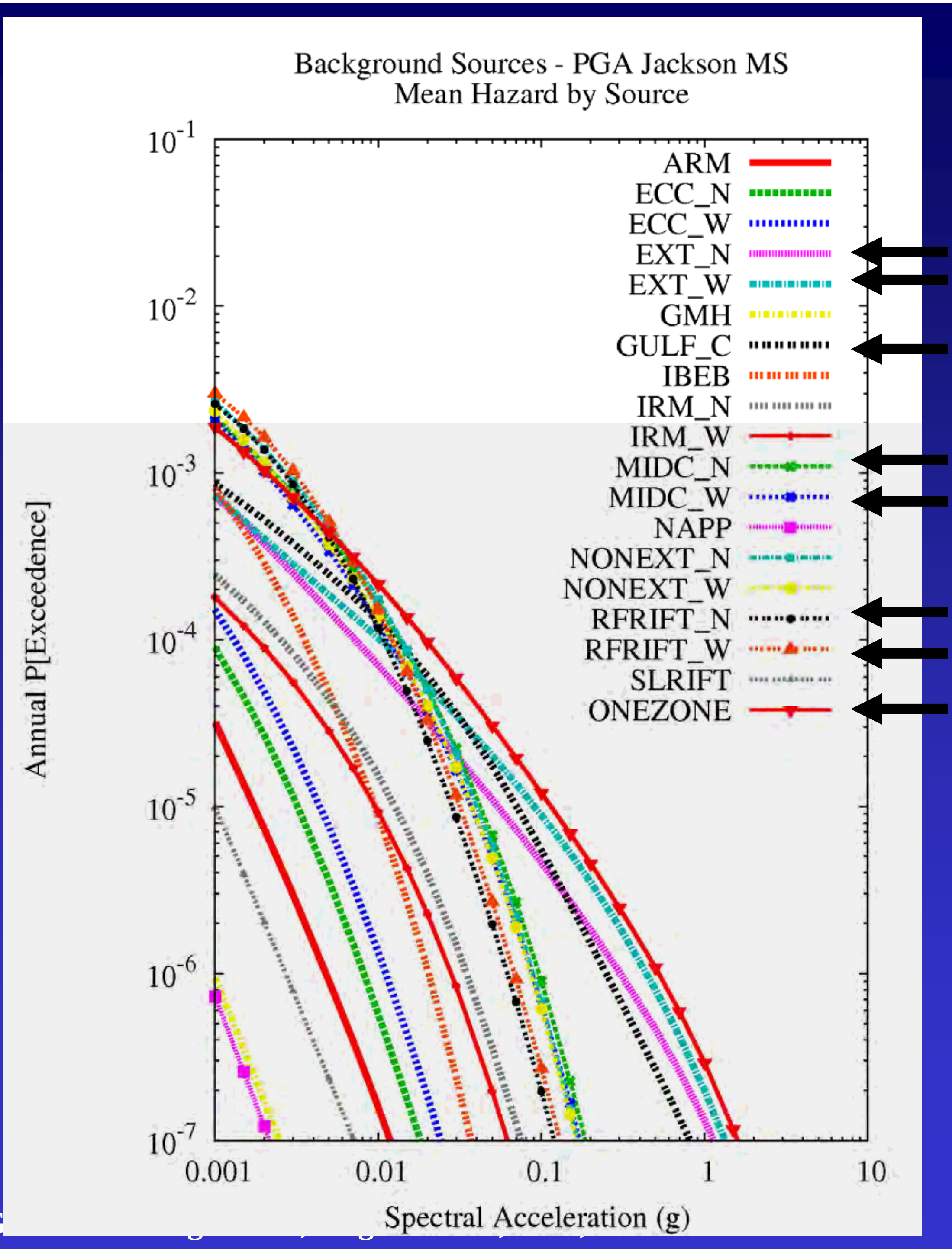

Background Sources - PGA Jackson MS
Mean Hazard by Source

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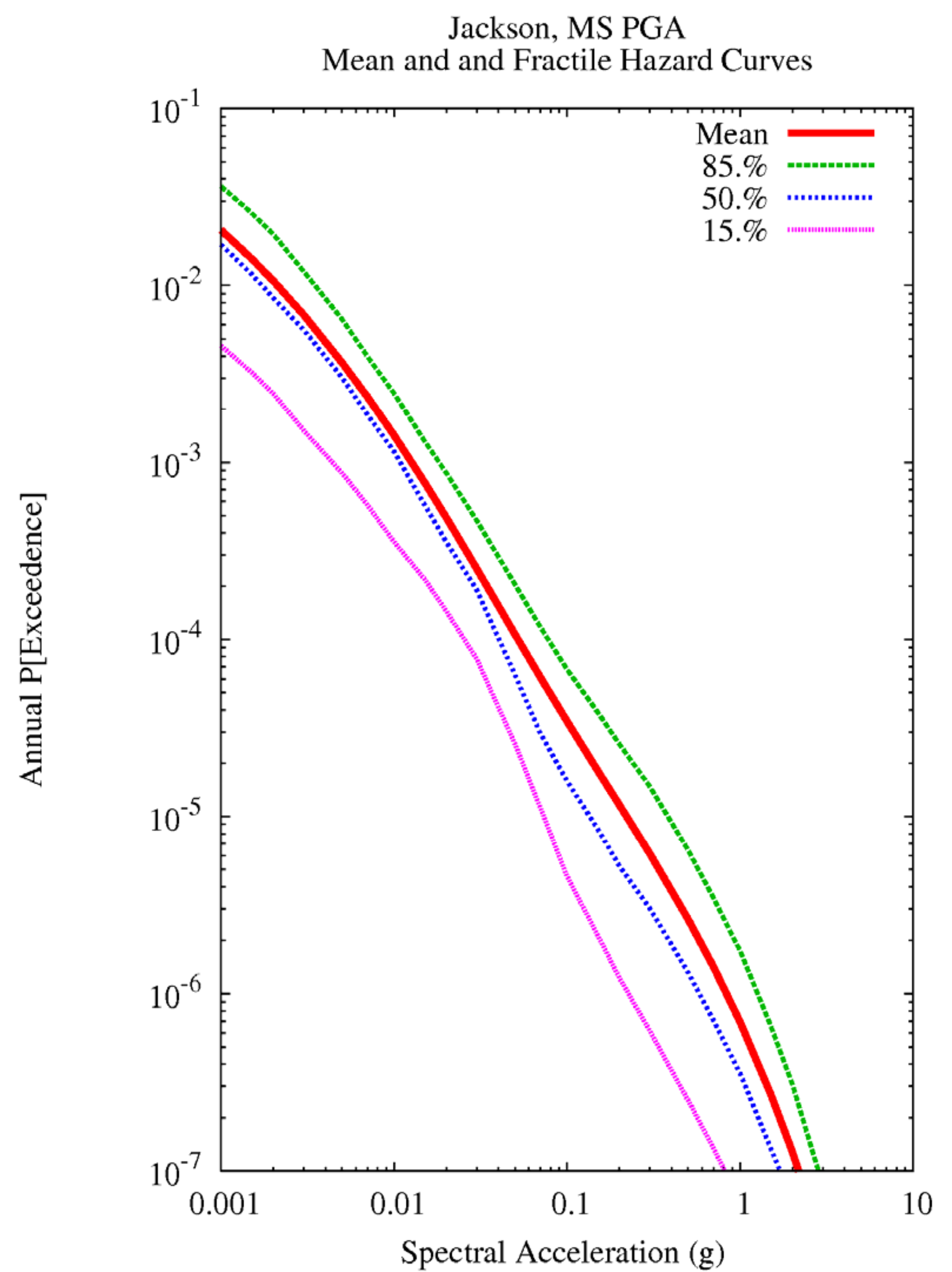

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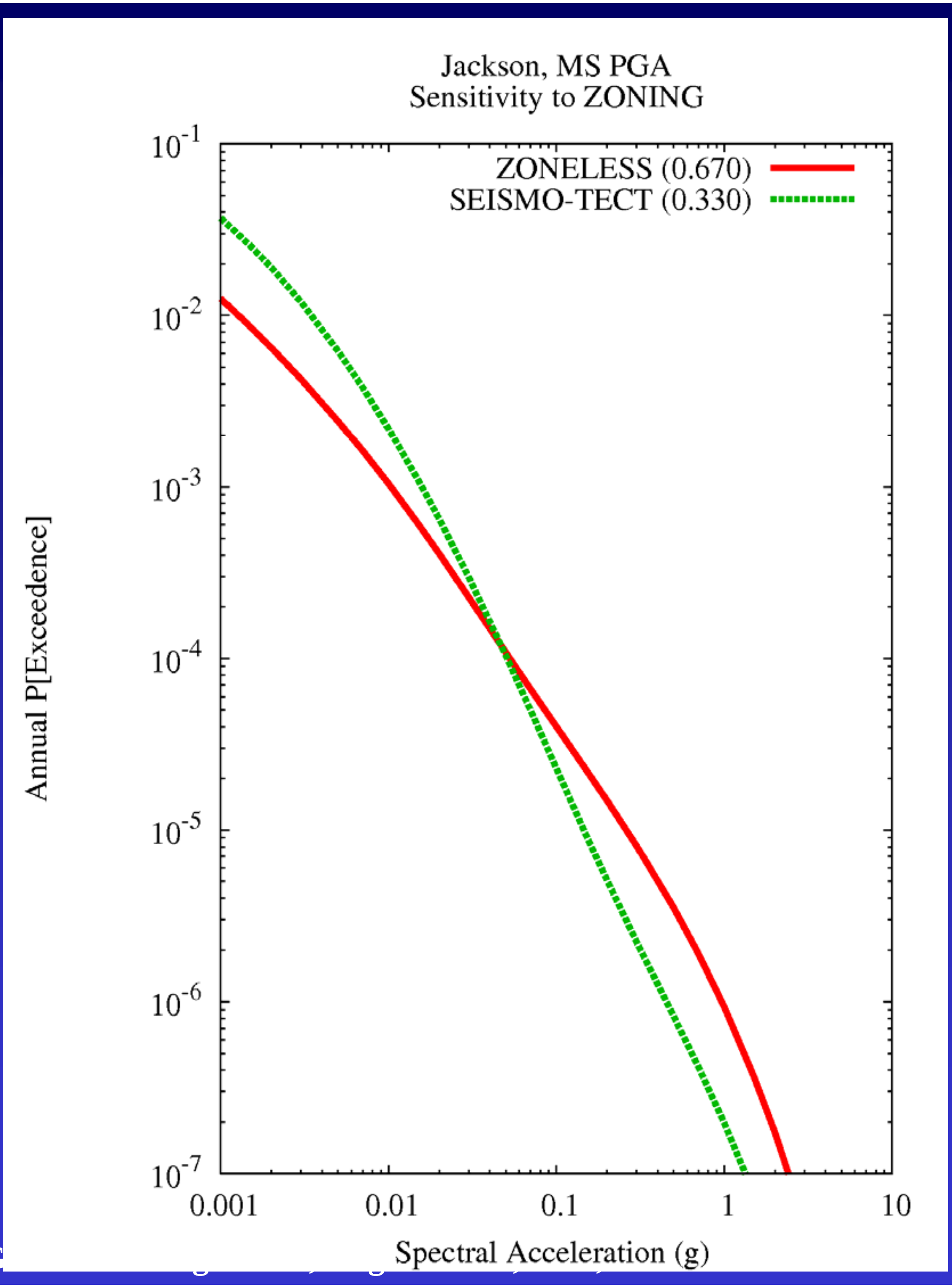

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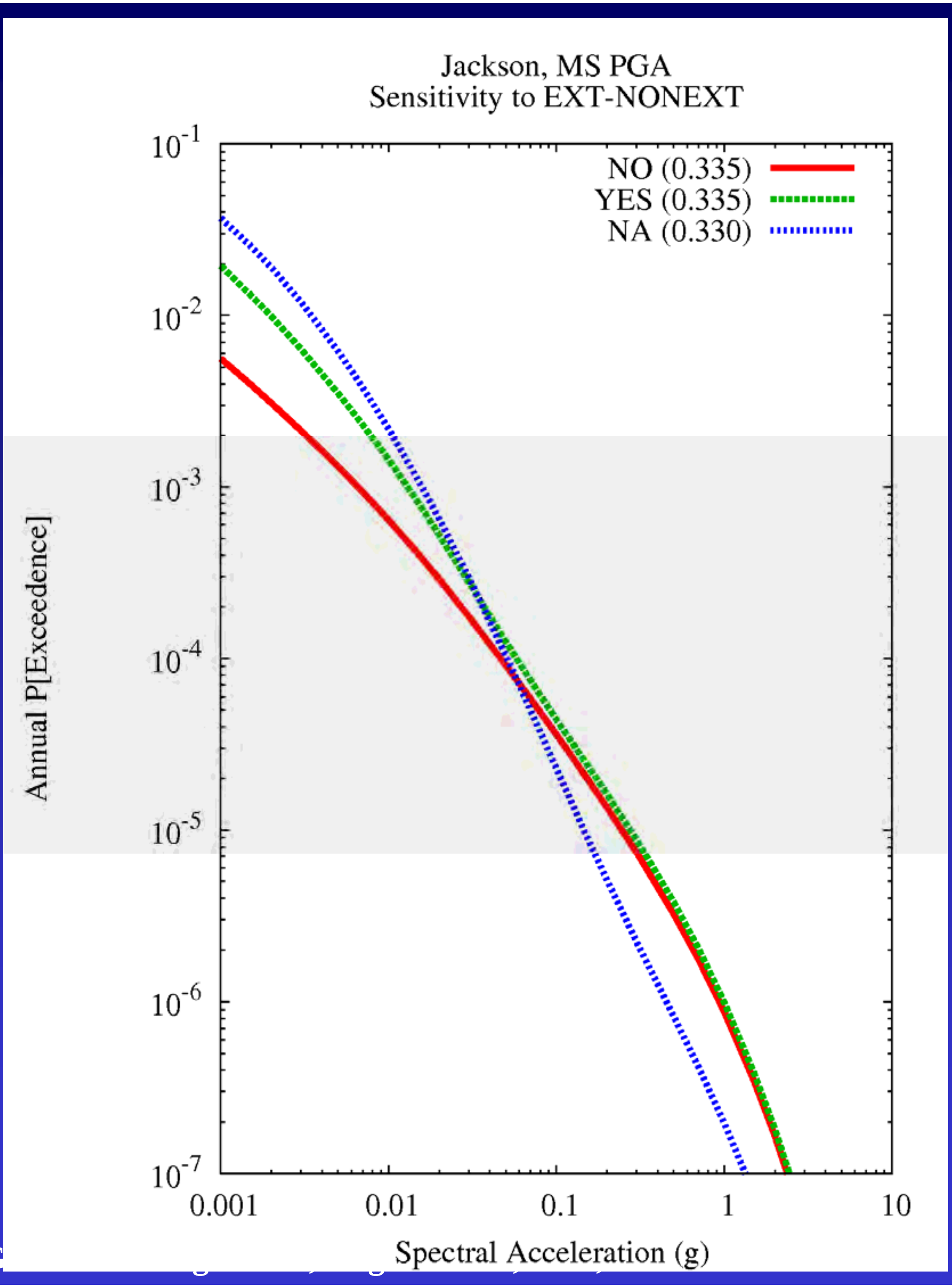
RISK
ENGINEERING



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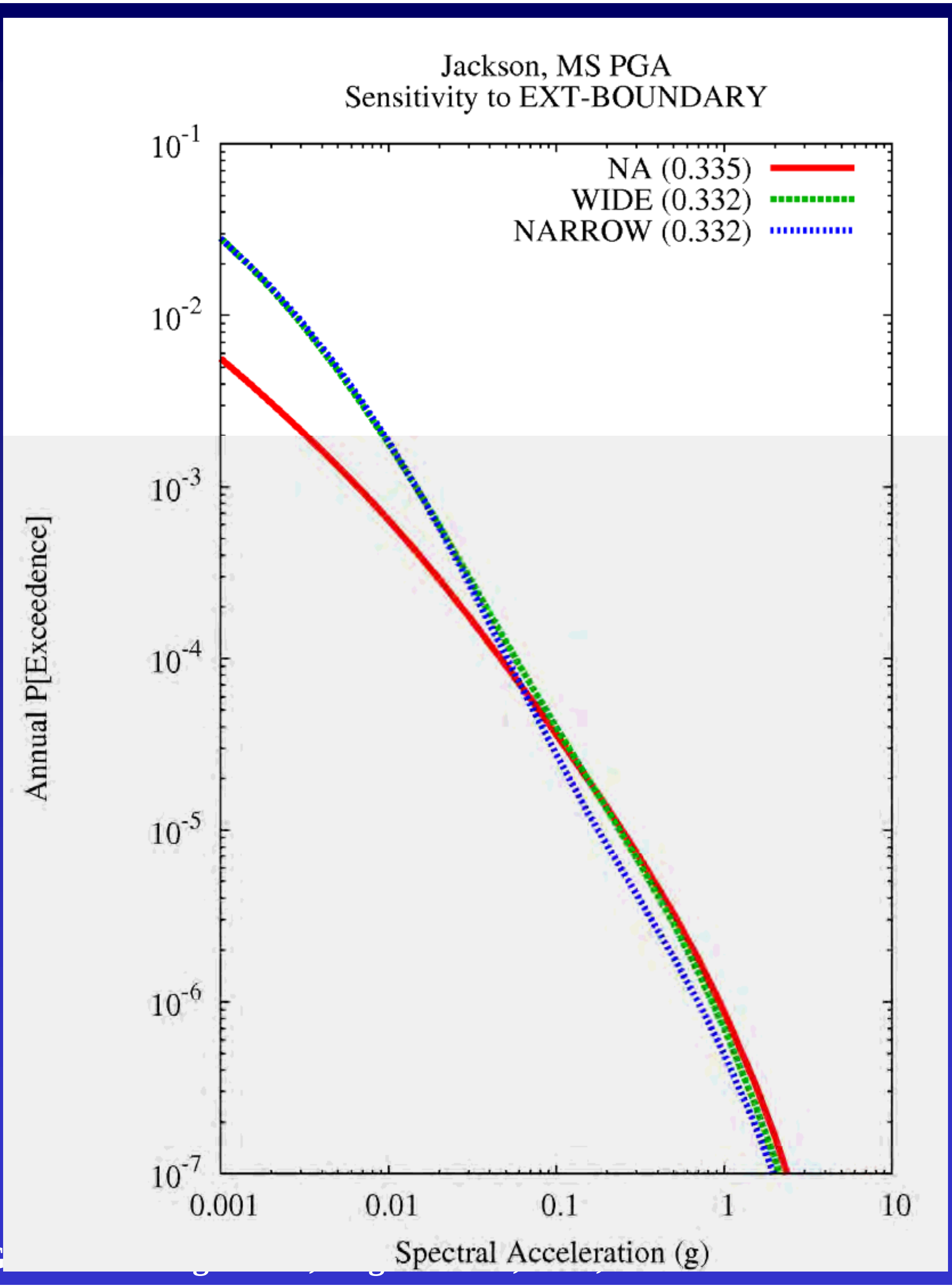
RISK ENGINEERING



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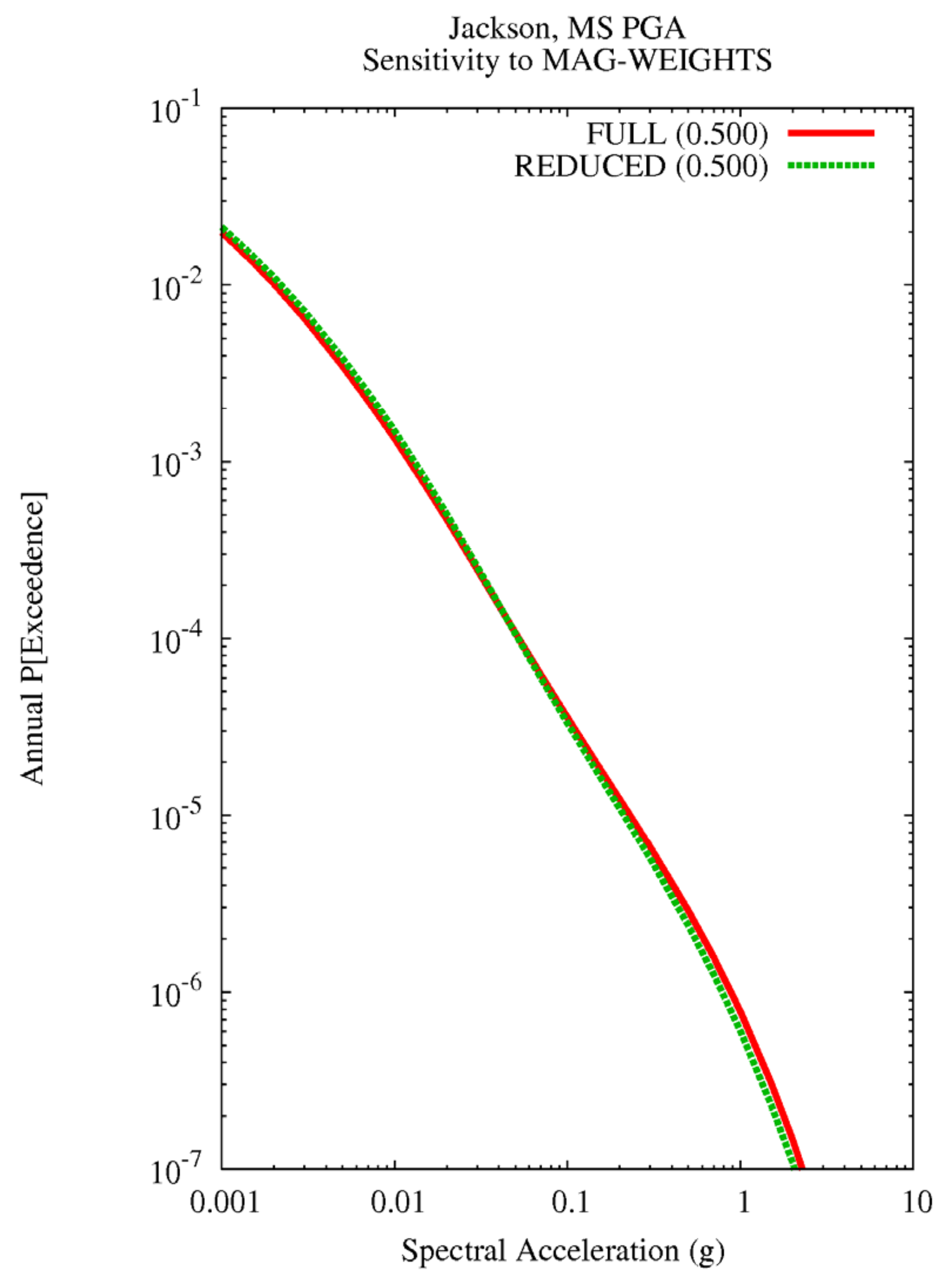
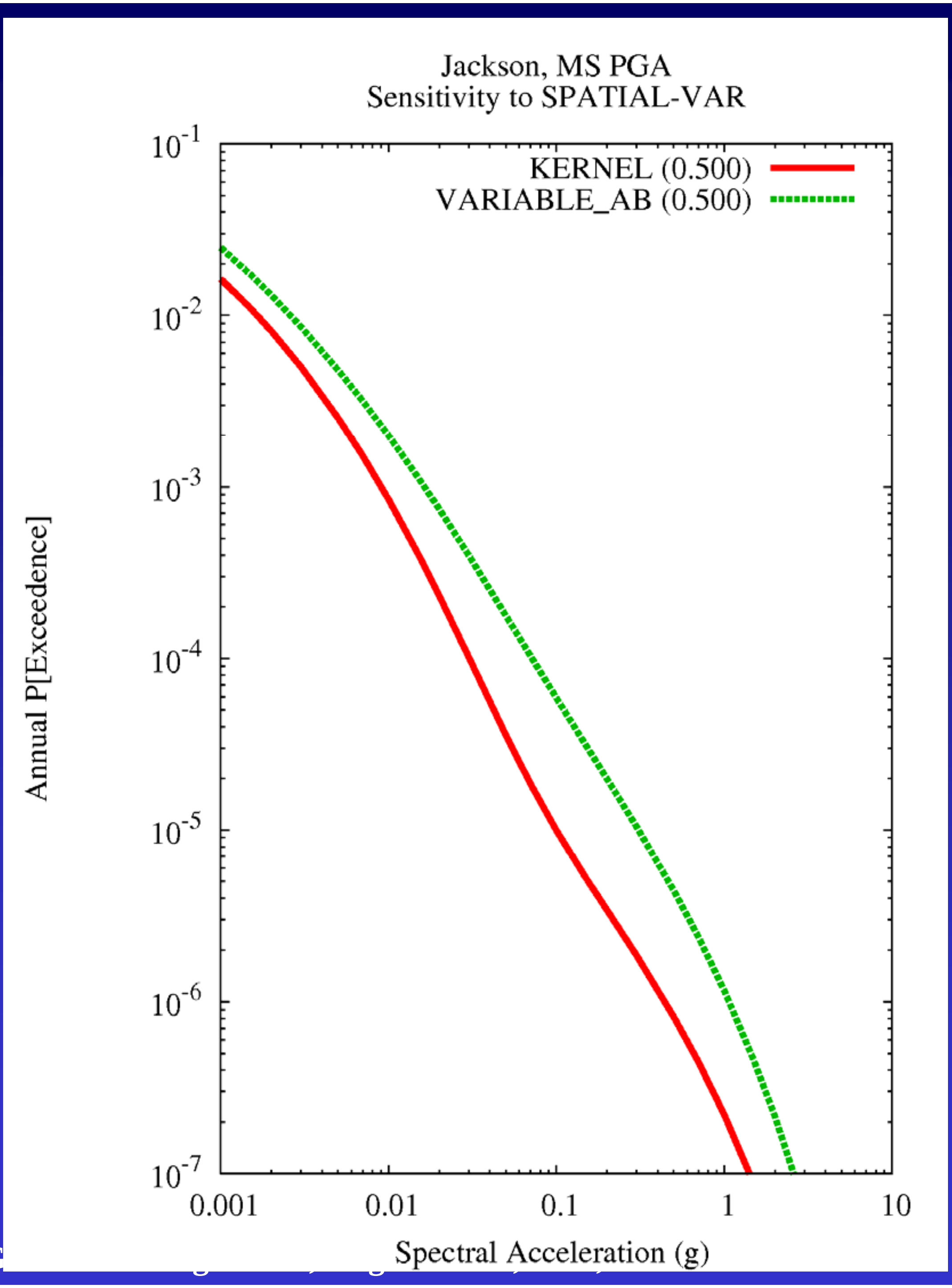
William Lettis & Associates, Inc.

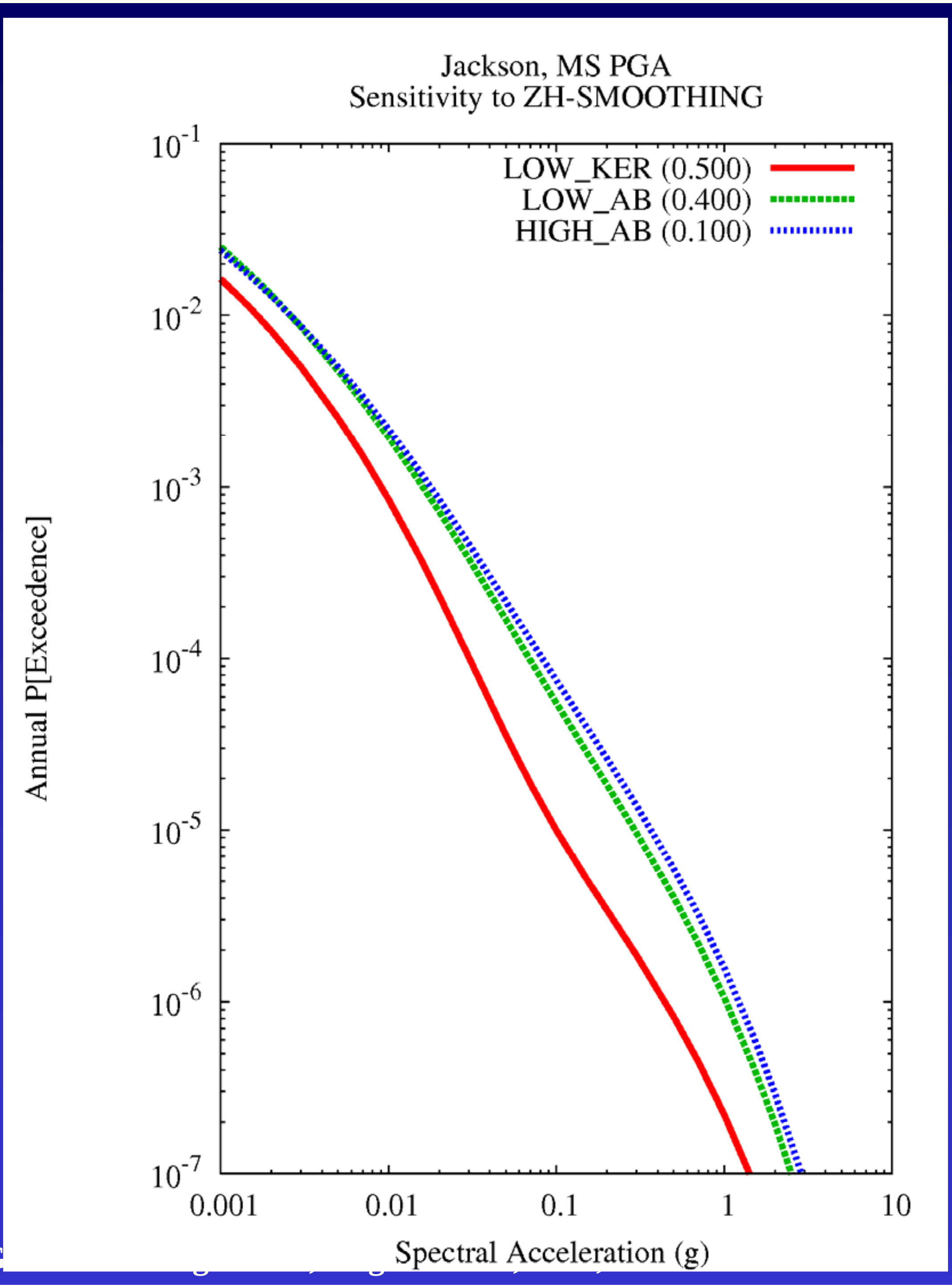
RISK ENGINEERING

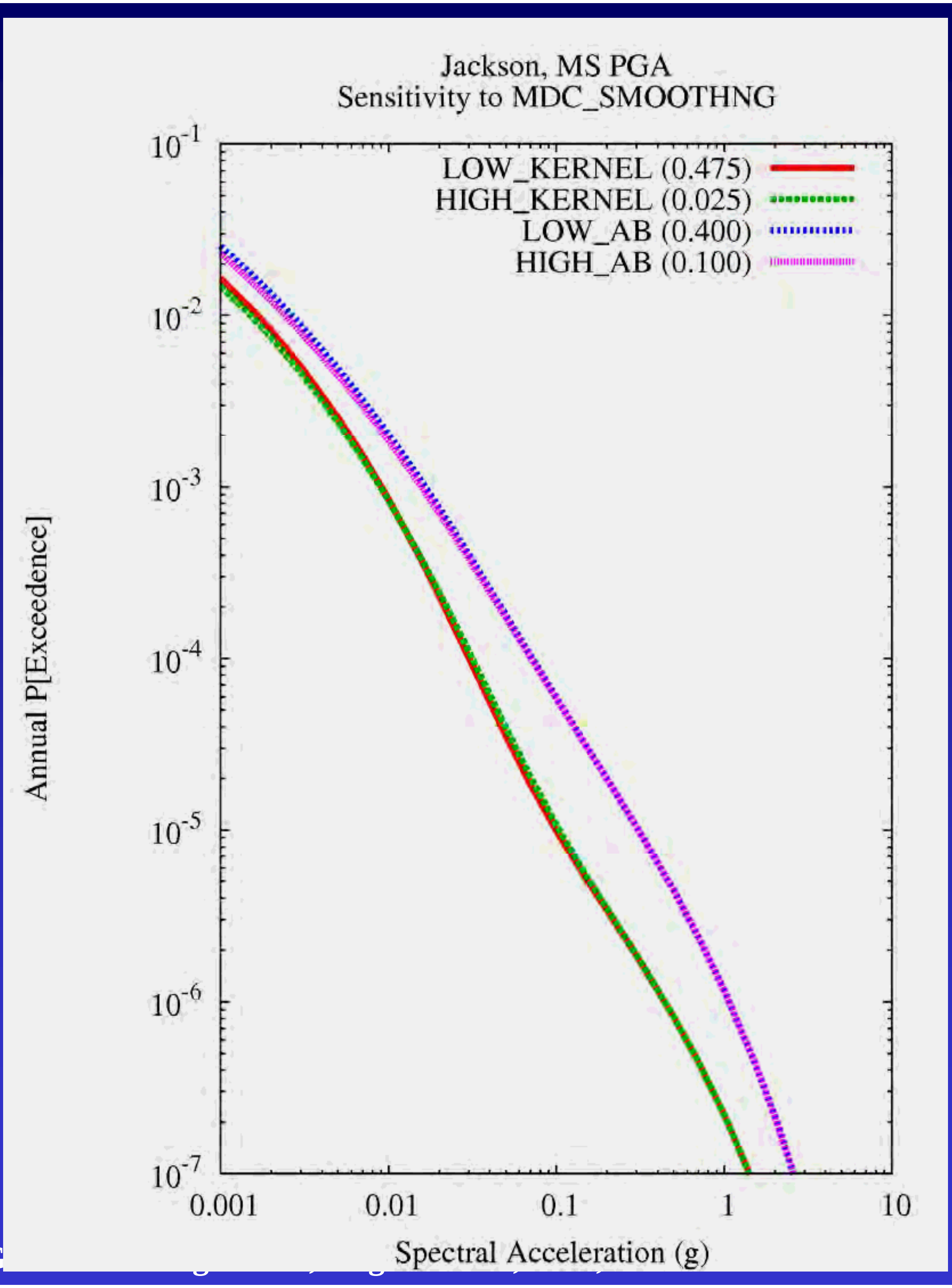

Jackson, MS PGA
Sensitivity to MAG-WEIGHTS
FULL (0.500)
REDUCED (0.500)
Annual P[Exceedence]
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
0.001
0.01
0.1
1
10
Spectral Acceleration (g)



William Lettis & Associates, Inc.

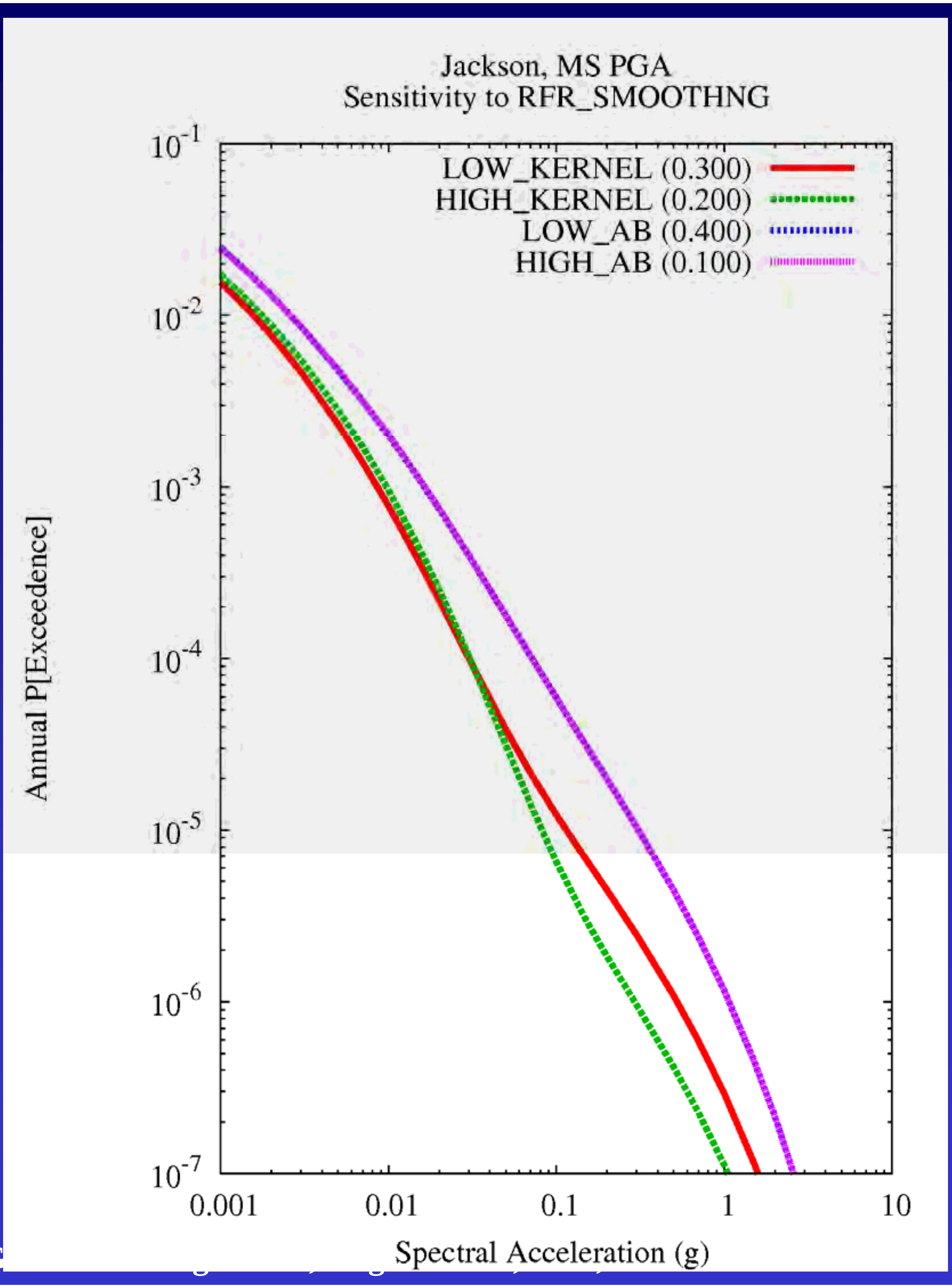
RISK ENGINEERING


Jackson, MS PGA
Sensitivity to ZH-SMOOTHING
LOW_KER (0.500)
LOW_AB (0.400)
HIGH_AB (0.100)
Annual P[Exceedence]
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
0.001
0.01
0.1
1
10
Spectral Acceleration (g)



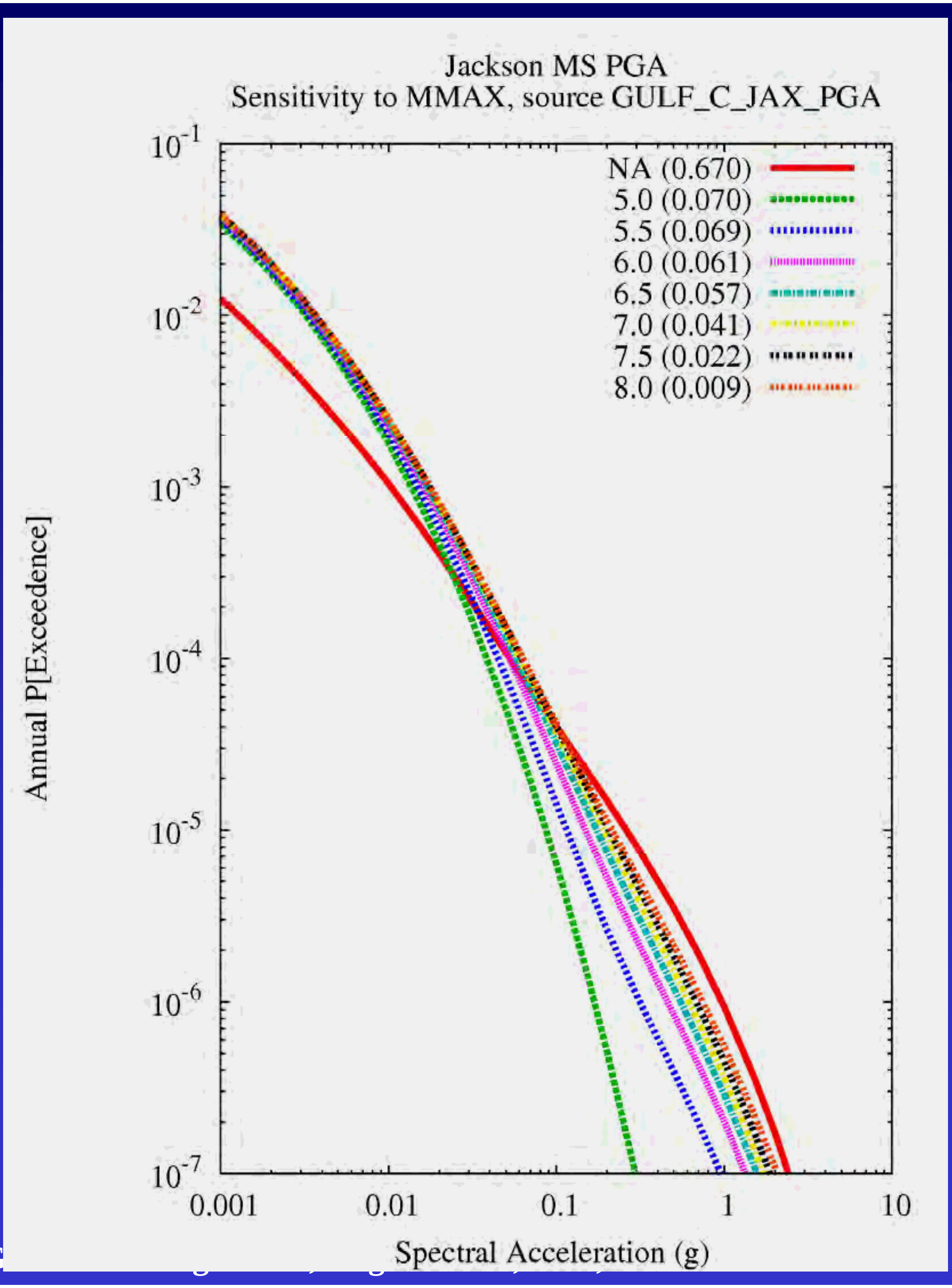
William Lettis & Associates, Inc.

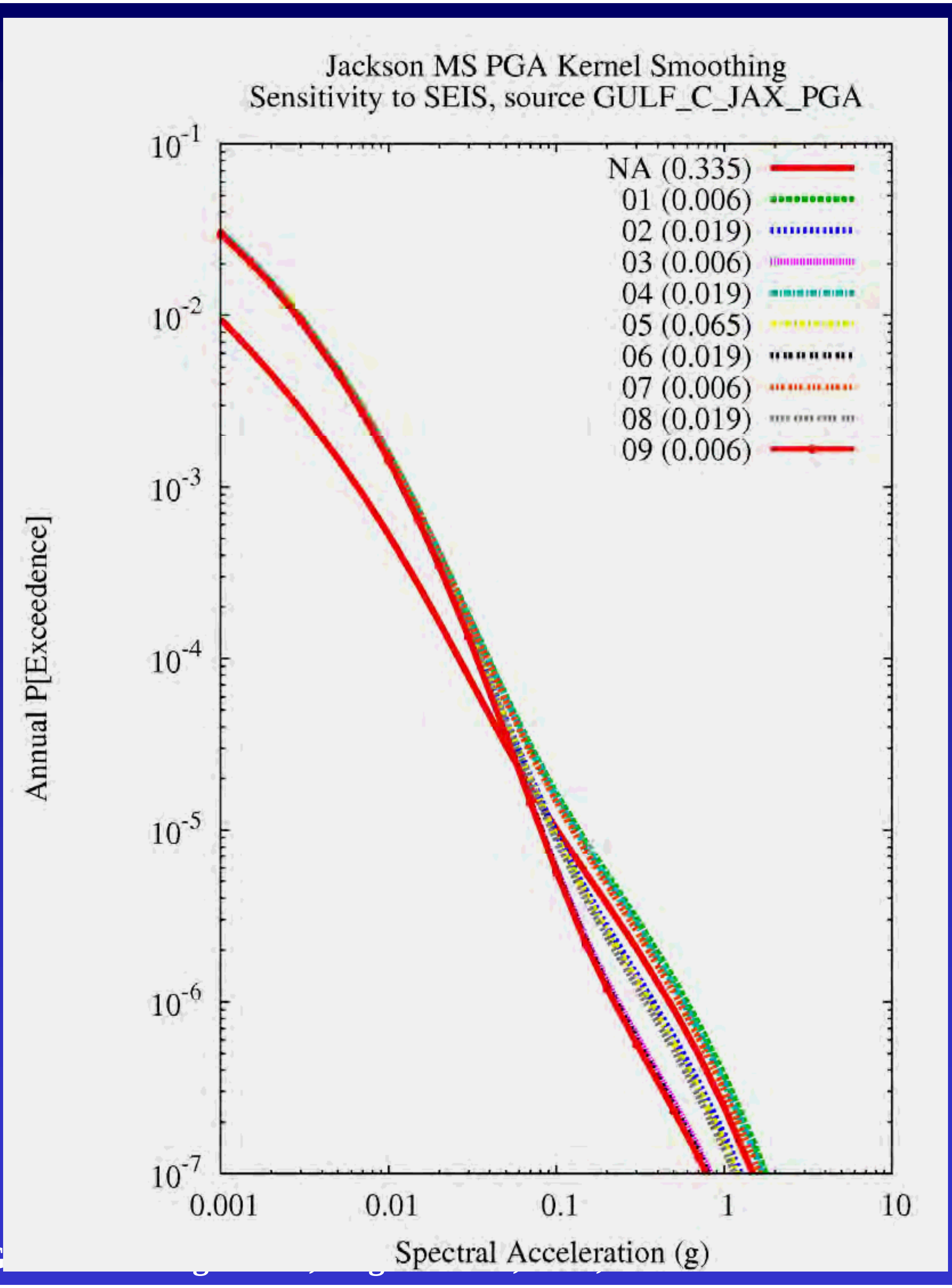
RISK ENGINEERING

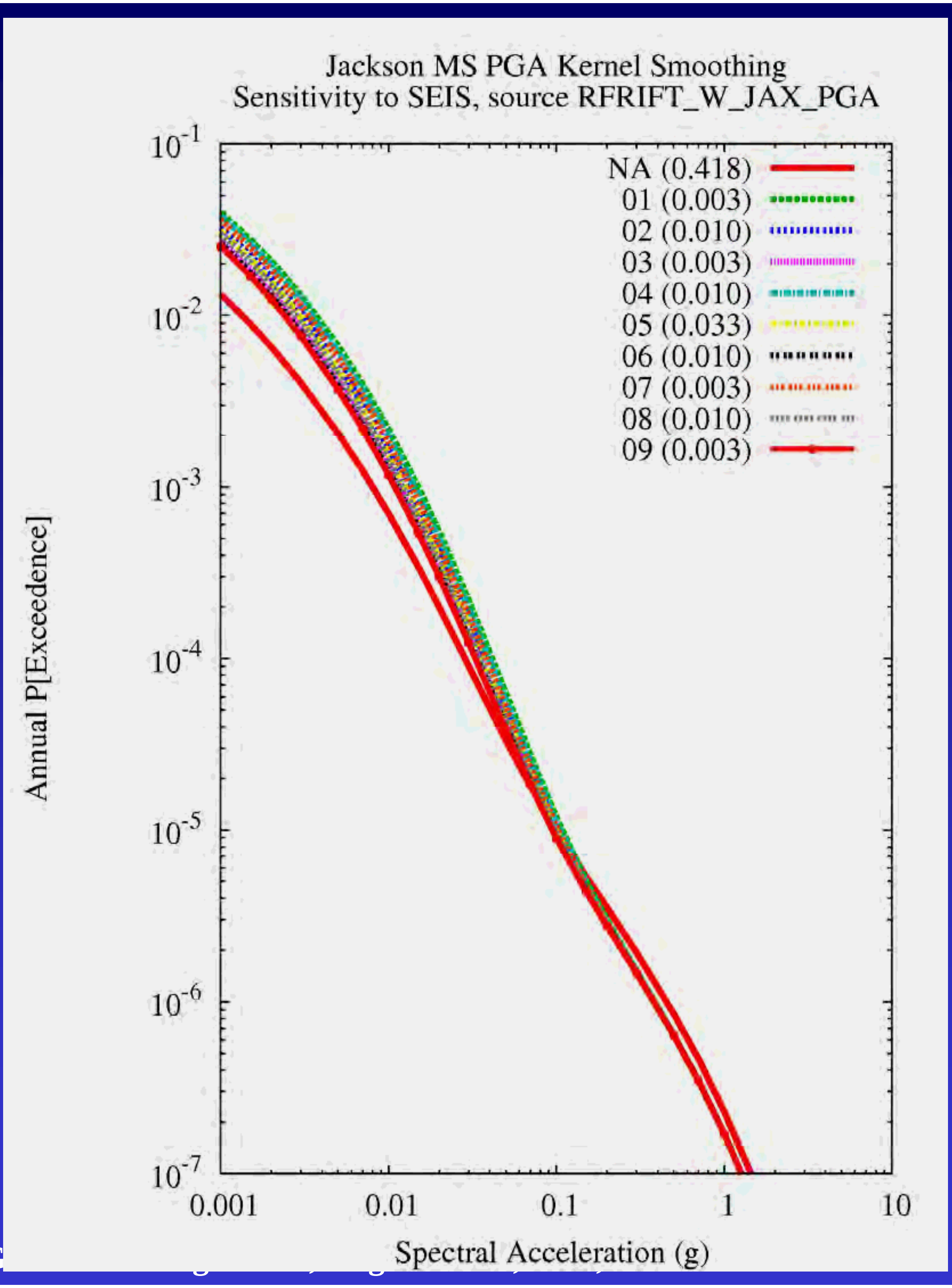


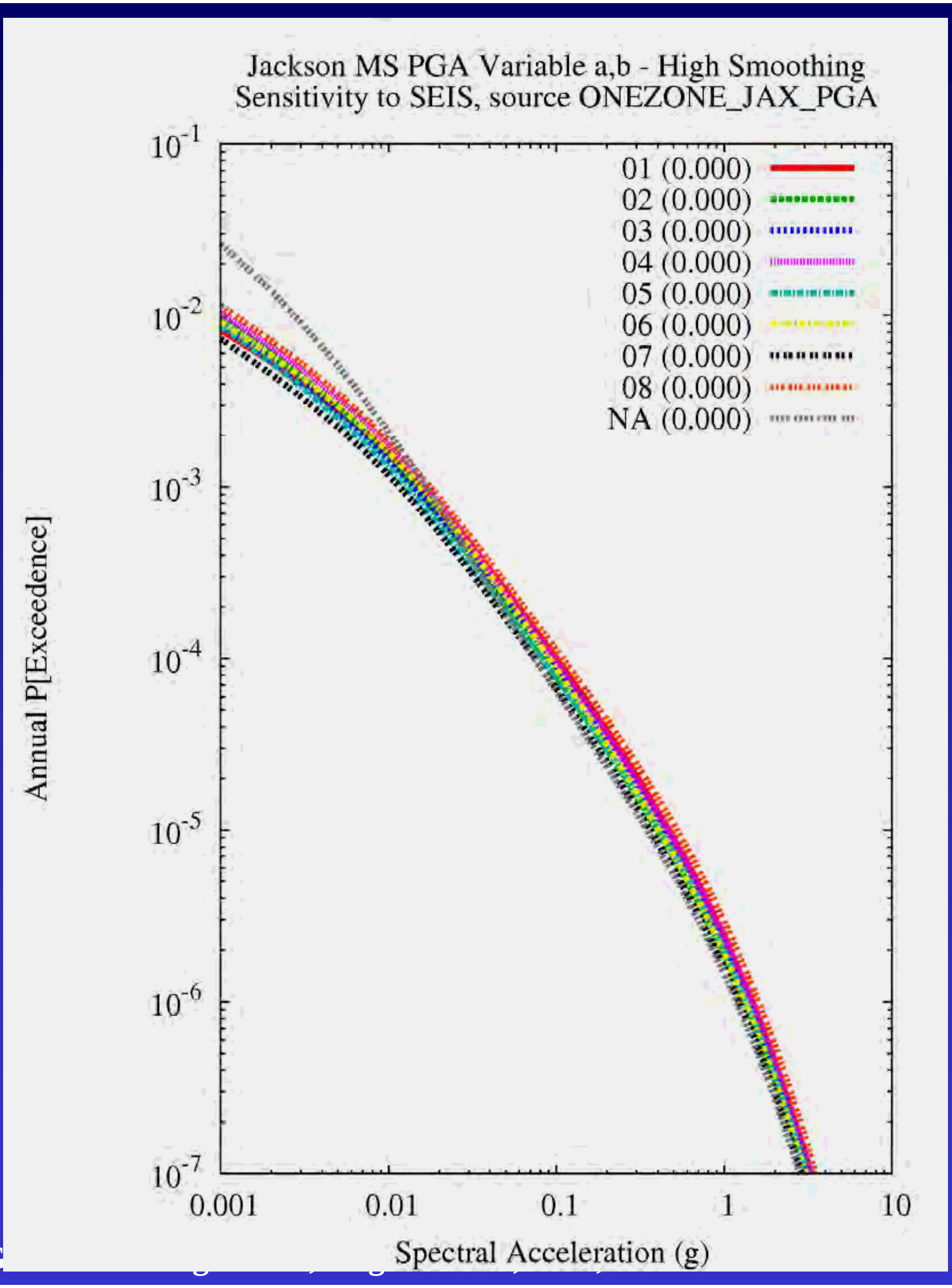
WLA William Lettis & Associates, Inc.

RISK ENGINEERING


Jackson MS PGA
Sensitivity to MMAX, source GULF_C_JAX_PGA
NA (0.670)
5.0 (0.070)
5.5 (0.069)
6.0 (0.061)
6.5 (0.057)
7.0 (0.041)
7.5 (0.022)
8.0 (0.009)
Annual P[Exceedence]
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
0.001
0.01
0.1
1
10
Spectral Acceleration (g)


Jackson MS PGA Kernel Smoothing
Sensitivity to SEIS, source GULF_C_JAX_PGA
Annual P[Exceedence]
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
0.001
0.01
0.1
1
10
Spectral Acceleration (g)
NA (0.335)
01 (0.006)
02 (0.019)
03 (0.006)
04 (0.019)
05 (0.065)
06 (0.019)
07 (0.006)
08 (0.019)
09 (0.006)


Jackson MS PGA Kernel Smoothing
Sensitivity to SEIS, source RFRIFT_W_JAX_PGA
Annual P[Exceedence]
Spectral Acceleration (g)
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
0.001
0.01
0.1
1
10
NA (0.418)
01 (0.003)
02 (0.010)
03 (0.003)
04 (0.010)
05 (0.033)
06 (0.010)
07 (0.003)
08 (0.010)
09 (0.003)



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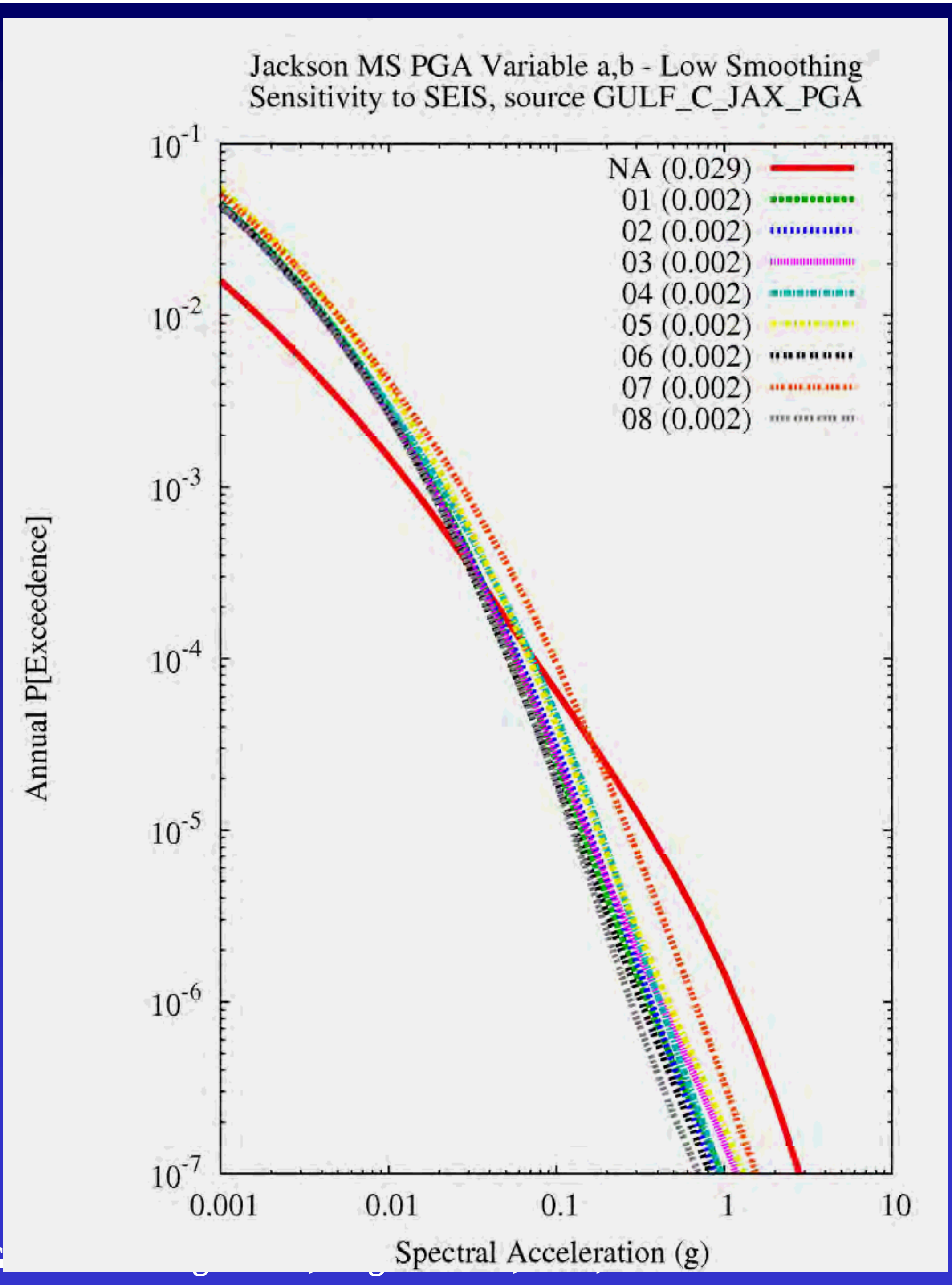

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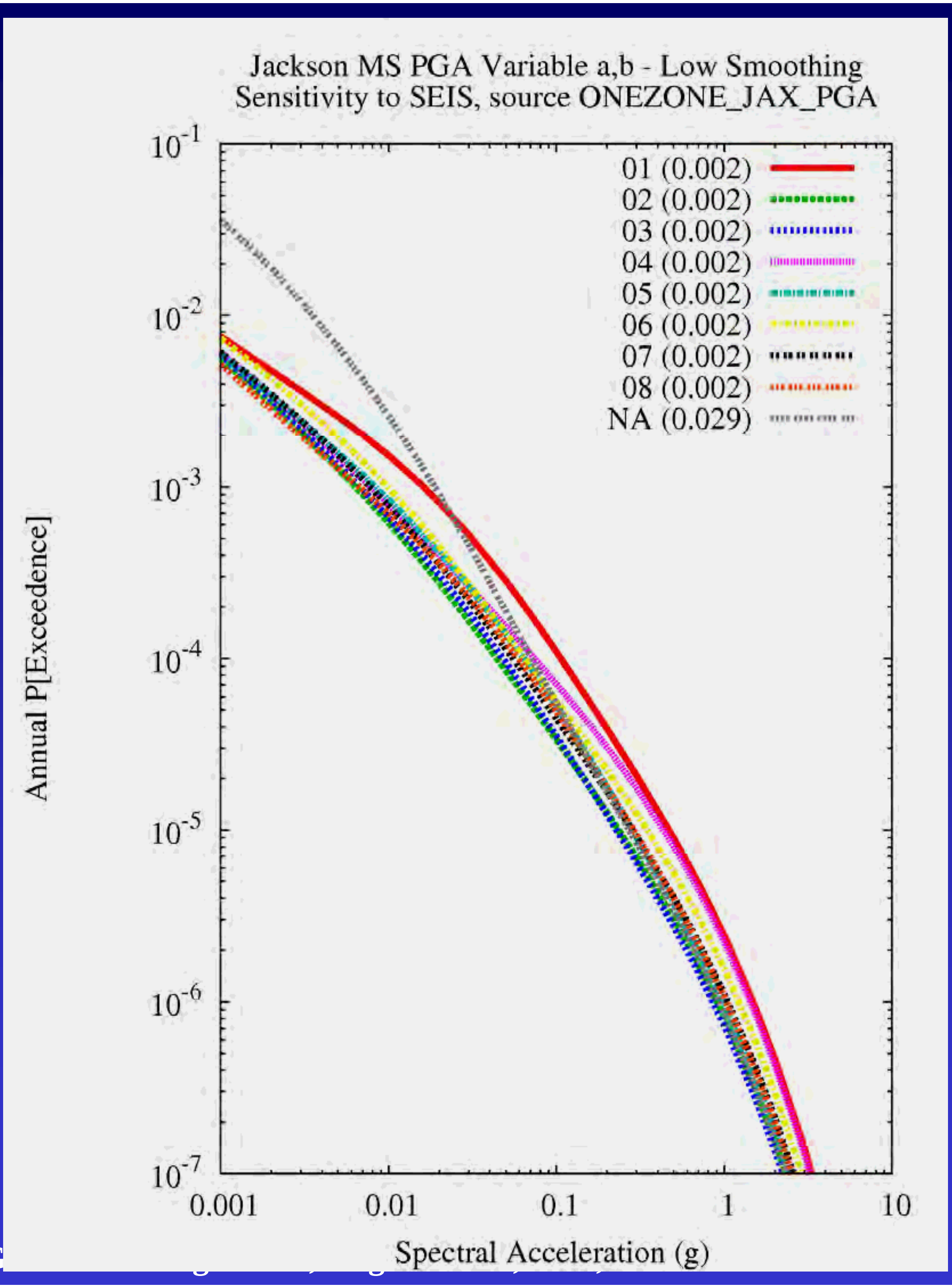
RISK ENGINEERING



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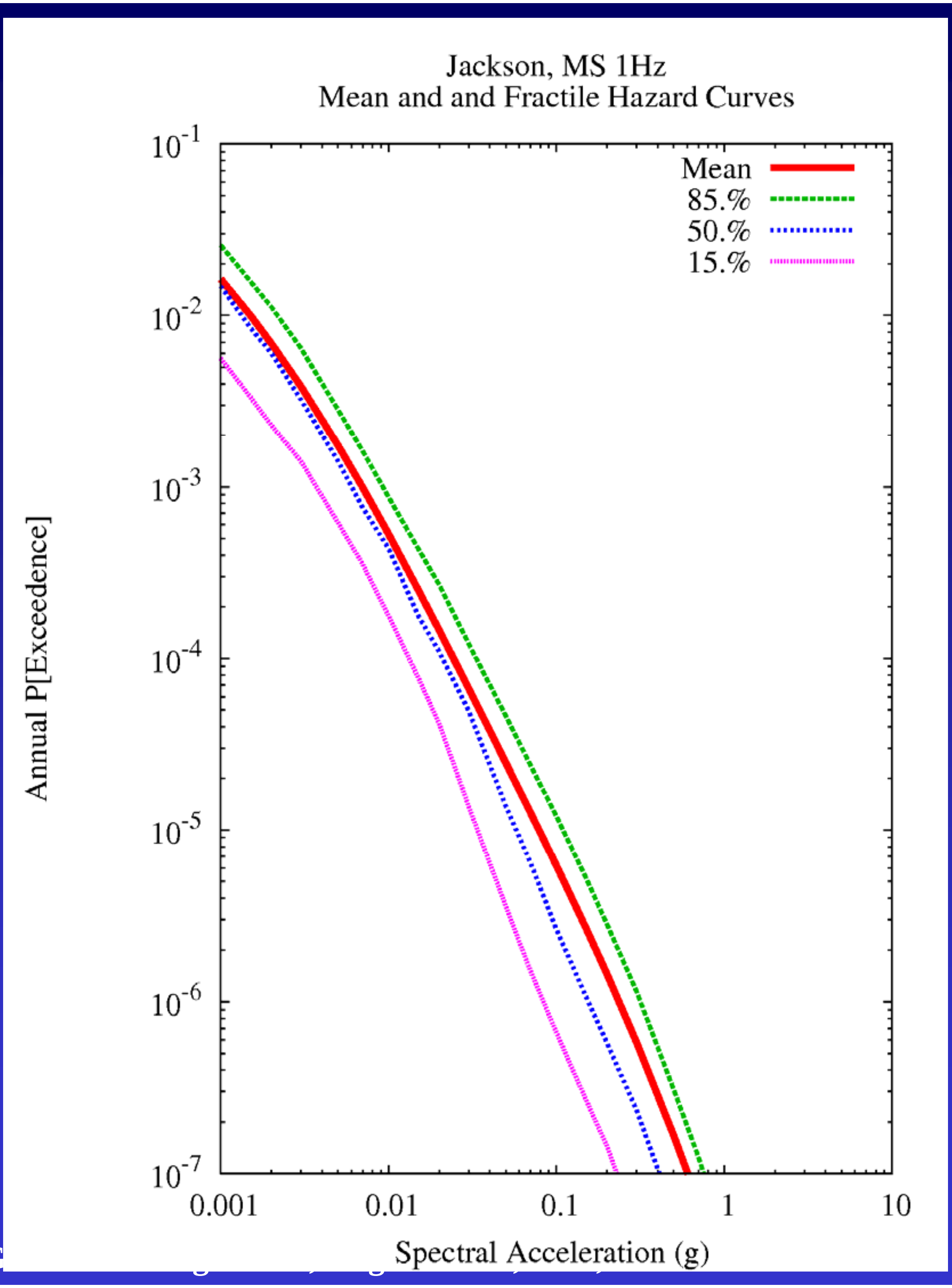
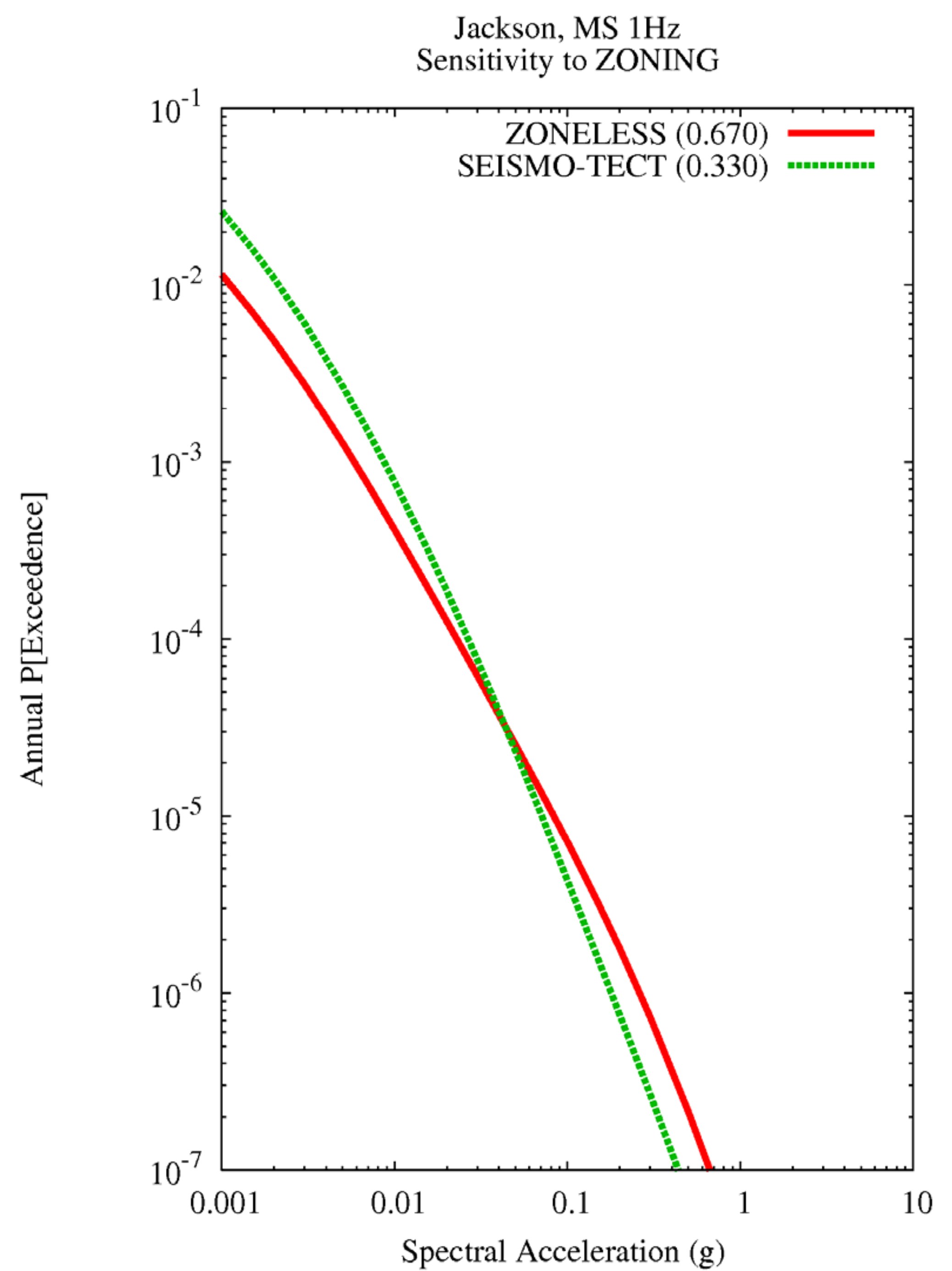
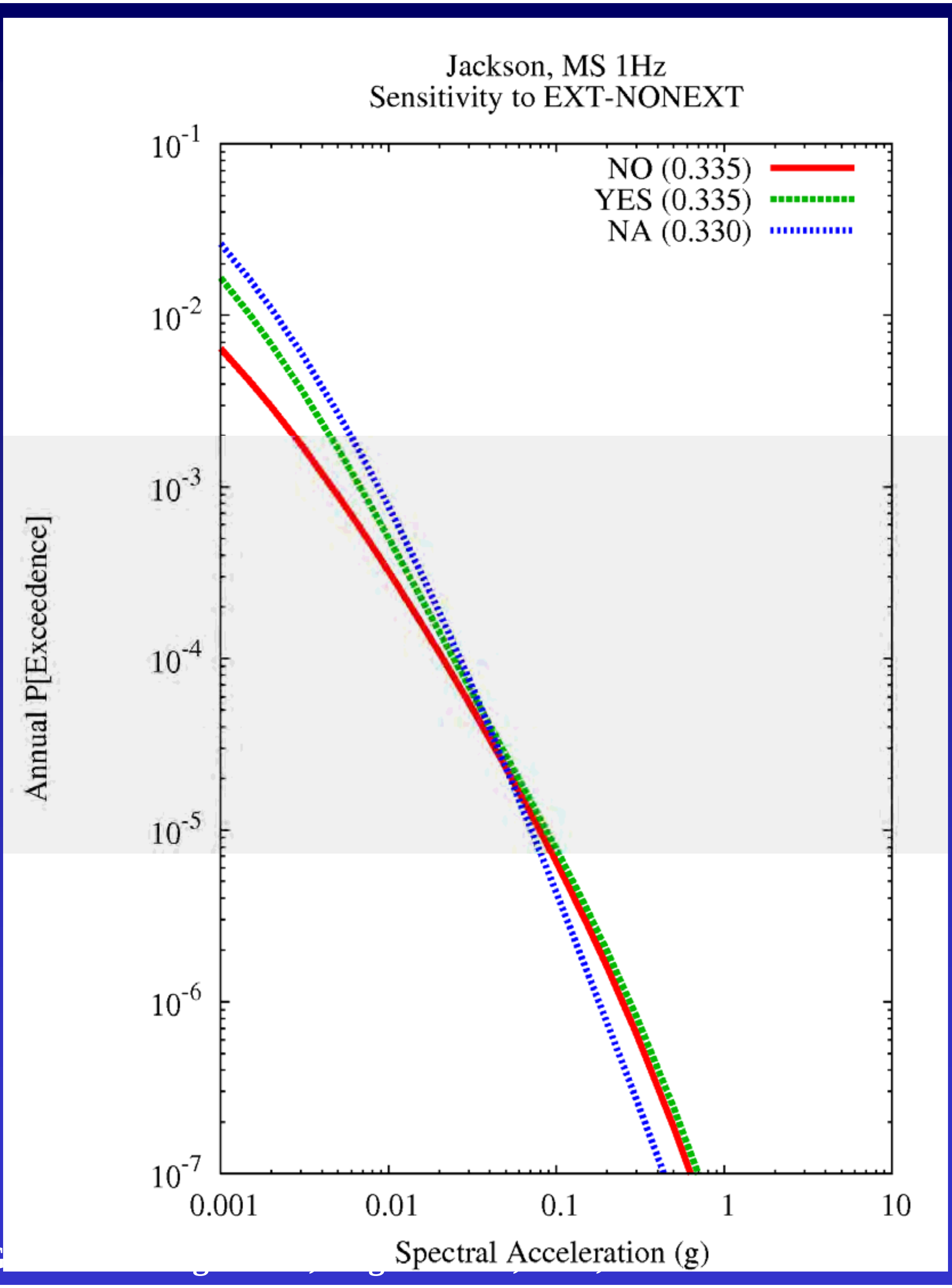
RISK ENGINEERING

Jackson 1 Hz results


Jackson, MS 1Hz
Mean and and Fractile Hazard Curves
Annual P[Exceedence]
Spectral Acceleration (g)
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
0.001
0.01
0.1
1
10
Mean
85.%
50.%
15.%



Jackson, MS 1Hz
Sensitivity to ZONING



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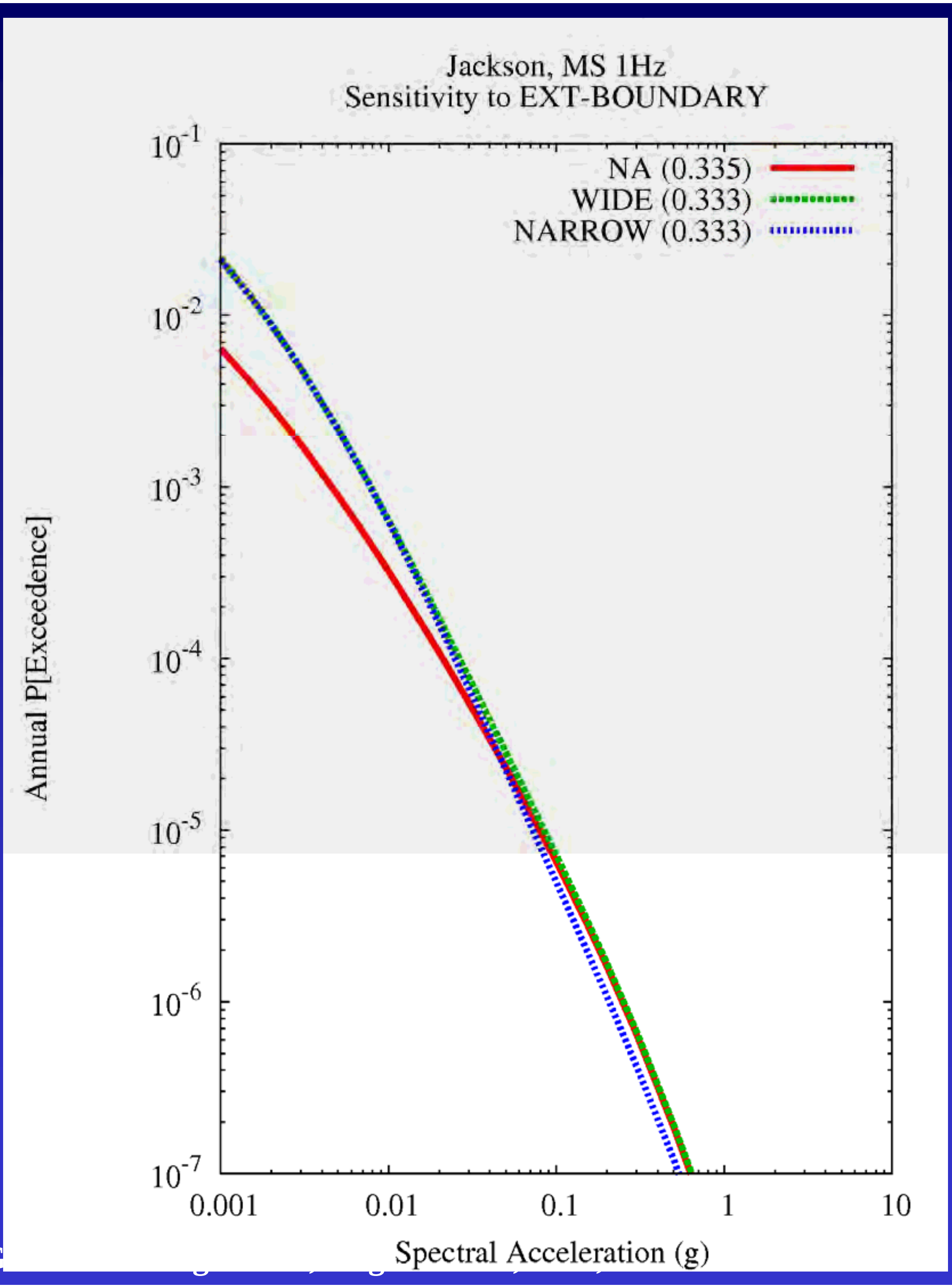
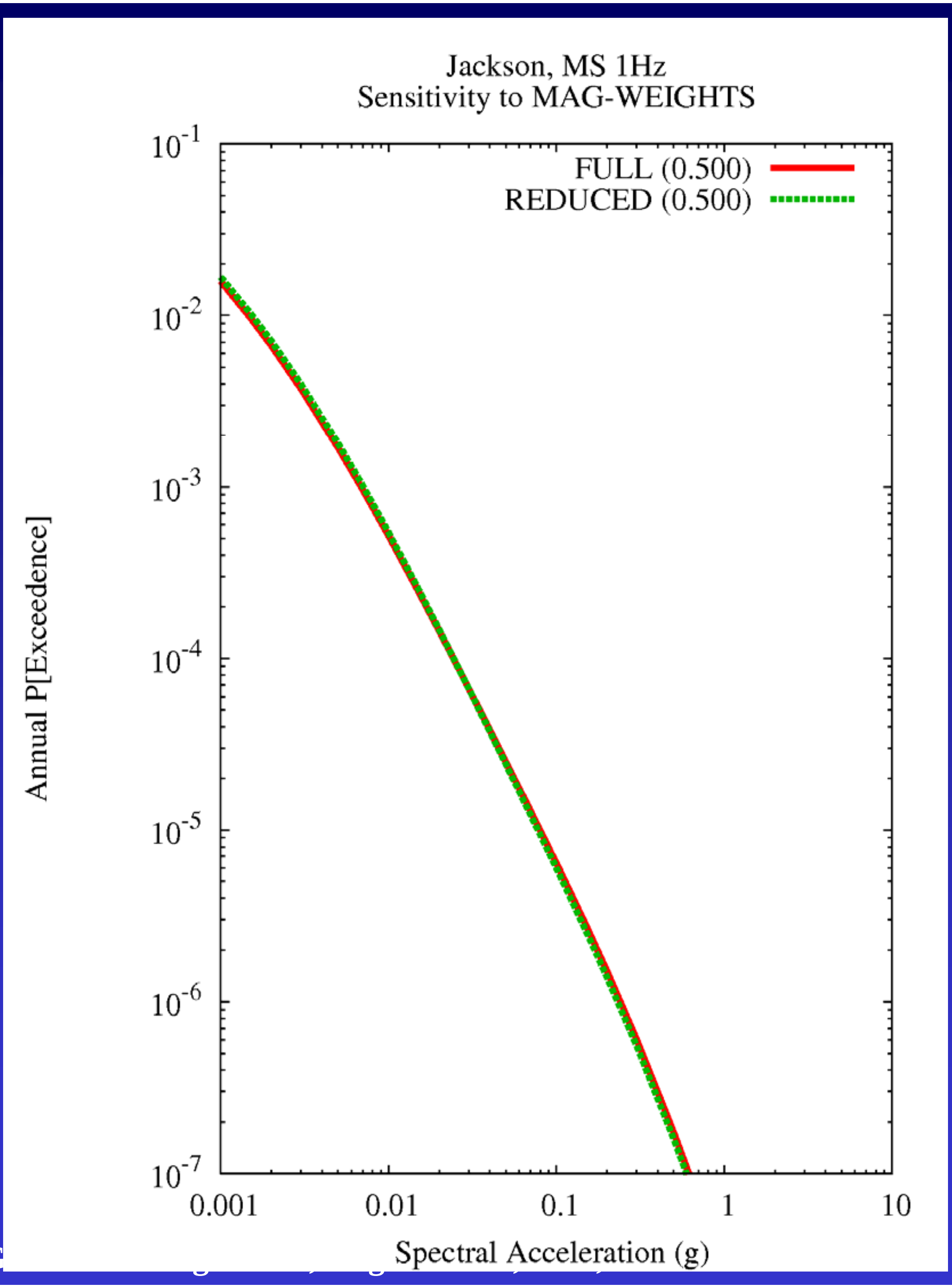
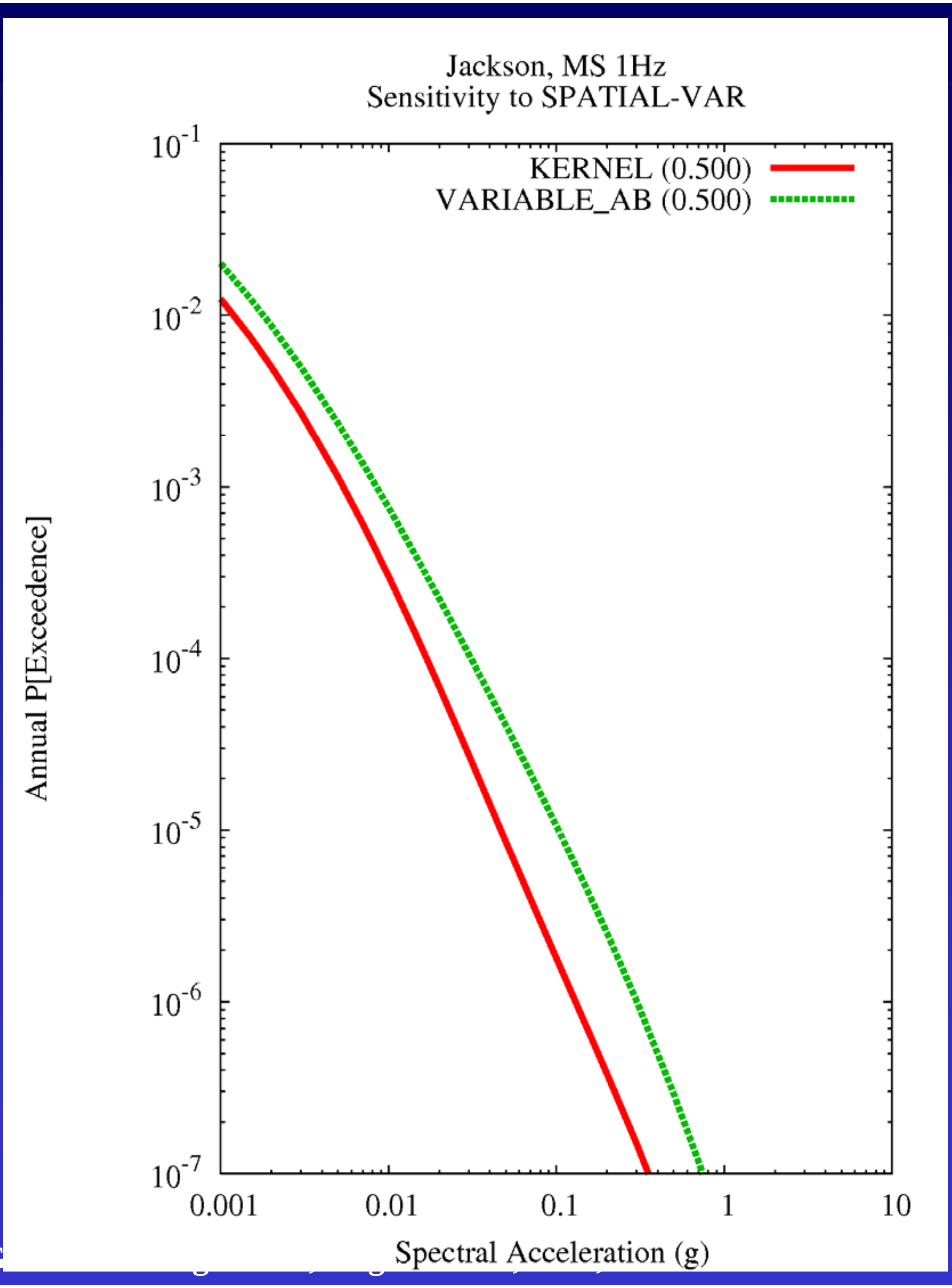
RISK ENGINEERING

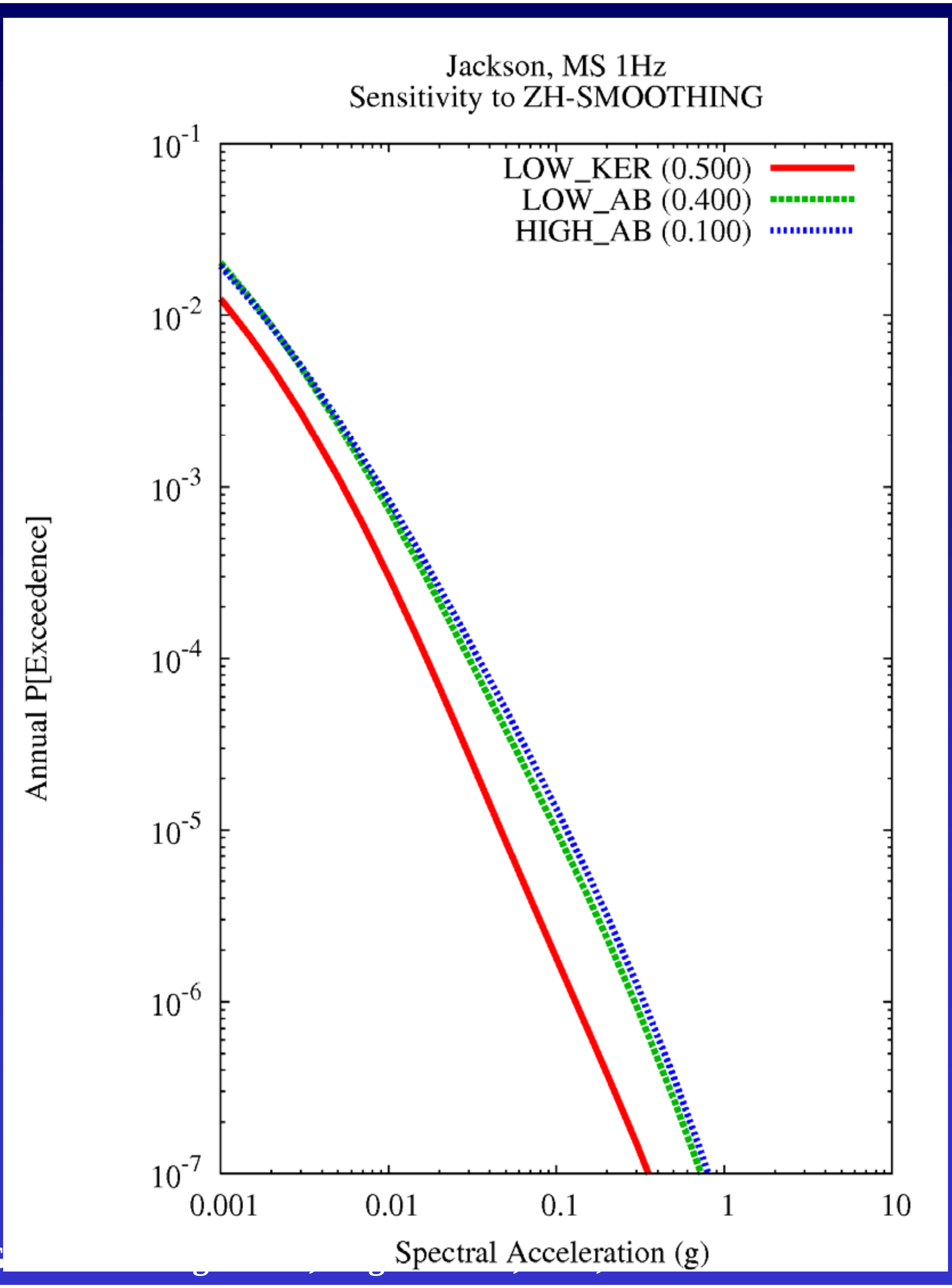

Jackson, MS 1Hz
Sensitivity to EXT-BOUNDARY
NA (0.335)
WIDE (0.333)
NARROW (0.333)
Annual P[Exceedence]
10^-1
10^-2
10^-3
10^-4
10^-5
10^-6
10^-7
0.001
0.01
0.1
1
10
Spectral Acceleration (g)

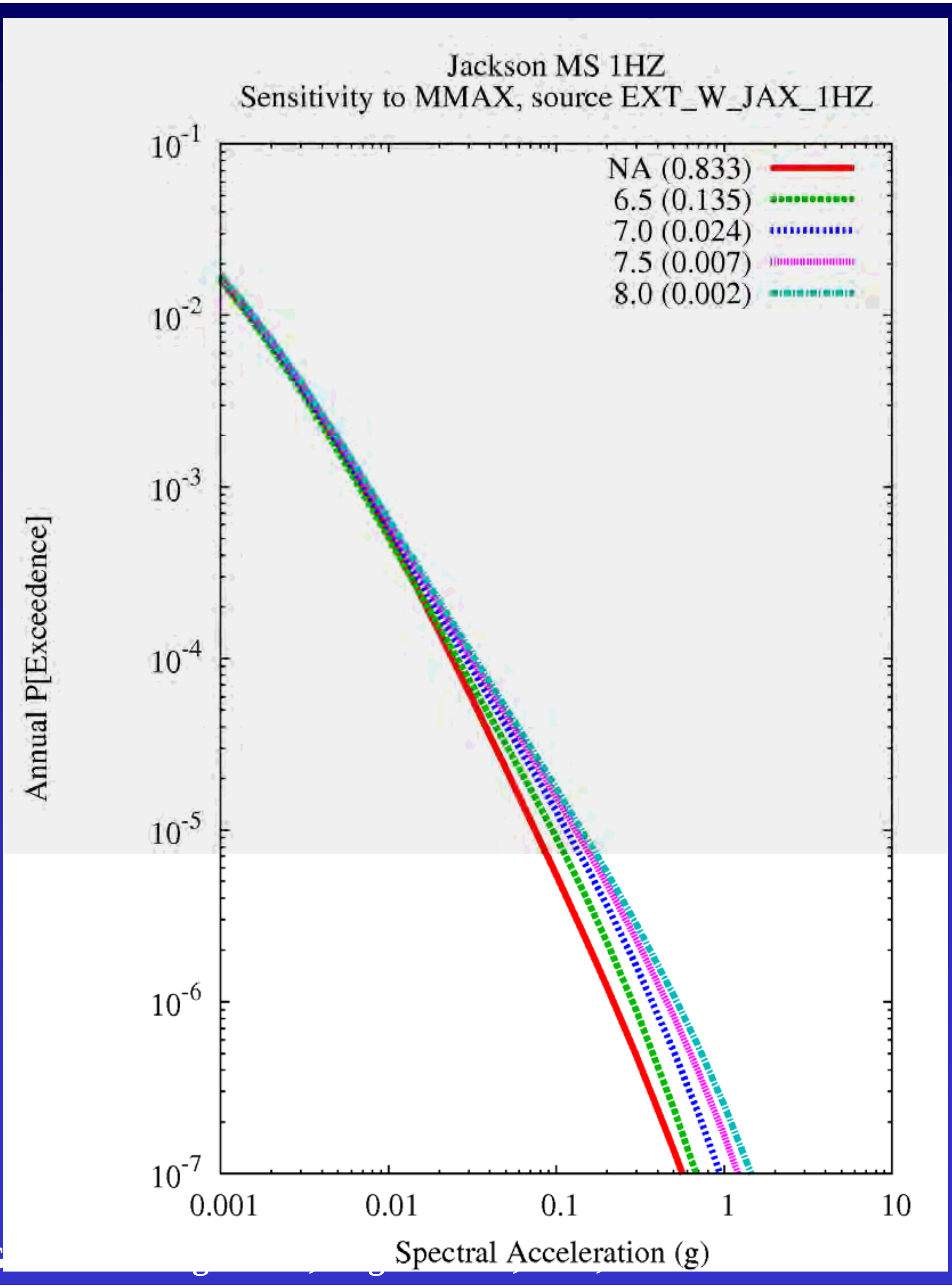

Jackson, MS 1Hz
Sensitivity to MAG-WEIGHTS
FULL (0.500)
REDUCED (0.500)
Annual P[Exceedence]
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
0.001
0.01
0.1
1
10
Spectral Acceleration (g)



WLA William Lettis & Associates, Inc.

RISK ENGINEERING


Jackson, MS 1Hz
Sensitivity to ZH-SMOOTHING
LOW_KER (0.500)
LOW_AB (0.400)
HIGH_AB (0.100)
Annual P[Exceedence]
10^-1
10^-2
10^-3
10^-4
10^-5
10^-6
10^-7
0.001
0.01
0.1
1
10
Spectral Acceleration (g)



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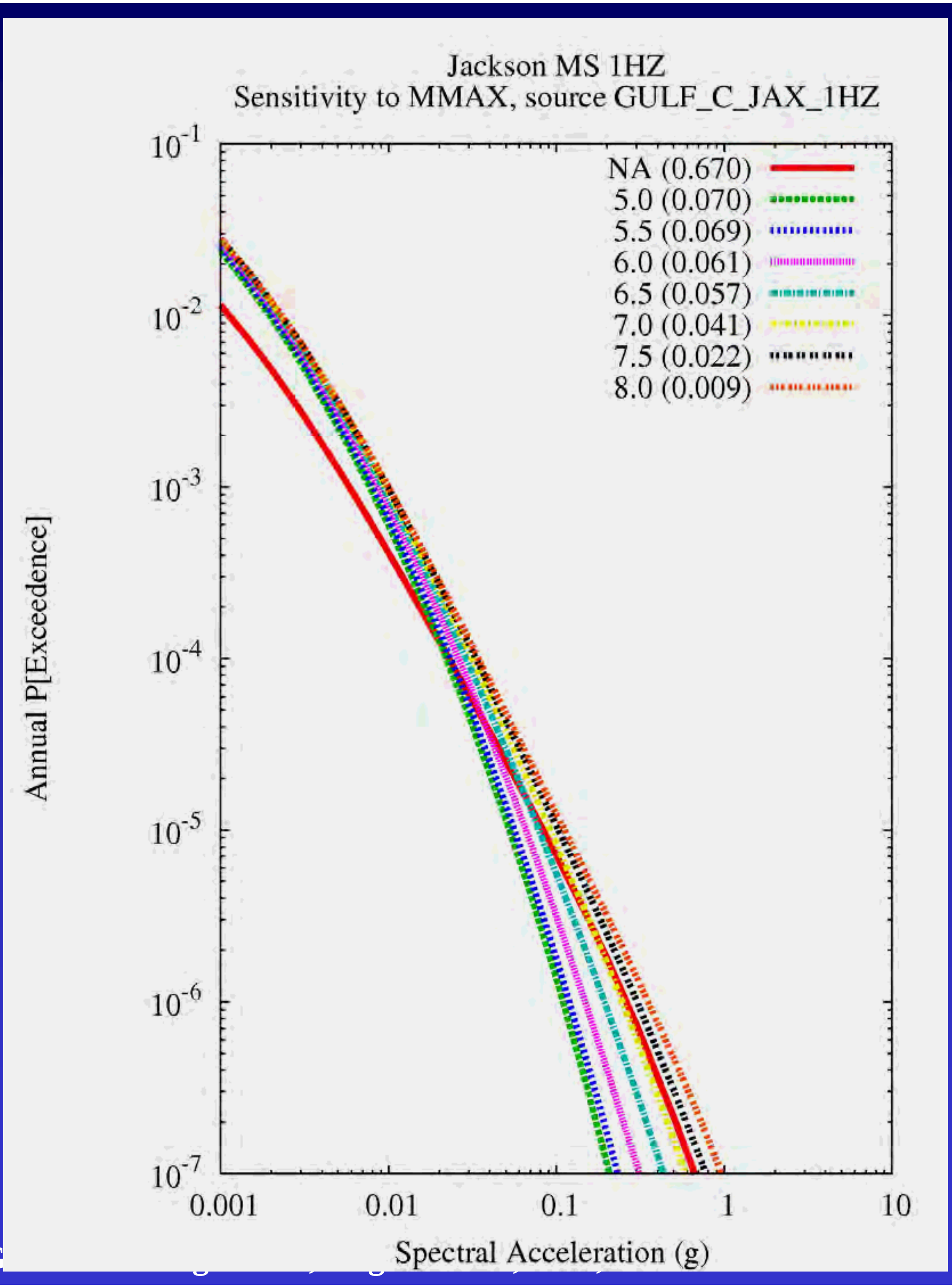
RISK ENGINEERING



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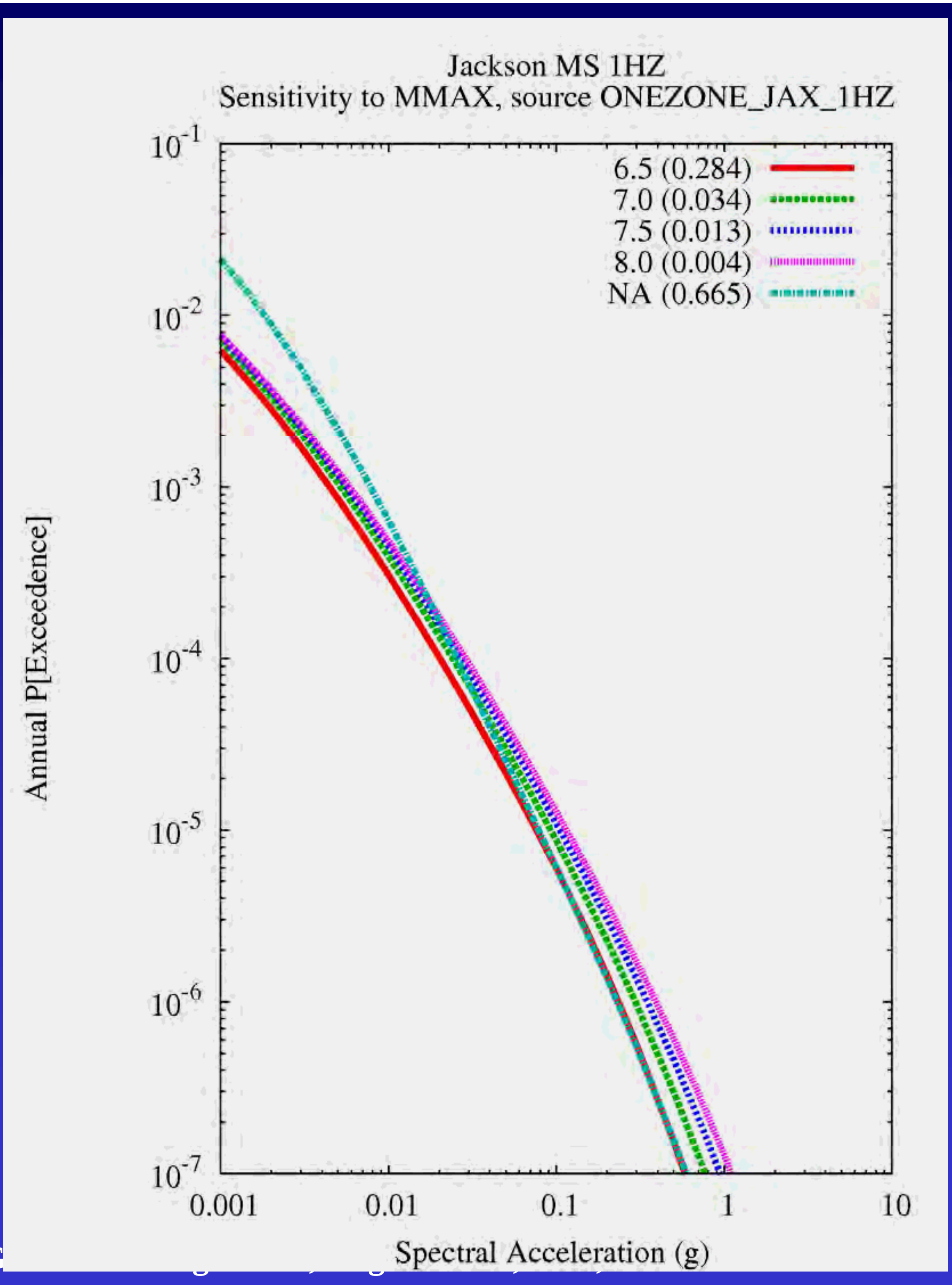
RISK ENGINEERING



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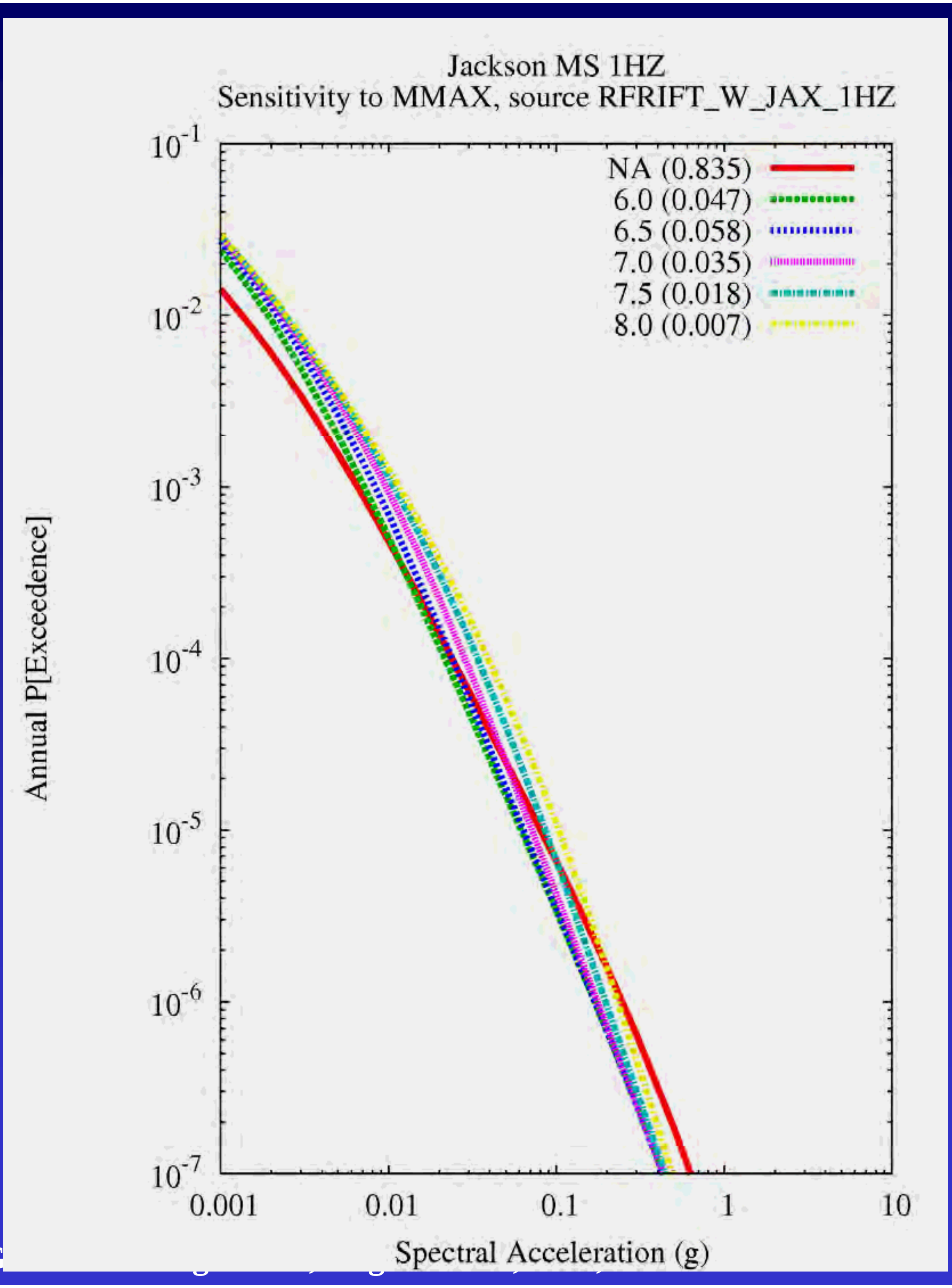

WLA
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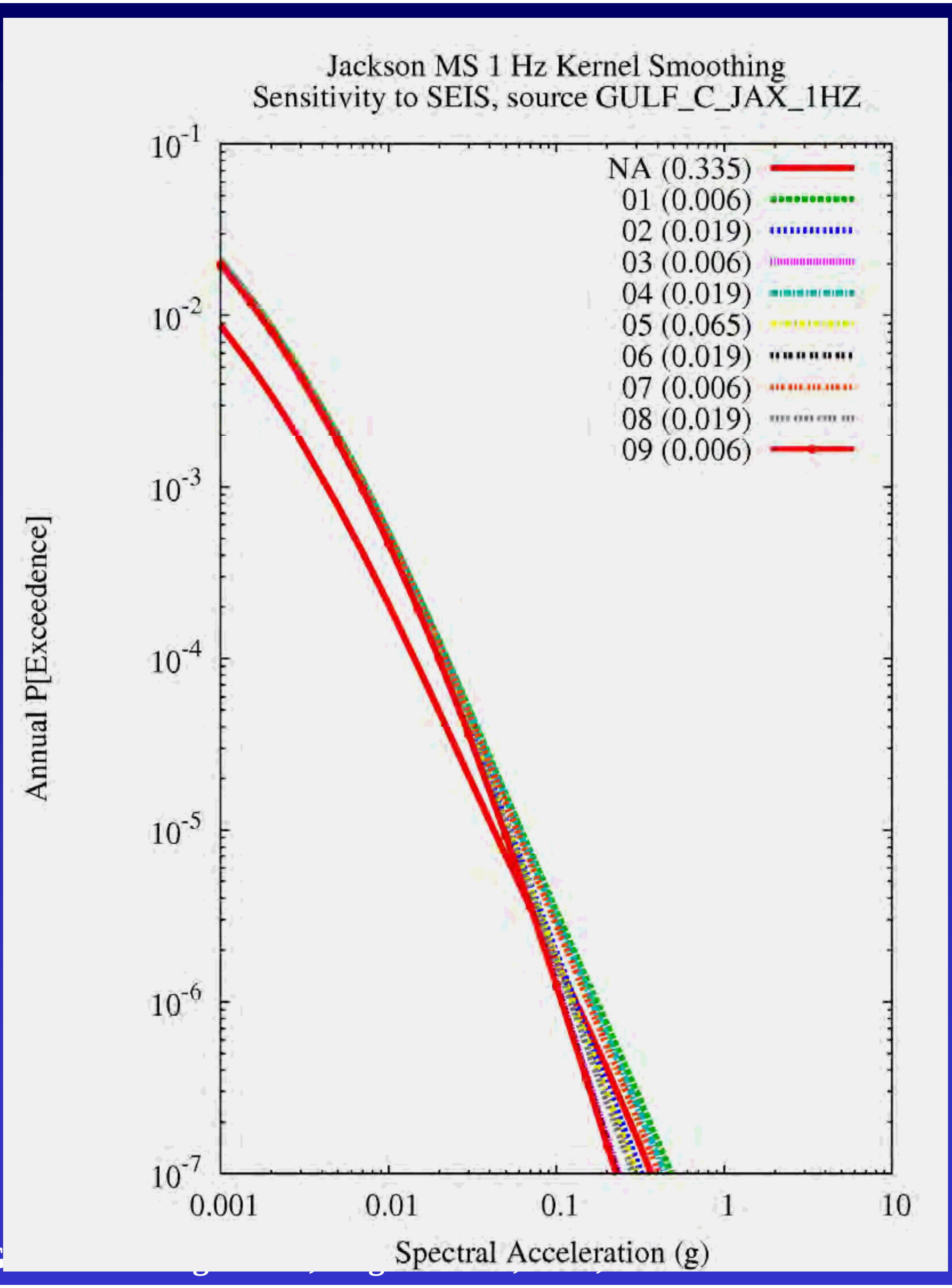
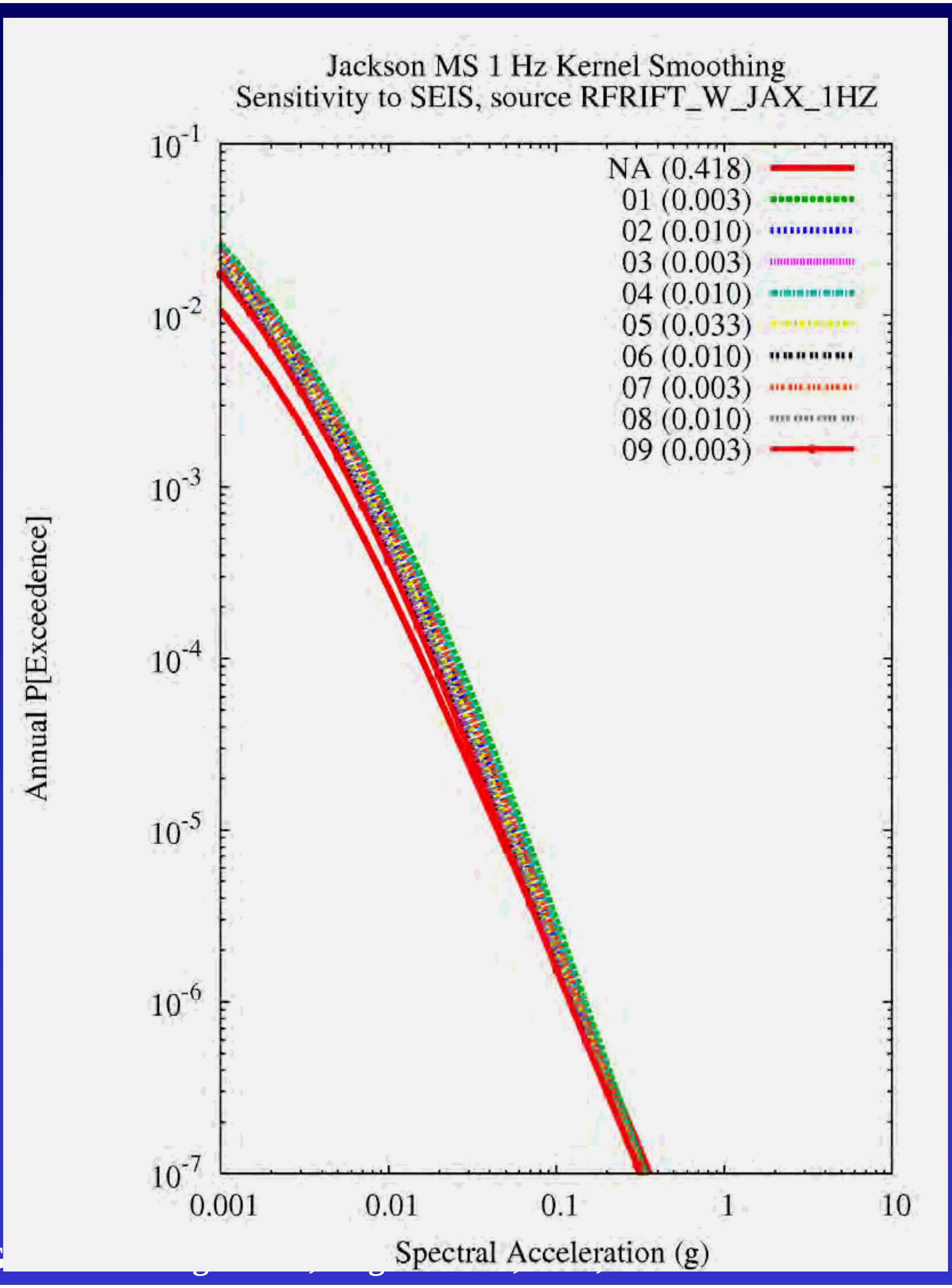
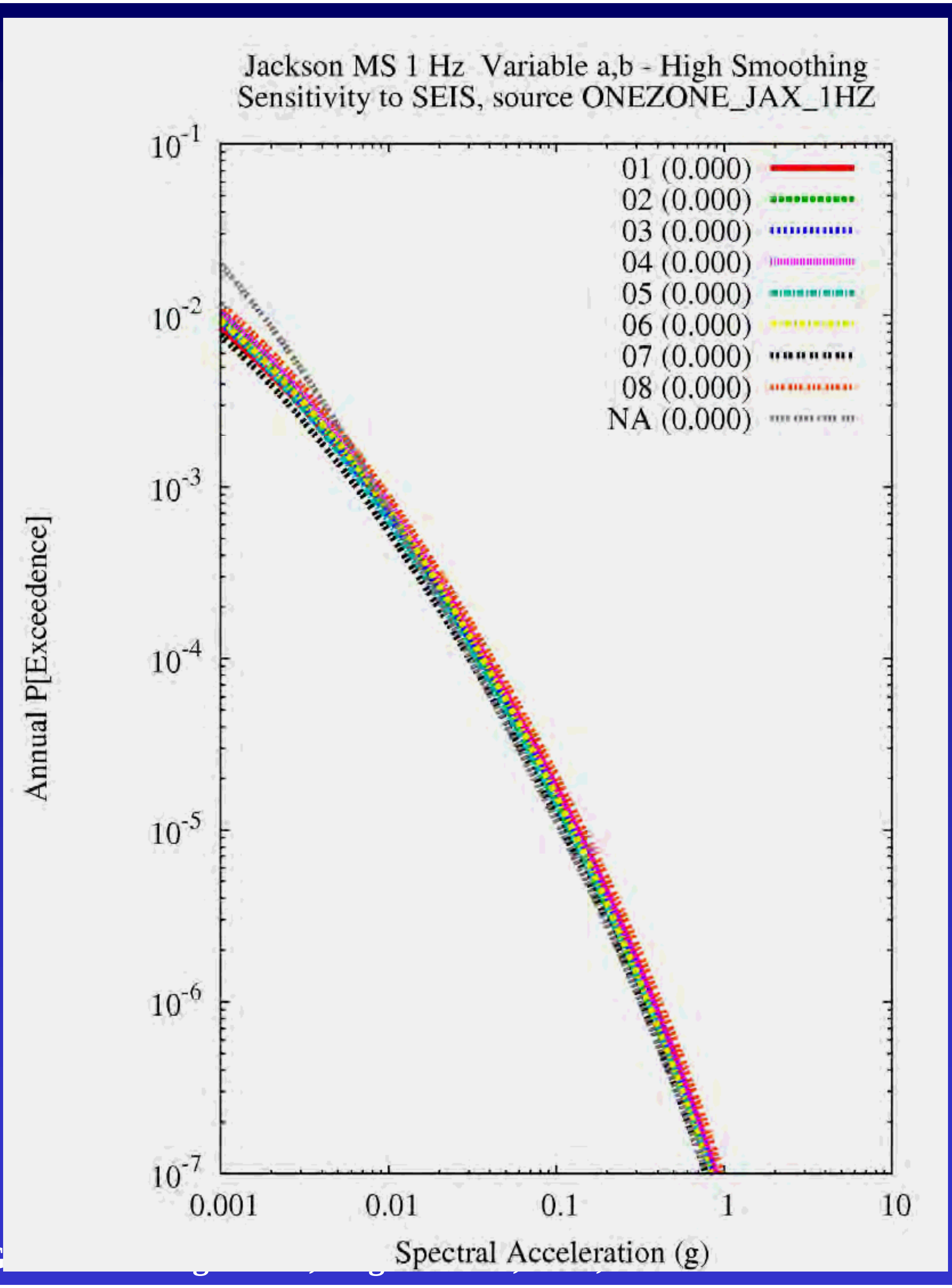
RISK
ENGINEERING



WLA William Lettis & Associates, Inc.

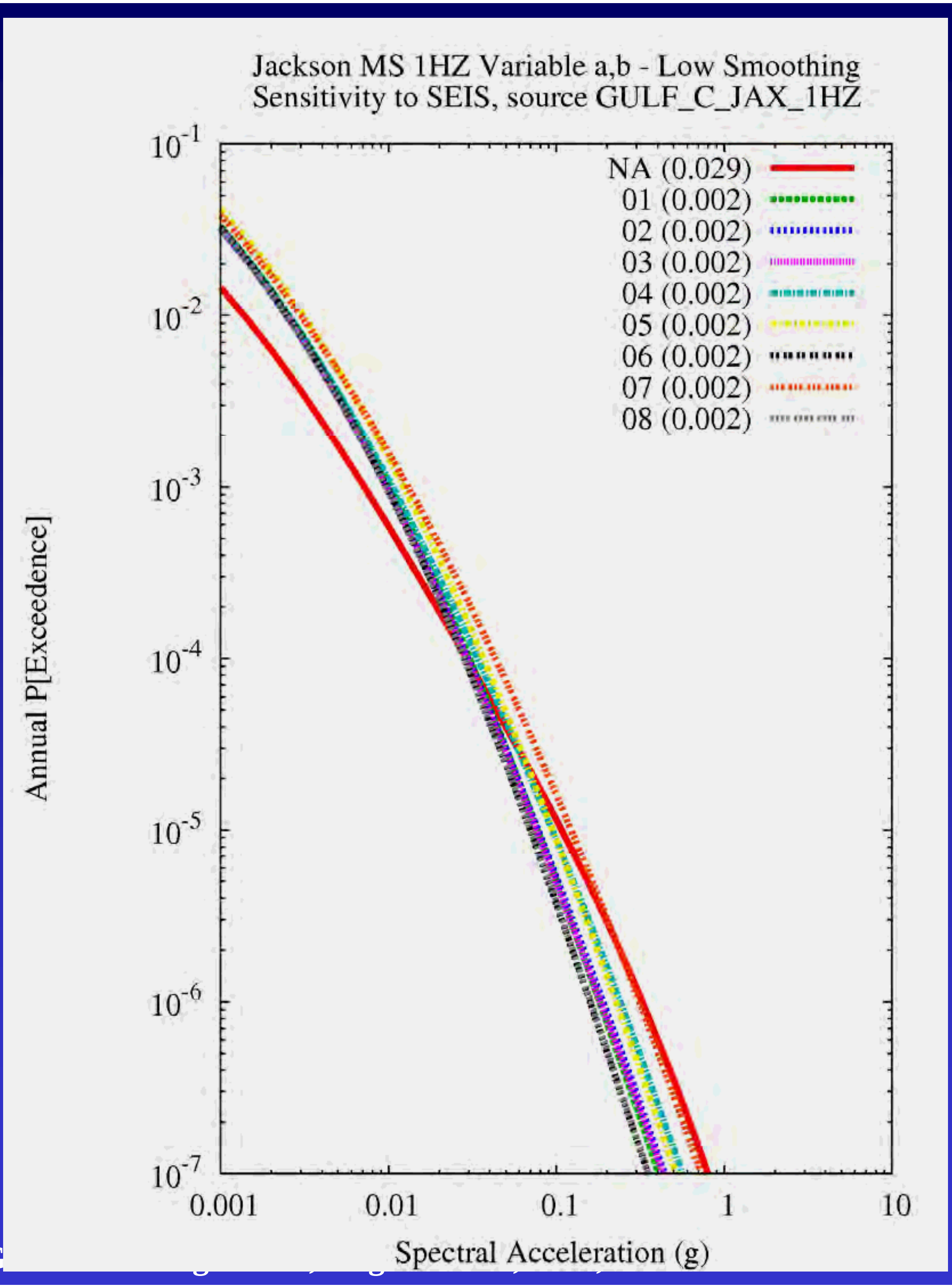
RISK ENGINEERING


Jackson MS 1 Hz Kernel Smoothing
Sensitivity to SEIS, source RFRIFT_W_JAX_1HZ
NA (0.418)
01 (0.003)
02 (0.010)
03 (0.003)
04 (0.010)
05 (0.033)
06 (0.010)
07 (0.003)
08 (0.010)
09 (0.003)
Annual P[Exceedence]
10-1
10-2
10-3
10-4
10-5
10-6
10-7
0.001
0.01
0.1
1
10
Spectral Acceleration (g)



William Lettis & Associates, Inc.

RISK ENGINEERING



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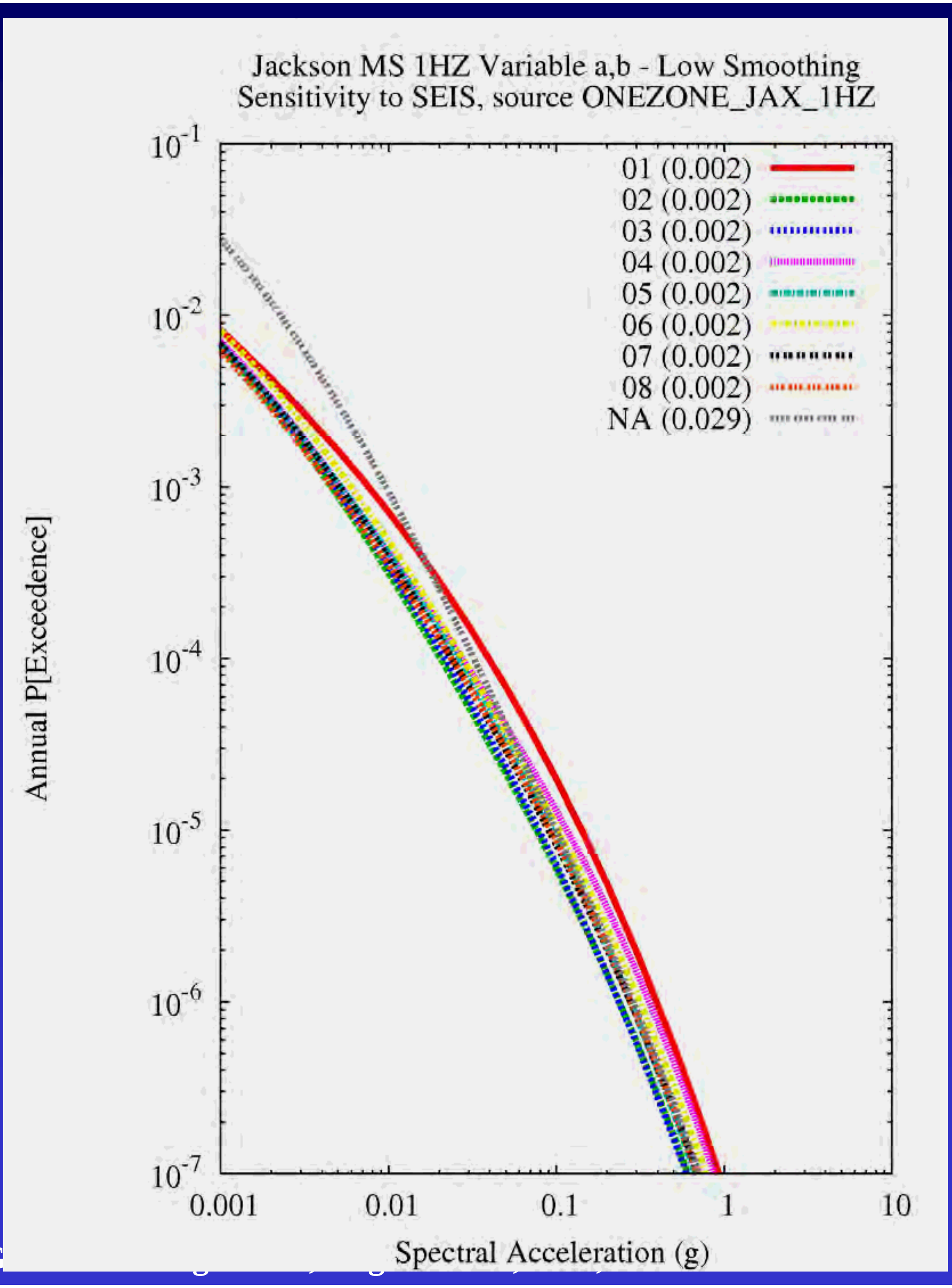
RISK
ENGINEERING



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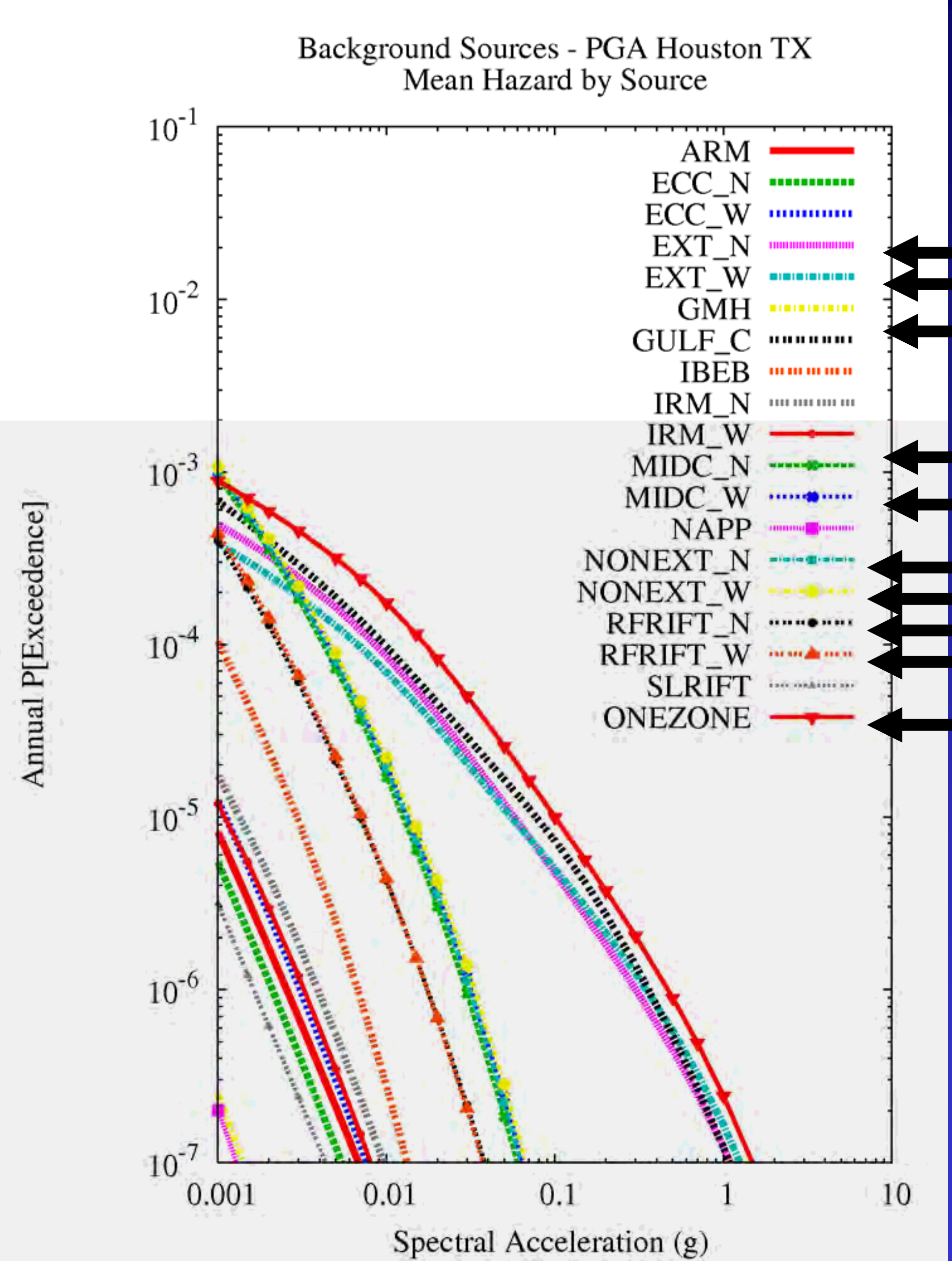
Summary of results for South od NMSZ (Jackson, MS)

- Moderate sensitivity to Zoneless/Seismotectonic
- Sensitivity to Mmax in Gulf of Mexico zone
- Sensitivity to smoothing of OneZone and Gulf of Mexico zones

Gulf Coast Site
(Houston, TX)



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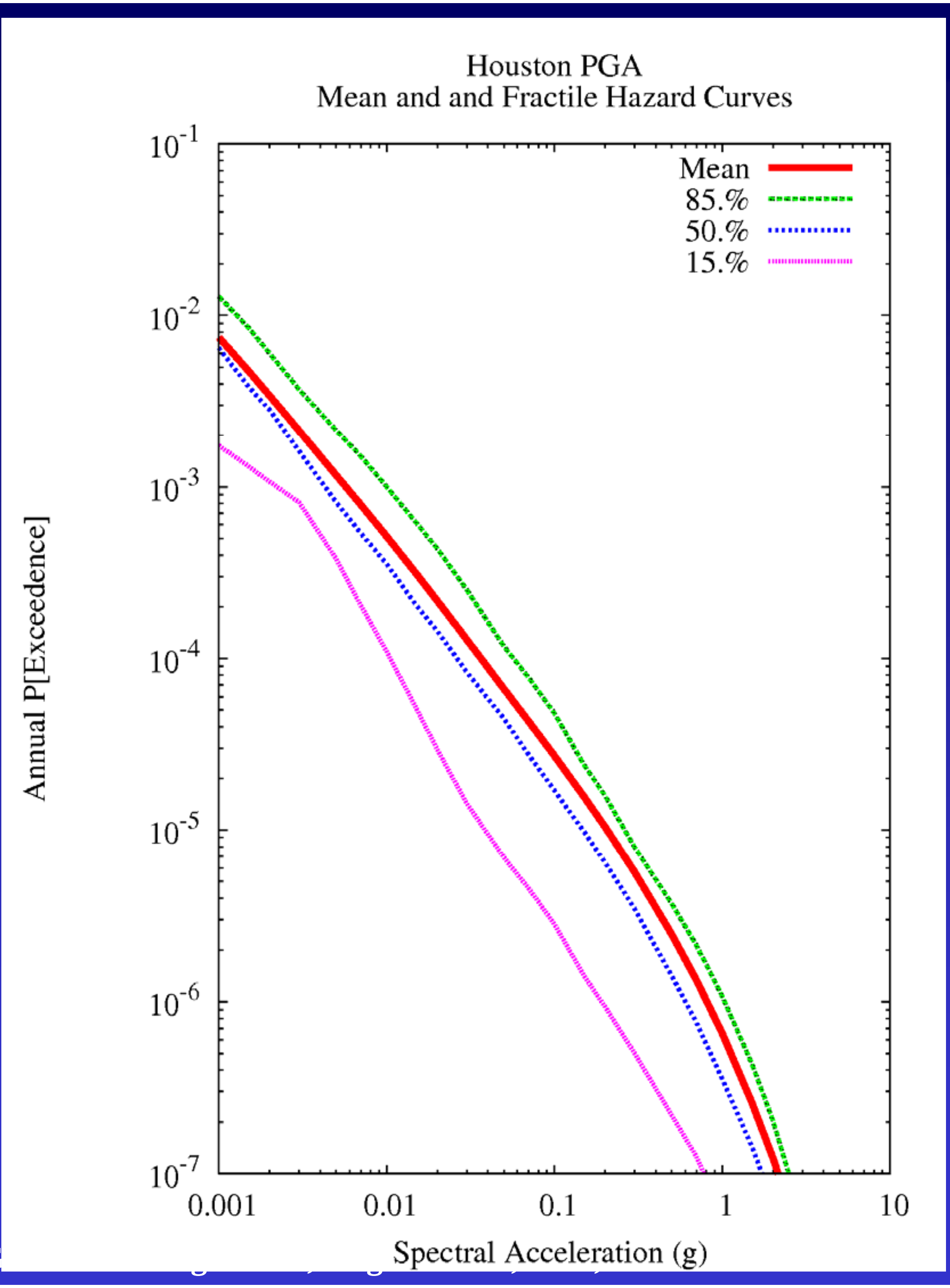
RISK ENGINEERING



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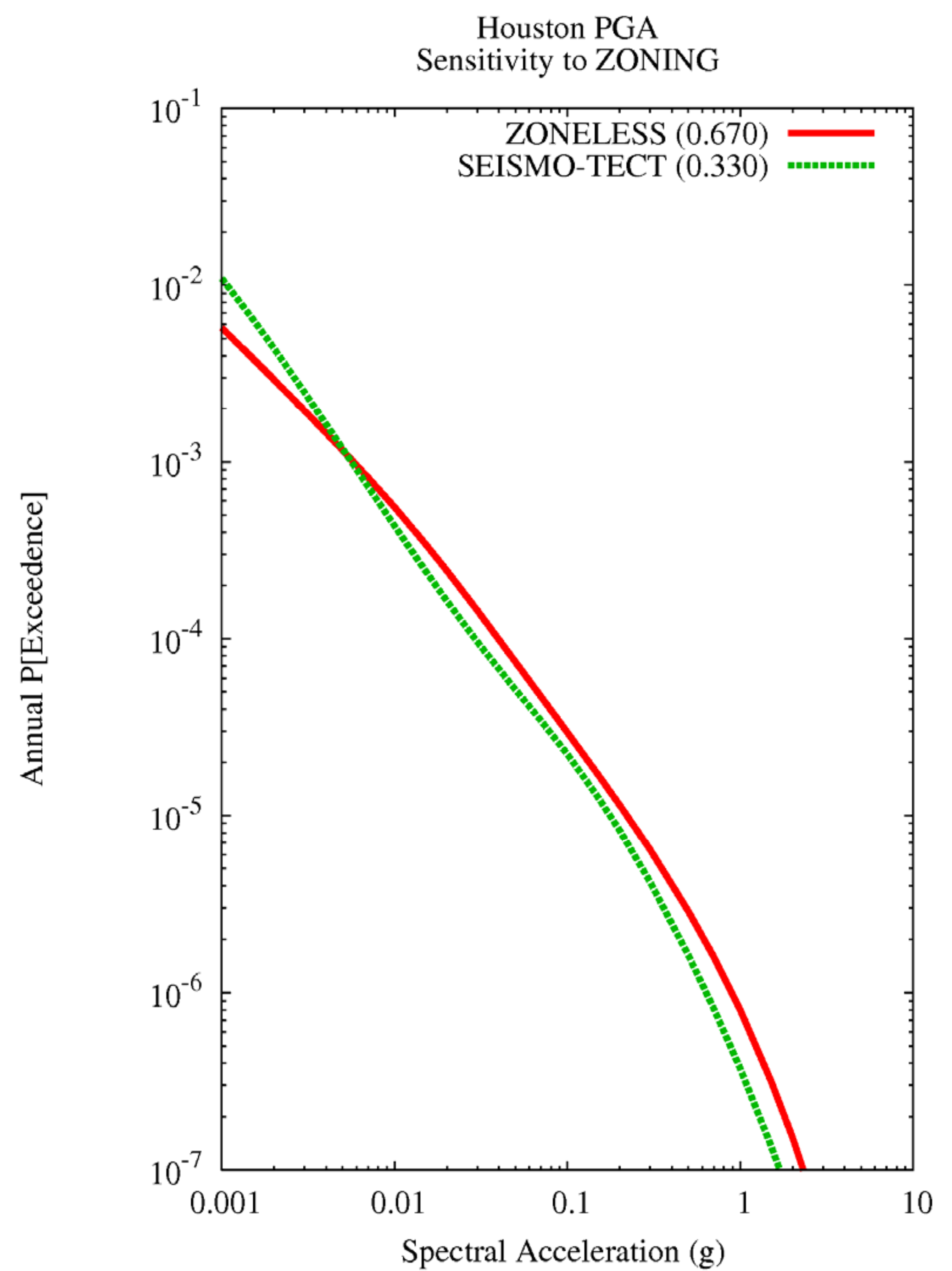

Houston PGA
Sensitivity to ZONING

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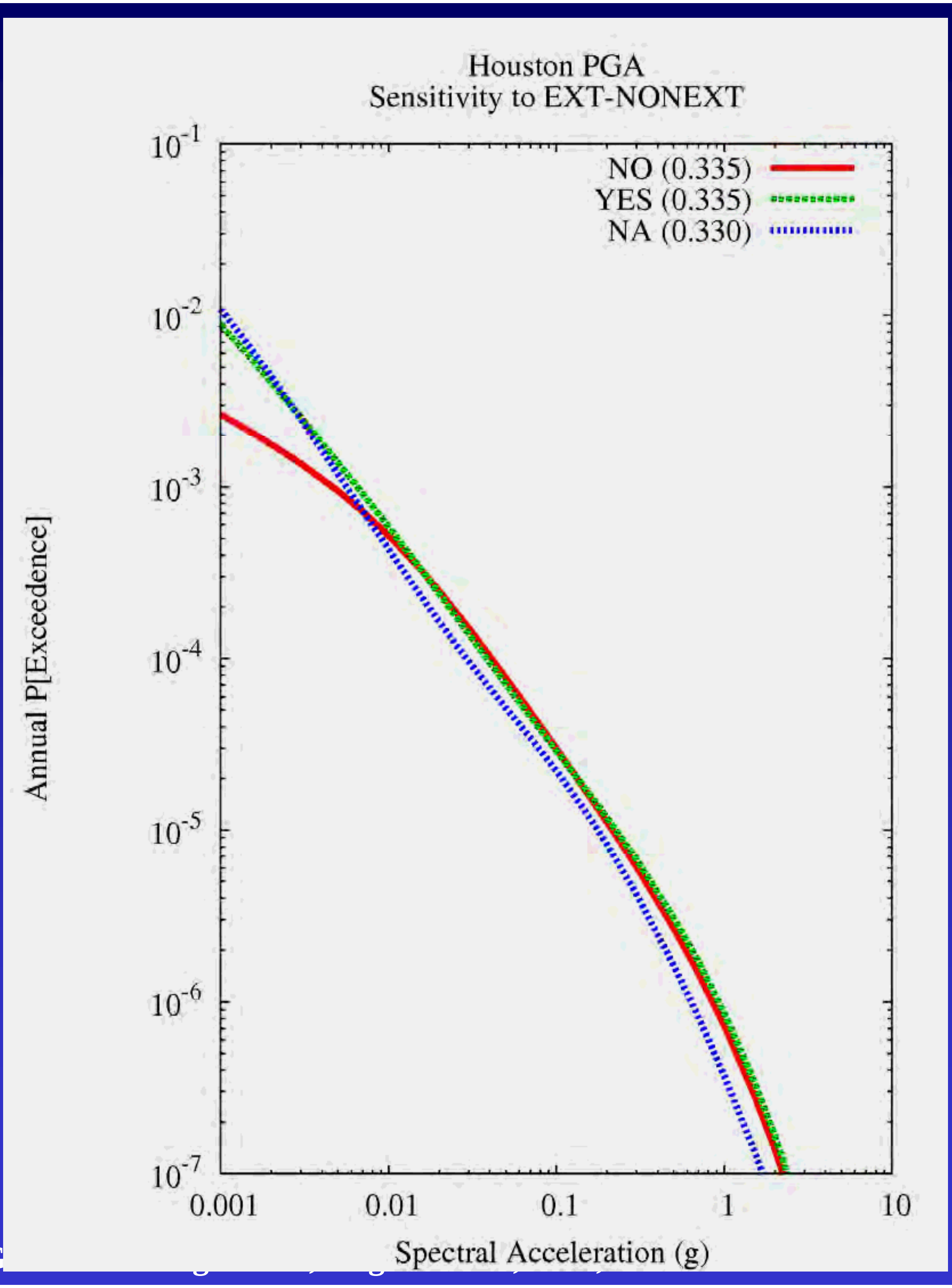
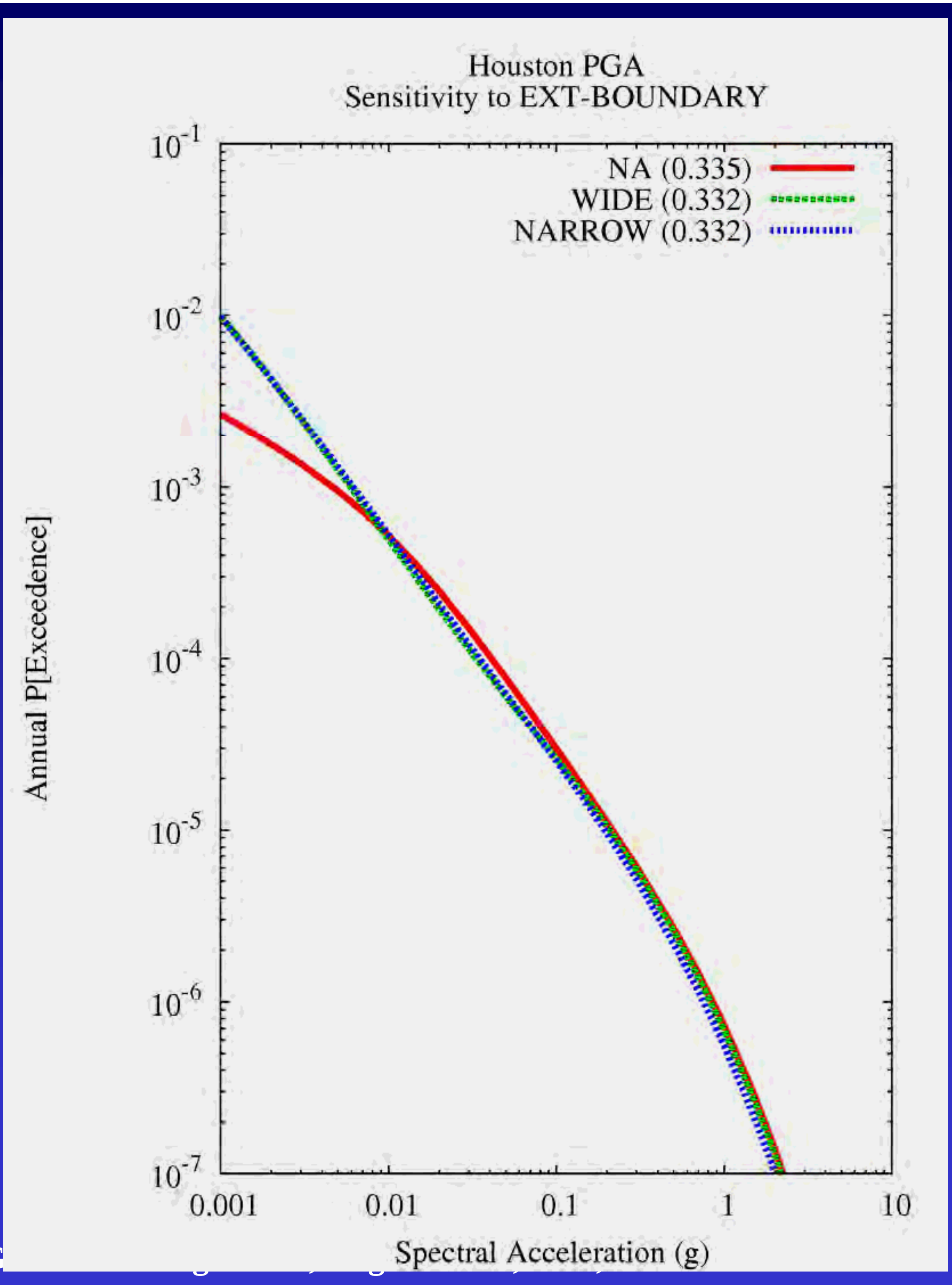
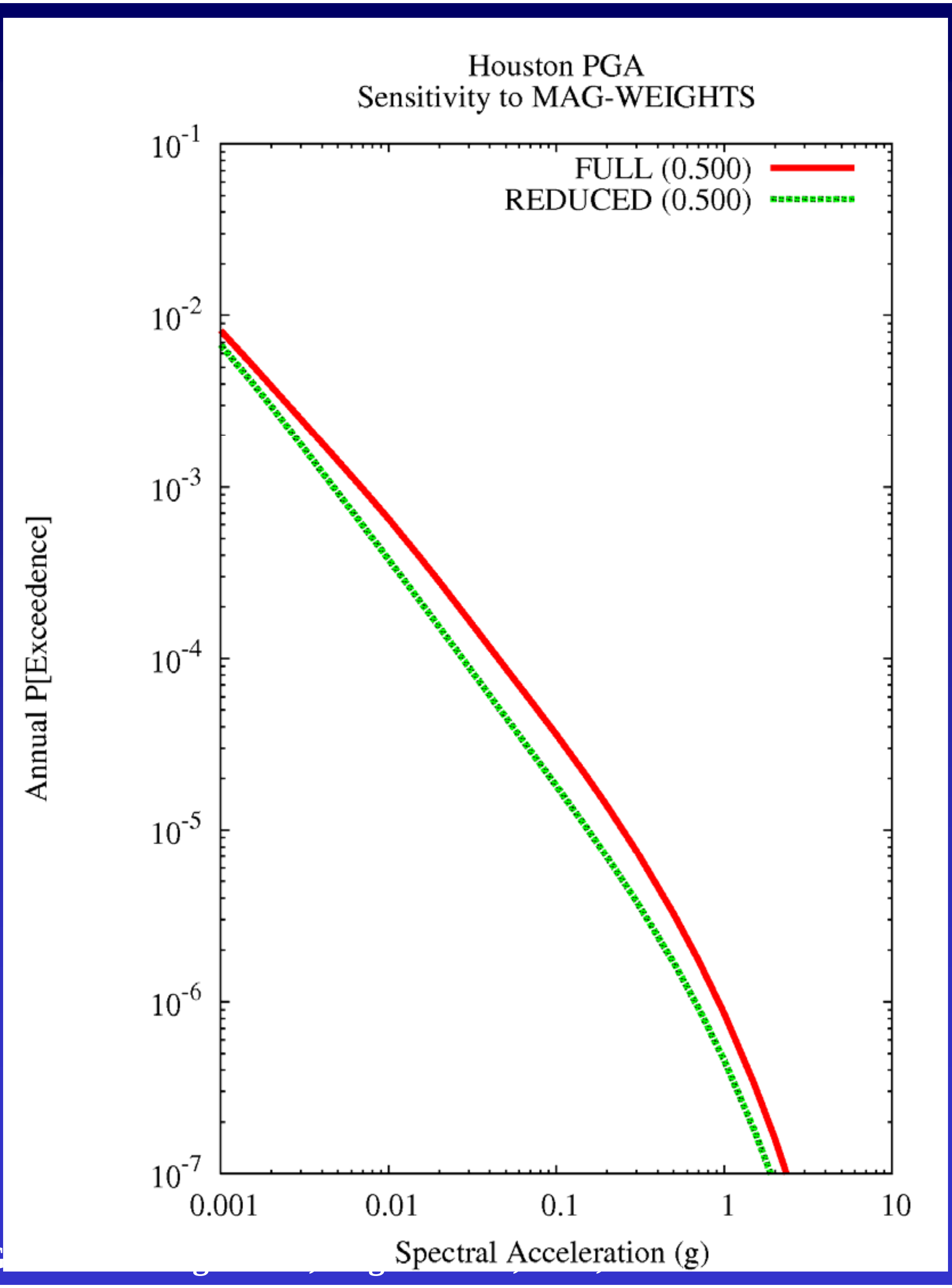
ENGINEERING



WLA
William Lettis & Associates, Inc.

RISK
ENGINEERING


Houston PGA
Sensitivity to EXT-BOUNDARY



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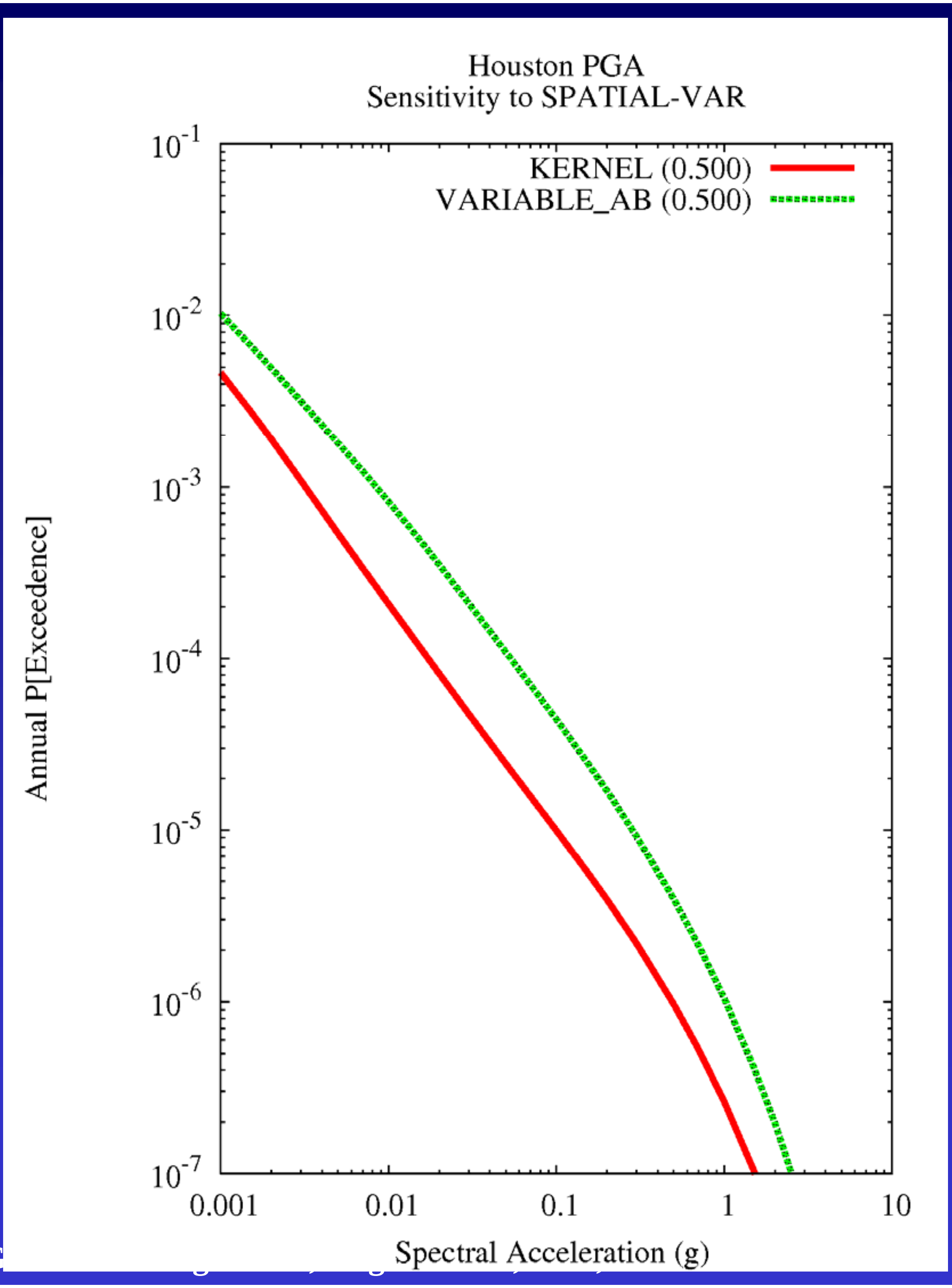
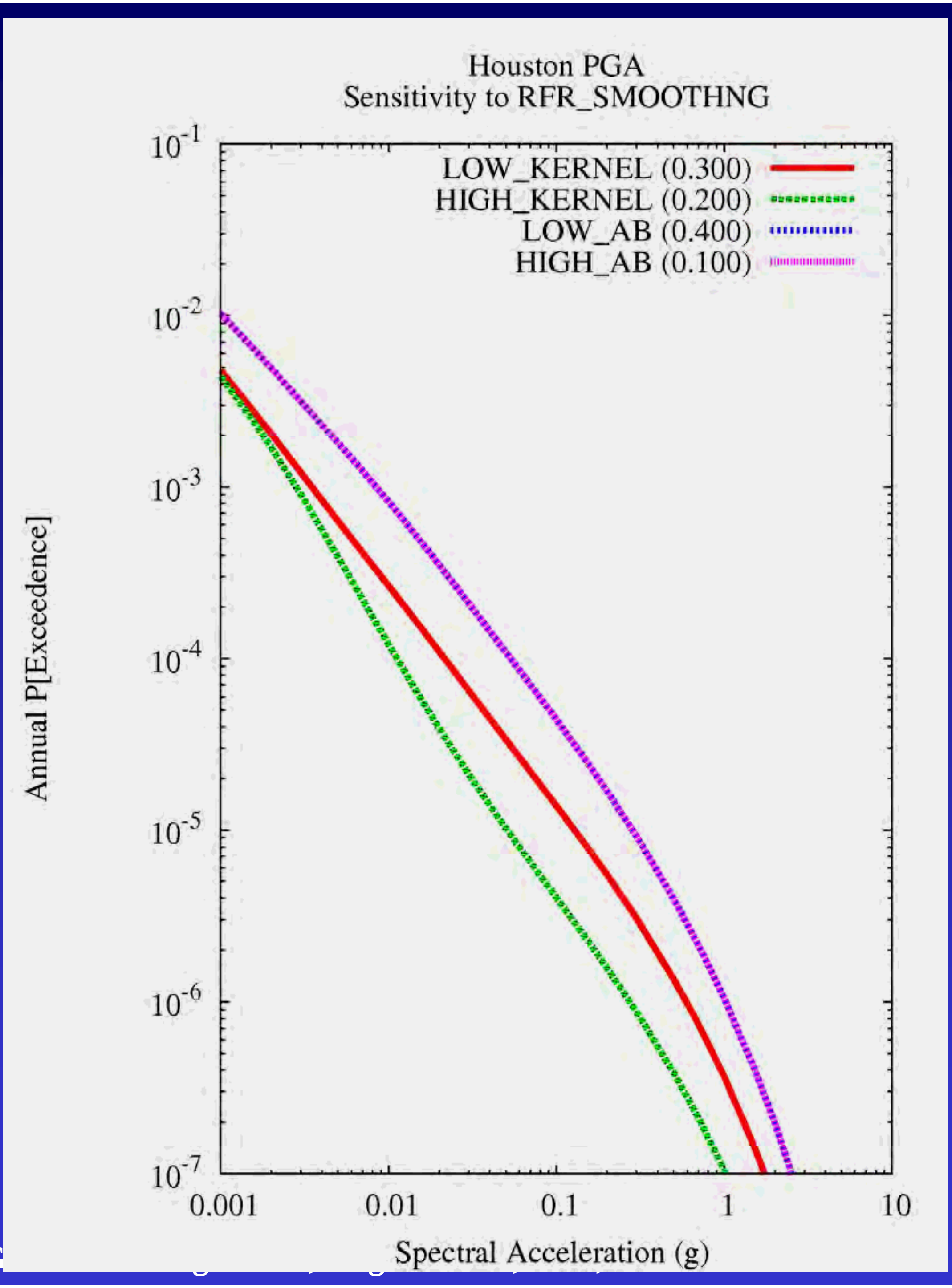
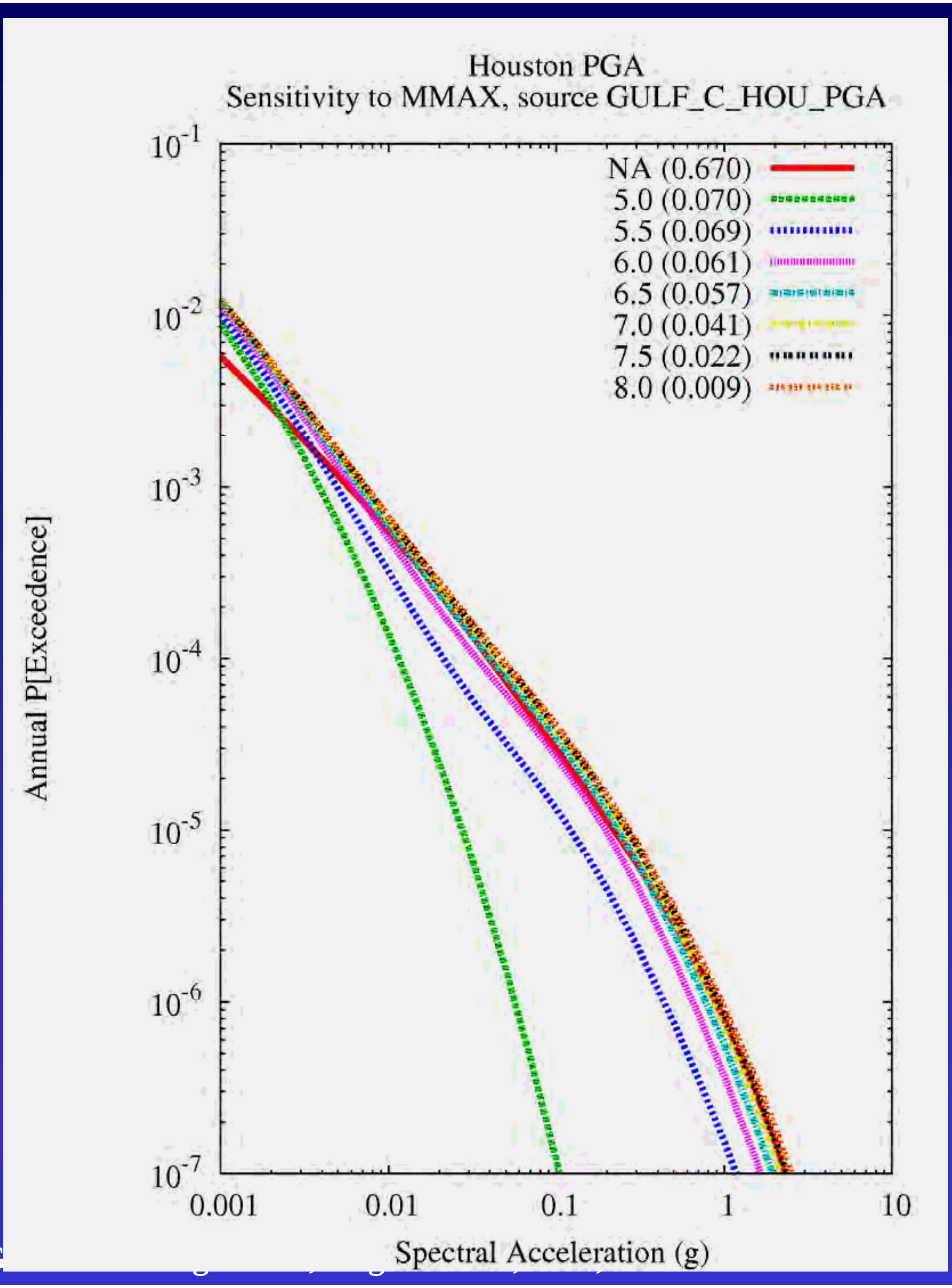
RISK ENGINEERING



WLA William Lettis & Associates, Inc.

RISK ENGINEERING


Houston PGA
Sensitivity to RFR_SMOOTHNG
LOW_KERNEL (0.300)
HIGH_KERNEL (0.200)
LOW_AB (0.400)
HIGH_AB (0.100)
Annual P[Exceedence]
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
0.001
0.01
0.1
1
10
Spectral Acceleration (g)



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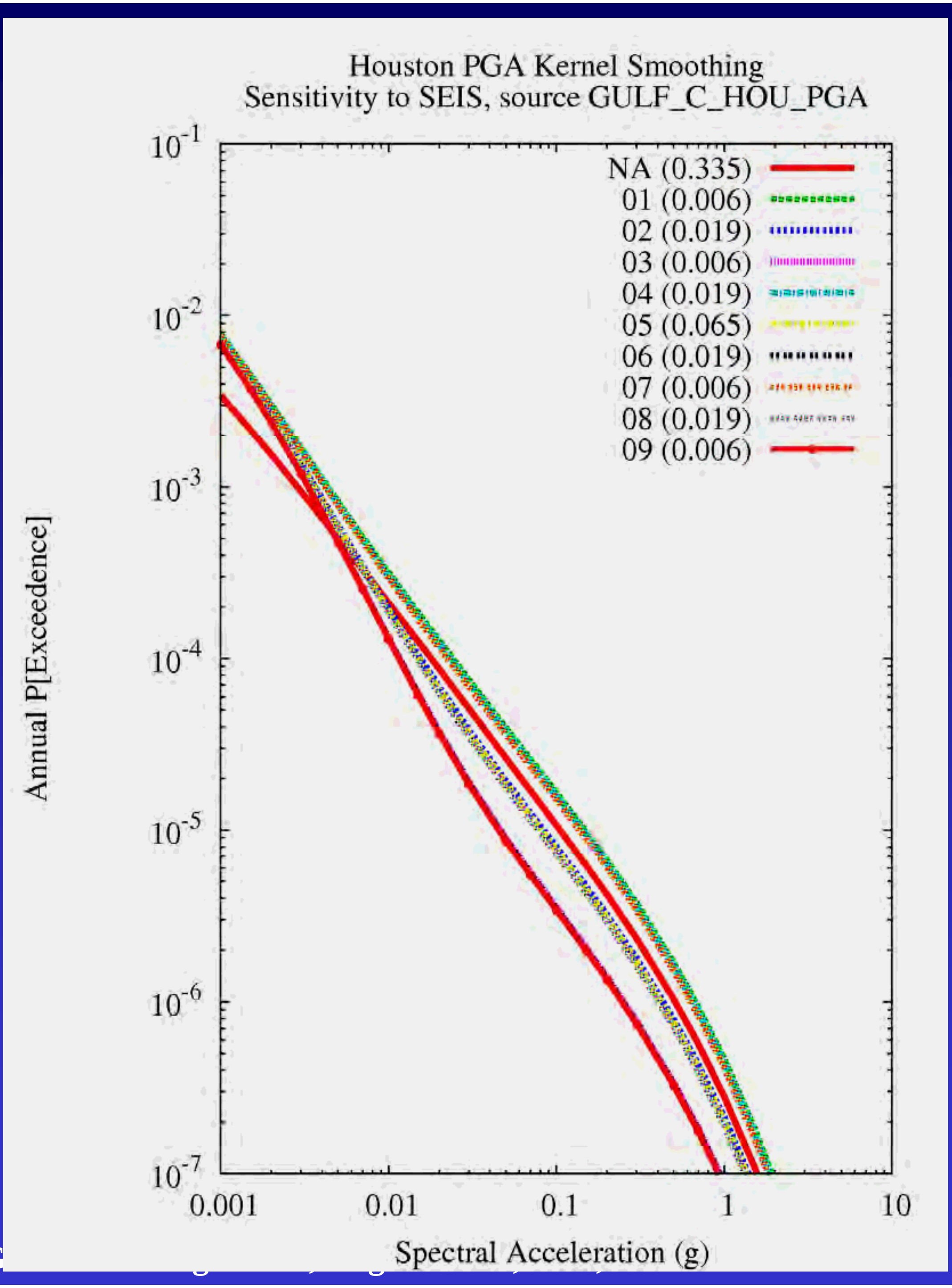
RISK
ENGINEERING



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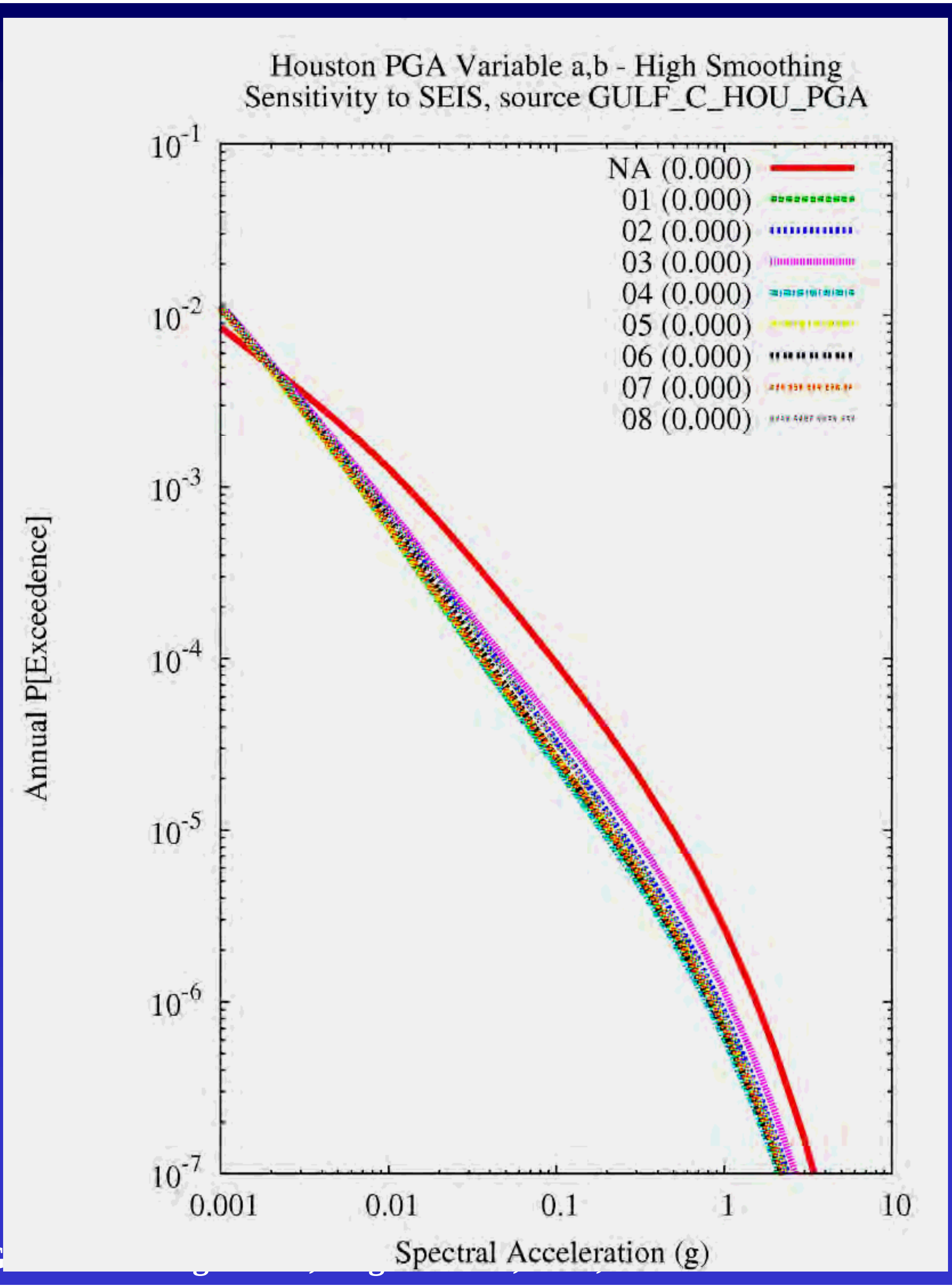
RISK ENGINEERING



WLA
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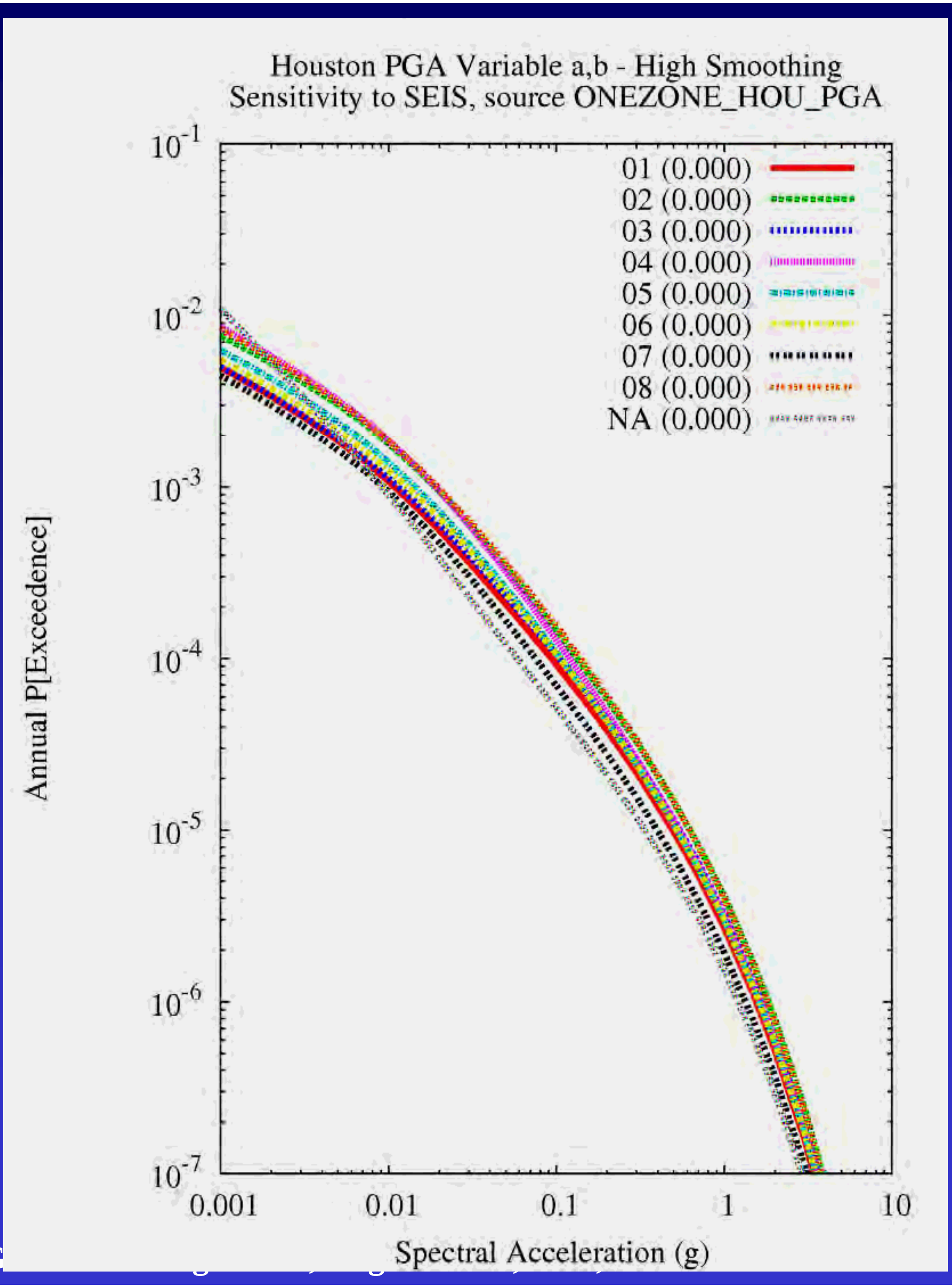
RISK
ENGINEERING



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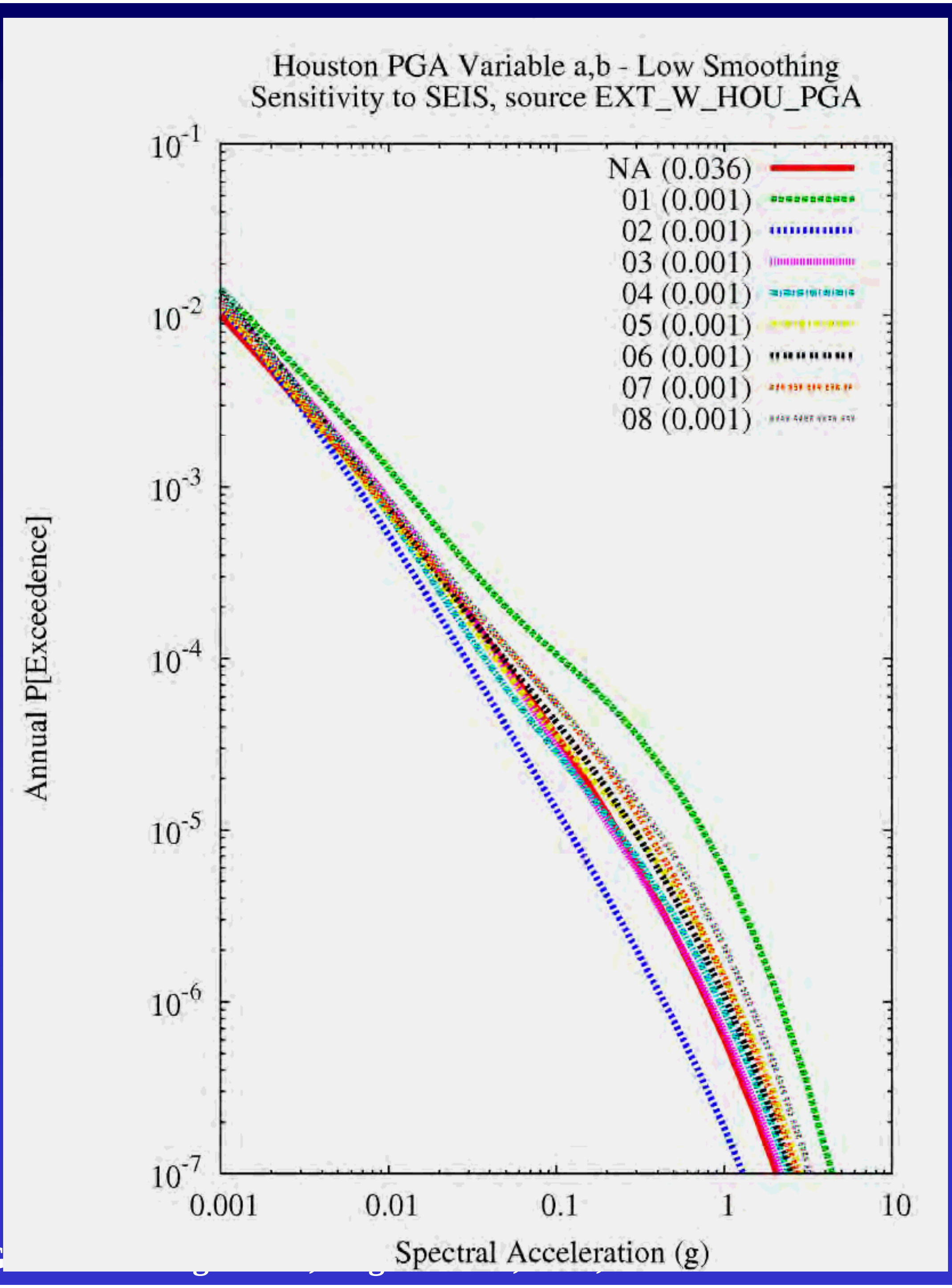
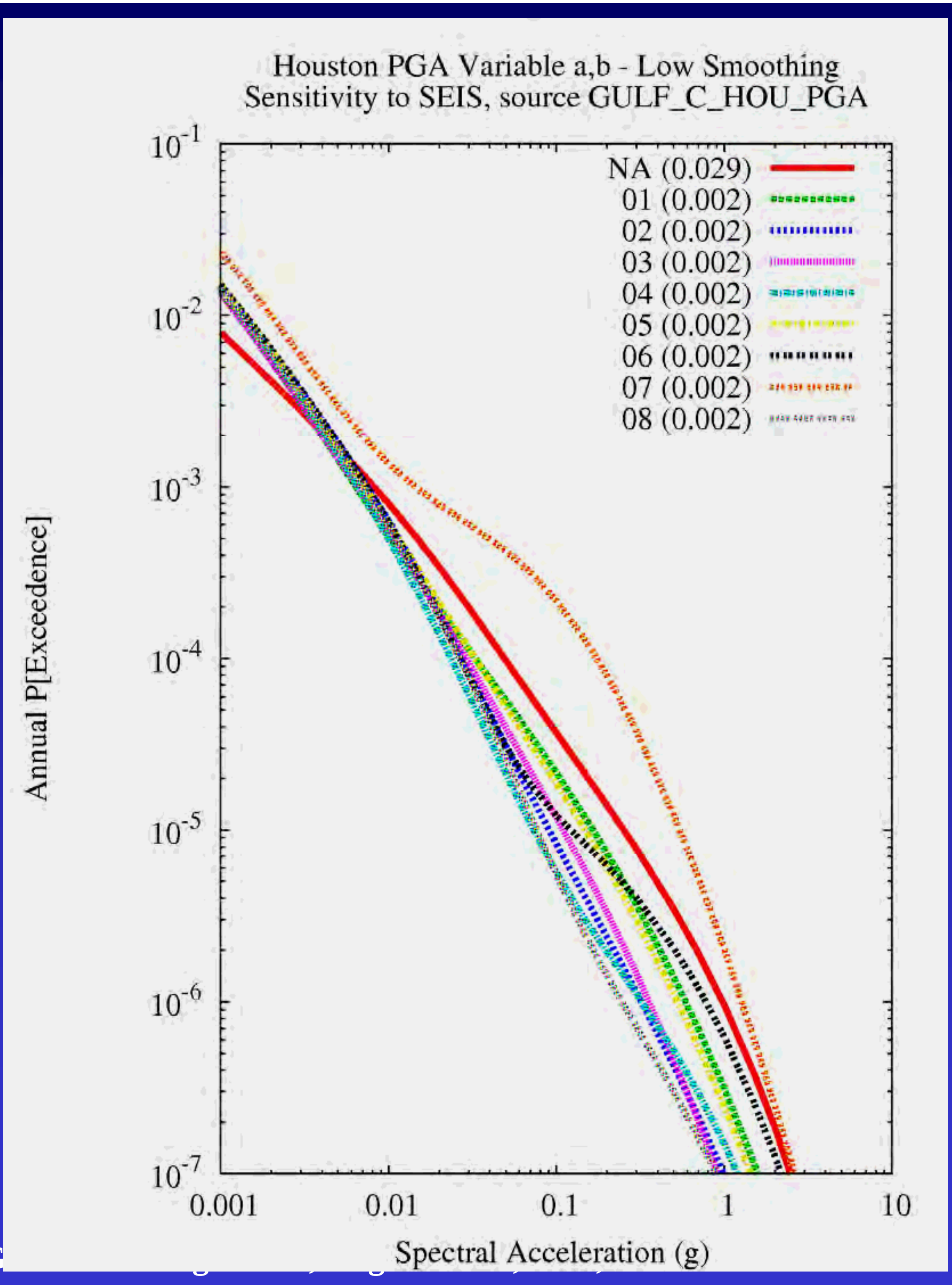
RISK
ENGINEERING



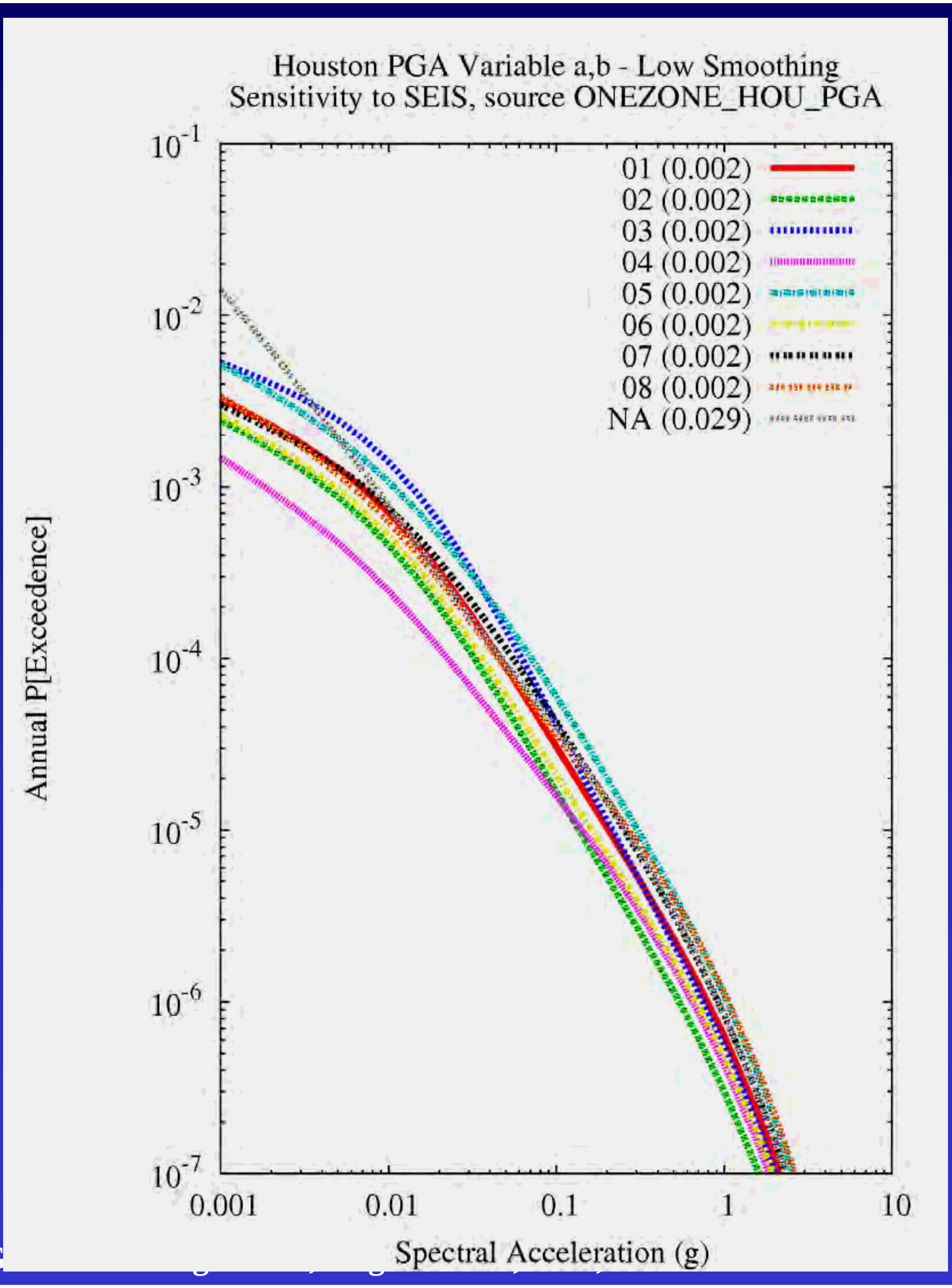
WLA
William Lettis & Associates, Inc.

RISK ENGINEERING



WLA
William Lettis & Associates, Inc.

RISK
ENGINEERING



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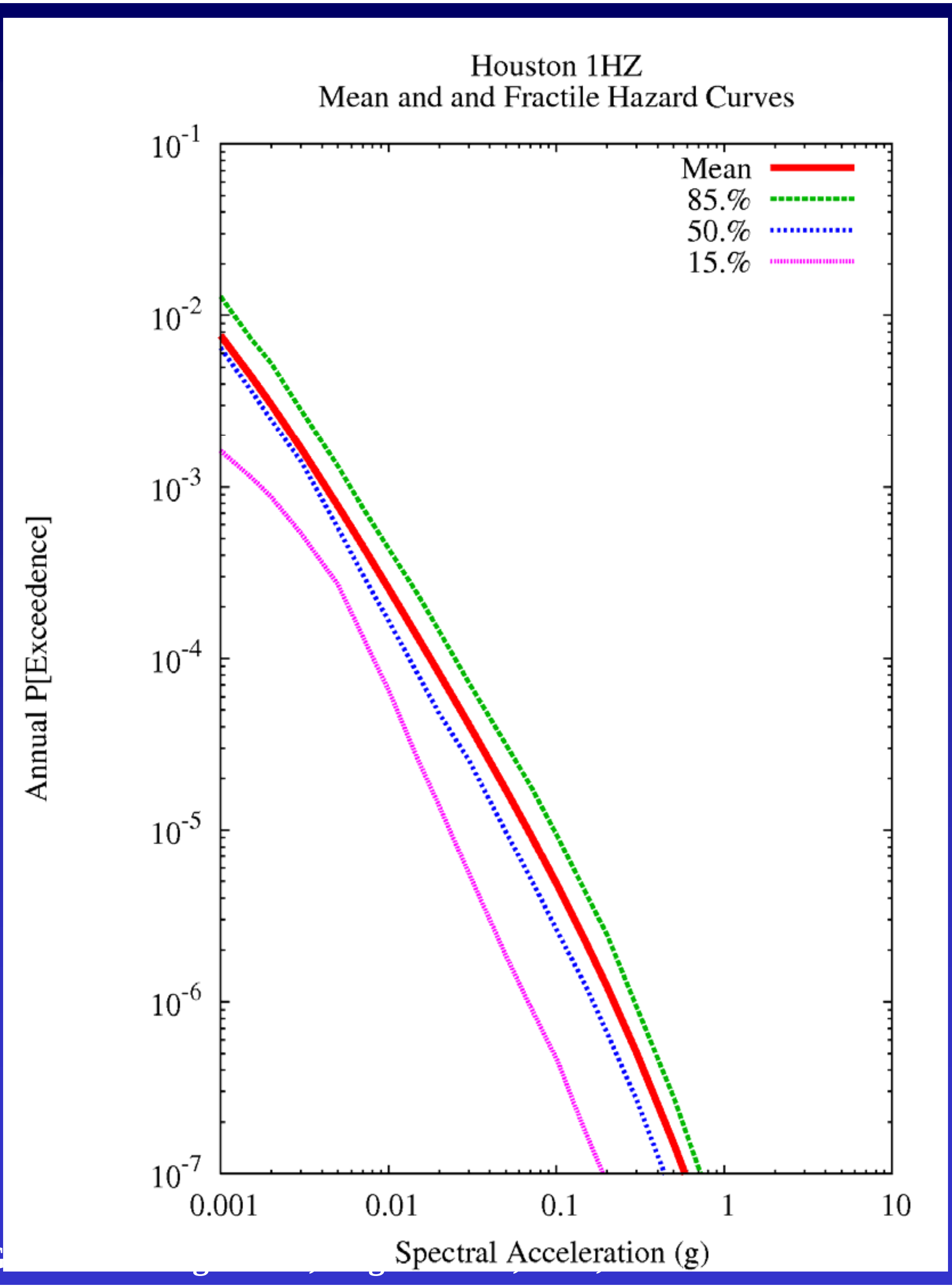
RISK ENGINEERING

Houston 1 Hz results

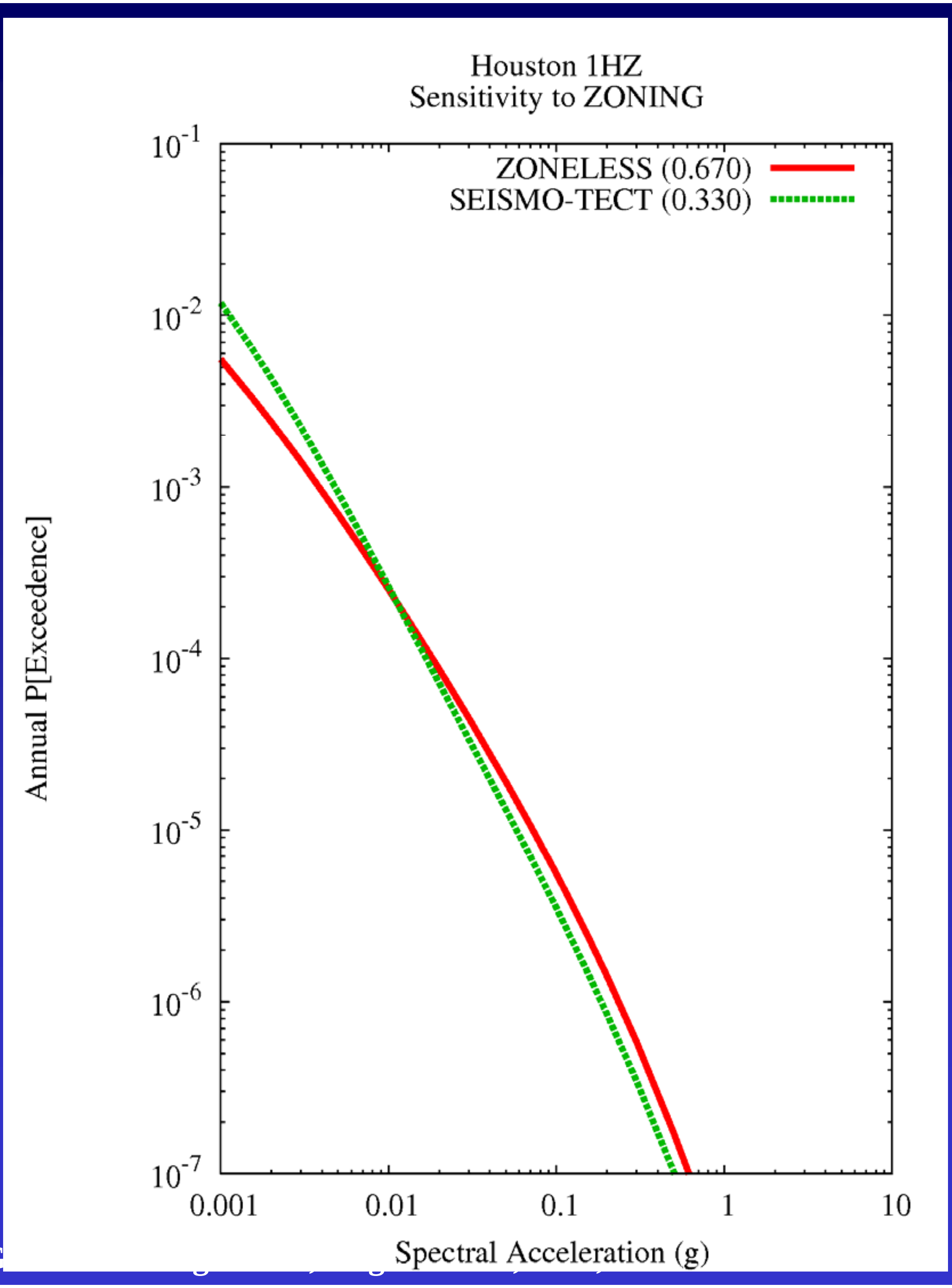
William Lettis & Associates, Inc.

RISK ENGINEERING



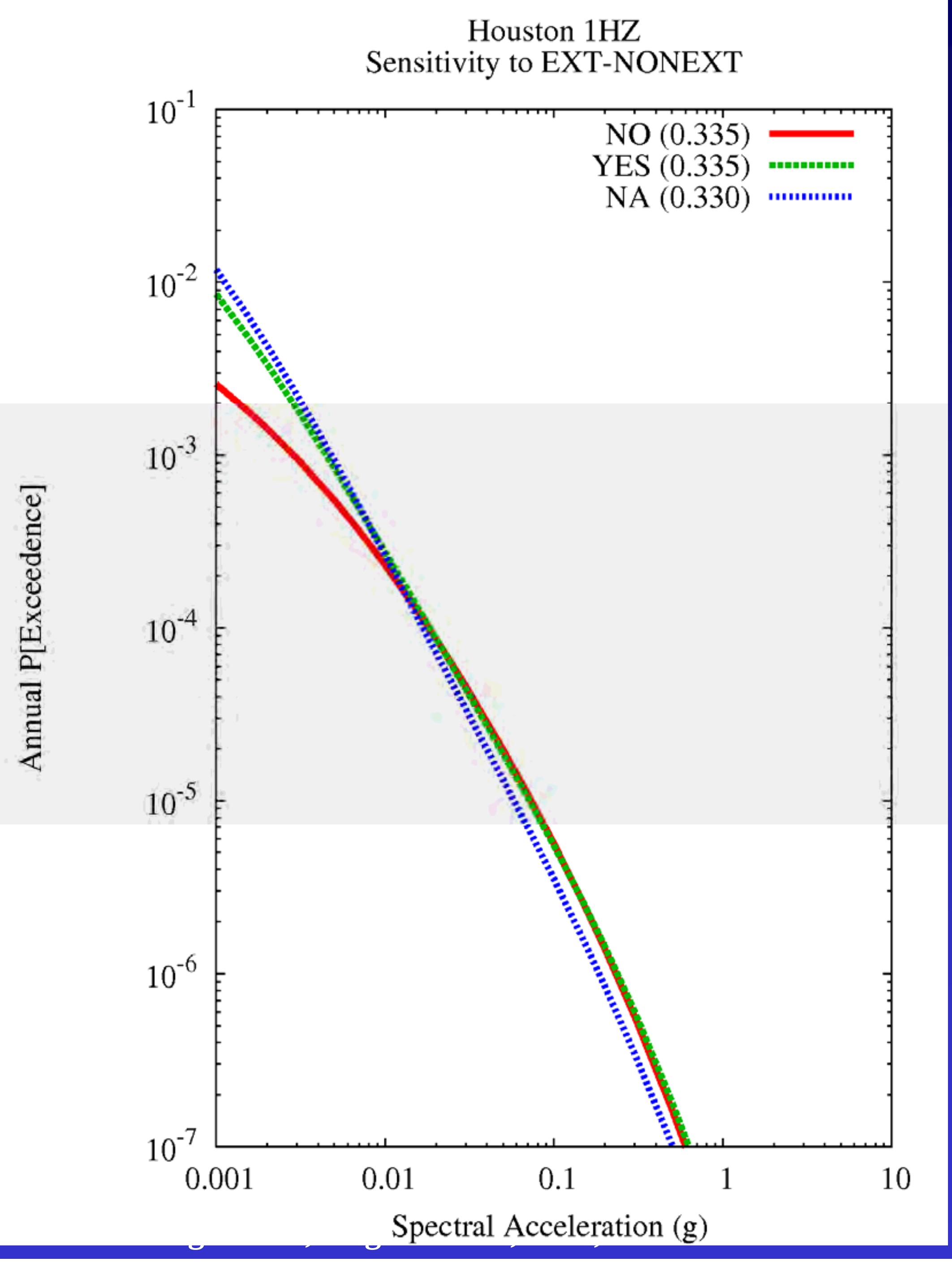
WLA
William Lettis & Associates, Inc.

RISK
ENGINEERING



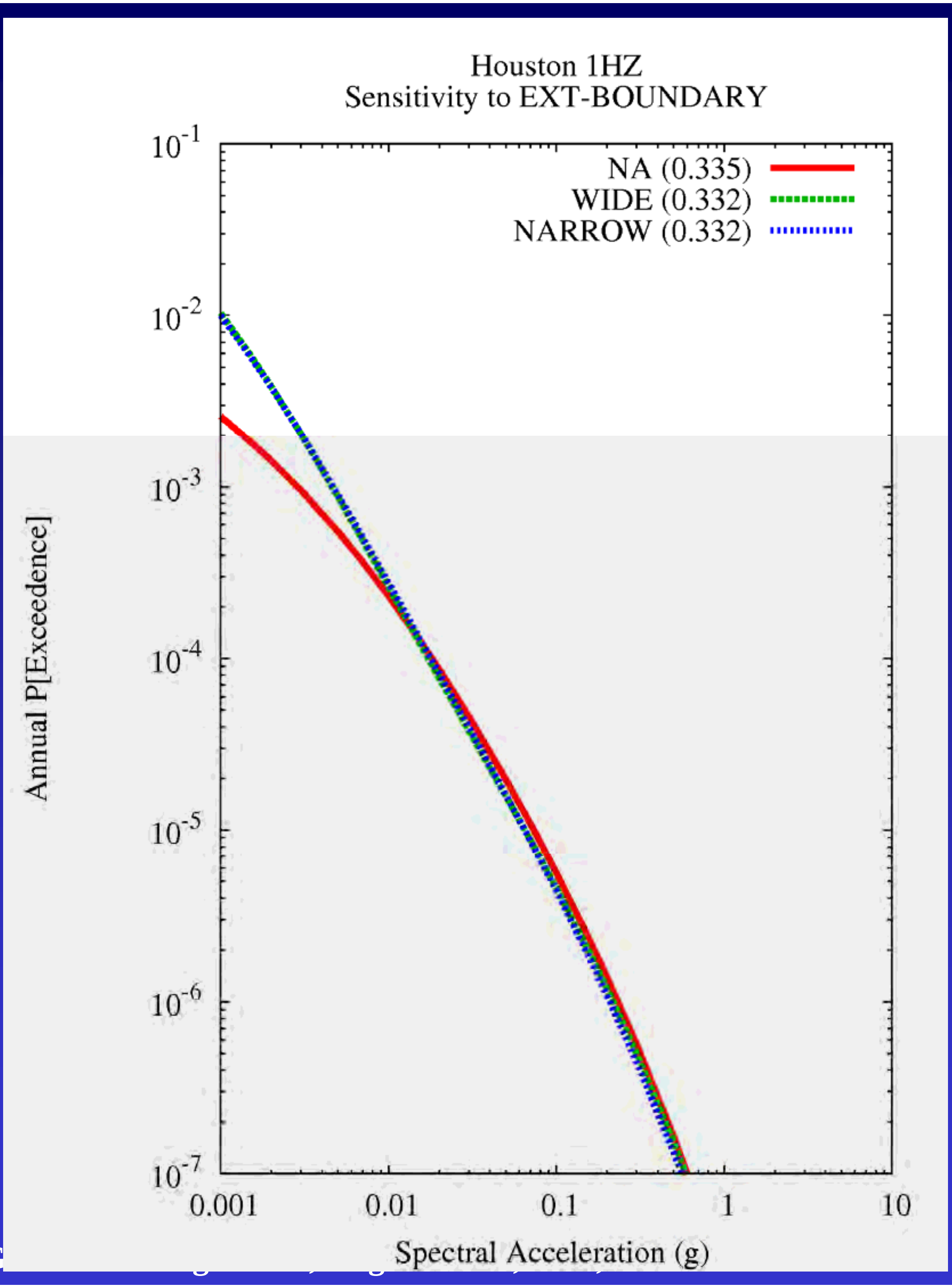
WLA
William Lettis & Associates, Inc.

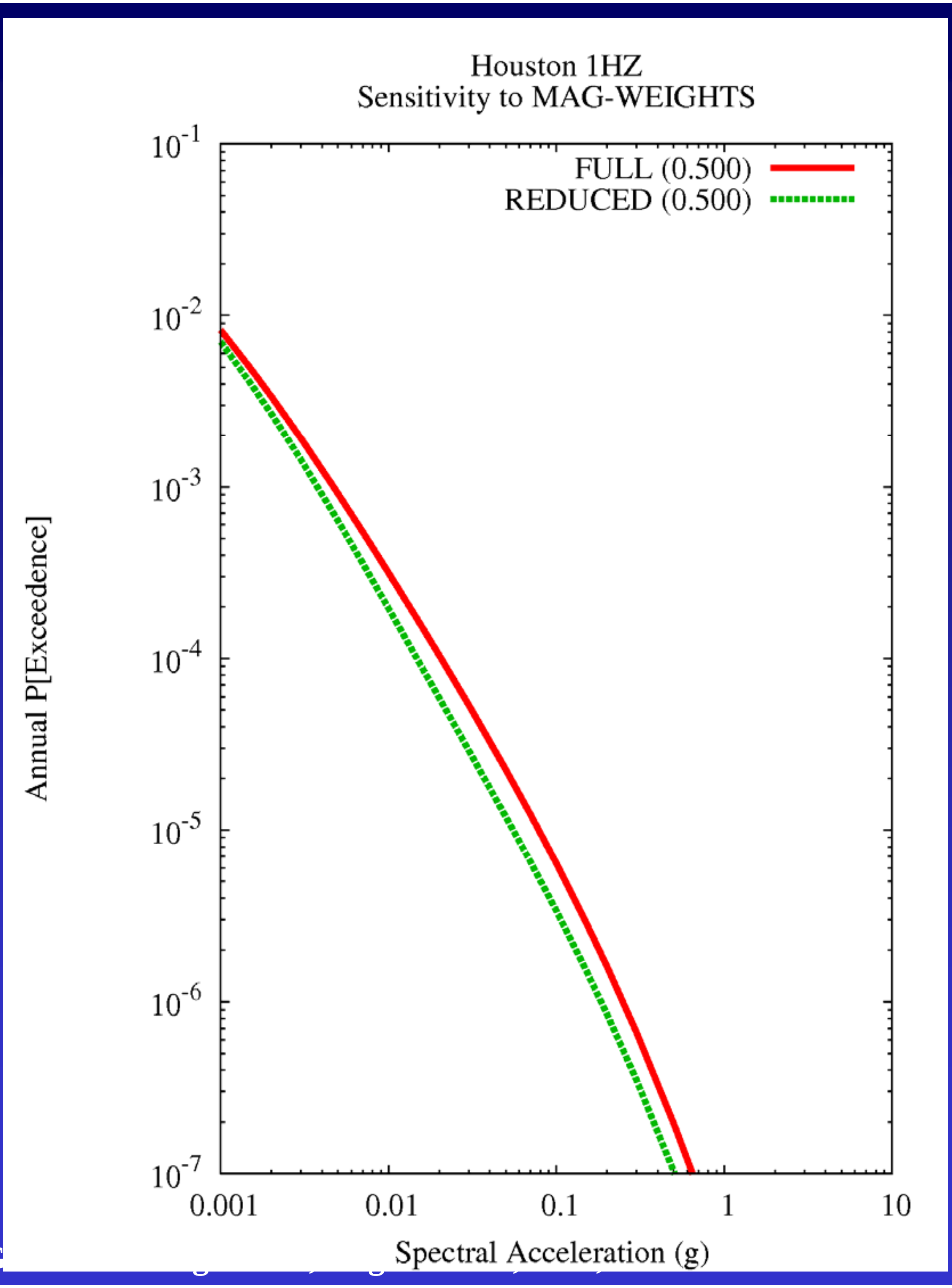
RISK
ENGINEERING



WLA
William Lettis & Associates, Inc.

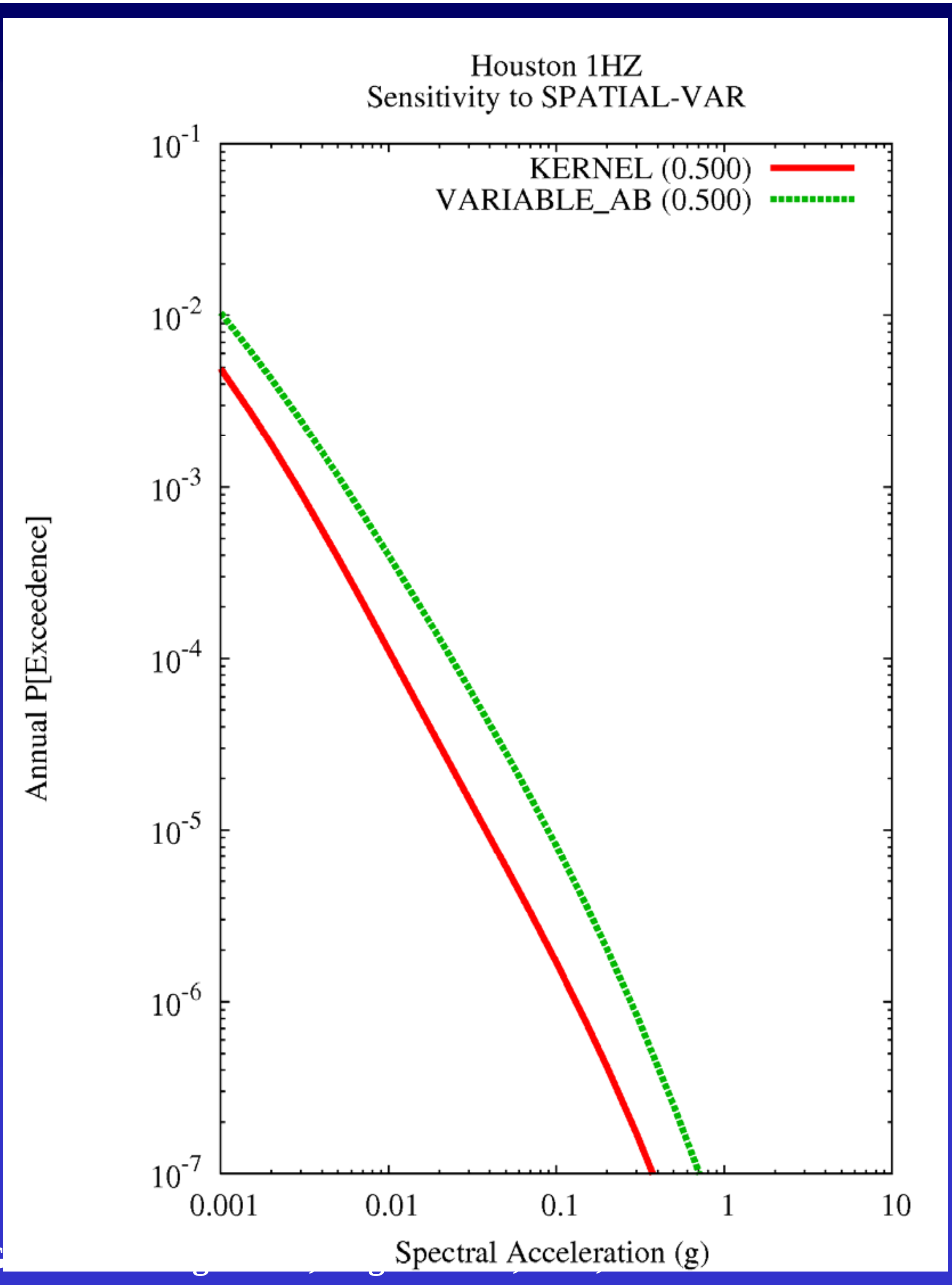
RISK
ENGINEERING

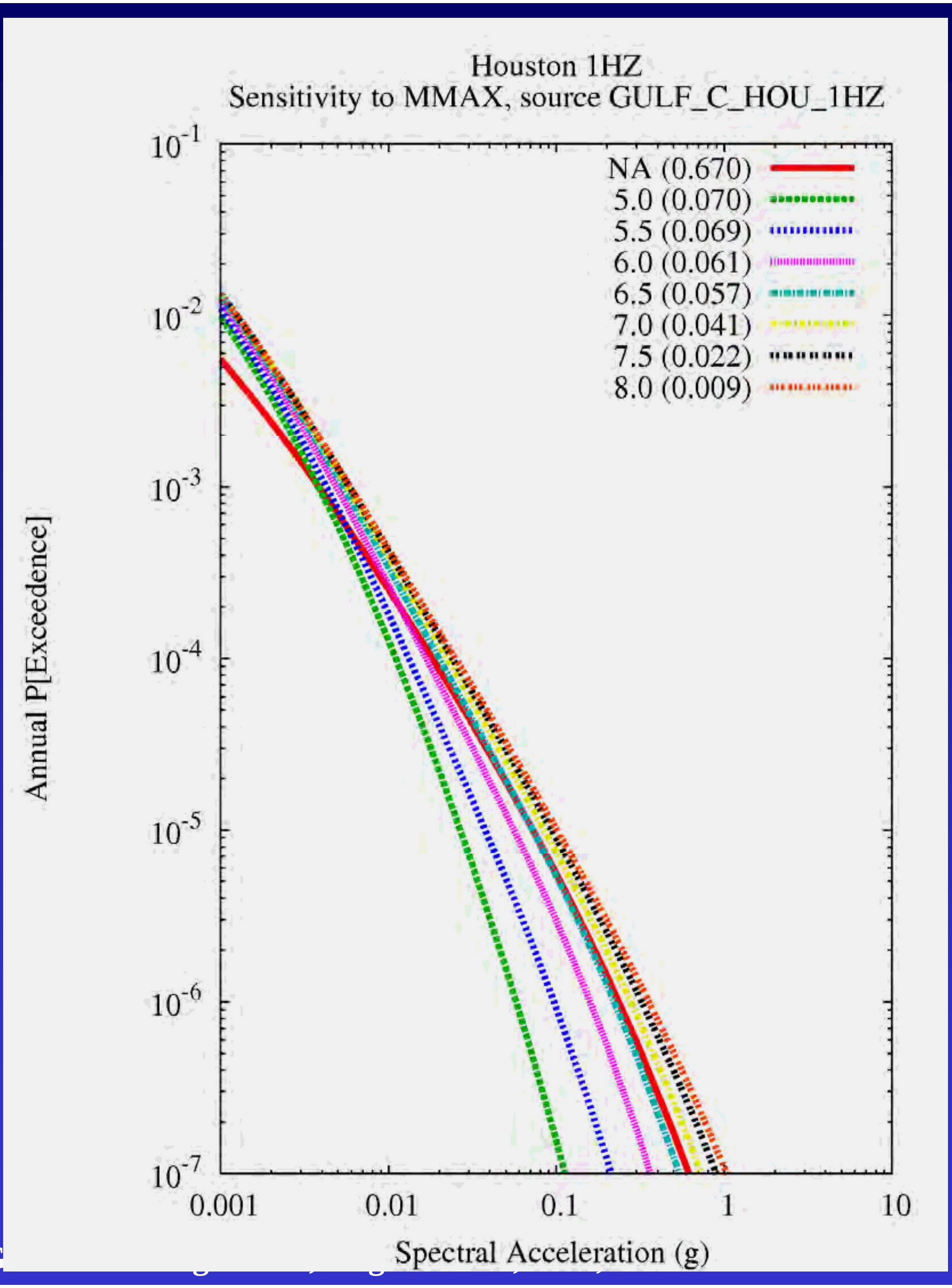

Houston 1HZ
Sensitivity to EXT-BOUNDARY
NA (0.335)
WIDE (0.332)
NARROW (0.332)
Annual P[Exceedence]
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
0.001
0.01
0.1
1
10
Spectral Acceleration (g)

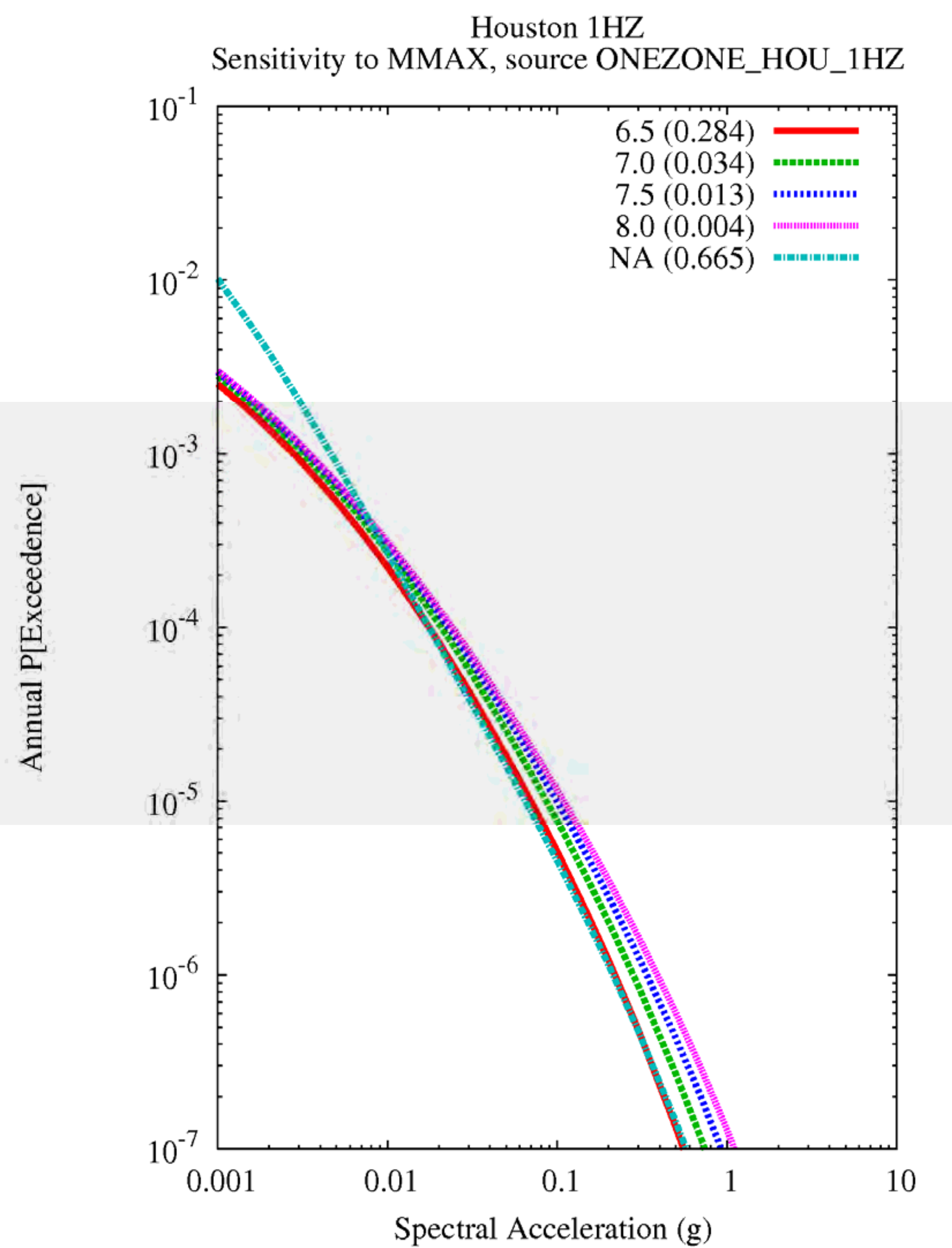


WLA William Lettis & Associates, Inc.

RISK ENGINEERING


Houston 1HZ
Sensitivity to SPATIAL-VAR
KERNEL (0.500)
VARIABLE_AB (0.500)
Annual P[Exceedence]
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
0.001
0.01
0.1
1
10
Spectral Acceleration (g)


Houston 1HZ
Sensitivity to MMAX, source GULF_C_HOU_1HZ
NA (0.670)
5.0 (0.070)
5.5 (0.069)
6.0 (0.061)
6.5 (0.057)
7.0 (0.041)
7.5 (0.022)
8.0 (0.009)
Annual P[Exceedence]
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
0.001
0.01
0.1
1
10
Spectral Acceleration (g)



Houston 1HZ
Sensitivity to MMAX, source ONEZONE_HOU_1HZ

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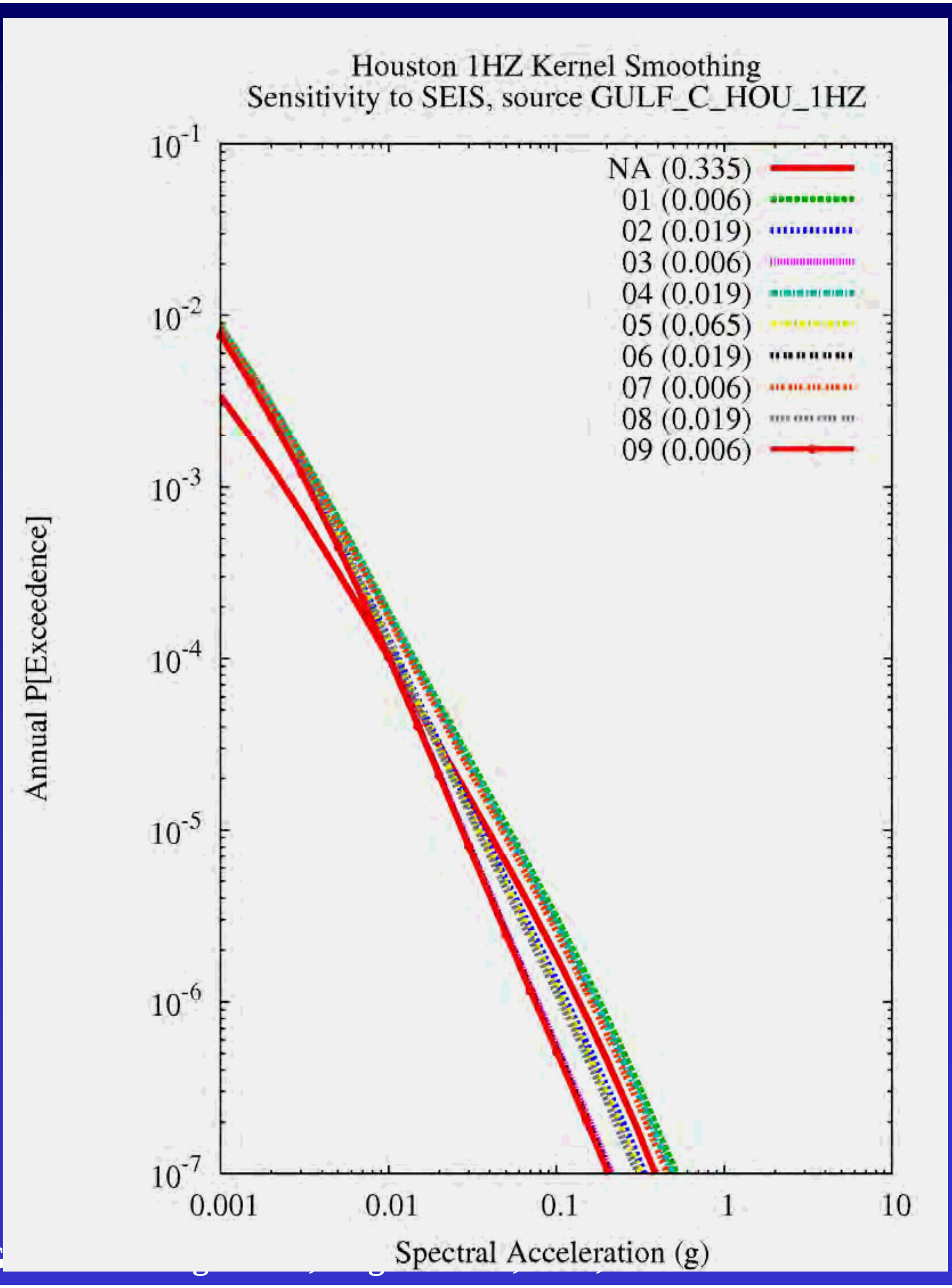
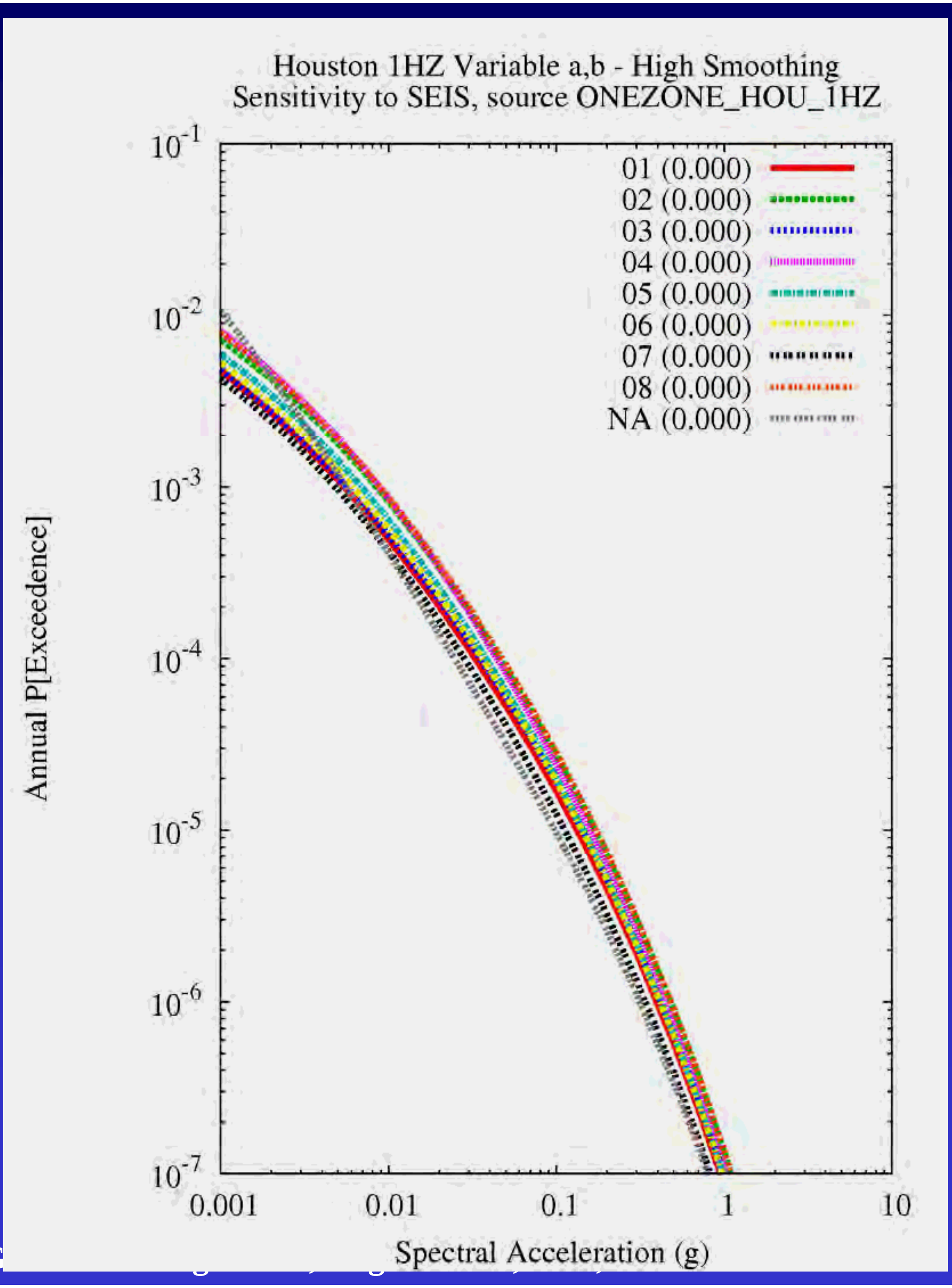

Houston 1HZ Kernel Smoothing
Sensitivity to SEIS, source GULF_C_HOU_1HZ
Annual P[Exceedence]
Spectral Acceleration (g)
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
0.001
0.01
0.1
1
10
NA (0.335)
01 (0.006)
02 (0.019)
03 (0.006)
04 (0.019)
05 (0.065)
06 (0.019)
07 (0.006)
08 (0.019)
09 (0.006)



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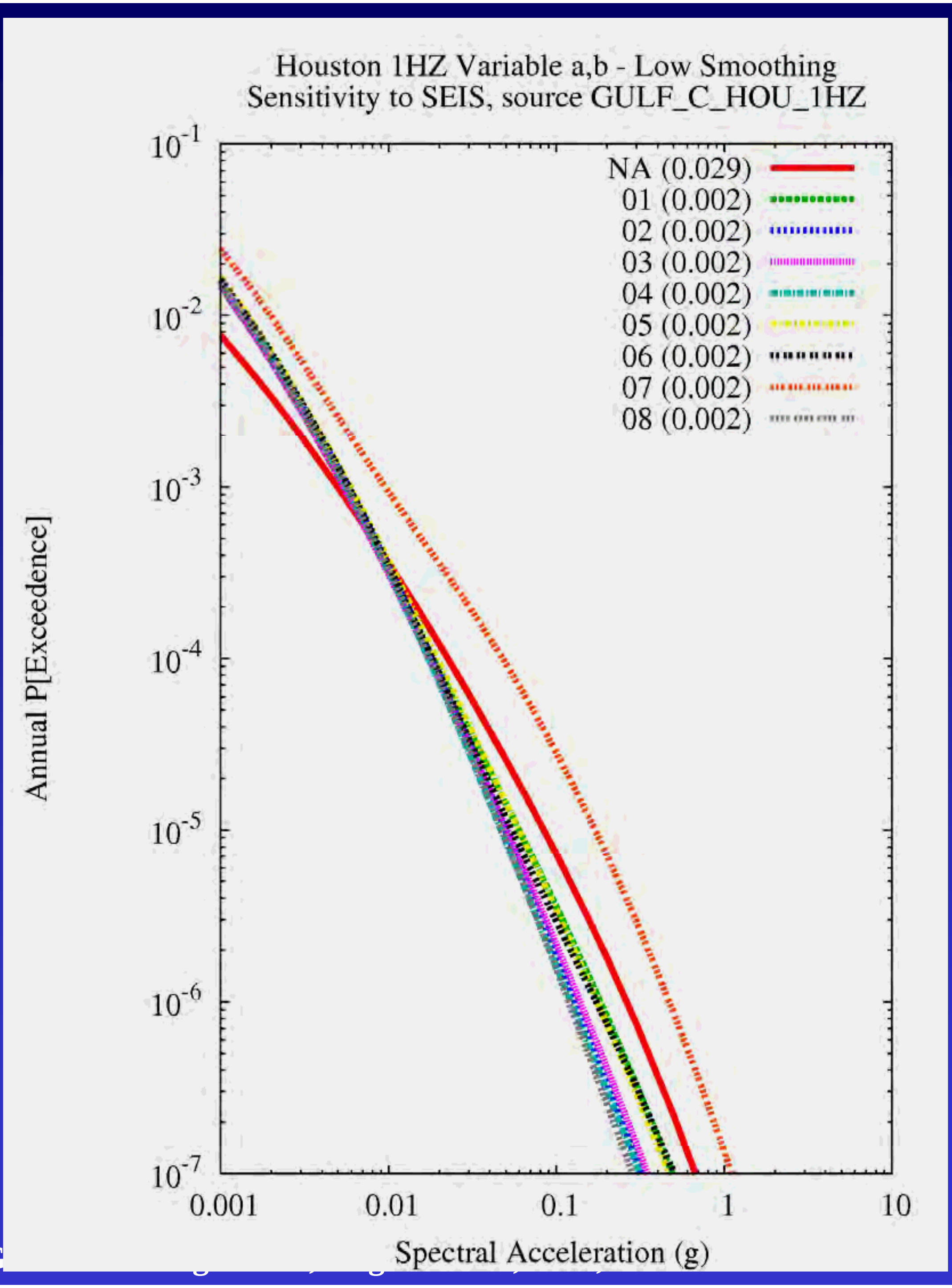

Houston 1HZ Variable a,b - Low Smoothing
Sensitivity to SEIS, source GULF_C_HOU_1HZ

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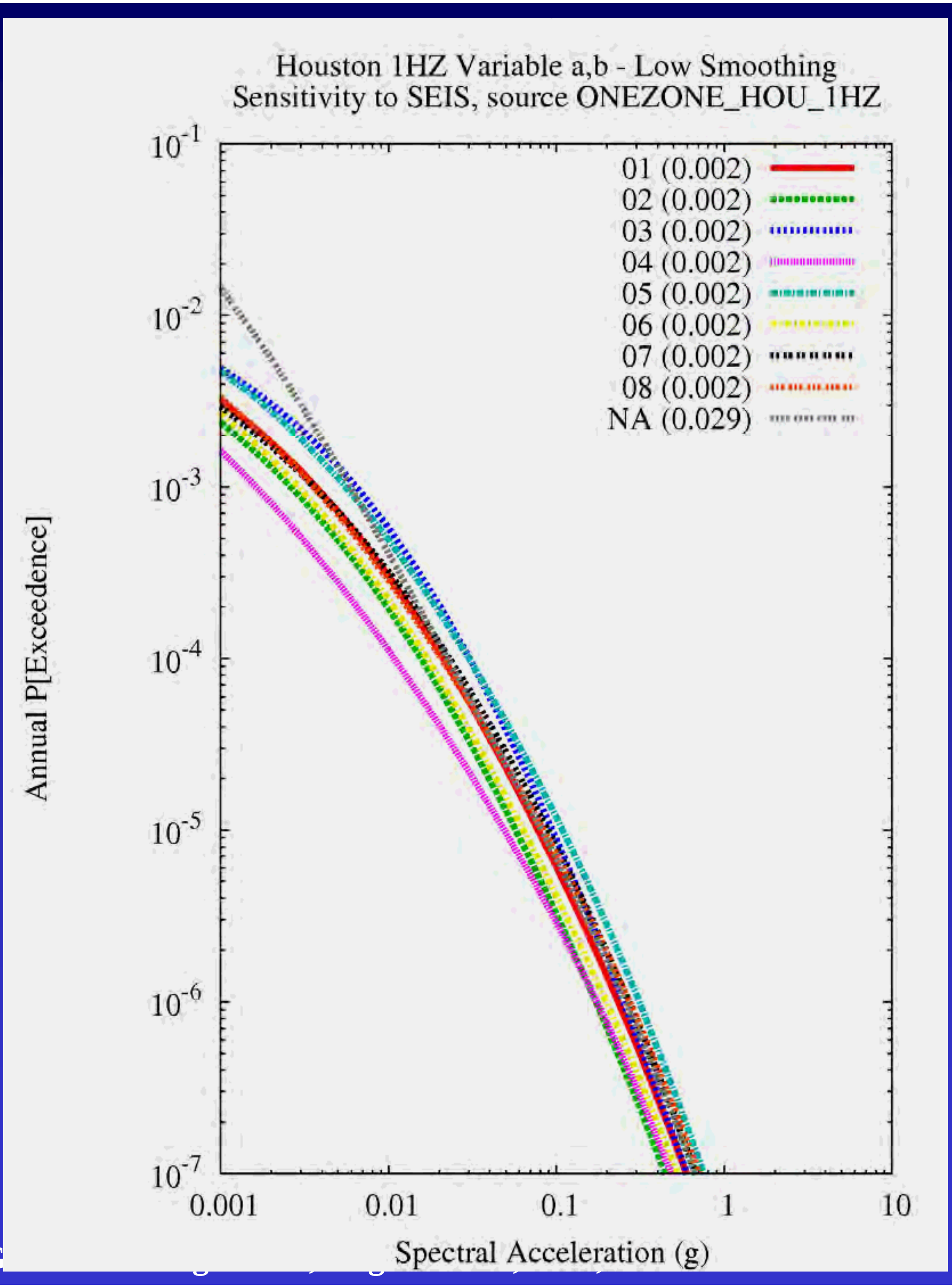

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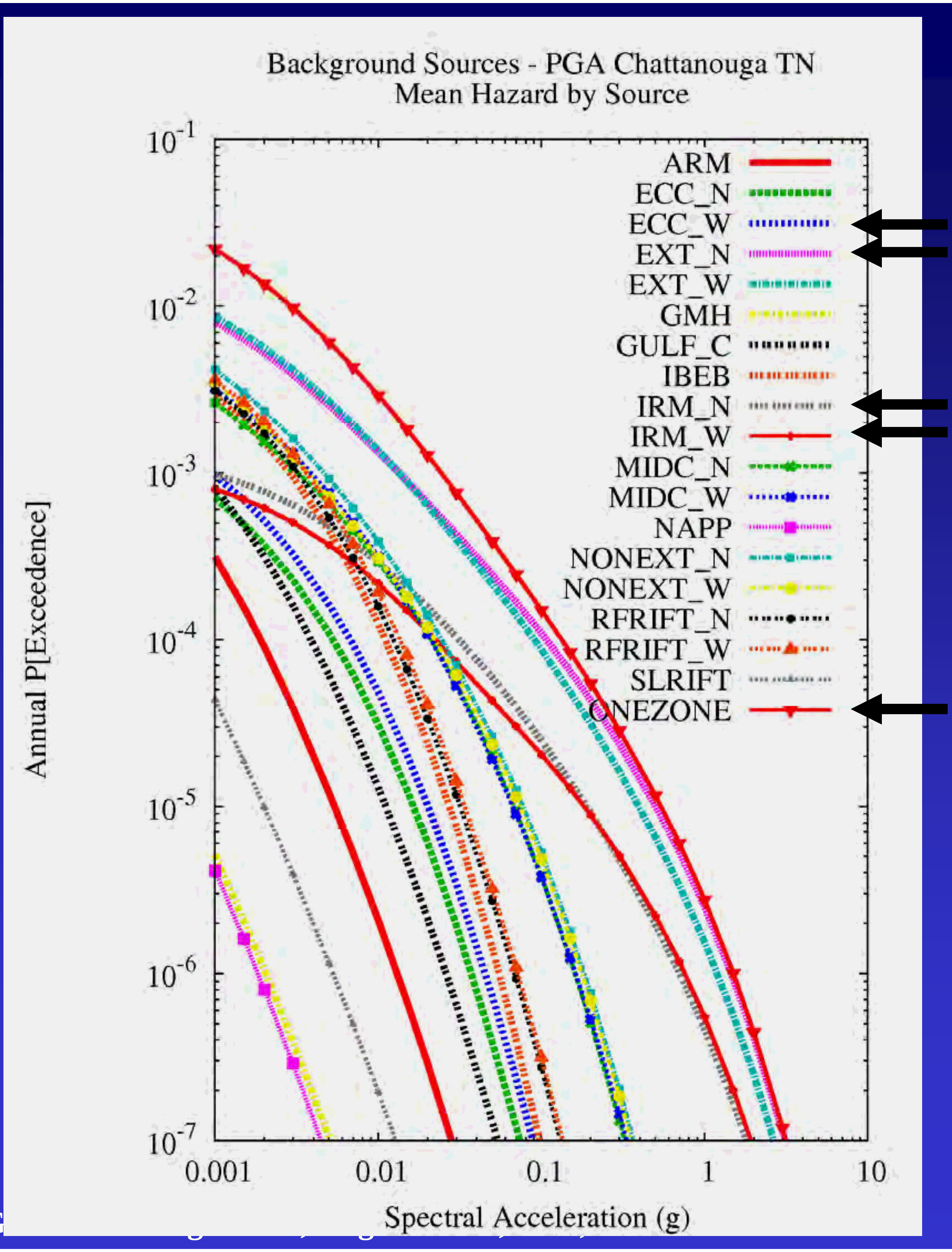
Summary of Results for Houston

- Sensitivity to Mmax of Gulf Source Zone
- Sensitivity to recurrence parameters of Gulf Source Zone (and alternative host zones)

Active Seismic Source Site (Chattanooga, TN)



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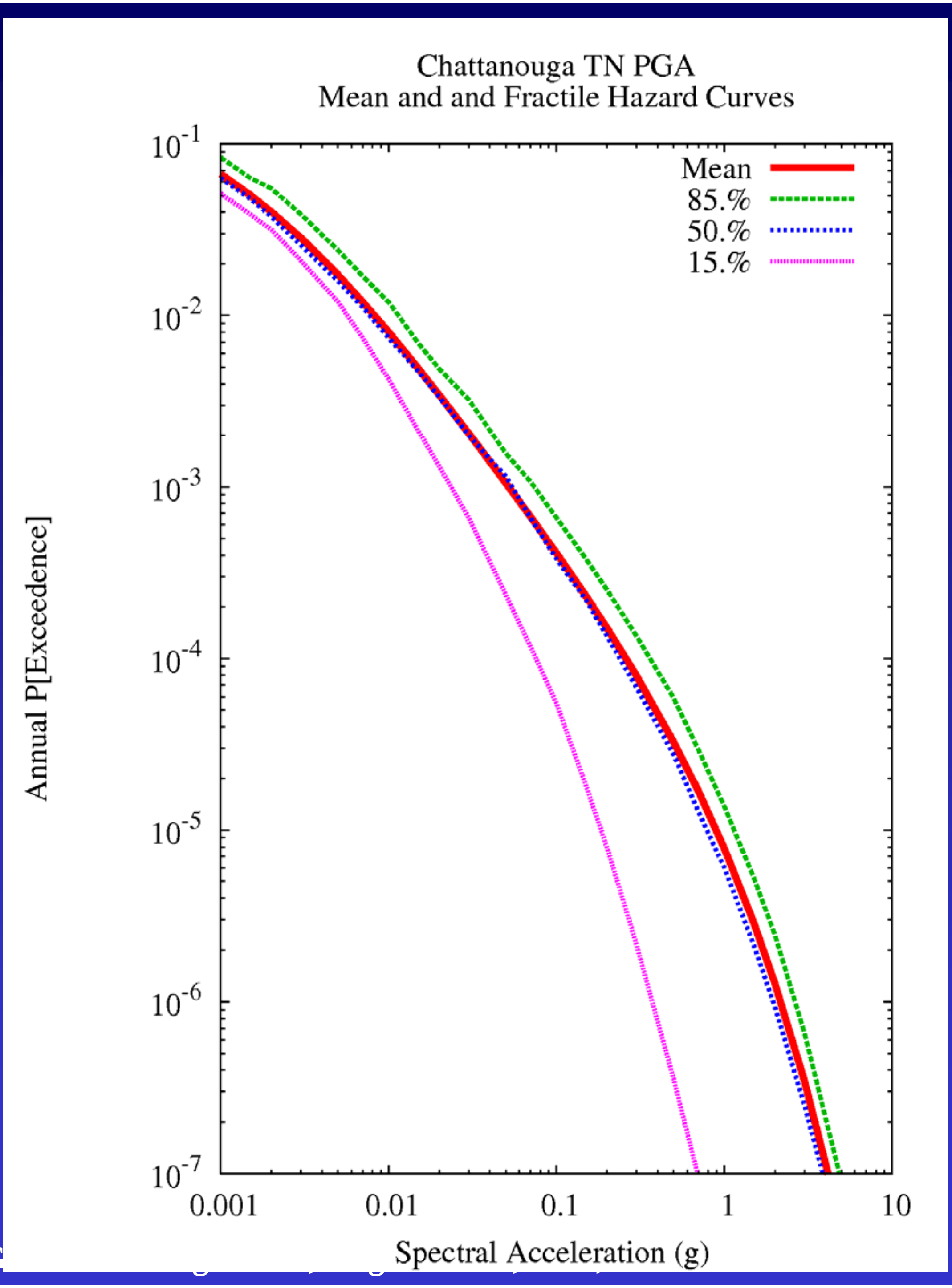

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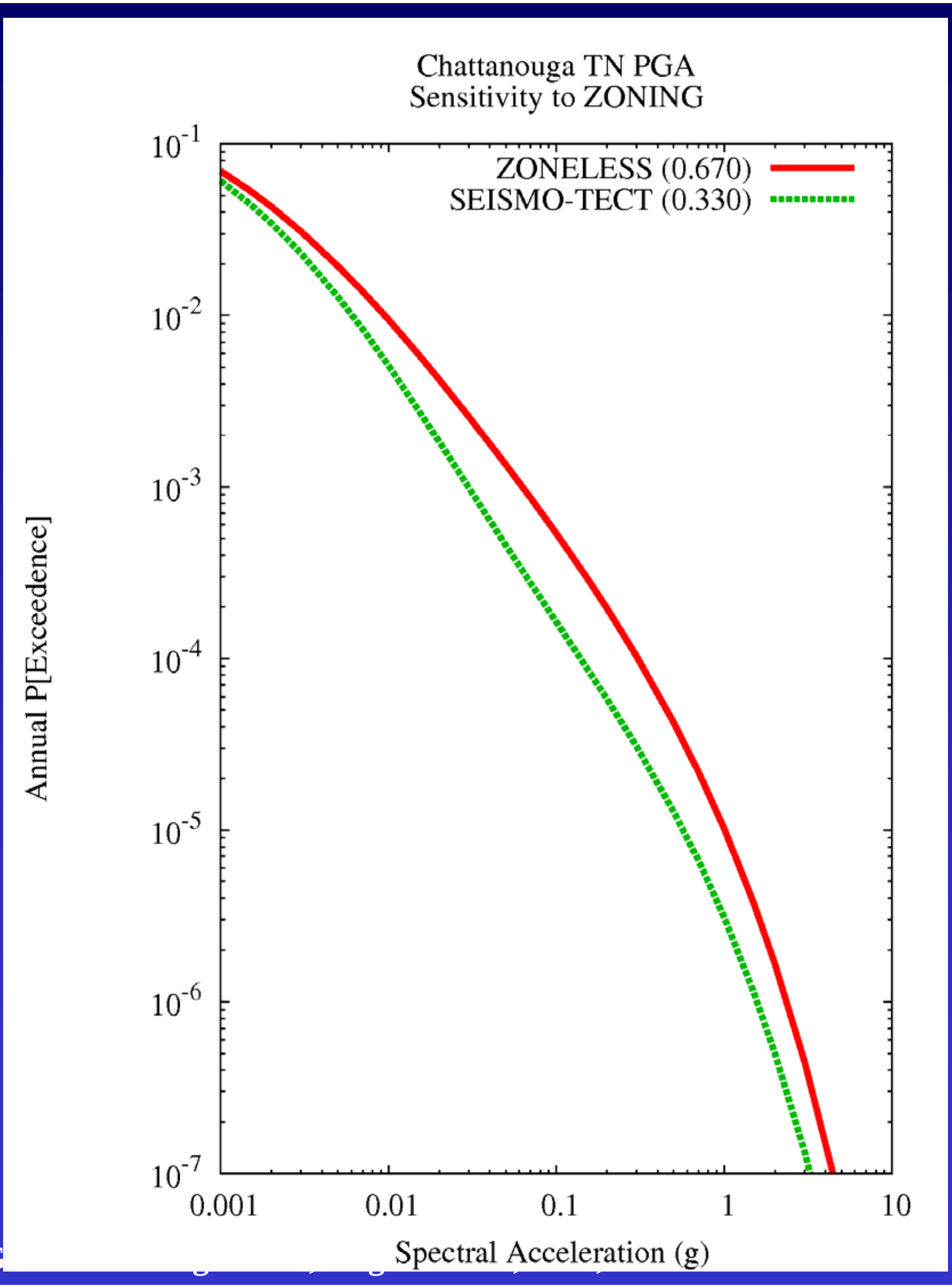
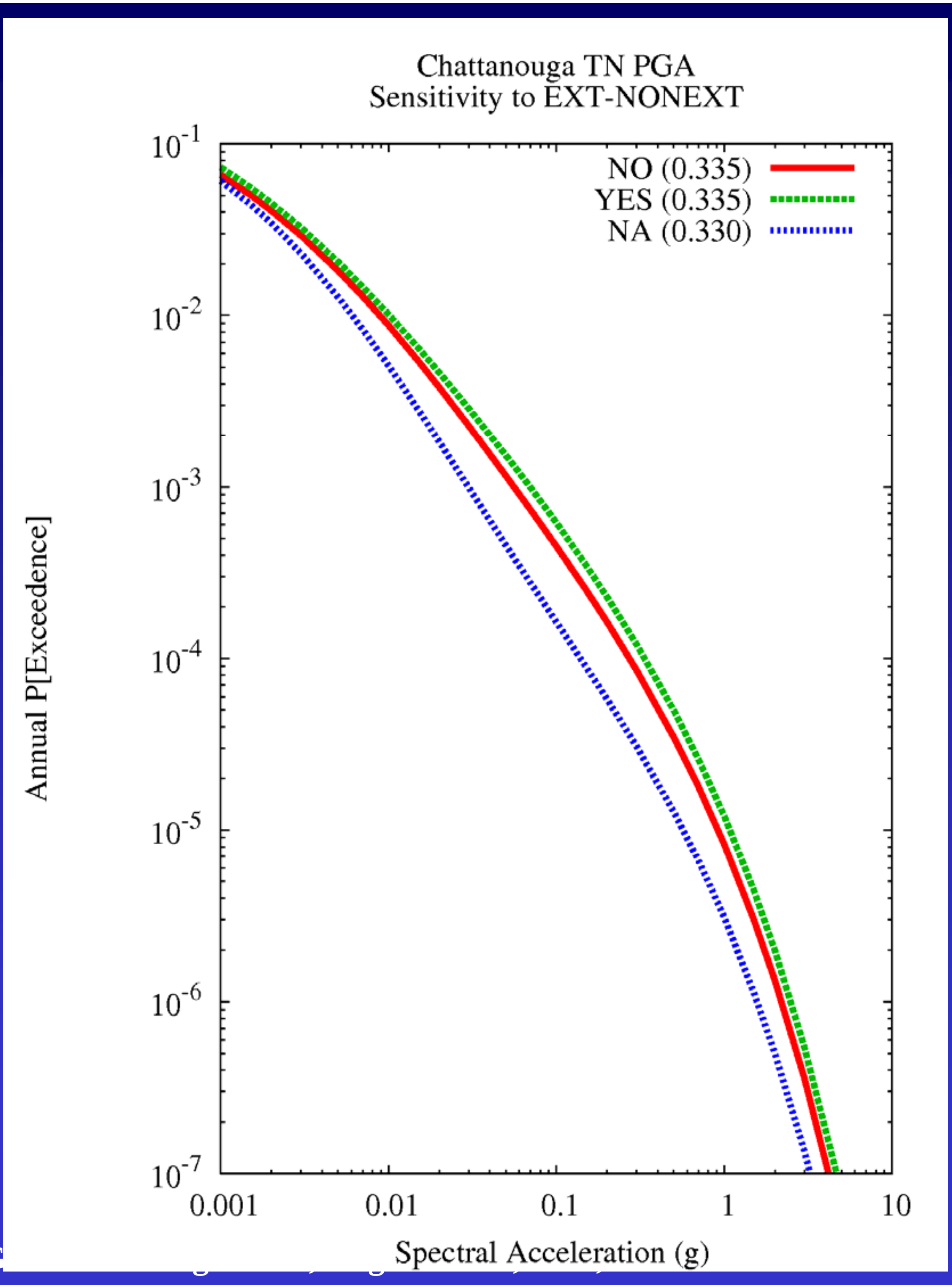
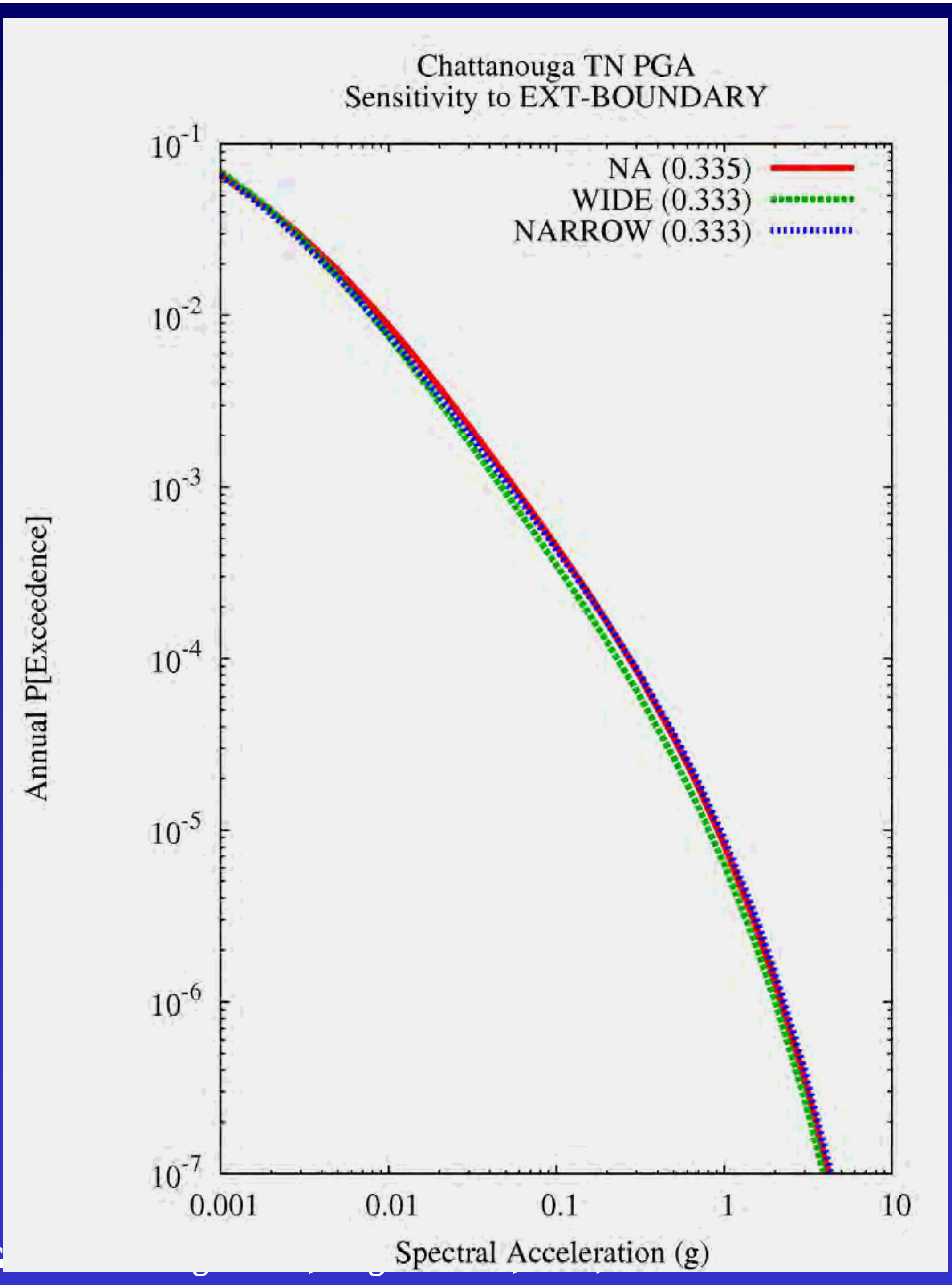

Chattanouga TN PGA
Sensitivity to ZONING
ZONELESS (0.670)
SEISMO-TECT (0.330)
Annual P[Exceedence]
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
0.001
0.01
0.1
1
10
Spectral Acceleration (g)


Chattanouga TN PGA
Sensitivity to EXT-NONEXT



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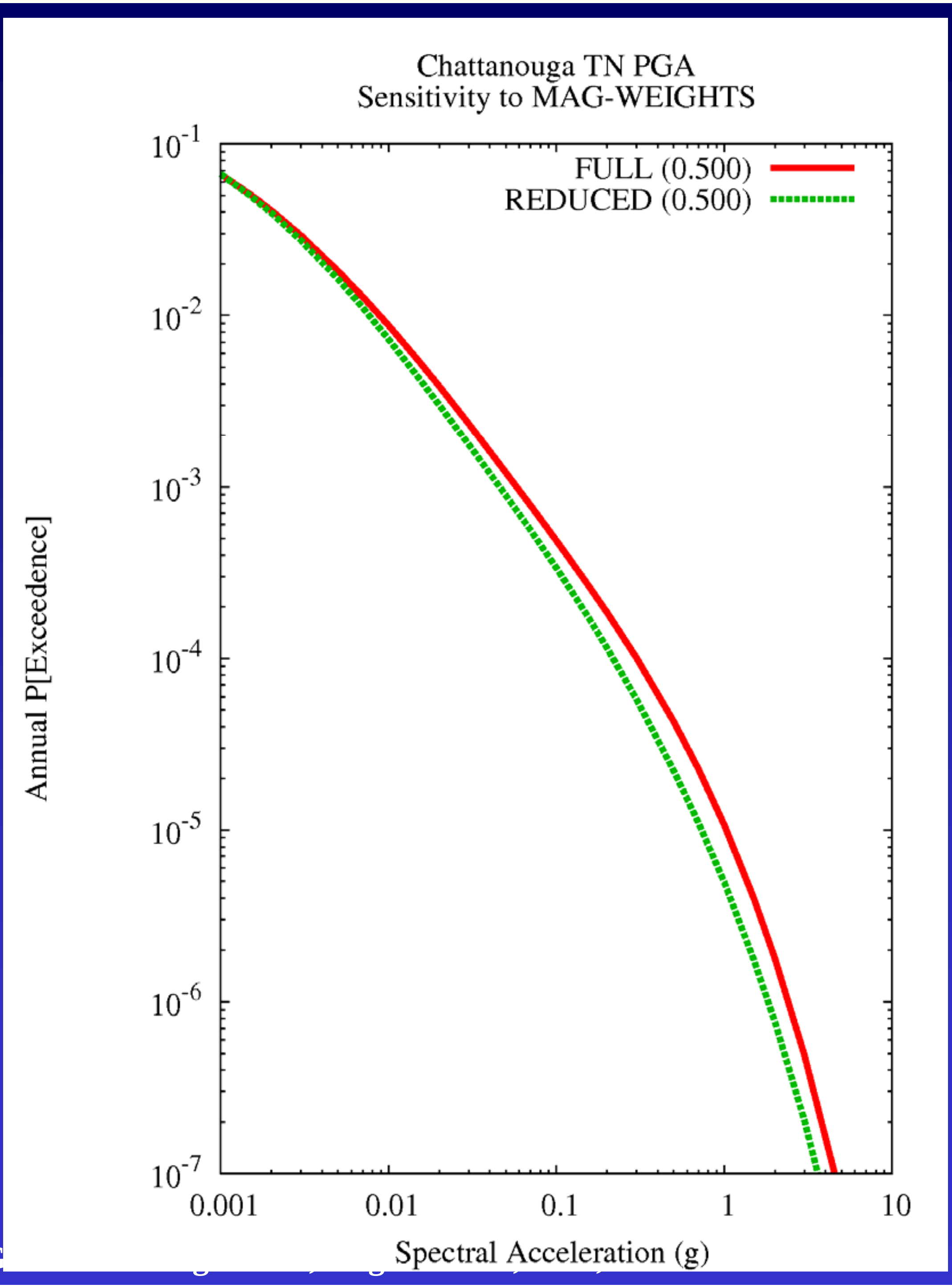

WLA
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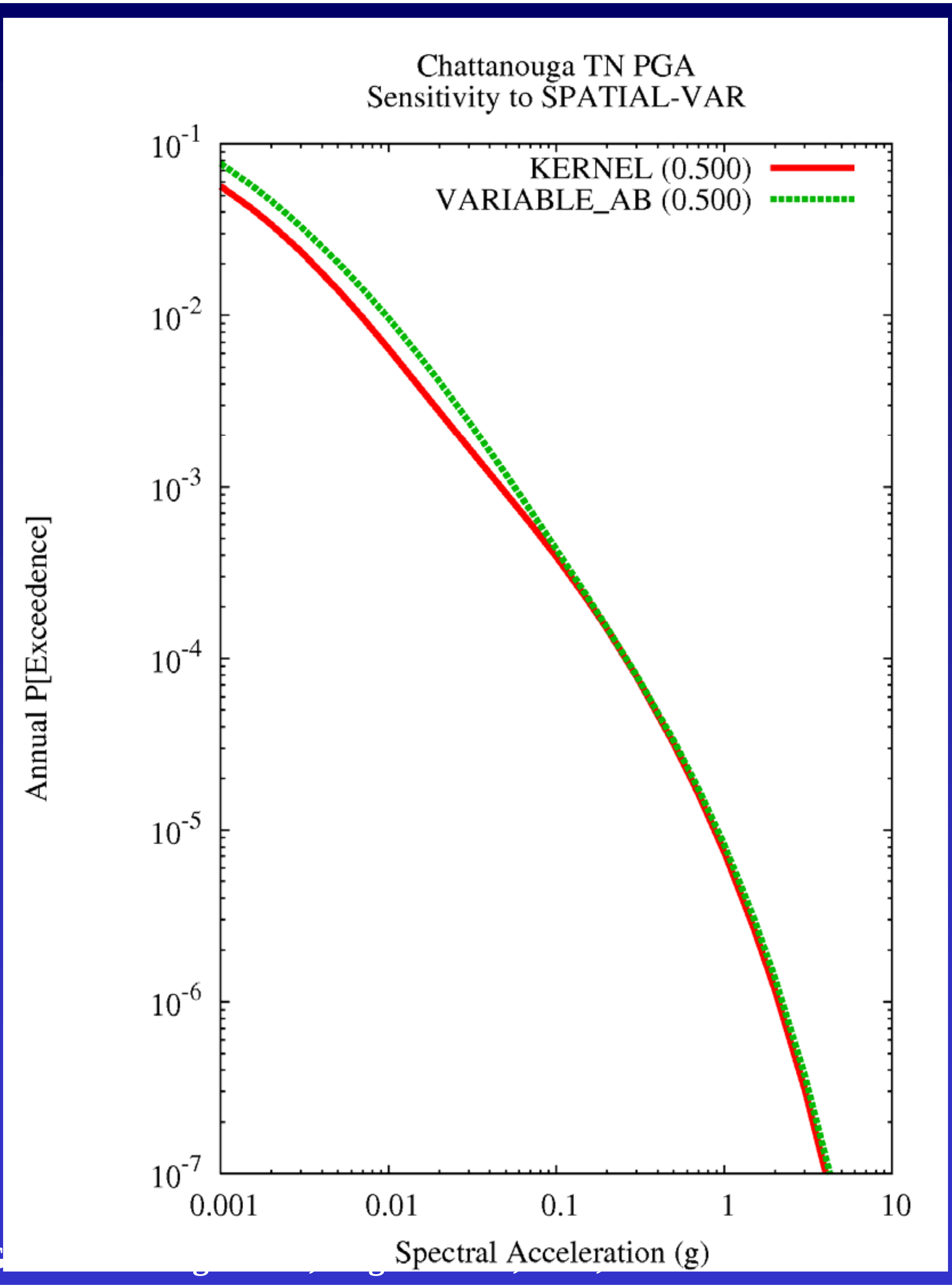
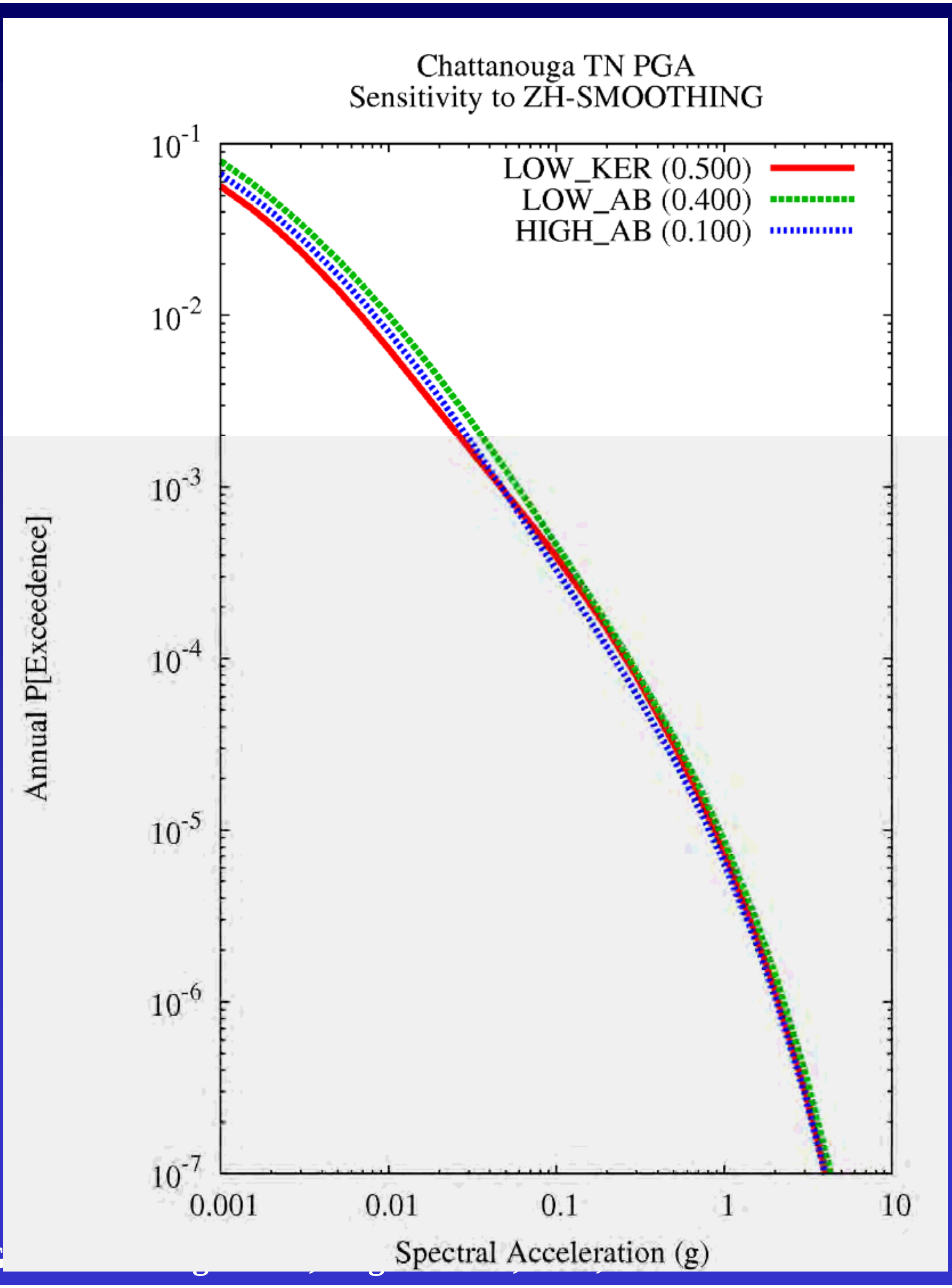
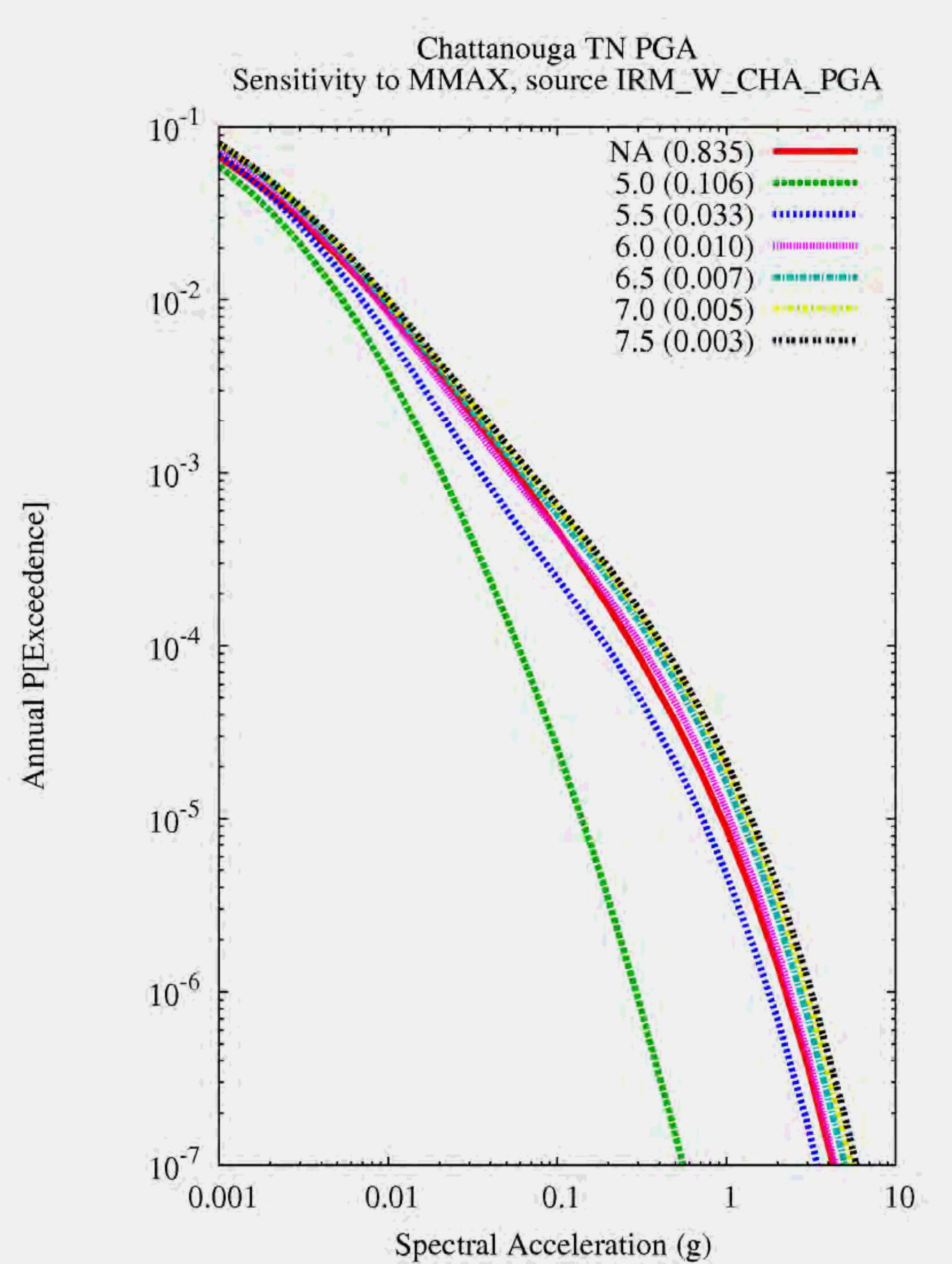
RISK ENGINEERING

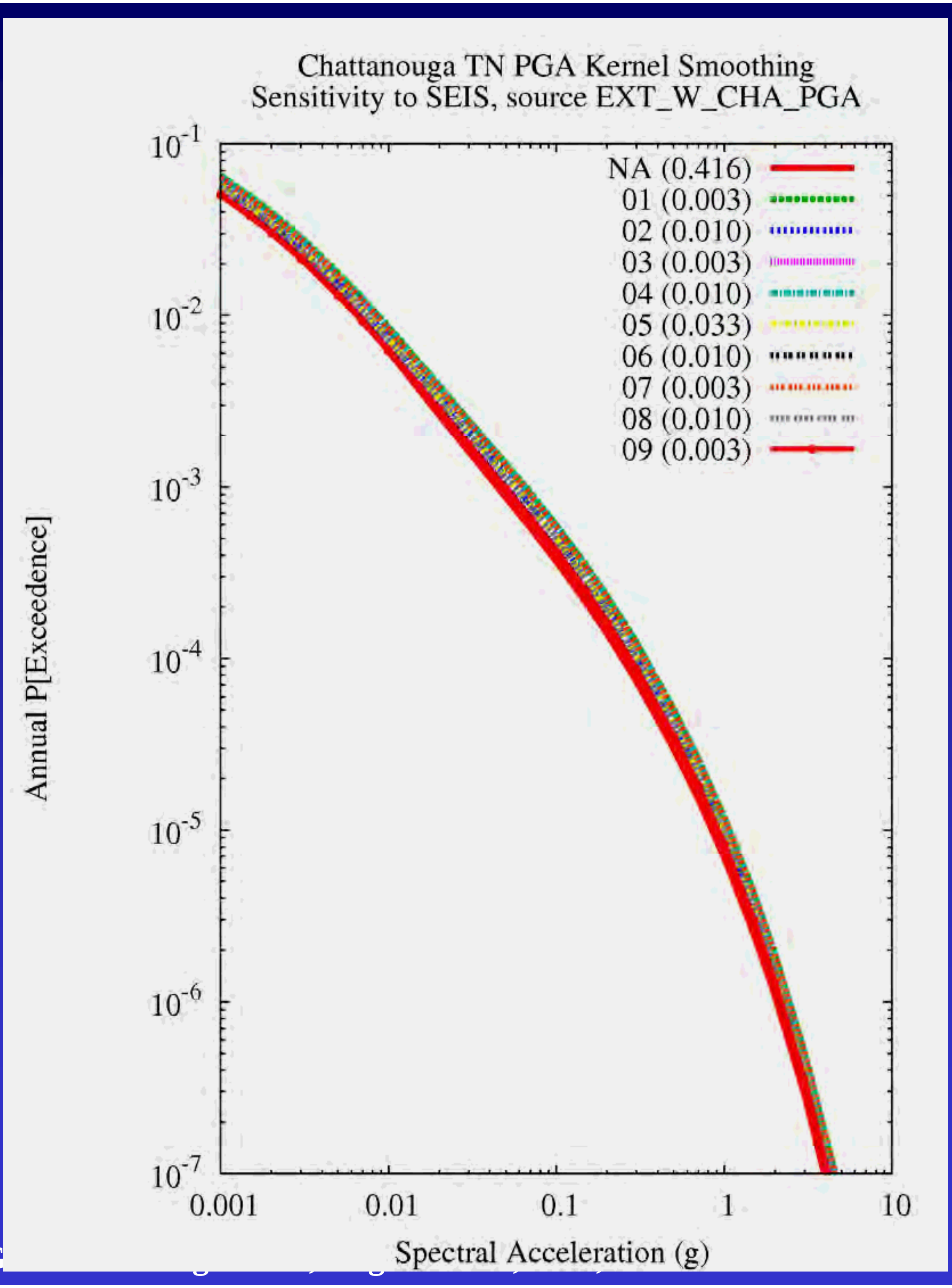


WLA William Lettis & Associates, Inc.

RISK ENGINEERING


Chattanouga TN PGA
Sensitivity to ZH-SMOOTHING
LOW_KER (0.500)
LOW_AB (0.400)
HIGH_AB (0.100)
Annual P[Exceedence]
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
0.001
0.01
0.1
1
10
Spectral Acceleration (g)


Chattanouga TN PGA
Sensitivity to MMAX, source IRM_W_CHA_PGA
NA (0.835)
5.0 (0.106)
5.5 (0.033)
6.0 (0.010)
6.5 (0.007)
7.0 (0.005)
7.5 (0.003)
Annual P[Exceedence]
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
0.001
0.01
0.1
1
10
Spectral Acceleration (g)



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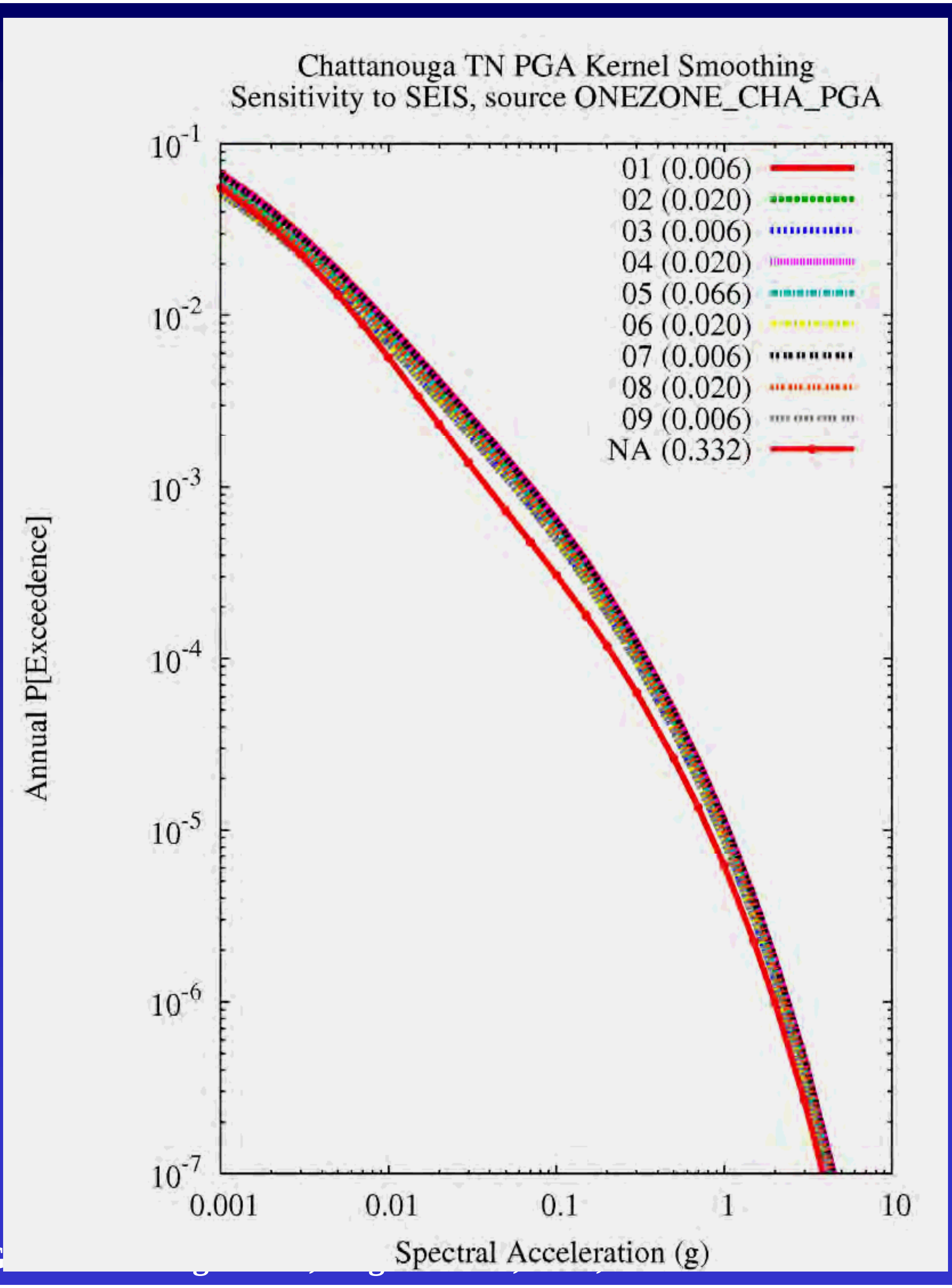

Chattanouga TN PGA Kernel Smoothing
Sensitivity to SEIS, source ONEZONE_CHA_PGA

WLA
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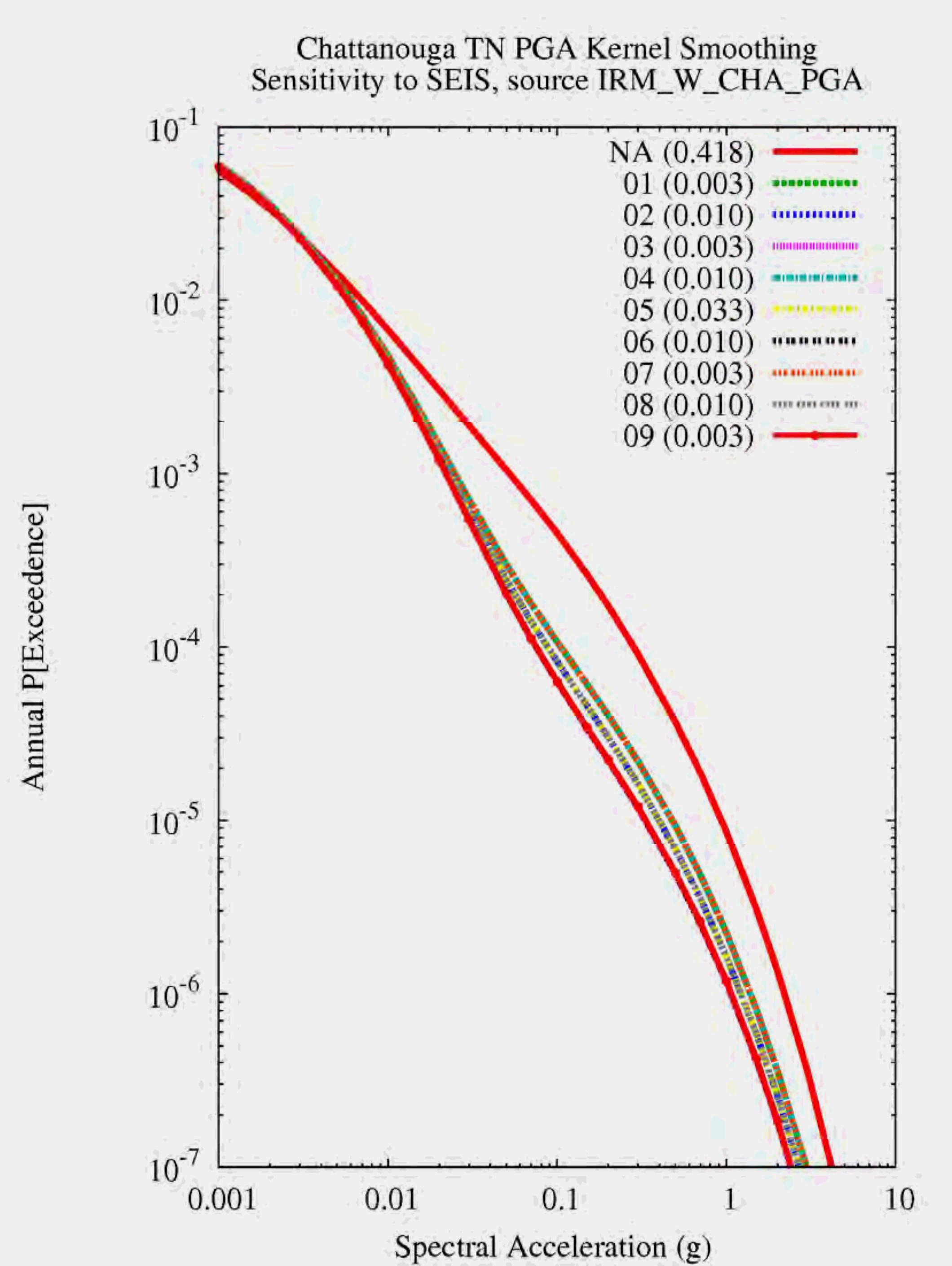
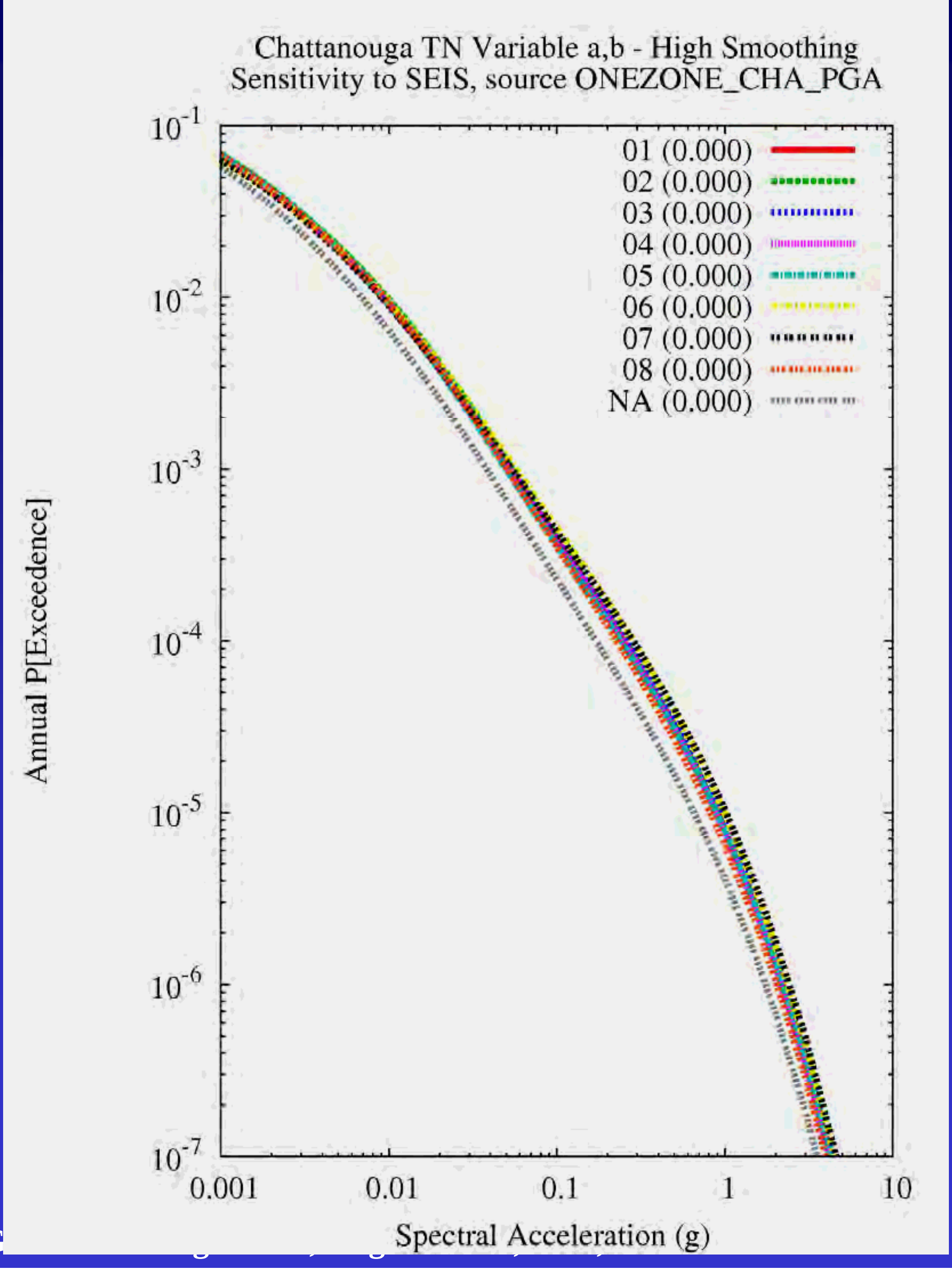
RISK
ENGINEERING



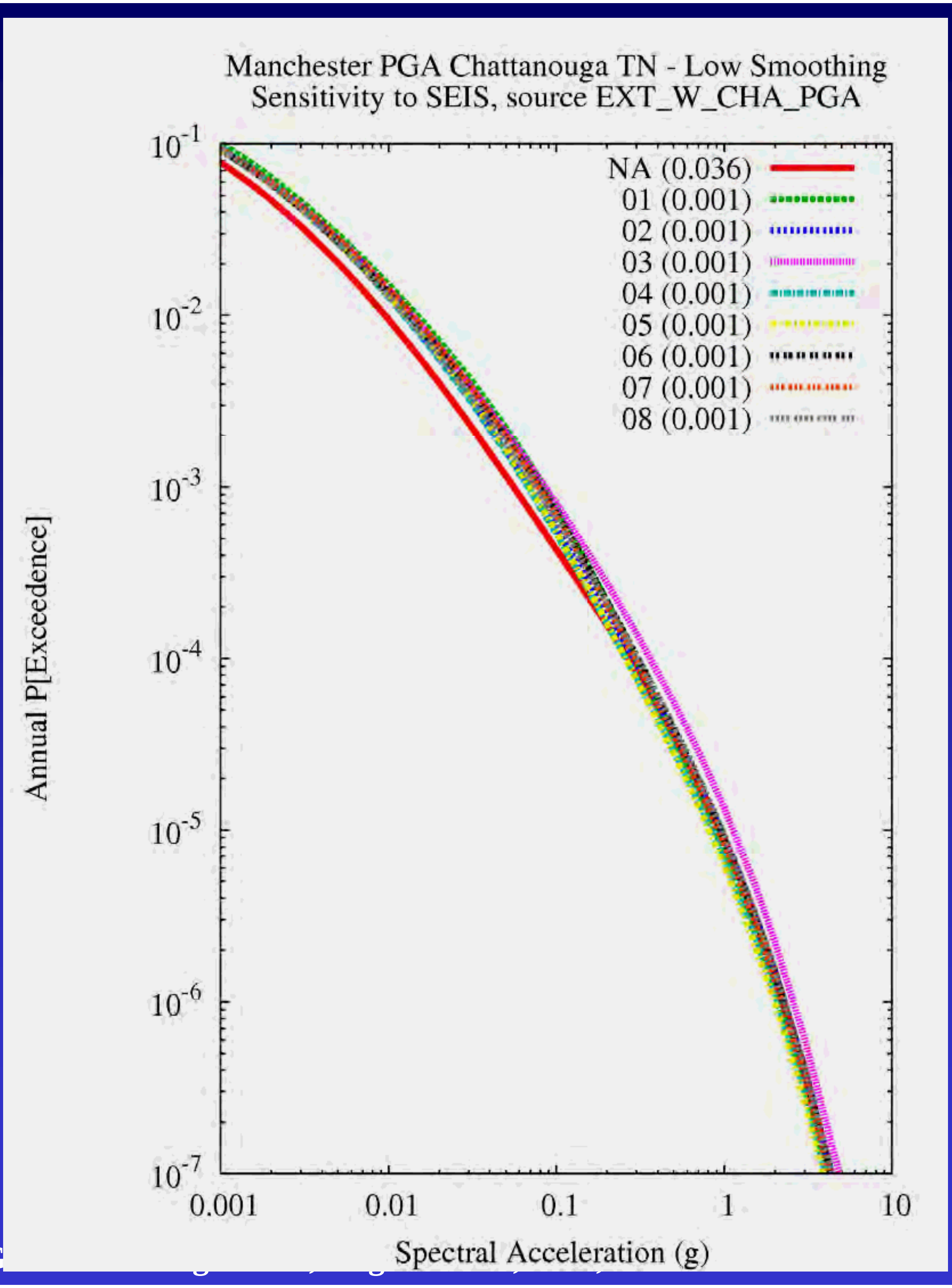
WLA William Lettis & Associates, Inc.

RISK ENGINEERING



WLA
William Lettis & Associates, Inc.

RISK
ENGINEERING



WLA
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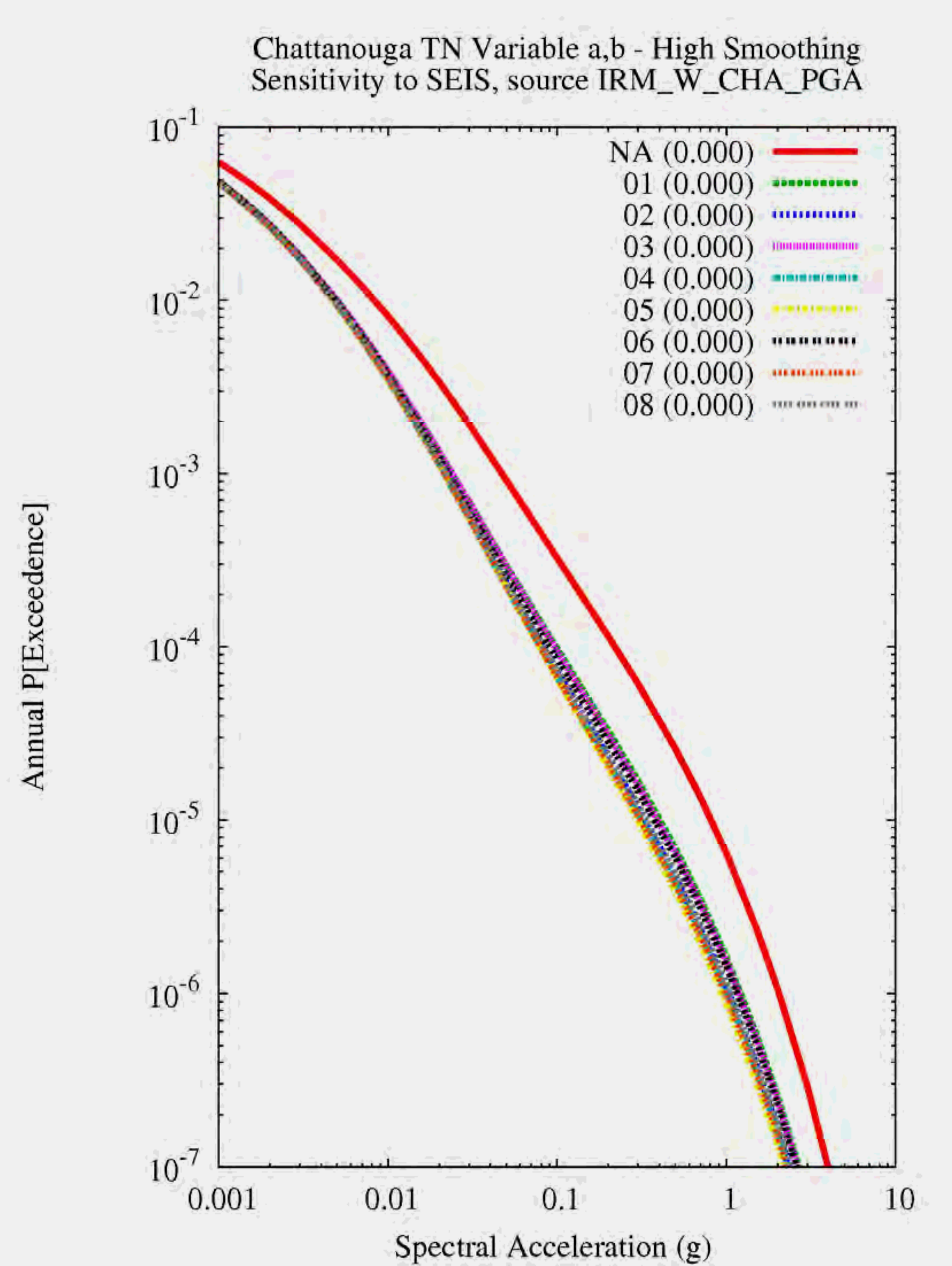
RISK
ENGINEERING



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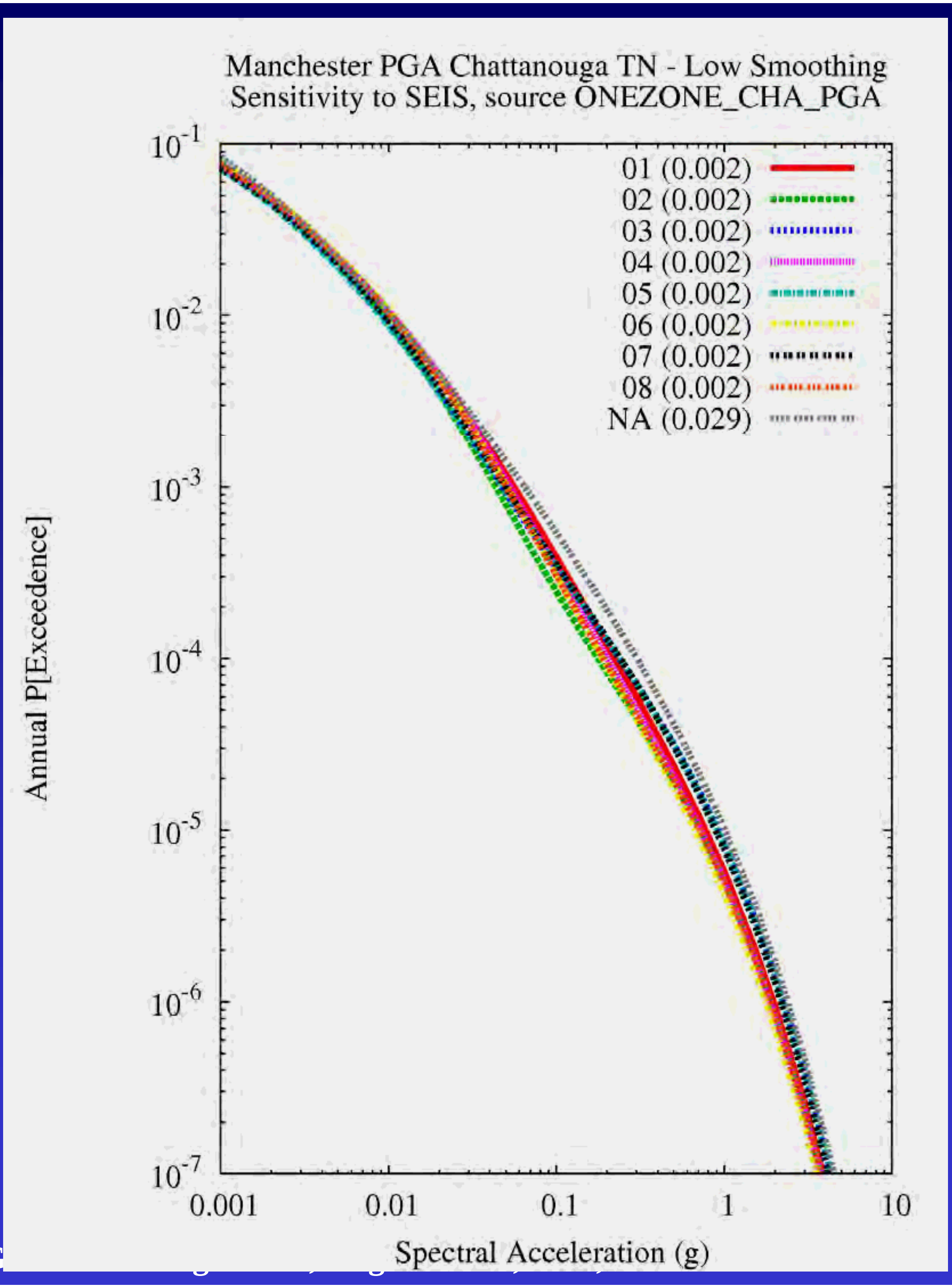
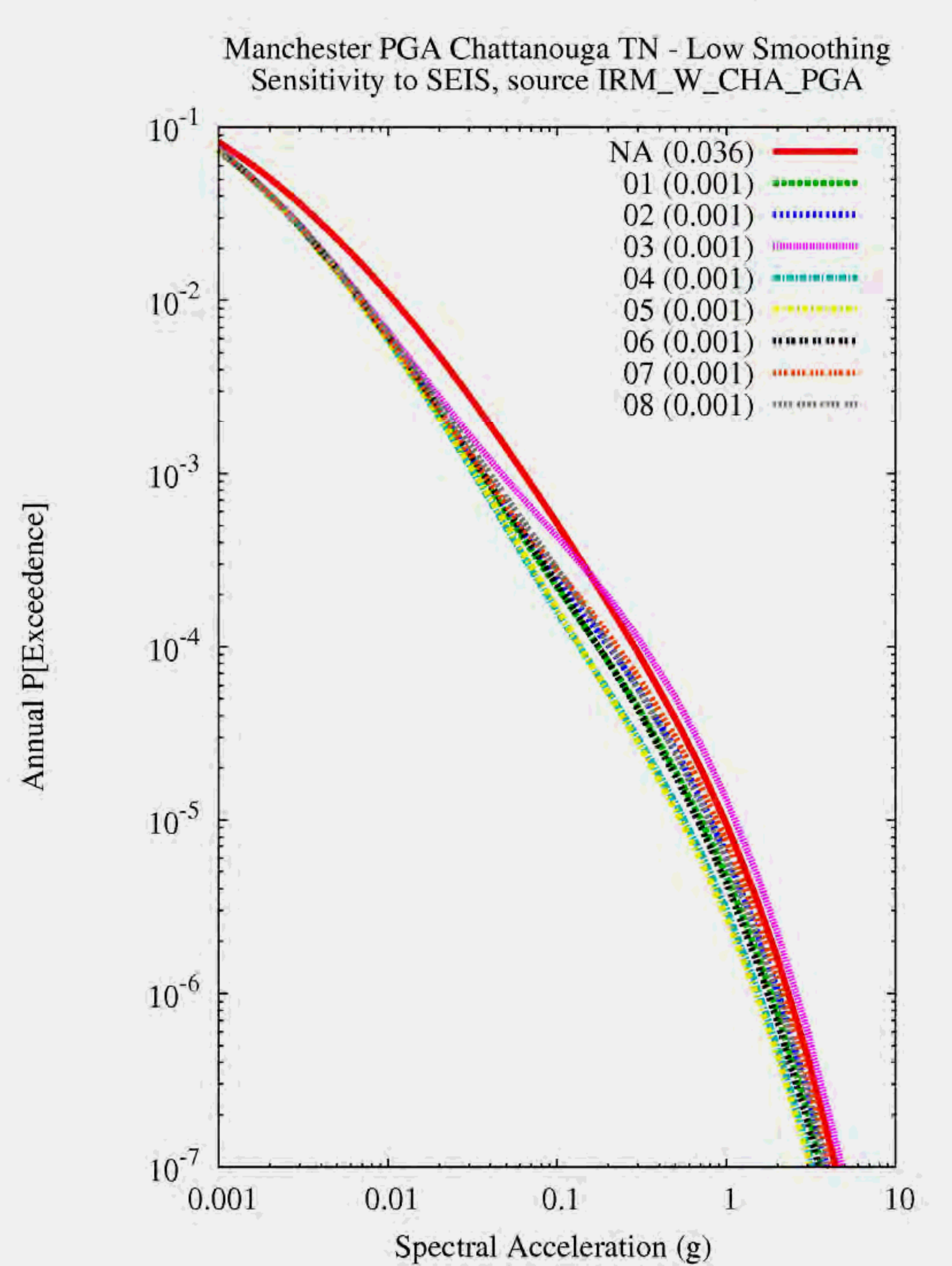
ENGINEERING


Manchester PGA Chattanouga TN - Low Smoothing
Sensitivity to SEIS, source ONEZONE_CHA_PGA



WLA William Lettis & Associates, Inc.

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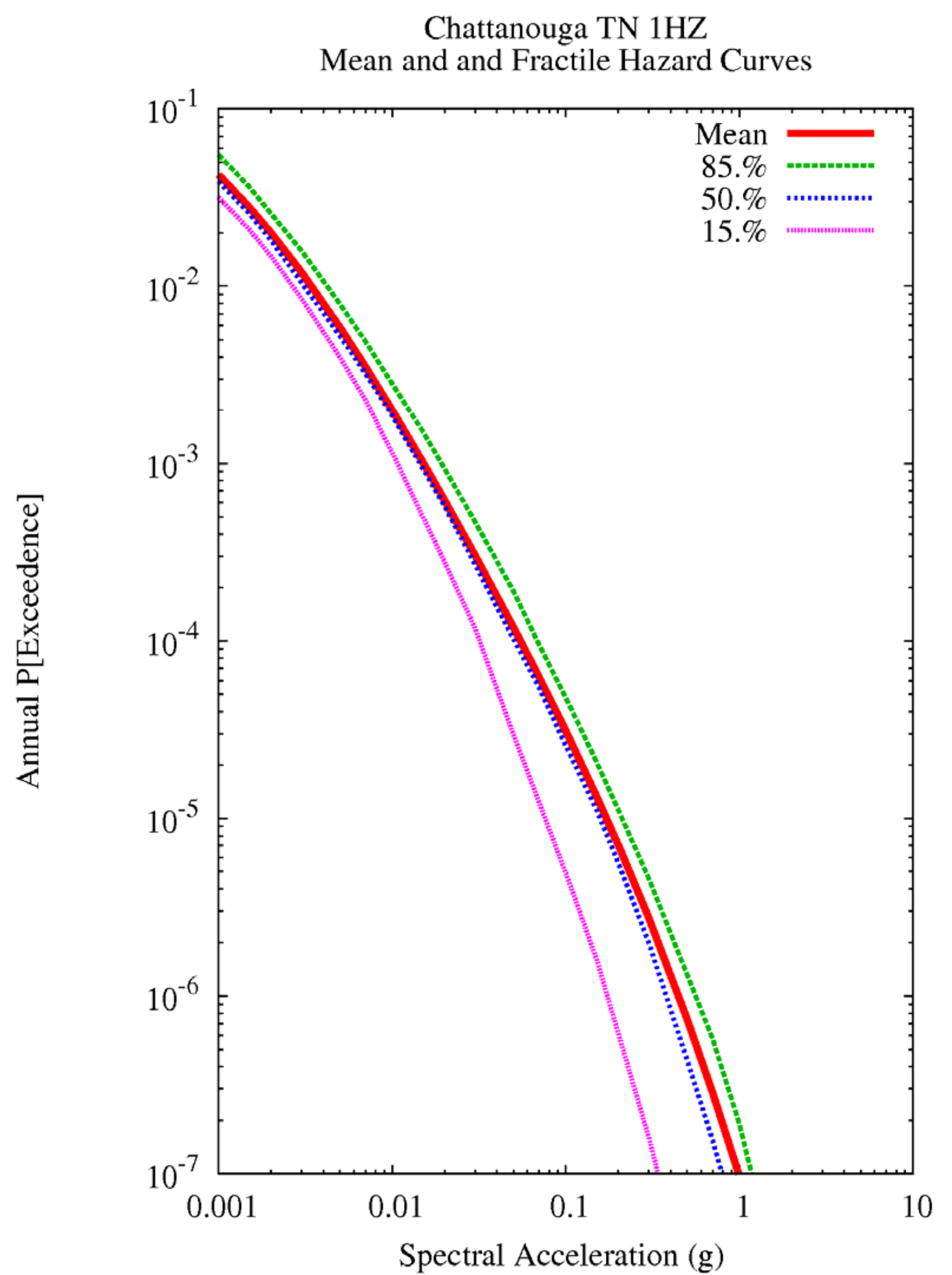
Chattanooga 1Hz



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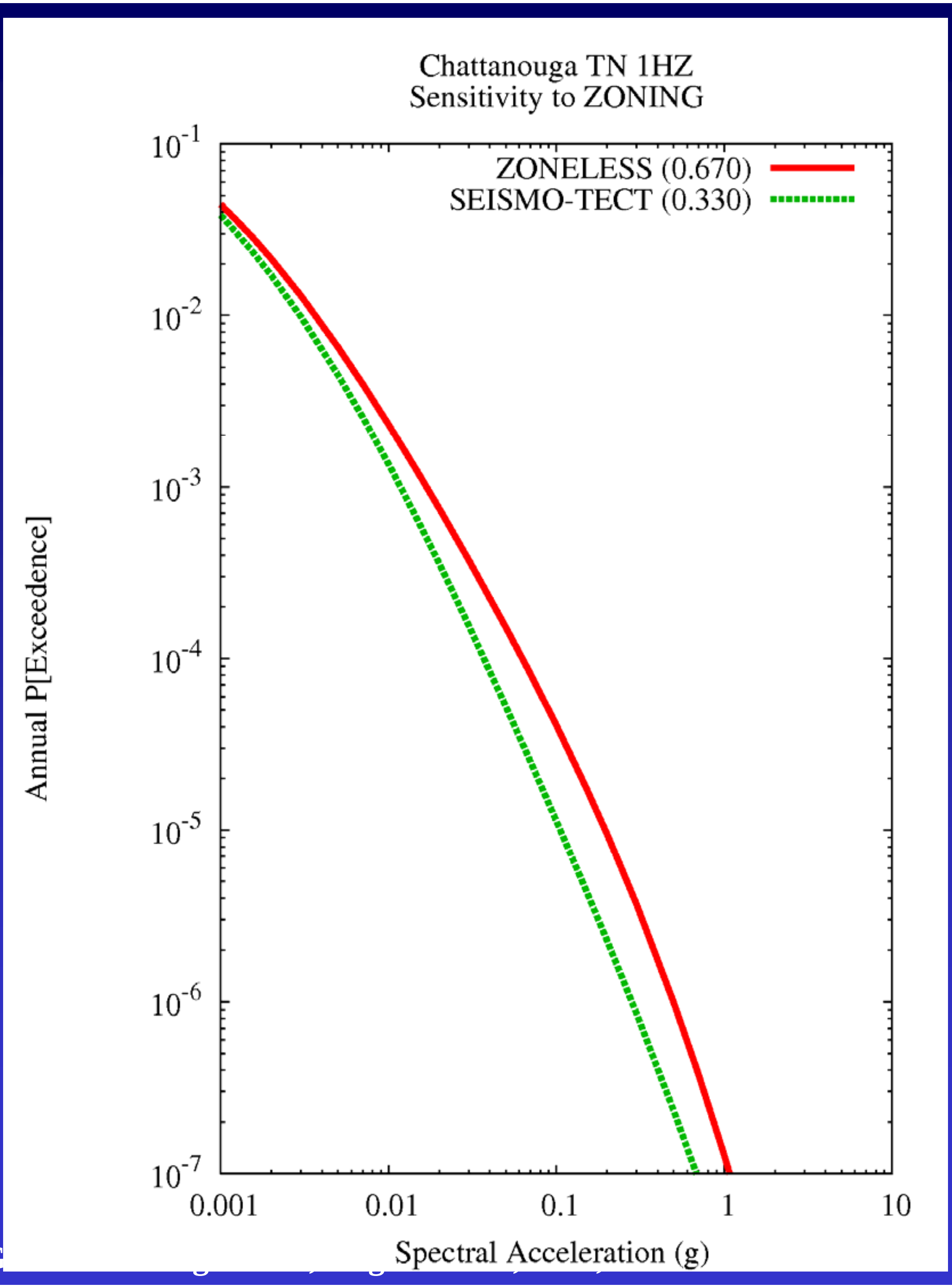

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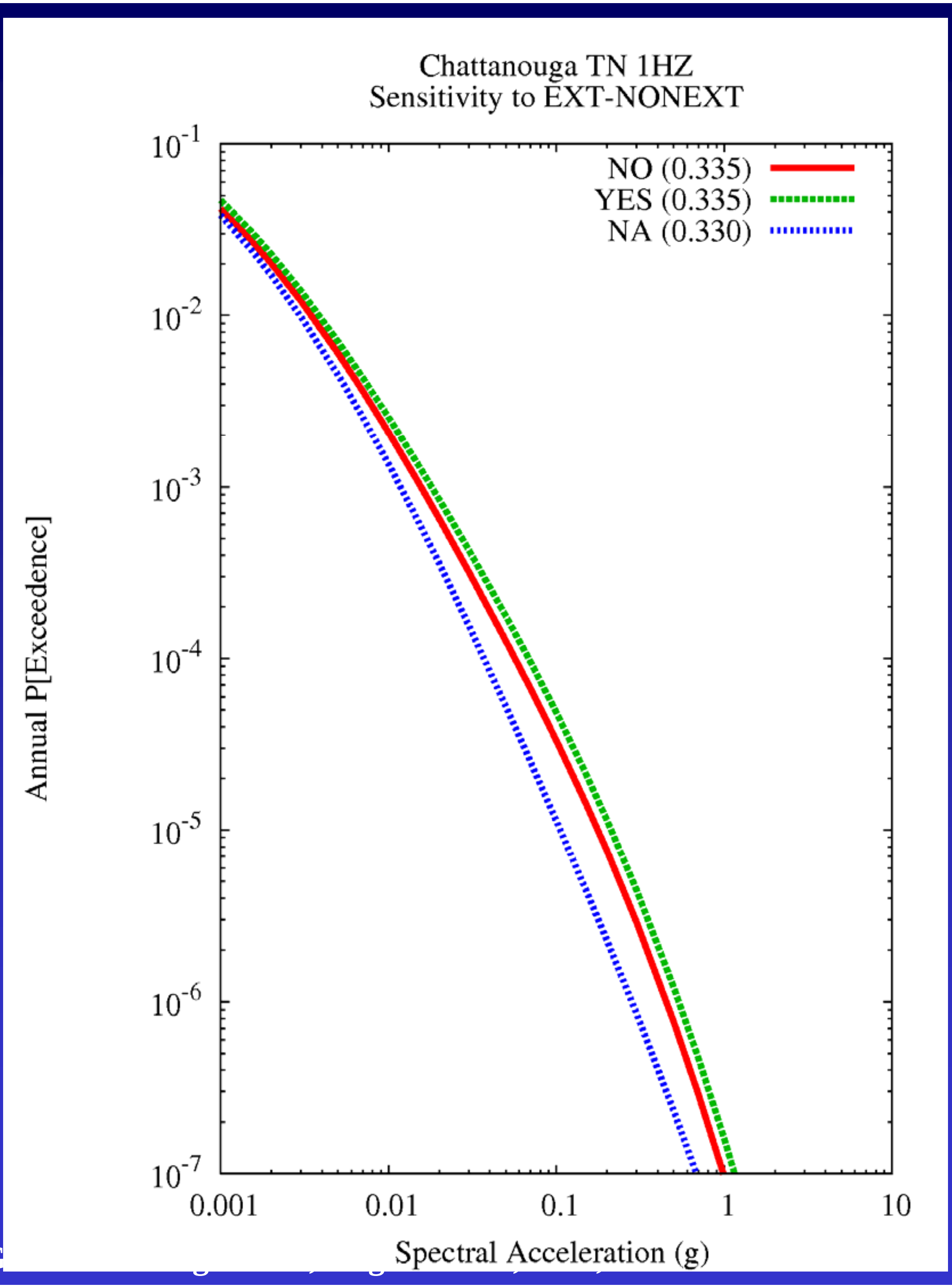
ENGINEERING



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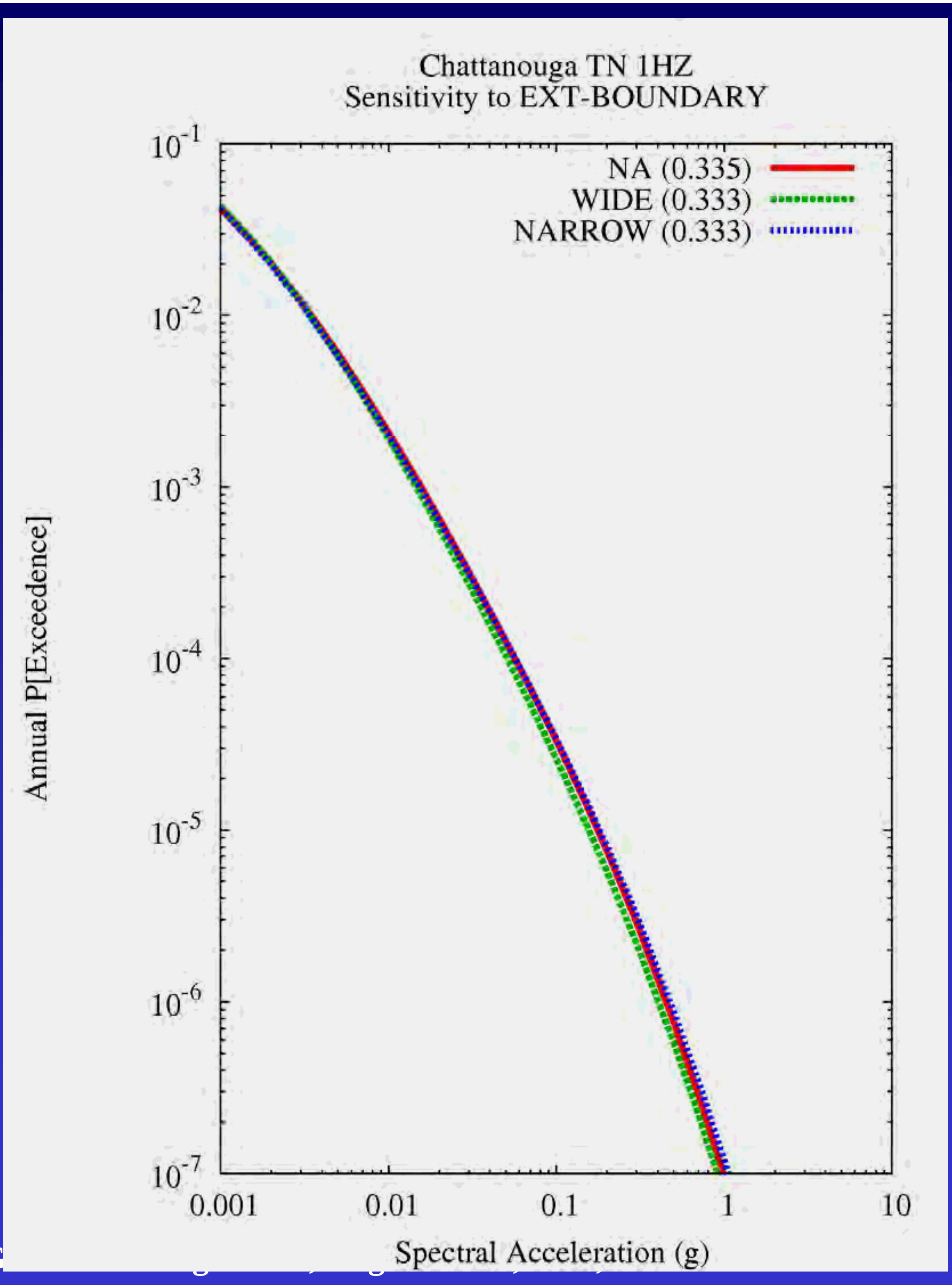
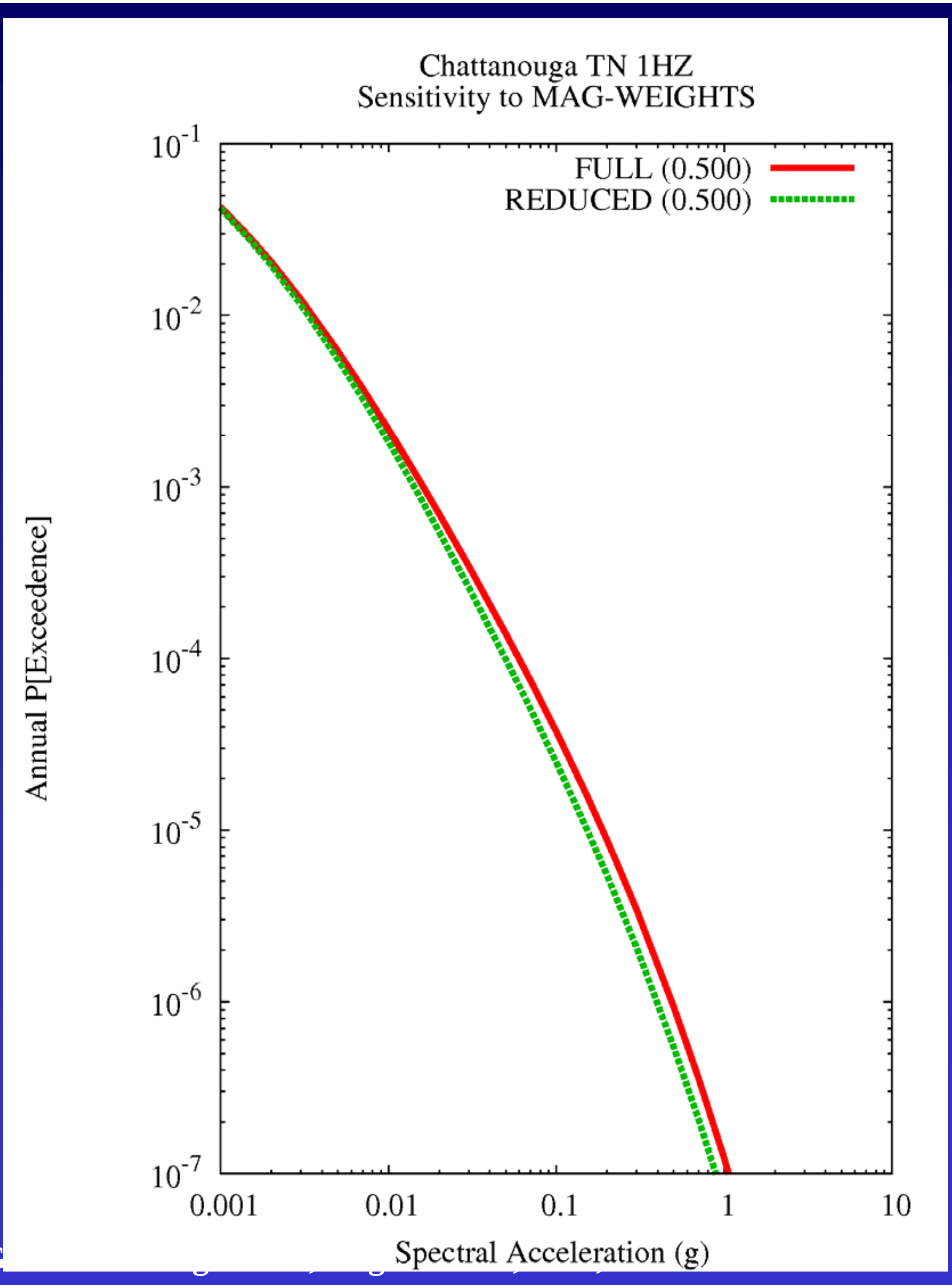
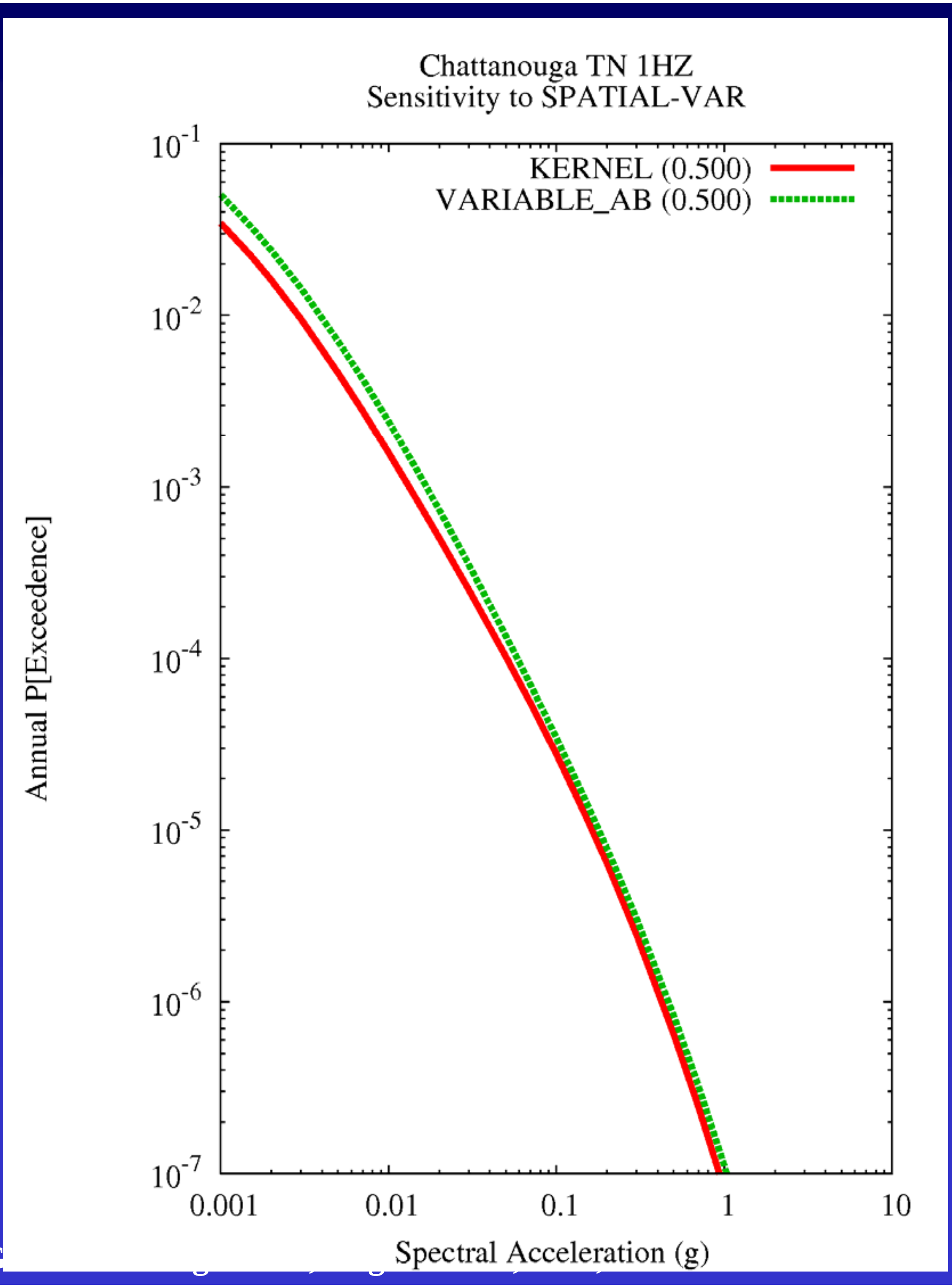
ENGINEERING

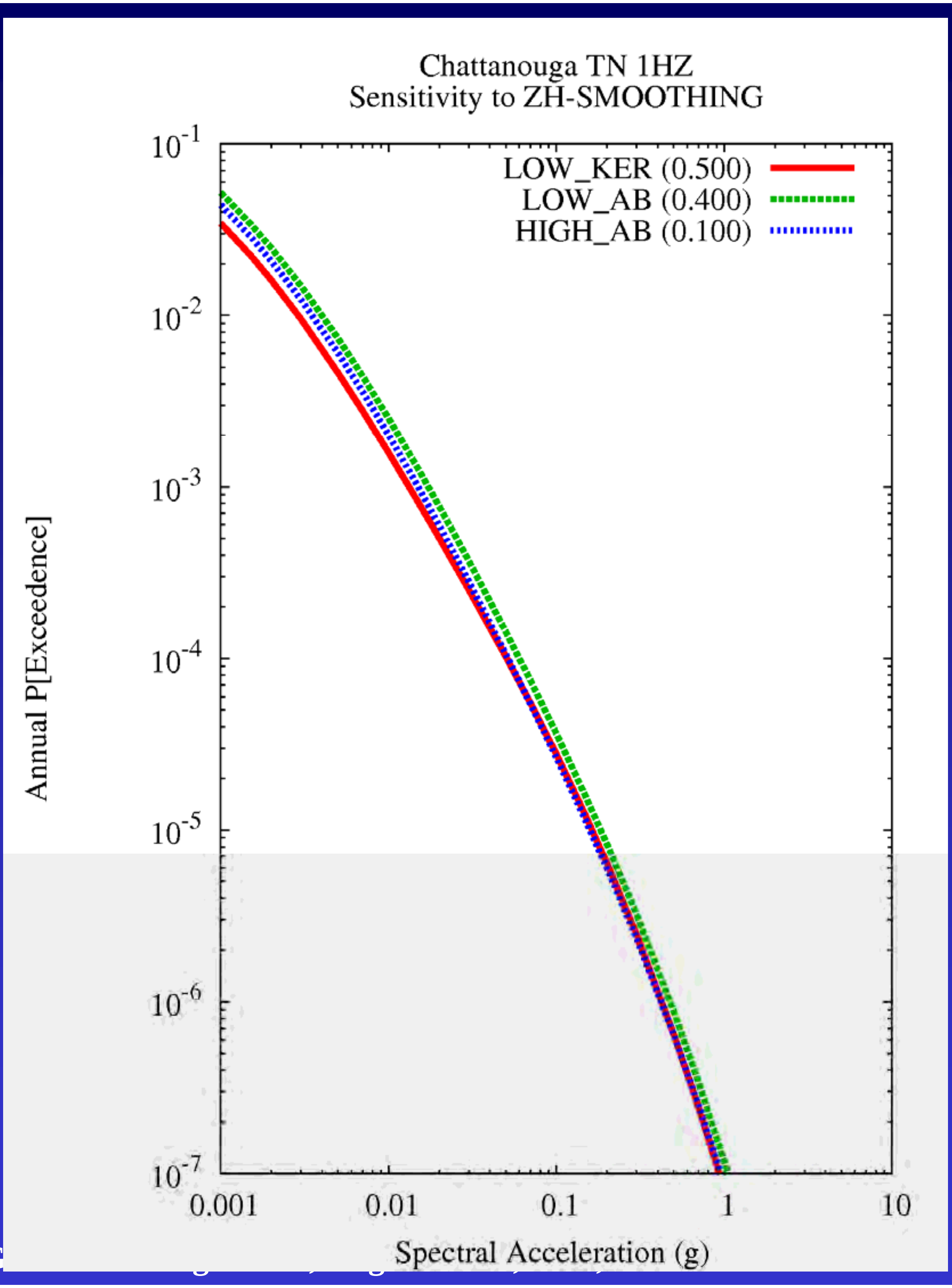


WLA William Lettis & Associates, Inc.

RISK ENGINEERING

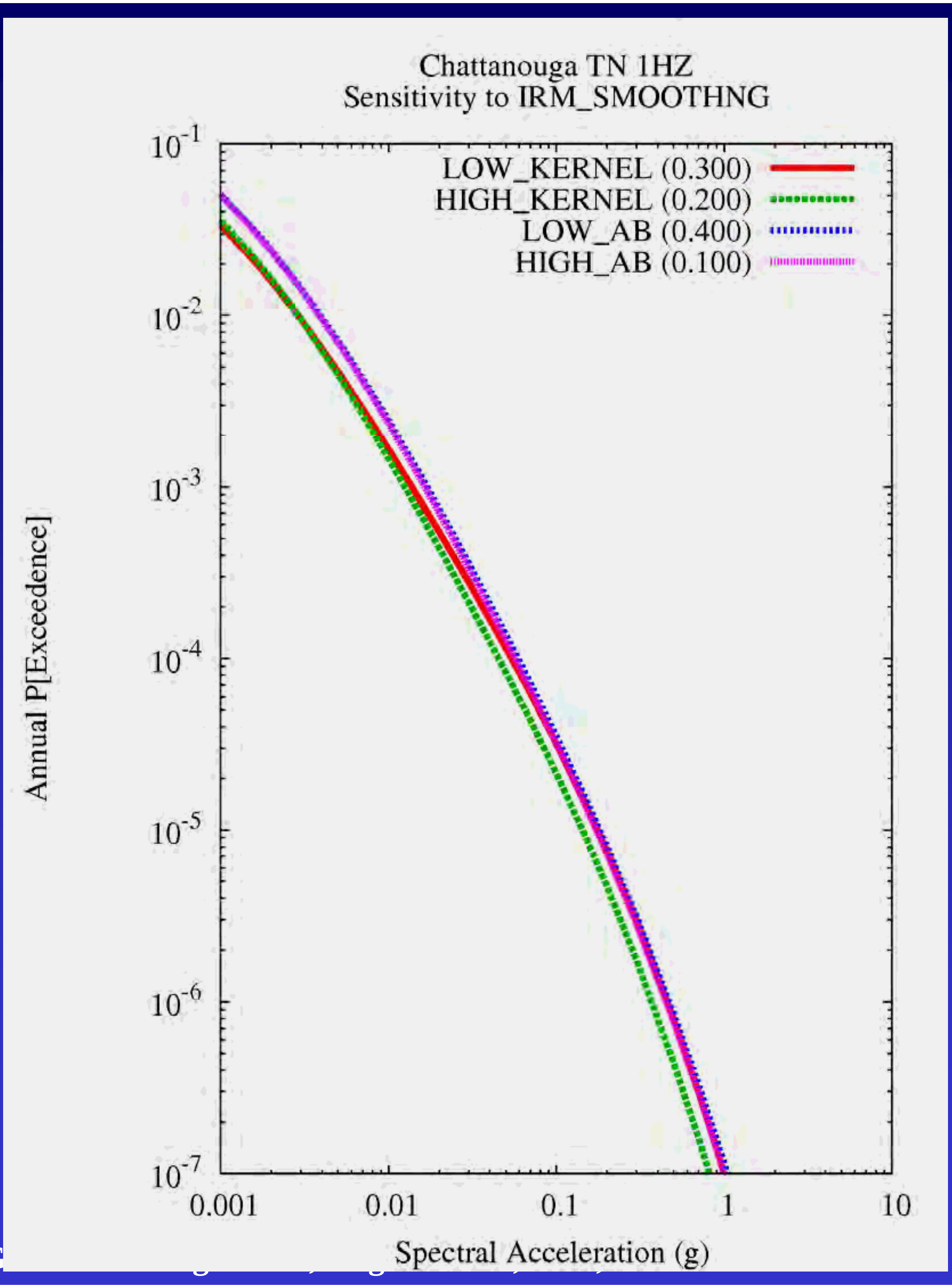

Chattanouga TN 1HZ
Sensitivity to MAG-WEIGHTS
FULL (0.500)
REDUCED (0.500)
Annual P[Exceedence]
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
0.001
0.01
0.1
1
10
Spectral Acceleration (g)


Chattanouga TN 1HZ
Sensitivity to SPATIAL-VAR
KERNEL (0.500)
VARIABLE_AB (0.500)
Annual P[Exceedence]
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
0.001
0.01
0.1
1
10
Spectral Acceleration (g)



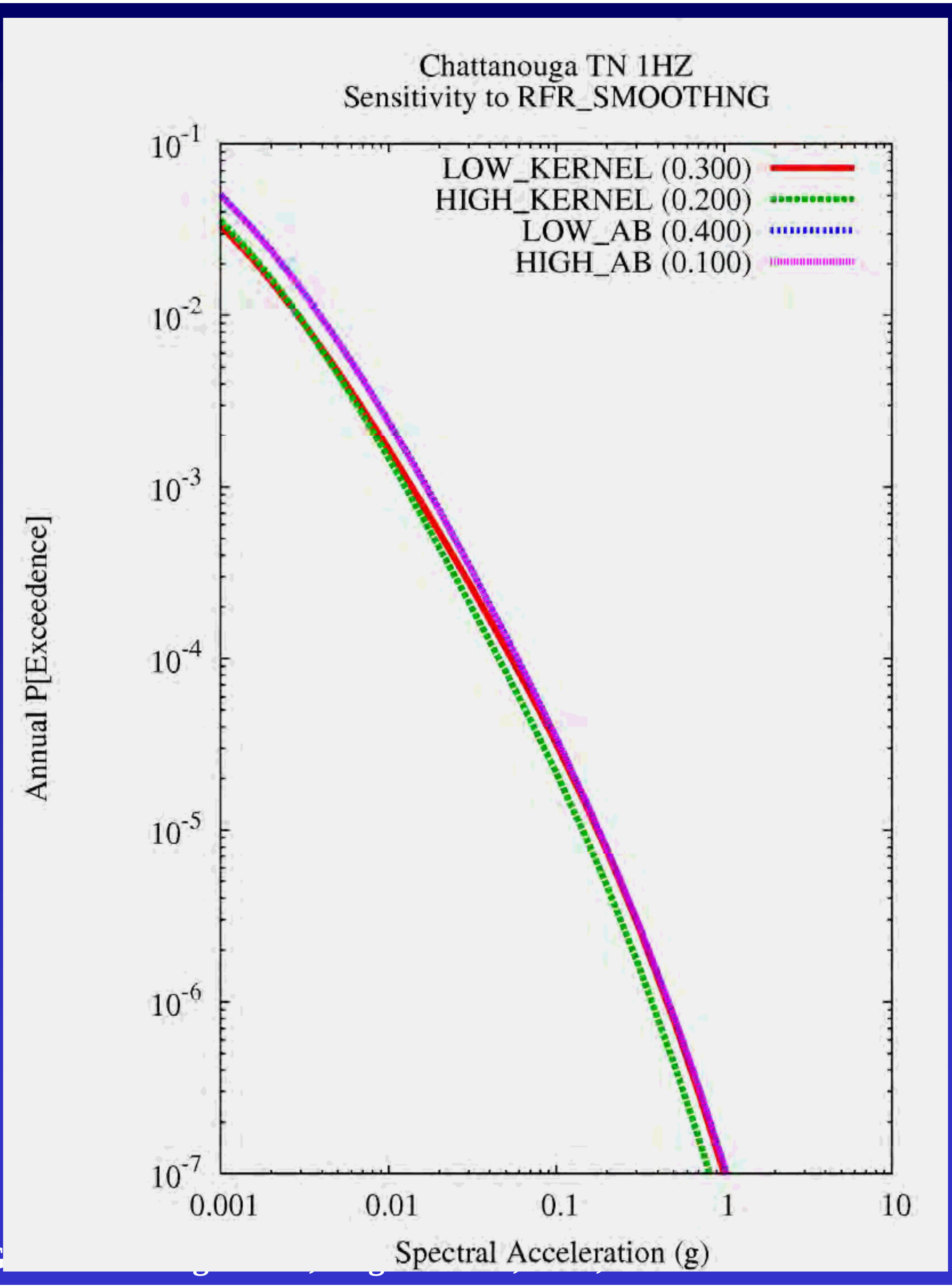
William Lettis & Associates, Inc.

RISK ENGINEERING



William Lettis & Associates, Inc.

RISK ENGINEERING



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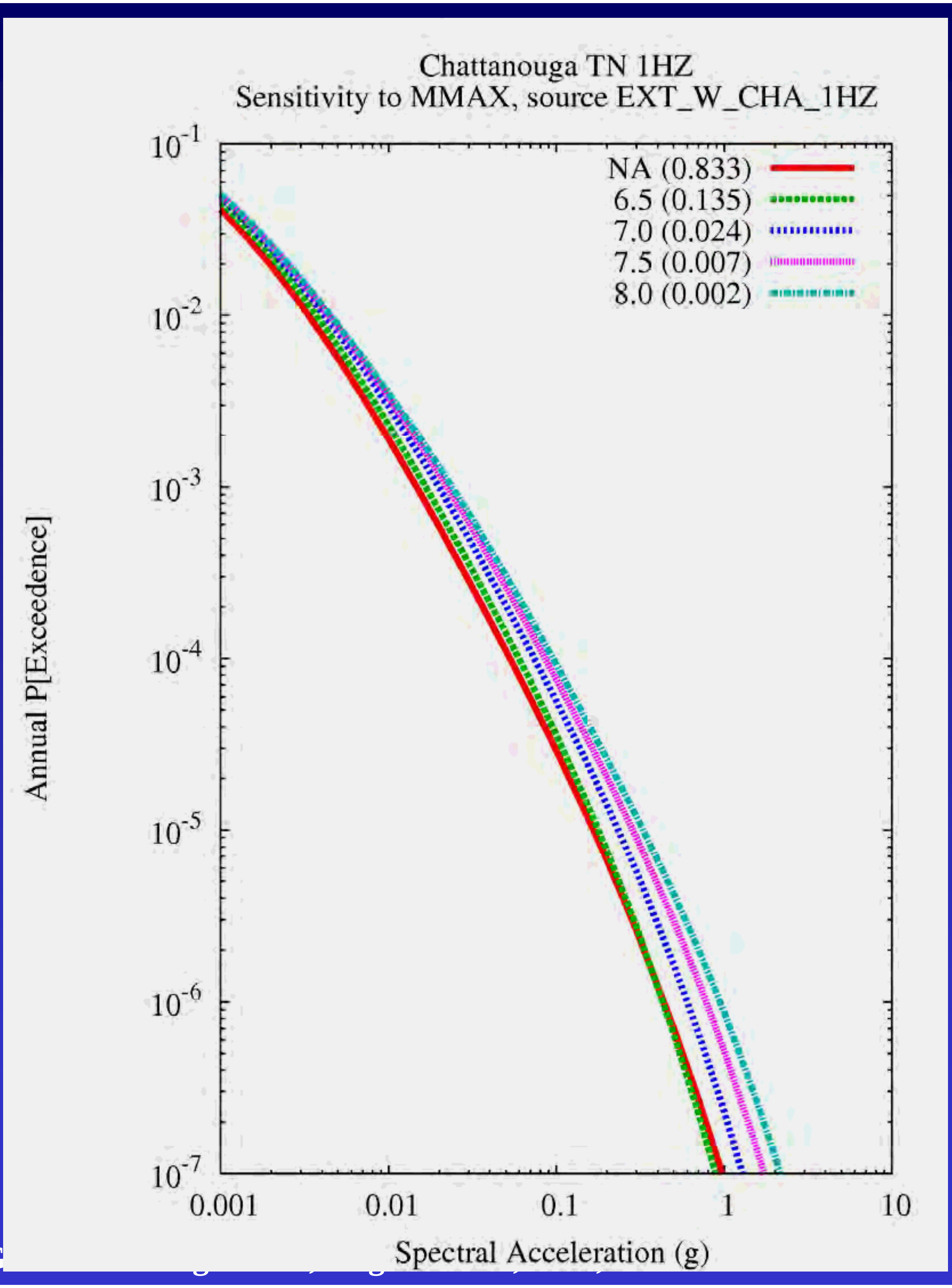
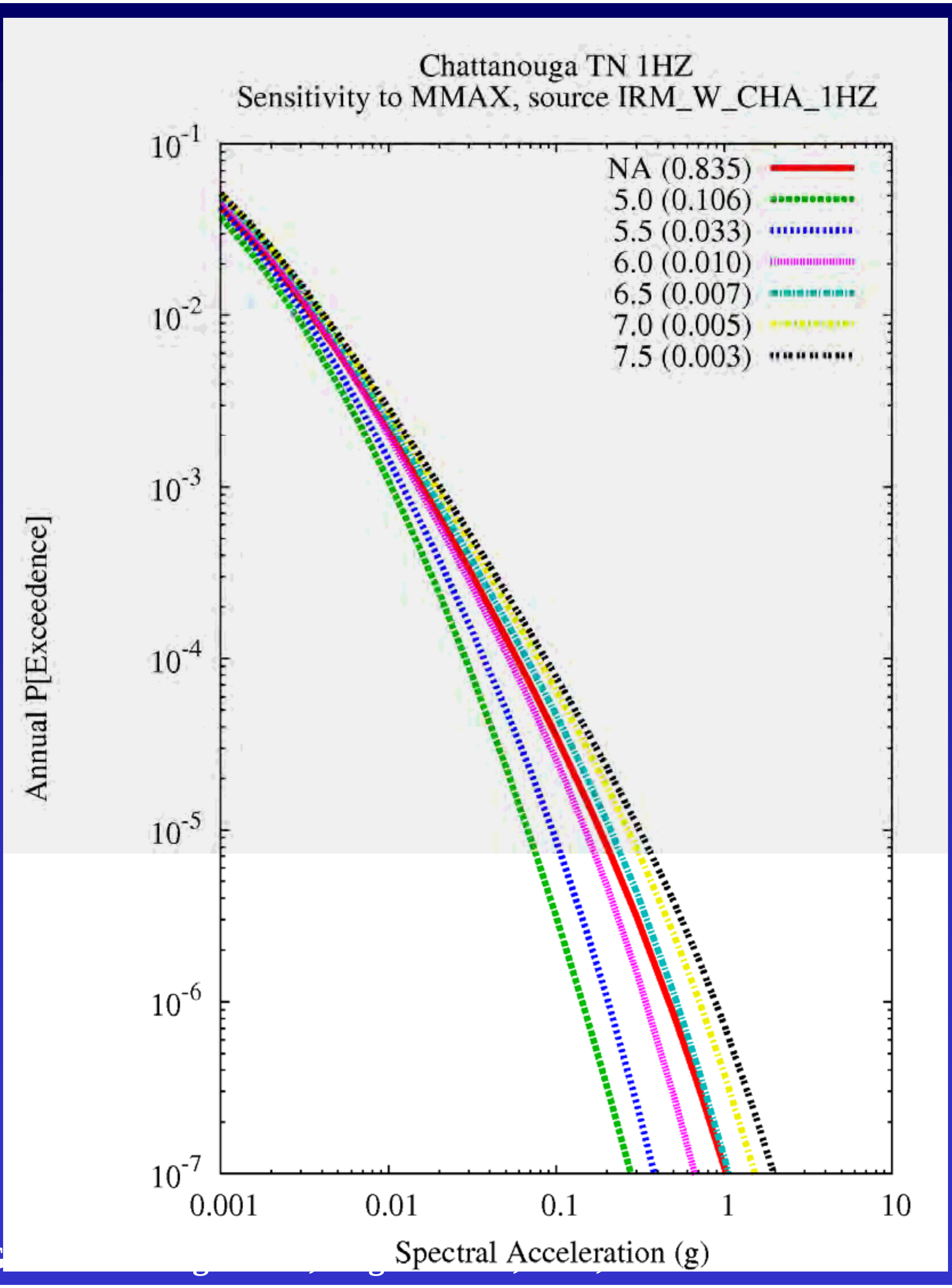
ENGINEERING



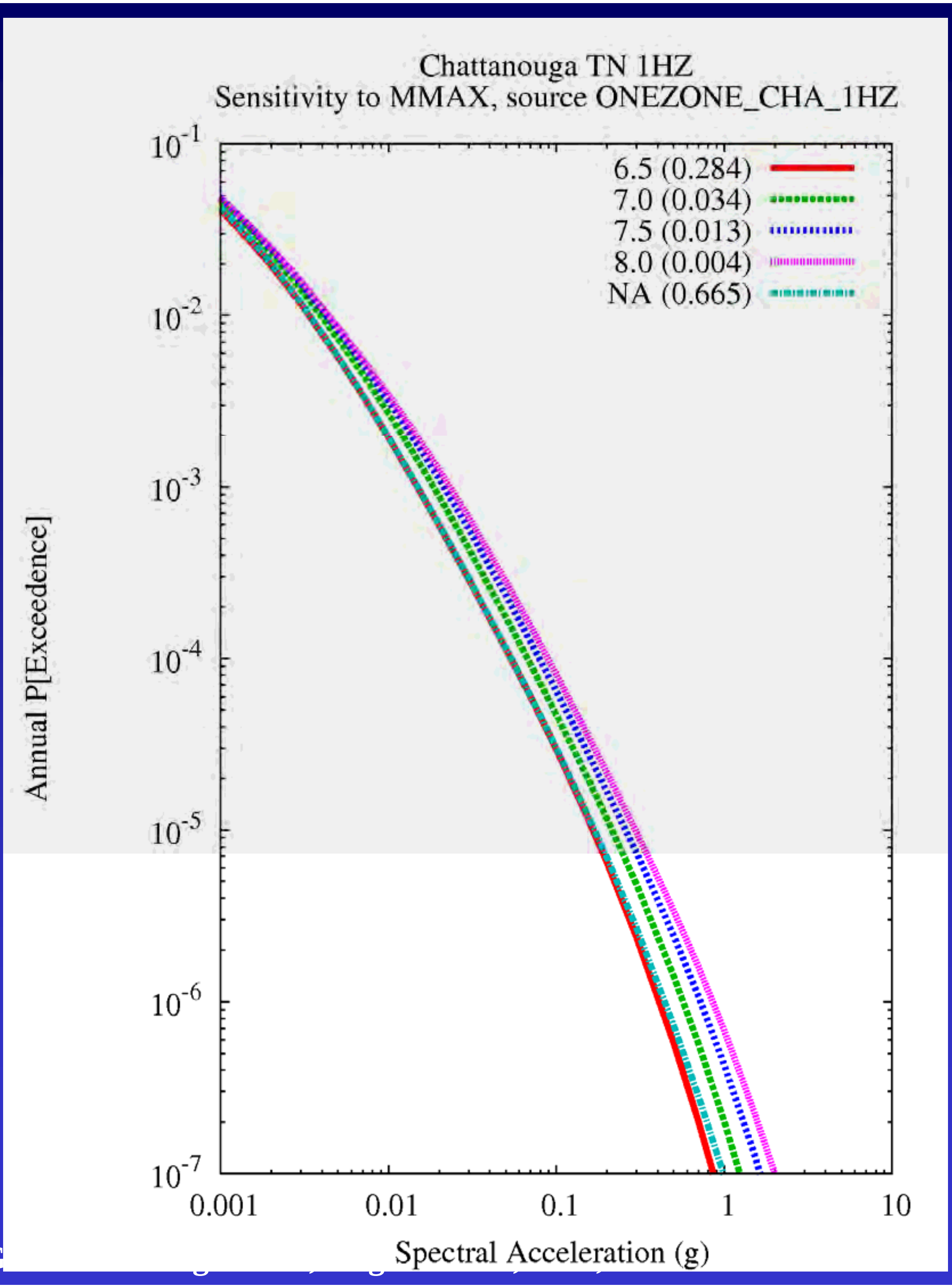
WLA William Lettis & Associates, Inc.

RISK ENGINEERING



WLA William Lettis & Associates, Inc.

RISK ENGINEERING



WLA
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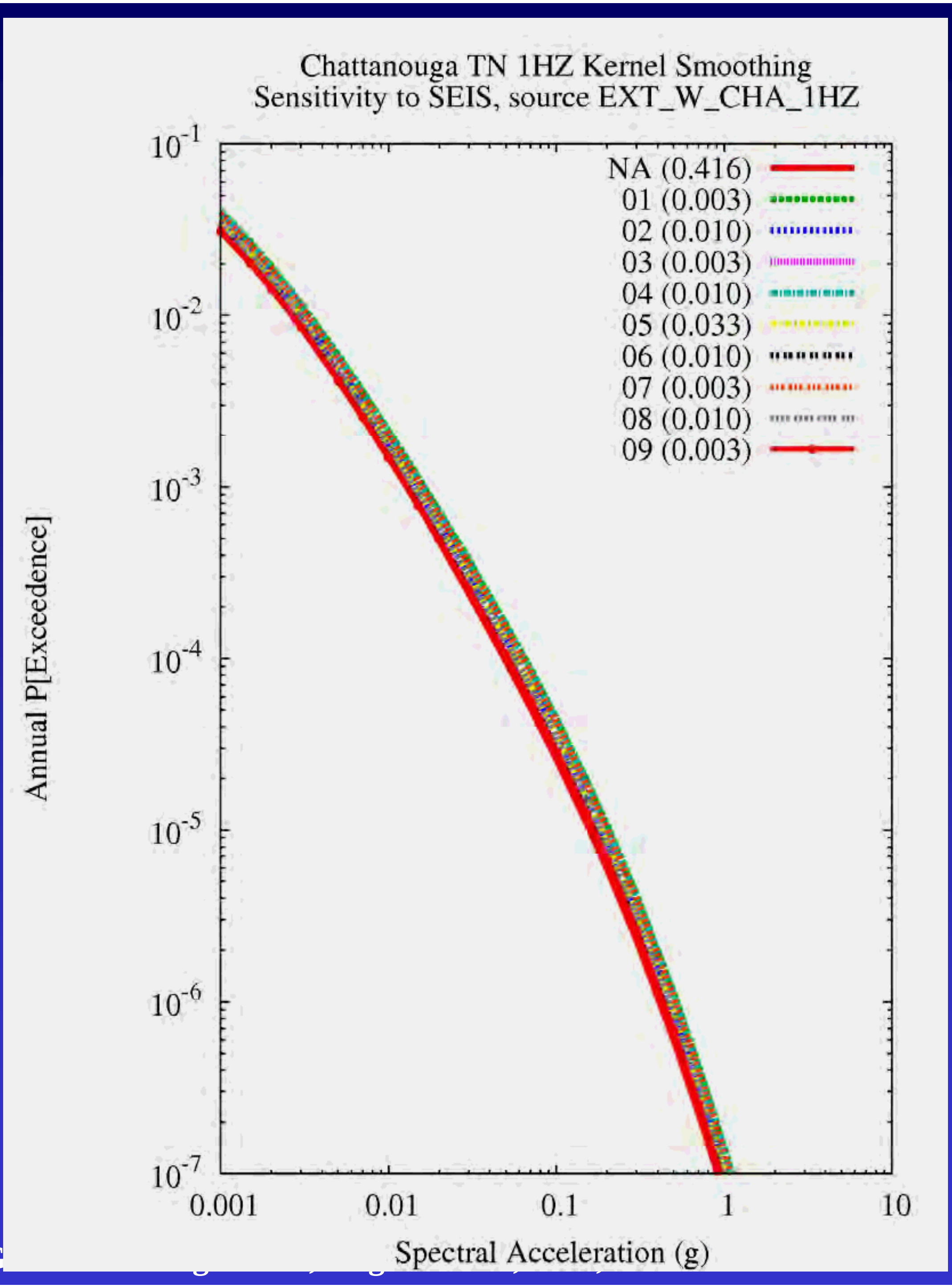
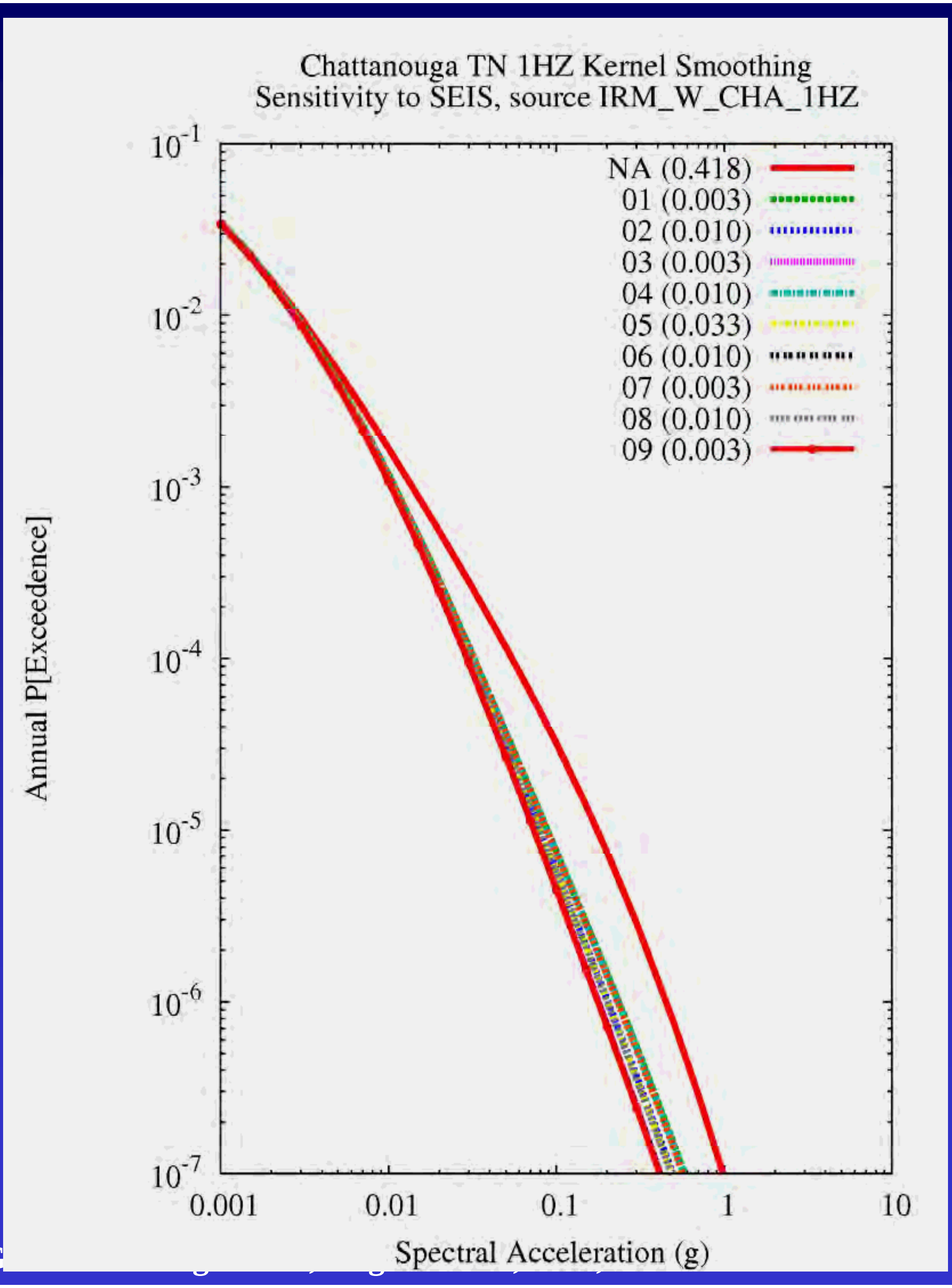
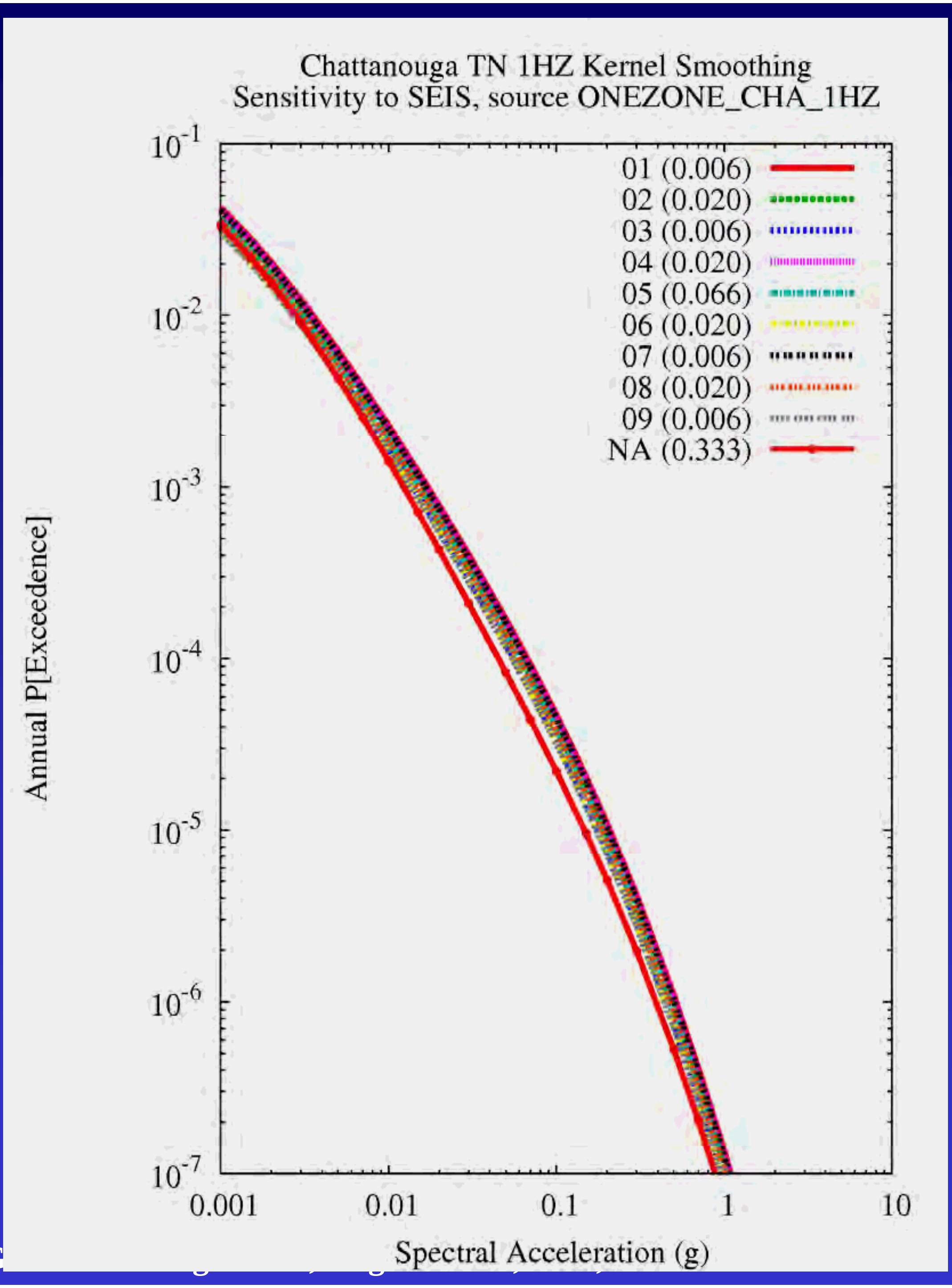
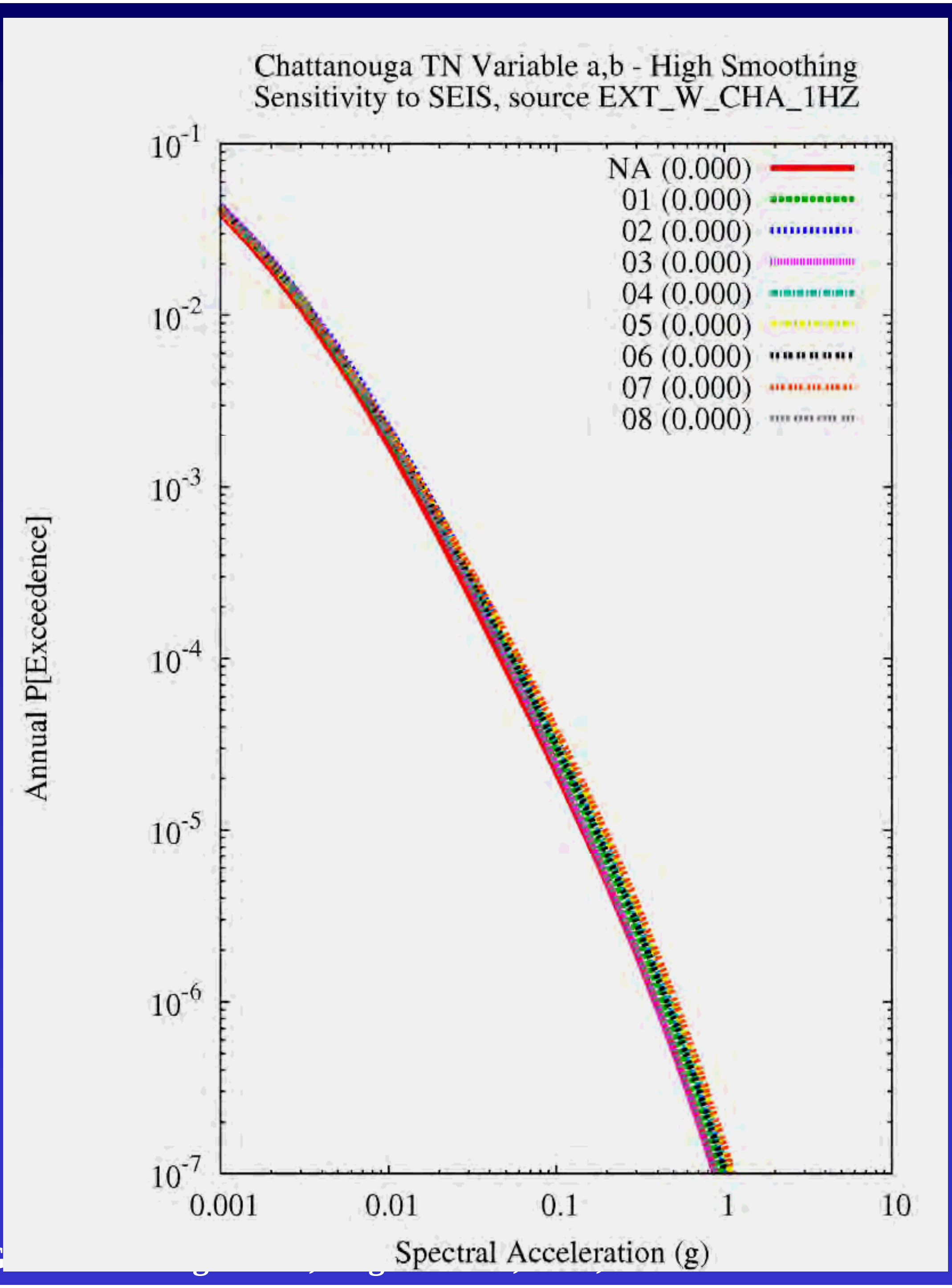

Chattanouga TN 1HZ Kernel Smoothing
Sensitivity to SEIS, source EXT_W_CHA_1HZ
Annual P[Exceedence]
Spectral Acceleration (g)
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
0.001
0.01
0.1
1
10
NA (0.416)
01 (0.003)
02 (0.010)
03 (0.003)
04 (0.010)
05 (0.033)
06 (0.010)
07 (0.003)
08 (0.010)
09 (0.003)

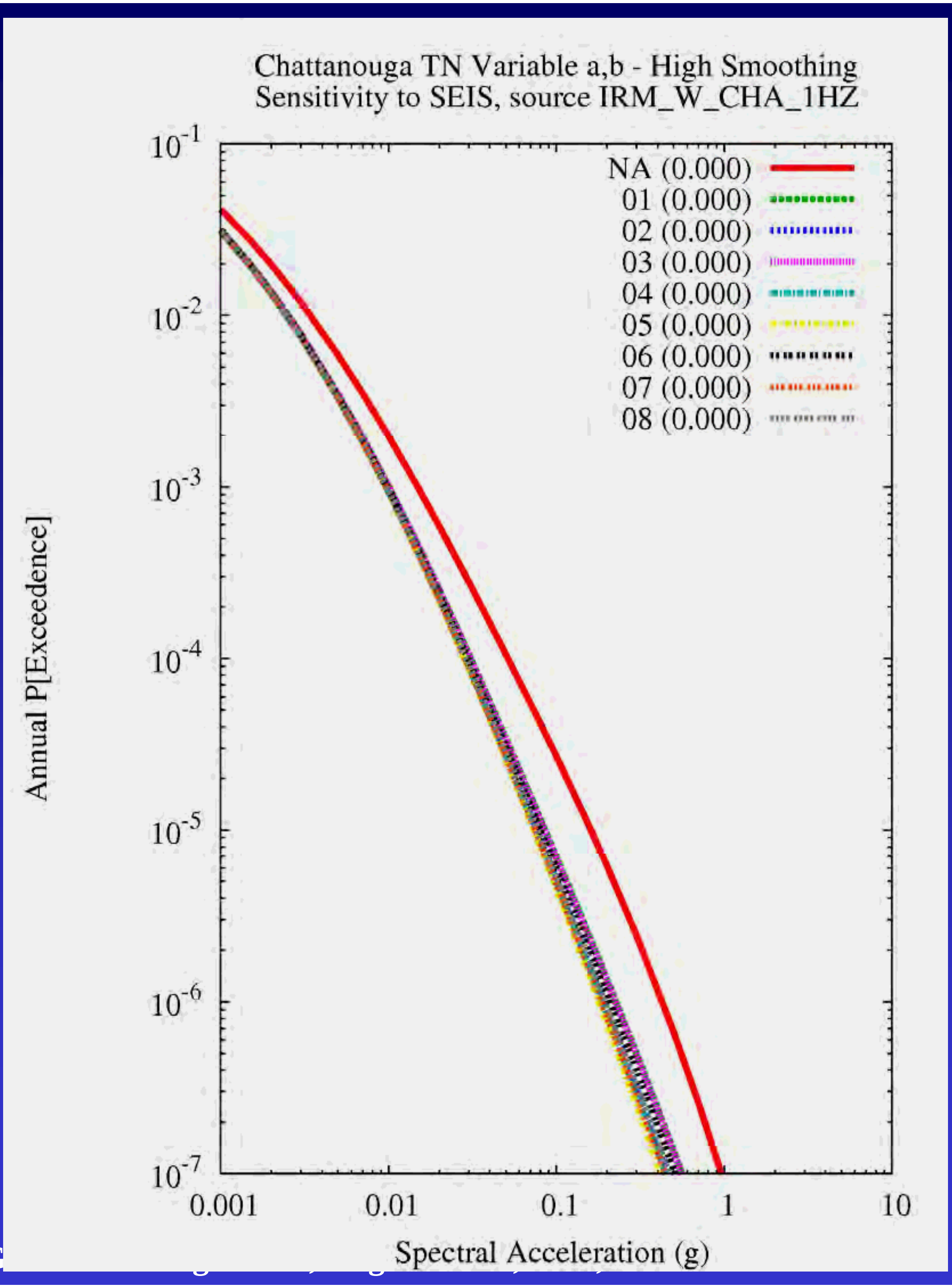

Chattanouga TN 1HZ Kernel Smoothing
Sensitivity to SEIS, source IRM_W_CHA_1HZ
NA (0.418)
01 (0.003)
02 (0.010)
03 (0.003)
04 (0.010)
05 (0.033)
06 (0.010)
07 (0.003)
08 (0.010)
09 (0.003)
Annual P[Exceedence]
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
0.001
0.01
0.1
1
10
Spectral Acceleration (g)



WLA William Lettis & Associates, Inc.

RISK ENGINEERING


Chattanouga TN Variable a,b - High Smoothing
Sensitivity to SEIS, source EXT_W_CHA_1HZ



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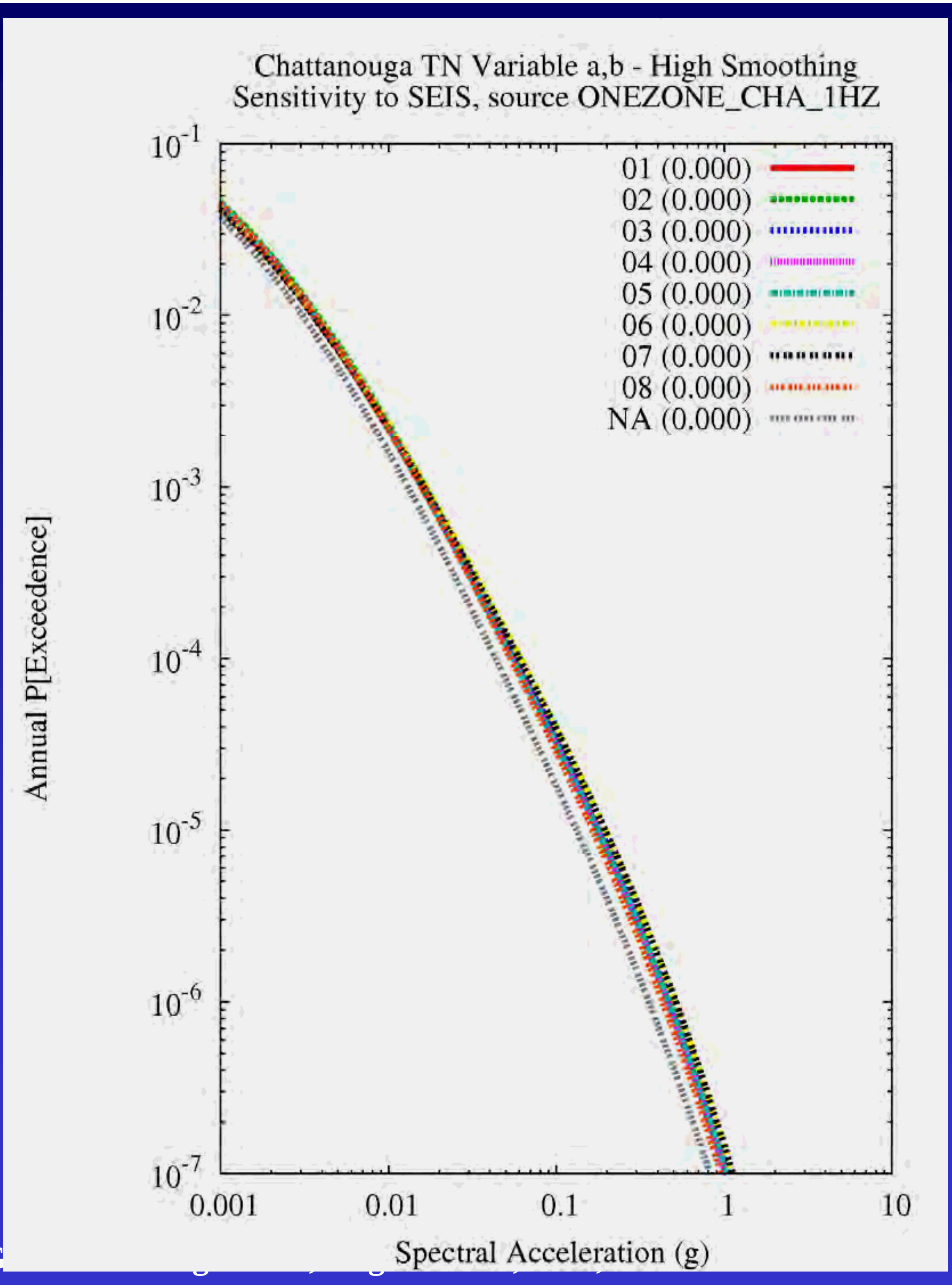
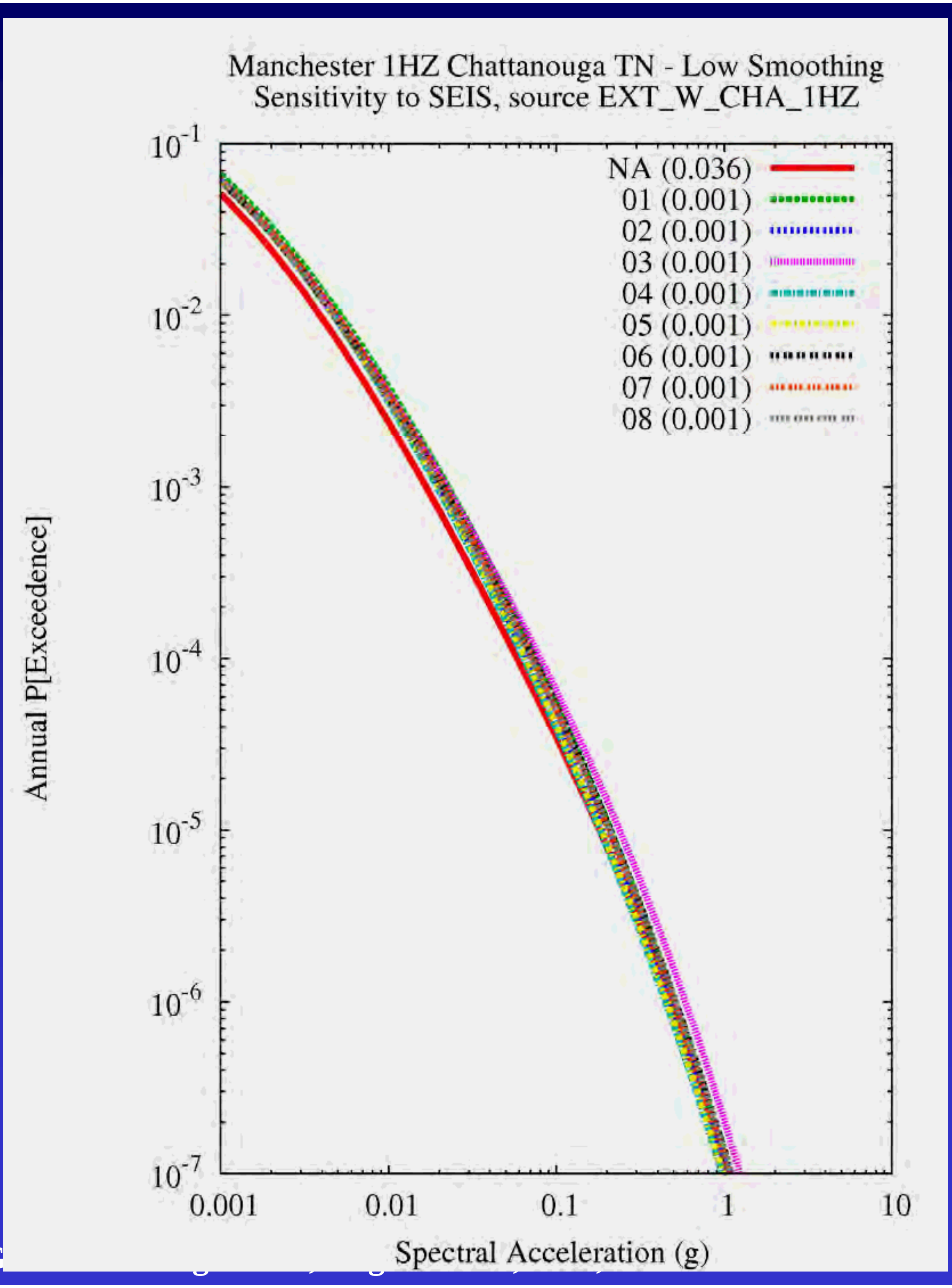
RISK ENGINEERING

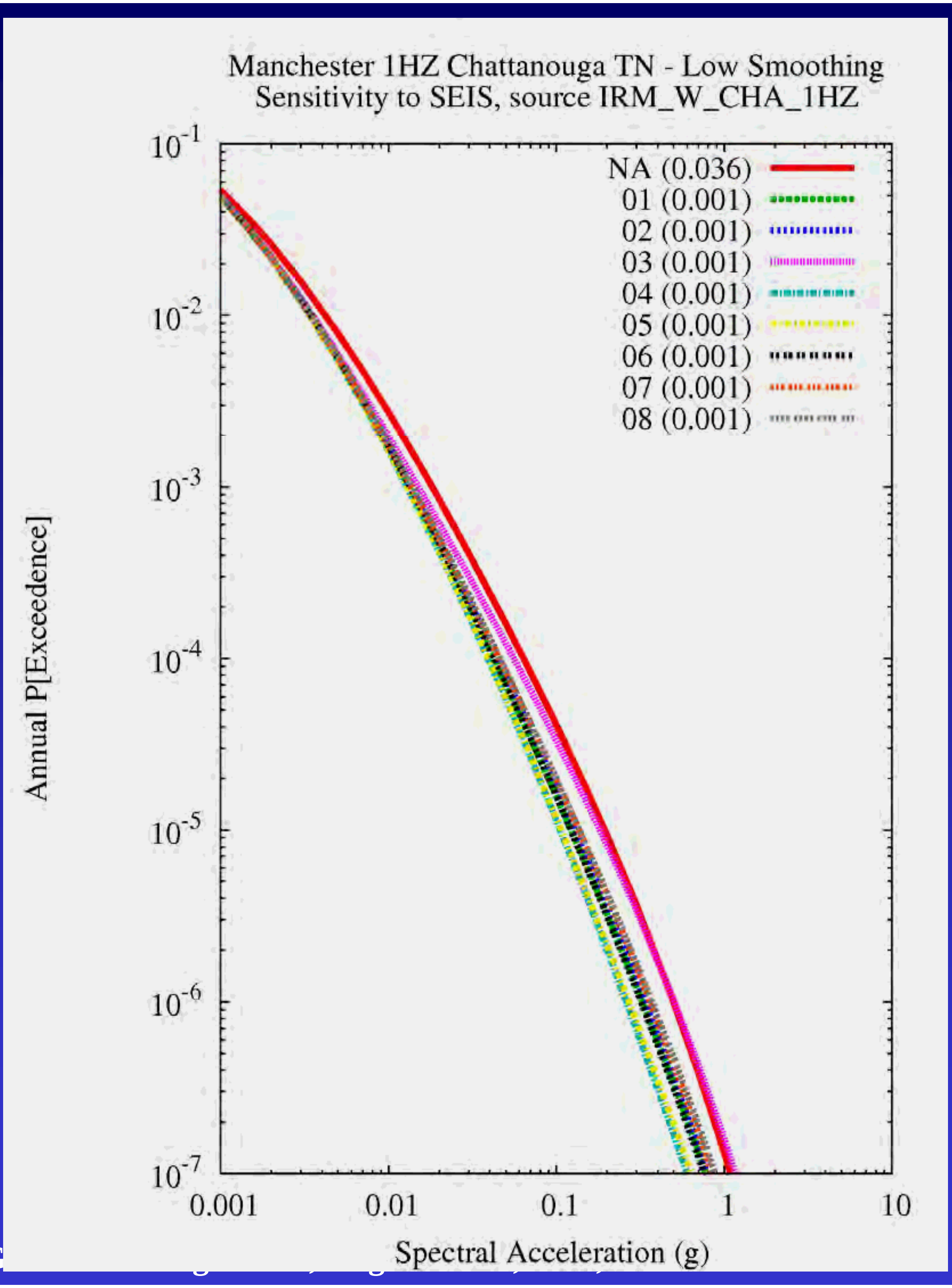


William Lettis & Associates, Inc.



William Lettis & Associates, Inc.

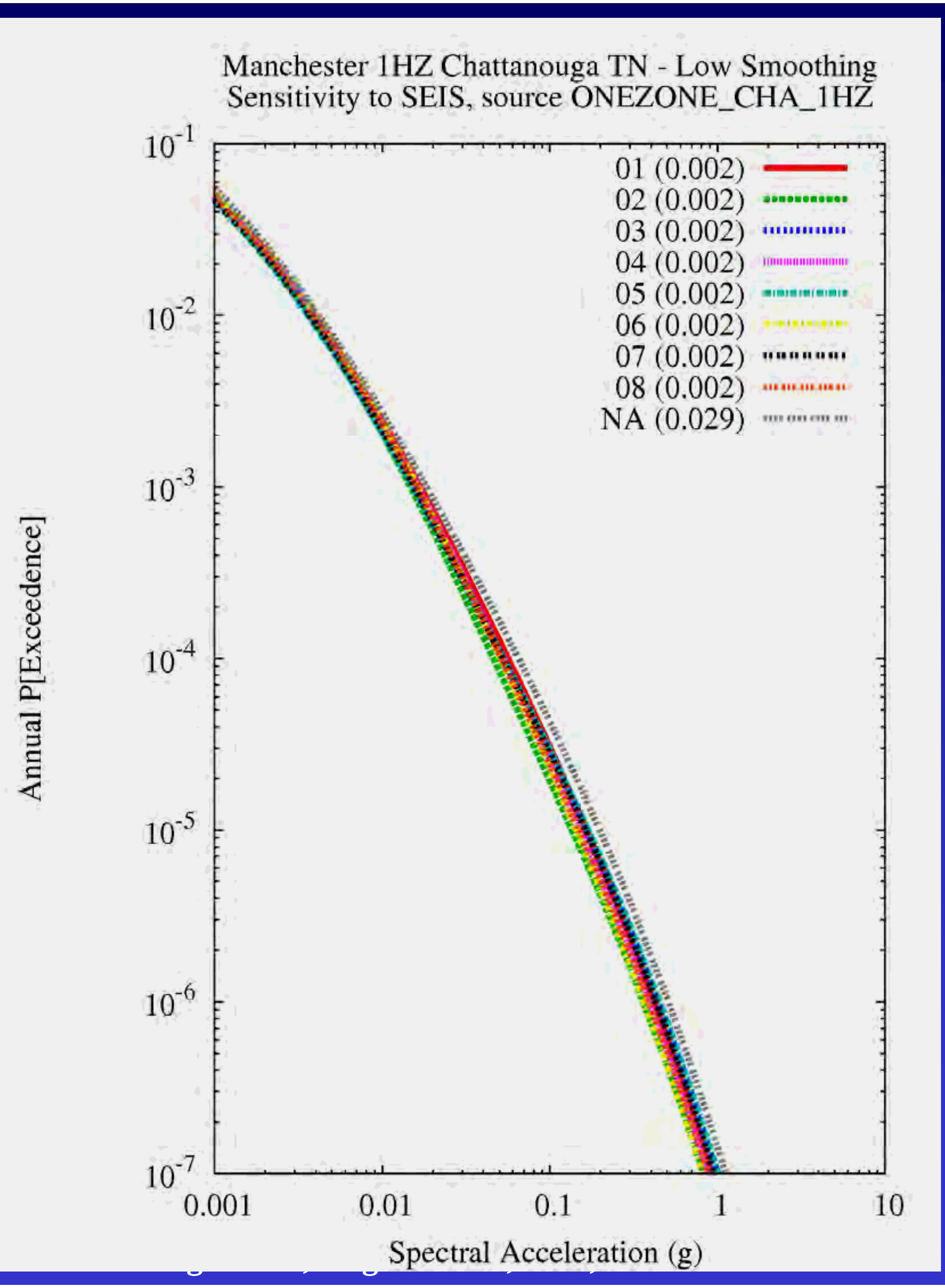
RISK ENGINEERING



Manchester 1HZ Chattanouga TN - Low Smoothing
Sensitivity to SEIS, source IRM_W_CHA_1HZ

William Lettis & Associates, Inc.

RISK ENGINEERING



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Summary of Results for Chattanooga

- Moderate sensitivity to Zoneless vs. Seismotectonic branch
- Sensitivity to Mmax of IRM (Iapetan Rift Margin) and other host sources (Zoneless and Extended)
- Sensitivity to IRM recurrence map for penalized-likelihood approach with low smoothing

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Additional Feedback Needed

- Hazard significance of all logic tree branches at all logic tree nodes at all 7 sites (shown as conditional at particular nodes of logic tree)
  - SSC approach: zoneless, hybrid, seismotectonic
  - One zone versus two in zoneless
  - In-cluster vs. out of cluster
  - Renewal vs. Poisson
  - Orientation of modeled ruptures
  - Alternative source geometries
  - Paleoliquefaction interpretations at ALM (correlation, assoc. with NM)
- Alternative definition of “extended/non-extended” boundary (Mesozoic; check EPRI 94)
- Relative contribution of RLME sources versus host source at all sites
  - Relative importance at increasing distance
- Predicted vs. observed seismicity
  - Entire CEUS and for subregions (e.g., seismotectonic zones)
  - Compare with paleoseismic events
- Explanation for hazard significance of kernel vs. variable a, b smoothing approaches

Feedback Needed (continued)

- Should look at with a single attenuation equation to see if the reason for the differences in the slope differences of hazard curves; Jackson site
- Explore the differences between kernel and cell approach (e.g., at edges, at locations of low seismicity, tails of distribution)
  - Explore smoothing approaches in low seismicity sites (e.g., importance of low vs high smoothing; strength of priors)
- Look at contribution of IRM to Chattanooga and associated uncertainties
- Extended/Non-extended boundary
  - Explore alternative types of zone boundaries
  - Explore the importance of the boundary vv. Mmax (e.g., difference in the sigma for the prior)

- Can we actually implement a full zoneless model?
- Are we double counting the RLME mags and the larger mags of host zone
- EQs off coast of LA; controlling from larger mags; effect of completeness
- Migrating RLME issue (e.g., like the Meers); may be related to rate vs. background
- Edge effect of smoothing (e.g., narrow OK aulo)
- Mmax distributions for all zones

Quantifying the precision of seismic hazard results in the CEUS

Robin K. McGuire
Risk Engineering, Inc.
Boulder, Colorado

August 26, 2009

Purpose:

---Derive quantitative estimates of how seismic hazard estimates might change if studies were to be repeated with the same basic information by different researchers

---Estimate levels of precision that should be associated with current estimates

General sources of imprecision

<u>Random error and statistical variation</u>

What was the size of the 1886 Charleston EQ?

Can a larger EQ occur in Charleston?

Can a larger EQ occur elsewhere on the east coast?

General sources of imprecision (cont'd)

Systematic error and subjective judgment

Judgments guided by previous studies

Over-confidence in estimating confidence intervals

Do EQs occur in clusters with high probability?

Will future **M**'s be similar to past **M**'s?

How well can we interpret pre-instrumental EQs?

General sources of imprecision (cont'd)

Linguistic imprecision

What is meant by "maximum magnitude that can occur?"

What is meant by the "distribution of maximum magnitude?"

What is meant by the "spatial distribution of the distribution of maximum magnitude?"

General sources of imprecision (cont'd)

Variability

EQ occurrence models are calibrated to historical data (inherently variable)

What is the appropriate distribution for events not yet observed?

General sources of imprecision (cont'd)

<u>Randomness and unpredictability</u>

EQ processes are not steady-state

What are appropriate parameters for renewal models?

What are appropriate renewal models for Charleston? Charlevoix?

General sources of imprecision (cont'd)

Expert disagreement

What is the appropriate $\mathbf{M}_{\mathrm{max}}$ distribution for large areas?

What aleatory distribution do we use for ground motion at near-source distances?

How do we extrapolate soil properties below our deepest borehole data?

General sources of imprecision (cont'd)

Approximations

Do we model rupture lengths|**M** with a single rupture length?

Do we keep 25 estimates of activity rate in the model, or collapse them to a smaller number?

How high (and low) do we extend $\mathbf{M}_{\mathrm{max}}$ distributions?

RISK ENGINEERING

Available studies to quantify levels of precision of seismic hazard results

Input	Subset of application	Available studies
(1) Seismic sources and parameters	Area sources	(1A) EPRI 1889 project (6 teams at 7 sites) (1B) PEGASOS project (4 teams at 4 sites)
	RLME sources (Charleston, New Madrid)	(1C) Charleston: WLA (1D) New Madrid: Youngs
(2) Ground motion equations	All	(2A) EPRI 2004 equations applied to 7 sites (2B) PEGASOS study (5 experts applied to 4 sites)
(3) Site response	All (non-rock) sites	(3A) EPRI 2007 study (1 expert applied to 60 sites) (3B) PEGASOS study (4 experts applied to 4 sites)

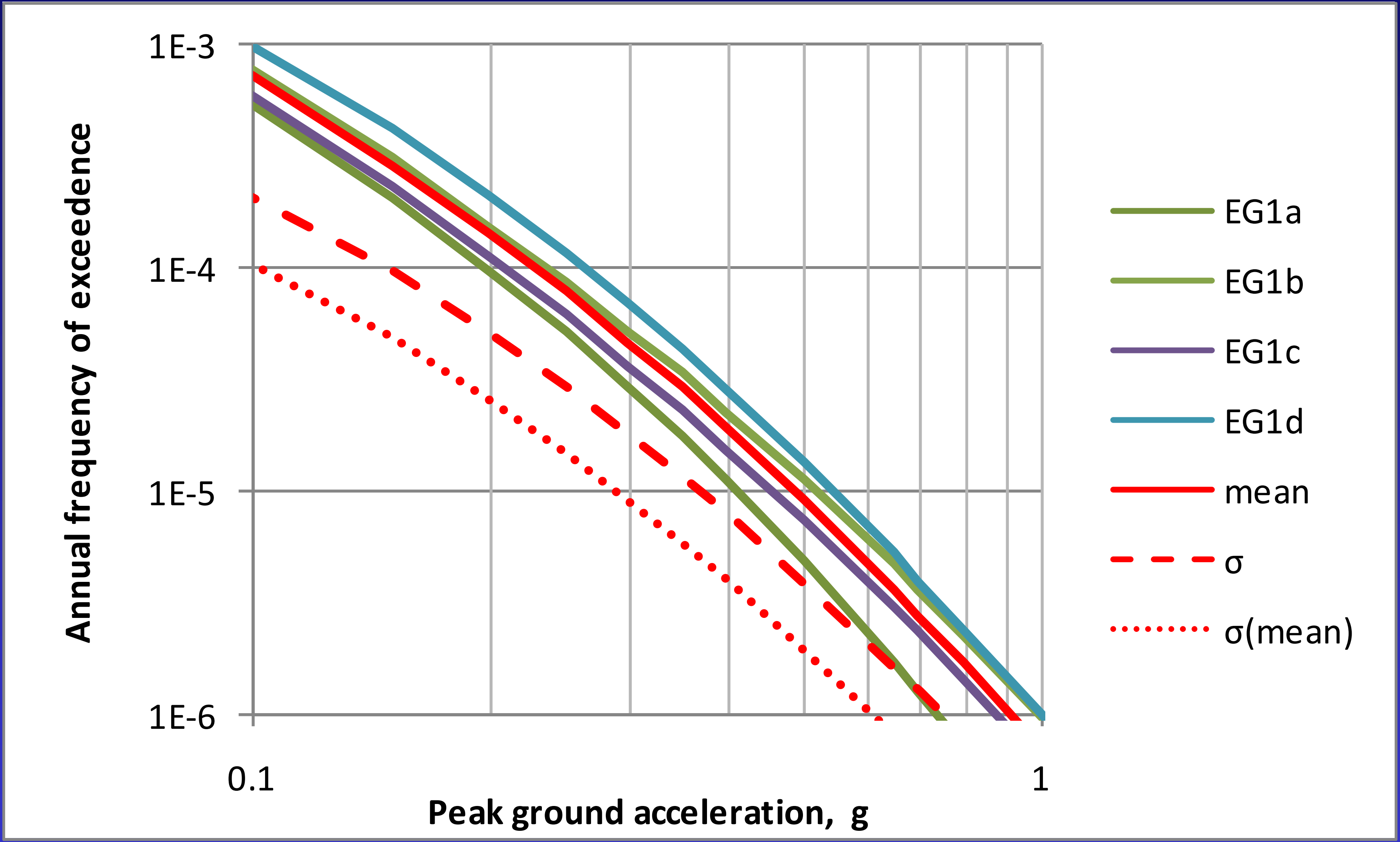
Combining sources of imprecision

$$\begin{aligned}\text{Mean P[exceedence]} = H_{\text{mean}} &\times Z_{\text{source char.}}\\ &\times Z_{\text{ground motion}}\\ &\times Z_{\text{site response}}\end{aligned}$$

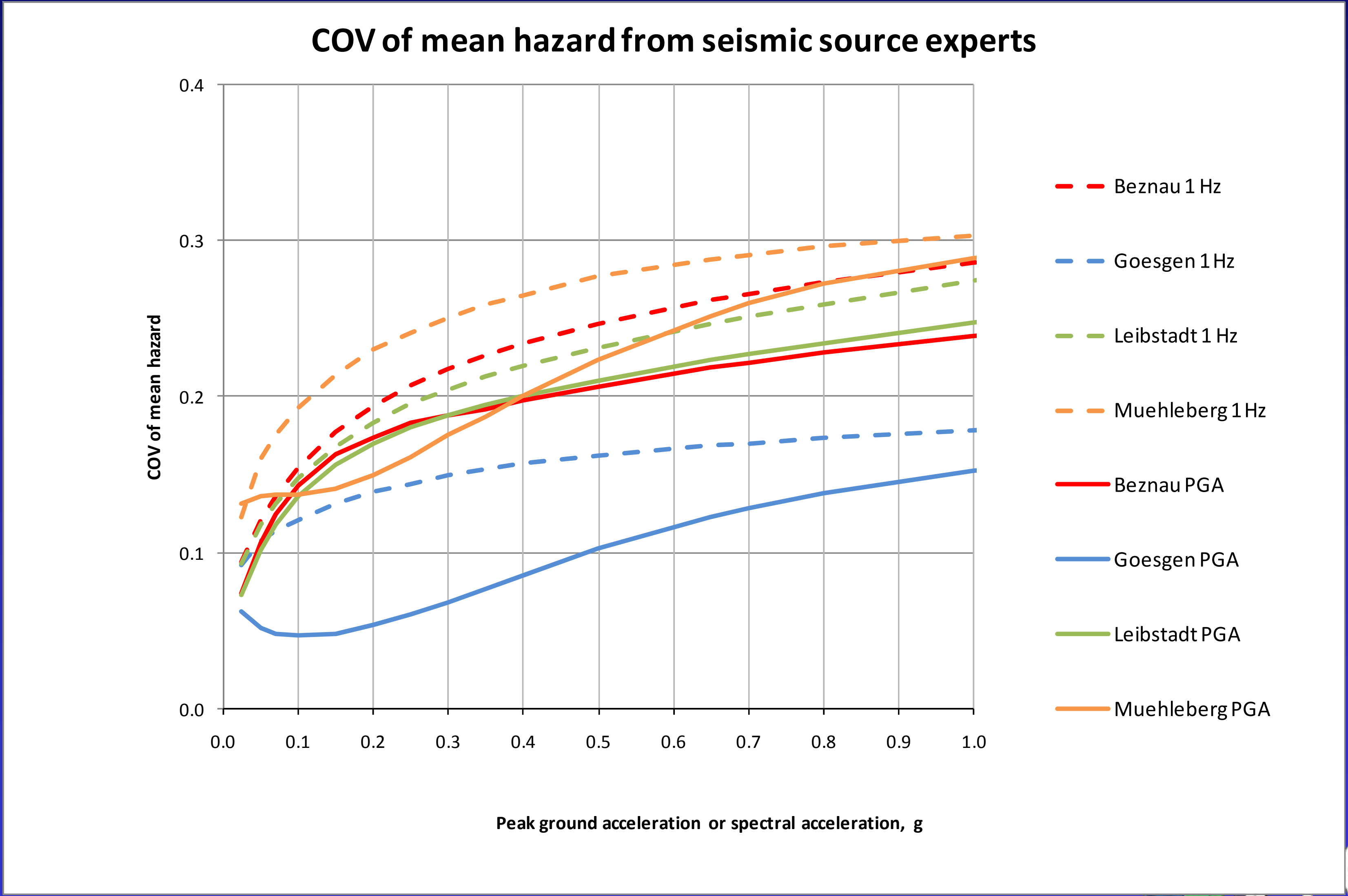
where the Z_i's are independent.

$$(\text{COV}_{\text{mean}})^2 = (\sigma_{\text{mean}}/\text{mean})^2 \simeq \Sigma\,(\text{COV}_{Zi})^2$$

Pegasos PGA hazard results for Beznau



Pegasos: COV from seismic source experts vs. amplitude



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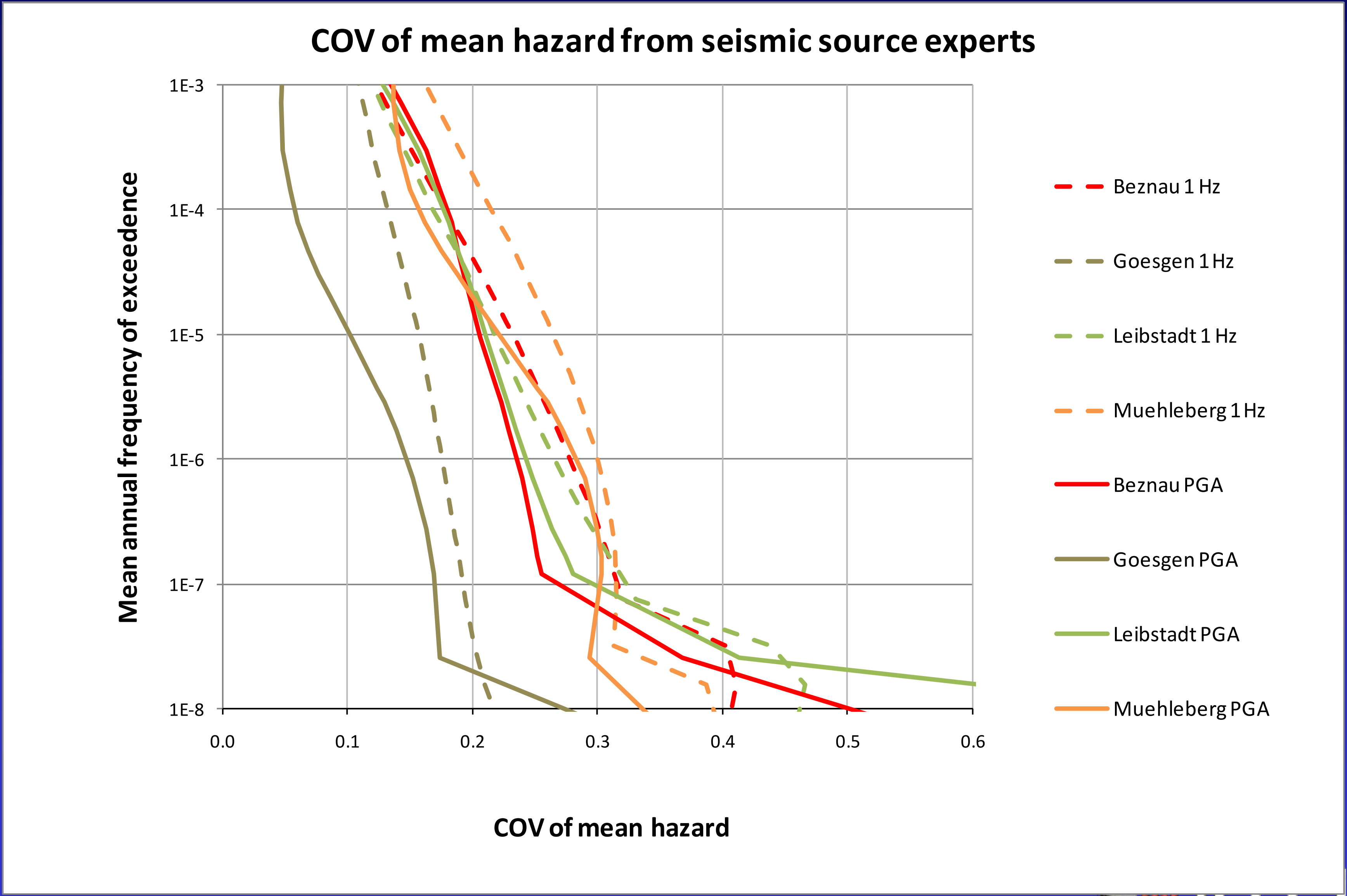
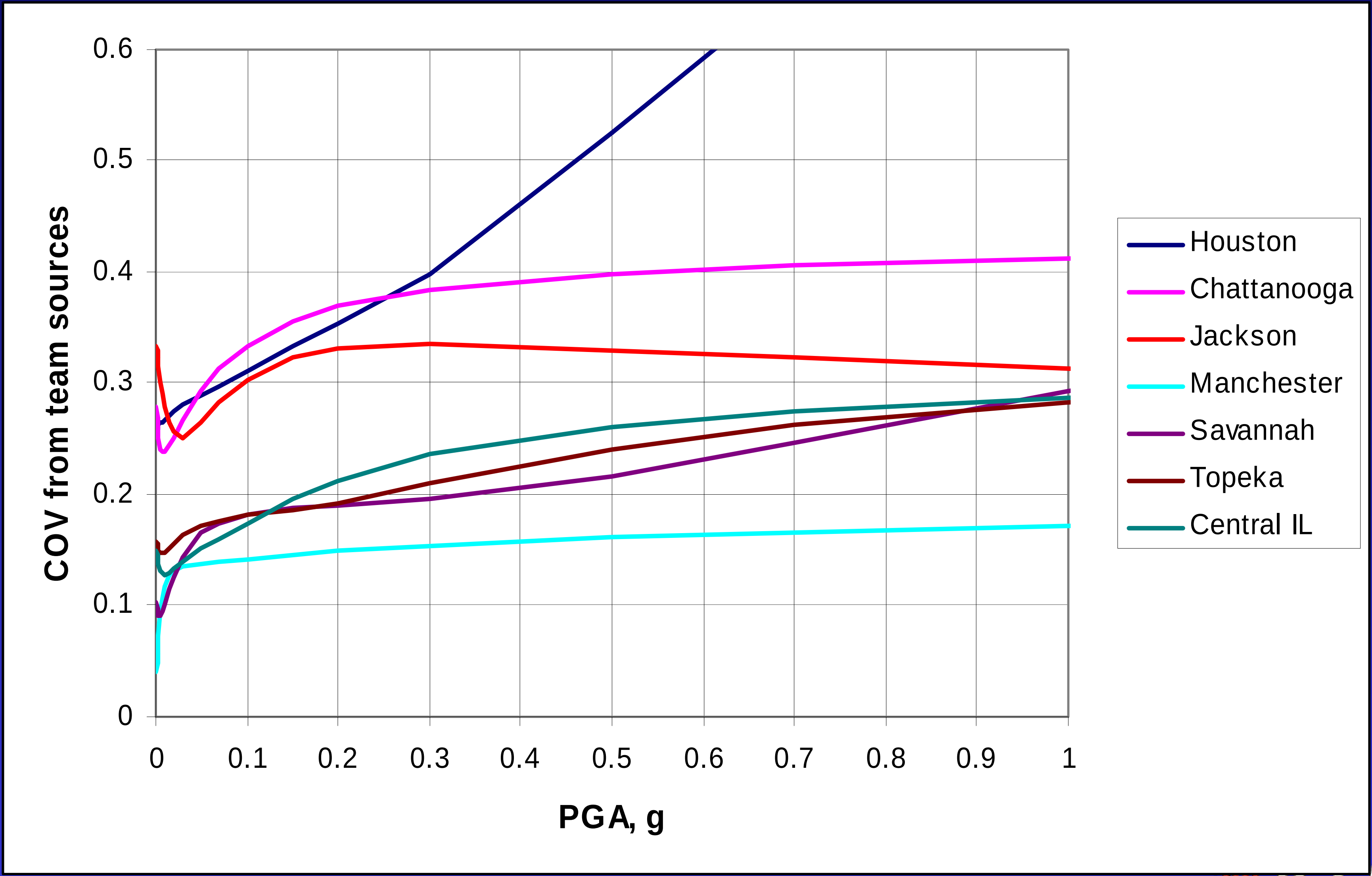
Pegasos: COV from seismic source experts vs. hazard



COV of PGA (EPRI 1989 teams)



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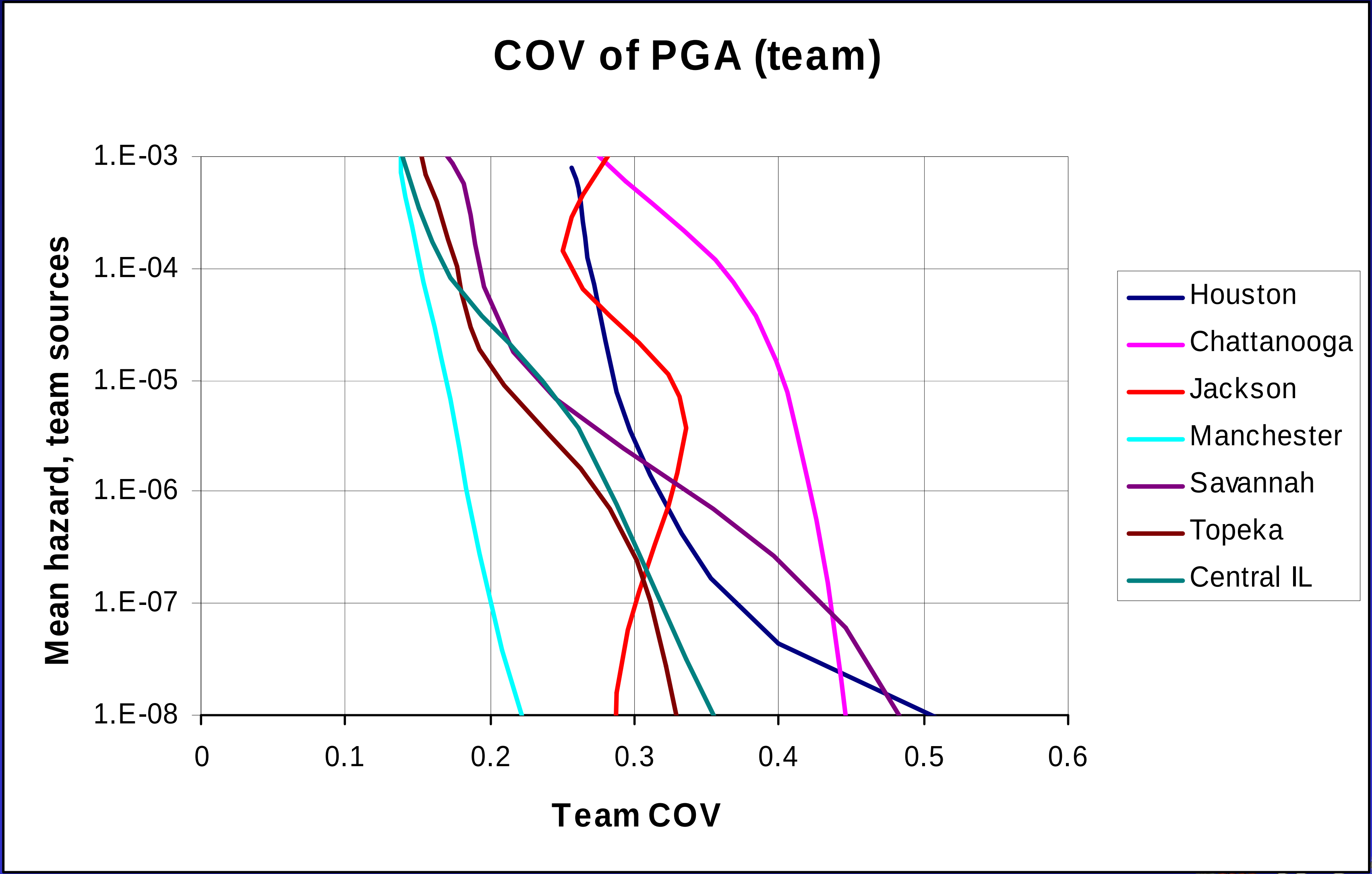
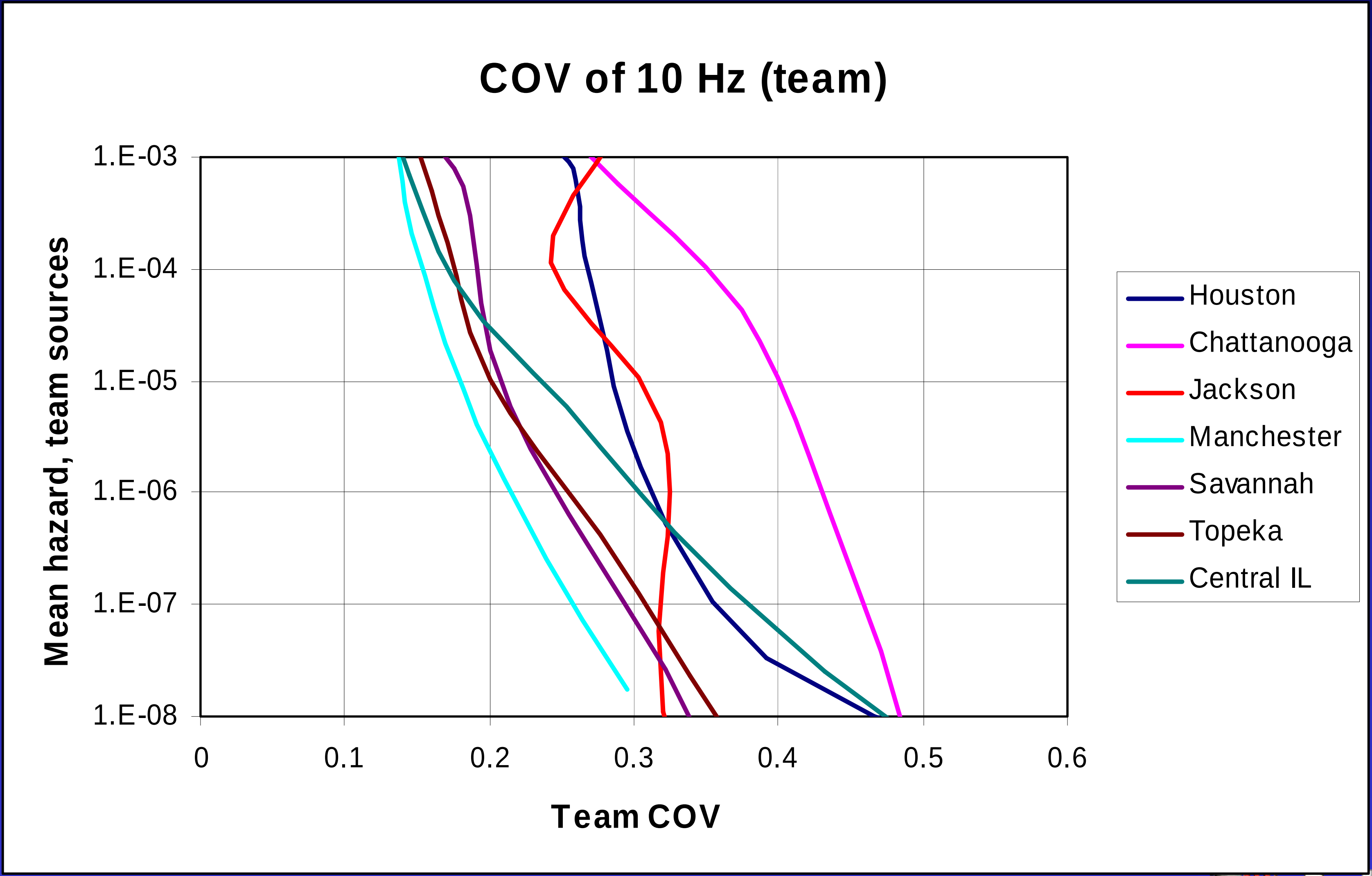
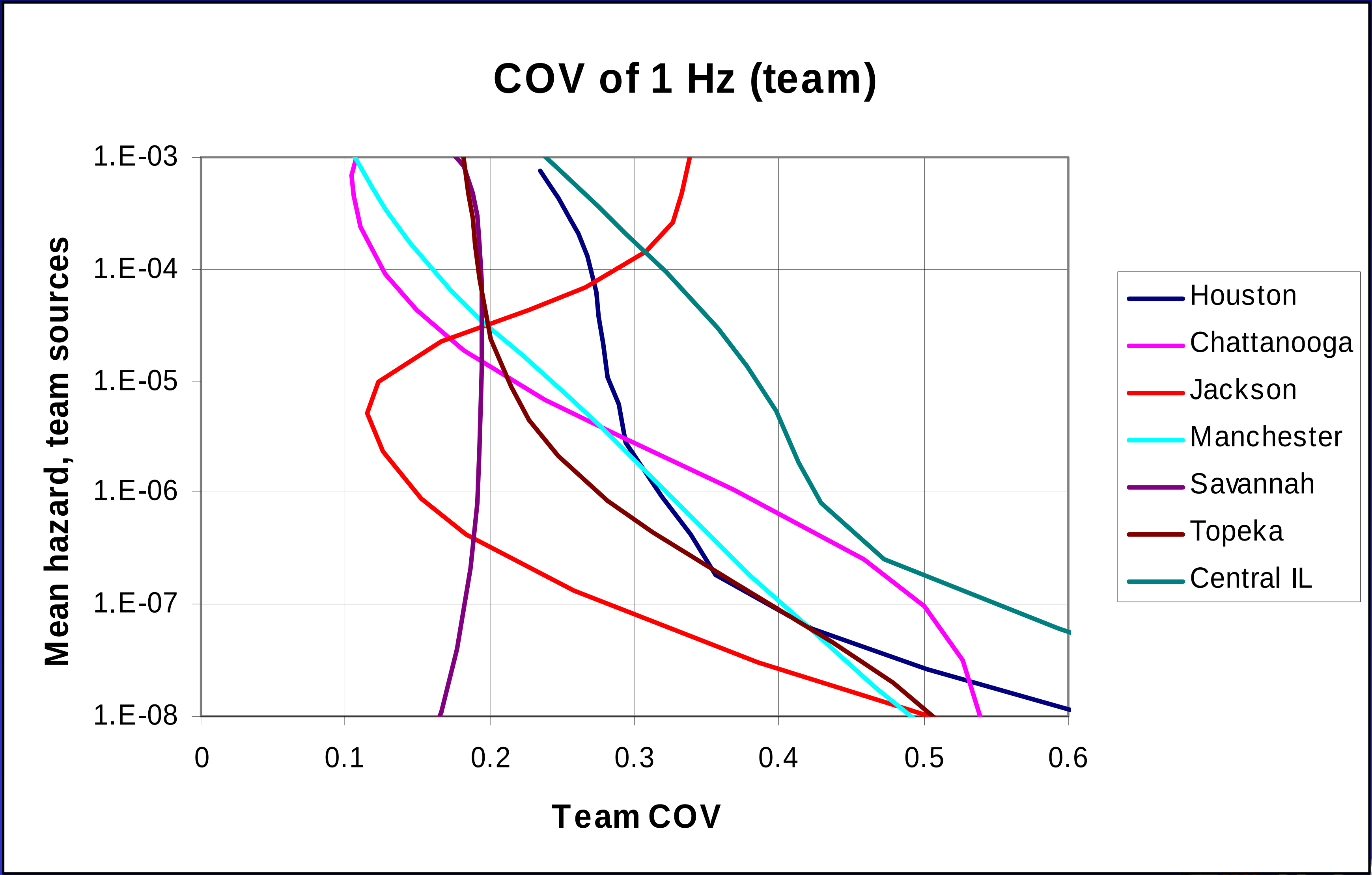
COV of PGA (EPRI 1989 teams)



COV of 10 Hz (EPRI 1989 teams)



COV of 1 Hz (EPRI 1989 teams)



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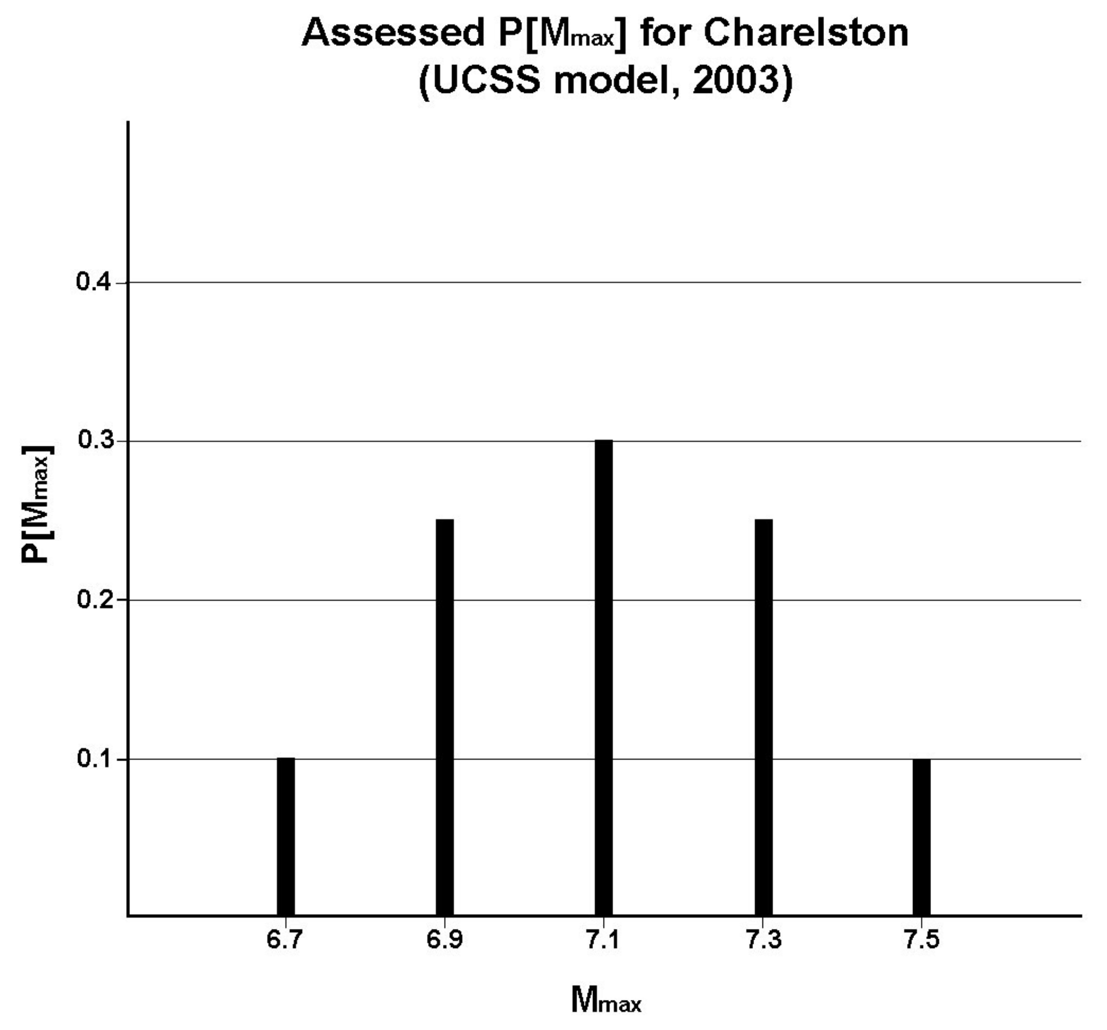
Summary of logic tree representing uncertainties for the Charleston seismic zone

Interpretation	**Alternatives**	**Weights on alternatives**
Geometry of source	4 geometries	0.7, 0.1, 0.1, 0.1
Maximum magnitude	5 values	0.1, 0.25, 0.3, 0.25, 0.1
Paleoseismic record length	2 periods	0.8, 0.2
Activity rate given record	5 rates	0.1, 0.2, 0.4, 0.2, 0.1


Assessed P[Mmax] for Charelston
(UCSS model, 2003)
P[Mmax]
0.4
0.3
0.2
0.1
6.7
6.9
7.1
7.3
7.5
Mmax

Mean and variance of hazard when weights on models are variable

$$\text{mean }(H) = W_1\,H_1 + W_2\,H_2 + W_3\,H_3 + W_4\,H_4 \qquad (1)$$

$$\text{mean }(H) = \Sigma_i\ E[W_i]H_i \qquad (2)$$

$$\sigma_k^{\,2}\,(H) = \Sigma\ \sigma_i^{\,2}\,H_i^{\,2} + 2\ \Sigma_i\ \ \Sigma_{j>i}\ H_i\ H_j\ \mathrm{cov}(W_i,\ W_j) \qquad (3)$$

Summary of logic tree representing uncertainties for the Charleston seismic zone

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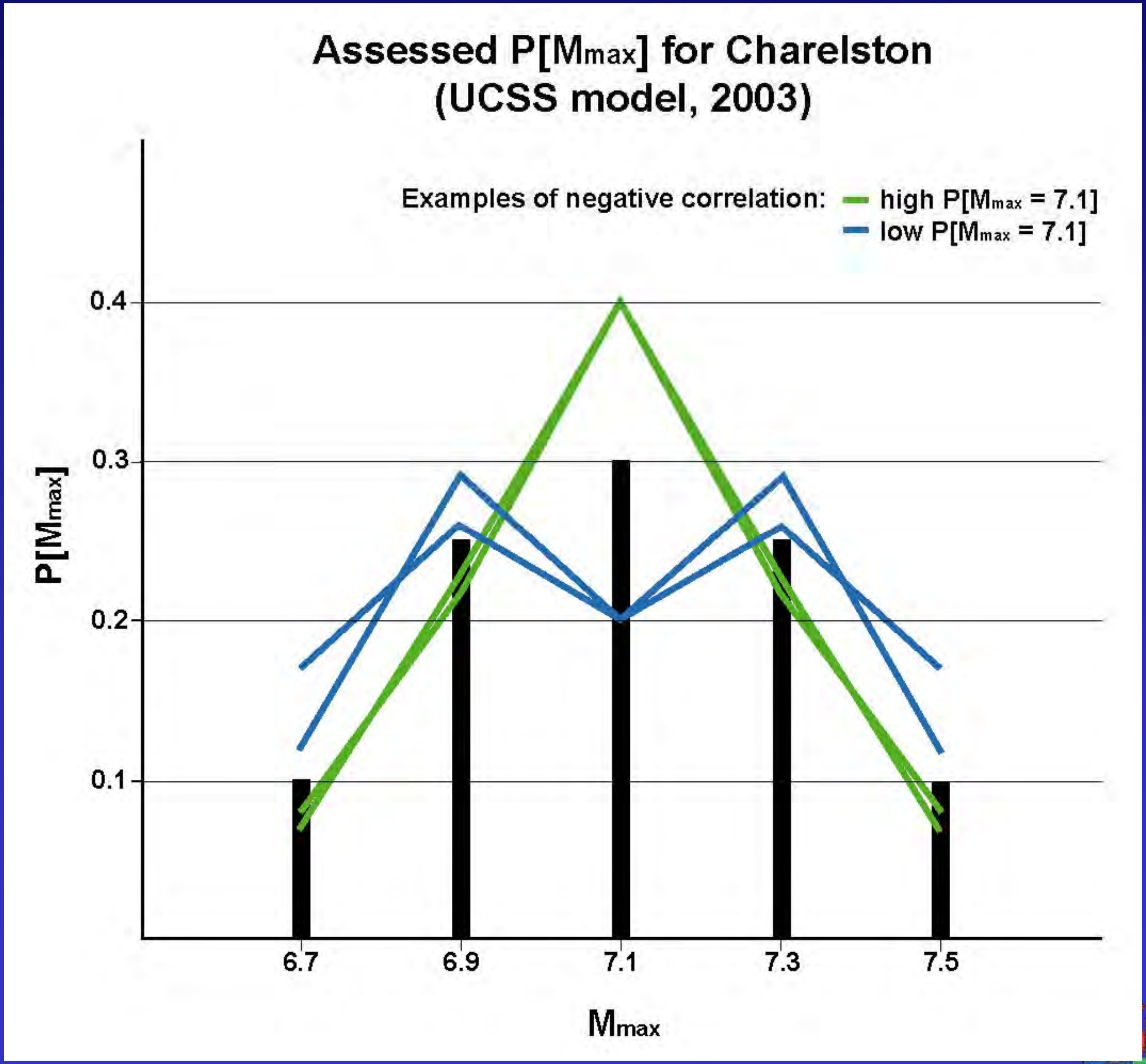
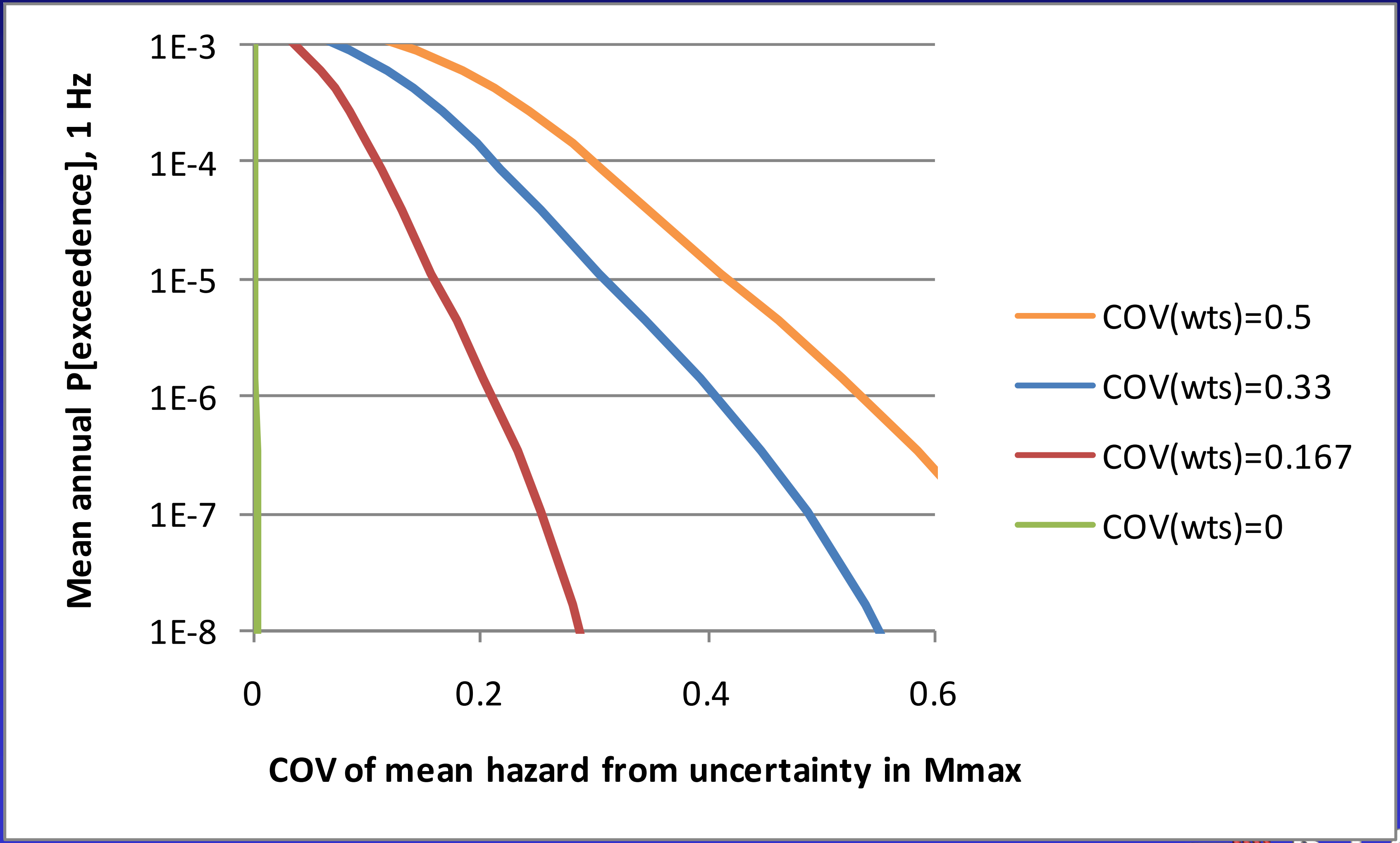
Paleoseismic record length	2 periods	0.8, 0.2
Activity rate given record	5 rates	0.1, 0.2, 0.4, 0.2, 0.1

	COV of weights
Geometries:	0.1/0.7 = 0.143
Maximum magnitudes:	0.1/0.3 = 0.333
Paleoseismic record length:	0.1/0.8 = 0.125
Activity rate give record:	0.1/0.4 = 0.25

Variability in weights leads to negative correlation



Effect of COV(wts) on COV(hazard) for Charleston M_{max} weights



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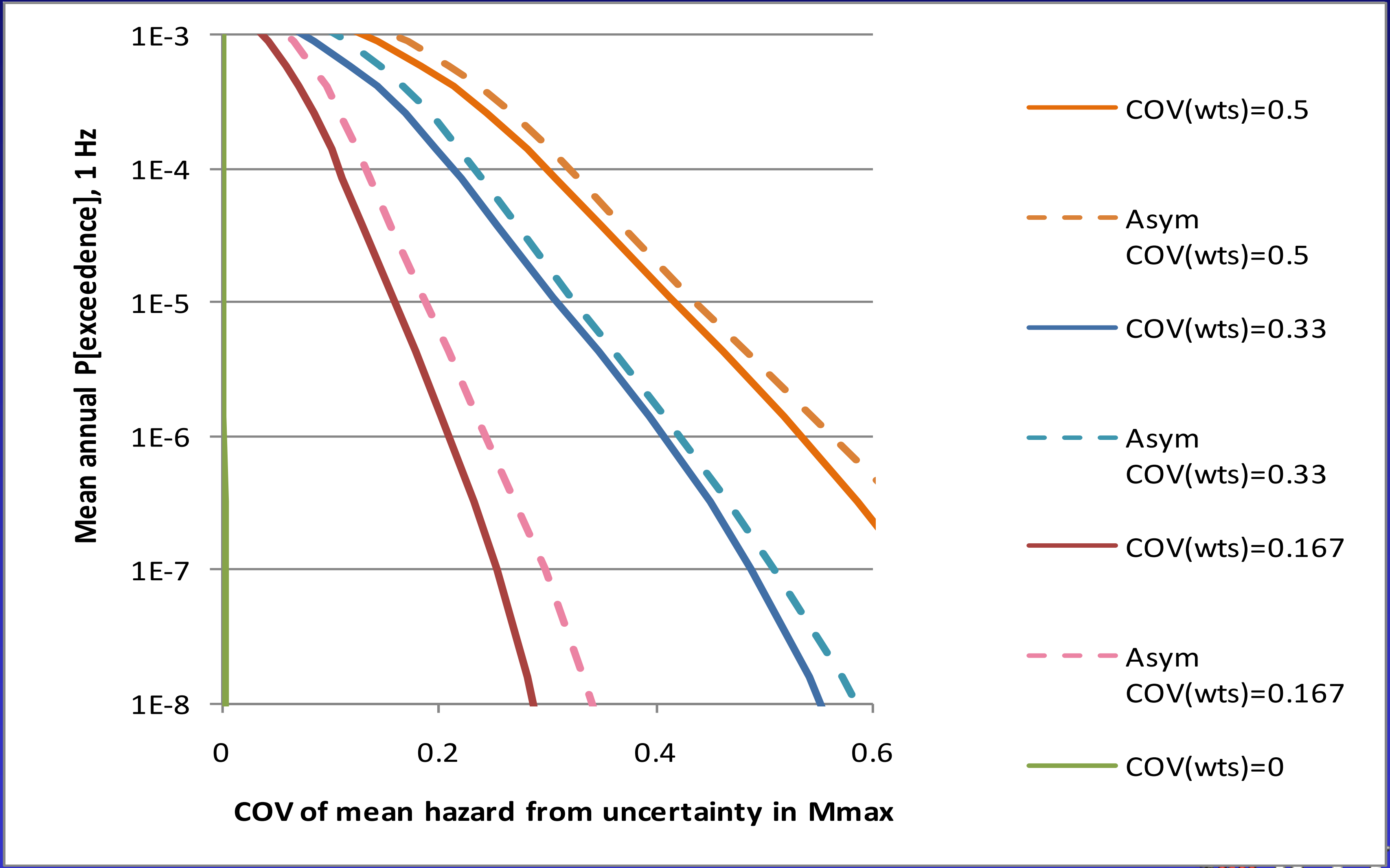
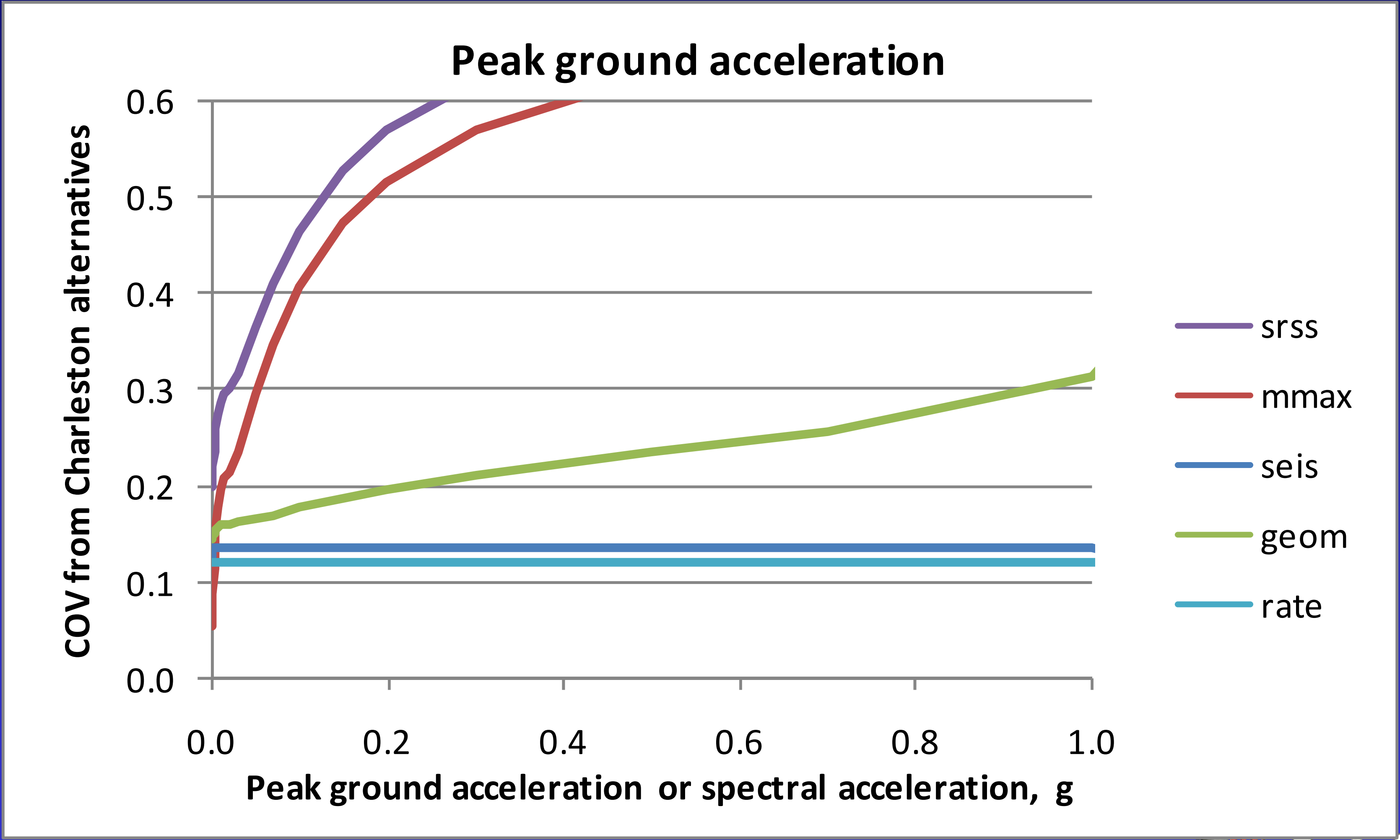
Effect of COV(wts) on COV(hazard) for Charleston M_{max} weights (asymmetrical)

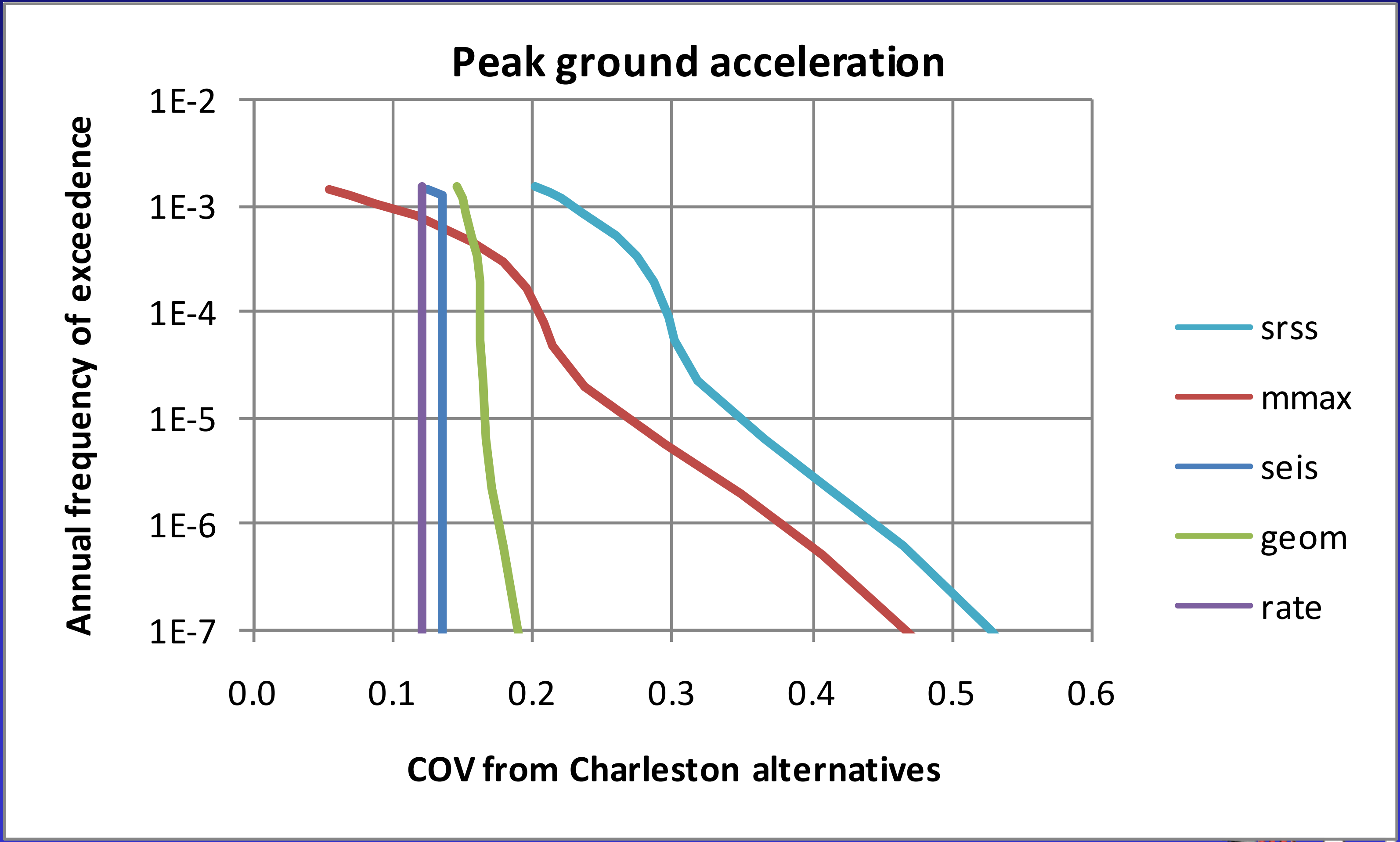


COVs from Charleston alternatives for PGA, plotted vs PGA amplitude

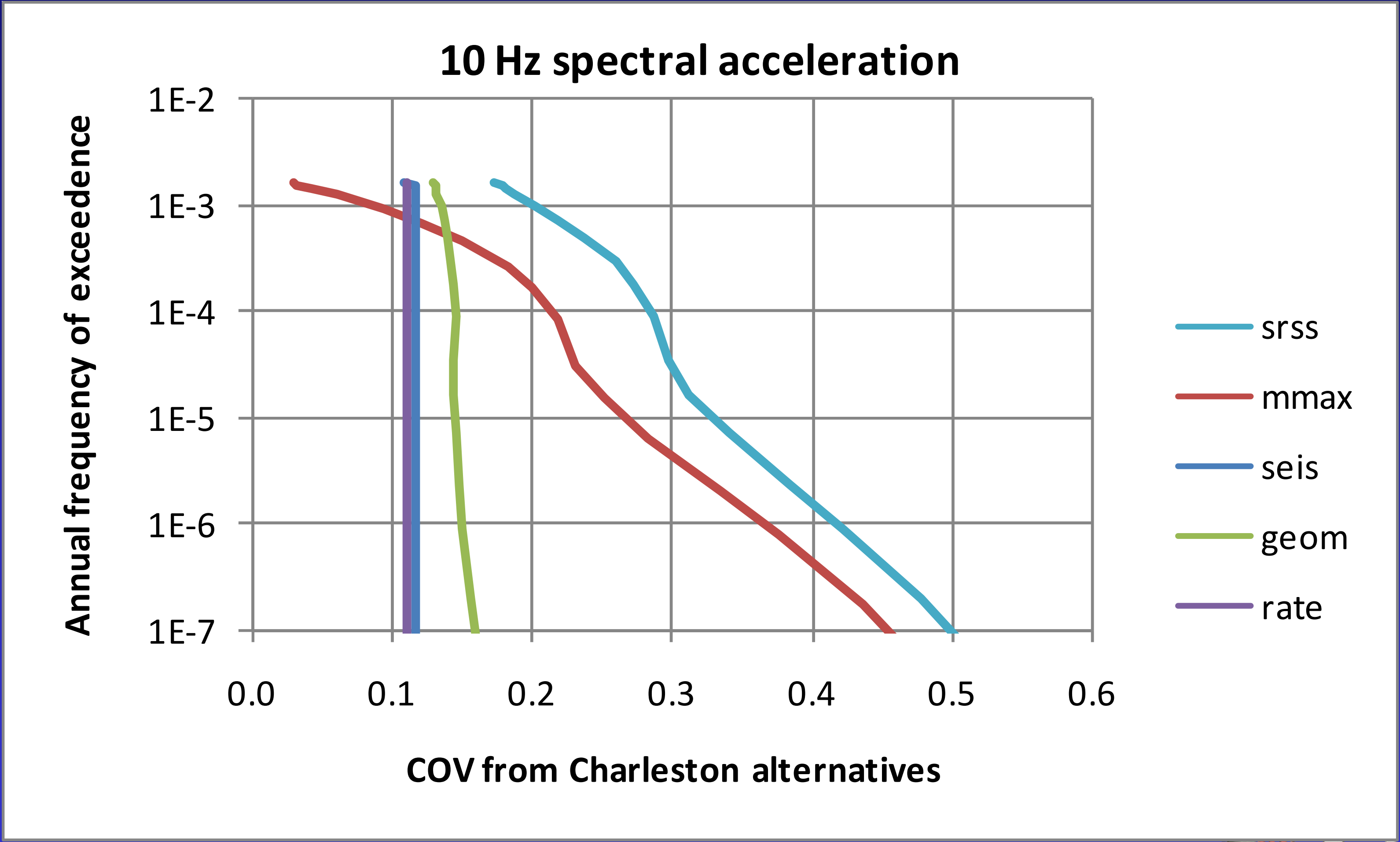


RISK ENGINEERING

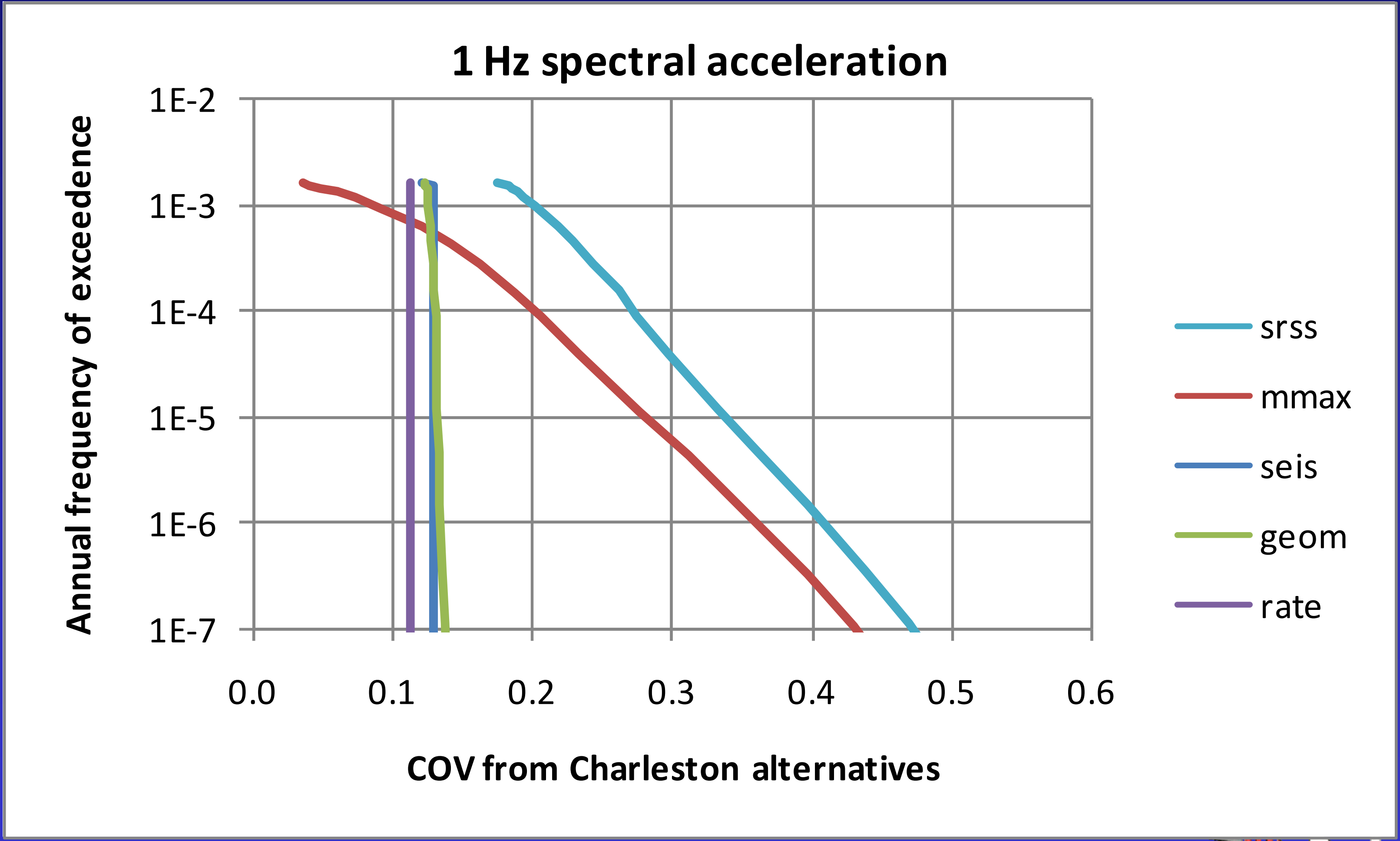
COVs from Charleston alternatives for PGA, plotted vs hazard



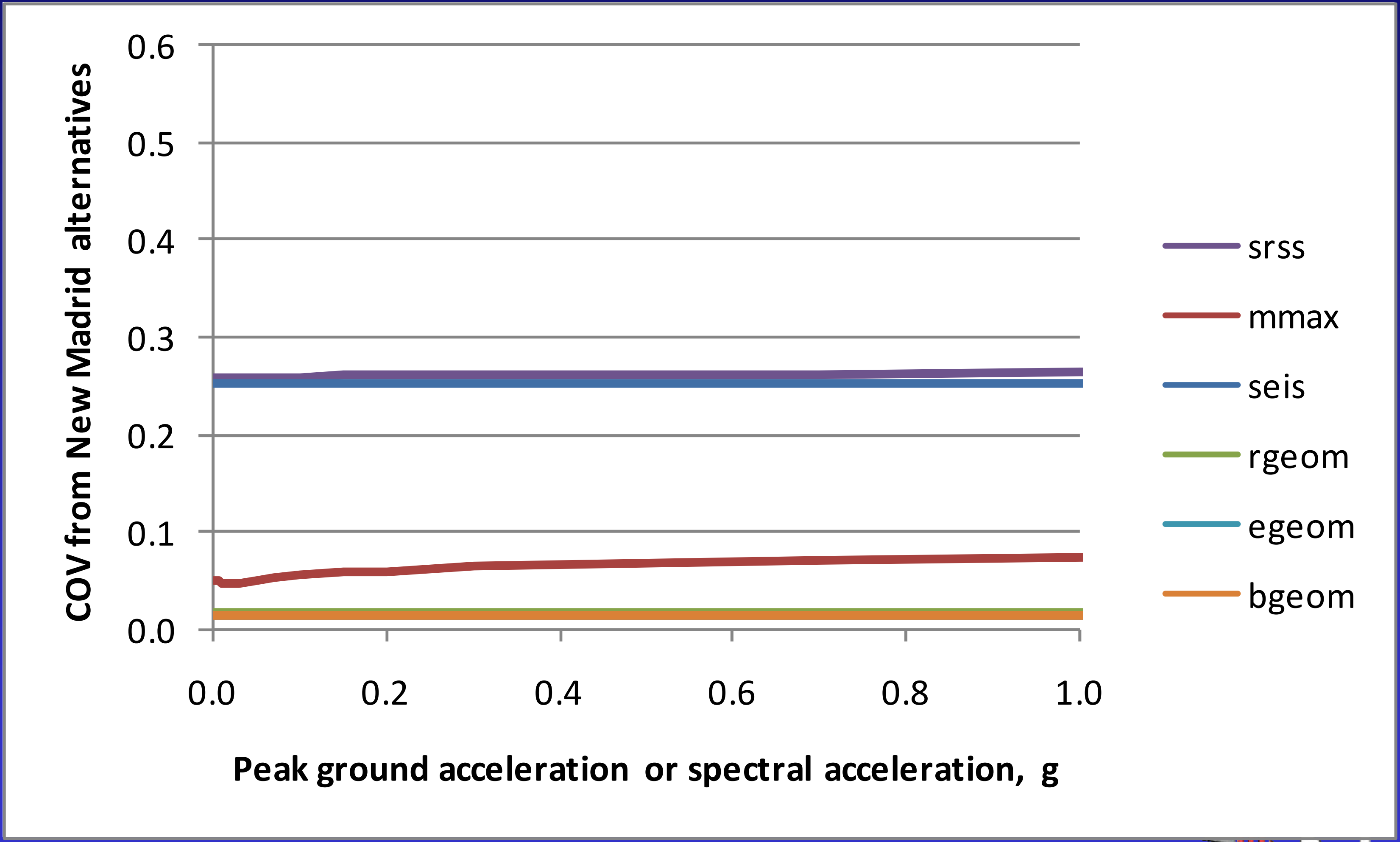
COVs from Charleston alternatives for 10 Hz, plotted vs hazard



COVs from Charleston alternatives for 1 Hz, plotted vs 1 Hz hazard



COVs of total hazard from New Madrid for 1 Hz, plotted vs 1 Hz amplitude



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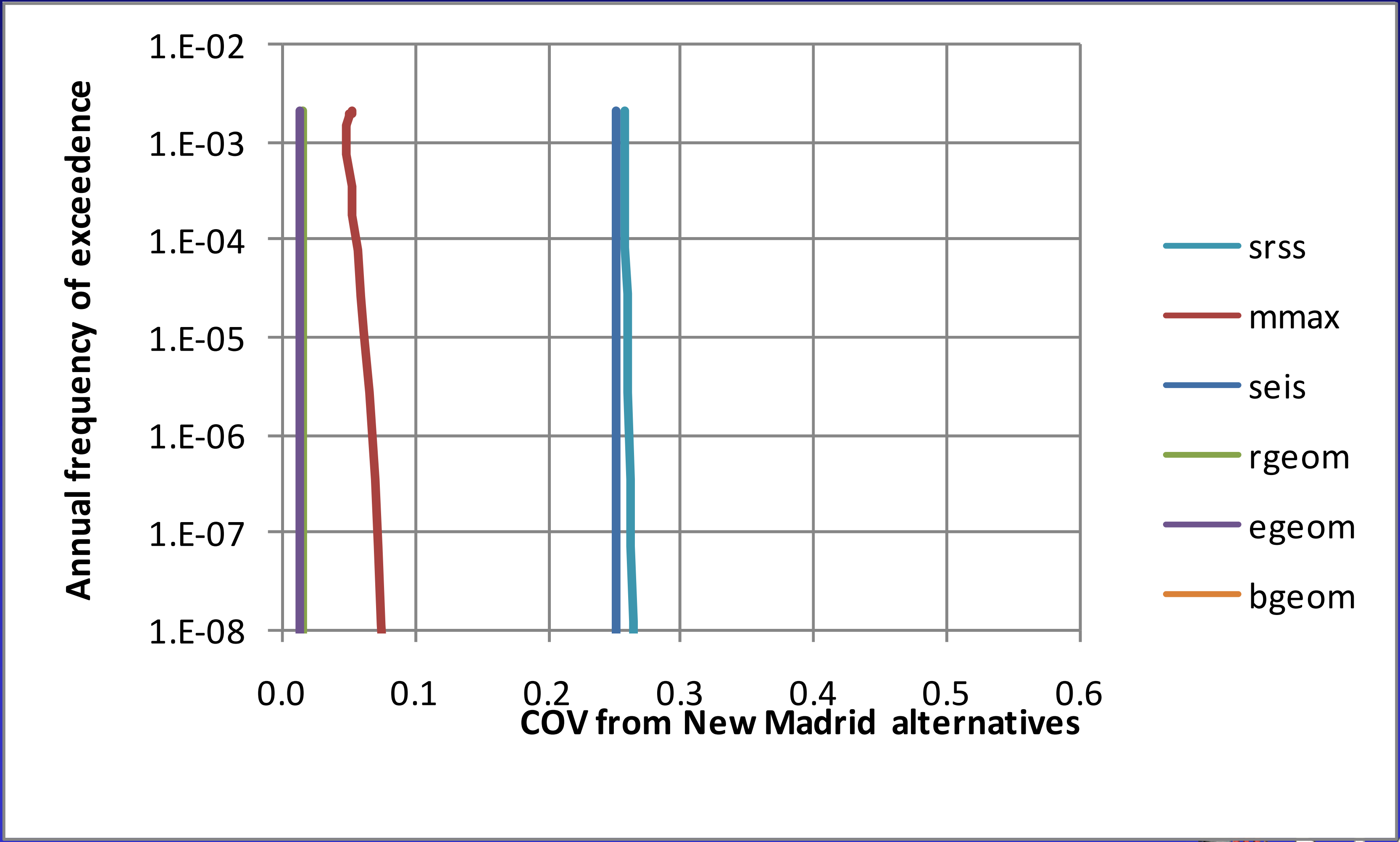
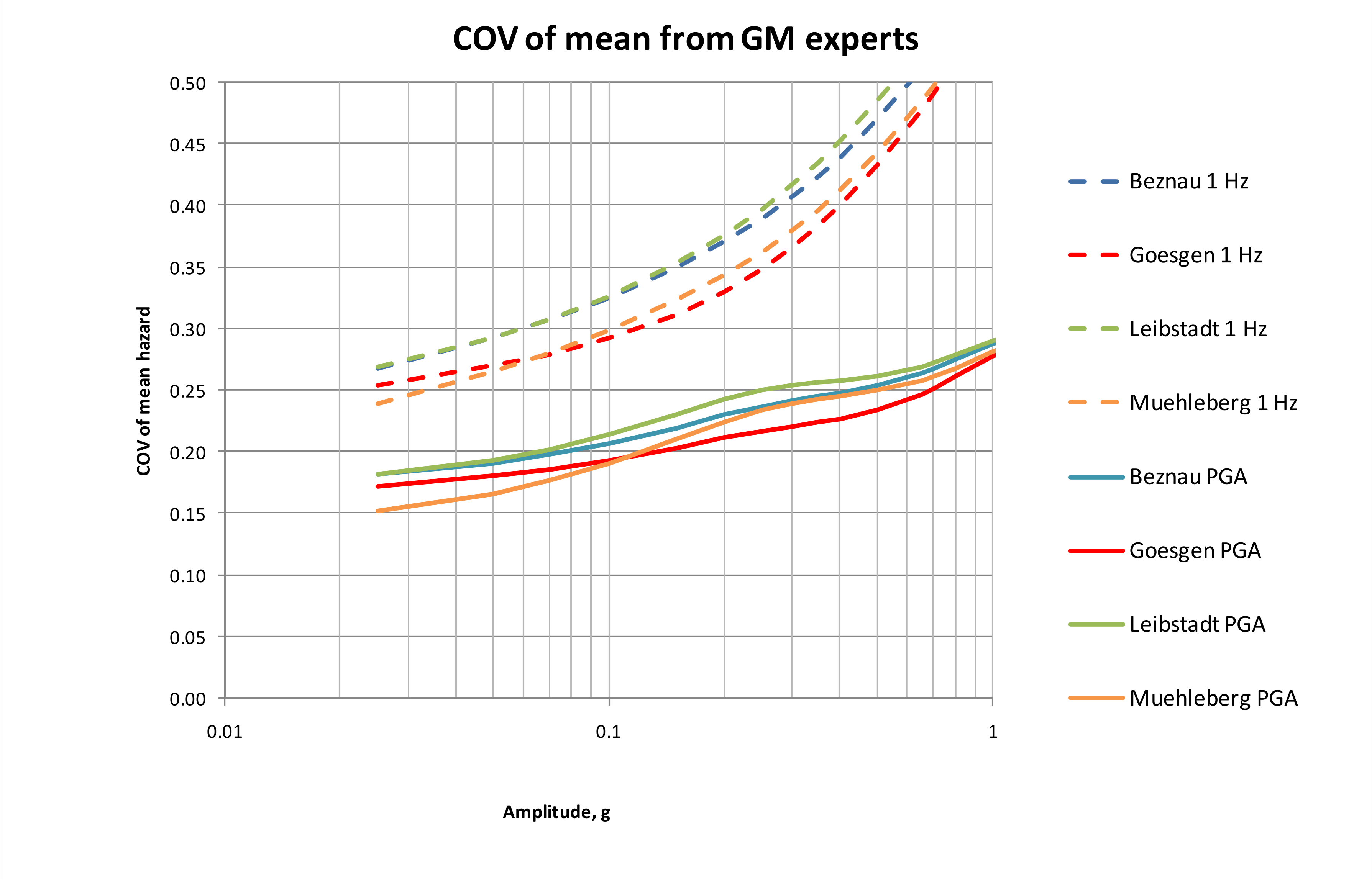
COVs of total hazard from New Madrid for 1 Hz, plotted vs 1 Hz hazard



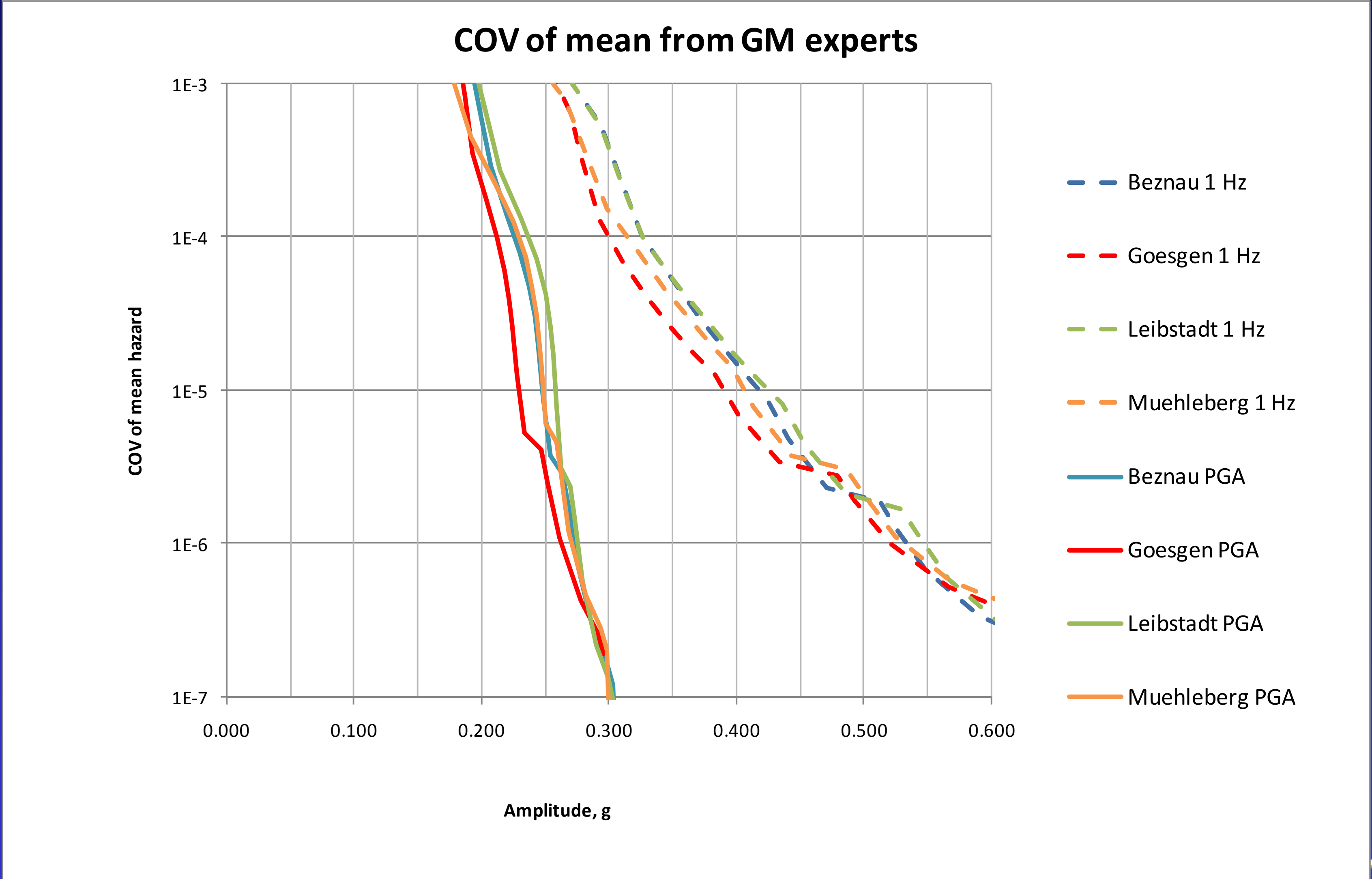
Earthquake magnitudes in New Madrid cluster model (Geomatrix, 2003)

Earthquake Rupture Set	Magnitude for Individual Faults			Weight
	New Madrid South	Reelfoot Thrust	New Madrid North	
1	7.8	7.7	7.5	0.01667
2	7.9	7.8	7.6	0.01667
3	7.6	7.8	7.5	0.25
4	7.2	7.4	7.2	0.0833
5	7.2	7.4	7.0	0.01667
6	7.3	7.5	7.0	0.01667

COV of mean hazard for PGA and 1 Hz SA resulting from alternative ground motion experts, from PEGASOS study



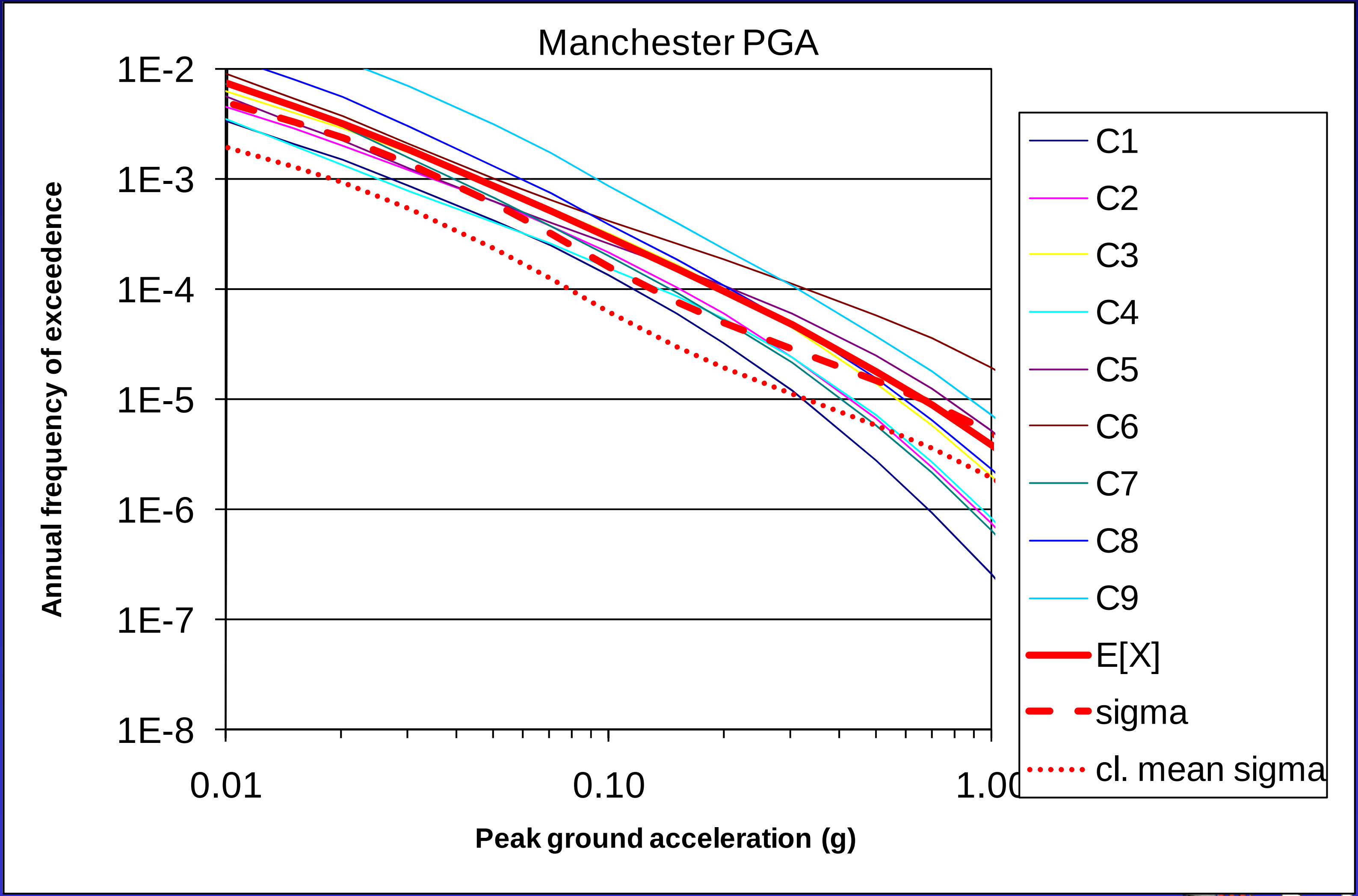
COV of mean hazard for PGA and 1 Hz SA resulting from alternative ground motion experts, from PEGASOS study



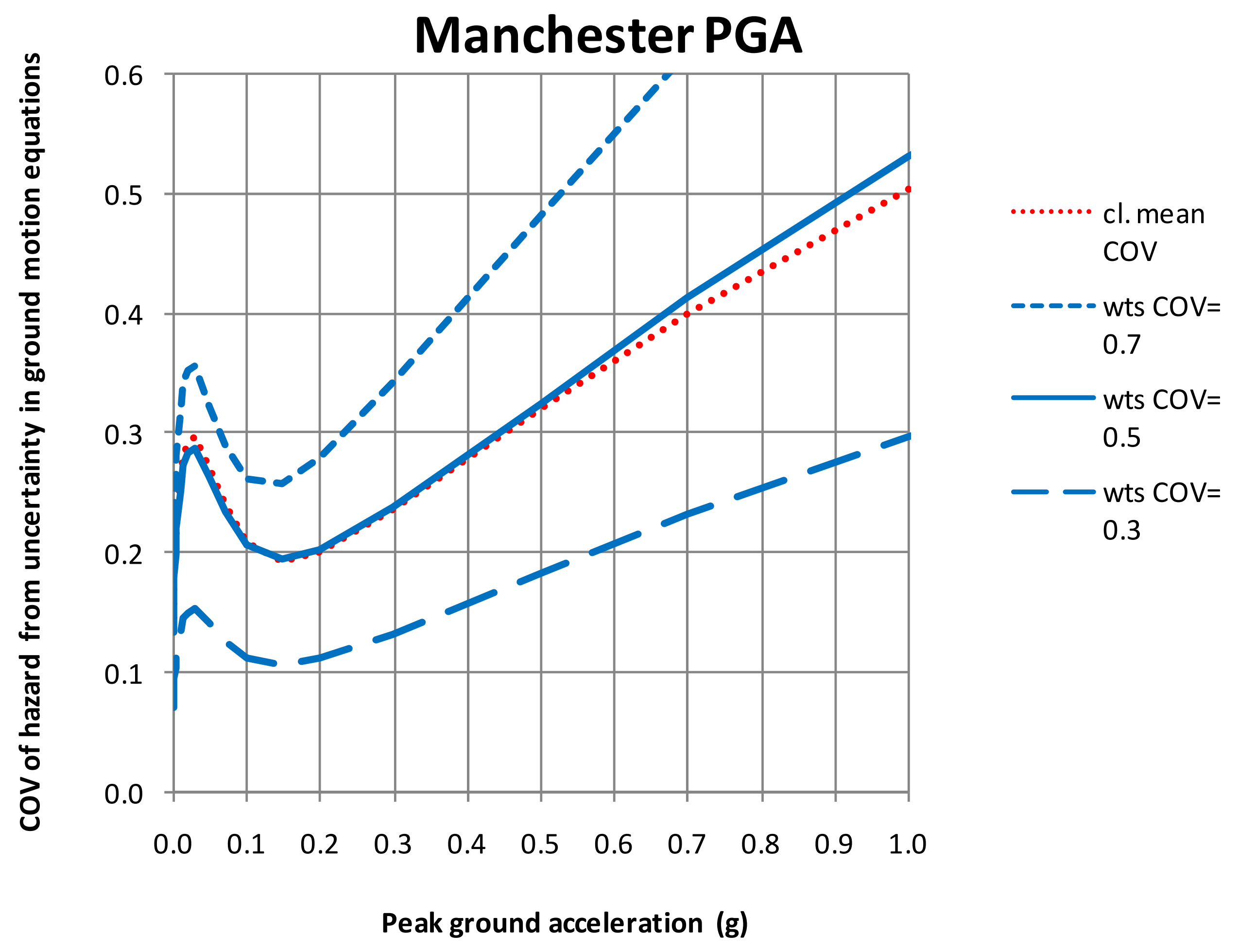
Basic weights given in EPRI (2004) for ground motion equations

Local sources			RLME sources		
Equation	Weight	Comment	Equation	Weight	Comment
C1	0.065	---	1	0.0509	---
C2	0.221	---	2	0.173	---
C3	0.065	wt equal to #1	3	0.0509	wt equal to #1
C4	0.0737	---	4	0.0577	---
C5	0.251	---	5	0.197	---
C6	0.0737	wt equal to #4	6	0.0577	wt equal to #4
C7	0.0463	---	7	0.0363	---
C8	0.158	---	8	0.124	---
C9	0.0463	wt equal to #7	9	0.0363	wt equal to #7
---	(not used)	---	10	0.0401	---
---	(not used)	---	11	0.137	---
---	(not used)	---	12	0.0401	wt equal to #10

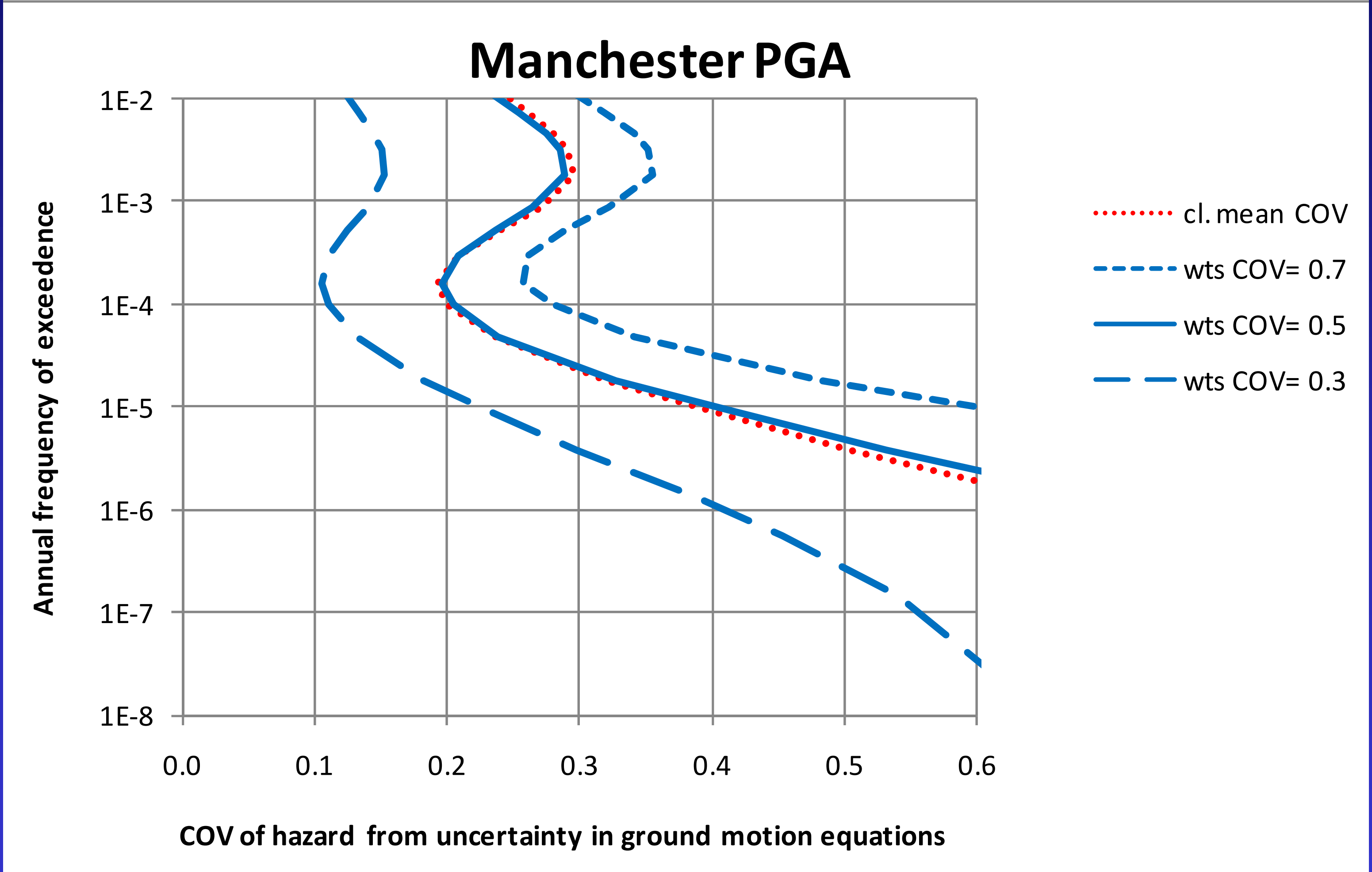
PGA hazard curves for Manchester test site



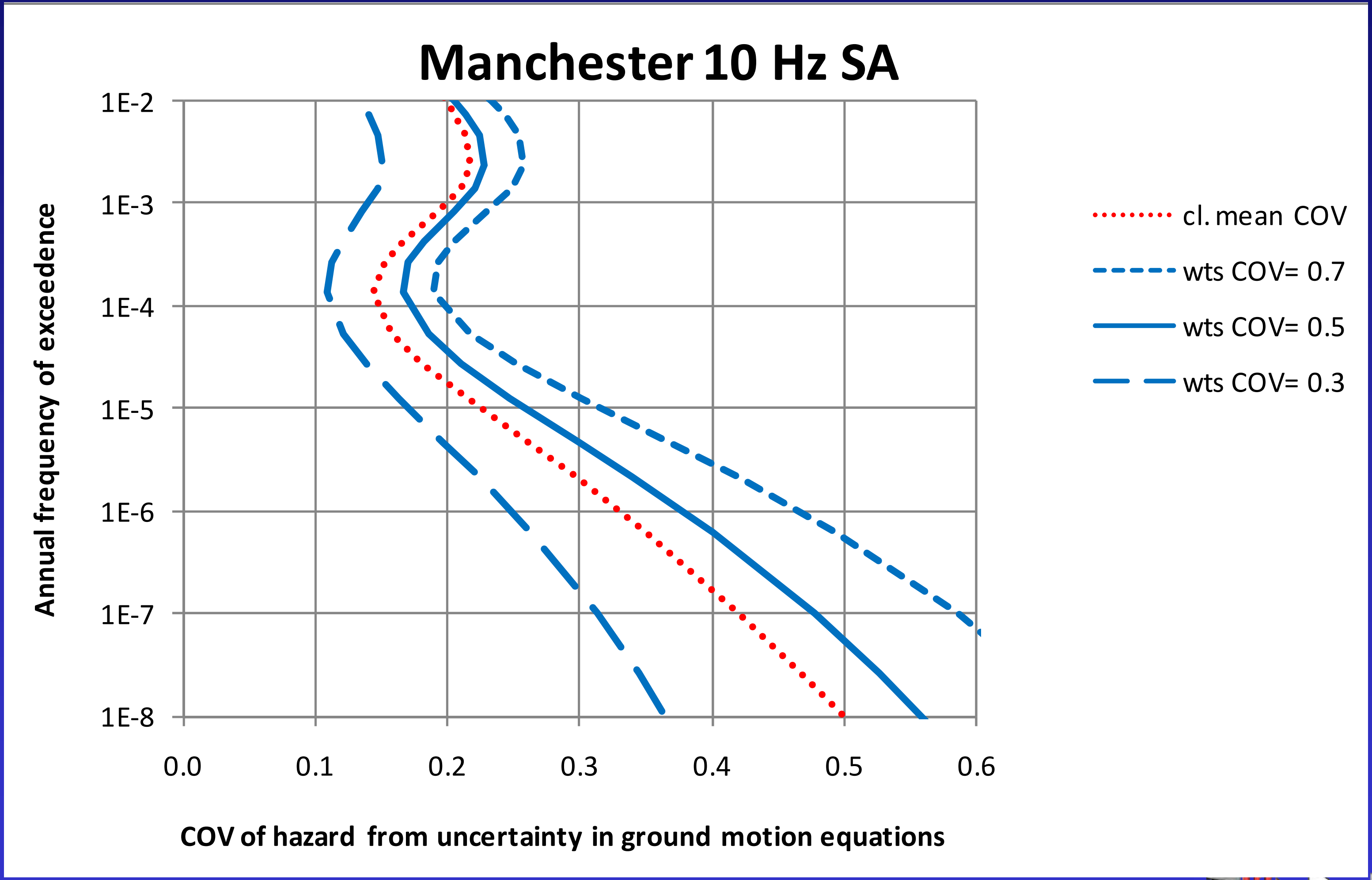
COV$_{HAZ}$ of PGA hazard at Manchester site from ground motion equations vs. PGA



COV of PGA hazard at Manchester site from ground motion equations vs. hazard



COV of 10 Hz hazard at Manchester site from ground motion equations vs. hazard



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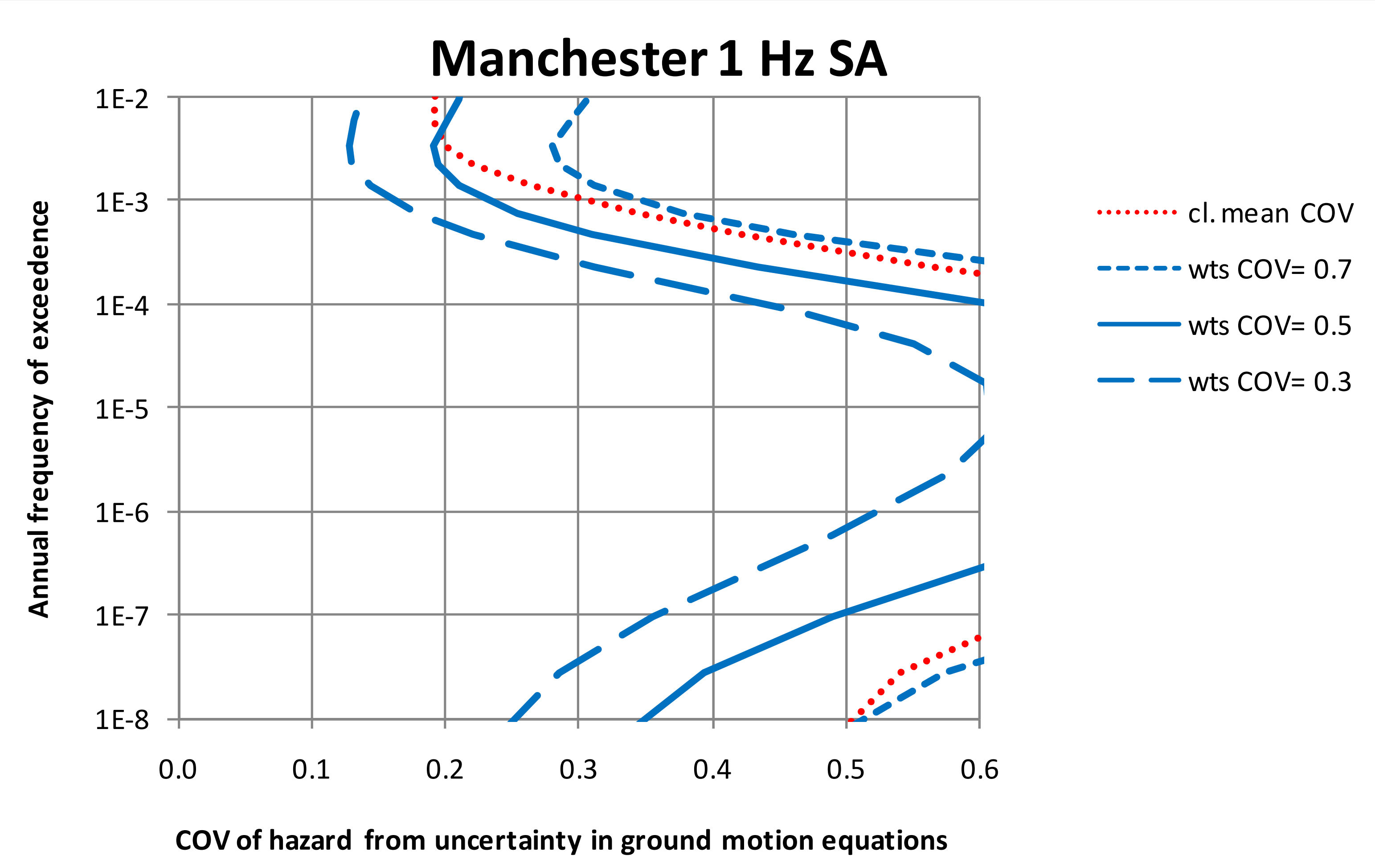
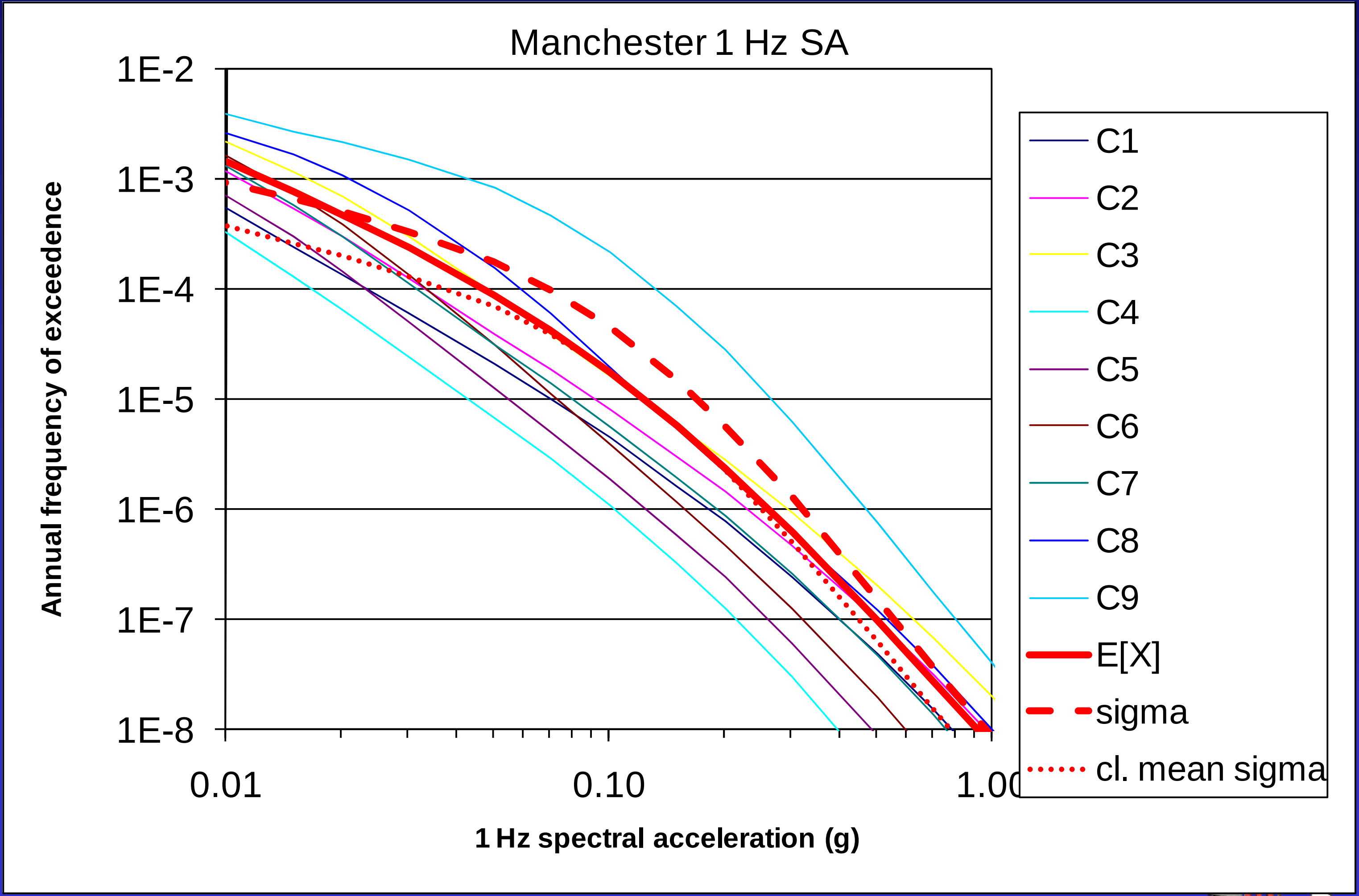
COV of 1 Hz hazard at Manchester site from ground motion equations vs. hazard



1 Hz spectral acceleration hazard curves for Manchester test site



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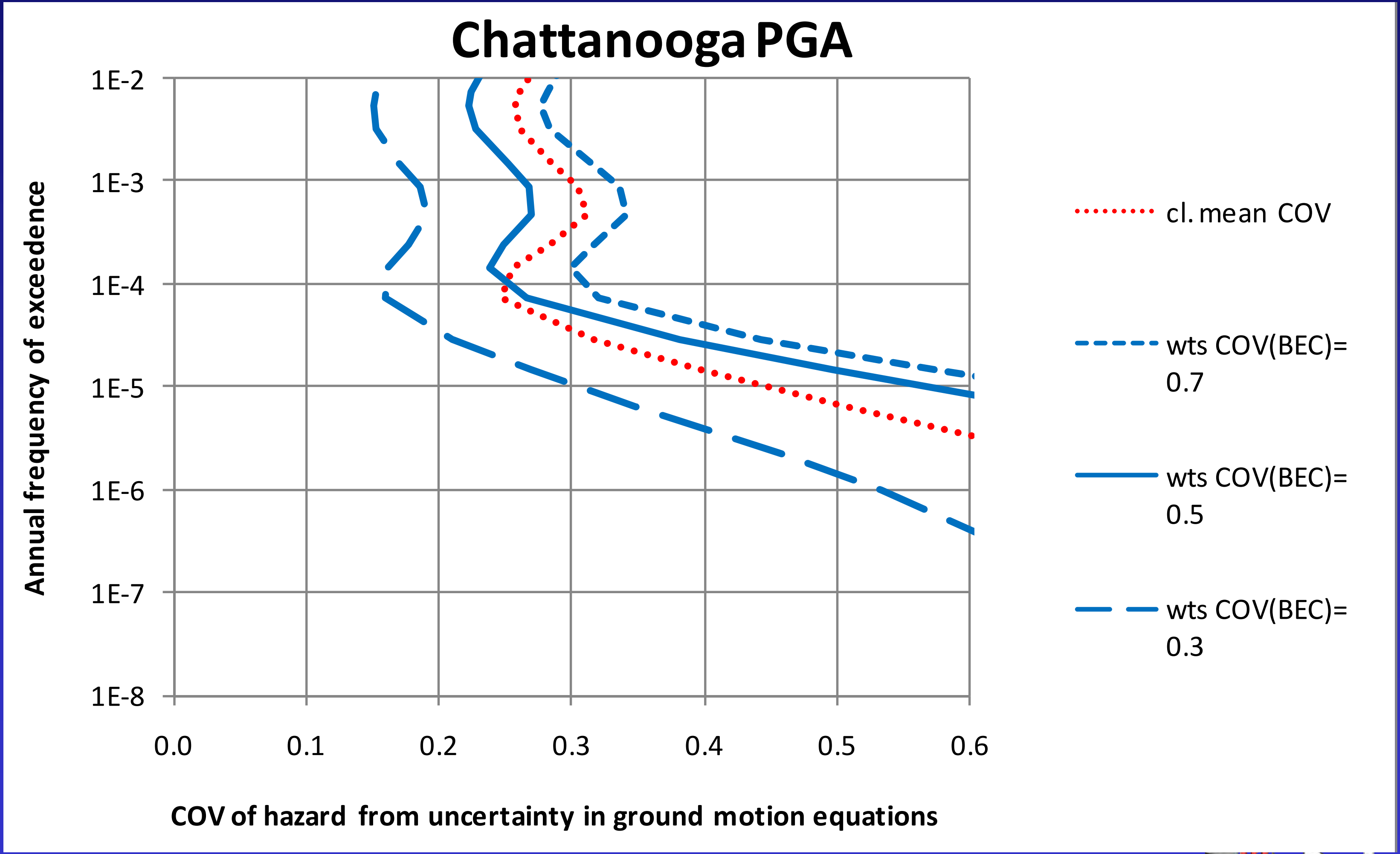
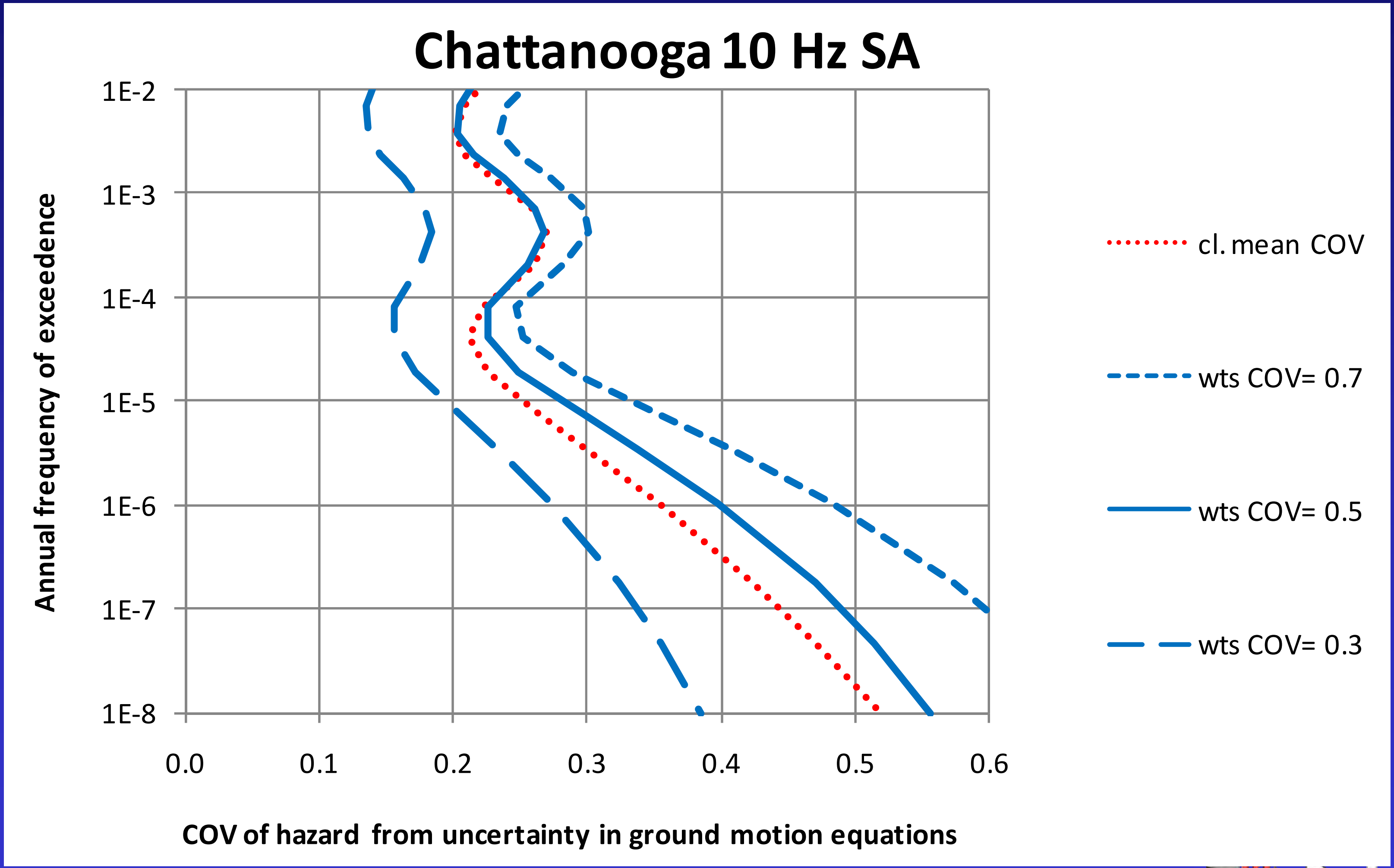
COV_{HAZ} of PGA hazard at Chattanooga site from ground motion equations vs. hazard

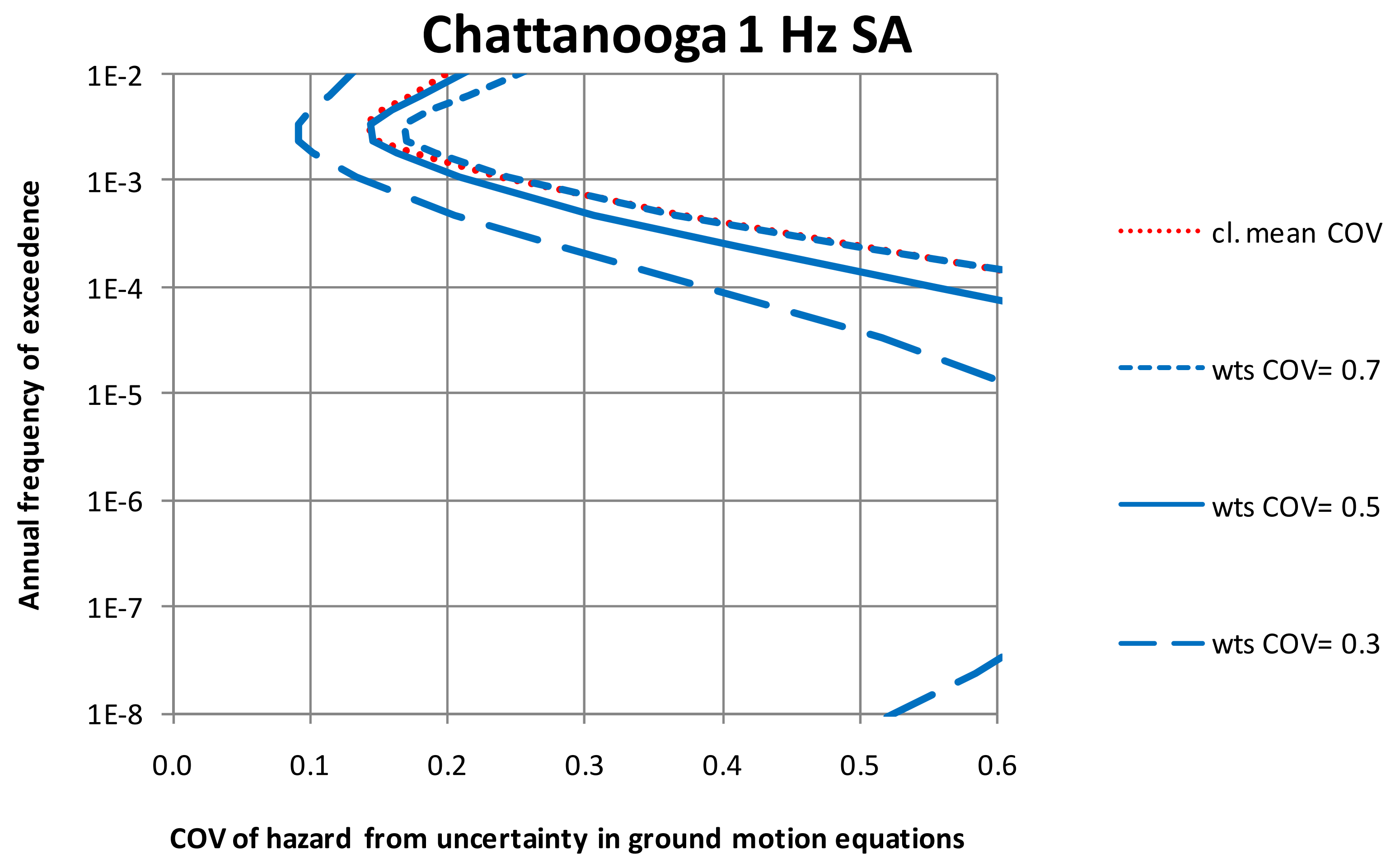


RISK ENGINEERING

COV$_{HAZ}$ of 10 Hz hazard at Chattanooga site from ground motion equations vs. hazard



COV_{HAZ} of 1 Hz hazard at Chattanooga site from ground motion equations vs. hazard



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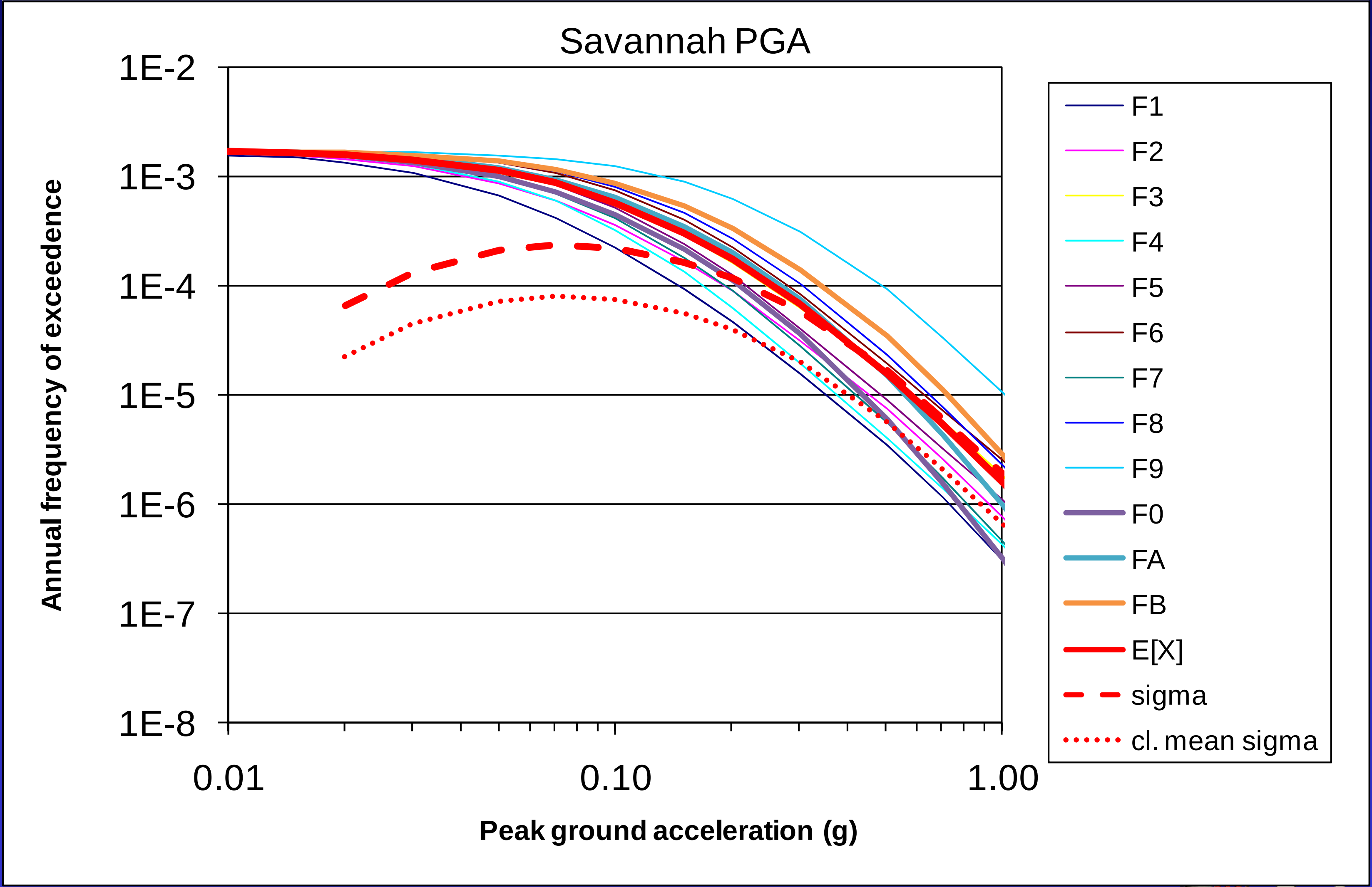
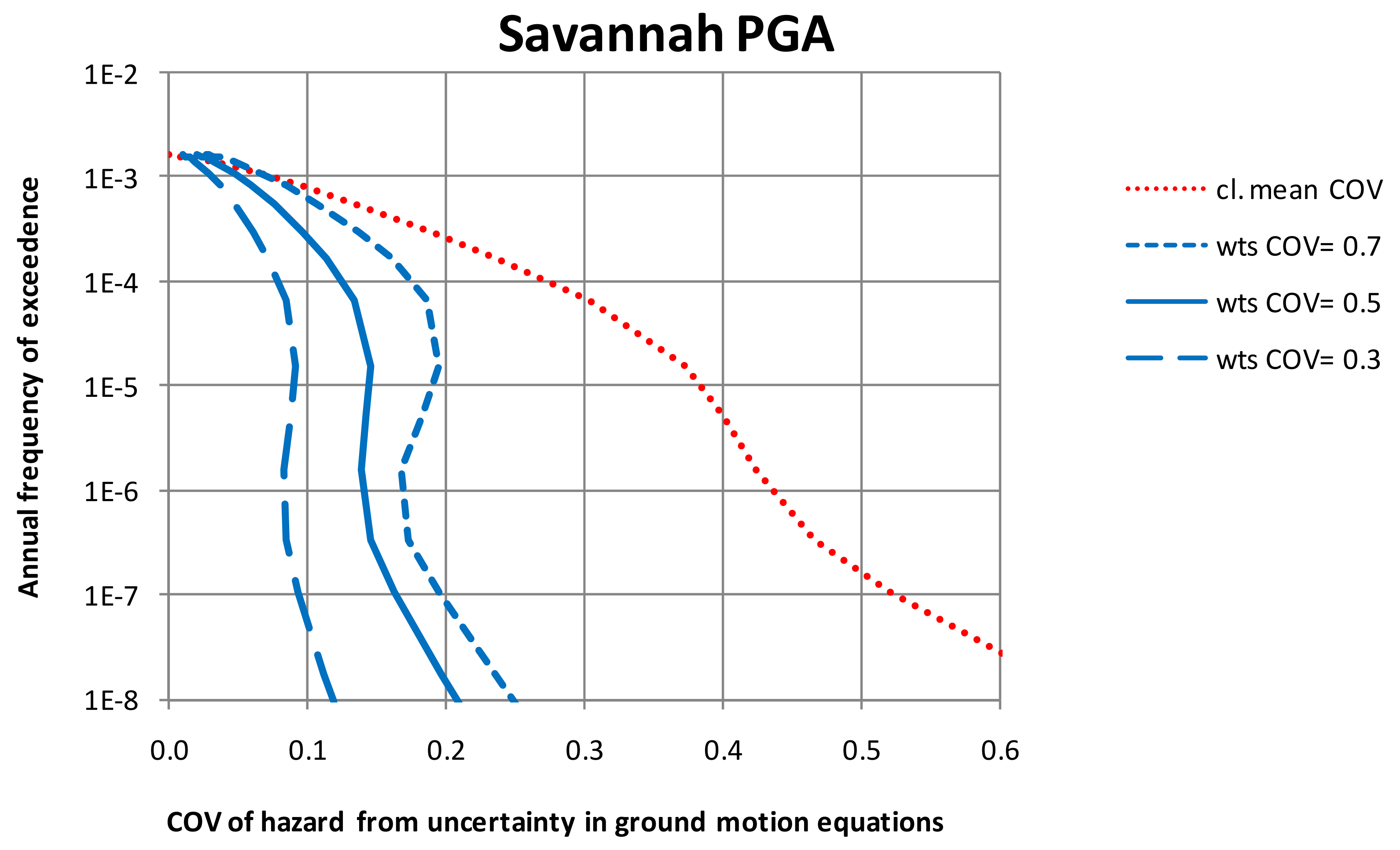
PGA hazard curves for Savannah test site



COV of PGA hazard at Savannah site from ground motion equations vs. hazard



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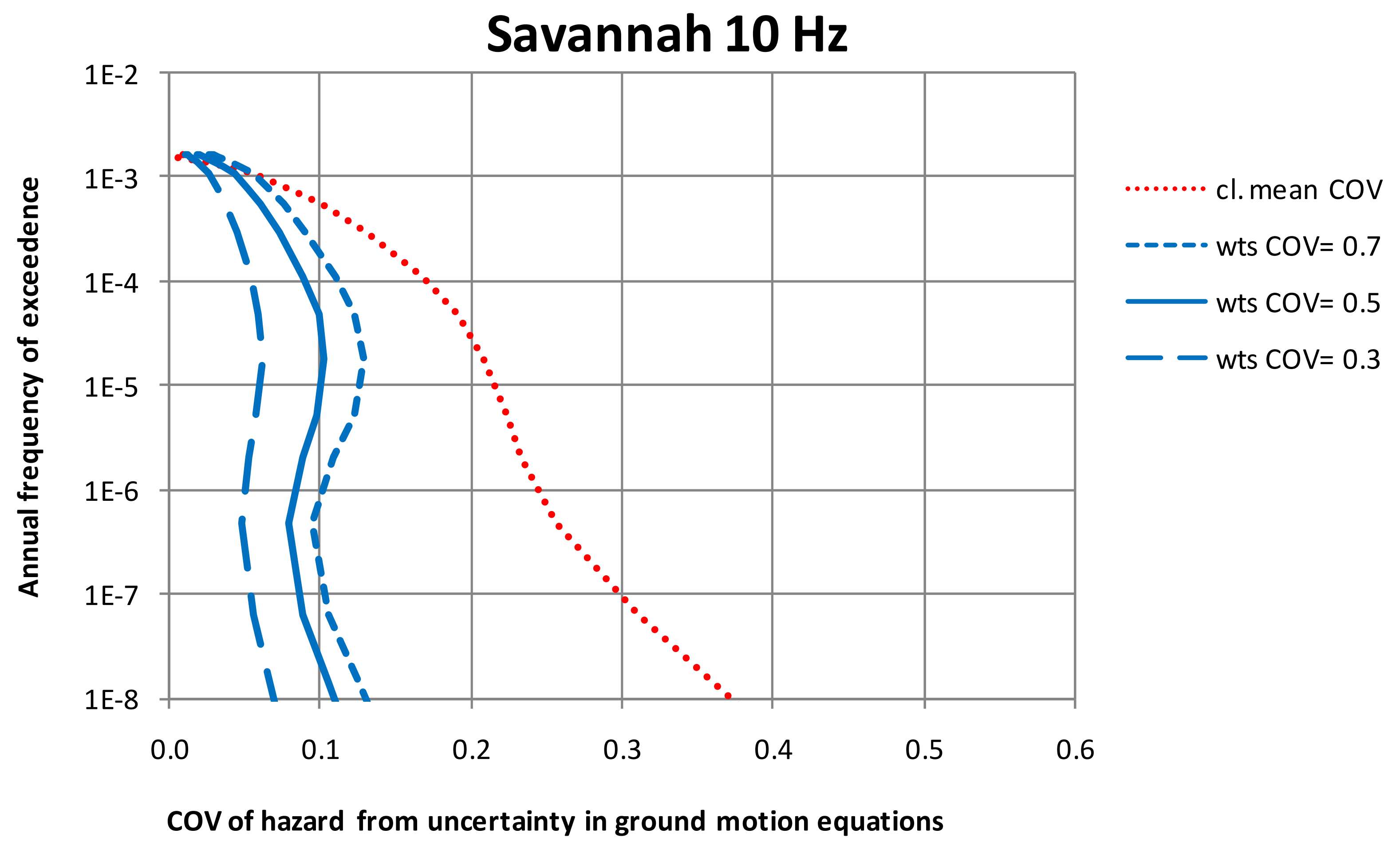
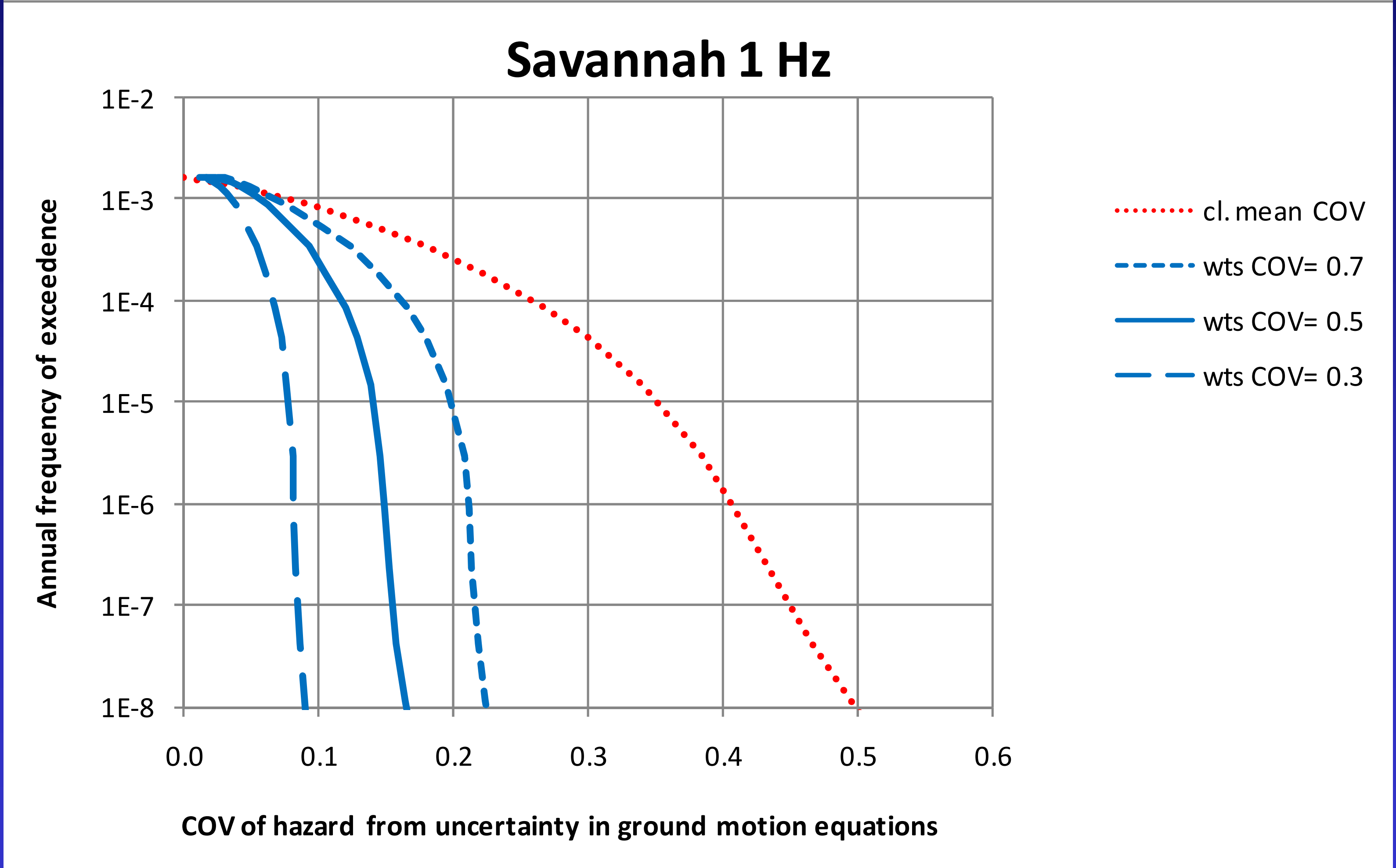
COV of 10 Hz hazard at Savannah site from ground motion equations vs. hazard



COV_{HAZ} of 1 Hz hazard at Savannah site from ground motion equations vs. hazard



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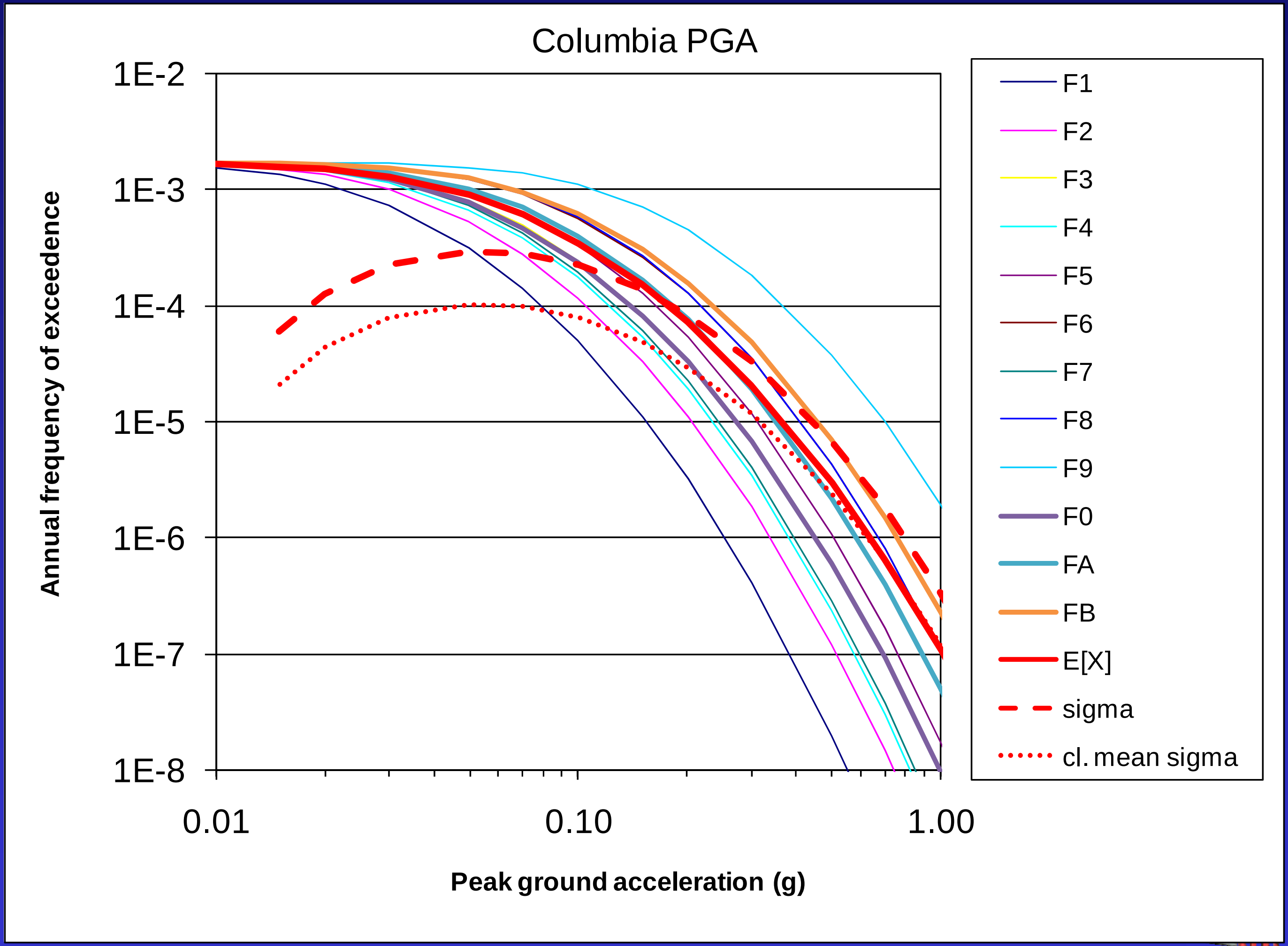
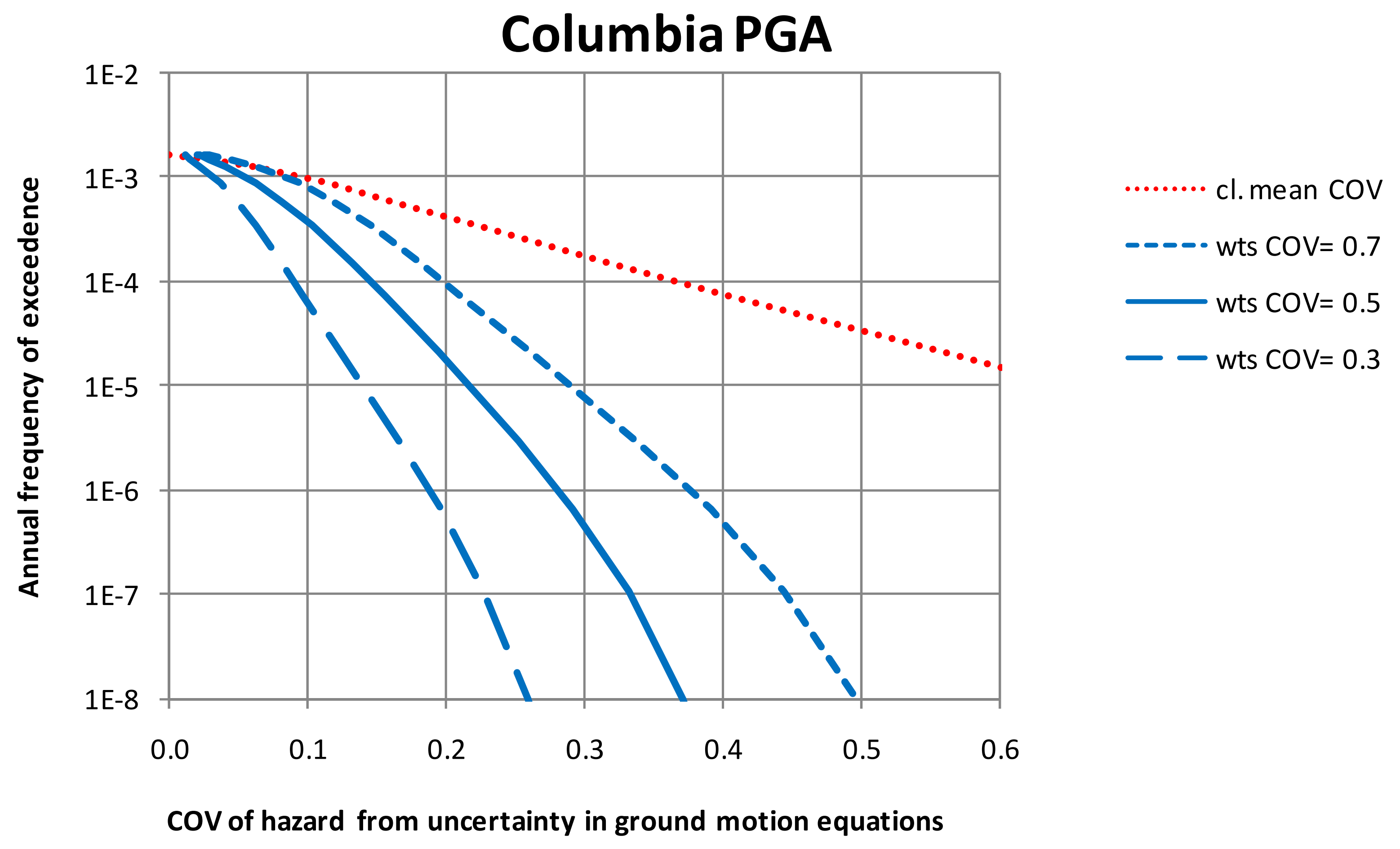
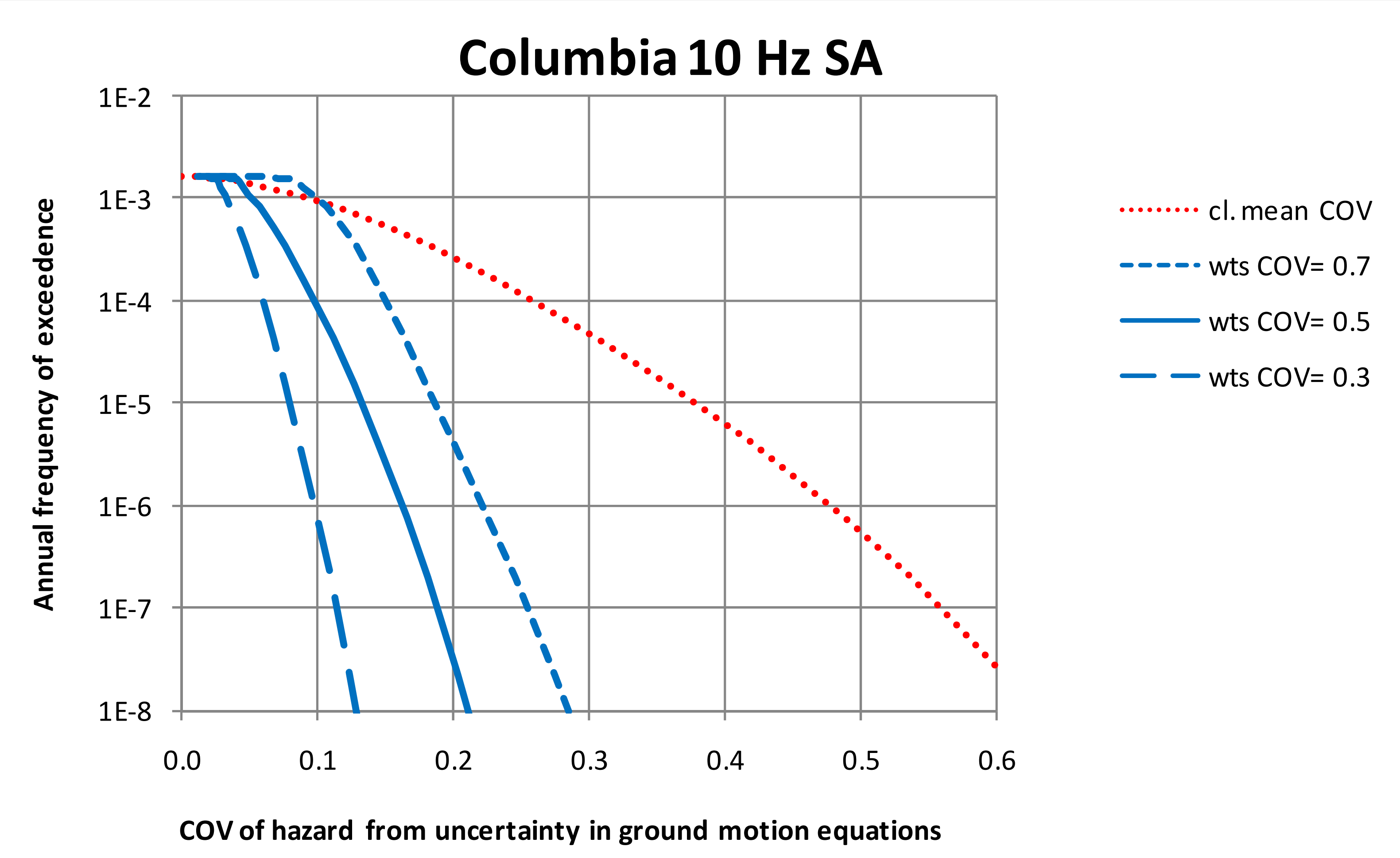
PGA hazard curves for Columbia, South Carolina site



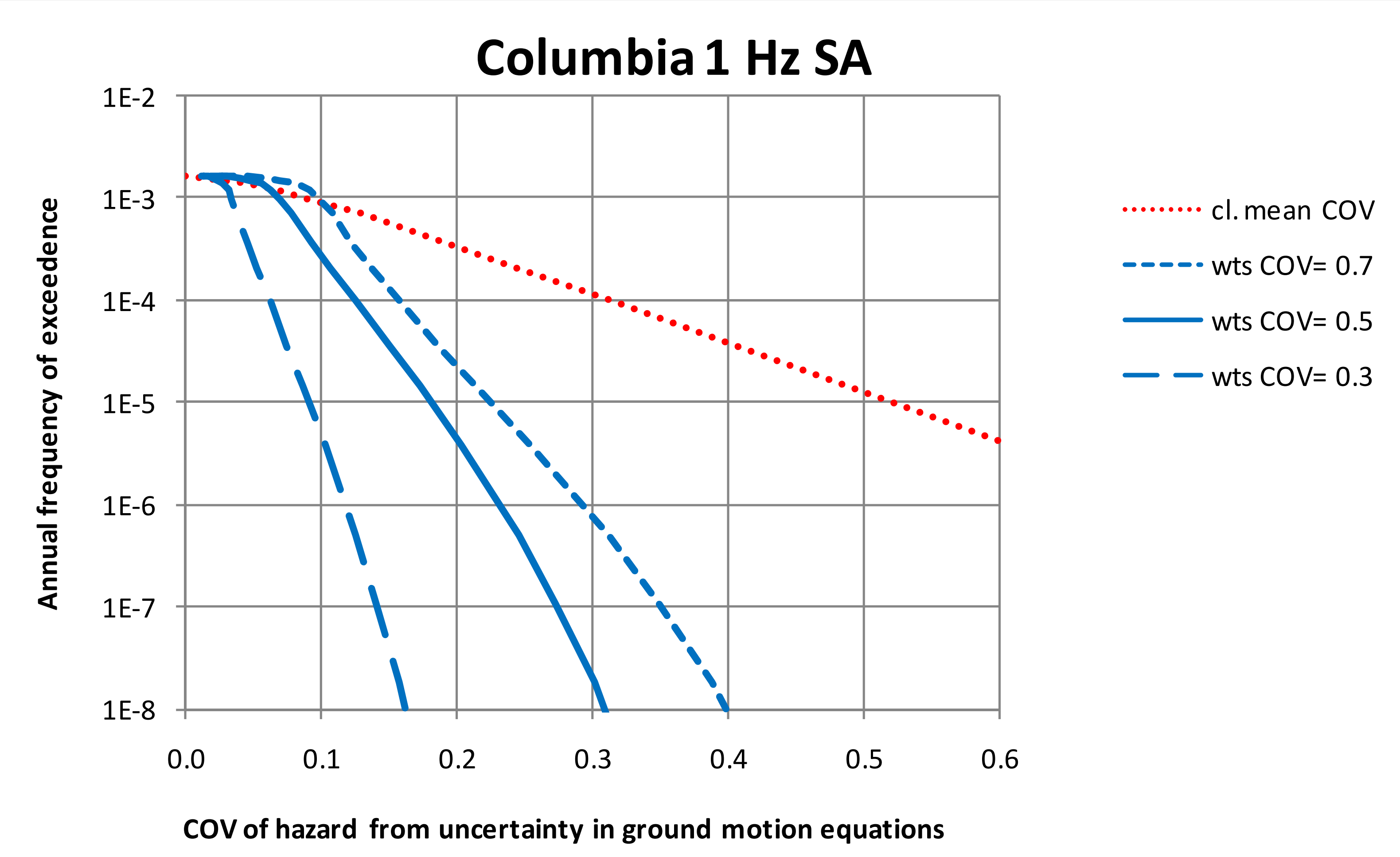
$\mathrm{COV}_{\mathrm{HAZ}}$ of PGA hazard at Columbia from ground motion equations vs. hazard



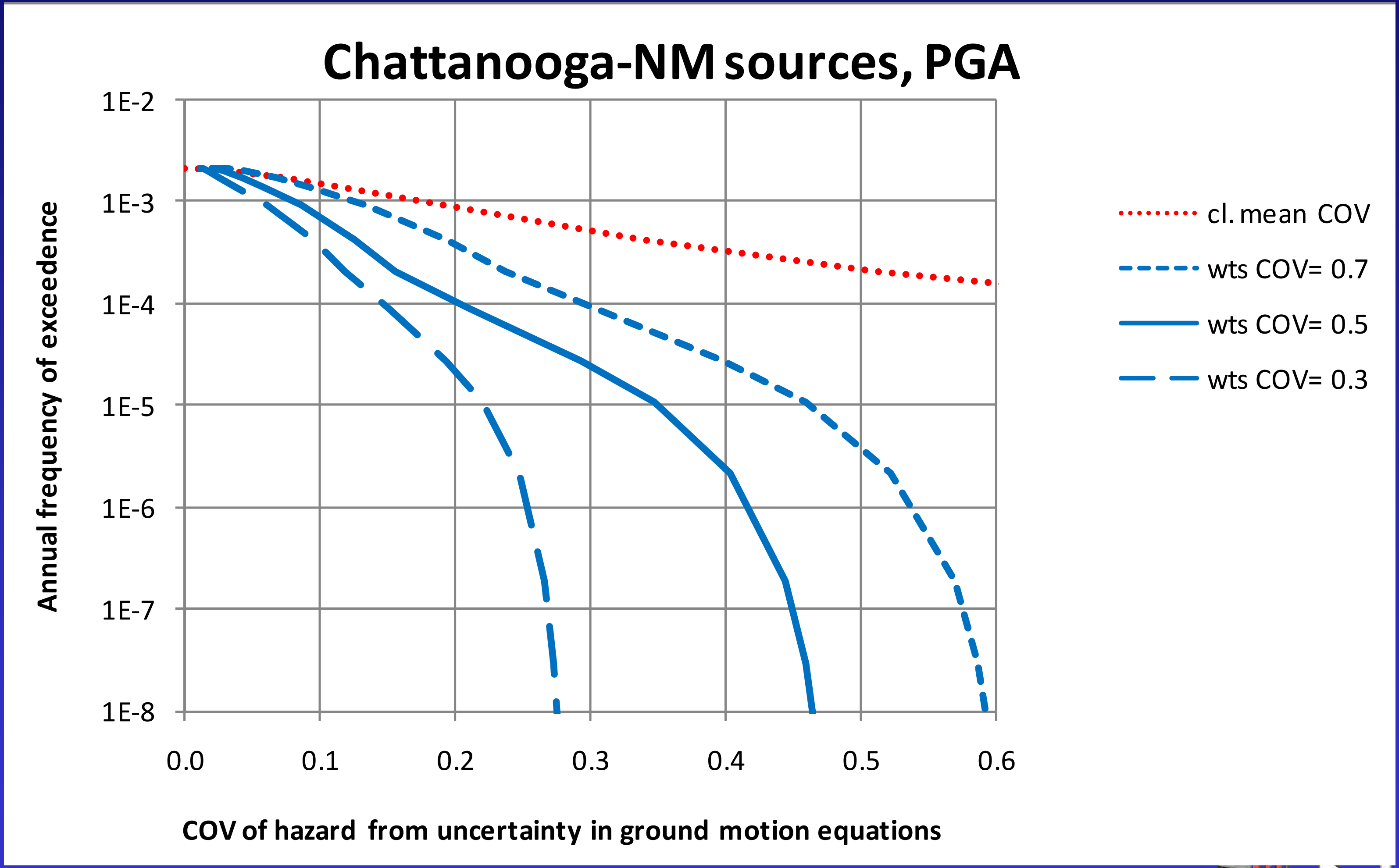
$\mathrm{COV}_{\mathrm{HAZ}}$ of 10 Hz hazard at Columbia from ground motion equations vs. hazard



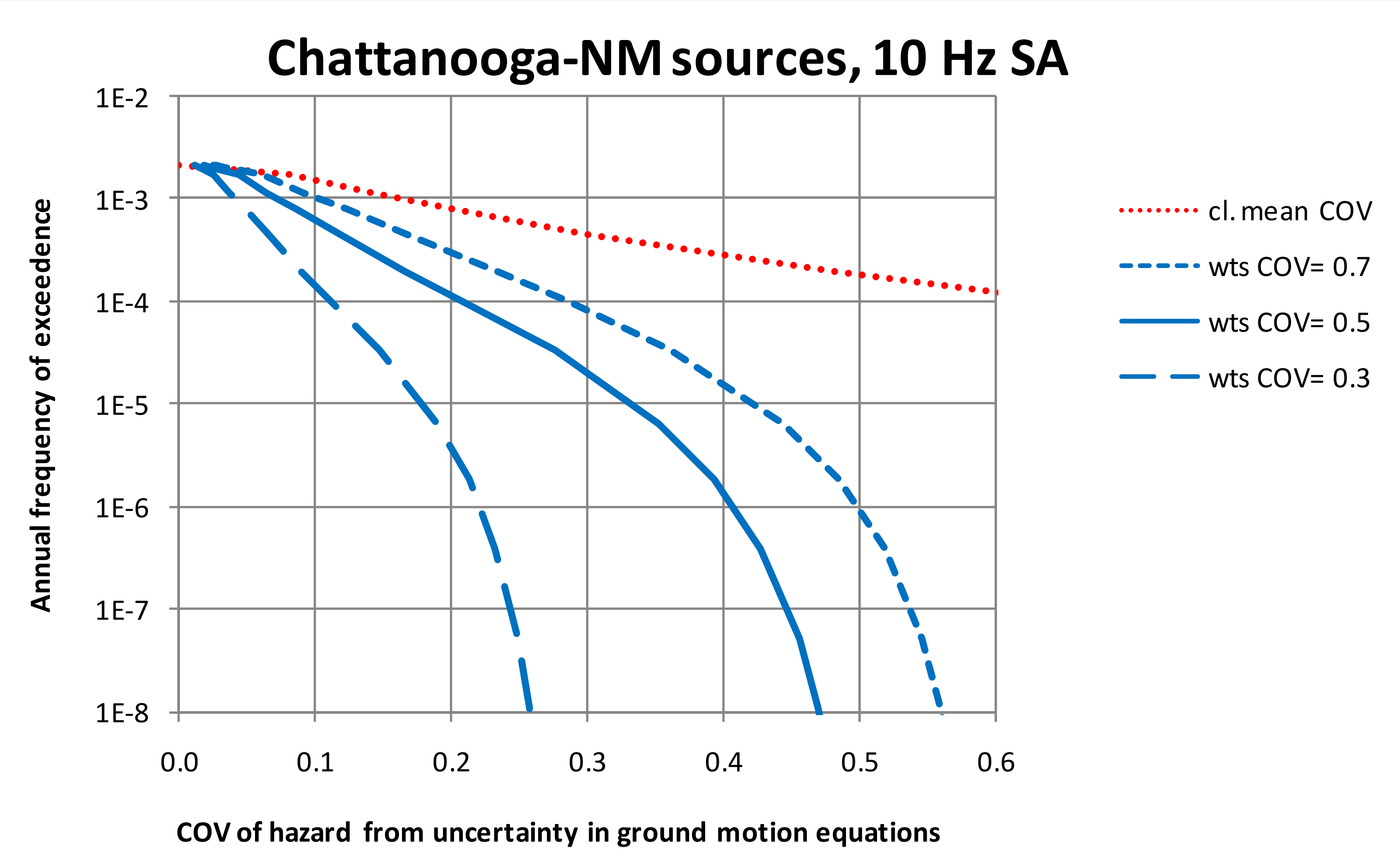
COV_{HAZ} of 1 Hz hazard at Columbia from ground motion equations vs. hazard



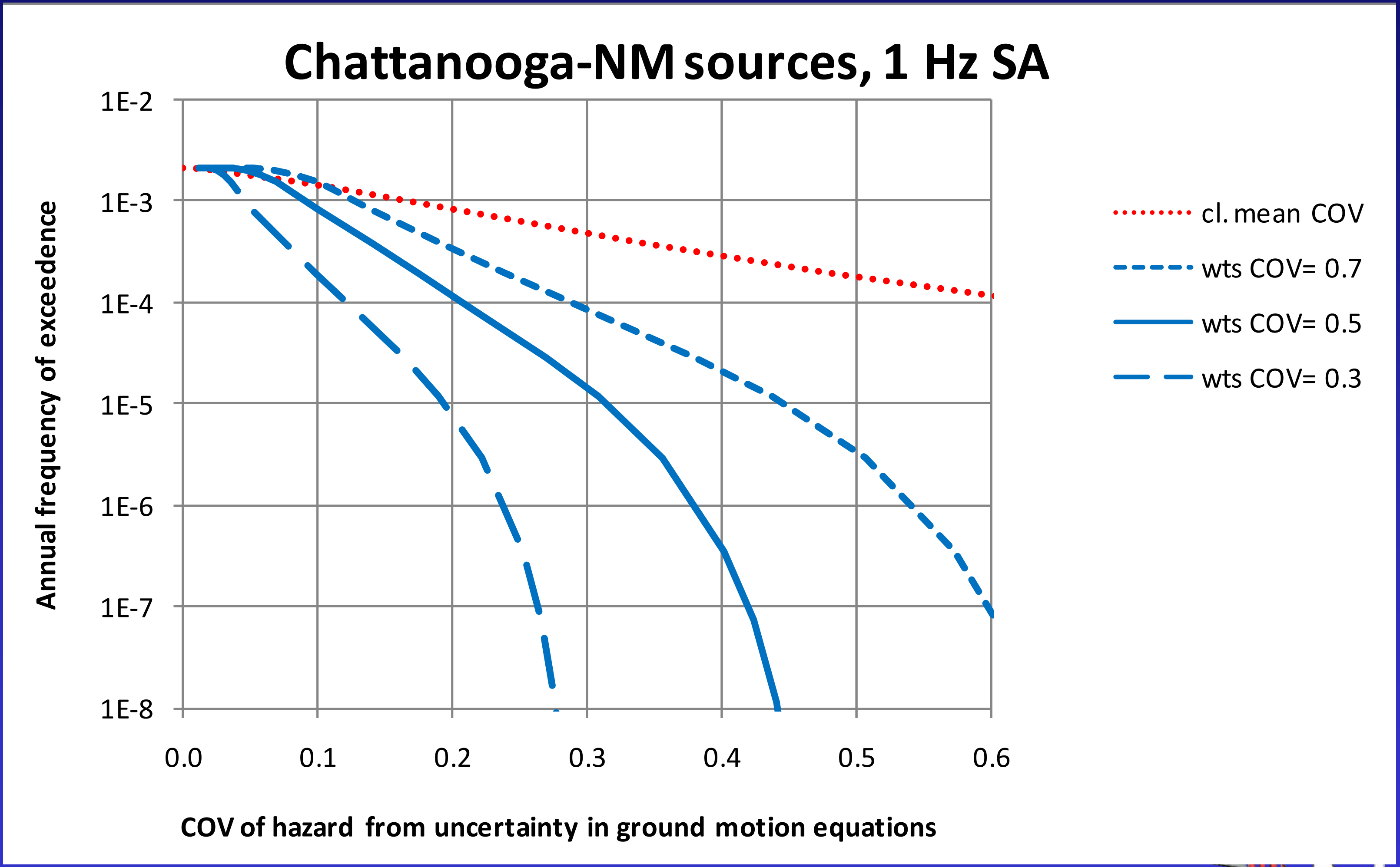
COV_{HAZ} of PGA hazard at Chattanooga (New Madrid only) vs. hazard



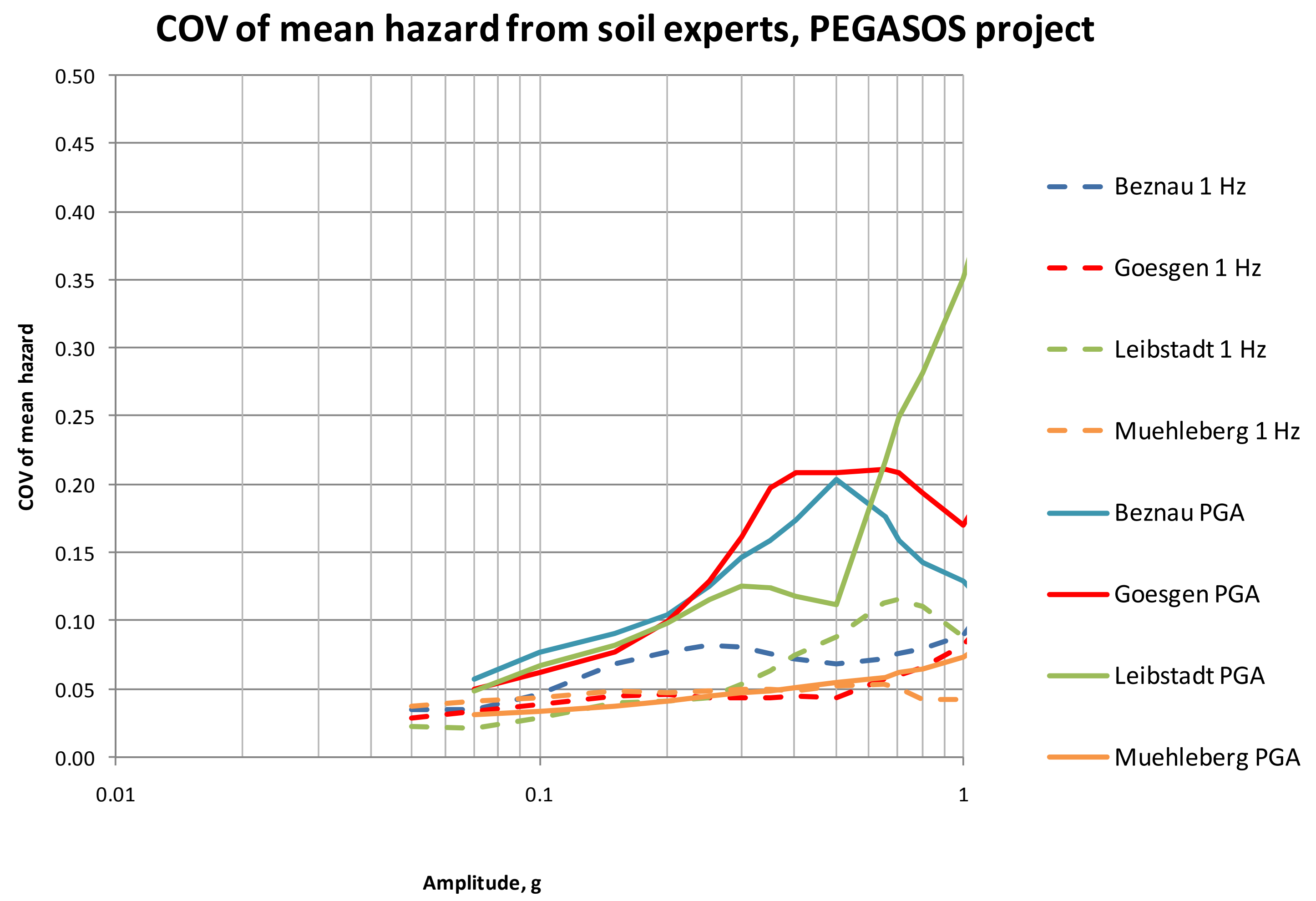
COV_{HAZ} of 10 Hz hazard at Chattanooga (New Madrid only) vs. hazard



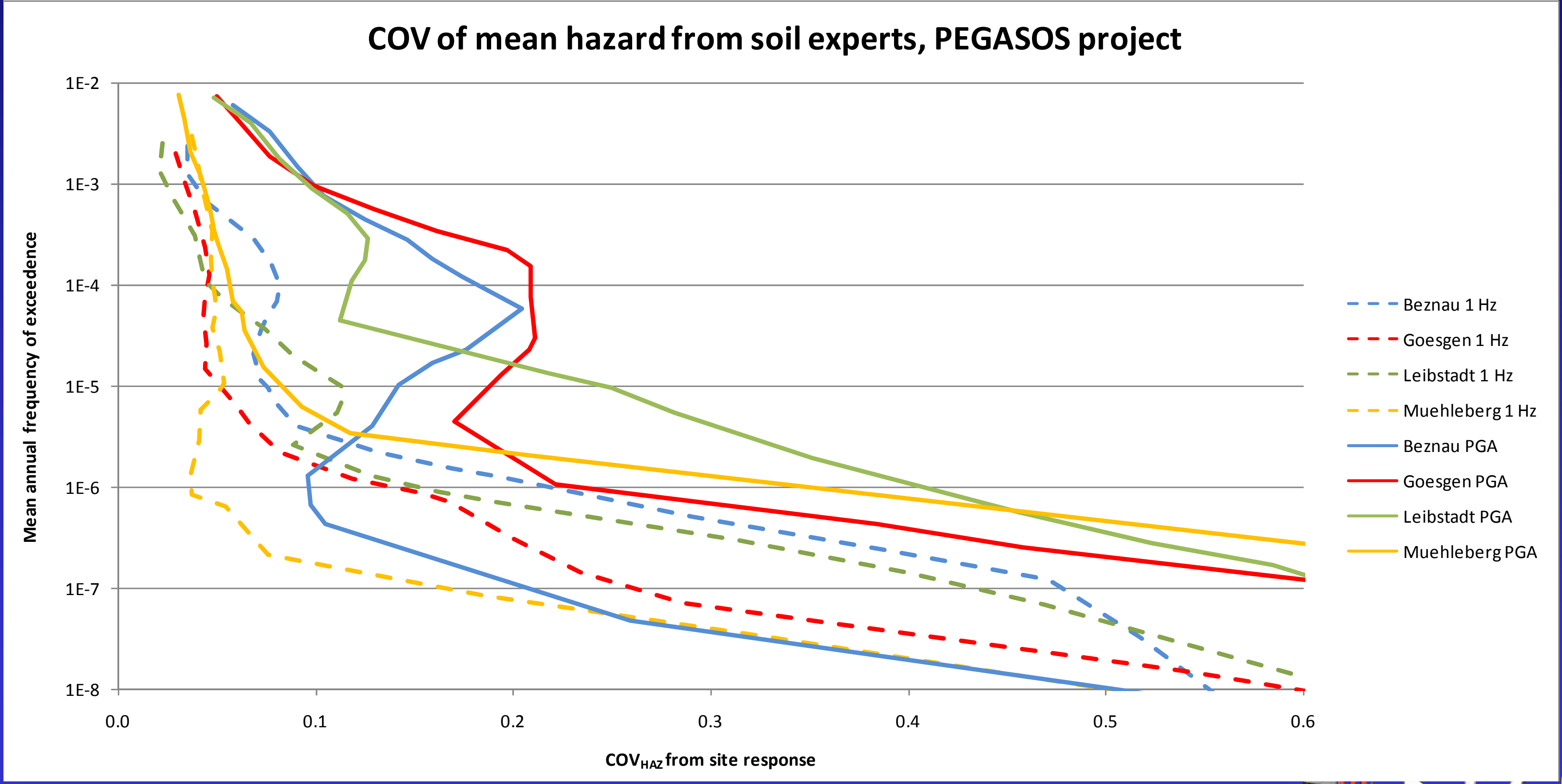
COV_{HAZ} of 1 Hz hazard at Chattanooga (New Madrid only) vs. hazard



COV_{HAZ} of mean hazard from soil experts vs. PGA and 1 Hz spectral acceleration, PEGASOS project



COV_{HAZ} of mean hazard from soil experts vs. mean hazard, for PGA and 1 Hz SA, PEGASOS project



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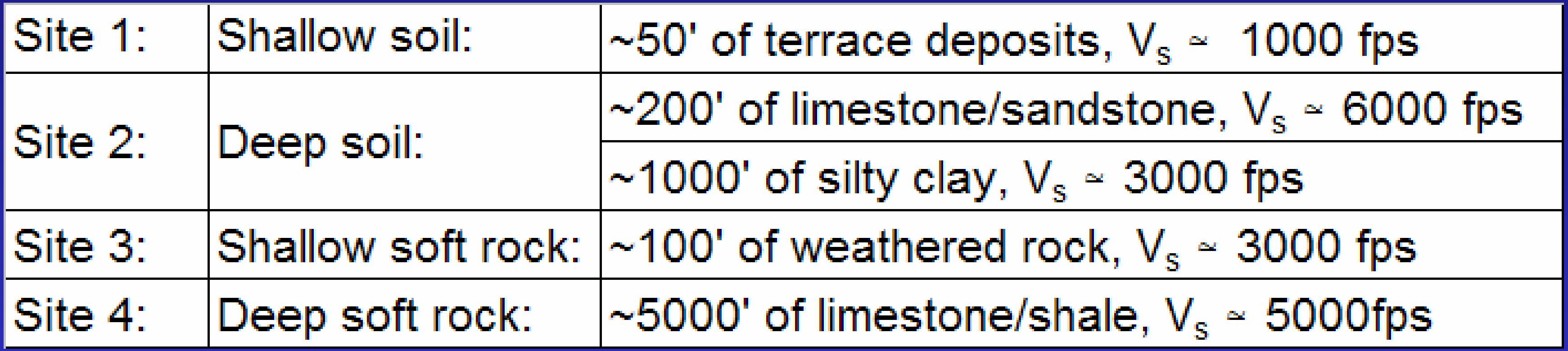
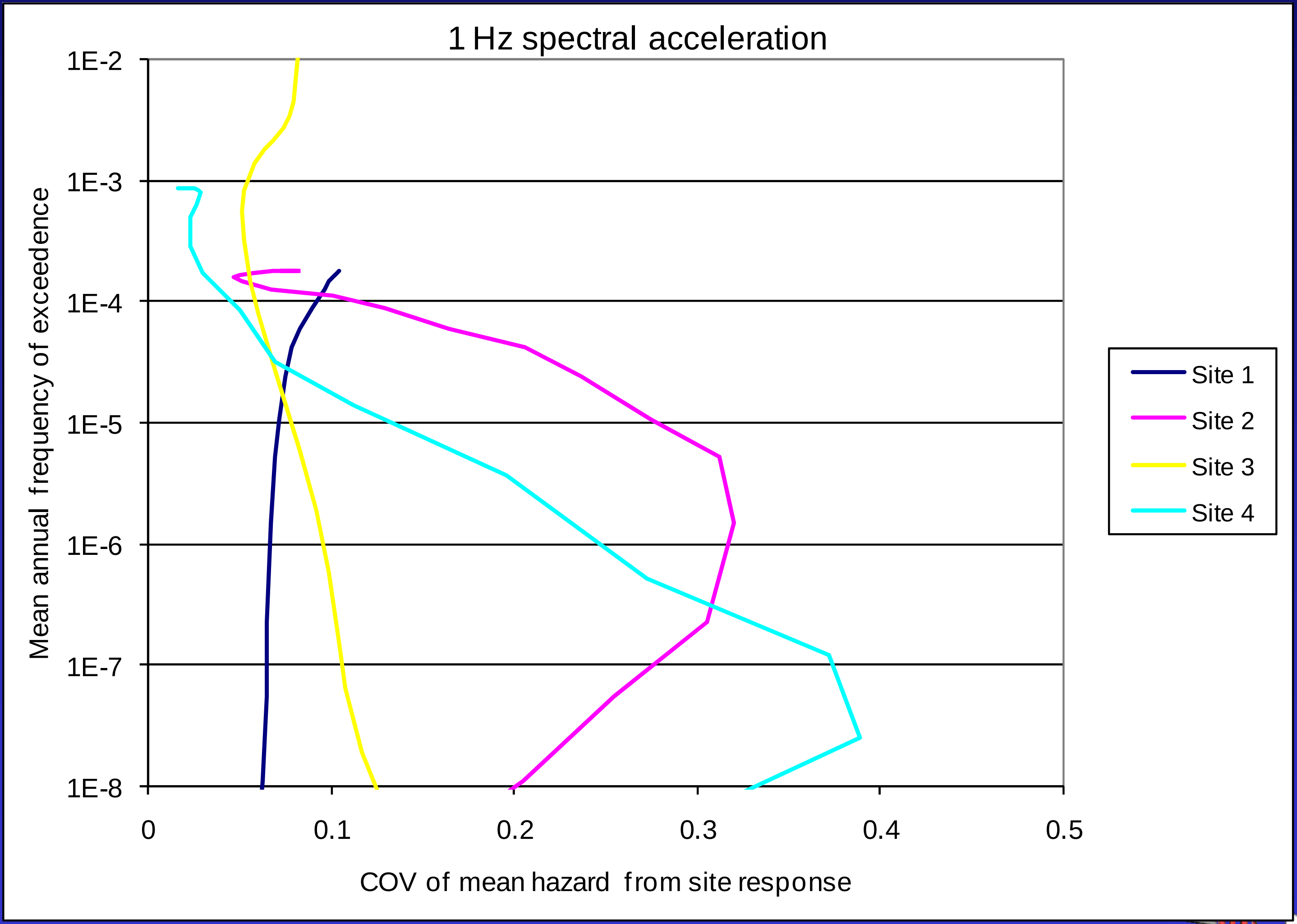
General description of site characteristics

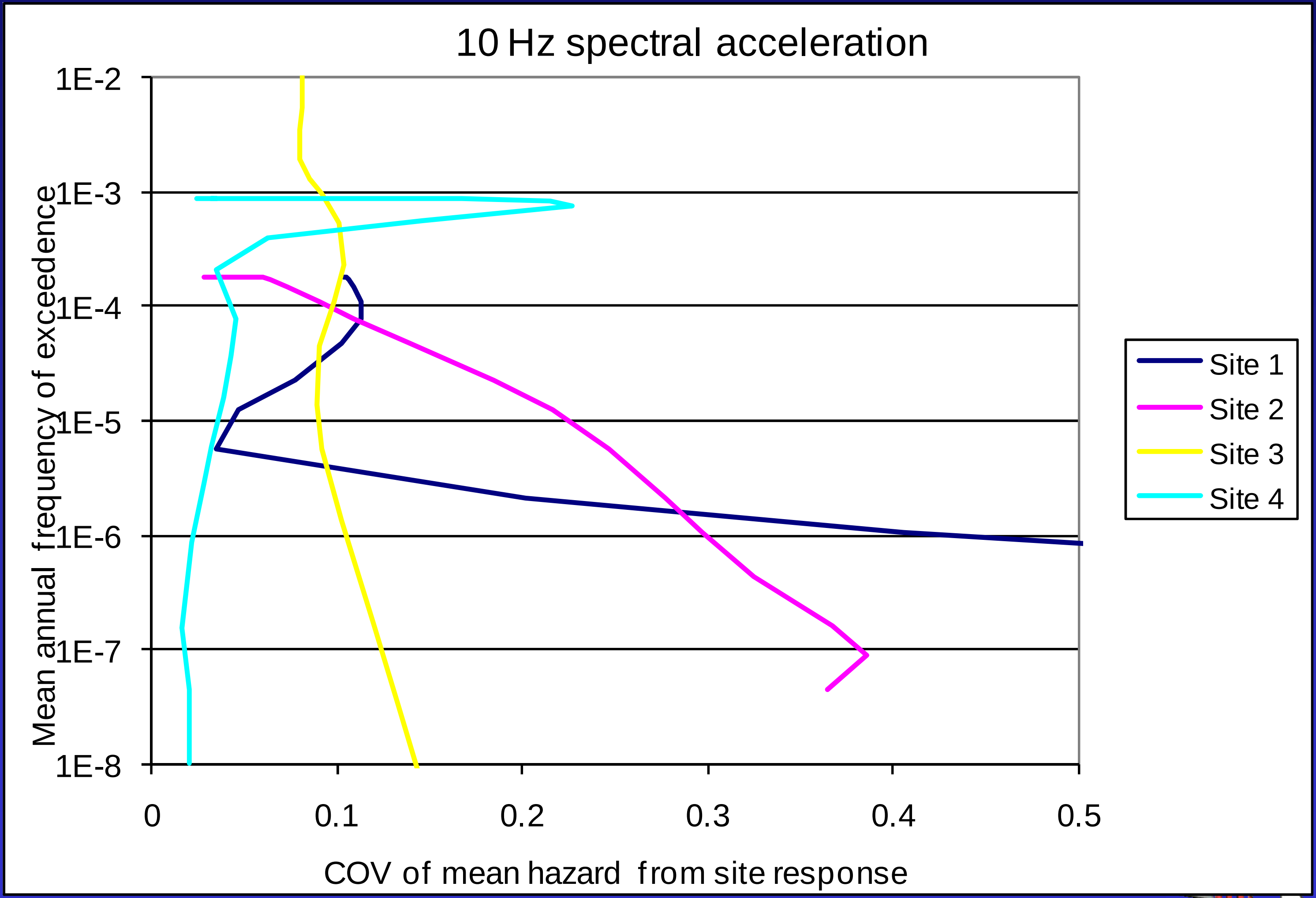


Site 1:	Shallow soil:	~50' of terrace deposits, $V_S \simeq$ 1000 fps
Site 2:	Deep soil:	~200' of limestone/sandstone, $V_S \simeq$ 6000 fps
		~1000' of silty clay, $V_S \simeq$ 3000 fps
Site 3:	Shallow soft rock:	~100' of weathered rock, $V_S \simeq$ 3000 fps
Site 4:	Deep soft rock:	~5000' of limestone/shale, $V_S \simeq$ 5000fps

COV of mean hazard resulting from site response models vs. mean hazard for 4 sites, 1 Hz



COV of mean hazard resulting from site response models vs. mean hazard for 4 sites, 10 Hz



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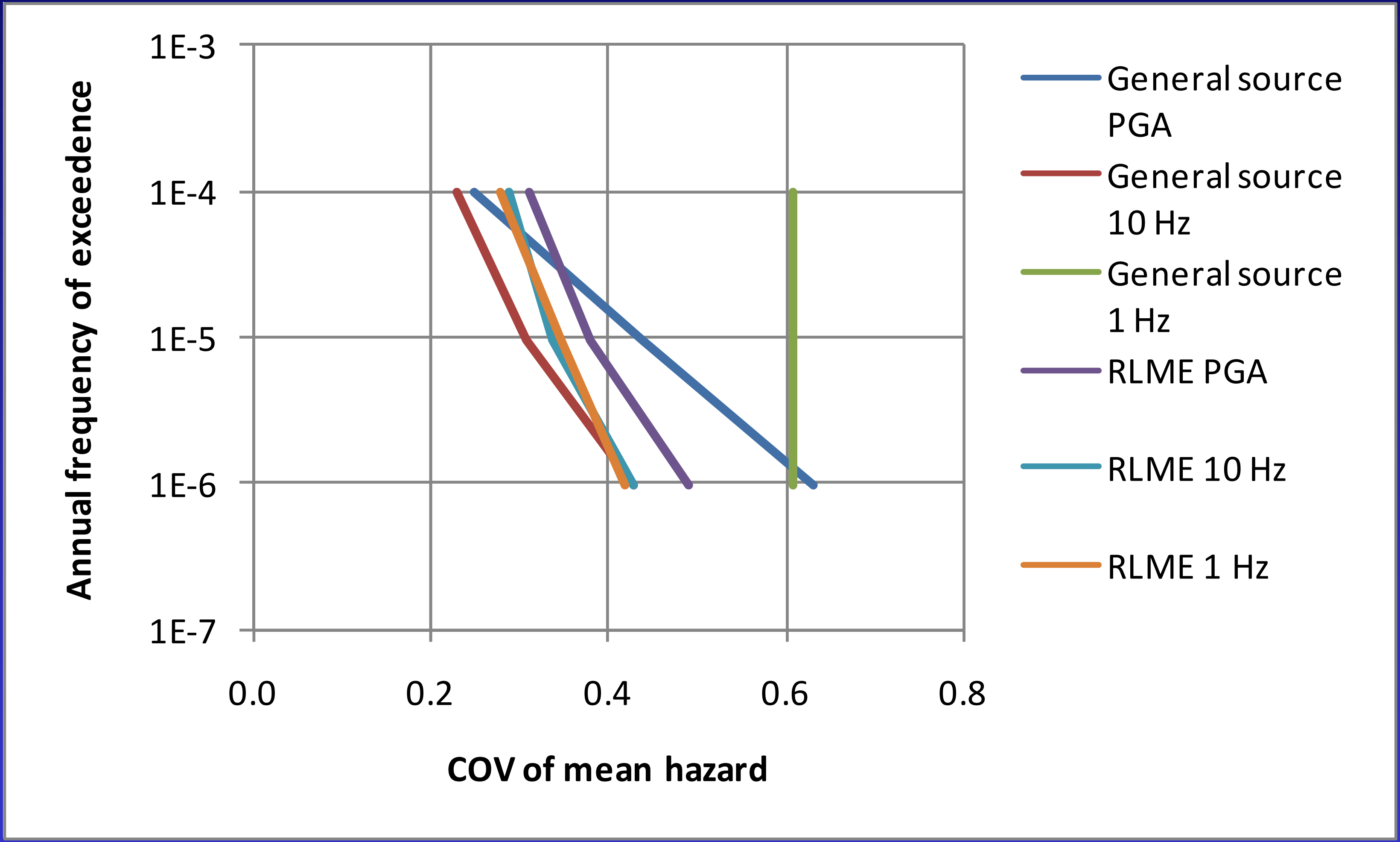
Summary of minimum COVs over all results

	Area sources	RLME sources	GM, area sources	GM, RLME sources*	Site response	SRSS, general site	SRSS, RLME site
PGA, 1E-4	0.15	0.27	0.2	0.15	0.05	~0.25	~0.31
PGA, 1E-5	0.18	0.31	0.4	0.22	0.05	~0.44	~0.38
PGA, 1E-6	0.2	0.4	0.6	0.28	0.05	~0.63	~0.49
10 Hz, 1E-4	0.15	0.27	0.17	0.1	0.05	~0.23	~0.29
10 Hz, 1E-5	0.18	0.31	0.25	0.13	0.05	~0.31	~0.34
10 Hz, 1E-6	0.21	0.4	0.37	0.16	0.05	~0.43	~0.43
1 Hz, 1E-4	0.1	0.25	0.6	0.12	0.05	~0.61	~0.28
1 Hz, 1E-5	0.1	0.3	0.6	0.18	0.05	~0.61	~0.35
1 Hz, 1E-6	0.1	0.35	0.6	0.23	0.05	~0.61	~0.42

* Excluding Savannah site

Table 3: Minimum COVs observed

Summary of minimum COVs over all results



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Path Forward

Kevin Coppersmith, TI Lead
WS-3 CEUS SSC Project
Palo Alto, CA
August 26, 2009

Short-Term Activities

- Conference call with TI Team and Staff to discuss additional feedback and schedule (August 31)
- Prepare and issue CD for WS3
- Working meeting (October 20-21) to:
    - Review all data evaluations
    - Consider additional feedback
    - Identify tasks for developing preliminary SSC model

Key Activities	**Date**
Task 10 - Workshop #3 Feedback	August 25-26, 2009
Working Conference Call	August 31, 2009
Distribute Workshop #3 CD	October 15, 2009
Working Meeting #6	October 20-21, 2009
Task 2.1- Reprocessing gravity data	October 30, 2009
Task 2.2 - Magnetic Field Compilation and Processing	October 30, 2009
Task 2.4 - Update Current World Stress Map	October 30, 2009
Task 2.3 - Initial results for Priority Study Areas and TI Team and Staff Guidance in Paleoliquefaction Task	December 31, 2009
USGS provide feedback to TI Team and Staff on CEUS SSC sensitivity model	December 31, 2009 (Tentative)
Working Meeting #7	January 12-13, 2010

Key Activities	**Date**
Consider initial results from WS#1 Additional Tasks and Items and consider USGS feedback	December 31, 2009 – January 31, 2010
Review feedback, revise assessments, and prepare complete preliminary SSC model (TI team)	September 1 – January 31, 2010
Task 8 - Complete HID for complete preliminary SSC model	**February 26, 2010**
Hold briefing with PPRP and USGS representatives to review complete preliminary SSC model	March 3, 2010 (tentative)
Task 11- Finalize SSC model	**April 30, 2010**
Task 2.3 - Final results and report for paleoliquefaction task (see Note 1)	June 15, 2010
Task 12 - Complete Draft Project Report	**July 31, 2010**
Task 13 - Obtain PPRP and Sponsor review comments	**August 31, 2010**
Task 14 - Complete Final Project Report	**December 31, 2010**
Task 15 - Hold briefing with Industry, NRC, DOE, and DNFSB	1st quarter 2011

Development of CEUS Seismic Source Characterization Model

Workshop #3 Closing Remarks
August 26, 2009

Lawrence Salomone
Project Manager

Savannah River
Nuclear Solutions, LLC
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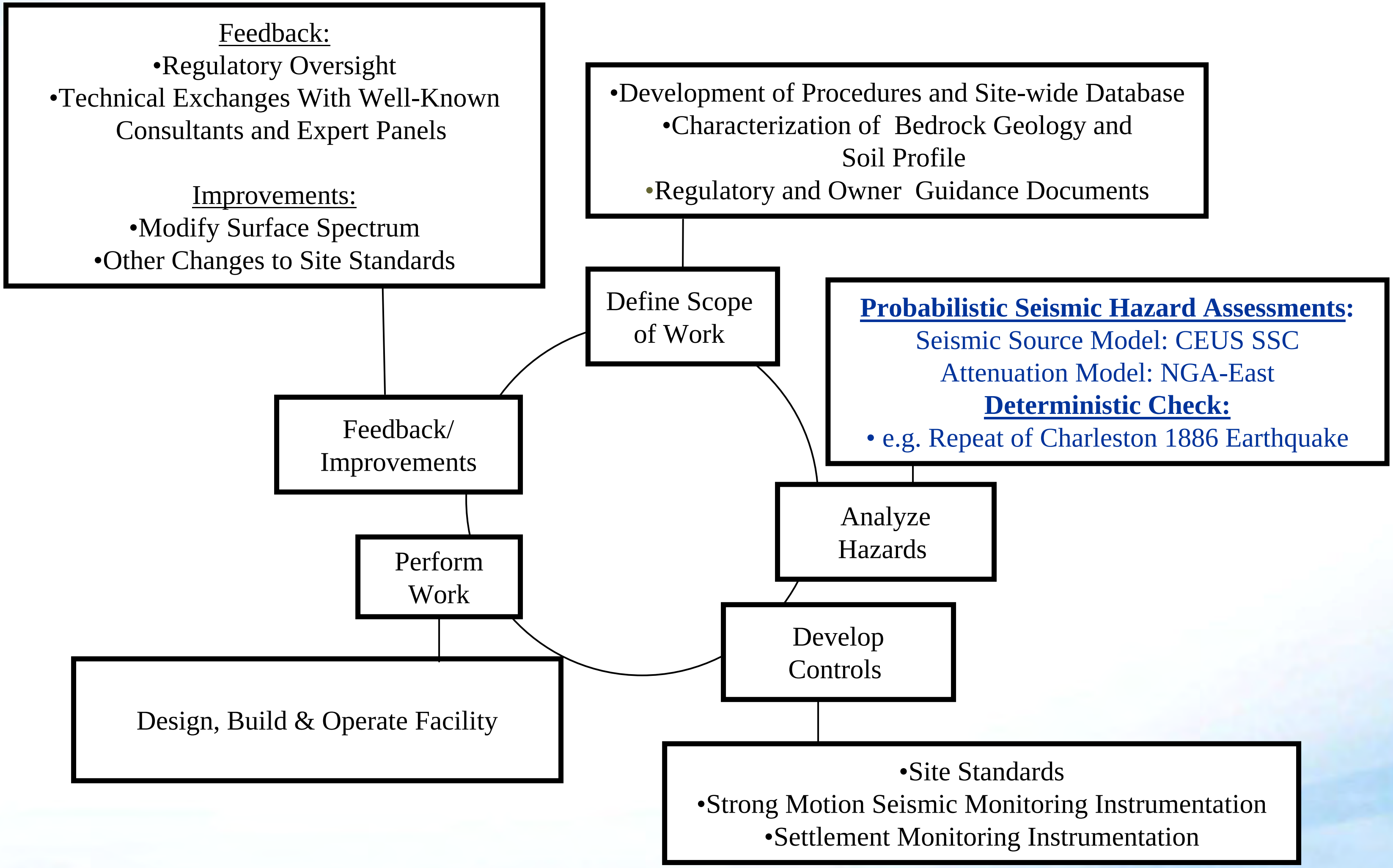
GENERAL GUIDING PRINCIPLES

- 1) Managing the seismic issue is critical to control cost and delays for critical mission nuclear facilities.
- 2) Having a stable, consistent and defensible seismic design spectrum throughout the design phase of critical mission nuclear facilities is essential.
- 3) Accomplishing more for less with reduced risk through standardization and partnering is important to advance science and the state of practice.

Disciplined, Systematic Approach to Seismic Safety



Feedback:
- Regulatory Oversight
- Technical Exchanges With Well-Known Consultants and Expert Panels

Improvements:
- Modify Surface Spectrum
- Other Changes to Site Standards

- Development of Procedures and Site-wide Database
- Characterization of Bedrock Geology and Soil Profile
- Regulatory and Owner Guidance Documents

Probabilistic Seismic Hazard Assessments:
Seismic Source Model: CEUS SSC
Attenuation Model: NGA-East
Deterministic Check:
- e.g. Repeat of Charleston 1886 Earthquake

- Site Standards
- Strong Motion Seismic Monitoring Instrumentation
- Settlement Monitoring Instrumentation

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CEUS SSC Project Workshop #3 - Feedback
August 25-26, 2009
Palo Alto, CA

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SUMMARY

CENTRAL AND EASTERN UNITED STATES SEISMIC SOURCE CHARACTERIZATION FOR NUCLEAR FACILITIES (CEUS SSC) PROJECT

WORKSHOP 3: FEEDBACK
August 25-26, 2009

Electric Power Research Institute
3420 Hillview Ave.
Palo Alto, California 94304

The Workshop on Feedback was the third in a series of workshops jointly sponsored by the Electric Power Research Institute (EPRI) Advanced Nuclear Technology (ANT) Program, U.S. Nuclear Regulatory Commission (NRC), and U.S. Department of Energy (DOE) in support of the Central and Eastern United States (CEUS) Seismic Source Characterization (SSC) for Nuclear Facilities Project. The objective of the CEUS SSC is to develop a comprehensive and up-to-date SSC for a probabilistic seismic hazard analysis (PSHA) that is appropriate for use at any site in the CEUS. The technical integration (TI) team and TI staff are charged with developing a seismic source model that captures the knowledge and uncertainties within the larger informed technical community.

The goals of this workshop were as follows:

- Review the progress of the project in terms of meeting key milestones, such as the database development and earthquake catalog.
- Review the processes being followed to attain the SSHAC goal of capturing the informed technical community.
- Discuss the seismicity catalog developed for the CEUS SSC project.
- Discuss the seismic source characteristics of the SSC sensitivity model.
- Present feedback to the TI team and staff in the form of SSC sensitivity analyses and hazard sensitivity analyses.
- Identify the key issues of most significance to the SSC models.
- Discuss the analyses being conducted related to hazard significance.
- Discuss the path forward for the CEUS SSC project.

These goals were accomplished by a series of presentations and discussions.

DAY 1 – TUESDAY, AUGUST 25

Workshop participants were welcomed by **Mr. Frank Rahn** (EPRI), who reviewed workshop logistics. **Mr. Lawrence Salomone**, project manager for the CEUS SSC project, then welcomed workshop participants and thanked them for attending. He reviewed the project goals:

- Replace the previous EPRI Seismicity Owners Group (EPRI-SOG) and Lawrence Livermore National Laboratory (LLNL) seismic hazard studies that were conducted in the 1980s (EPRI-SOG, 1988; Bernreuter et al., 1989).
- Capture the knowledge and uncertainties of the informed scientific community using the SSHAC process (documented in NUREG/CR-6372; Budnitz et al., 1997).
- Present a new CEUS SSC model to the NRC, DOE, and others for review.

Next Mr. Salomone showed a map of the study area and the demonstration sites used for sensitivity analyses for the project. He reviewed the topics of the previous two workshops, noting the contributions of numerous resource experts, and went over the goals of Workshop 3. He also described communications with the Participatory Peer Review Panel (PPRP) and project and tracking milestones. The project appears to be on track to meet the target completion date in December 2010.

Dr. Kevin Coppersmith (Coppersmith Consulting, Inc.), the lead of the TI team, then welcomed the workshop participants. He began by reviewing aspects of the SSHAC project, including basic principles for a PSHA, key attributes of the process, and expert roles. He reviewed the purpose and goals of Workshop 3. The TI team has developed a sensitivity SSC model that is complete in that it captures the range of views in the technical community, but the TI team has not devoted a lot of effort to weighting the alternative branches of the model until they see the results of the sensitivity analyses. Sensitivity analyses to be presented in the workshop will allow understanding of the importance of key assessments of most significance to the SSC models. Dr. Coppersmith clarified that a draft data summary package—consisting of the Data Summary and Data Evaluation Tables—completed prior to the workshop and distributed to PPRP members is a “work in progress” (i.e., it is incomplete and subject to revision). Nonetheless, he noted that the data evaluation process was conducted with a focus on identifying and evaluating the data, models, and methods that have credibility. By understanding the potentially important elements of the SSC model, subsequent work for the CEUS SSC can be prioritized.

Dr. Coppersmith went on to give a talk titled “SSHAC Goal of Capturing the Informed Technical Community.” He explained that the talk is based on his experience both from being a SSHAC member and from subsequently implementing SSHAC processes during the years since the 1997 SSHAC study was completed. After giving a brief historical context to probabilistic risk studies and the use of expert assessments, he noted that there has been increasing recognition of the importance of uncertainties. Probabilistic hazard is important to risk analysis, and uncertainties are important to hazard, thus quantifying uncertainties is an important aspect of the analysis. Dr. Coppersmith stated that more stable estimates of hazard are obtained by incorporating the range of views within the expert community. Based on this knowledge, there has been increased attention to concerns about expert issues, including representativeness, independence, consensus, and aggregation. Of particular importance have been strategies to deal with potential outlier judgments that may have a disproportionately large influence on results.

Dr. Coppersmith described the SSHAC concept of integration as capturing the view of the informed technical community (ITC). (Being "informed" in this case refers to being familiar with site-specific databases as well as participating in the SSHAC interactive process.) He stated that integration is not just an aggregation process for parameter values across a panel of experts, as very few parameters can be directly assessed in PSHA. Instead it is necessary to evaluate data, develop models, and quantify uncertainties. Obtaining a composite, or community, distribution is the most important objective of consensus in the SSHAC process.

Dr. Coppersmith described the steps taken in the CEUS SSC project to ensure that the views of the ITC have been captured. All participants understood their roles and agreed to abide by them within the framework of the SSHAC process. The TI team and staff, as well as members of the PPRP, have first-hand knowledge of data sets, reflecting their extensive experience in SSC for the CEUS. They have developed and are using explicit data evaluation processes to demonstrate a thorough awareness of all applicable data. Dr. Coppersmith noted that the interactive workshop processes used have proven to be a highly effective mechanism for identifying all available data and models that presently exist or are under development. In addition, he noted that the TI team and staff have expertise with the integration process. He said steps are in place that will ensure that the views of the ITC are reflected in the final results of the CEUS SSC project.

Dr. Coppersmith then gave a case history for the CEUS SSC project and traced the documentation in place to date. The case history was about the work of Drs. Eric Calais and Seth Stein, both of whom made presentations at Workshop 2, who suggested a lack of deformation in the New Madrid seismic zone and the potential that the zone will not be seismically active in the future. Dr. Coppersmith showed the questions they were asked to address in their talks, as well as a photograph of them as workshop participants, slides from their presentations, text included in the Workshop 2 summary and in a letter from the PPRP, text in a data summary table, and the logic tree used to model the hazard associated with the New Madrid fault source. He noted that the full documentation of the evaluations made by the TI team and the justification for all elements of the final SSC model will be part of the project final report. Dr. Coppersmith concluded his talk by stating that the SSHAC study will provide approaches that are instrumental in achieving the goal of capturing the views of the ITC. These approaches have been followed in the CEUS SSC project and they provide reasonable assurance that the ITC has been captured.

Workshop participants then discussed such concepts as "range of the technical opinions that the informed technical community would have," outlier judgments, and reasonable assurance. Regarding range of opinions, sensitivity studies are useful for showing when an analysis input has little or no hazard significance. There has been a gradual move away from a when-in-doubt-put-it-into-the-analysis approach and toward more careful consideration of whether or not an input is credible (e.g., tails on distributions that extend to infinity), as these approaches affect computational efforts and analysis results differently.

Workshop participants also discussed the possible subjectivity inherent in efforts to limit outlier views by promoting evaluator roles instead of proponent roles for expert inputs. A representation of the distribution of community judgments, as represented by the ITC, is the goal of the SSHAC process and underlies the importance of the evaluator role. Finally, the group addressed the concept of reasonable assurance as an accepted standard for safety decision making, based on meeting standards of practice. A member of PPRP and others at the workshop believe that the SSHAC process, if properly implemented, goes beyond the standard of preponderance of evidence in assuring that the views of the ITC have been considered and represented.

Following a short break, **Dr. Robert Youngs** (AMEC Geomatrix, Inc.) gave a talk on development of the CEUS SSC earthquake catalog. A preliminary earthquake catalog was completed for use in preparing the sensitivity analyses. Dr. Youngs reviewed the catalog development beginning with compilation of earthquakes from available existing catalogs, through the process of declustering, noting that the approaches used for several of these steps were initially used for the EPRI-SOG study. The primary earthquake catalogs used for the compilation were from the U.S. Geological Survey (USGS) and the Geological Survey of Canada (GSC), but several other national, regional, and historical catalogs were also used. Information on relocated events was obtained from studies described in published literature. Nontectonic events (particularly blasts) were identified. Moment magnitudes were assessed for all events, and Dr. Youngs showed plots of the alternative relationships used to convert different magnitude scales into moment magnitude. He described the process used to combine estimates from multiple magnitude measurements, when available, into a uniform magnitude scale. After conversions were completed, additional corrections were made to account for the bias in recurrence parameters due to magnitude uncertainty.

Next, Dr. Youngs explained how declustering was performed and how of the 26,426 total events in the catalog, 14,674 dependent events were identified. The final step in the catalog development process was to assess catalog completeness for events of various magnitudes. He showed the plots of catalog completeness regions within the study region for 15 different regions identified based on instrumentation and population history. He has sent the catalog to PPRP, USGS, GSC, and TVA colleagues to review selected preferential catalog entries, identify any additional data sources, evaluate conversions to moment magnitude, and garner any other suggestions. Response is needed by the end of 2009. At the conclusion of Dr. Youngs's talk, the workshop participants discussed the declustering approach and the identification of earthquakes related to blasts and located in offshore regions.

Dr. Youngs then gave a talk titled "The "EPRI" Bayesian M_{max} Approach for Stable Continental Regions (SCR)—Updated Priors." In the EPRI (1994) study, SCRs were divided into domains based on crustal type, geologic age, stress regime, and stress angle with structures. For the CEUS SSC project source zones, observed M_{max} distributions were developed based on the SCR domains identified for the 1994 study. In the project update, revised magnitude estimates were added for the New Madrid (**M**7.8) and Charleston (**M**6.9) events, and additional worldwide earthquakes were added from recent catalogs. The number of **M** $\geq$ 4.5 events in the SCR increased from 940 to 1,550 earthquakes. Dr. Youngs described an interesting case of a large 1917 earthquake in China and the differences in the size and location of this event as reported in various catalogs. Next he discussed bias adjustment, which is used to move from the relatively small number of observed maximum earthquakes toward what could be expected if more data were available. He described domain "pooling," in which estimates of bias adjustment can be obtained by pooling similar domains to increase sample sizes (essentially, trading space for time). He concluded the talk by describing work that needs to be completed, including the criteria used to distinguish and combine domains and to examine bias correction techniques.

Following a lunch break, Dr. Youngs briefly described the talks planned for the afternoon; these consisted of feedback on various parameters and their effects on hazard, calculated for the seven demonstration sites examined in the study. Dr. Youngs gave the first talk, titled "Logic Tree Structure for Seismic Source Sensitivity Model." He began by describing the master logic tree developed for the CEUS SSC sensitivity model. Two types of seismic sources are recognized: (1) distributed seismicity within regional source zones, characterized using historical and instrumental seismicity, and (2) repeated large-magnitude earthquake (RLME) sources characterized using the paleoearthquake record. For each of these sources, zoneless and seismotectonic structure approaches are used for characterizations and assessment of M_{max}. Distributed seismicity sources have two alternative geometries based on different extended and non-extended crust delineations.

Next, Dr. Youngs discussed the two alternative methods used to address spatially varying seismicity rates. These are the kernel model approach, based on a constant *b*-value and a cell-by-cell model approach that uses a variable *b*-value. The uncertainties and advantages and disadvantages of using each of these approaches were discussed. Dr. Youngs then described the use of a zoneless treatment of RLMEs based on use of an earthquake catalog that includes paleoearthquakes, noting that an important issue is completeness with respect to spatial and temporal earthquake coverage. What to do in areas that have not been examined in detail is problematic; hence this model is not yet ready to be used. Dr. Youngs also described the logic tree structure used for the structure-specific approach to assessing RLMEs.

Dr. Youngs moved on to a talk titled "One Approach for Spatially Varying Seismicity," in which he discussed the kernel model smoothing approach in detail. This approach assumes a constant *b*-value within a zone and a variable "a." Uncertainty in overall seismicity parameters is largely decoupled from estimation of spatial density. Dr. Youngs discussed testing for spatial non-uniformity to assess if seismicity is occurring in clusters. He showed kernel density estimation in one dimension, depicting a "classical" uniform density graph and Gaussian kernels approach. When combined, these approaches give information important for assessing the size of the kernel, which is an important parameter.

Next, Dr. Youngs described alternative kernel forms and how they affect data density. Kernel size can be adjusted as a function of data density using an adaptive kernel. Dr. Youngs showed examples of fixed kernel estimates and adaptive kernel estimates and how they affect display of data using a normalized density. He described the issue of varying completeness and how to account for this using a single catalog; possibilities include using minimum completeness for the lowest magnitude used (minimum data) and assigning a weight to each earthquake interval based on specific measures of relative completeness. He reviewed the approaches of high smoothing using uniform spatial density and low smoothing using adaptive kernel density estimation. He concluded by describing estimation of uncertainty distributions for earthquake rate and *b*-value.

The next talk, given by **Dr. Gabriel Toro** (Risk Engineering, Inc.), was titled "Characterization of Variable Seismicity: Penalty Approach with Variable a and b." Dr. Toro stated that the variable seismicity approach is essentially a modification of the 1988 EPRI study approach developed by Veneziano and Van Dyke (1988). He began with an overview of the 1988 EPRI study approach and described the key elements and equations. Next he discussed the new features included in the updated approach, including smaller (0.25 degree) cell size and a new solution algorithm that estimates uncertainty in certain parameters and objectively estimates penalty terms to use in the calculation (i.e., downweighting is applied if there is a large difference in value between a cell and the adjoining cells).

He then described the solution algorithm and the results that can be obtained. The approach has been used for two cases: (1) a low smoothing case using objectively determined smoothness penalty terms and a low prior of b = 1, and (2) a high smoothing case with fixed smoothness penalty terms and no prior on b. Dr. Toro displayed the results of the CEUS SSC earthquake catalog using these approaches; with low smoothing there are more local peaks depicted than with high smoothing. He compared these results with results of the approaches used by Dr. Youngs and noted that they are similar.

Dr. Toro moved on to a discussion of uncertainty characterization for the variable seismicity approach, which represents a significant improvement over the EPRI 1988 model. He described the objective and approach, which includes randomization, and showed sample results obtained for low smoothing and high smoothing examples. His conclusions included the observation that the variable b approach is particularly well suited for large source zones, and that the approach allows both objective (data-driven) and subjective specification of the smoothing parameter (i.e., penalty terms). Finally, Dr. Toro described additional work that could be conducted in the future to make improvements in the application of the updated approach.

Dr. Youngs presented maps of the historical seismicity of the CEUS that depicted the alternative spatial density models, plotted as frequency of occurrence (i.e., events per year per 0.25 degree). These maps provided feedback for the project team on the results produced by different smoothing approaches. Dr. Youngs showed three sets of maps displaying $\mathbf{M} \geq 5$, $\mathbf{M} \geq 6$, and $\mathbf{M} \geq 7$ events for each of the alternative models. He described and compared the results of different models for selected regions. The number and magnitude of earthquakes within a particular region can have a strong effect on the nature of the boundary between adjoining zones. Workshop participants discussed some of the results of the various models, as well as the basis for defining the boundary between extended and non-extended crust.

After a break, Dr. Youngs announced that talks for the remainder of the afternoon would provide a whirlwind tour of seismic hazard in the CEUS. He began by showing a map of locations of the regional sources, RMLE sources, and the seven demonstration sites that are being analyzed for the CEUS SSC project. He described the master logic tree used to assess all the seismic sources and discussed various parameter estimation approaches. He showed results of M_{max} assessments for the regional sources. Next he described in detail the analyses for the Cheraw fault and Wabash area RLME sources. He showed the logic trees used for these sources and discussed results of analyses of event frequency and magnitude distributions for each source. He then went on to describe the New Madrid RLME. The analysis is based on two groups of sources (a central zone of faults and a set of faults on the boundary of the rift) and three models of characterization (one with all structures in active mode; one with all structures turned off and a default to background seismicity; and one with only the Reelfoot thrust active). Dr. Youngs concluded his talk by showing the results of analyses of event frequency and magnitude distributions for the various structures associated with the New Madrid RLME.

Dr. Robin McGuire (Risk Engineering, Inc.) gave the next talk, titled “Seismic Hazard Sensitivity in the CEUS,” noting that he would be giving his opinions of what is or is not important for hazard analyses. He began by discussing general sources of imprecision, including random and systematic errors, variability and unpredictability, expert disagreement, and approximations. Next he reviewed the hazard from the New Madrid RLME source at two demonstration sites (Central Illinois and Jackson, Mississippi). For each site he first showed PGA hazard fractiles and the mean for hard rock. He then showed the sensitivity to the ground motion model used, the cluster frequency, the characteristic magnitude, and rupture length scenarios. For the dependence on cluster frequency he noted that we are less then halfway into the recurrence interval following the 1811-1812 earthquakes; thus the renewal recurrence model gives higher hazard than the Poisson model. After showing the sensitivity results, Dr. McGuire showed the mean and fractile hazard results at 1 and 10 Hz spectral acceleration.

Next, Dr. McGuire showed PGA hazard curves from three New Madrid seismic zone models (2008 USGS, 2003 Geomatrix, and 2009 CEUS SSC) that had been computed by different analysts at Risk Engineering, and he noted that all give near-identical results. The hazard curve for additional faults (e.g., Commerce and Fluorspar) and the hazard curves for 1 and 10 Hz are also all virtually identical. Dr. McGuire also showed hazard results at the Topeka, Kansas, demonstration site. Again, at 1 and 10 Hz, the newly calculated hazard results are virtually the same as those obtained in the 2008 USGS and 2003 Geomatrix studies. Dr. McGuire emphasized that this comparison was not done using total hazard, but with the hazard contributions from the New Madrid seismic sources only. Workshop participants discussed the agreement between the different models, which is based in part on the long source-to-site distances. Also, it was noted that results from pre-2000 models would have varied, in part because these were based only on observed seismicity (i.e., no paleoearthquakes).

The next speaker was **Ms. Allison Shumway** (William Lettis & Associates, Inc.), who described hazard results from the Cheraw fault and Wabash Valley seismic sources at the Topeka demonstration site. The recurrence rate parameter for the Cheraw fault has the greatest effect on hazard at the Topeka site. For the Wabash Valley source, two alternative source geometry interpretations were used: narrow and wide (circular shape, consistent with the 2008 USGS source zone); the geometry has a moderate effect on hazard. The source recurrence rates used in the analysis give a factor-of-10 range, however, so this parameter is the most sensitive. The paleoseismic record appears to indicate a higher recurrence rate than the historical seismicity. To clarify the basis for the source logic trees, Ms. Kathryn Hanson (AMEC Geomatrix, Inc.) briefly described the paleoseismic record of the Cheraw fault, which includes three events in the past 20,000 years. For the Wabash source, she described the basis for rates from the paleoearthquakes near Vincennes, Indiana.

Dr. Youngs spoke next about the Oklahoma Aulacogen (OKA)/Meers fault RLME; the Meers fault is located within the OKA, so the two sources are always linked. He showed the logic tree and reviewed the branches for an in- or out-of-earthquake cluster, source geometry, earthquake model, rupture size relation, magnitude approach, and recurrence approach. A separate logic tree has been developed for OKA with broad and narrow source geometry and with the Meers fault in or out of a cluster. Additionally, given the alternative that the Meers fault is “turned off,” there is a probability that seismic activity will move to another location within the OKA but have the same source characteristics as the Meers fault. This alternative was added because numerous structures have been identified within the OKA that parallel the Meers fault.

The Alabama-Louisiana-Mississippi source (ALM; this source includes the Saline River region) located on the southern edge of the Reelfoot rift system was described next by Dr. Youngs. Four alternative source geometries were evaluated and Dr. Youngs described the data used to develop each alternative. Logic tree branches included consideration of event correlation or no correlation for paleoliquefaction interpretations, plus alternative numbers of paleoearthquakes related to these interpretations. This region does not have elevated seismicity, but paleoliquefaction evidence is present and possibly represents multiple earthquakes.

Ms. Shumway showed sensitivity results for the OKA/Meers fault RLME source. Alternative geometries may be sensitive, but this interpretation needs to be checked. The background M_{max} earthquake within the aulacogen only (i.e., without the influence of the Meers fault) is also potentially important. Next she discussed the ALM source. Four alternative geometries are considered and hazard was calculated for the highest weighted source (the Cox/Quaternary alternative) at the Jackson, Mississippi, and Houston, Texas, sites. Randomly oriented structures that are or are not allowed to extend beyond the boundary of the source zone were tested (“leaky” or “strict” source cases) and shown to have low sensitivity. Recurrence rate has a high sensitivity, and Ms. Shumway noted that with more small events, higher hazard is indicated at higher probabilities. Workshop participants discussed the paleoliquefaction data and hazard sensitivity results for the ALM source.

Dr. Coppersmith adjourned the meeting for the day.

DAY 2 – WEDNESDAY, AUGUST 26

Mr. Salomone welcomed the group to the second day of the workshop. He announced that in October there would be a workshop on earthquake hazards sponsored by the USGS; this workshop is one of several synergistic projects currently under way that overlap the work being conducted as part of the CEUS SSC project. He introduced Mr. Oliver Boyd (of the USGS), who is an organizer of the upcoming earthquake hazards workshop. Mr. Boyd said that the workshop will be held October 27-28, 2009, in Memphis, Tennessee. It will provide an opportunity for researchers to present and discuss their recent investigations, discuss upcoming New Madrid bicentennial activities, and identify topics for future research priorities.

Dr. Coppersmith gave a summary of the model sensitivity information presented on Day 1 of the workshop. He noted the apparently large impact locally on predicted rate density of alternative interpretations of the position of the extended/non-extended crust boundary and seismotectonic zone boundaries. Some of the smoothing results show a distinct rate change (step function) at the boundary, which could be important for sites very near the boundary. This also highlights the potential importance of evaluating the need for source boundaries or boundaries for purposes of M_{max} assessment (i.e., the extended/non-extended boundary). For the repeated large-magnitude earthquake (RLME) sources, he noted that comparisons made the previous day showing similarity in hazard for post-2000 PSHAs near New Madrid indicate that these studies are comparable in their treatment of the New Madrid seismic zone.

Given that the RLME sources are within a cluster, there is strong sensitivity to the recurrence rate. Sensitivity analyses have not yet been conducted to demonstrate the differences between within-cluster and out-of-cluster hazard at nearby sites, but it is expected that there will be strong sensitivity to in- or out-of-earthquake-cluster recurrence rates, as well as to characteristic magnitude distributions at all RLME sources. A renewal model was developed and exercised for some of the RLME sources; the short elapsed time at New Madrid relative to the mean RLME repeat time results in somewhat lower hazard estimates than the Poisson model. The results illustrate the importance of the parameters of the renewal model, including the coefficient of variation (COV) of the mean repeat time. Sensitivity studies for the Central Illinois site (which is not immediately adjacent to the New Madrid source) indicate little sensitivity to alternative models for the rupture of the northernmost segment and to rupture length models. With increasing distances to an RLME source, the background or regional seismotectonic zones are increasingly important and contribute more than the RLME sources.

Dr. Coppersmith also reviewed the particular sensitivities associated with the RLME sources at the test sites. He listed additional feedback information that will be needed, including the hazard significance of all logic tree branches at all logic tree nodes at all seven demonstration sites. He noted that he would be adding to this list as the day progressed and would review it with the TI team at the end of the day.

Dr. Youngs continued the presentations on sensitivity models by discussing the Charleston, South Carolina, RLME source. He described the weights on various logic tree branches, including alternative interpretations for in- or out-of-earthquake-cluster recurrence rates; four source geometry configurations; various paleoliquefaction scenarios, including length of paleoliquefaction record (2,000 versus 5,000 years); the range of maximum magnitude (M_{max}) values (**M** 6.7 to 7.5); and the possible overlap in the earthquake magnitudes included within this RLME and those that are accounted for within the surrounding regional source zone.

Next, Ms. Shumway described the geometry, rate, and M_{max} sensitivity studies for the Charleston RLME and the resulting hazard at the Savannah, Georgia, and Chattanooga, Tennessee, demonstration sites. The hazard results reflect the wide range of input parameters. There is high sensitivity to earthquake recurrence models. The renewal (time-dependent) model results in lower recurrence rates for the next 50 years because the elapsed time since the large 1886 earthquake is relatively short compared to the mean repeat time for RLME events. Workshop participants discussed the relative merits of using renewal versus Poisson recurrence models. Weights on these model branches may need to reflect the maturity of the structures involved; additional feedback on sensitivity is needed.

Dr. Youngs recounted early discussions about placing an RLME source around the Charlevoix region. The project team decided this was unnecessary as the recurrence rate from the observed seismicity is comparable to or even exceeds the rates identified using paleoliquefaction data. Neither the cell-by-cell nor kernel-smoothing methods provide a close fit, in part because of uncertainty in the record of paleoliquefaction events. Checking the relative fit of the two smoothing methods using an RLME-equivalent source in the St. Lawrence and Charlevoix region may provide useful information.

Dr. Coppersmith asked PPRP members for their opinions about the use of the renewal versus Poisson smoothing approaches. Dr. Stepp remarked that if the in-cluster alternative is selected for the Charleston RLME, then a tectonic interpretation is being made and therefore the renewal model needs to be highly weighted. Dr. Coppersmith observed that the renewal model is sensitive to knowledge of COV and time since the last event; when the uncertainties in both of these factors are added, the problem is moved toward a Poissonian approach. Workshop participants discussed the use of the renewal approach for known seismic sources (e.g., structures in the New Madrid region). There was agreement that more work on COVs is needed, as there is extreme uncertainty in this parameter for many areas and thus the use of the renewal model may not be reasonable. Workshop participants also discussed how to structure a logic tree given that an in-cluster state is assumed. Dr. Coppersmith noted that the influence of the in-cluster versus out-of-cluster models on hazard still needs to be examined.

Following a break, Dr. Coppersmith announced that the next talks would address regional seismic source zones. Dr. Toro gave the first talk, titled “Sensitivity Results for CEUS Source Zones.” He began by comparing the CEUS SSC project hazard results (for the source zones only; no RLME sources) with hazard results using the zones defined by the USGS. In general, the hazard levels calculated for the CEUS project are lower than those for the USGS study, but this is likely due to not including the RLME events in the comparison. At the Savannah site the difference in hazard levels is about 50 percent; for the Chattanooga and Manchester, New Hampshire, sites the difference is closer to 20 percent. For the Central Illinois, Houston, Jackson, and Topeka sites, the hazard curves are closer together.

Dr. Toro then discussed hazard sensitivity results for seismic source zones for each of the seven demonstration sites. He noted that he would concentrate on the results from the CEUS SSC study, which incorporates SSC uncertainty but does not address ground motion uncertainty. For each demonstration site, he showed hazard results at PGA and 1 Hz and discussed the contributions to hazard for the dominant seismic sources. He also showed the mean and fractile hazard curves and described sensitivity to branches of the master logic tree, focusing on M_{max} and recurrence for the dominant sources.

Dr. Toro stated that for all sites there is moderate sensitivity to choice of smoothing approach (i.e., kernel or variable a and b) and to selection of M_{max} values. He believes that in areas having higher levels of seismicity (e.g., many low-magnitude events), the two smoothing approaches are in better agreement; however, this observation needs to be tested further. Dr. Coppersmith noted that areas having higher levels of seismicity tend to have lower uncertainty in the recurrence parameters and, hence lower sensitivity to most alternative input parameters. These observations apply to the Savannah, Manchester, Central Illinois, Topeka, and Chattanooga sites. The hazard results for the two sites in regions of lower seismicity, Houston and Jackson, have more pronounced differences in sensitivity between PGA and 1 Hz hazard curves. For both sites there is a moderately high sensitivity to the M_{max} of the Gulf of Mexico source zone and to choice of smoothing parameter. Dr. Toro noted that these differences can be at least partially attributed to the low seismicity (fewer data points) in these regions. Another potential contributor to these differences is the use of the Gulf of Mexico attenuation equations for local zones and the Midcontinent attenuation equations for distant zones.

Workshop participants discussed whether or not to keep all of the branches of the logic tree used for the initial hazard calculations, given the apparent low sensitivity of many branches. Advantages include the relative ease of making future changes to update the models; disadvantages include longer computational time. Several individuals noted that results will vary by site. The general preference of the group was to keep all of the branches as the study moves forward, since this will serve to demonstrate that all alternative hypotheses have been considered. Although the CEUS SSC project is applicable to the entire CEUS, its future applications will be for individual sites and it will be possible to simplify (e.g., by pruning the logic tree) for individual sites by showing that there is no sensitivity to more distant sources in the model.

Following a lunch break, Dr. Coppersmith showed a slide with a list of additional feedback items needed, based on the discussions at the workshop, as follows:

- the hazard significance of all logic tree branches, at all logic tree nodes, at all seven demonstration sites;
- additional evaluation of predicted versus observed seismicity for the entire CEUS and all seismotectonic zones;
- differences in earthquake recurrence related to smoothing approach and alternative zone boundaries; and
- the issue of a migrating RLME (e.g., the Meers fault versus another structure within the OKA source region).

Dr. Coppersmith indicated that these items would be addressed by the TI team during an upcoming telephone conference call. Workshop participants discussed these and related topics, including the zoneless model concept (smoothing of seismicity used in place of defined zone boundaries); separating large-magnitude events within the RLME sources from events in the surrounding host zones; offshore earthquakes in the Gulf region; and appropriate truncation of M_{max} distributions.

Dr. McGuire gave the next talk, titled “Quantifying the Precision of Seismic Hazard Results in the CEUS.” The purpose of the analysis described in the talk was to derive quantitative estimates of how seismic hazard results might change if studies were repeated by different researchers using the same basic information. Dr. McGuire began by listing many general sources of imprecision, which include random error and statistical variation, overconfidence in estimating uncertainties, unpredictability, expert disagreement, and the use of approximations. Then he listed the hazard studies that provided data used to quantify levels of precision of seismic hazard results. Data on SSC was obtained from the 1989 EPRI-SOG study, the PEGASOS project that evaluated seismic hazard for nuclear power plant sites in Switzerland, and recent characterizations of the Charleston and New Madrid seismic sources.

Dr. McGuire explained the formula he used for combining sources of imprecision. He showed hazard results obtained from the PEGASOS project, including COV of mean hazard from SSC expert teams. Turning to the 1989 EPRI-SOG project, he showed COV of hazard at various levels for each of the seven demonstration sites used for the CEUS SSC project. He then provided a summary of uncertainties for the Charleston source by showing logic tree alternatives and weights. He also described the mean and variance of hazard when weights on models are variable (depending on who is making the interpretation) and how COV can be calculated for various weighted alternatives. Similar analyses were shown for the New Madrid source.

Turning to the ground motion and site response components of seismic hazard analysis, Dr. McGuire showed the relevant hazard results from the PEGASOS and 2004 EPRI Ground Motion studies. Next he used the data from the 2004 EPRI study to assess the

COV of hazard versus hazard results at each of the seven demonstration sites. He noted that there is a tendency to get much lower COV from seismic source and ground motion models, relative to site response. He then listed several conclusions:

- There is less uncertainty in site response than other components of hazard.
- The source parameter contribution is smaller for area sources than RLME sources.
- For ground motion equations, area sources have a higher COV than RLME sources.

Dr. McGuire showed a plot of these results, which indicate that a minimum estimate of uncertainty in mean hazard varies between a COV of mean hazard of 0.2 to a COV of mean hazard of 0.4 for an annual frequency of exceedance of 1×10^{-4} to 1×10^{-6}, respectively. Dr. McGuire stated that an overall level of precision in mean hazard estimates would be a COV of 0.25 in annual frequency, which corresponds to a precision in ground motion of +/–8%. He said that to apply this knowledge going forward, this method of quantification would give confidence in levels of mean hazard and how much they could change with additional analyses, which reflects on how well the hazard is understood.

Dr. Coppersmith followed this presentation with the final talk of the workshop. In this talk, titled “Path Forward,” he identified short-term activities to occur within the following few weeks, including meetings between the TI team and staff and preparation and distribution of documentation for Workshop 3. He then showed key dates and activities for the remainder of the calendar year, including delivery of new data sets of reprocessed gravity and magnetic field data and an updated world stress map. The preliminary SSC model will be completed by the end of February 2010, and discussed in a briefing with the PPRP in mid-March. The final SSC model is to be completed at the end of April 2010 and the draft report by the end of July 2010. The final project report will be delivered at the end of December 2010. The group discussed the schedules for the review of CEUS SSC project components by the NRC and USGS staff. Mr. Salomone will work with the NRC and the USGS to ensure the process goes smoothly.

Concluding remarks were made by Mr. Salomone, who noted that Workshop 3 was the last formal workshop for the project. For this reason he wanted to provide an engineering perspective and review the larger project context by looking at industry and government use of what will be developed for this project. He reviewed the following general guiding principles on which the project is based:

- Managing the seismic issue is critical to control cost and delays for critical mission nuclear facilities.
- Having a stable, consistent, and defensible seismic design spectrum throughout the design phase of critical mission nuclear facilities is essential.
- Accomplishing more for less with reduced risk through standardization and partnering is important to advance science and the state of practice.

Mr. Salomone showed a flow chart titled “Disciplined, Systematic Approach to Seismic Safety.” Key steps in the disciplined, systematic approach to seismic safety included:

1. Define scope of work as per regulatory and owner guidance documents.
2. Analyze seismic hazards by performing PSHAs using the CEUS SSC model and available attenuation models from studies such as the EPRI 2004/2006 CEUS Ground Motion and the Next Generation of Ground Motion Attenuation Models —East (in development). .
3. Develop controls through installation of strong motion seismic monitoring instrumentation and settlement monitoring instrumentation.
4. Perform work by designing, building, and operating facilities.
5. Obtain feedback from regulatory oversight and technical exchanges using qualified consultants and expert panel members; modify surface spectrum as required.

Mr. Salomone stated that the CEUS SSC project is part of an initial step to analyze hazards and will ultimately be used for facility design. He cautioned that factors used for increased conservatism should be applied to the design spectrum used by structural engineers and not the geologically, seismologically derived spectrum used by geotechnical engineers when performing soil response analyses.

Mr. Salomone finished by thanking Mr. Rahn for the hospitality of EPRI, and the workshop participants for their contributions to the CEUS SSC project.

September 18, 2009 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. 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. We recommend that the report be considered as part of the information base for assessment of the CEUS SSC model.

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.

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, 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.

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. 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.

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, we recommend that the sensitivity studies not be used to justify devoting a reduced effort to assessing any fundamental element of the SSC model. (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. 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.

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

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[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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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

Workshop # 3 Pre-Meeting with International Observers on August 24, 2009

Central and Eastern United States (CEUS) Seismic Source Characterization (SSC) Project Workshop # 3

Central and Eastern United States (CEUS) Seismic Source Characterization (SSC) Project Workshop # 3

Technical Integration (TI) Team & Staff

Participatory Peer Review Panel (PPRP)

Workshop #3 Observers