Seismic Hazard Basics

Best Practices in Dam and Levee Risk Analysis

Part B Hazard and Loading

Chapter B-2

Last modified July 2018, presented July 2019

US Army Corps of Engineers®

U.S. Department of the Interior Bureau of Reclamation

Department of Energy Federal Energy Regulatory Commission

TVA

Outline / Key Concepts

Introduction

- Seismic Stability Analyses in a Risk-informed Framework

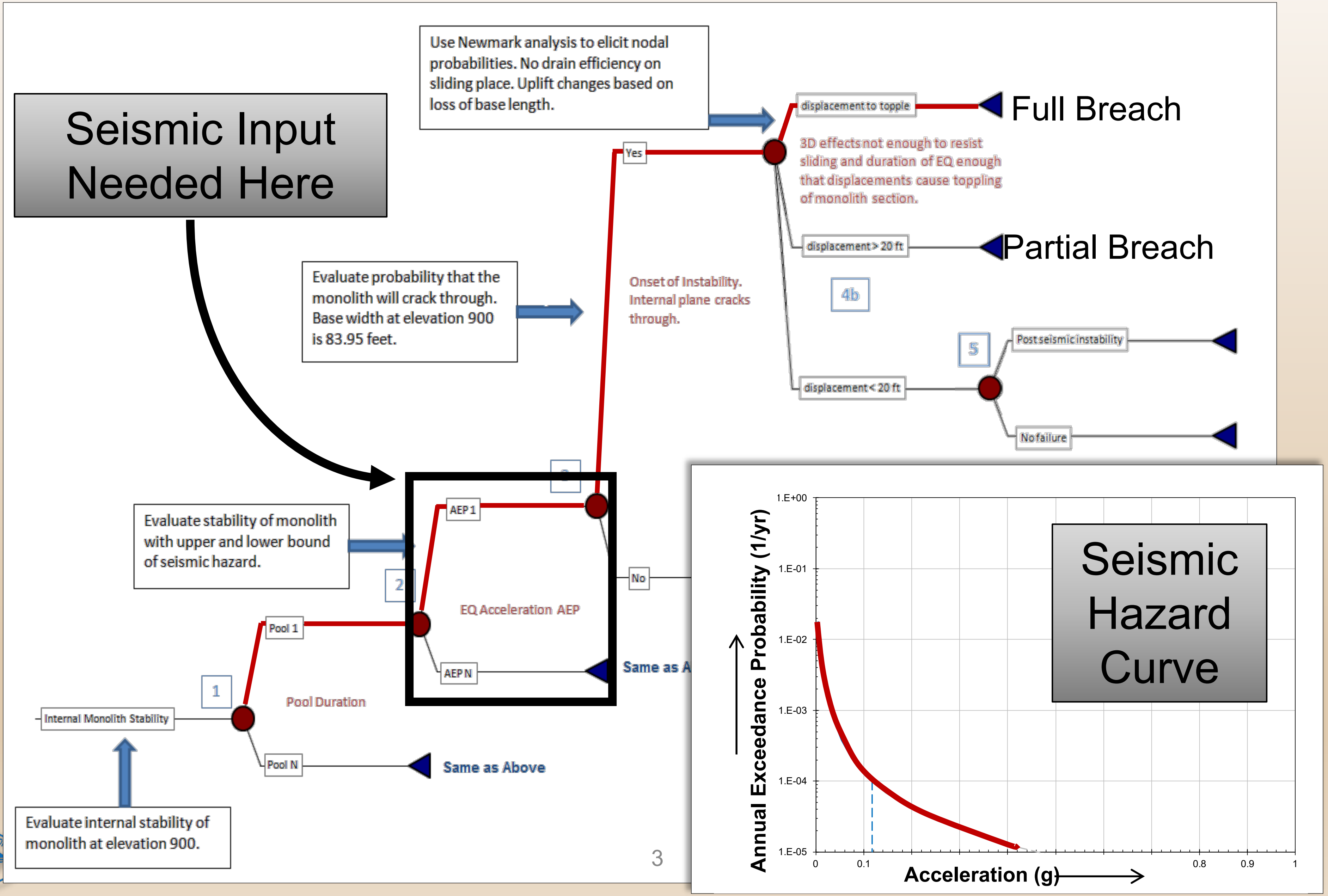
Deterministic Seismic Hazard Analysis (DSHA)

- Ground Motion Analyses: Basic Components
- "Worst-Case" vs. "Reasonable"

Probabilistic Seismic Hazard Analysis (PSHA)

- Seismic Source Characterization (Areal Sources, Fault Sources)
- Estimating Expected Strong Ground Motions
- Developing Seismic Hazard Curves
- Source-specific Contributions to Hazard
- Ground Motion Time Histories

Seismic Loading in Risk Assessments: PFMA Event Tree



Outline / Key Concepts

Introduction

- Seismic Stability Analyses in a Risk-informed Framework

Deterministic Seismic Hazard Analysis (DSHA)

- Ground Motion Analyses: Basic Components
- "Worst-Case" vs. "Reasonable"

Probabilistic Seismic Hazard Analysis (PSHA)

- Seismic Source Characterization (Areal Sources, Fault Sources)
- Estimating Expected Strong Ground Motions
- Developing Seismic Hazard Curves
- Source-specific Contributions to Hazard
- Ground Motion Time Histories

Seismic Hazard Analyses

Deterministic (DSHA):

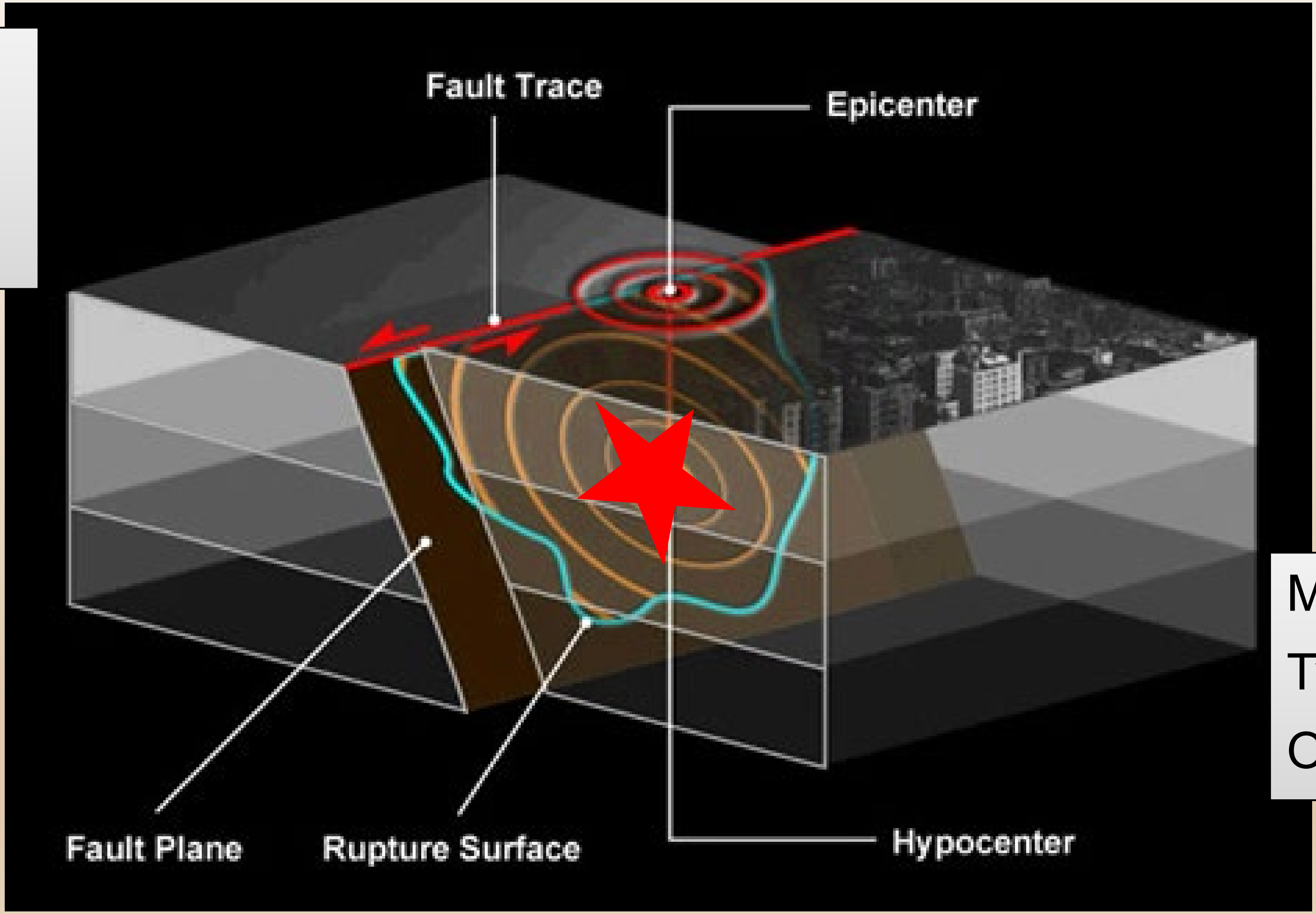
- Selects a few scenarios (magnitude, distance, standard dev. [“epsilon”])
- For dams, typically “worst-case” **earthquake** (Max Credible EQ, “MCE”)
- Chooses largest **expected ground motion** from selected scenarios

Probabilistic (PSHA):

- Considers all scenarios (magnitude, distance, epsilon)
- Computes the rate of every scenario
- Combines rates of all scenarios and selected ground motion thresholds to evaluate probabilities of exceedance of strong shaking

Ground Motion Analysis: Basic Components

Source Effects
Path Effects
Site Effects



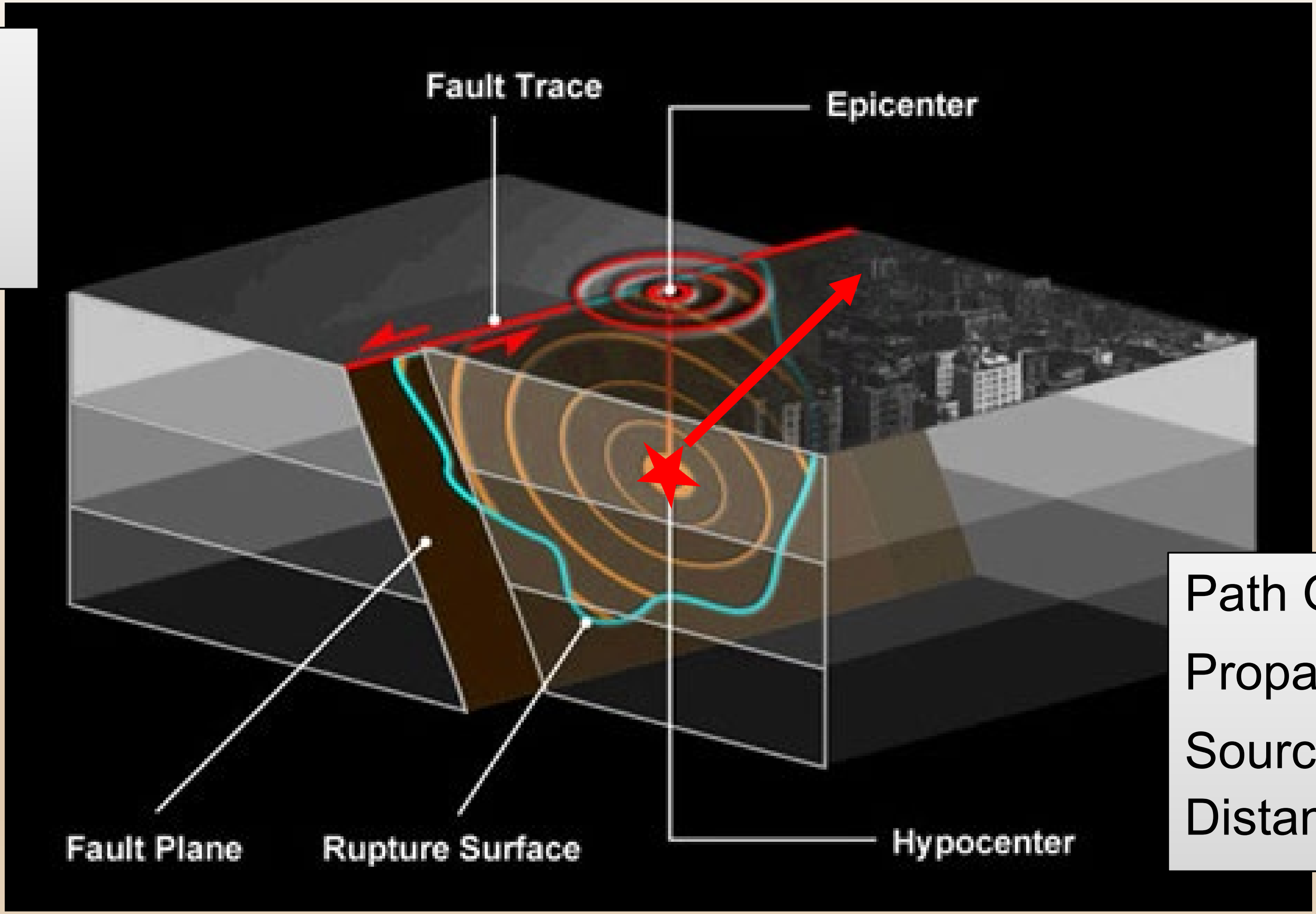
Magnitude
Type of Slip
Occurrence Rate

Ground Motion Analysis: Basic Components

Source Effects

Path Effects

Site Effects



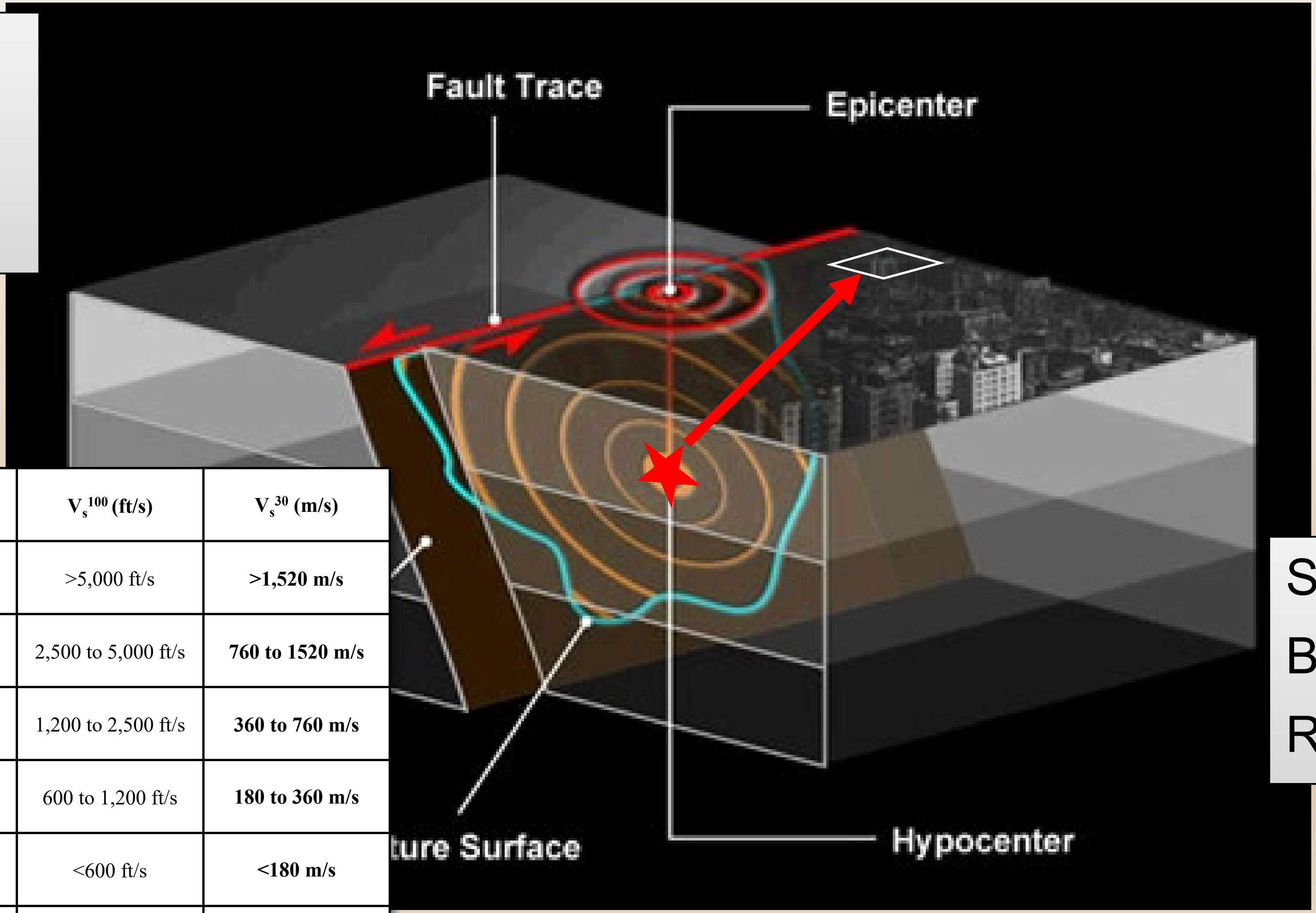
Path Geology

Propagation Direction

Source-to-Site Distance

Ground Motion Analysis: Basic Components

- Source Effects
- Path Effects
- Site Effects

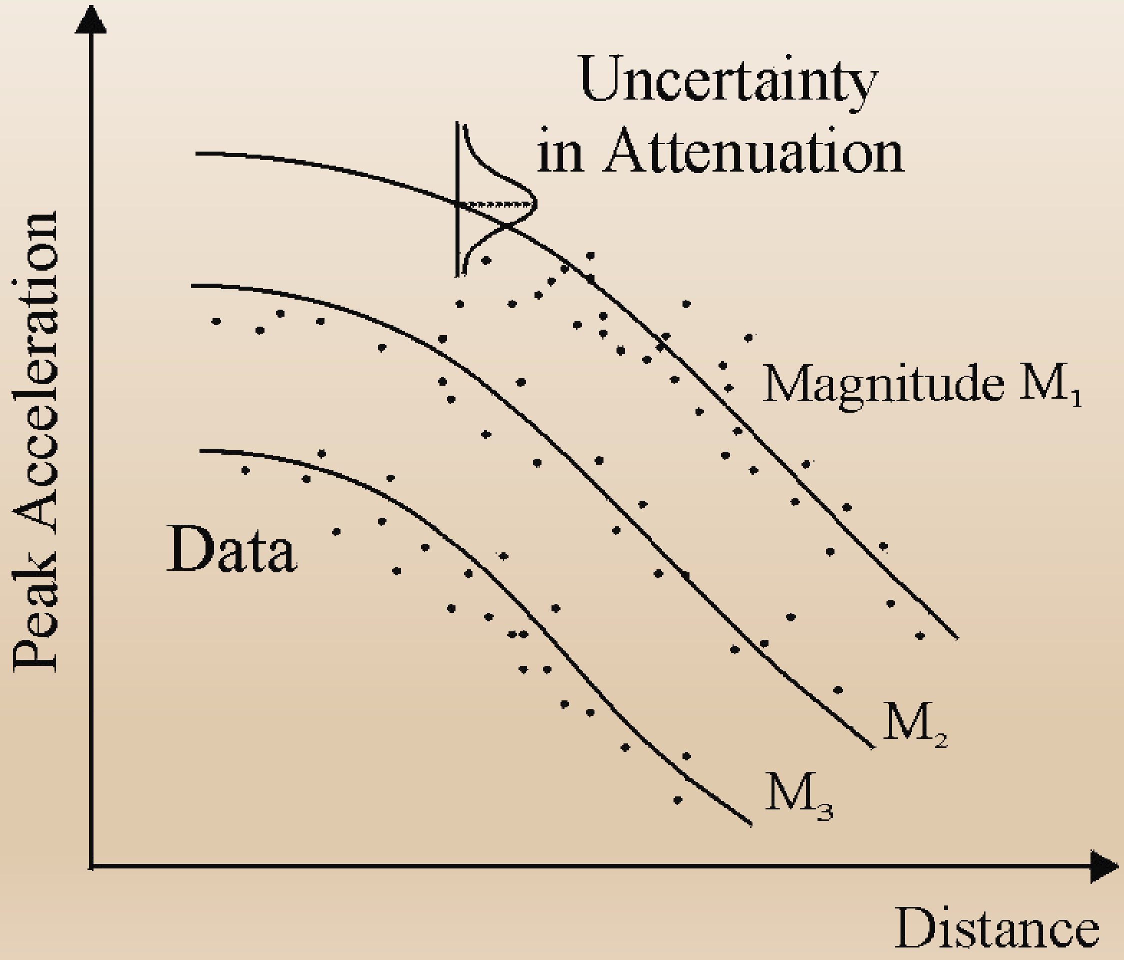


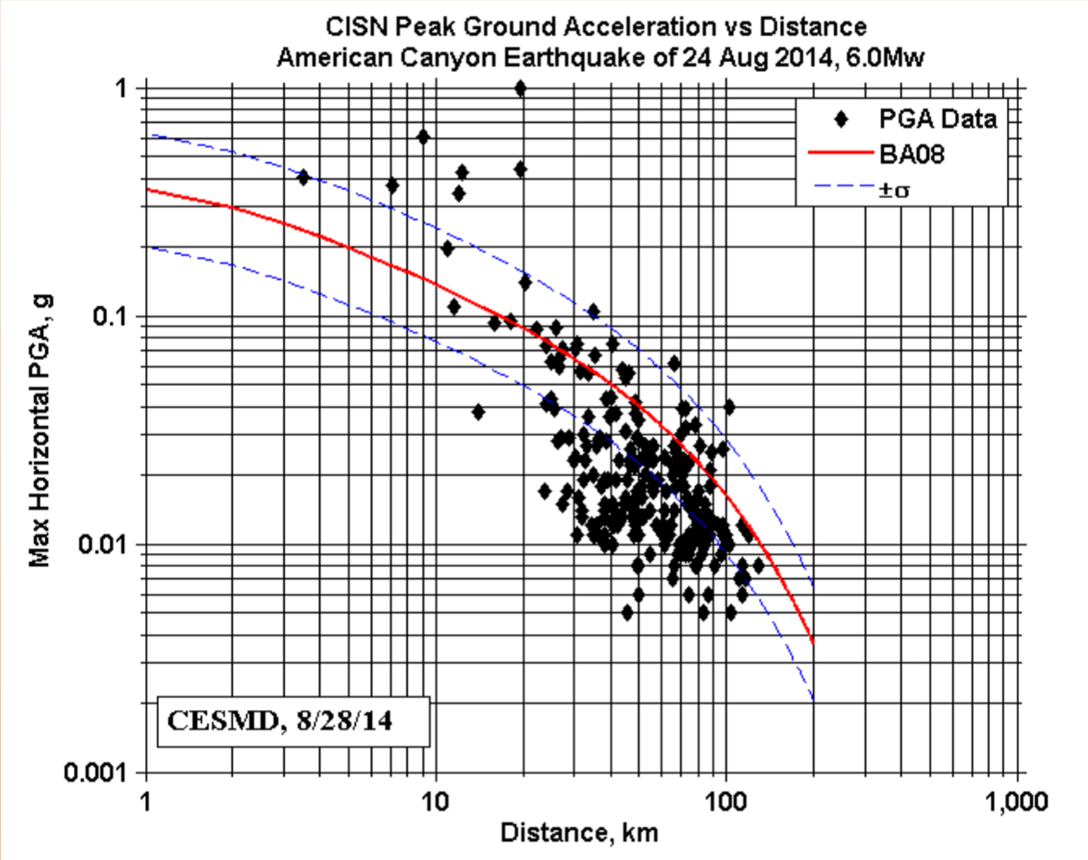
Site Class	Generalized Description	V_s^{100} (ft/s)	V_s^{30} (m/s)
A	Hard Rock	>5,000 ft/s	**>1,520 m/s**
B	Rock	2,500 to 5,000 ft/s	**760 to 1520 m/s**
C	Very Dense Soil/Soft Rock	1,200 to 2,500 ft/s	**360 to 760 m/s**
D	Stiff Soil	600 to 1,200 ft/s	**180 to 360 m/s**
E	Soft Clay Soil	<600 ft/s	**<180 m/s**
F	Requires Site Response Analysis		

- Site Class
- Basin Effects
- Ridgetop Effects

Ground Motion Analysis: Basic Components

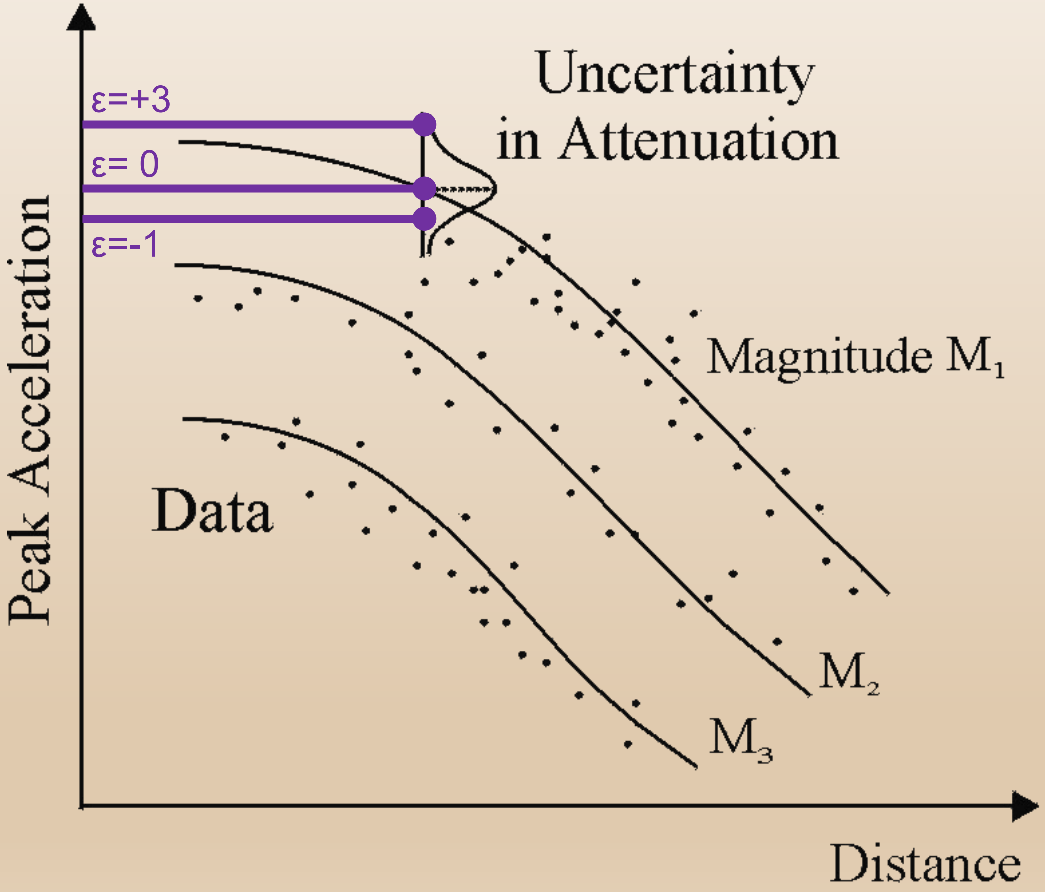
Ground Motion Prediction Equations (GMPEs)



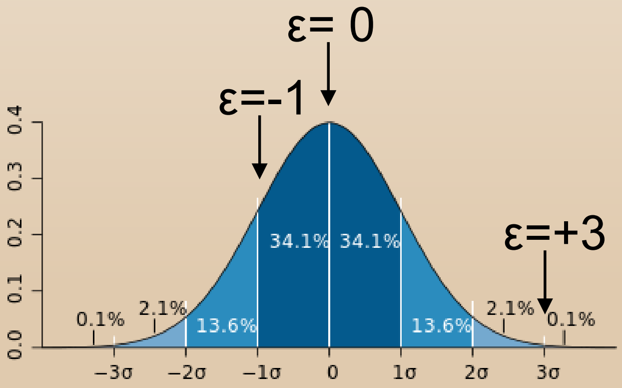


Ground Motion Analysis: Basic Components

Ground Motion Prediction Equations (GMPEs)



Given GM variability, what ground motion should be selected as a deterministic maximum?

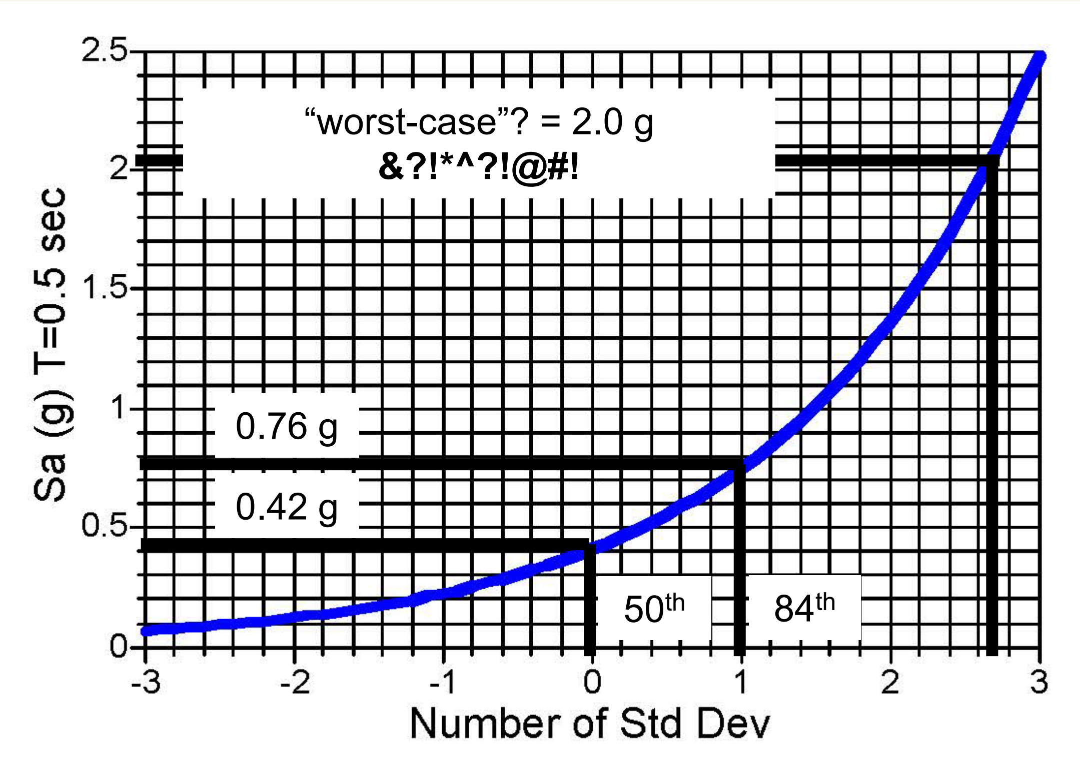


10

Deterministic Approach: Variability in Ground Motion Prediction

Common practice:
- Select 50th(median) or 84th-percentile ground motion level

But "worst-case" ground motion will exceed these selected values



Outline / Key Concepts

Introduction

- Seismic Stability Analyses in a Risk-informed Framework
- Key Guidance Documents

Deterministic Seismic Hazard Analysis (DSHA)

- Ground Motion Analyses: Basic Components
- “Worst-Case” vs. “Reasonable”

Probabilistic Seismic Hazard Analysis (PSHA)

- Seismic Source Characterization (Areal Sources, Fault Sources)
- Estimating Expected Strong Ground Motions
- Developing Seismic Hazard Curves
- Source-specific Contributions to Hazard
- Ground Motion Time Histories

Probabilistic Seismic Hazard Analysis (PSHA)

Considers all possible EQs and all possible ground motion levels

- Computes rates for each EQ/GM scenario
- Ranks scenarios in order of decreasing severity of shaking, using specified spectral acceleration
- Sums all rates of scenarios having ground motions above a specific level

Results in site-specific seismic hazard curve

Form of Hazard Calculation, with explicit treatment of ground motion aleatory variability (M, R, ε):

$$v(Sa > z) = \sum_{i=1}^{nSource} N_i(M_{\min}) \int_M \int_R \int_\varepsilon f_{mi}(M)\, f_{Ri}(r,M)\, f_\varepsilon(\varepsilon)\, P(Sa > z \mid m,R,\varepsilon)\, d\varepsilon\, dR\, dM$$

Seismic Source Characterization
Areal Source Zones (Background Seismicity)

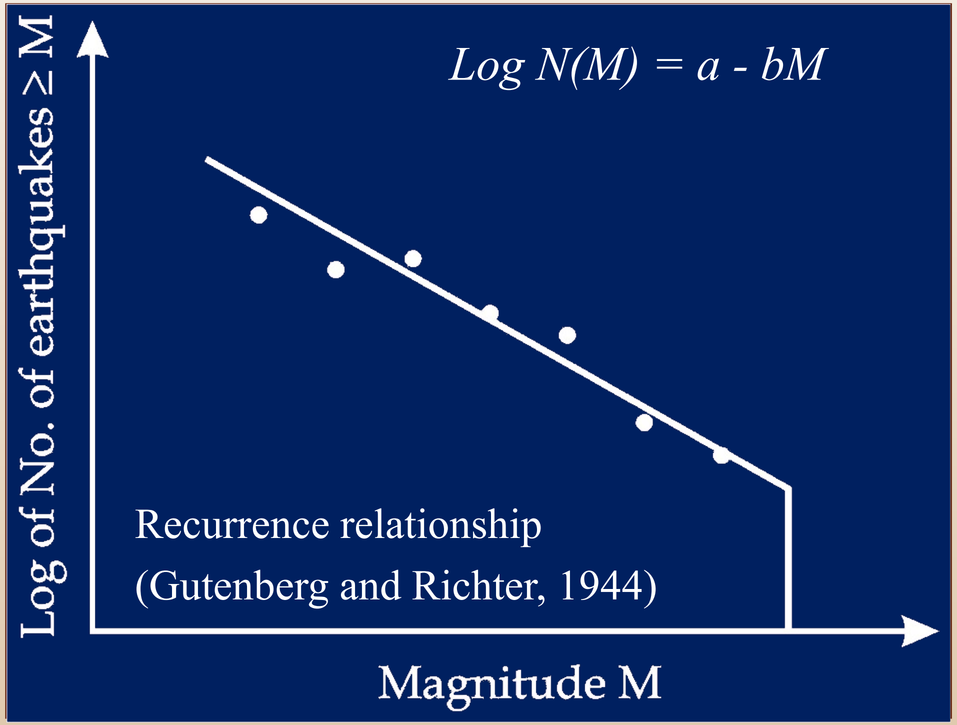
Rate of activity from historical and instrumental seismicity catalogs

- Within seismotectonic zones, assume spatial homogeneity for specified grid size
- Calculate *a*- and *b*-values in G-R relationship for each grid cell

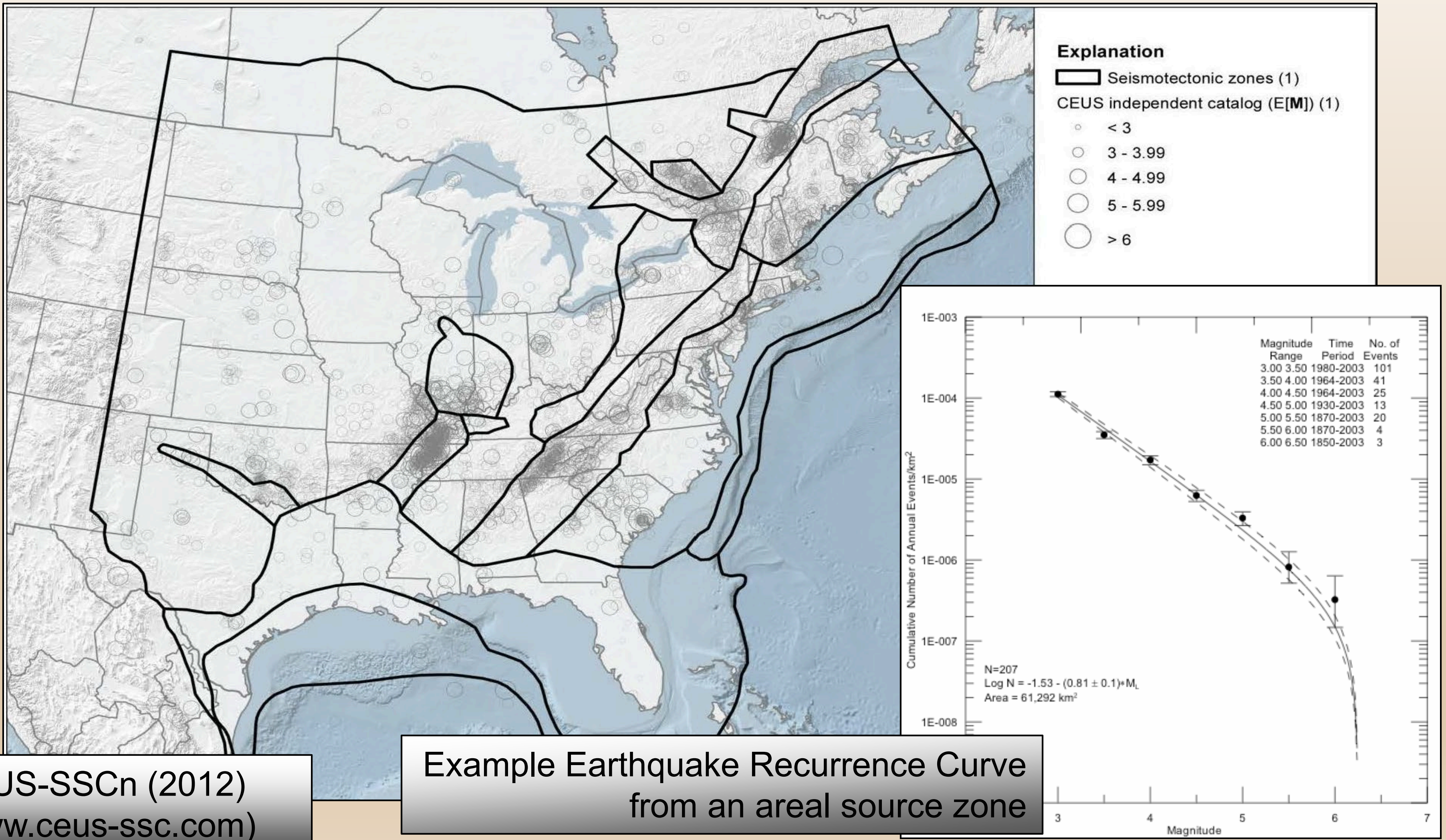
Accounts for earthquakes on unidentified faults

Maximum magnitude

- Western US usually assume M_{mx} ~ 6.5
- Central_Eastern US assume M_{mx} ~ 8



Regional Seismotectonic Zones
(example: Central and Eastern US)

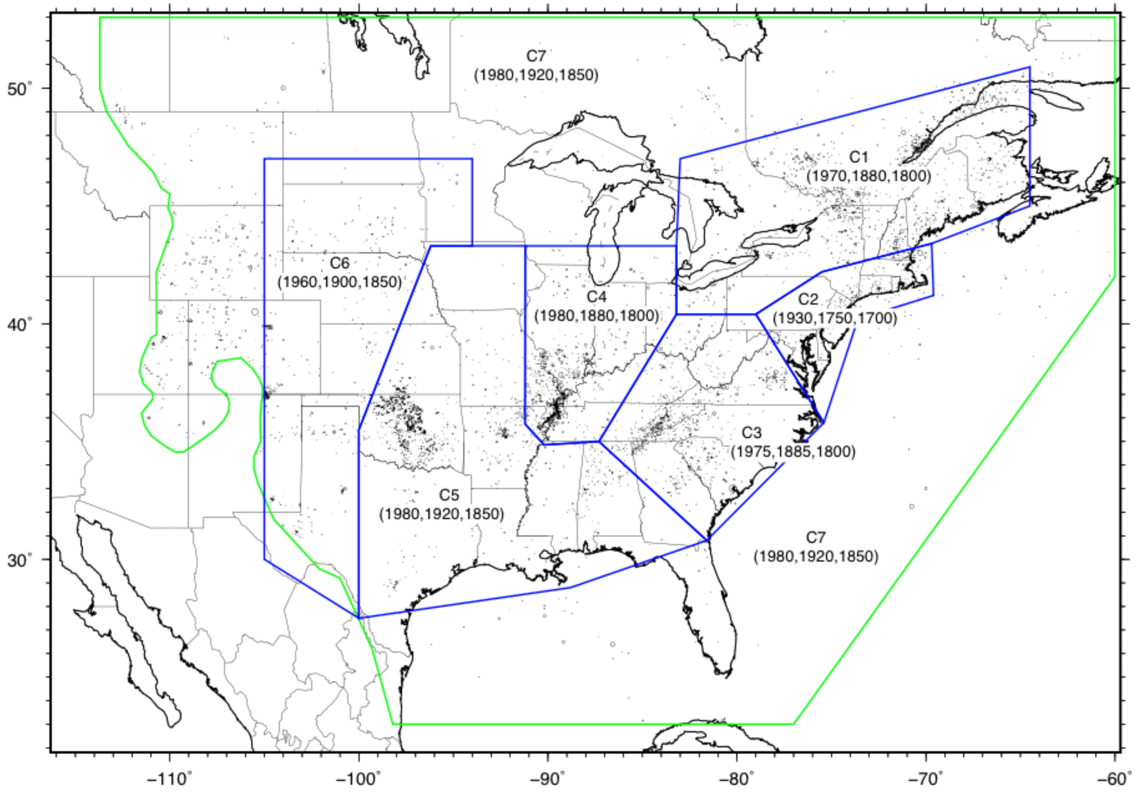


CEUS-SSCn (2012)
(www.ceus-ssc.com)

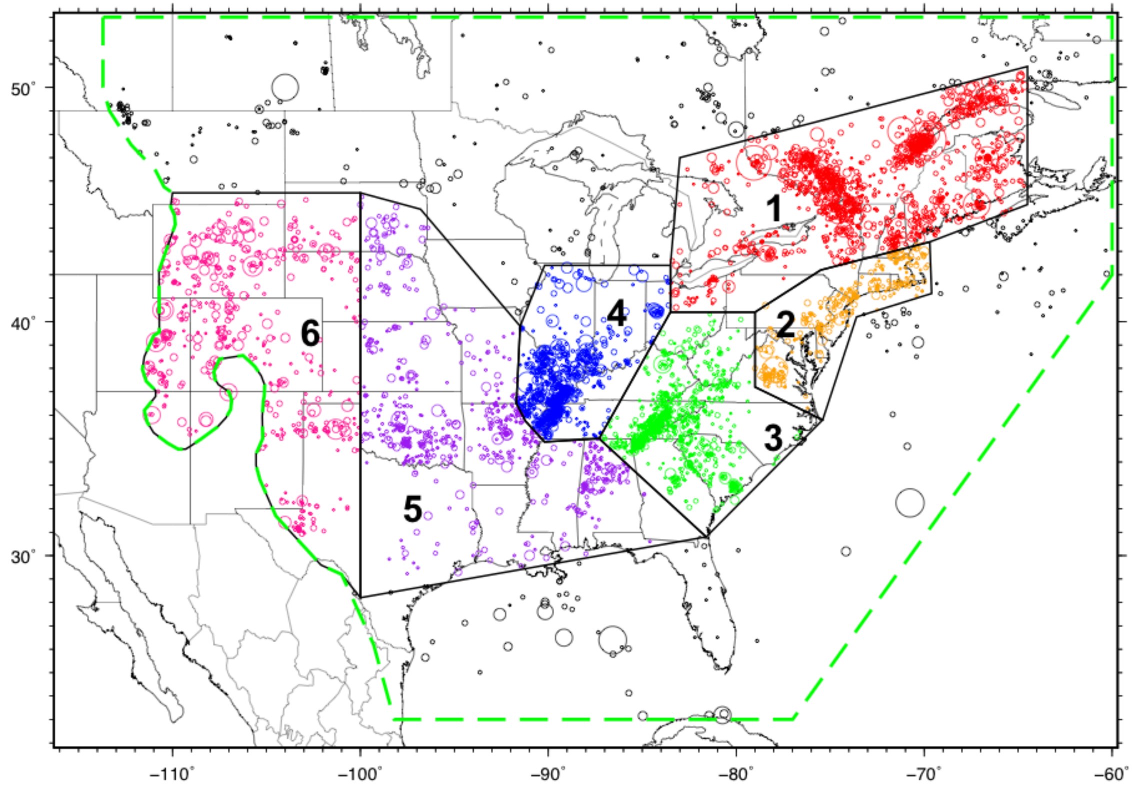
Example Earthquake Recurrence Curve
from an areal source zone

Regional Seismotectonic Zones (example: Central and Eastern US)

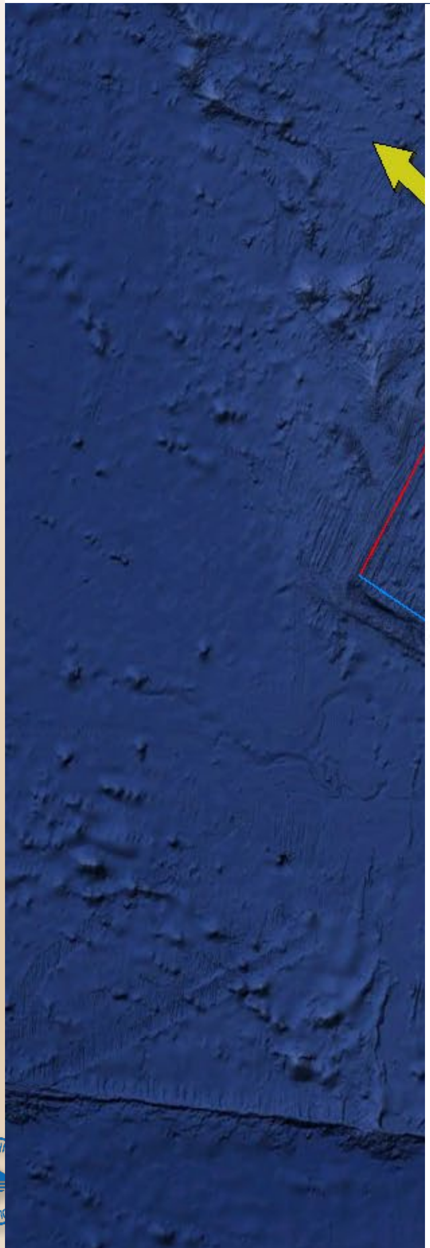
2014 NSHM CEUS catalog zones

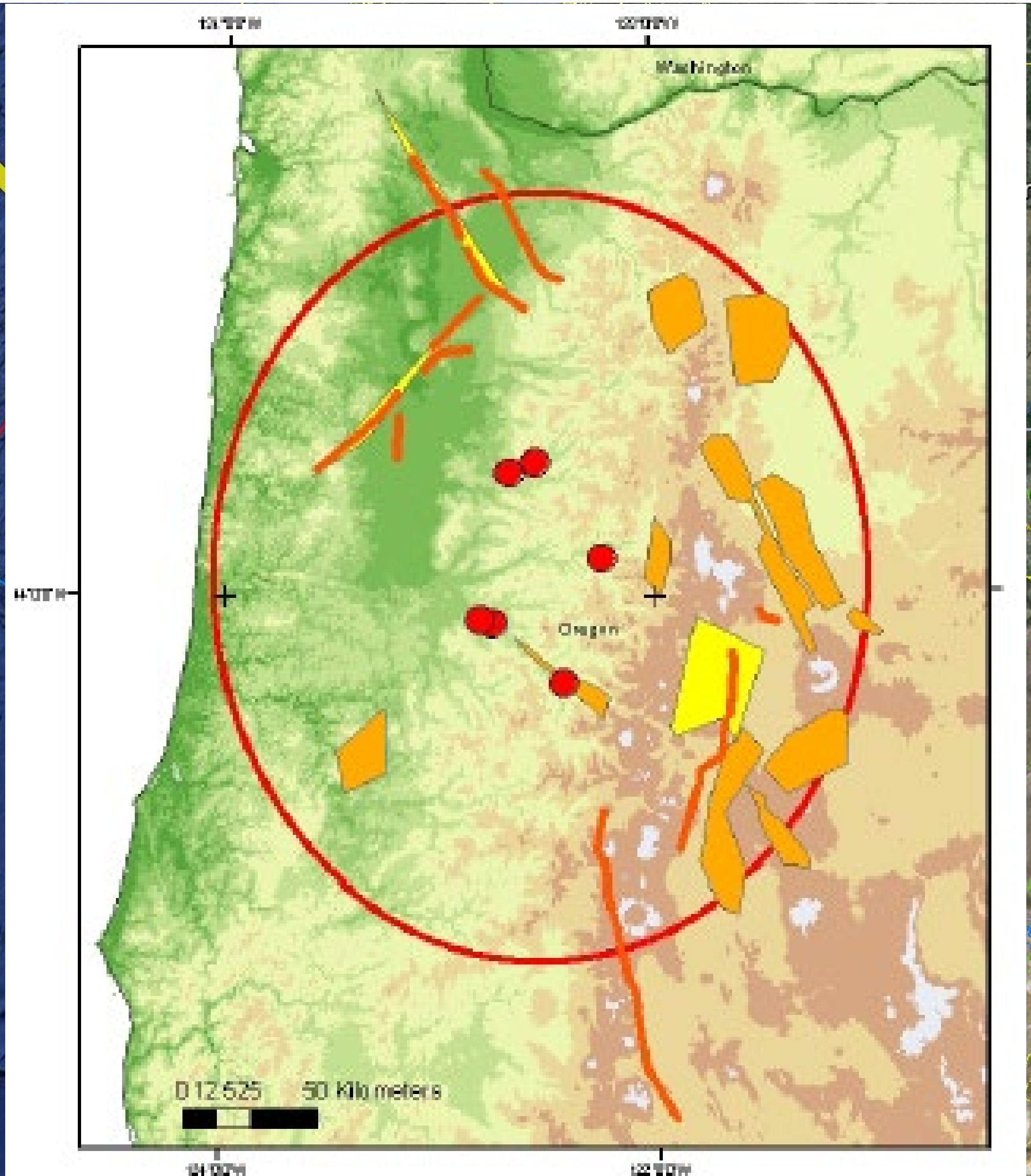


2018 NSHM CEUS catalog zones



Seismic Source Model: Faults



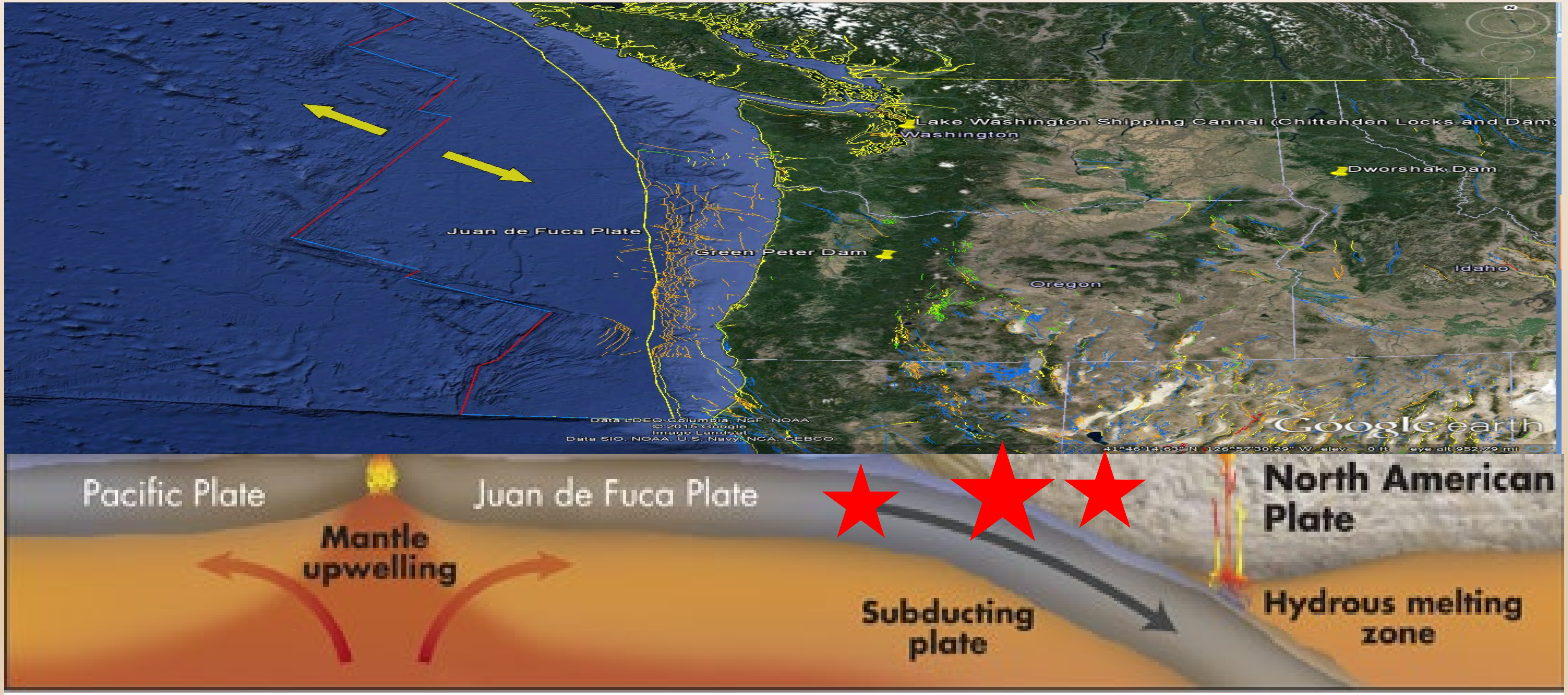


Cascadia Subduction Zone Seismic Sources

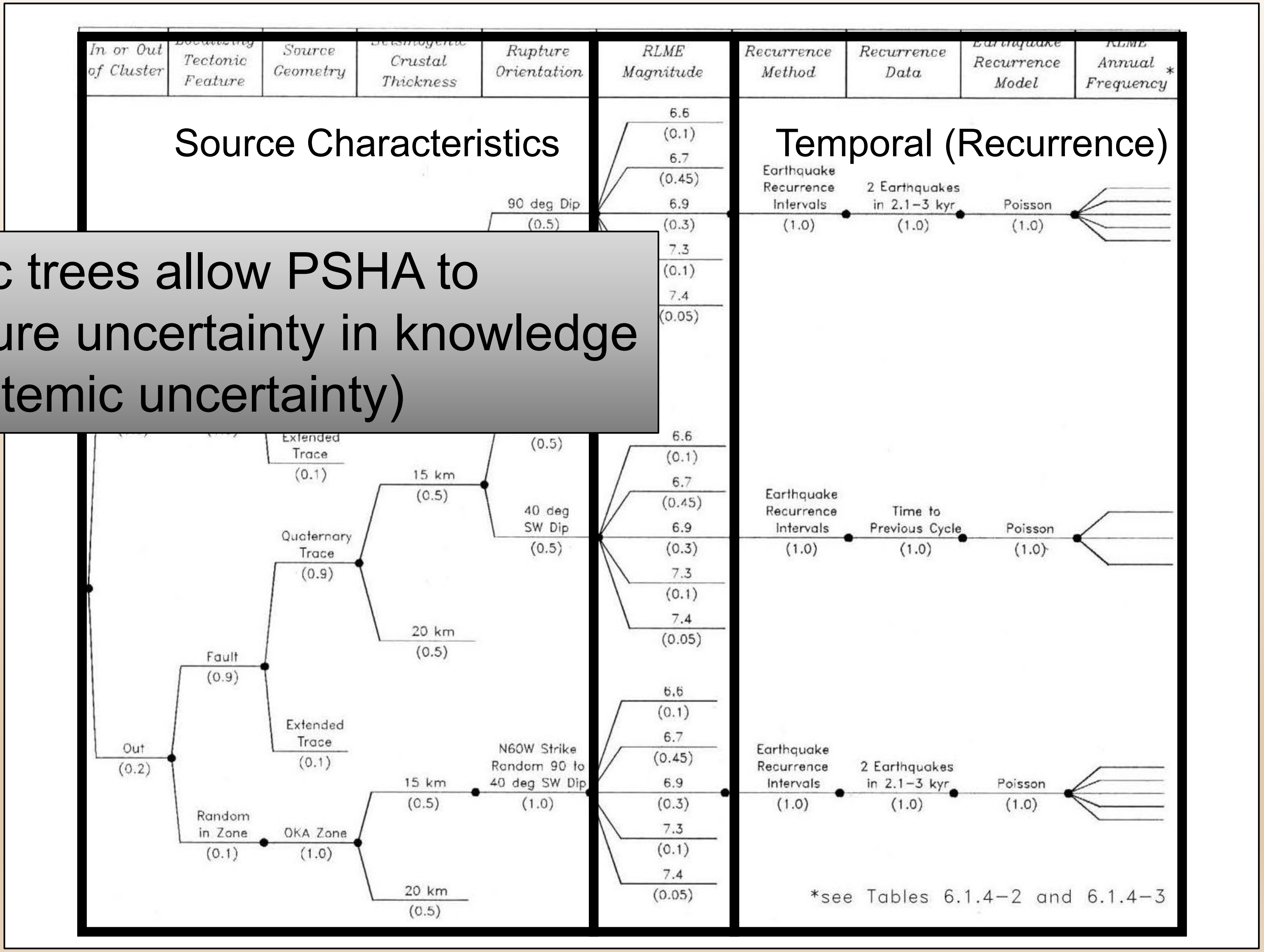
Ductile Zone
Intraslab Earthquakes
M_w from ~5.0-7.5

Locked Zone
Interface Earthquakes
M_w from ~8.0-9.2

Crustal Source
Earthquakes
M_w from ~5.0-7.0



Source Characterization Logic Tree (example)



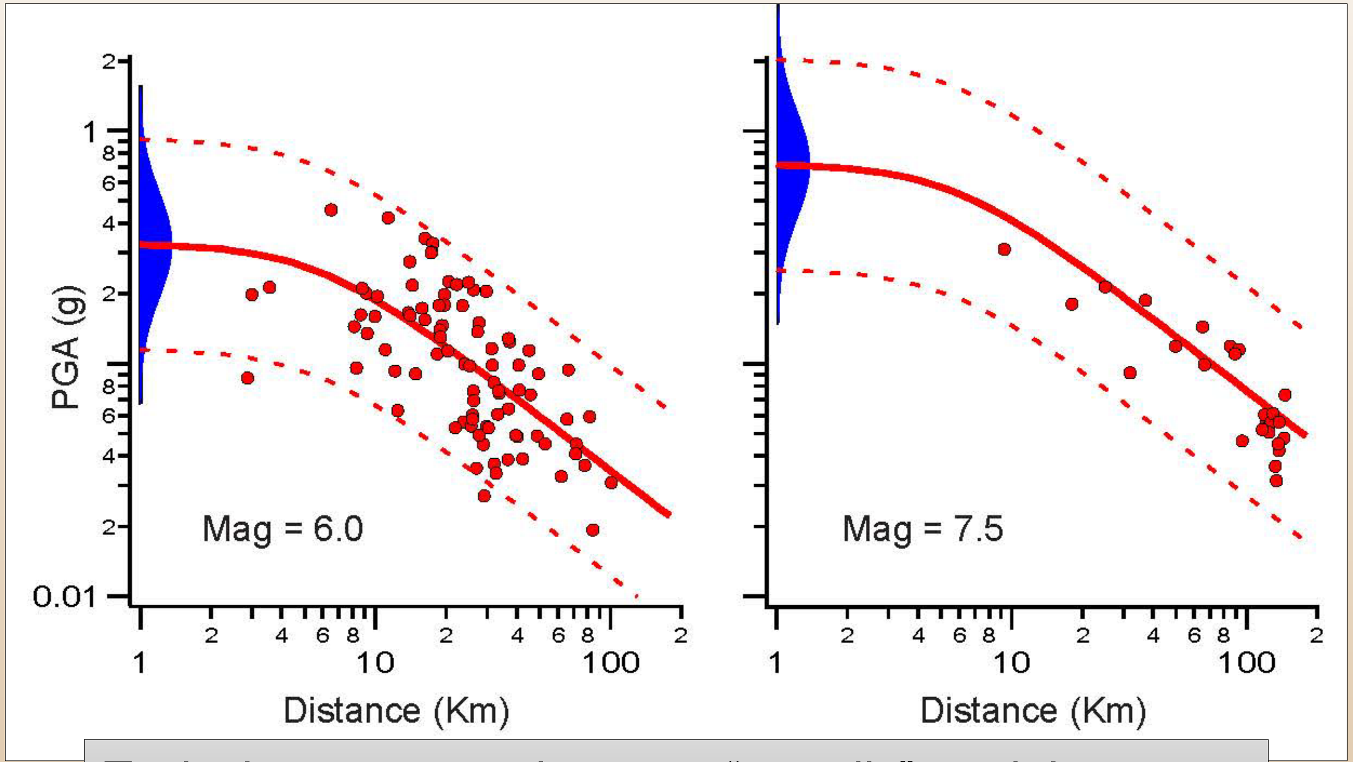
Logic trees allow PSHA to capture uncertainty in knowledge (epistemic uncertainty)

CEUS-SSCn (2012) Meers fault, Oklahoma

TVA

PSHA: Ground Motion Prediction Equations (GMPE)

Examples of GMPEs for two magnitudes, with schematic uncertainties



Typical current practice uses "ergodic" models:
- USGS (2014) for screening and regional analyses
- NGA-West2 or NGA-East for site-specific analyses

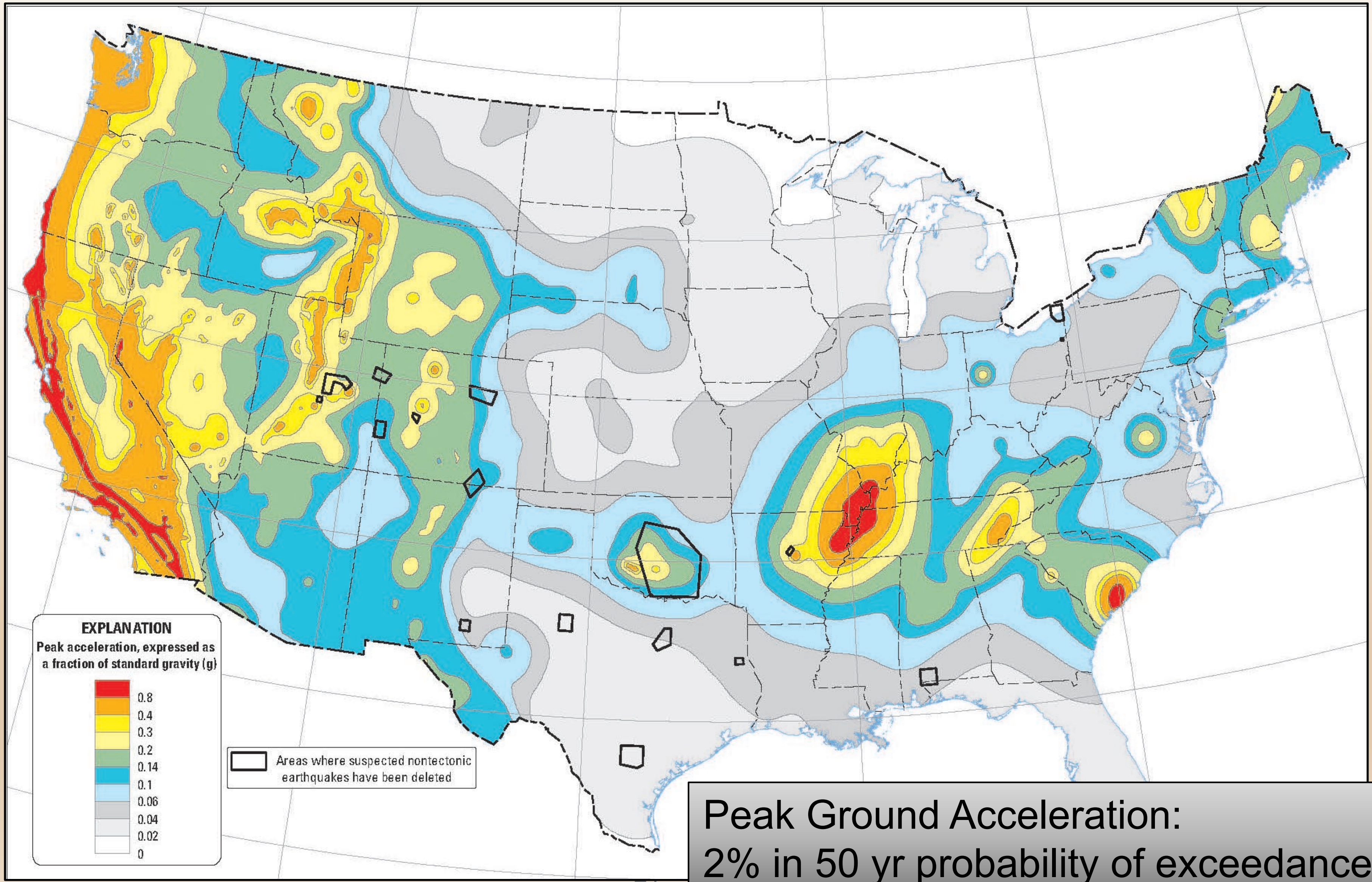
Research moving toward "non-ergodic" models

Estimating Expected Strong Ground Motions using worldwide empirical databases

"Next Generation Attenuation" equations

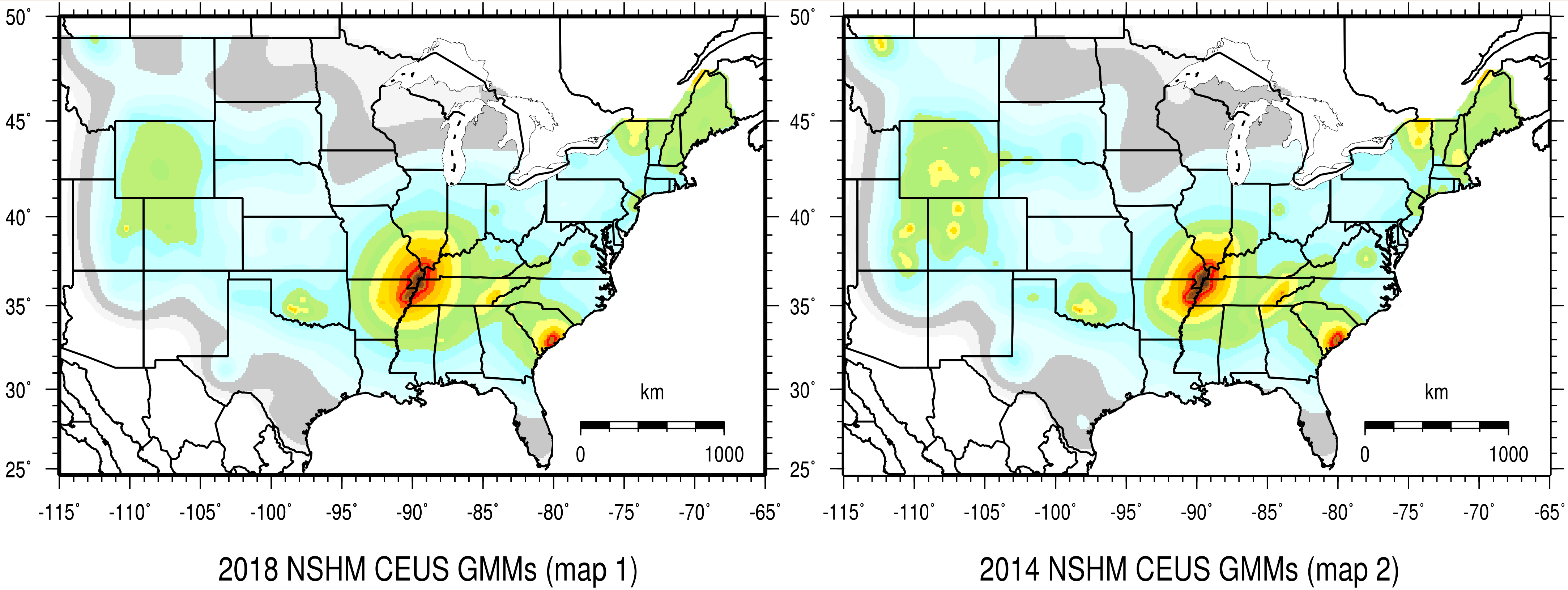
- Western US: "NGA-West 2"
- Central + eastern US: "NGA-East" (Sept 2017?)
- Cascadia Subduction Zone: "NGA-Cascadia" (2018?)

USGS (2014)
National Seismic Hazard Mapping Project

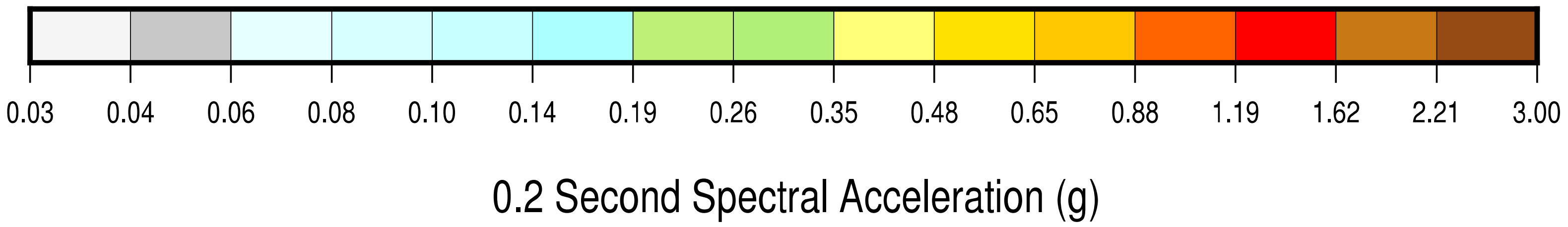


Peak Ground Acceleration:
2% in 50 yr probability of exceedance

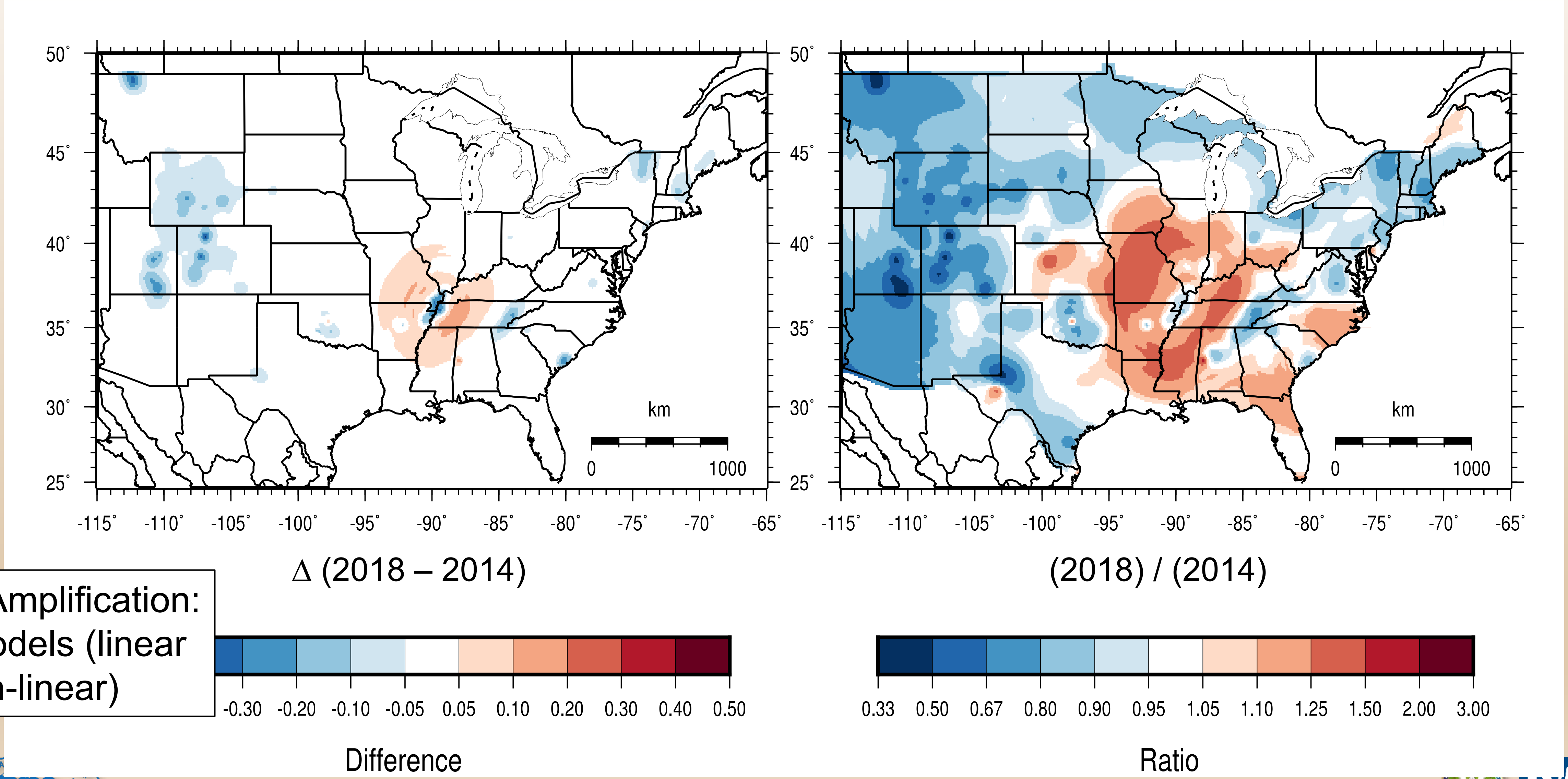
USGS (2018) – PRELIMINARY RESULTS
National Seismic Hazard Mapping Project



CEUS Amplification: New models (linear and non-linear)



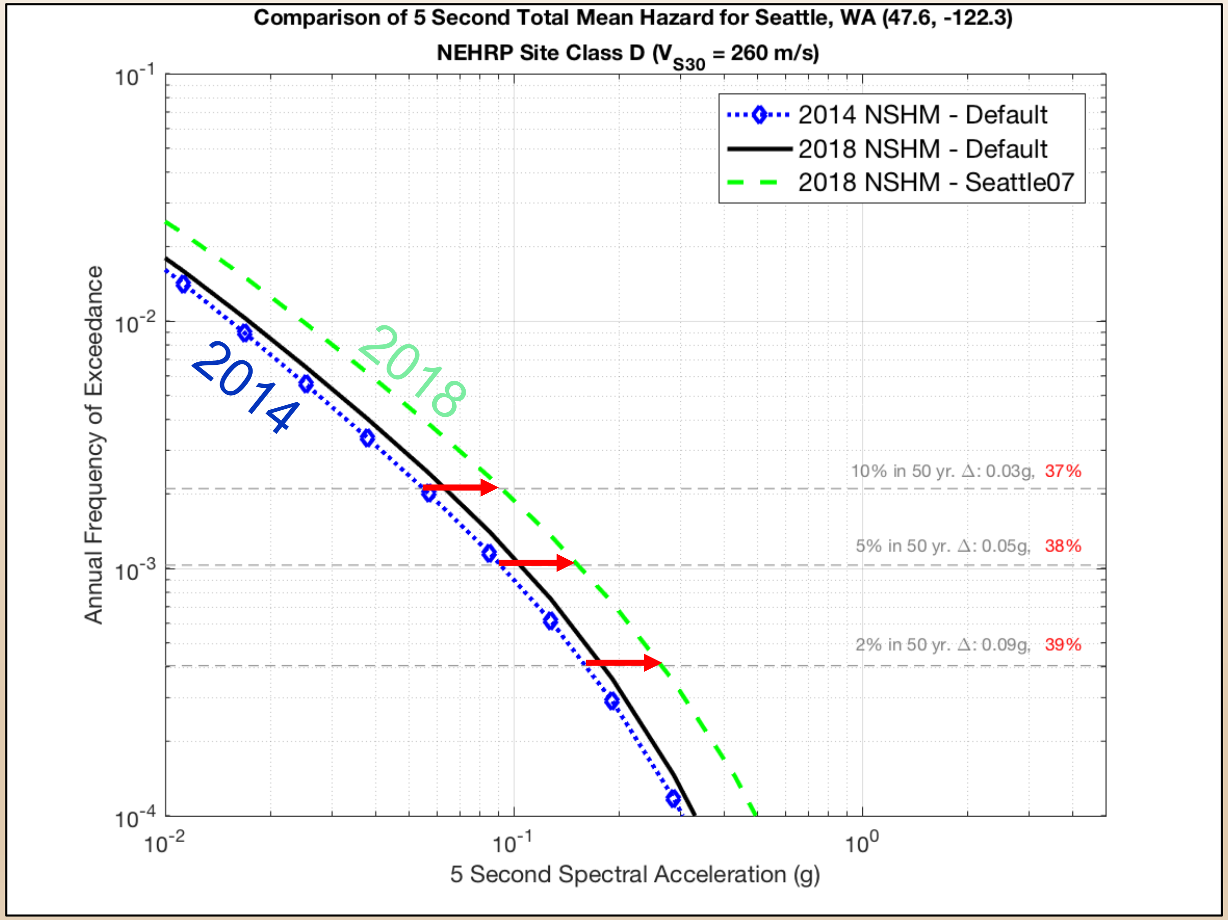
USGS (2018) – PRELIMINARY RESULTS
National Seismic Hazard Mapping Project

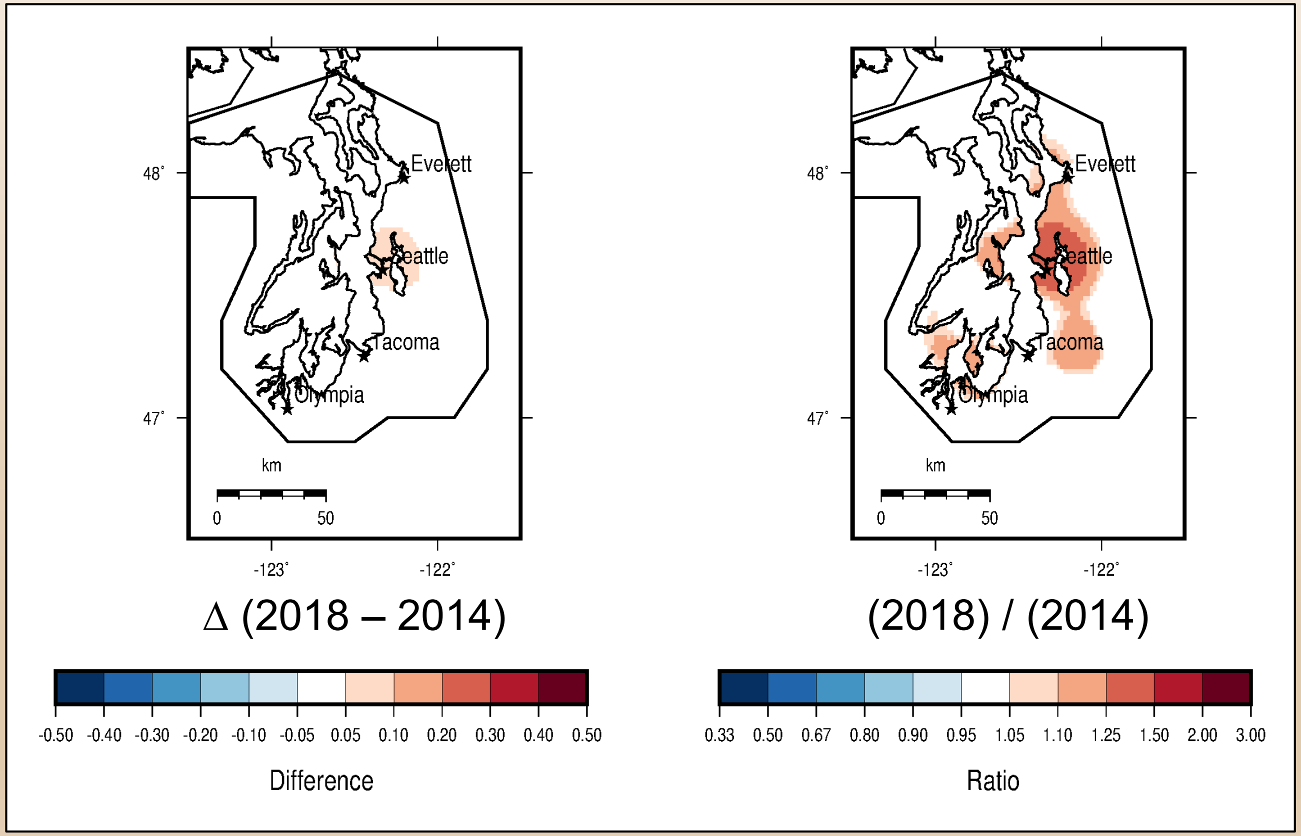


CEUS Amplification: New models (linear and non-linear)

USGS (2018) – PRELIMINARY RESULTS
National Seismic Hazard Mapping Project

WUS Amplification:
Basin models for
SF, LA, UT, WA

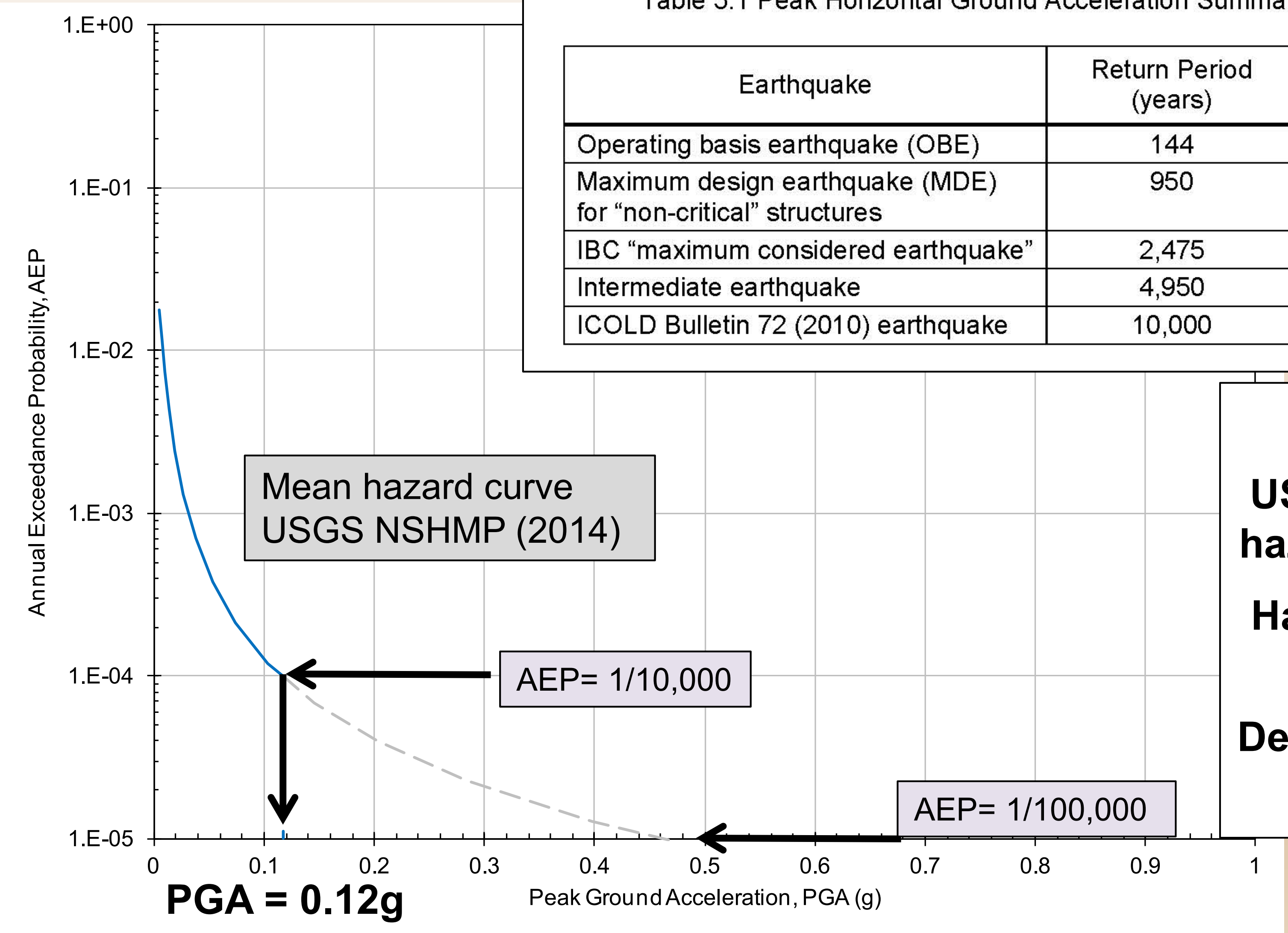




USGS Seismic Hazard Website Tools

Table 5.1 Peak Horizontal Ground Acceleration Summary (USGS 2014)

Earthquake	Return Period (years)	PGA (g)
Operating basis earthquake (OBE)	144	0.01
Maximum design earthquake (MDE) for “non-critical” structures	950	0.03
IBC “maximum considered earthquake”	2,475	0.05
Intermediate earthquake	4,950	0.07
ICOLD Bulletin 72 (2010) earthquake	10,000	0.10



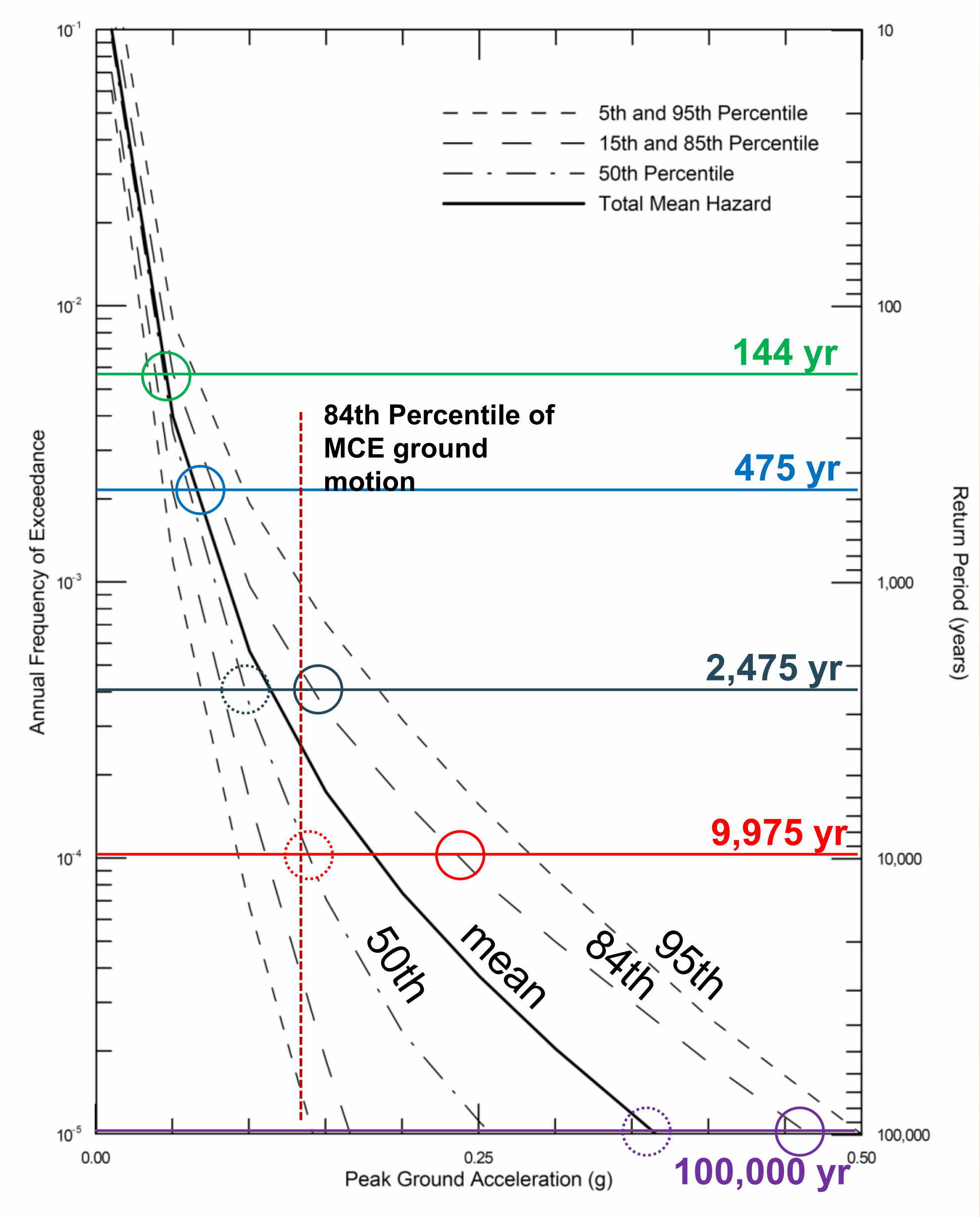
Important Note:

USGS website tools acceptable for regional hazard screening and Periodic Assessments

Hazard estimates not acceptable for critical decisions or engineering design

Detailed analyses required for high-level risk assessments and design

Site-Specific Seismic Hazard Curve



Site-Specific Probabilistic Seismic Hazard Analysis (PSHA)

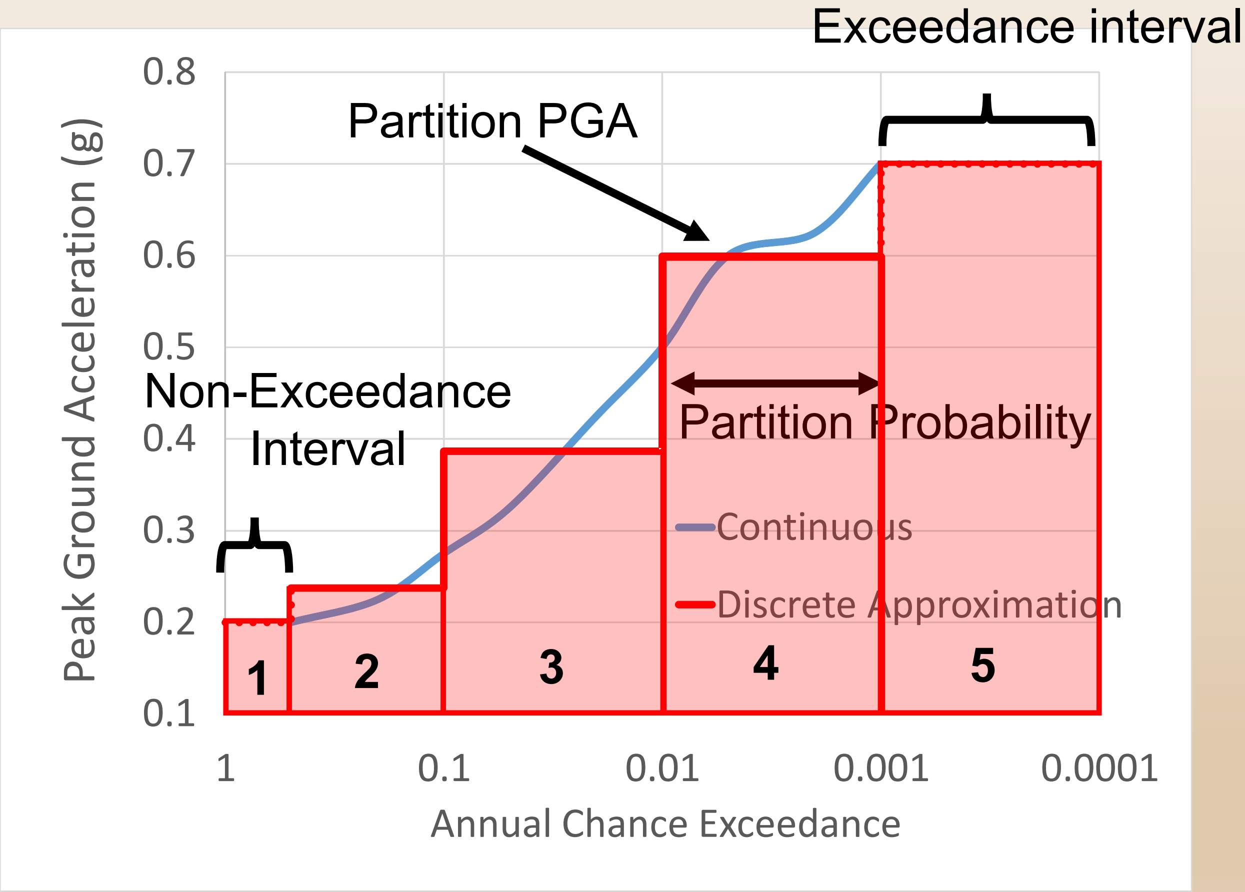
For design

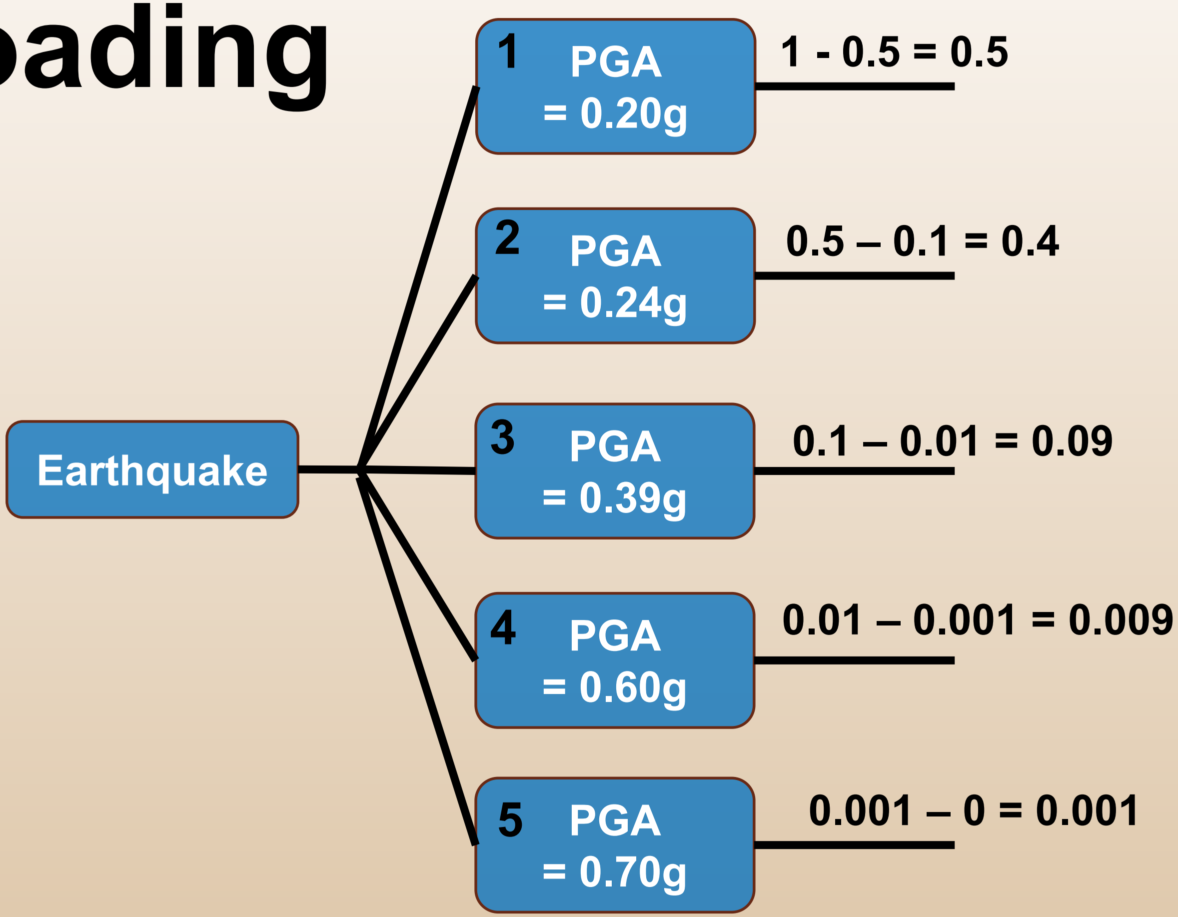
- Operating Basis EQ (OBE, 144 yr)
- MCE GM (50th or 84th percentile)

For risk assessment

- 2,475 yr GM (AEP=4xE-04)
- 9,975 yr GM (AEP=1xE-04)
- 100,000 yr GM (AEP=1xE-05) (if GMPE allow)
- 50th or 84th percentile

Example: Seismic Loading

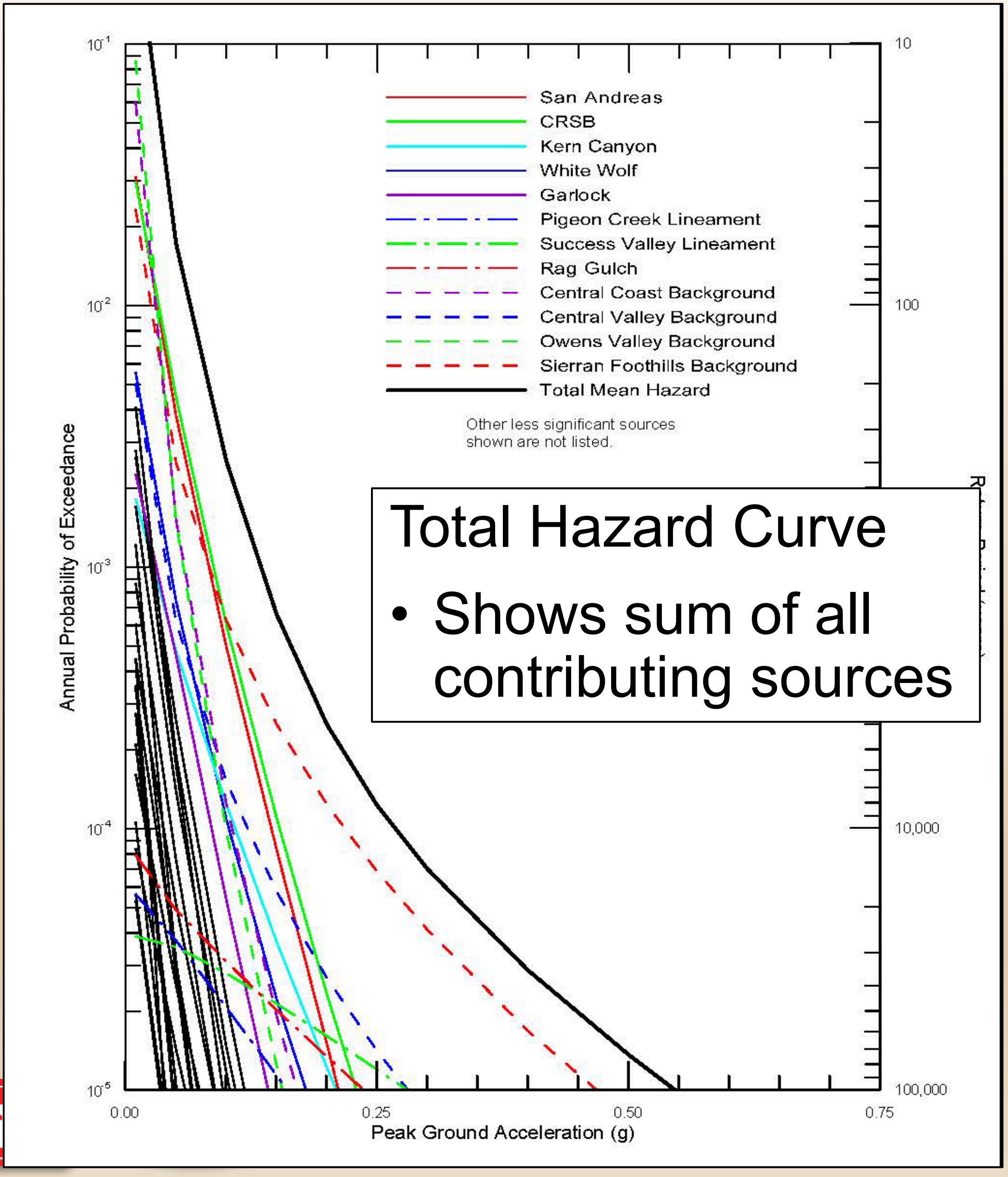




$\sum$ (partition probabilities)= 1

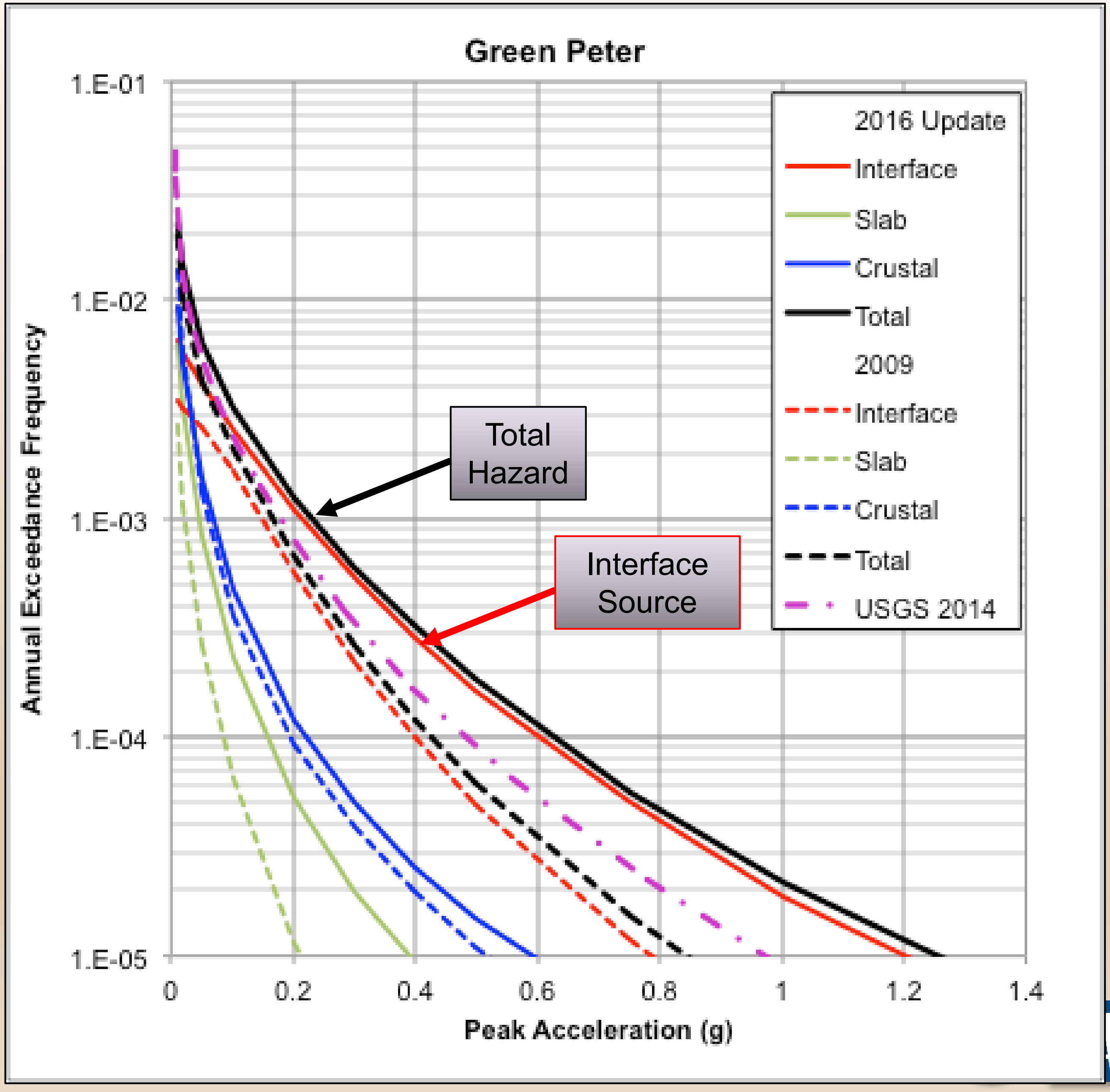
These partitions are mutually exclusive

Site-Specific Seismic Hazard Curve: Fault Contributions



Total Hazard Curve

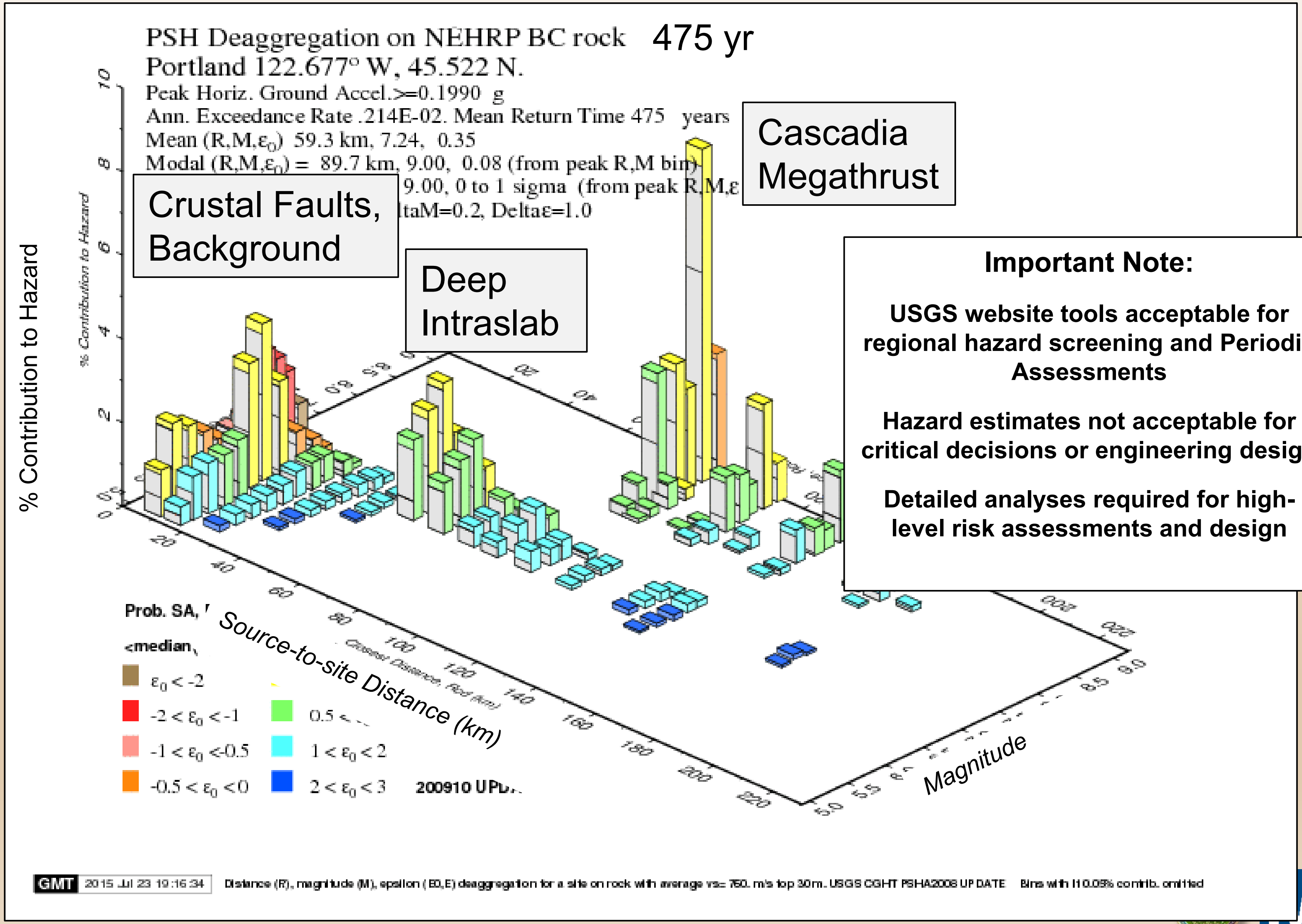
- Shows sum of all contributing sources



Site-Specific Seismic Hazard Curve: Fault Contributions

De-aggregation Plot

- Shows distance and magnitude characteristics of specific sources
- Identify primary contributors to hazard
- Use for selecting historical GM records while developing GM time histories



Important Note:

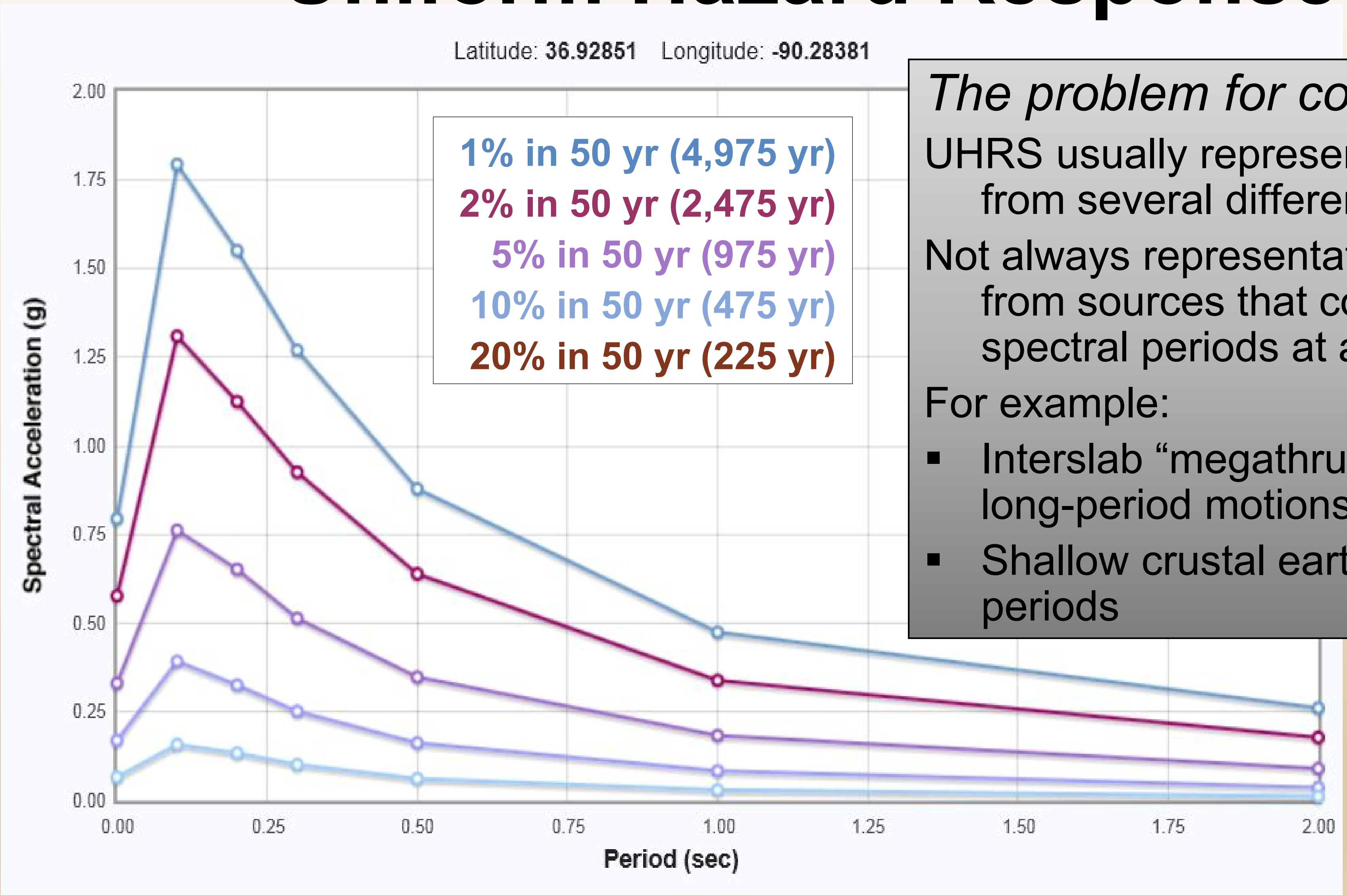
USGS website tools acceptable for regional hazard screening and Periodic Assessments

Hazard estimates not acceptable for critical decisions or engineering design

Detailed analyses required for high-level risk assessments and design

U.S. DEPARTMENT OF THE INTERIOR BUREAU OF RECLAMATION

Uniform Hazard Response Spectra



The problem for complex structural analyses:

UHRS usually represent expected ground motions from several different seismic sources

Not always representative of spectral accelerations from sources that contribute most to certain spectral periods at a site

For example:

- Interslab “megathrust” earthquakes may dominate long-period motions
- Shallow crustal earthquakes may dominate short periods

http://geohazards.usgs.gov/hazardtool/application.php

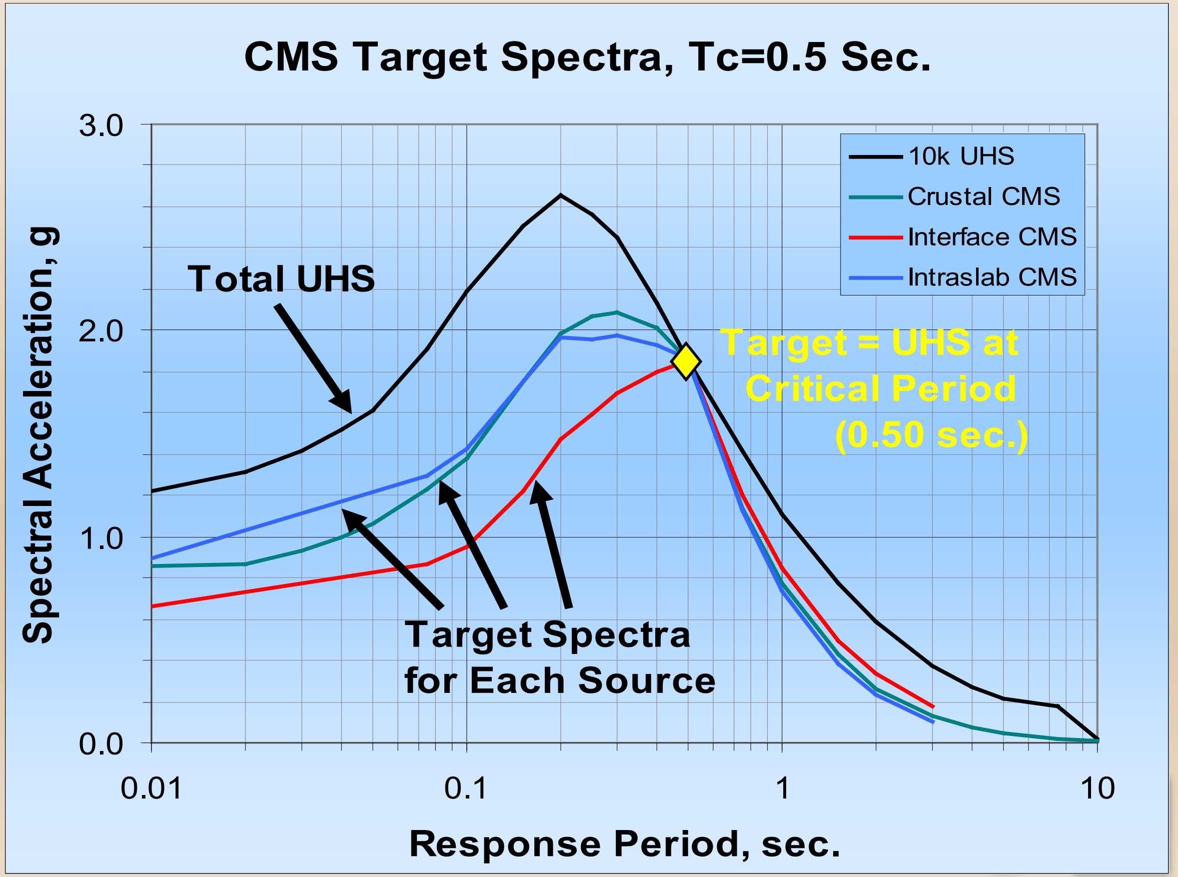
Conditional Mean Spectra (CMS)

"Composite" response spectrum obtained from multiple source-specific EQs

- Conditioned on peak response for a specified target spectral period (i.e., 0.3 sec)
- Target spectral period: typically chosen as the critical period of a structure

The sticky parts:

- Critical periods for structures rarely known
- Structures may have nonlinear behavior
- Many potential critical periods should be considered
- Central range of response periods may be best depicted by UHRS
- CMS can also be applied outside this central range of response periods



Ground Motion Time Histories

Using only PGA from PSHA neglects timing and duration of strong shaking

Instead, use ground motion records from actual EQs

- Similar to expected EQ at the site
- De-aggregate hazard to understand main contributors and types of EQs

"Scale" the history of expected ground motion to fit site hazard

- Scaling vs. Spectral Matching
- Select several historical earthquake records with comparable magnitude, shaking duration, fault type, basin effects, etc.

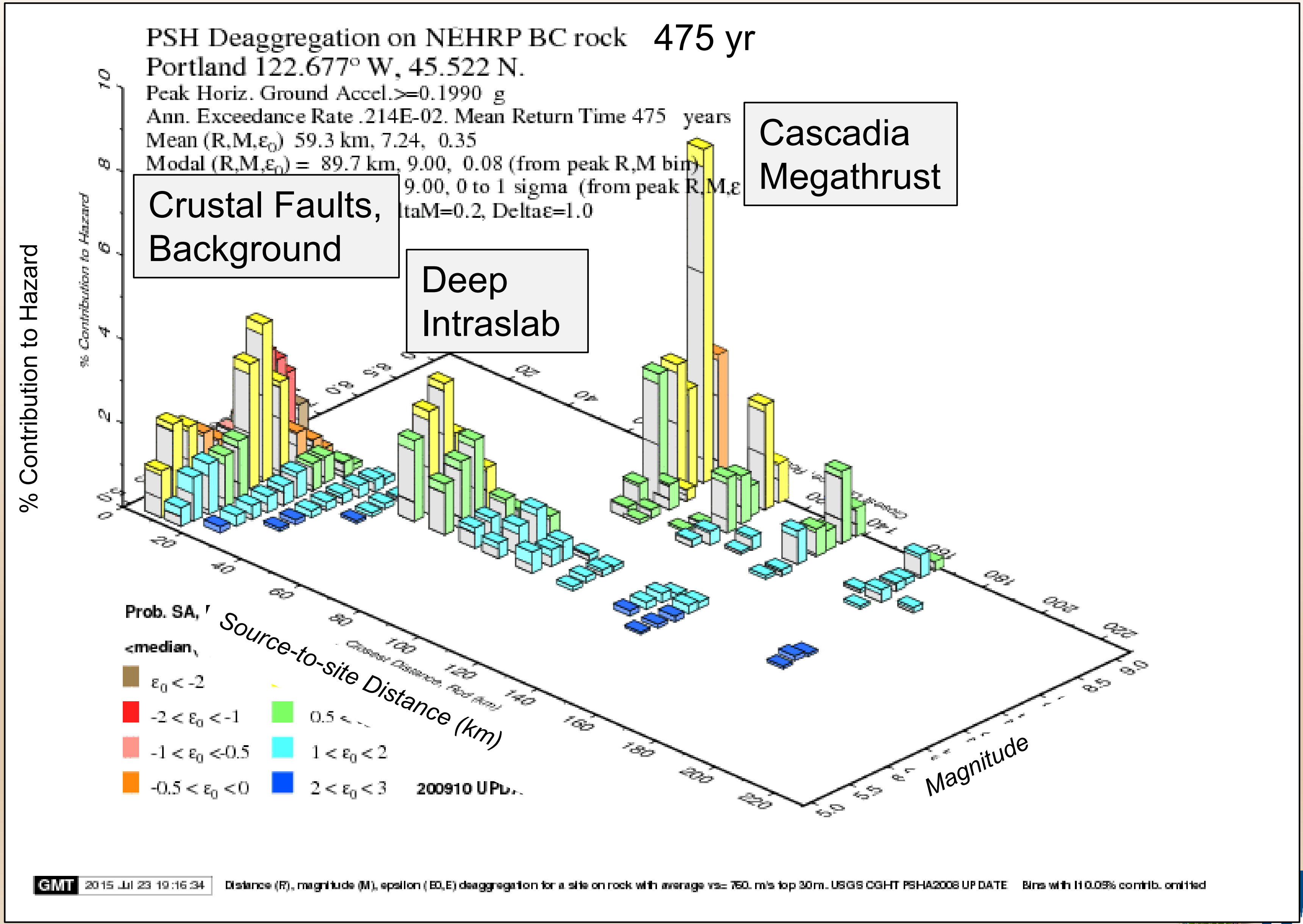
Suites of time histories should be developed for multiple return periods

Needed for dynamic stability analyses (*FLAC*, *SHAKE,* or *LS-DYNA)*

Ground Motion Time Histories

De-aggregation Plot

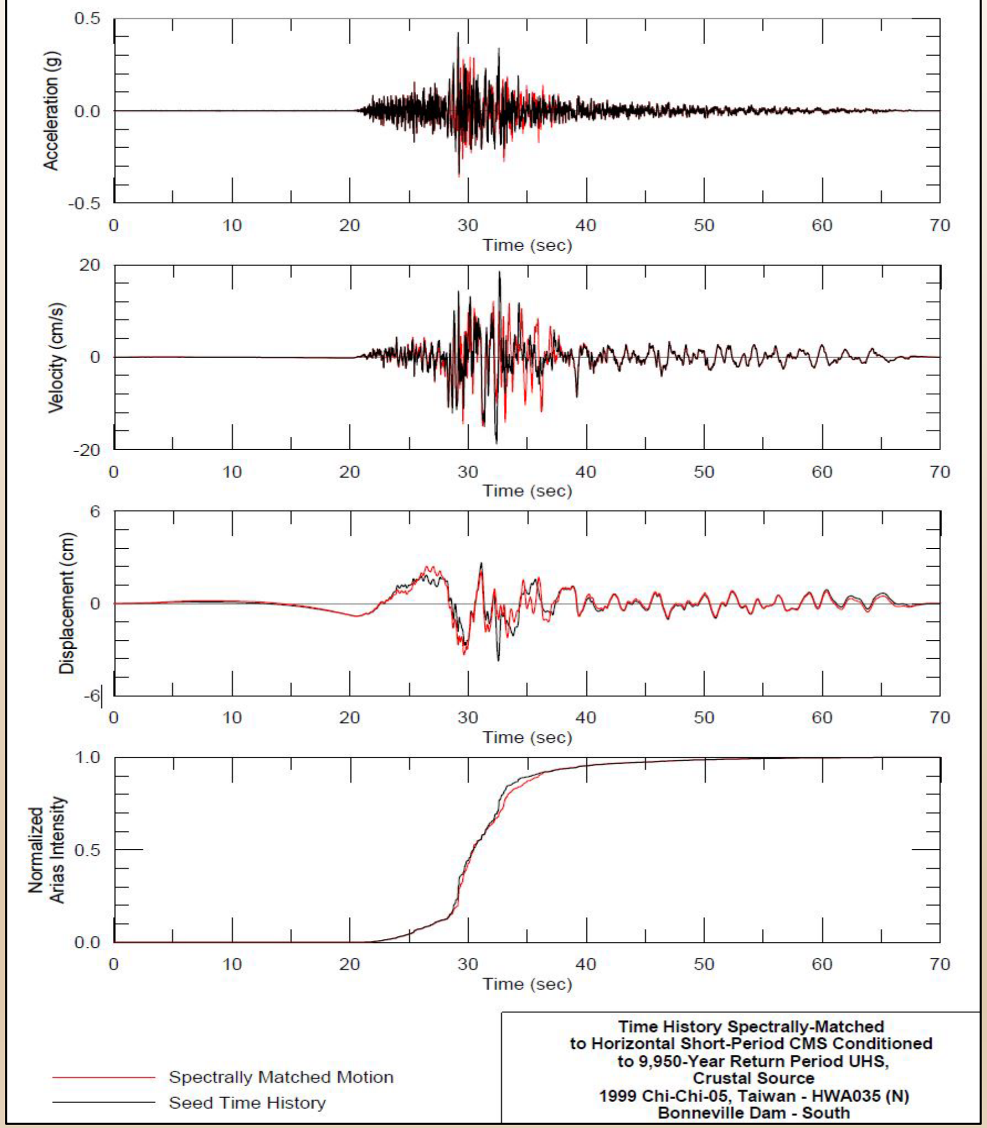
- Shows distance and magnitude characteristics of specific sources
- Identify primary contributors to hazard
- Use for selecting historical GM records while developing GM time histories



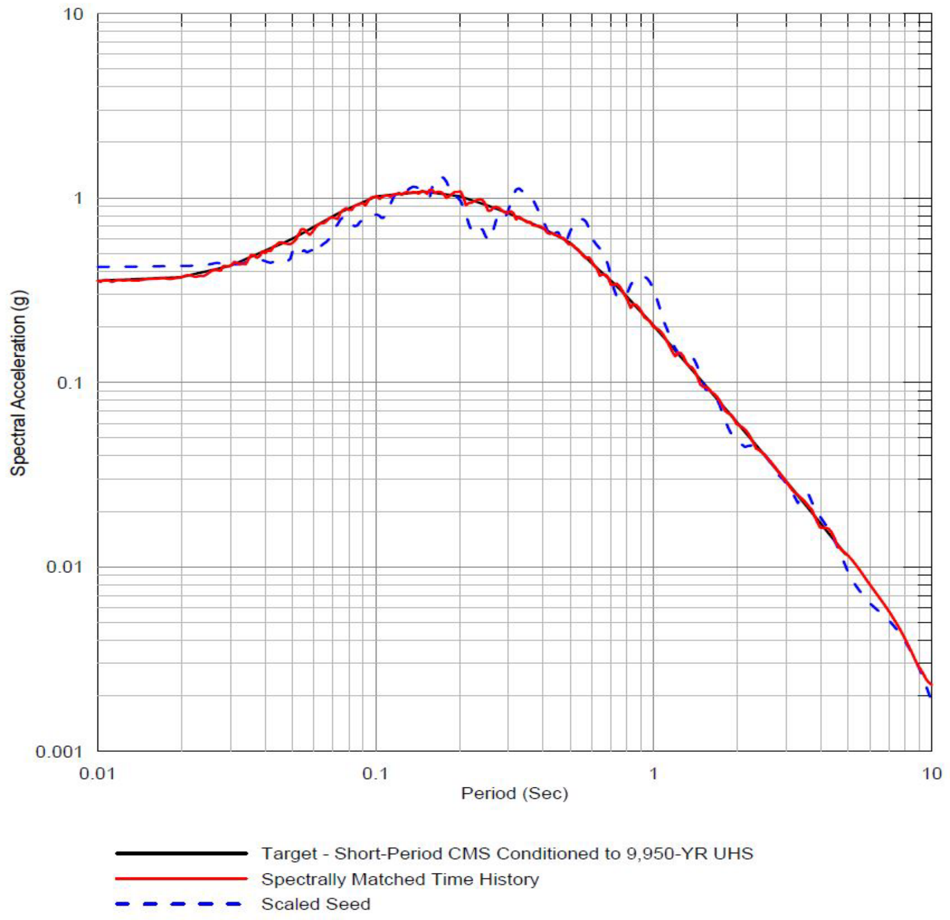
Ground Motion "Seed" Time Histories

For comparable hazard-driving seismic source:

- Similar source type, magnitude, distance, and site conditions
- Identify reliable historical GM record(s)
- Scale or match historical record to target spectrum

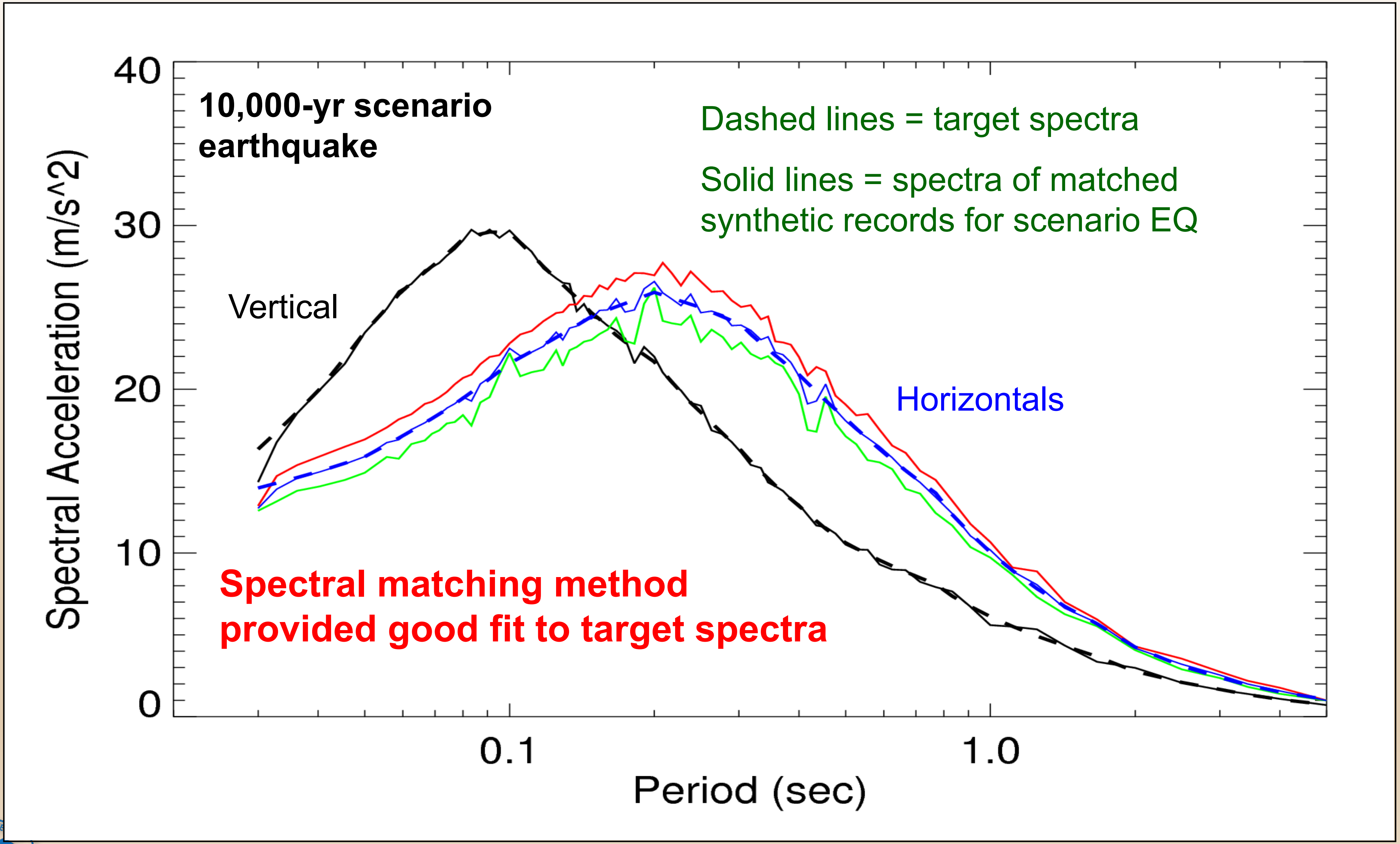


Time History Spectrally-Matched
to Horizontal Short-Period CMS Conditioned
to 9,950-Year Return Period UHS,
Crustal Source
1999 Chi-Chi-05, Taiwan - HWA035 (N)
Bonneville Dam - South

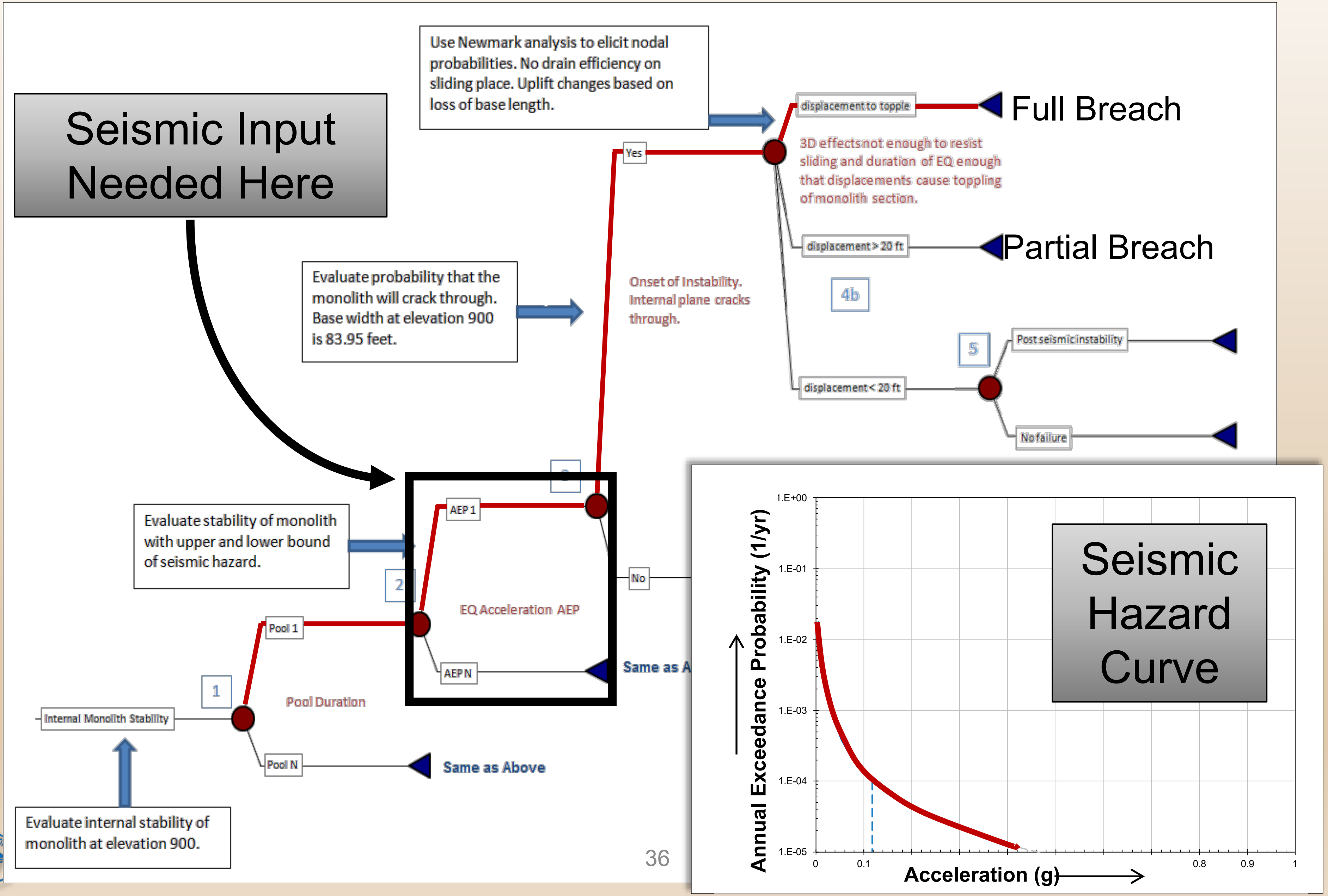


Response Spectra for Time History
Spectrally-Matched to Horizontal Short-Period CMS
Conditioned to 9,950-Year Return Period UHS,
Crustal Source
1999 Chi-Chi-05, Taiwan - HWA035 (N)
Bonneville Dam - South

Ground Motion Time Histories



Seismic Loading in Risk Assessments: PFMA Event Tree



Outline / Key Concepts

Introduction

- Seismic Stability Analyses in a Risk-informed Framework

Deterministic Seismic Hazard Analysis (DSHA)

- Ground Motion Analyses: Basic Components
- “Worst-Case” vs. “Reasonable”

Probabilistic Seismic Hazard Analysis (PSHA)

- Seismic Source Characterization (Areal Sources, Fault Sources)
- Estimating Expected Strong Ground Motions
- Developing Seismic Hazard Curves
- Source-specific Contributions to Hazard
- Ground Motion Time Histories

Thank You