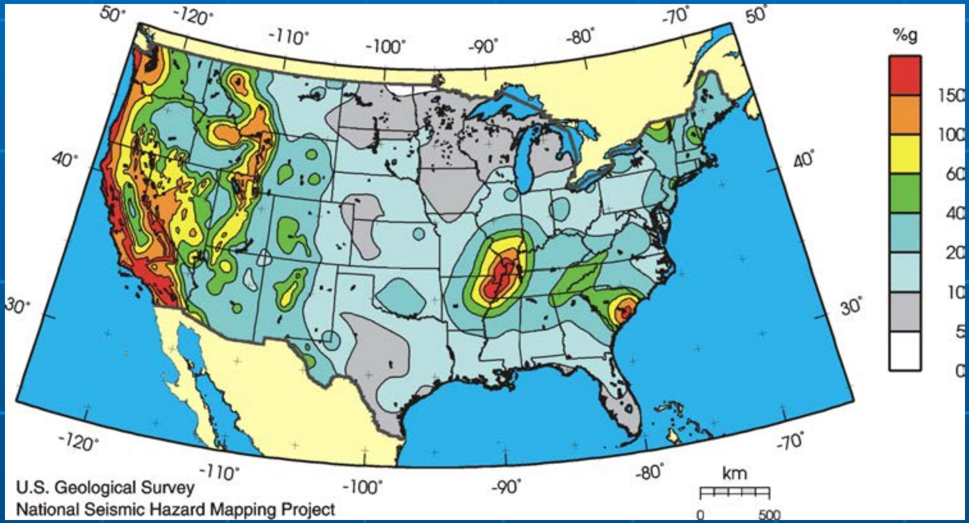
The 2007 U.S. National Seismic Hazard Maps: Methodology and Issues



National Seismic Hazard Map Advisory Panel Meeting May 3-4, 2007

http://earthquake.usgs.gov/hazmaps/

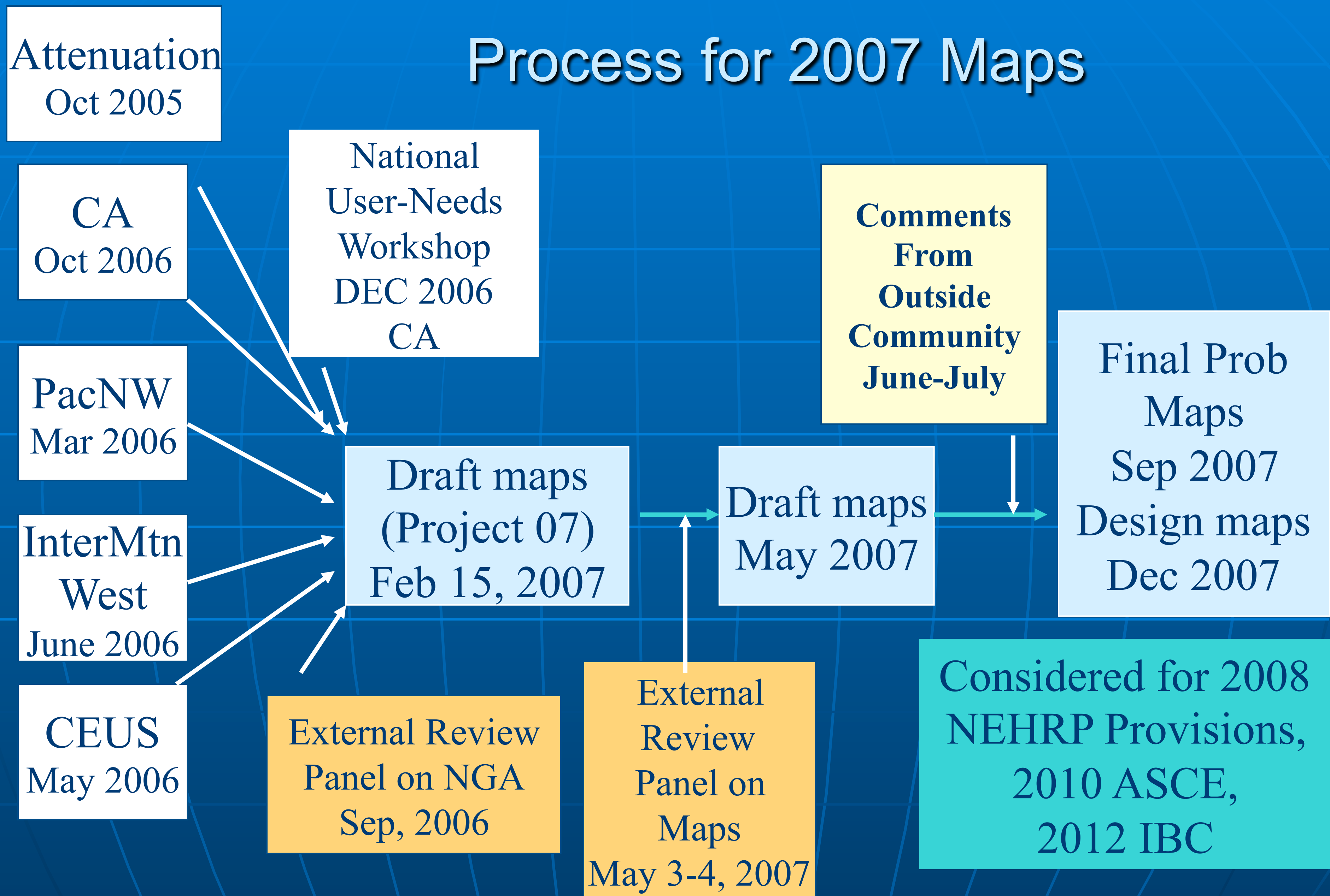
USGS
science for a changing world

USGS National

- Lunch: Menu needed by 10 am
- Parking: Need visitor pass
- Travel reimbursement: Sarah sent forms
- Approval sheet:

- Goals:
  - 1. Improve the national seismic hazard maps using new science based information
  - 2. Assess the epistemic and aleatory uncertainties

Process for 2007 Maps



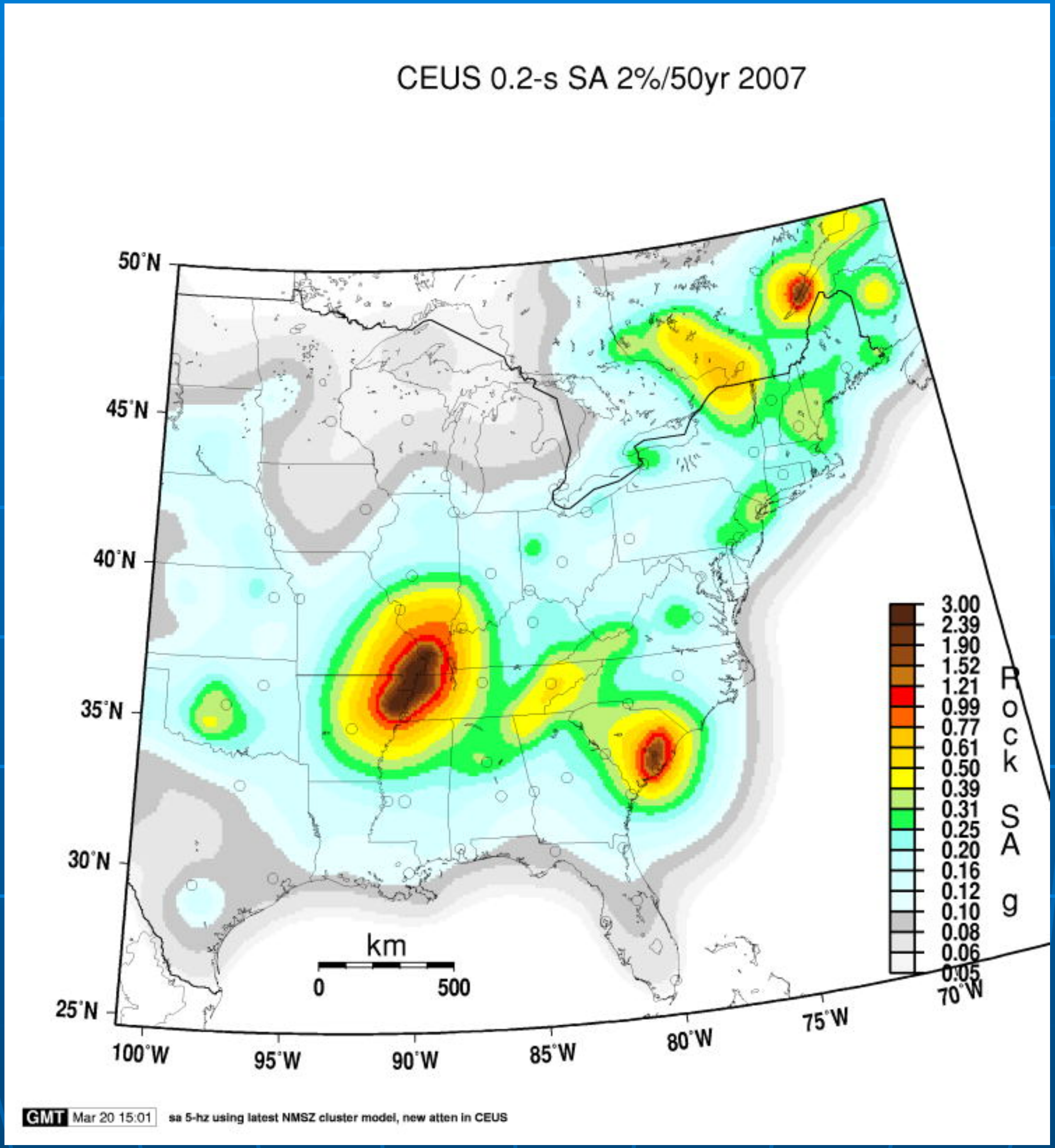


Figure 18: 2007 National seismic hazard map for CEUS at 0.2 s SA and 2% probability of exeedance in 50 years on firm rock site condition 760 m/s Vs30.

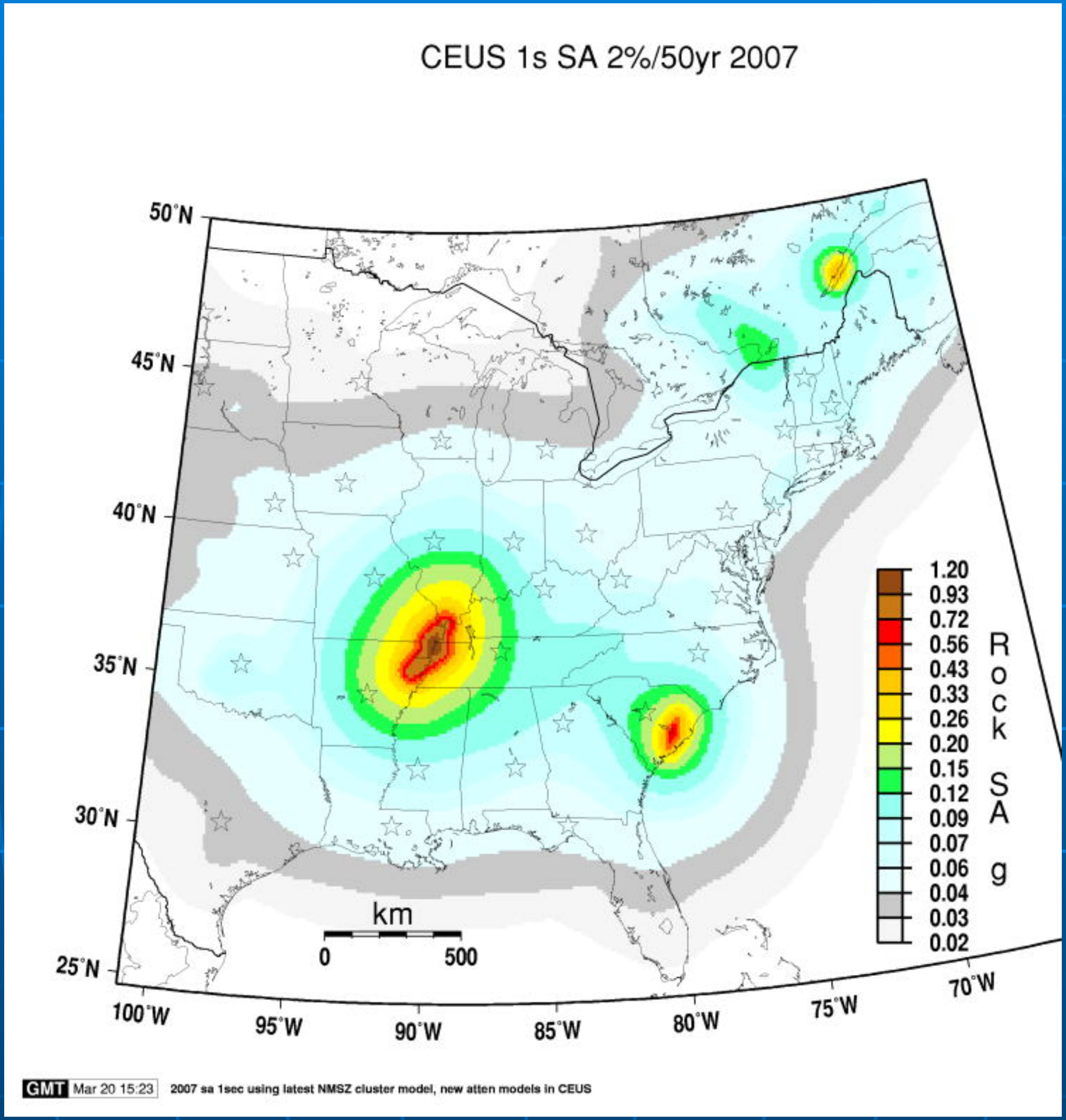


Figure 19: 2007 National seismic hazard map for CEUS at 1.0 s SA and 2% probability of exeedance in 50 years on firm rock site condition 760 m/s Vs30

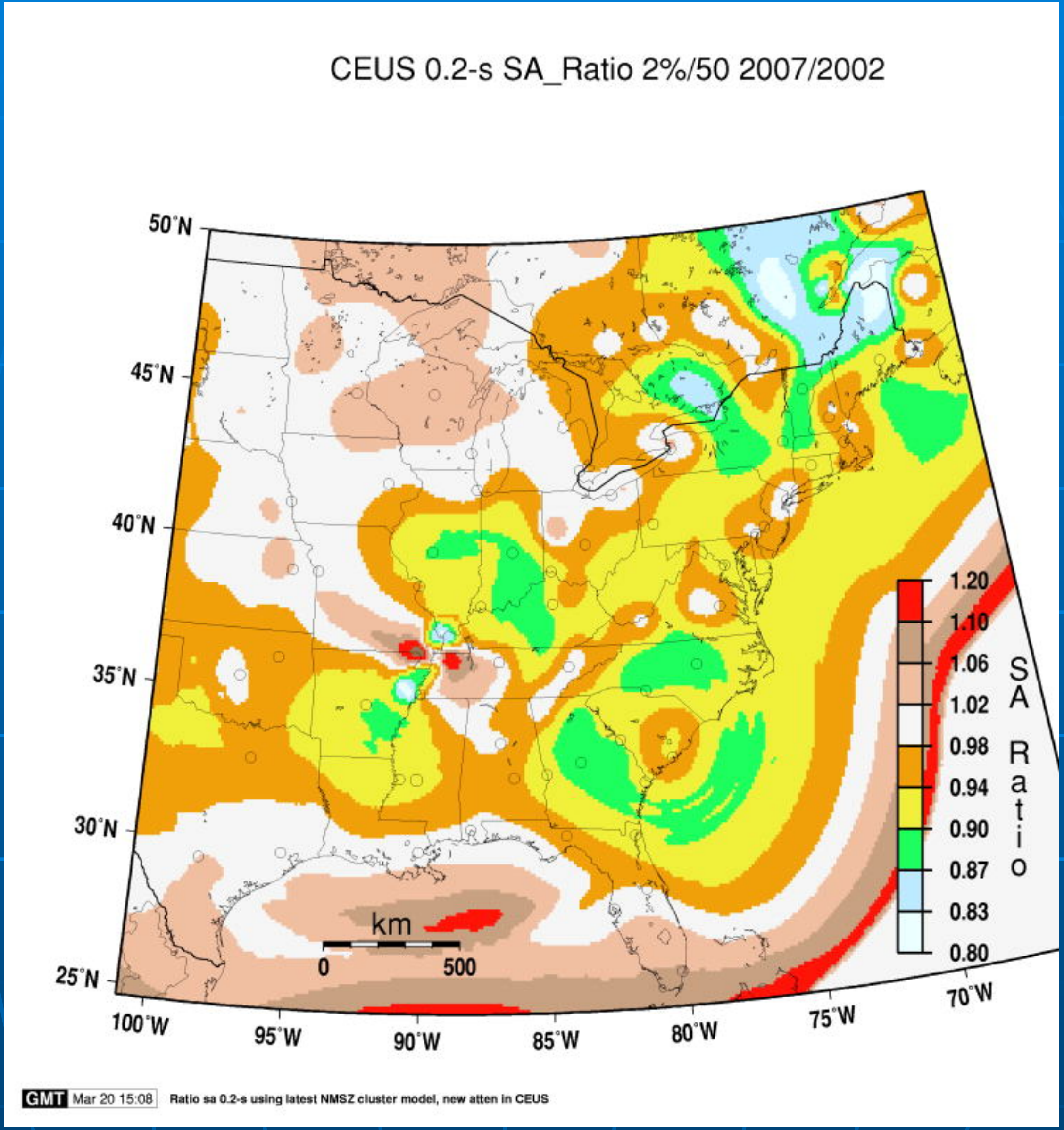


Figure 20: Ratio of 0.2 s SA 2007 and 2002 national seismic hazard maps for CEUS at 2% probability of exceedance in 50 years.

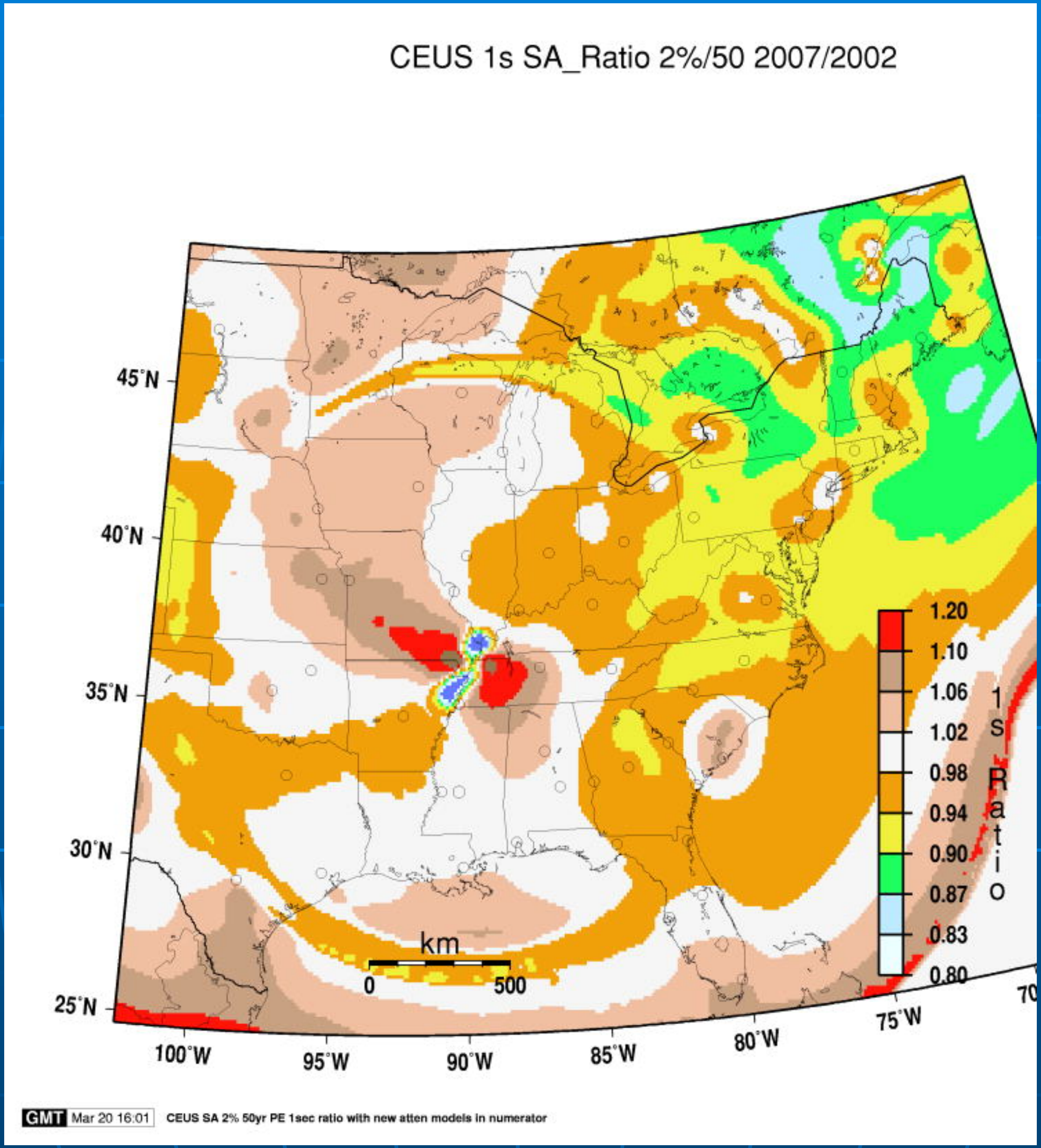


Figure 21: Ratio of 1.0 s SA 2007 and 2002 national seismic hazard maps for CEUS at 2% probability of exceedance in 50 years.

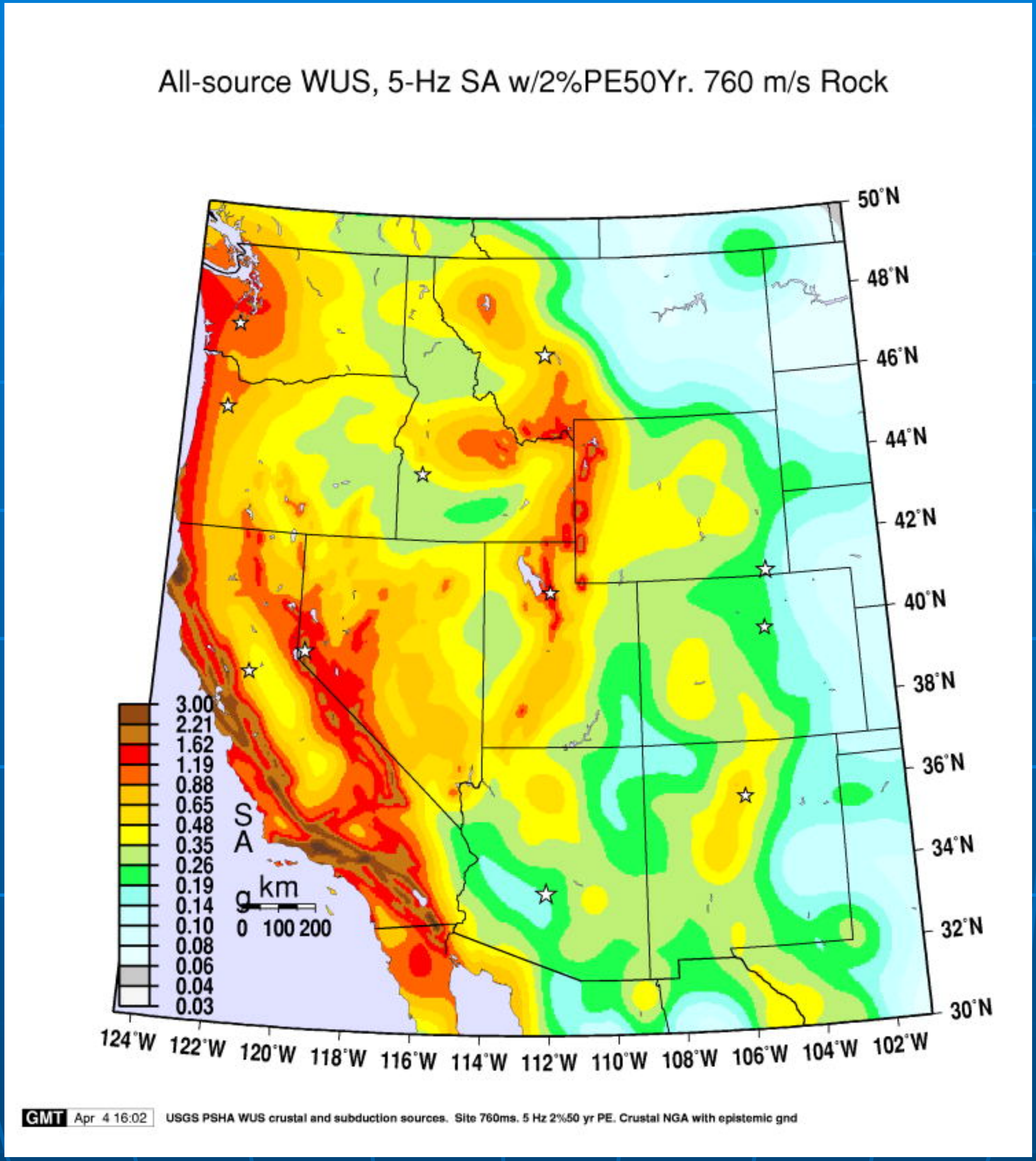


Figure 22: 2007 National seismic hazard map for WUS at 0.2 s SA at 2% probability of exeedance in 50 years on firm rock site condition 760 m/s Vs30.

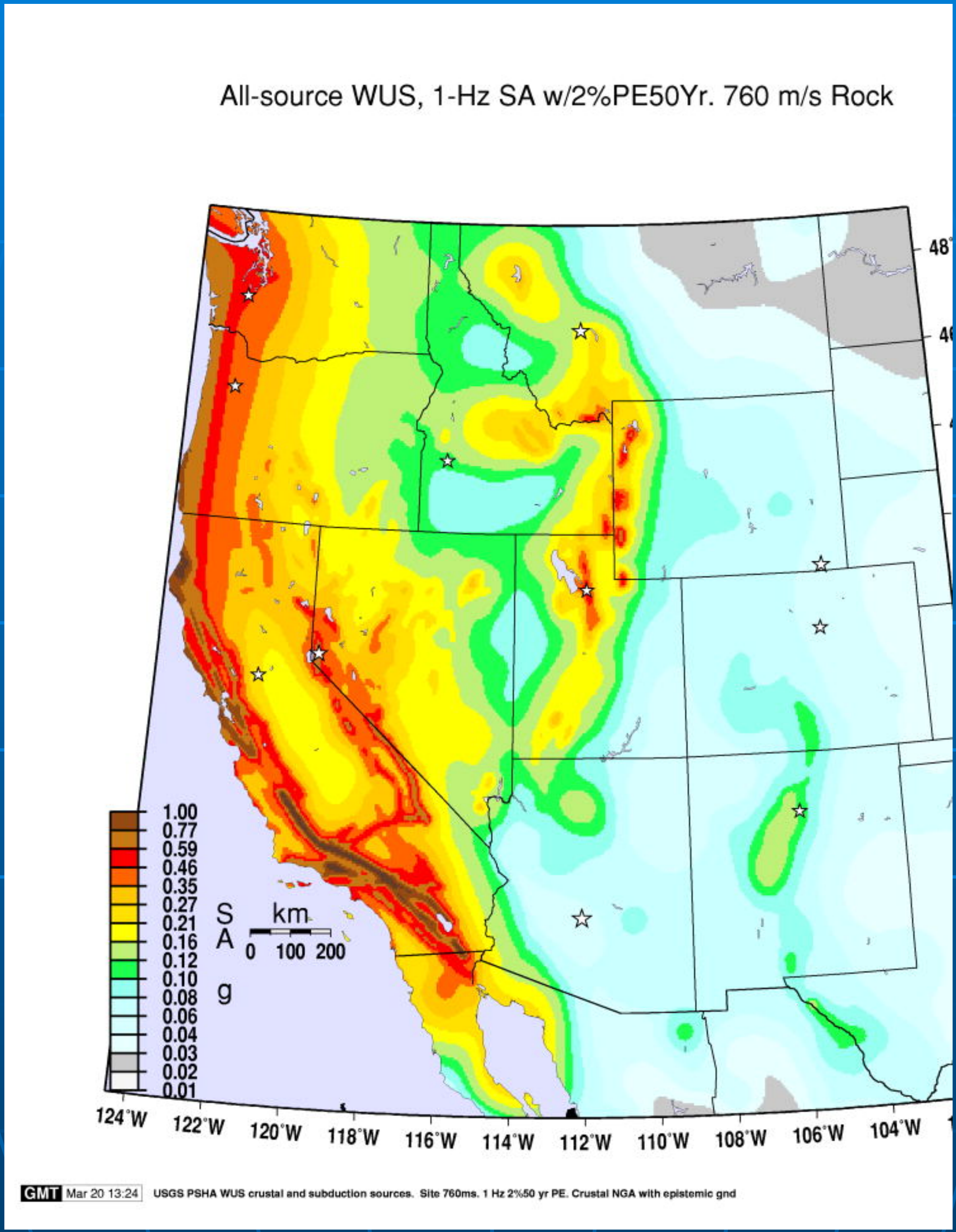


Figure 23: 2007 National seismic hazard map for WUS at 1.0 s SA at 2% probability of exeedance in 50 years on firm rock site condition 760 m/s Vs30.

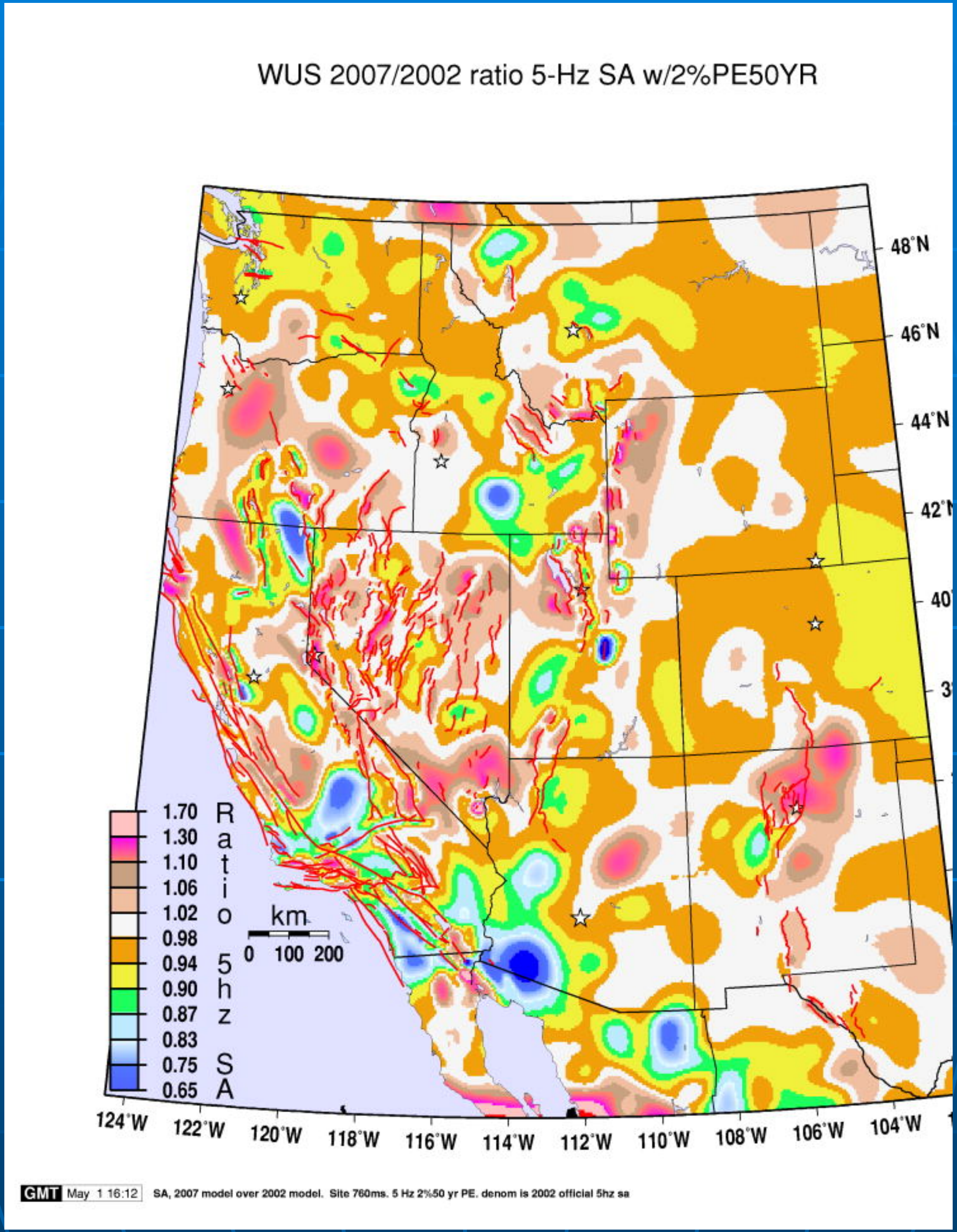


Figure 24: Ratio of 0.2 s SA 2007 and 2002 national seismic hazard maps for WUS at 2% probability of exceedance in 50 years.

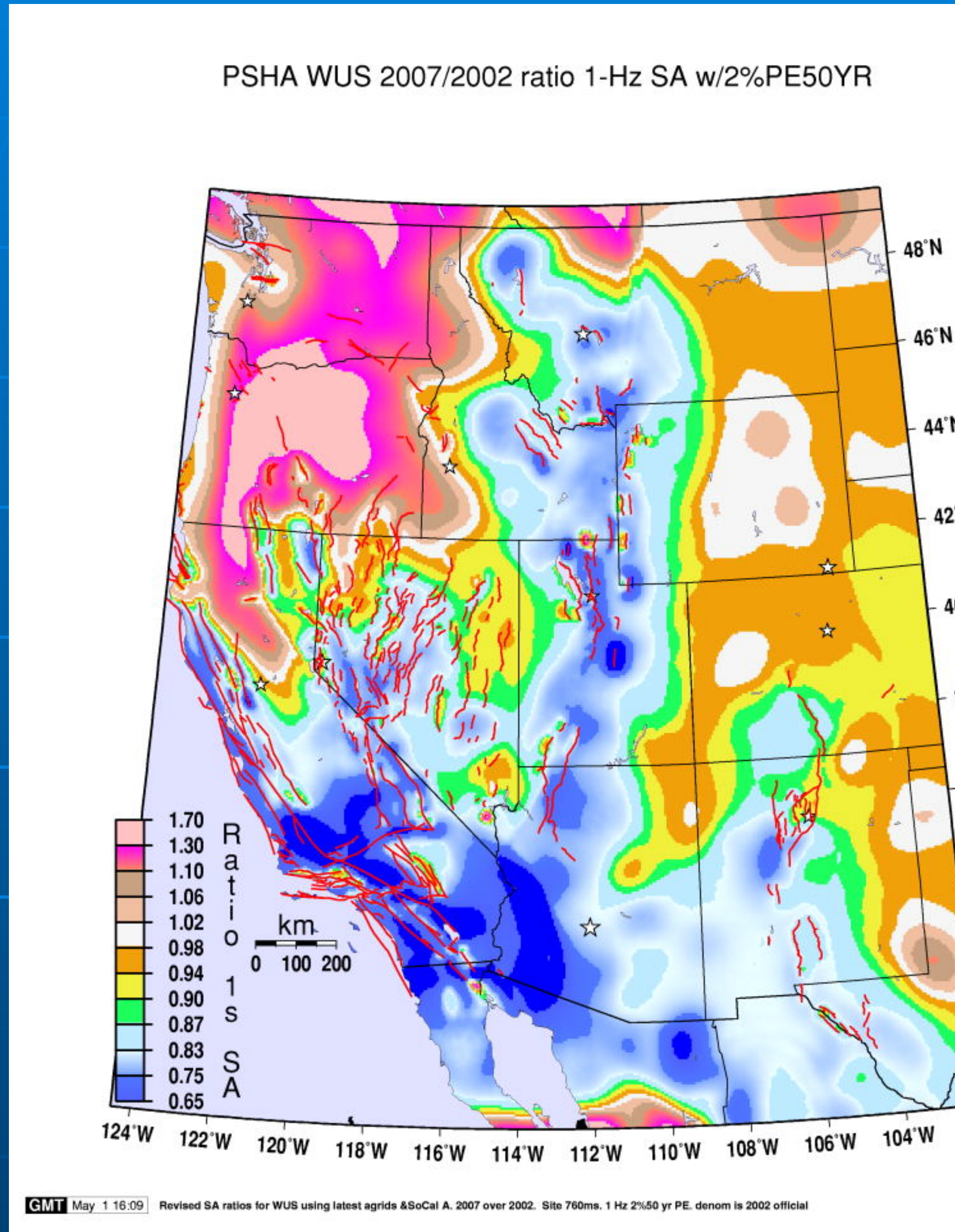


Figure 25: Ratio of 1.0 s SA 2007 and 2002 national seismic hazard maps for WUS At 2% probability of exceedance in 50 years.

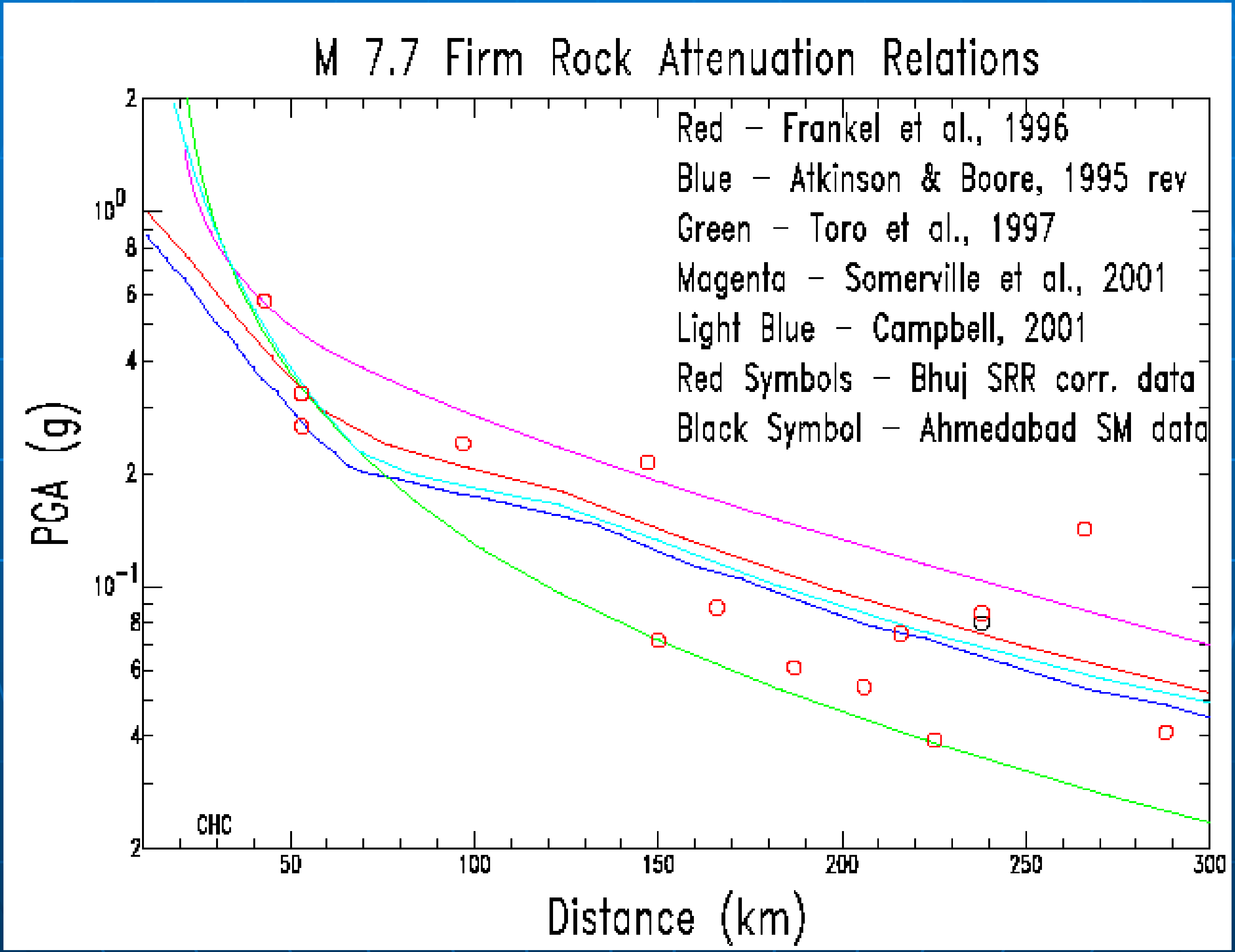
Attenuation Relations

- CEUS
- WUS
- Subduction/Deep

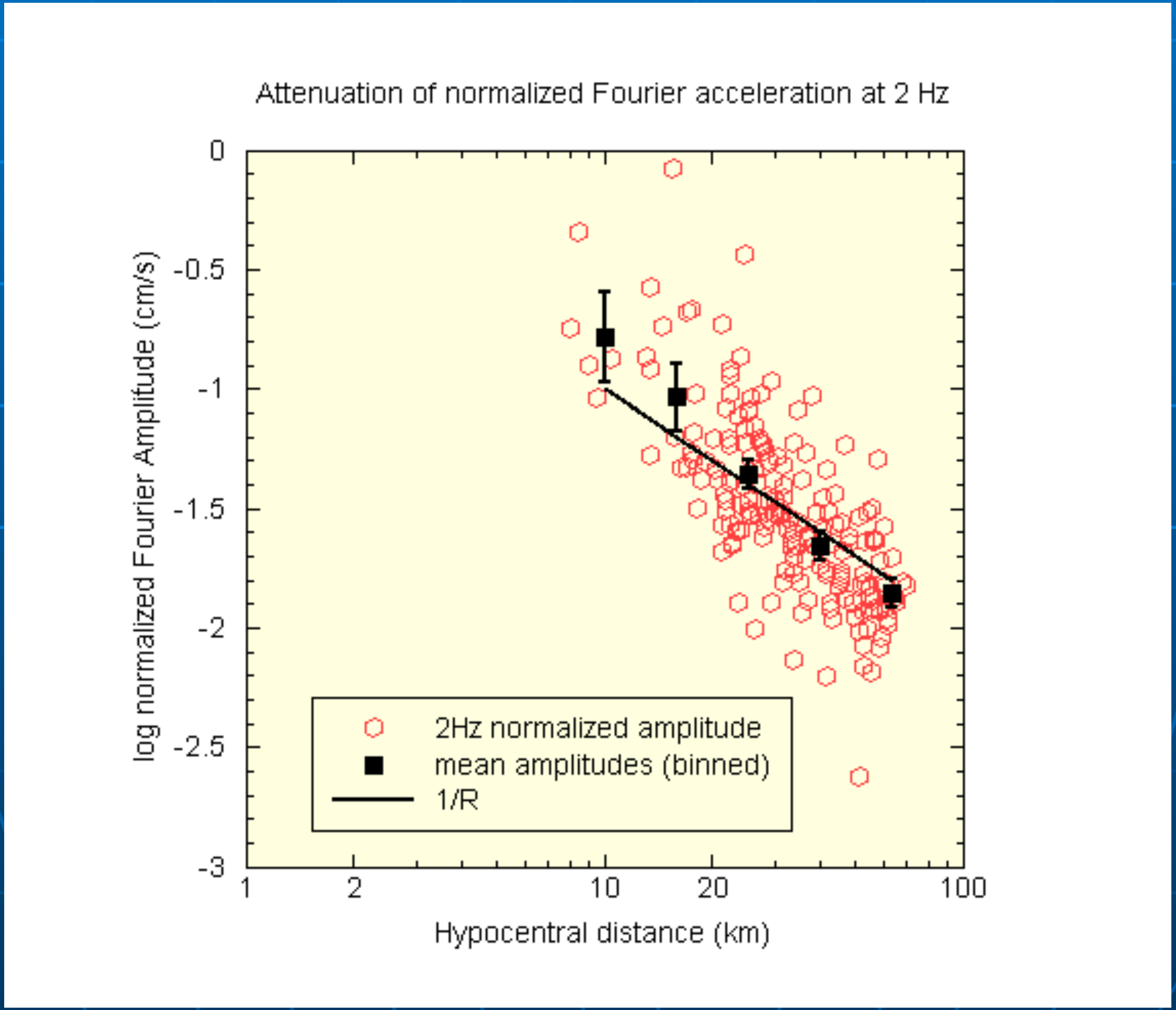
CEUS Attenuation Relations

- Several new equation introduced since 2002 maps
- Some of the new equations have ground motions that fall off faster than earlier models

Ground motion models – Eastern U.S. – red symbols Bhuj data



Amplitudes decay faster than 1/R at R<70 km. This has important implications for ENA ground motion relations.



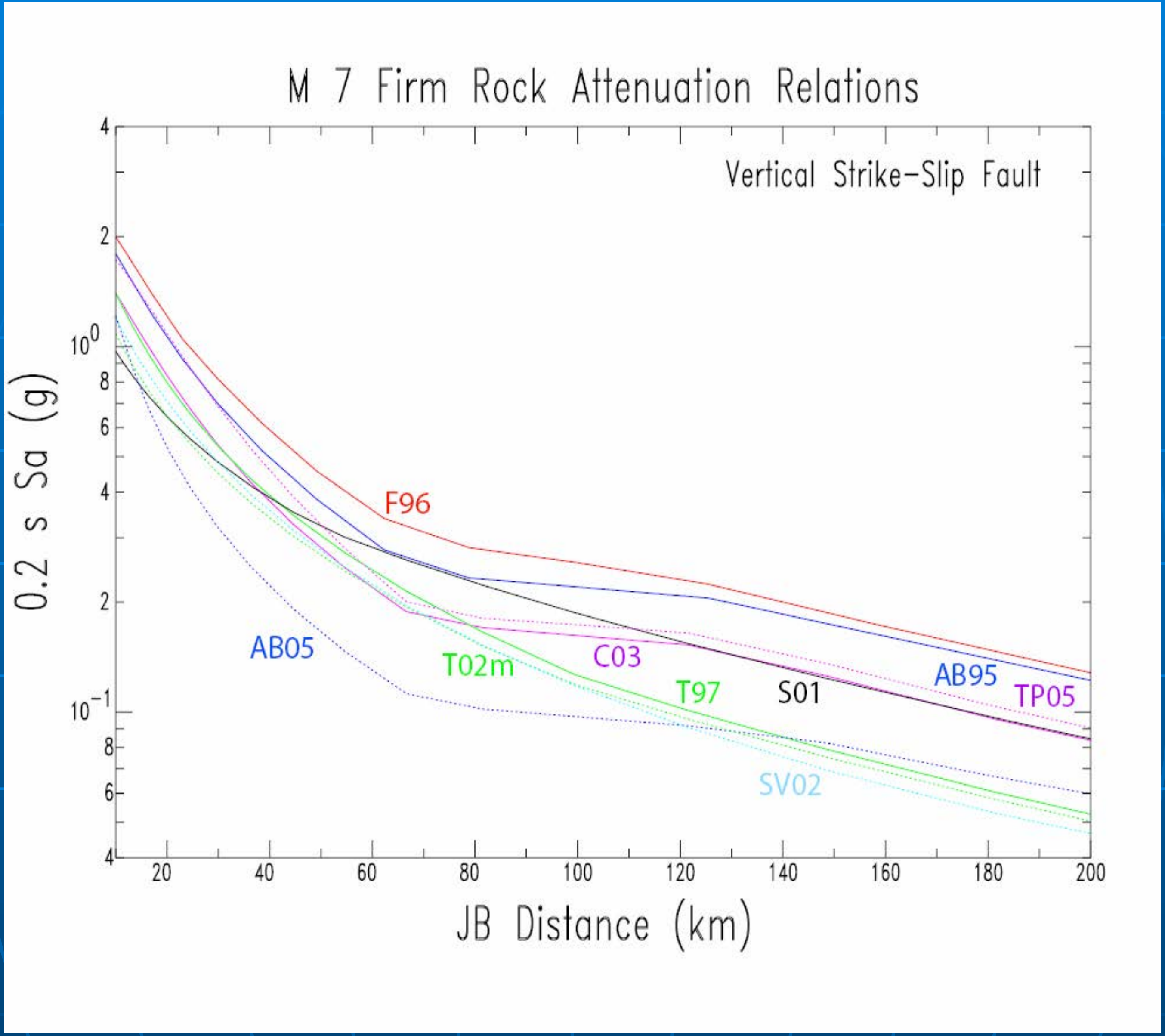


Figure 9: CEUS 0.2 s SA attenuation relations for M 7 earthquake on Vs30 760 m/s site conditions: AB95 AB05 (Atkinson and Boore, 1995, 2005; F96 (Frankel et al., 1996); T97 T02m (Toro, 1997, 2002); C03 (Campbell, 2003); S01 (Somerville 2001); SV02 (Silva et al., 2002); TP05 (Tavakoli And Pezeshk, 2005)

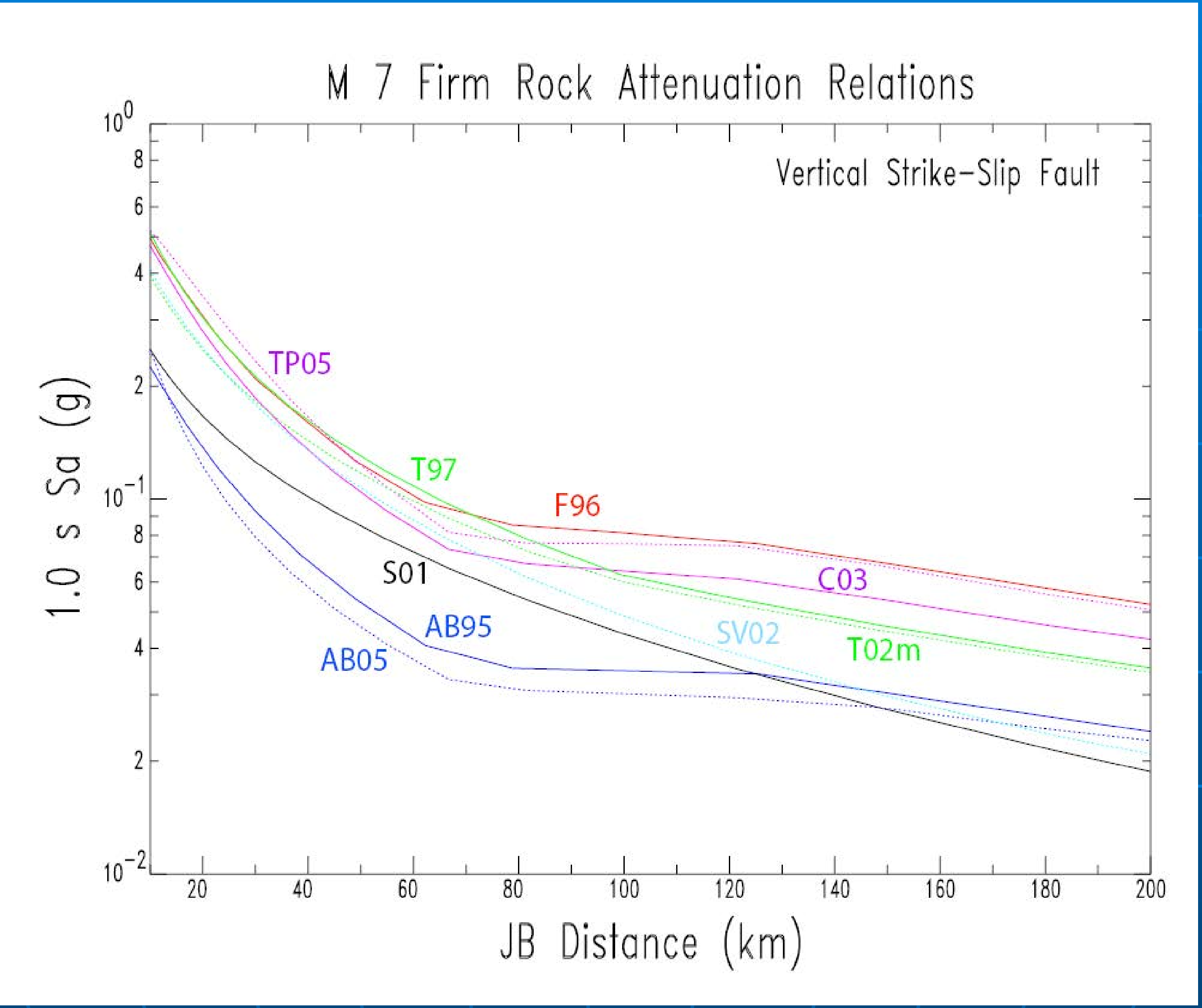


Figure 10: CEUS 1 s SA attenuation relations for M 7 earthquake on Vs30 760 m/s site conditions: AB95 AB05 (Atkinson and Boore, 1995, 2005; F96 (Frankel et al., 1996); T97 T02m (Toro, 1997, 2002); C03 (Campbell, 2003); S01 (Somerville 2001); SV02 (Silva et al., 2002); TP05 (Tavakoli And Pezeshk, 2005)

We use the following weighting scheme for the CEUS attenuation models:

Single corner finite fault:
Toro and others (wt 0.2)

Single corner point source:
Frankel and others (wt 0.1)
Silva and others (wt 0.1).

Dynamic corner frequency:
Atkinson and Boore 140 bar stress drop (wt 0.1),
Atkinson and Boore 200 bar stress drop (wt 0.1),

Full waveform simulation:
Somerville and others (wt 0.2),

Hybrid model:
Campbell (wt 0.1),
Tavakoli and Pezeshk (wt 0.1)

WESTERN US

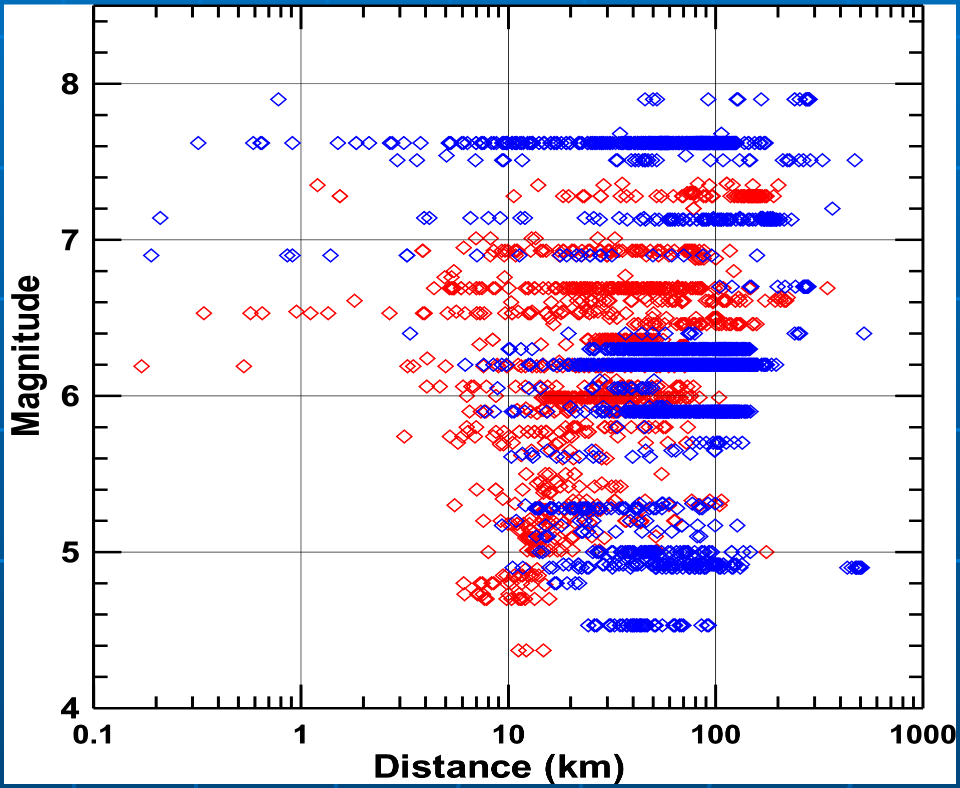
- NGA: Boore and Atkinson, Campbell and Bozorgnia, Chiou and Youngs (weighted equally)
  - Part of change is due to new strong motion database and modeling
  - Part of change is due to definition of 760 m/s Vs-30 for two equations used in 2002
- Subduction: Geomatrix, Sadigh, Atkinson and Boore, Gregor et al.

NGA Project Details:

- NGA developers: Chiou and Youngs, Campbell and Bozorgnia, Boore and Atkinson
- NGA developers applied their own selection criteria to the common database, with the requirement that
  - Criteria are explicitly defined and documented
  - Criteria are shared with other developers
  - Reasons for excluding data are justified
  - Other developers are notified if NGA metadata is modified
- USGS added additional epistemic uncertainty to account for uncertainty in large earthquakes not observed.
- NGA supporting studies
  - 1-D ground-motion simulations of rock ground motion
  - 3-D ground-motion simulations of basin response
  - 1-D ground-motion simulations of shallow site response

NGA Project Database

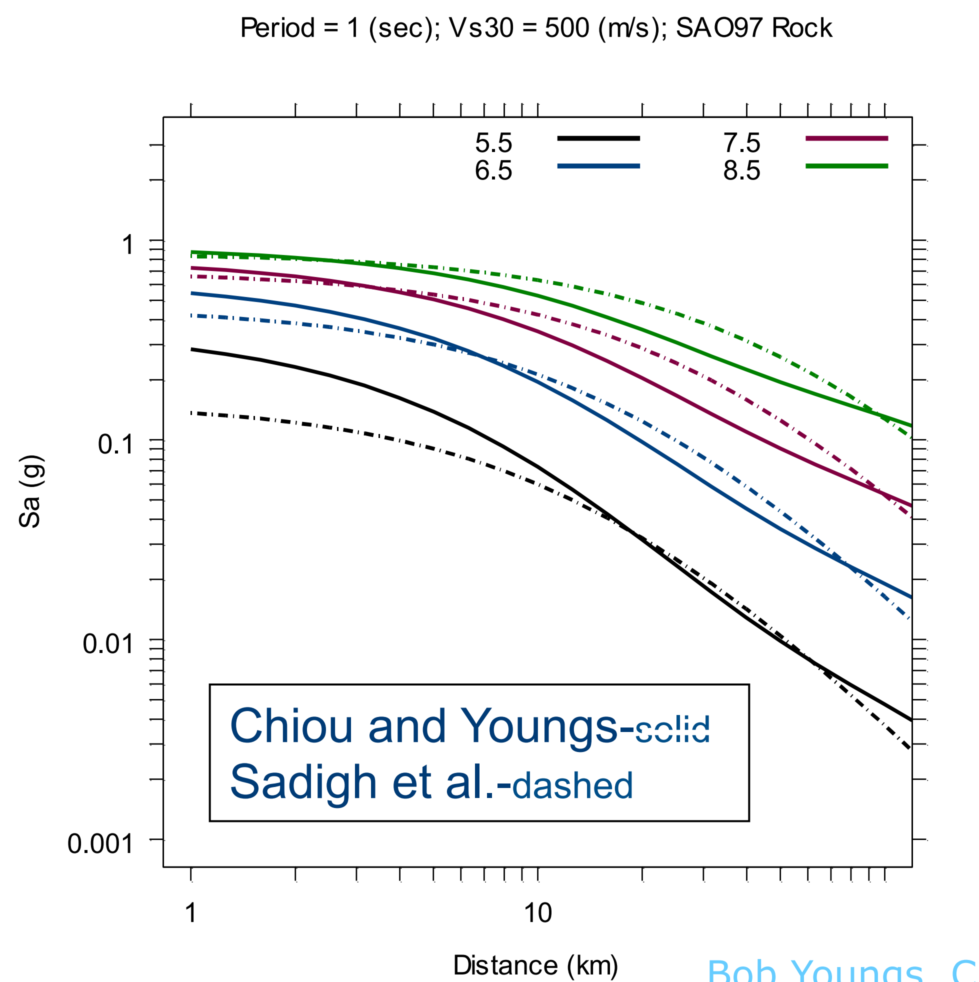
- NGA strong-motion database:
  - **172** worldwide earthquakes
  - **1,400** recording stations
  - **3,500** multi-component strong-motion recordings
  - **Over 100** parameters describing source, path, and site conditions



Previous Data New Data

Provided by Ken Campbell, EQECAT

PEER Next Generation Attenuation Relations: Common database, 5 model developers, global datasets

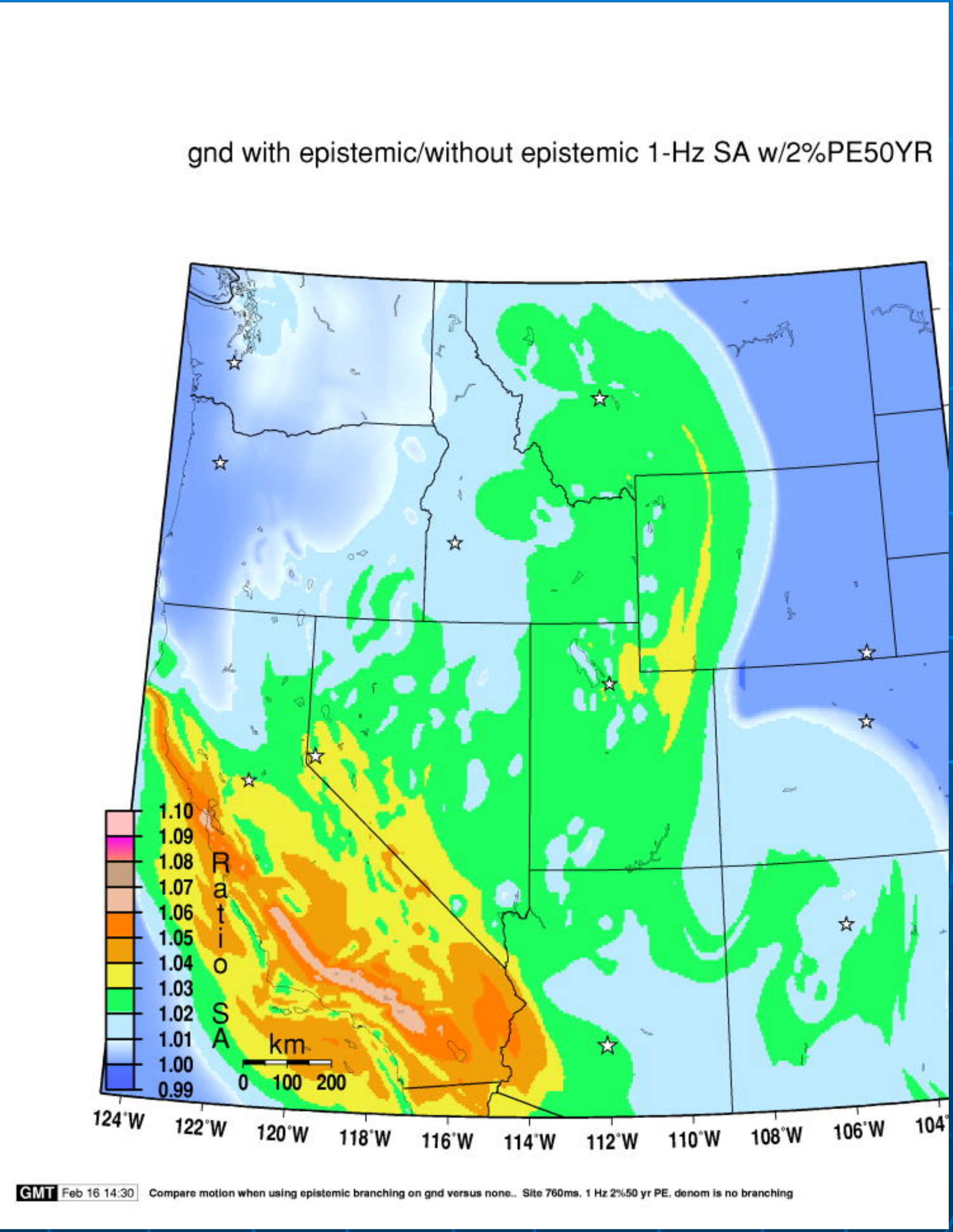


Bob Youngs, CA workshop

Epistemic Uncertainty

Table 6. Number of earthquakes (N) in each bin for the Chiou and Youngs (C&Y) and Campb and Bozorgnia (C&B) attenuation relations.

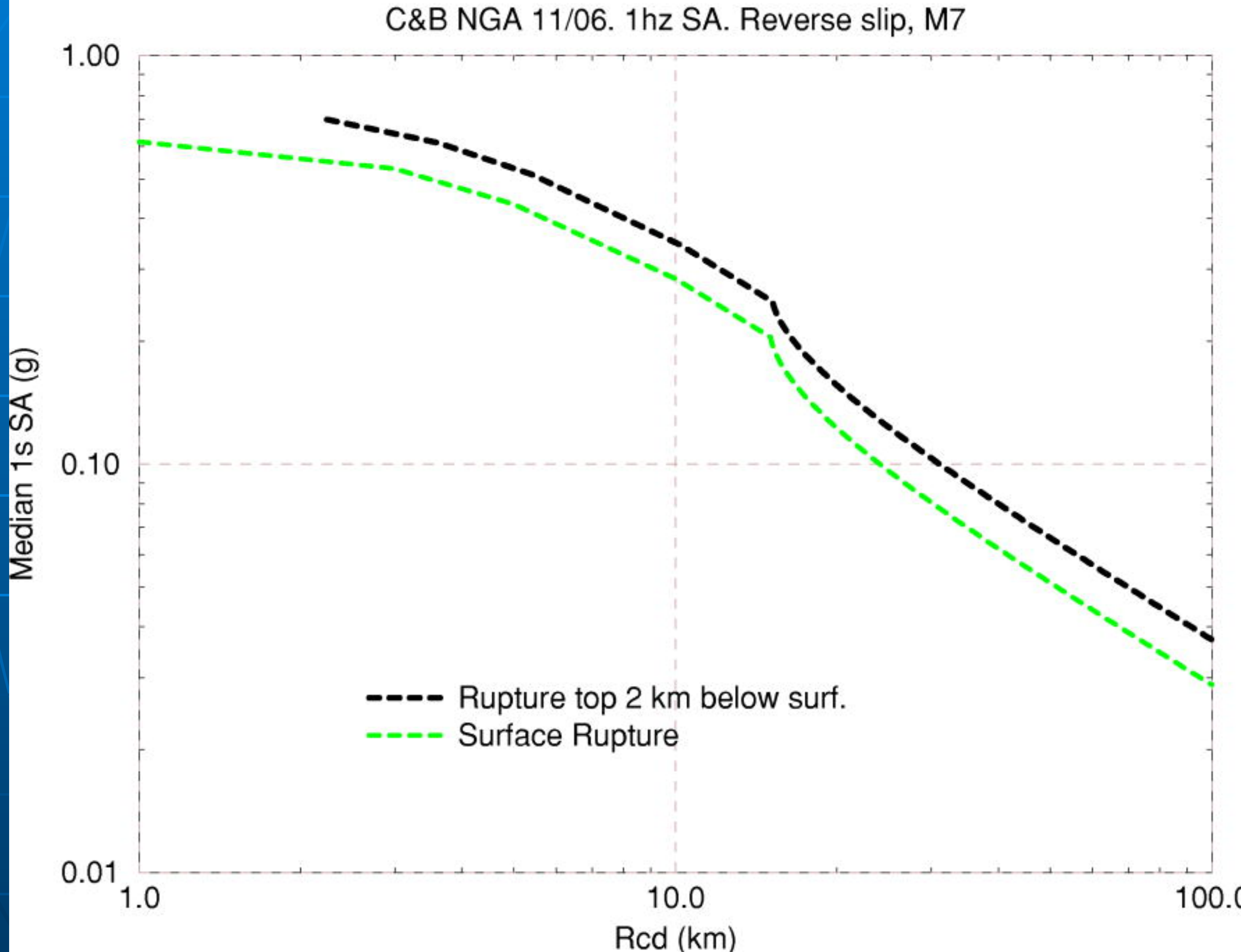
M and Rrup range	N_{eq} (C&Y)	C&Y *dgnd* term	N_{eq} (C&B)	C&B *dgnd* term	Average *dgnd* term
5≤M<6,Rrup<10	24	0.22	4	0.53	±0.375
5≤M<6,10≤Rrup<30	50	0.15	15	0.27	0.21
5≤M<6, Rrup≥30	26	0.21	14	0.28	0.245
6≤M<7,Rrup<10	24	0.22	19	0.24	0.23
6≤M<7,10≤Rrup<30	26	0.21	20	0.25	0.225
6≤M<7, Rrup≥30	23	0.21	18	0.25	0.23
M≥7, Rrup<10	7	0.40	7	0.40	0.40
M≥7,10≤Rrup<30	8	0.37	9	0.35	0.36
M≥7, Rrup≥30	10	0.33	13	0.29	0.31


gnd with epistemic/without epistemic 1-Hz SA w/2%PE50YR
1.10
1.09
1.08
1.07
1.06
1.05
1.04
1.03
1.02
1.01
1.00
0.99
Ratio SA
km
0 100 200
124°W
122°W
120°W
118°W
116°W
114°W
112°W
110°W
108°W
106°W
GMT Feb 16 14:30
Compare motion when using epistemic branching on gnd versus none.. Site 760ms. 1 Hz 2%50 yr PE. denom is no branching

2 of 3 NGA relations are sensitive to depth to top of rupture, or Ztor

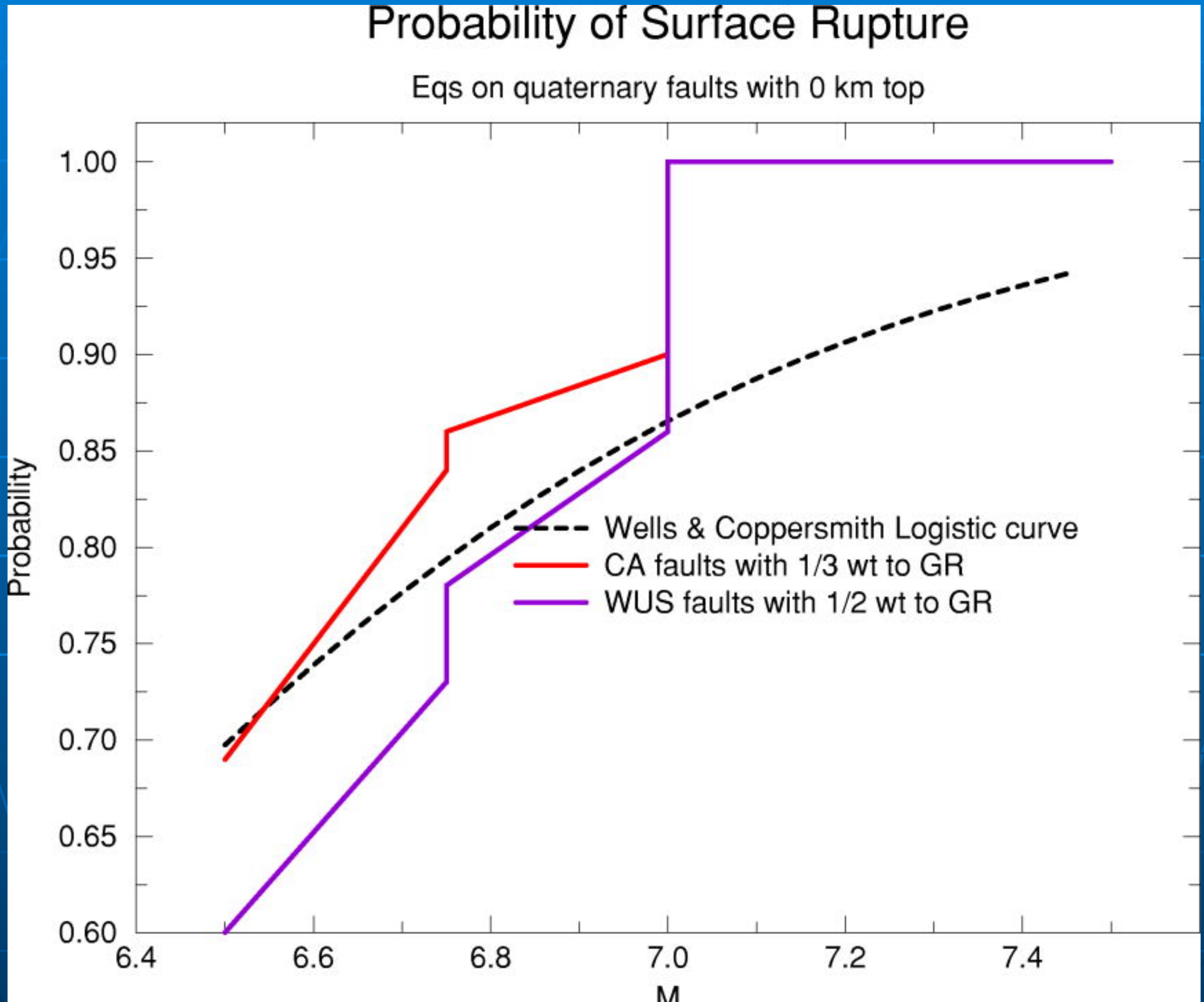
- Campbell and Bozorgnia
- Chiou and Youngs
- These relations have 2/3 of total weight in current PSHA model, WUS crustal sources.
- Depth to top of rupture was not a topic of interest in 2002 PSHA model.
- Implementation requires decisions about ztor distributions to use.
- Software retooling : depends on previous bullet

Effect of Rupture Top Below Surface



Current Procedure (April 2007) for sensitizing model to variable Ztor

- On daylighting GR-faults, we bury a percentage of the ruptures
- 2/3 of them for $6.5 \leq M \leq 6.75$
- 1/3 of them for $6.75 < M \leq 7.0$
- None of them for $M > 7.0$
- On non-daylighting GR-faults, follow similar procedure.
- Don’t mess with characteristic ruptures

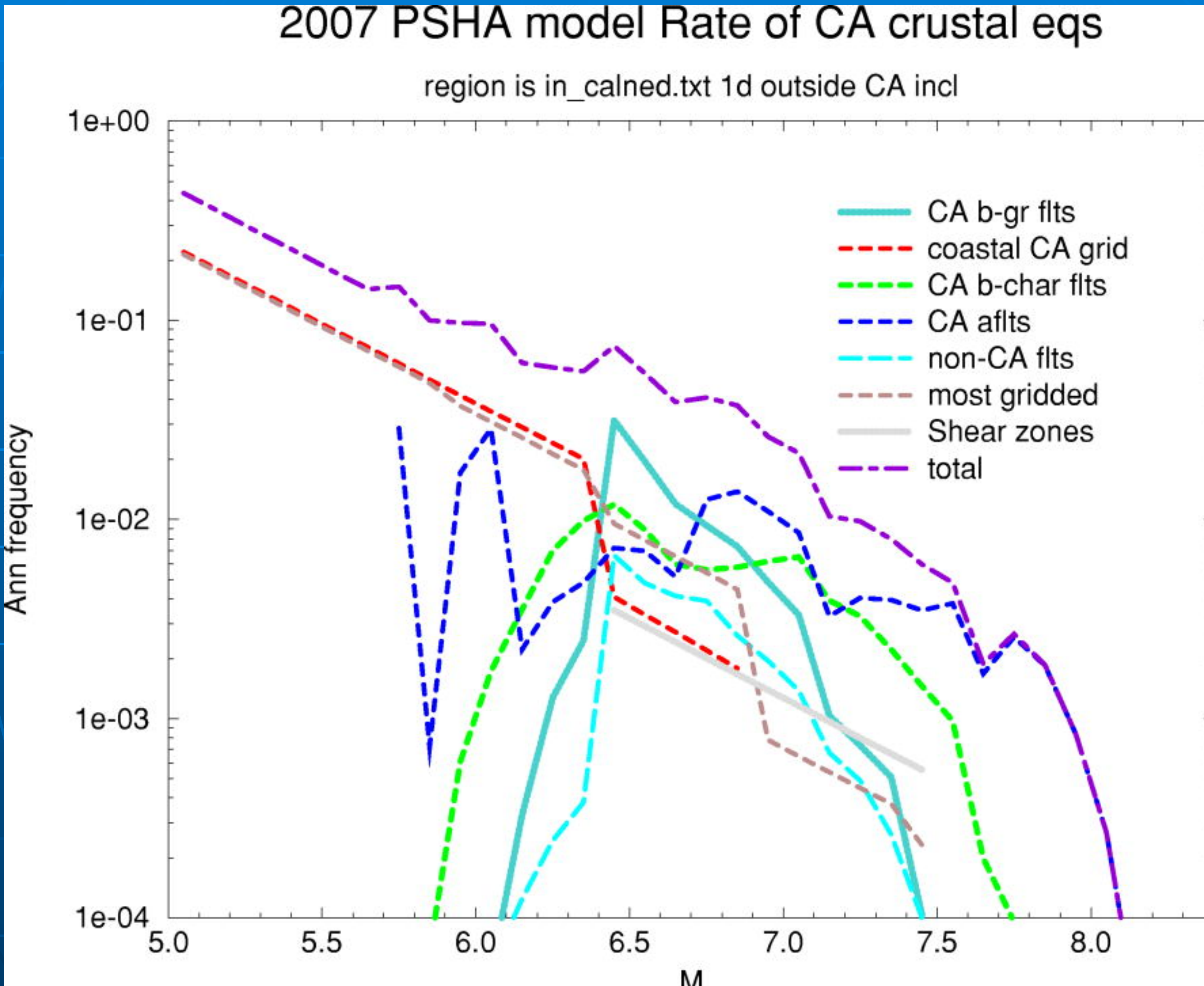

Probability of Surface Rupture
Eqs on quaternary faults with 0 km top
Probability
M
1.00
0.95
0.90
0.85
0.80
0.75
0.70
0.65
0.60
6.4
6.6
6.8
7.0
7.2
7.4
Wells & Coppersmith Logistic curve
CA faults with 1/3 wt to GR
WUS faults with 1/2 wt to GR

Two Outstanding Questions

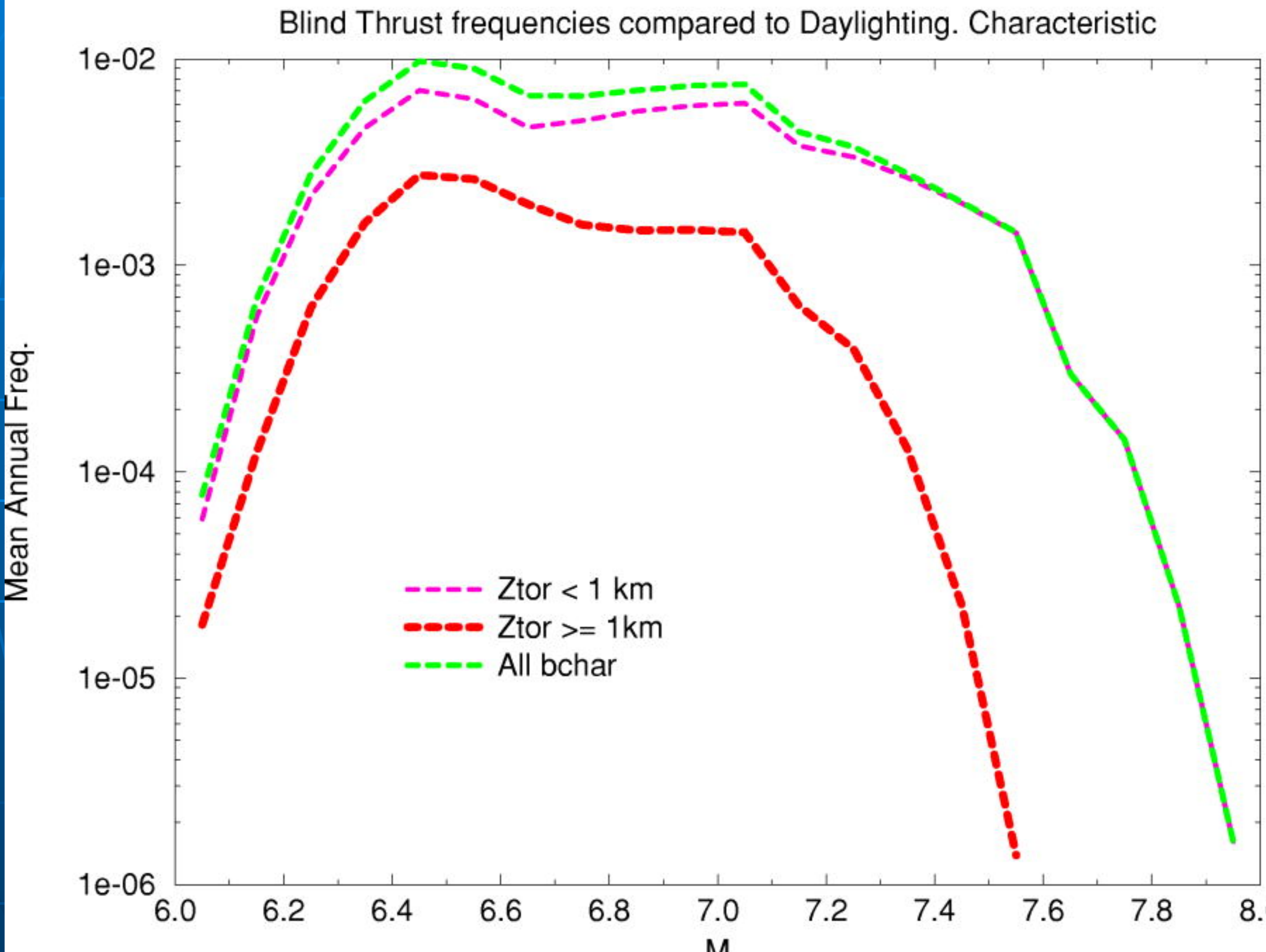
- Should we modify the ztor distribution for gridded (background) seismicity? Currently ztor is set at 5.0 km everywhere in WUS. (Software has been retooled for variable ztor in gridded hazard calcs.)
- Should we modify the ztor distribution for characteristic events on Quaternary faults? Currently ztor = depth0, i.e., the depth of the top of the fault, for these.

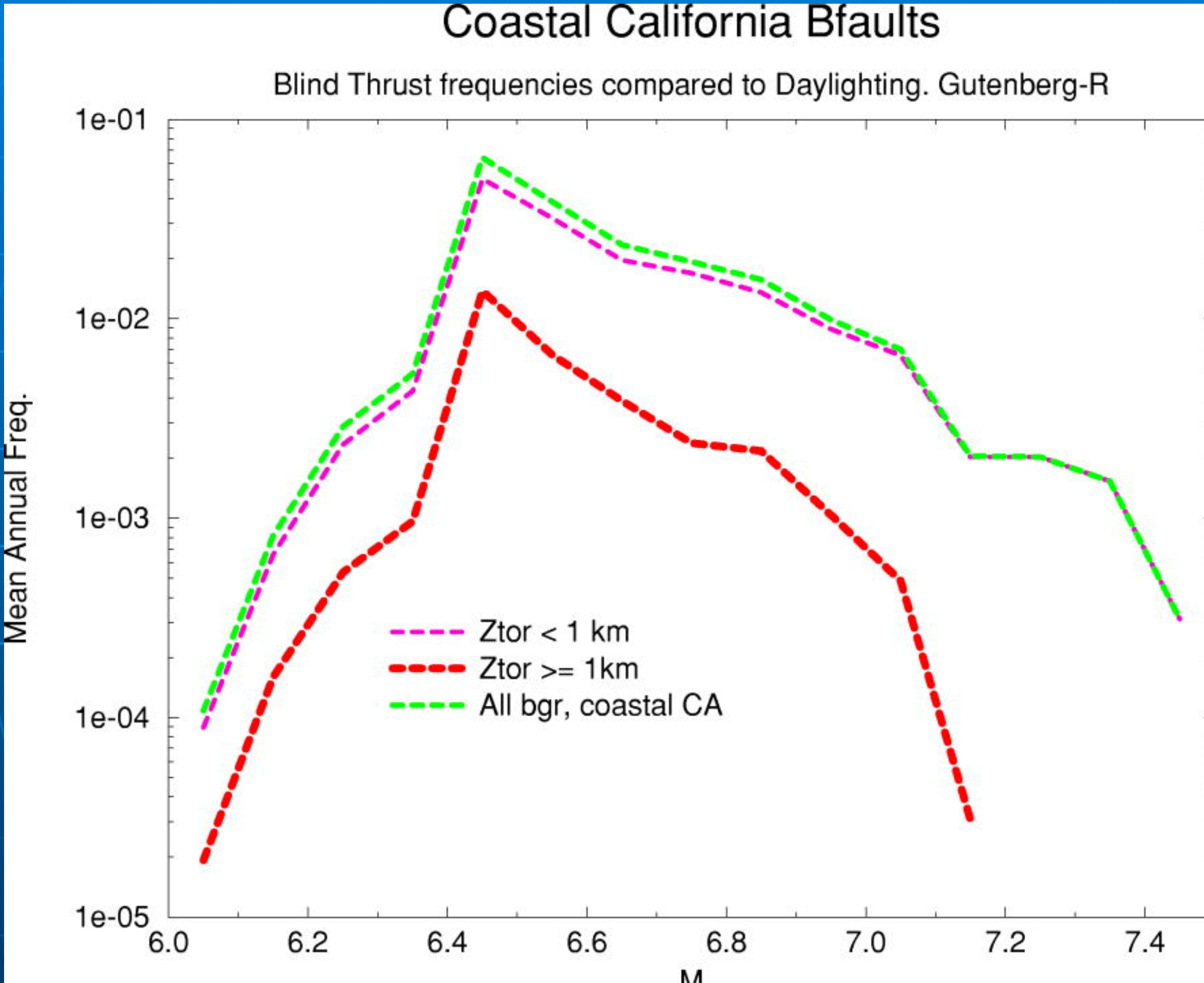
PSHA model for California crustal earthquakes

- All gridded events have depth 5 km.
- All characteristic events on Quaternary faults have ztor at top of fault
- There is a significant number of buried faults (i.e., blind thrusts) in coastal California. 10-20% by frequency of events compared to all bchar sources.
- PSHA model has no blind thrusts elsewhere in US (NMSZ Reelfoot rift possible exception?)
- G-R on bfaults dominates all other sources over a restricted range of M (6.5 to 6.75)


2007 PSHA model Rate of CA crustal eqs
region is in_calned.txt 1d outside CA incl
1e+00
1e-01
1e-02
1e-03
1e-04
Ann frequency
5.0
5.5
6.0
6.5
7.0
7.5
8.0
M
CA b-gr flts
coastal CA grid
CA b-char flts
CA aflts
non-CA flts
most gridded
Shear zones
total

Coastal California Bfaults

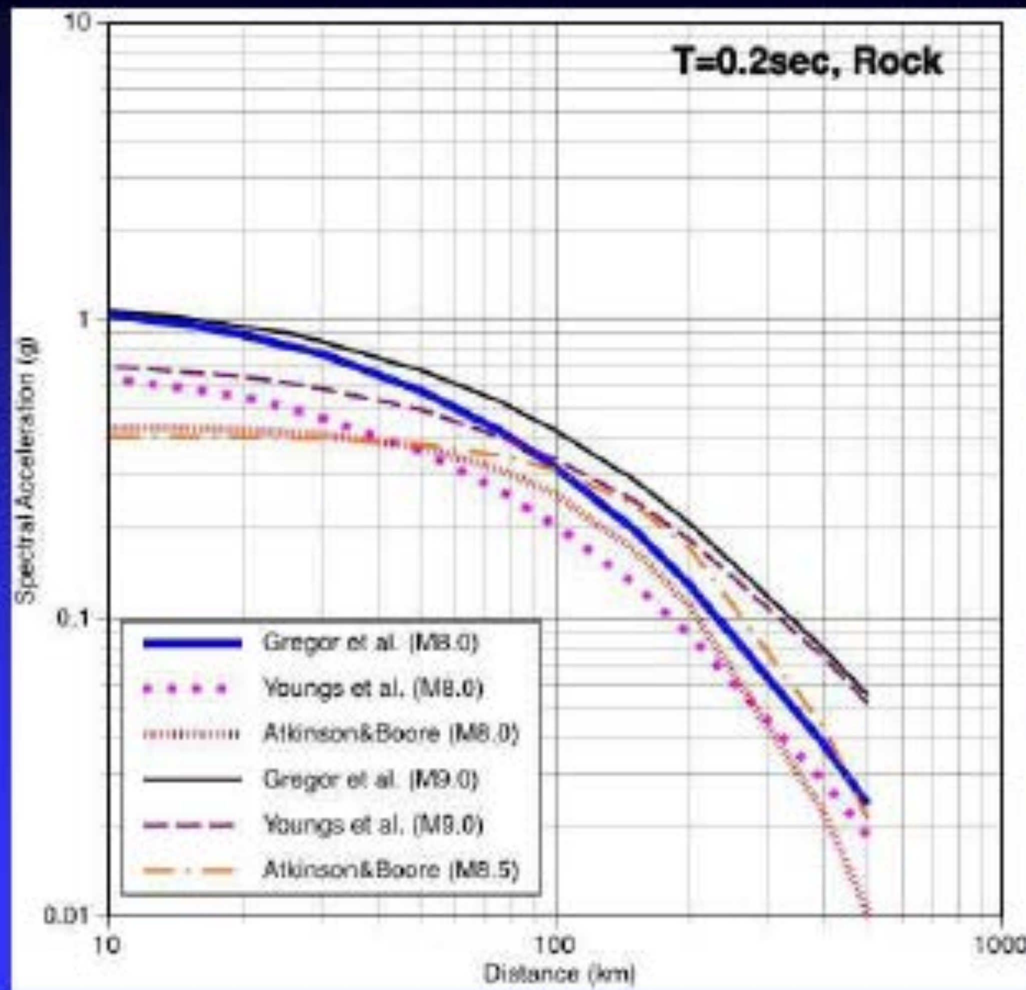




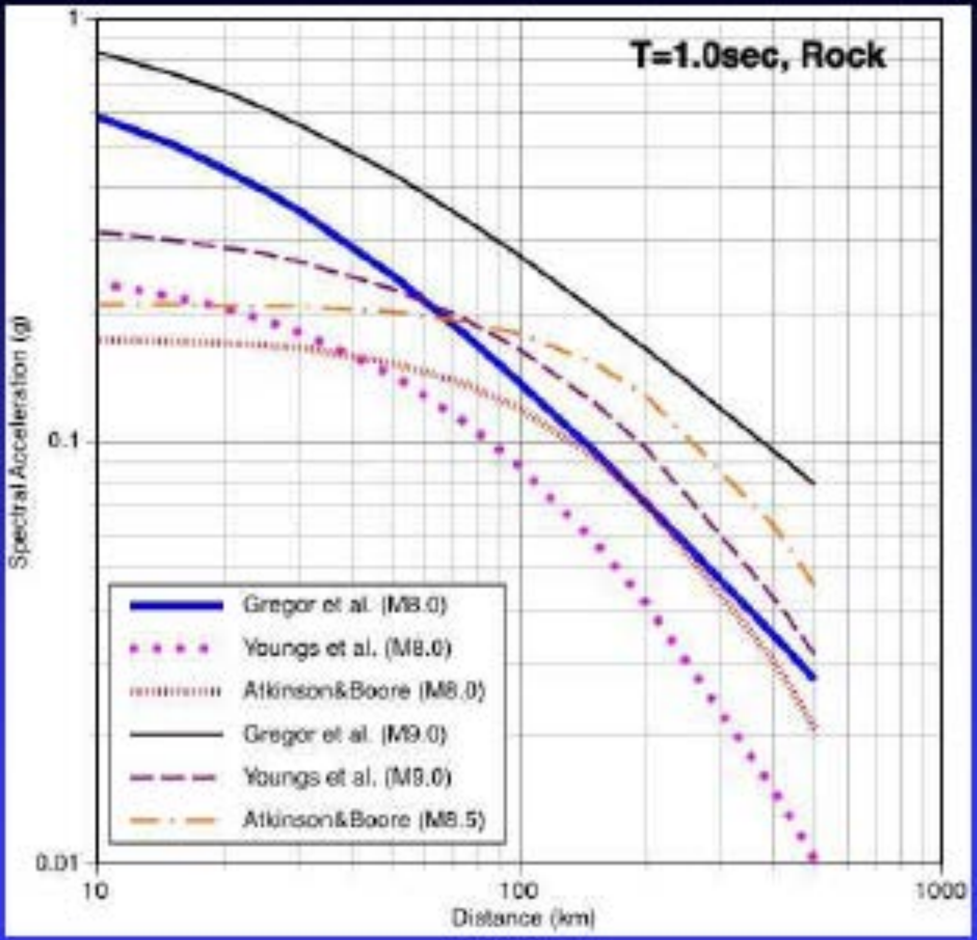
Coastal California Bfaults
Blind Thrust frequencies compared to Daylighting. Gutenberg-R
1e-01
1e-02
1e-03
1e-04
1e-05
Mean Annual Freq.
6.0
6.2
6.4
6.6
6.8
7.0
7.2
7.4
M
Ztor < 1 km
Ztor >= 1km
All bgr, coastal CA

Summary

- USGS-Golden has developed a preliminary model of variable ztor for 2007 PSHA map update.
- We have developed software to compute seismic hazard for this model.
- The new model is currently restricted to the GR part of the bfault hazard.
- We would like to know what further modifications would be helpful (if any).



T=0.2sec, Rock
Spectral Acceleration (g)
10
1
0.1
0.01
10
100
1000
Distance (km)
Gregor et al. (M8.0)
Youngs et al. (M8.0)
Atkinson&Boore (M8.0)
Gregor et al. (M9.0)
Youngs et al. (M9.0)
Atkinson&Boore (M8.5)



T=1.0sec, Rock
Spectral Acceleration (g)
1
0.1
0.01
10
100
1000
Distance (km)
Gregor et al. (M8.0)
Youngs et al. (M8.0)
Atkinson&Boore (M8.0)
Gregor et al. (M9.0)
Youngs et al. (M9.0)
Atkinson&Boore (M8.5)

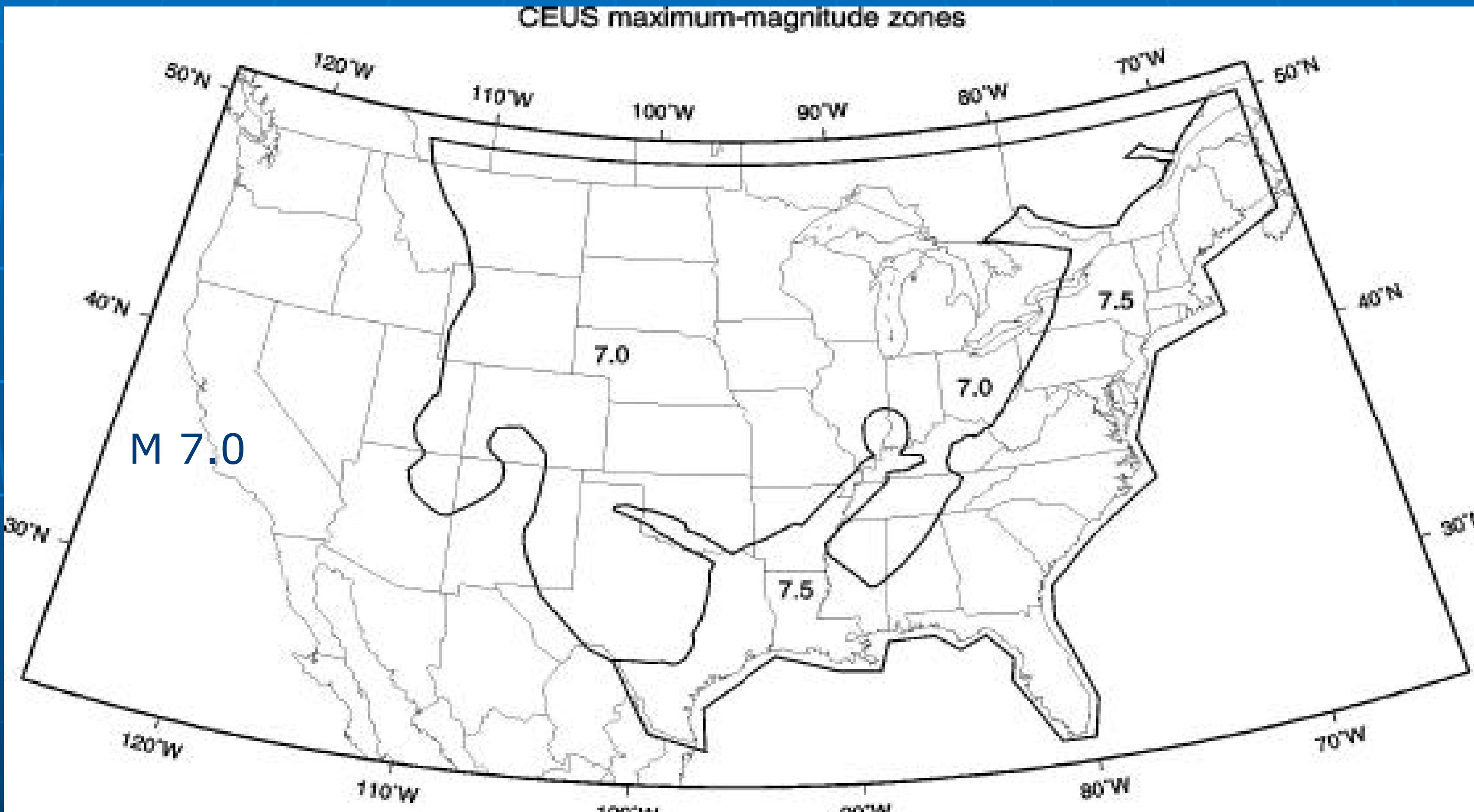
Central and Eastern U.S. Source Models

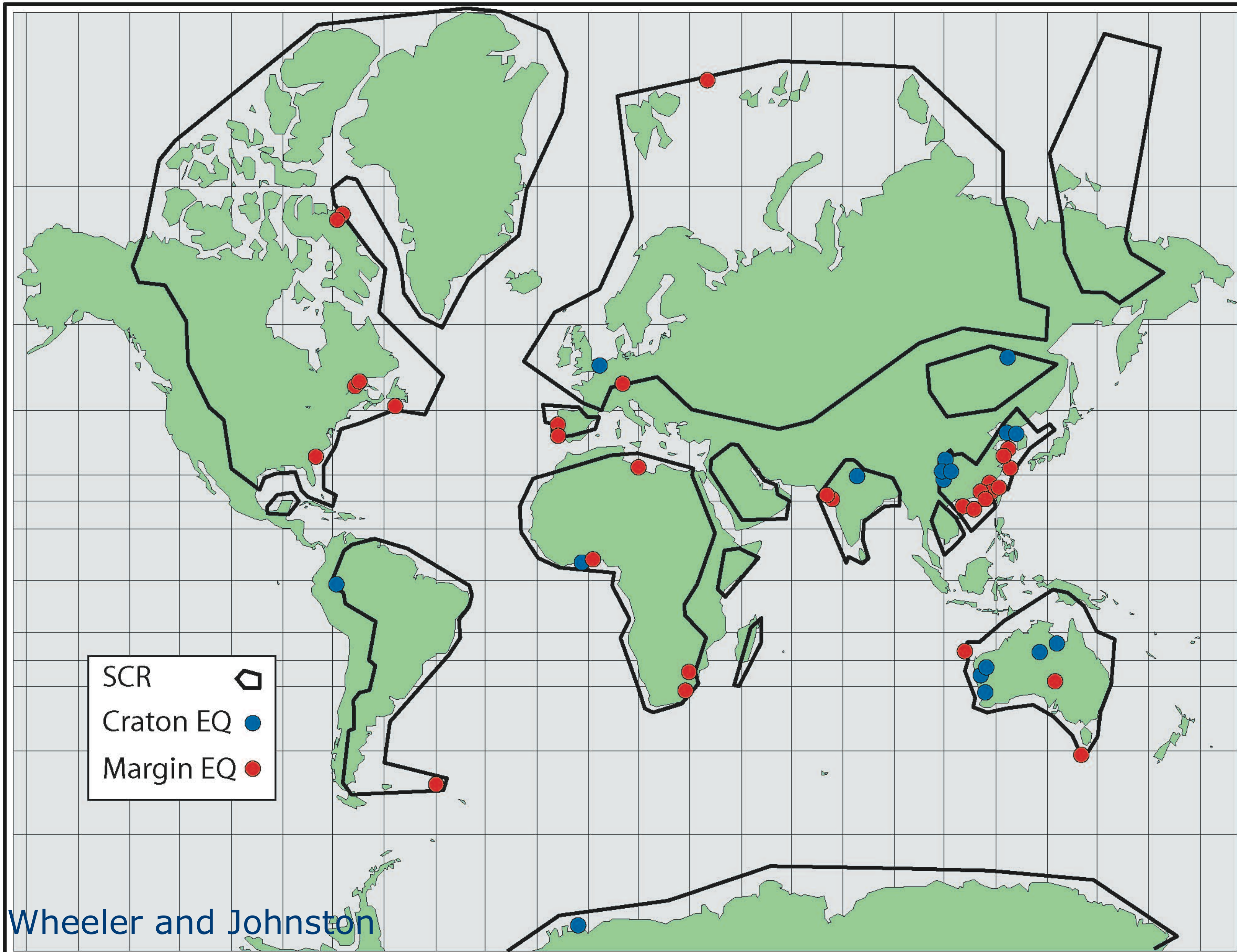
- Mmax
- New Madrid logic tree
- Charleston SC
- Maps

Methods used by EPRI teams to estimate M(max)

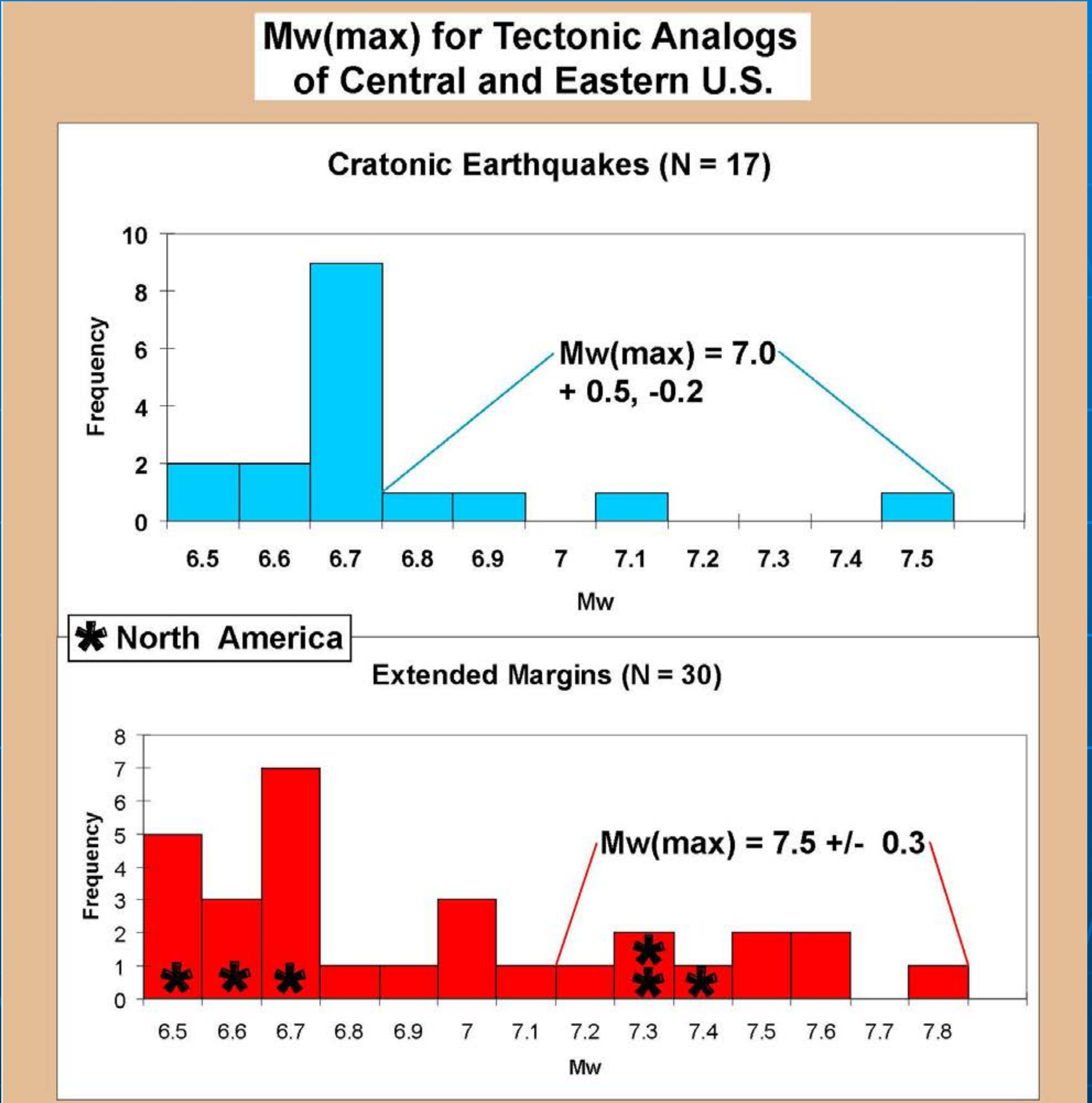
Method	BT	DM	LE	RO	WC	WG	Total
1. M(max) observed + increment	X		X		X		3
2. Seismic flux				X	X	X	3
3. G-R extrapolation of hist'l record		X			X		2
4. mb & ground motions saturate at 7.5		X					1
5. Local geologic features				X	X	X	3
6. North American analogs only				X			1
7. Global analogs	X		X				2

BACKGROUND SOURCE ZONES USGS 2002 model





Wheeler and Johnston



Wheeler and Johnston

NEW MADRID SEISMIC ZONE

- Geometry: (dip of Reelfoot fault, northern arm)
- Magnitude: magnitude lowest on northern arm
- Recurrence: northern arm may not have experienced 1450 event
- Clustering model (time-dependent): each event consists of 3 earthquakes (ground motion correlations)

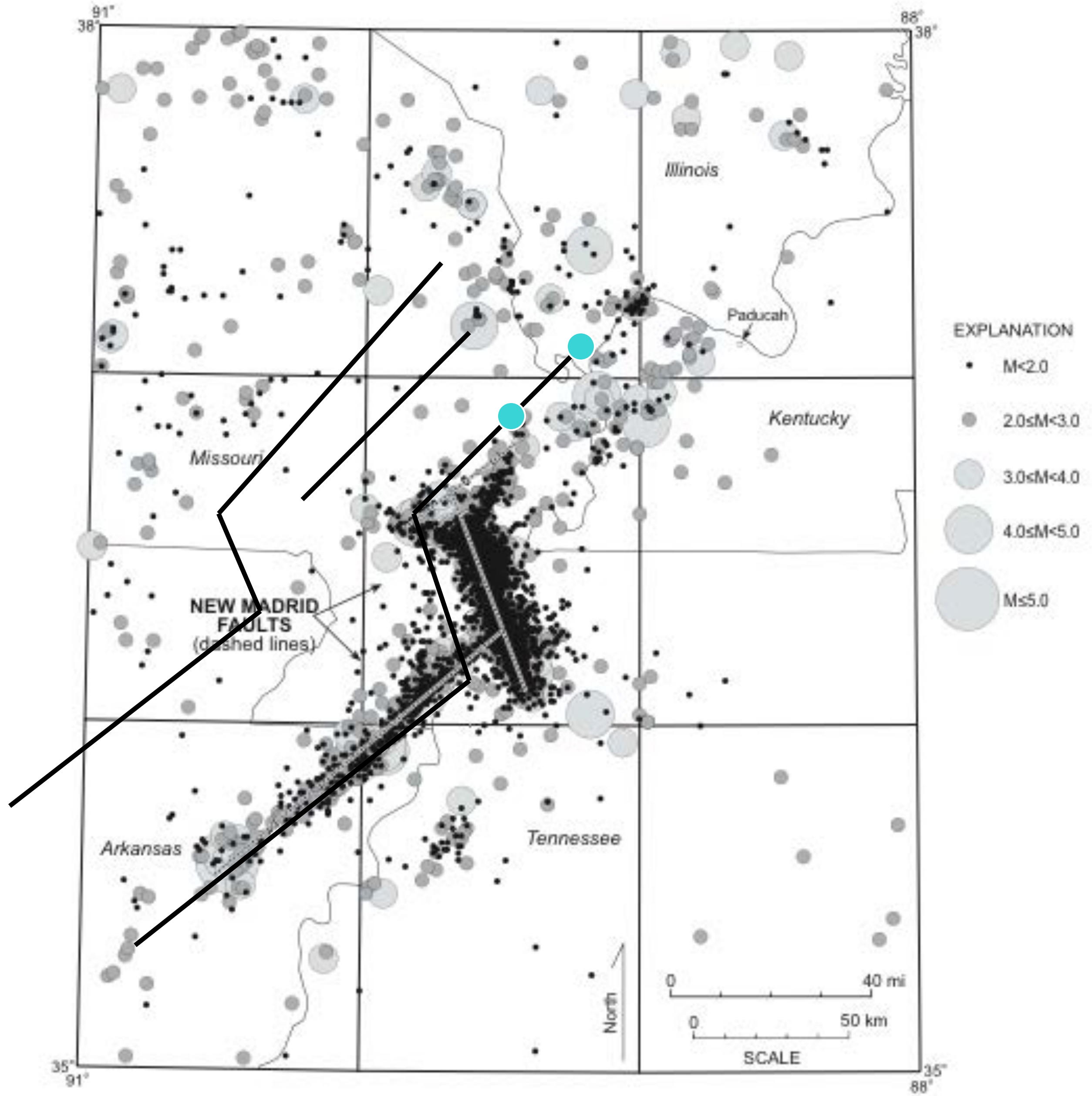


Figure 10. Locations of earthquakes in the central United States since 1974 (from the Center for Earthquake Research and Information).

KGS SP6

1811-1812 M7s

Event	Hough	Bakun	Johnston
Dec 16, 08 (S)	7.2-7.3	7.6	8.1
Dec 16, 14 (S)	7.0		
Jan 23, 15 (N)	7.0	7.5	7.8
Feb 7, 09 (C)	7.4-7.5	7.8	8.0

NEW MADRID Seismic zone

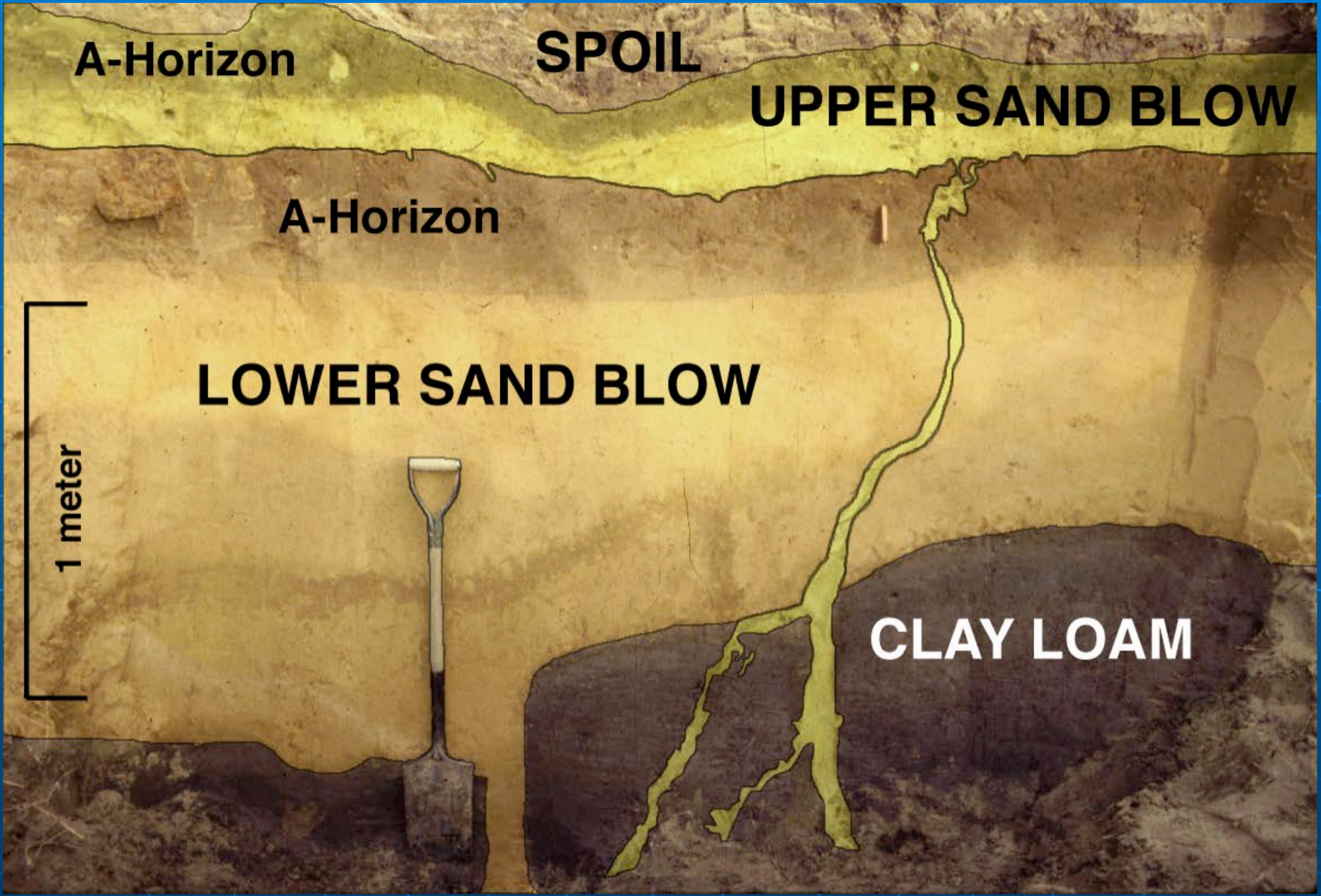


photo from Li et al. (1998)

900 A.D. and 1811-12 events

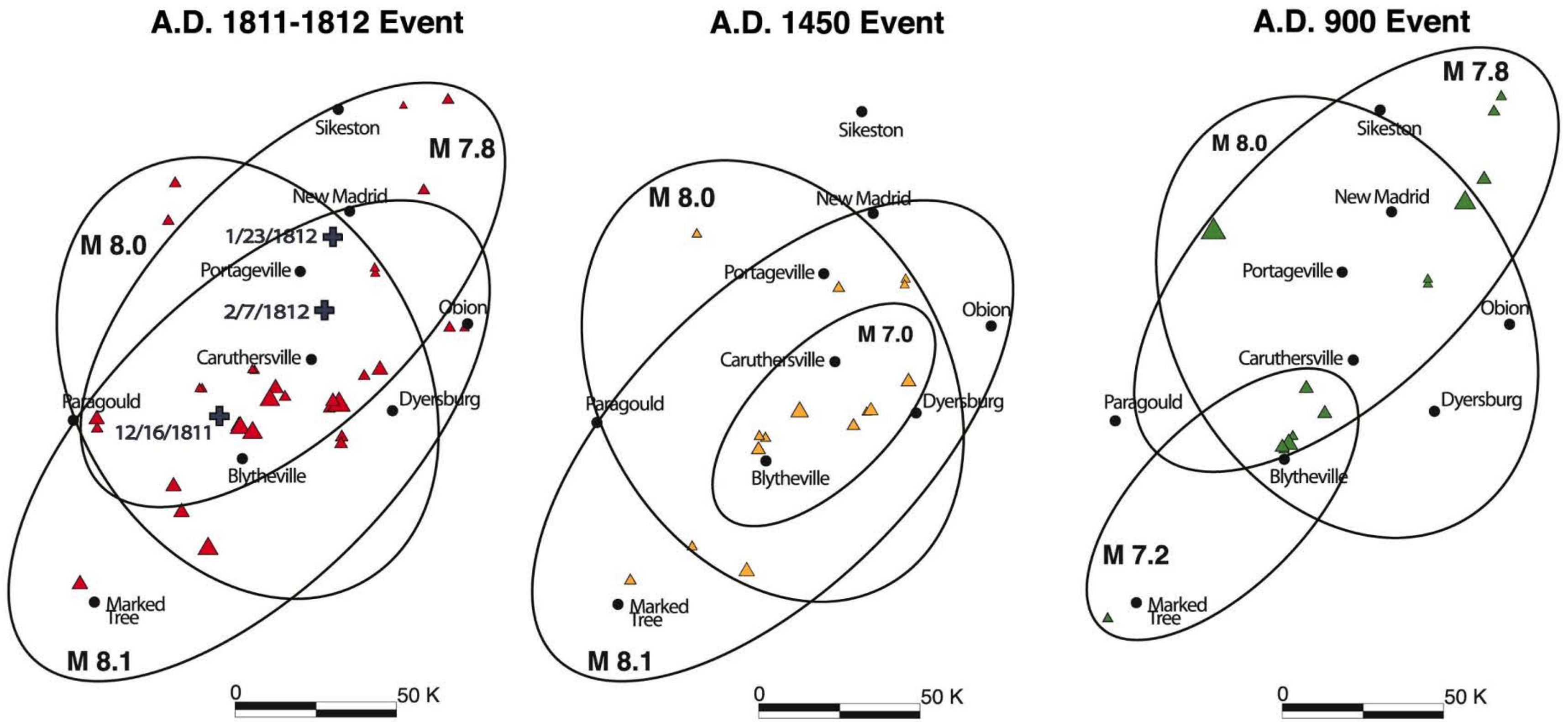
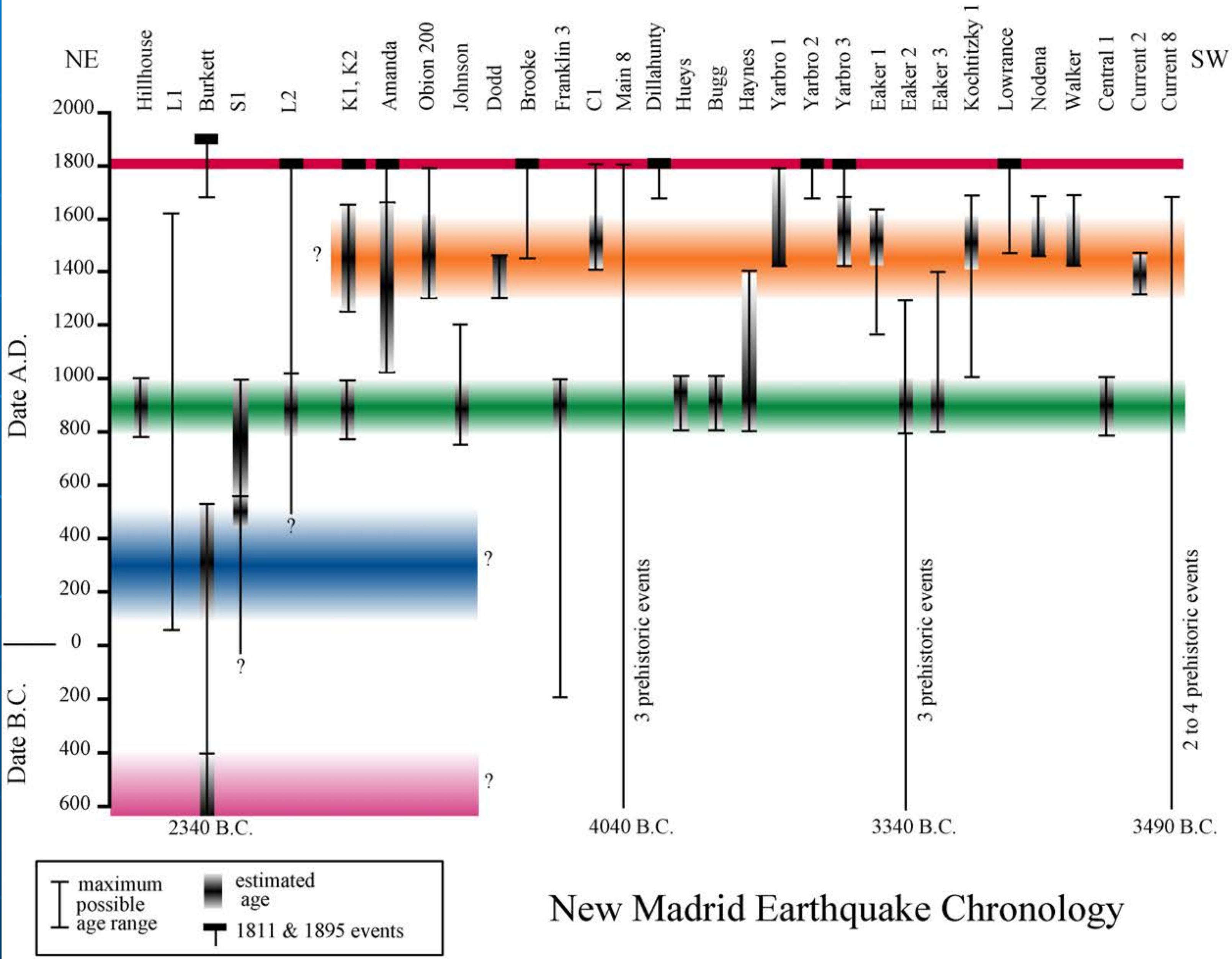
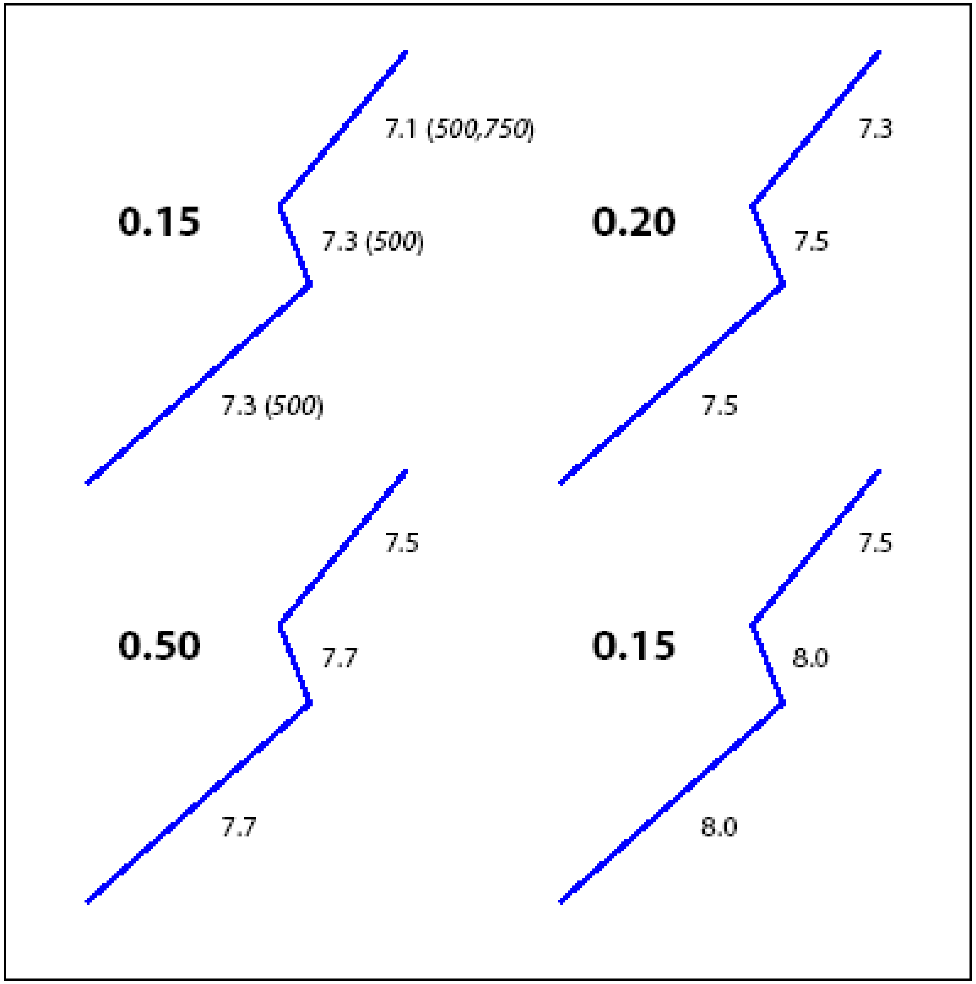


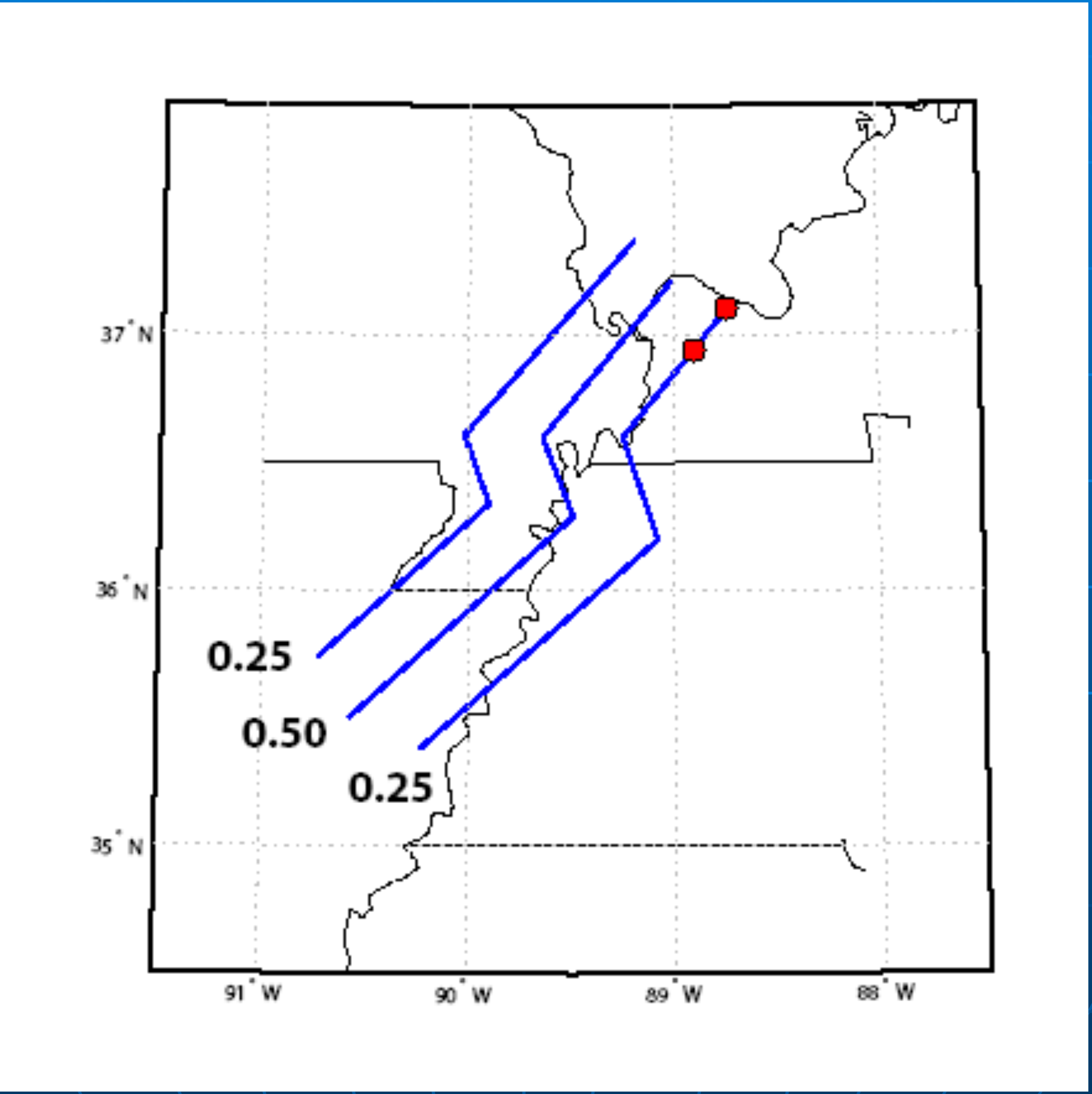
Figure 6. Liquefaction fields for 1811-1812, A.D. 1450, and A.D. 900 events as interpreted from spatial distribution and stratigraphy of sand blows. Magnitudes of individual earthquakes in A.D. 1450 and A.D. 900 are inferred on basis of size of liquefaction fields compared to those related to 1811-1812 earthquakes.



New Madrid Earthquake Chronology

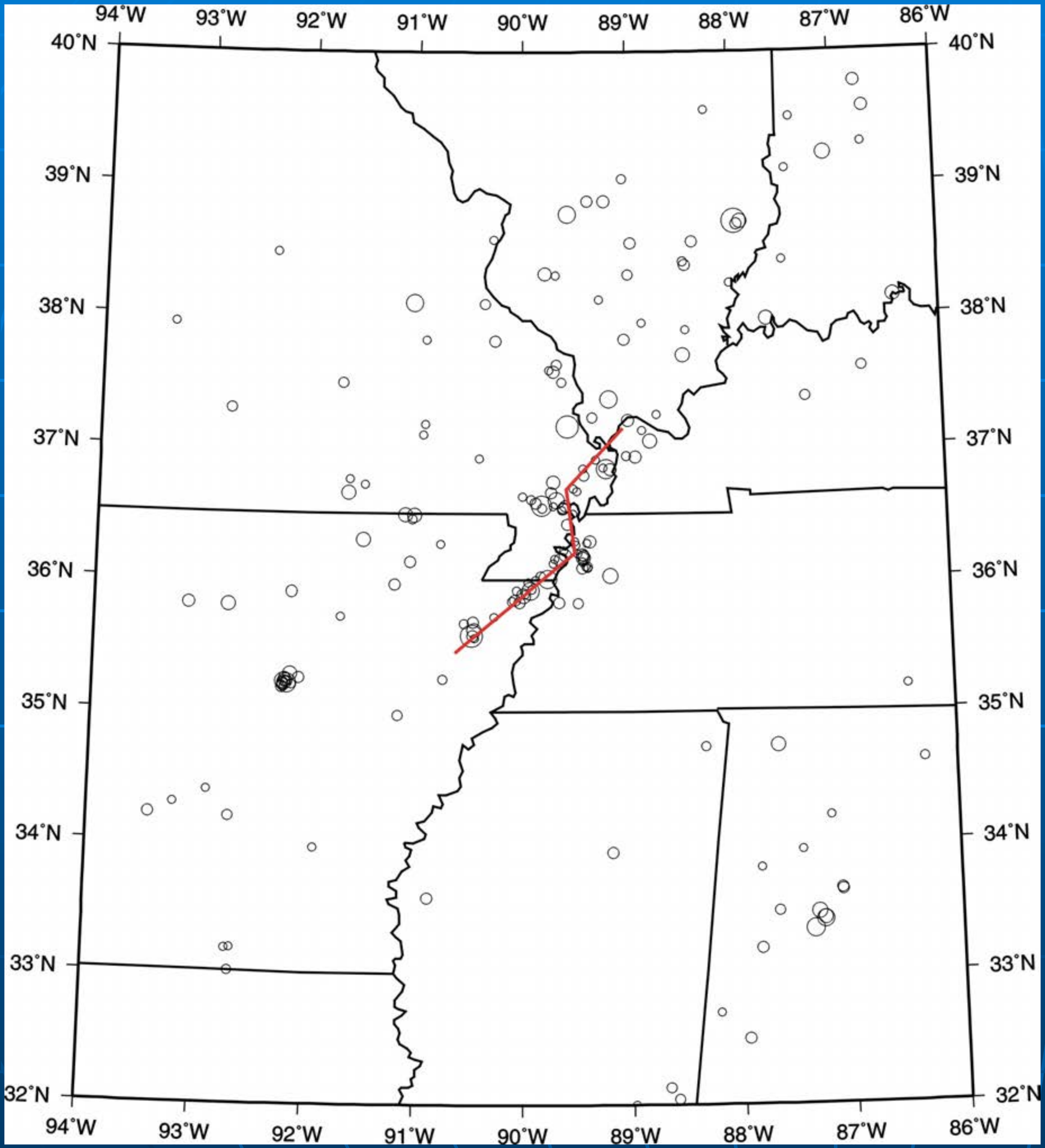
NEW MADRID LOGIC TREE





37° N
36° N
35° N
0.25
0.50
0.25
91° W
90° W
89° W
88° W

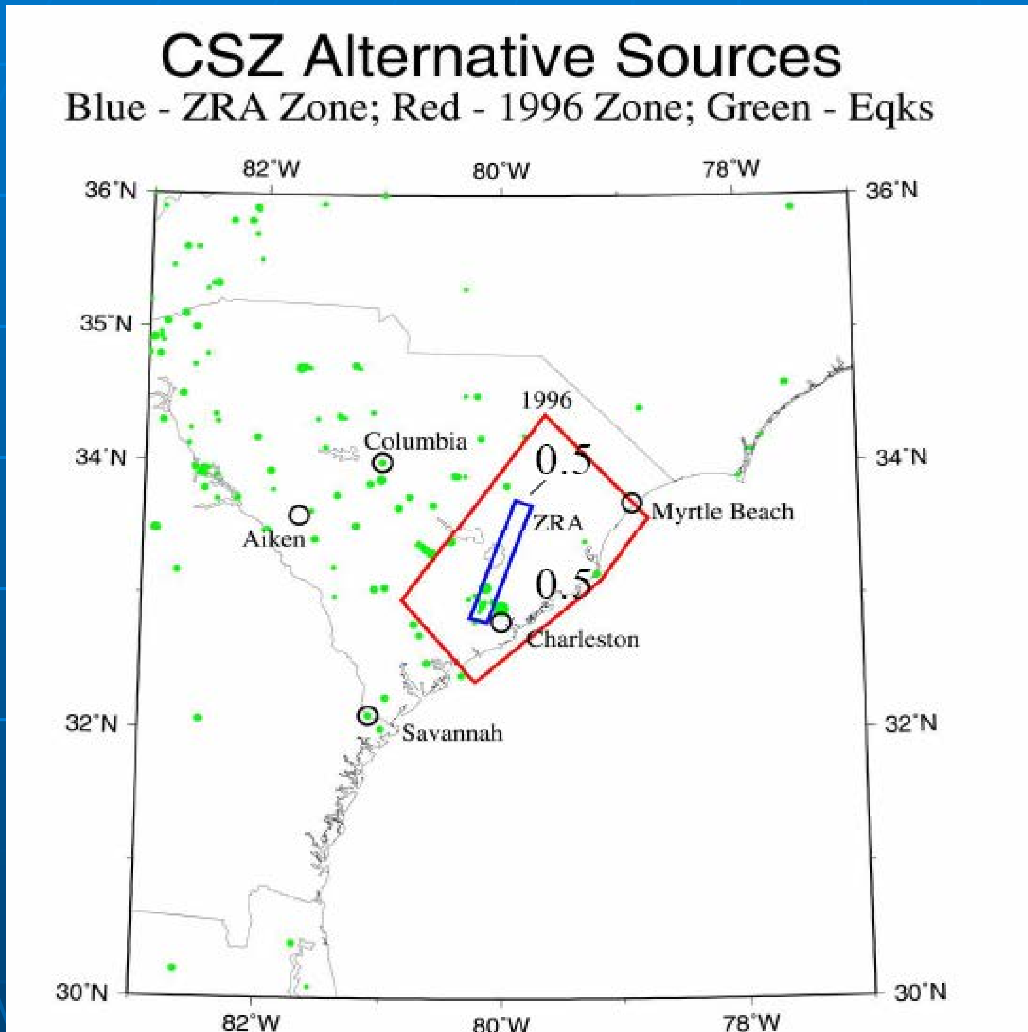
Temporal Clustering of 1811-12 type earthquakes



Used recurrence time of 500 years. Used entire trace when calculating ground motions, with variability. This will produce same median ground motions as each segment rupturing separately.

However, this neglects effects of variability of ground motions from earthquakes
on the individual segments.

You can't just add frequencies of exceedances assuming each segment ruptures independently, since the earthquakes are dependent events (Toro and Silva, 2001)

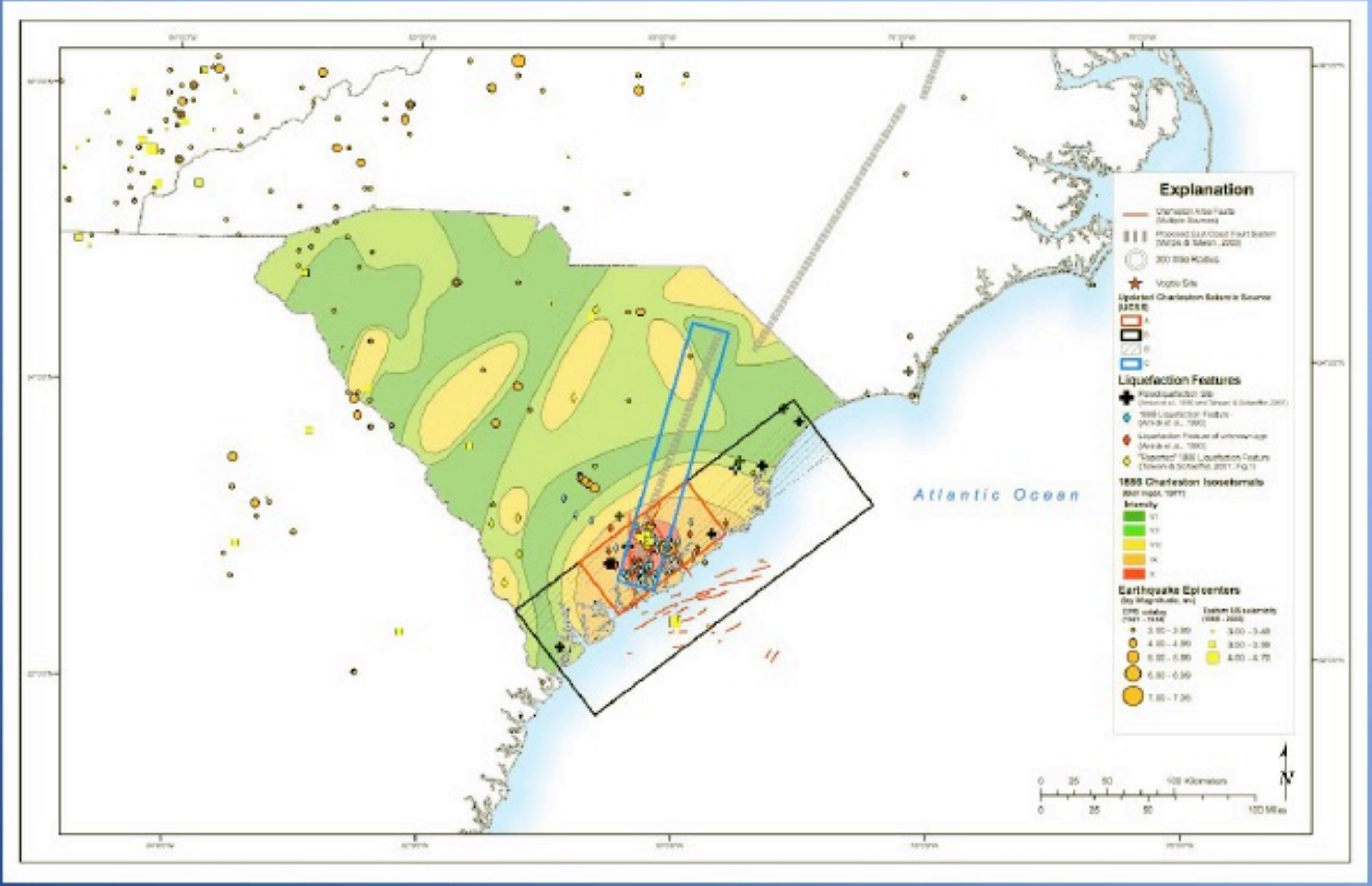


M 6.8-7.5, 550 yrs

Mag	wt
M 6.8	(0.2)
M 7.1	(0.2)
M 7.3	(0.45)
M 7.5	(0.15)

Figure 8: Alternative source zones near Charleston, South Carolina and logic tree

Updated Charleston Seismic Source (UCSS)

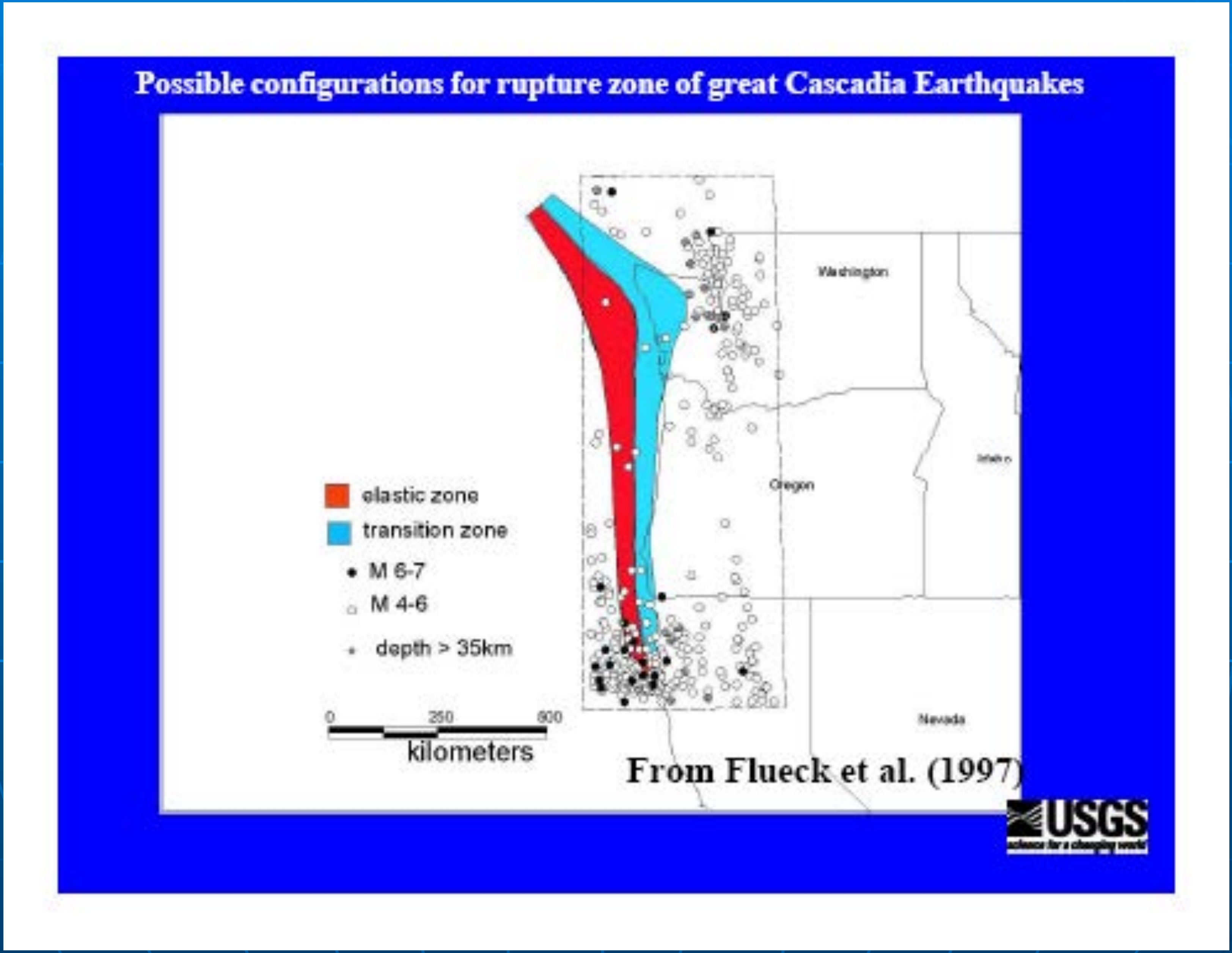


WESTERN U.S.

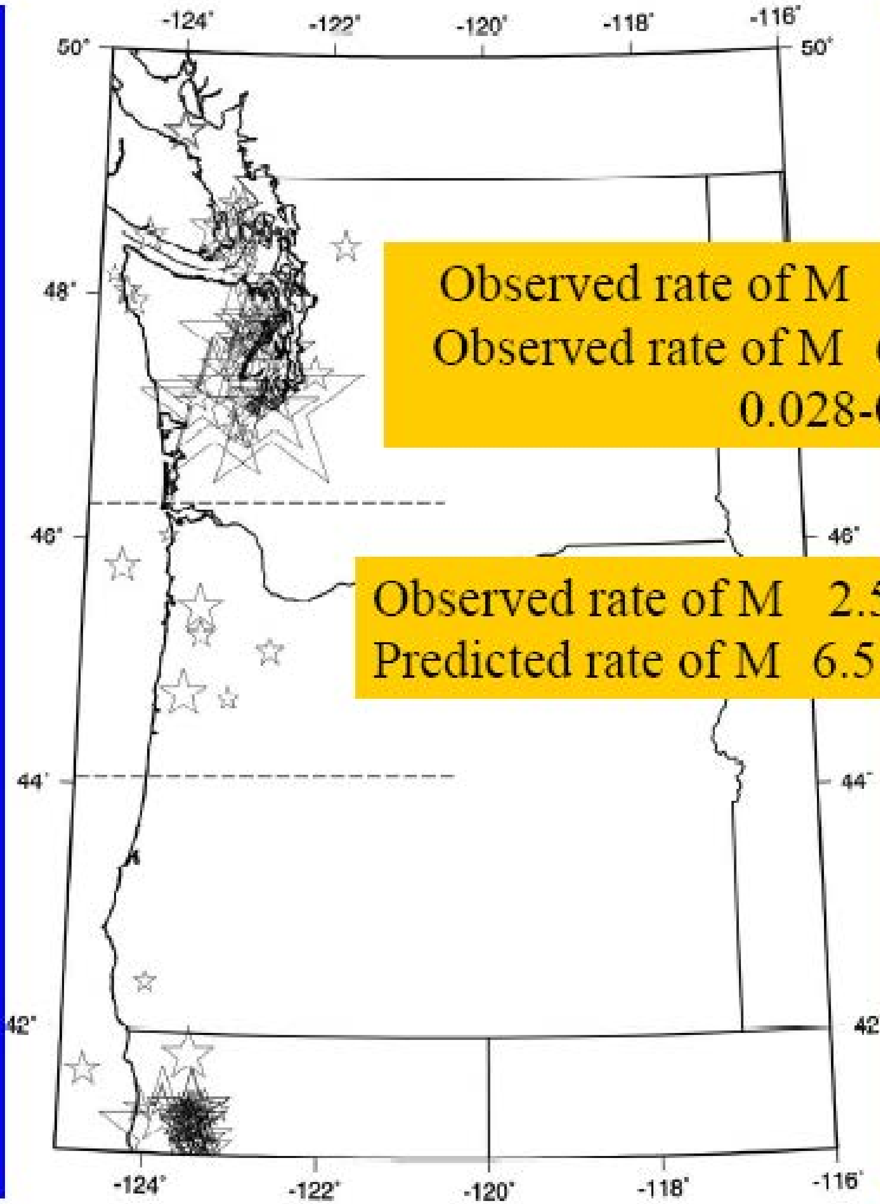
- Pacific NW: Cascadia M distribution, Portland, OR zone of deep earthquakes
- Intermountain West: WSSPC recommendations
- California: New fault models for San Andreas fault.

PACIFIC NW REGION

- Cascadia subduction zone
- Portland, OR deep zone



Working Groups, Downdip width (episodic tremor and slip), deep eqs, recurrence, clusters, magnitudes

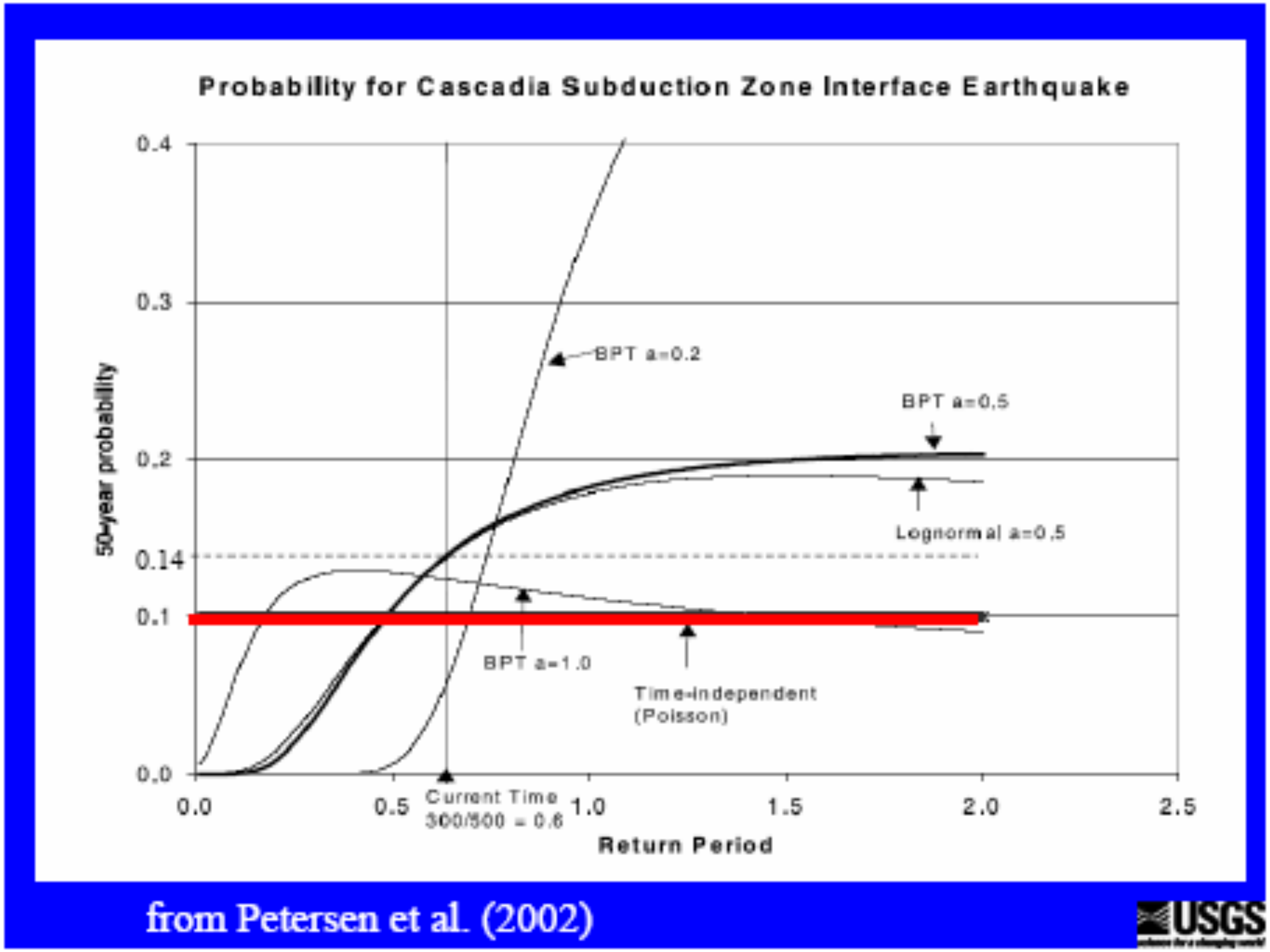


Observed rate of M   2.5 since 1990: 3.4 /yr
Observed rate of M 6.5 since 1940 or 1900: 0.028-0.045 /yr

Observed rate of M   2.5 since 1990: 0.38 /yr
Predicted rate of M 6.5: 0.003-0.005 /yr

USGS
science for a changing world

Time-dependent model for Cascadia



Intermountain West Region

Western States Seismic Policy Council Recommendations (May 2006)

Working Groups in Utah and Nevada

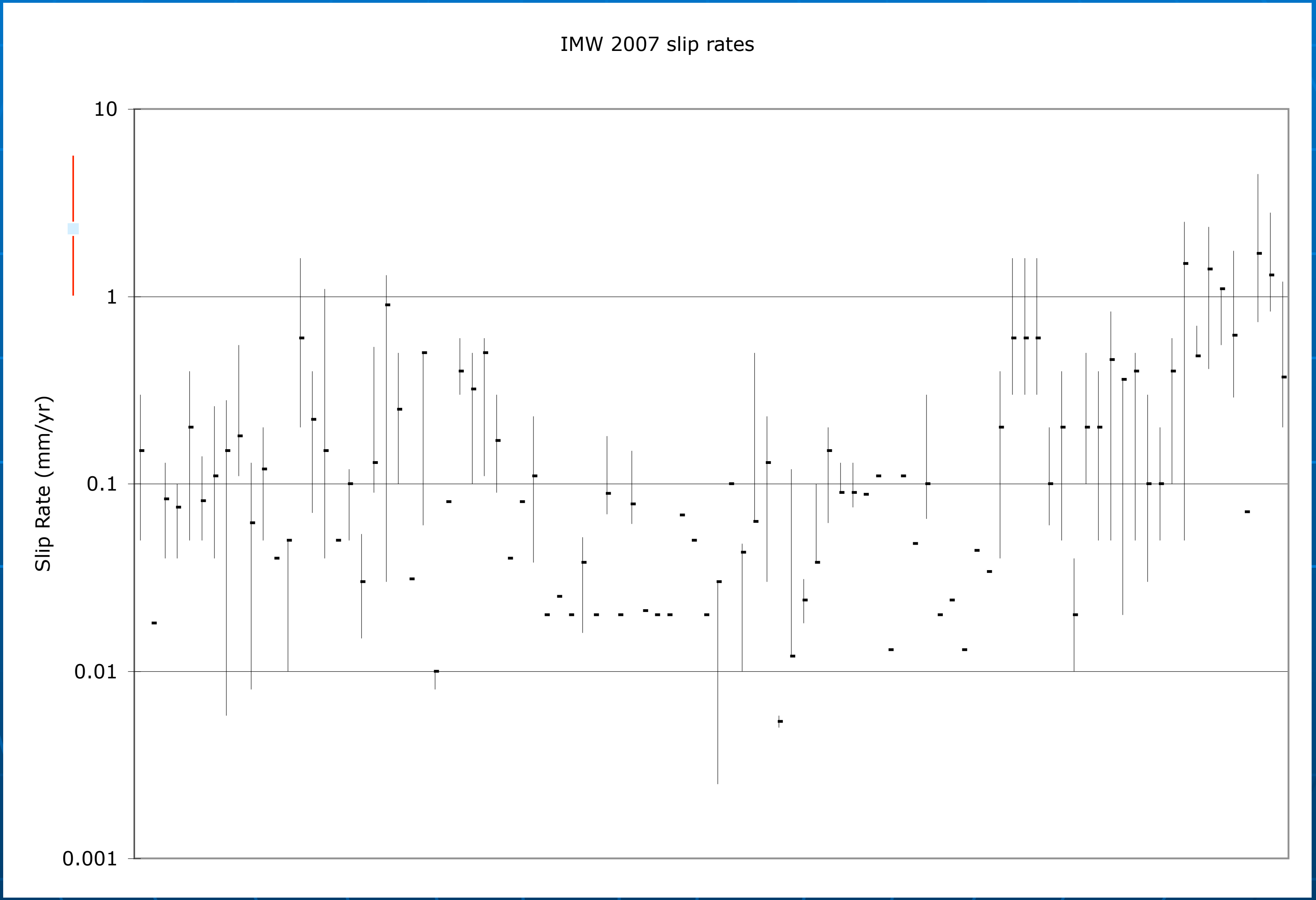
Short-Term Recommendation for the 2007 NSHMs

1. The USGS should incorporate uncertainties in slip rates and recurrence intervals for the more significant BRP faults.

    a. Most studies giving slip rates and recurrence intervals identify the range of uncertainties.

    b. In Utah, use the slip-rate/recurrence distributions developed by the Utah Quaternary Fault Parameters Working Group (Lund, 2005a).

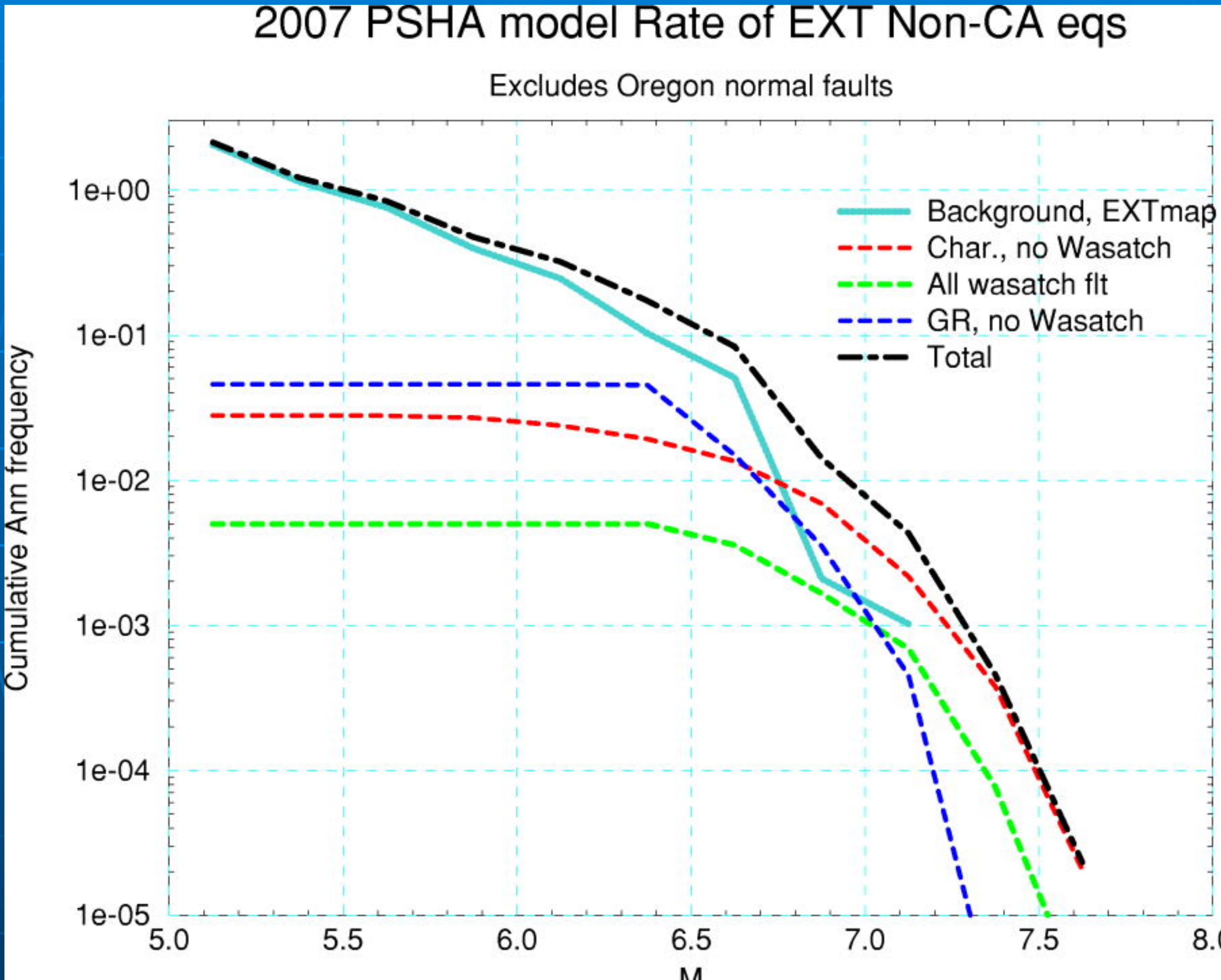
Uncertainty in slip rates in the Intermountain West region



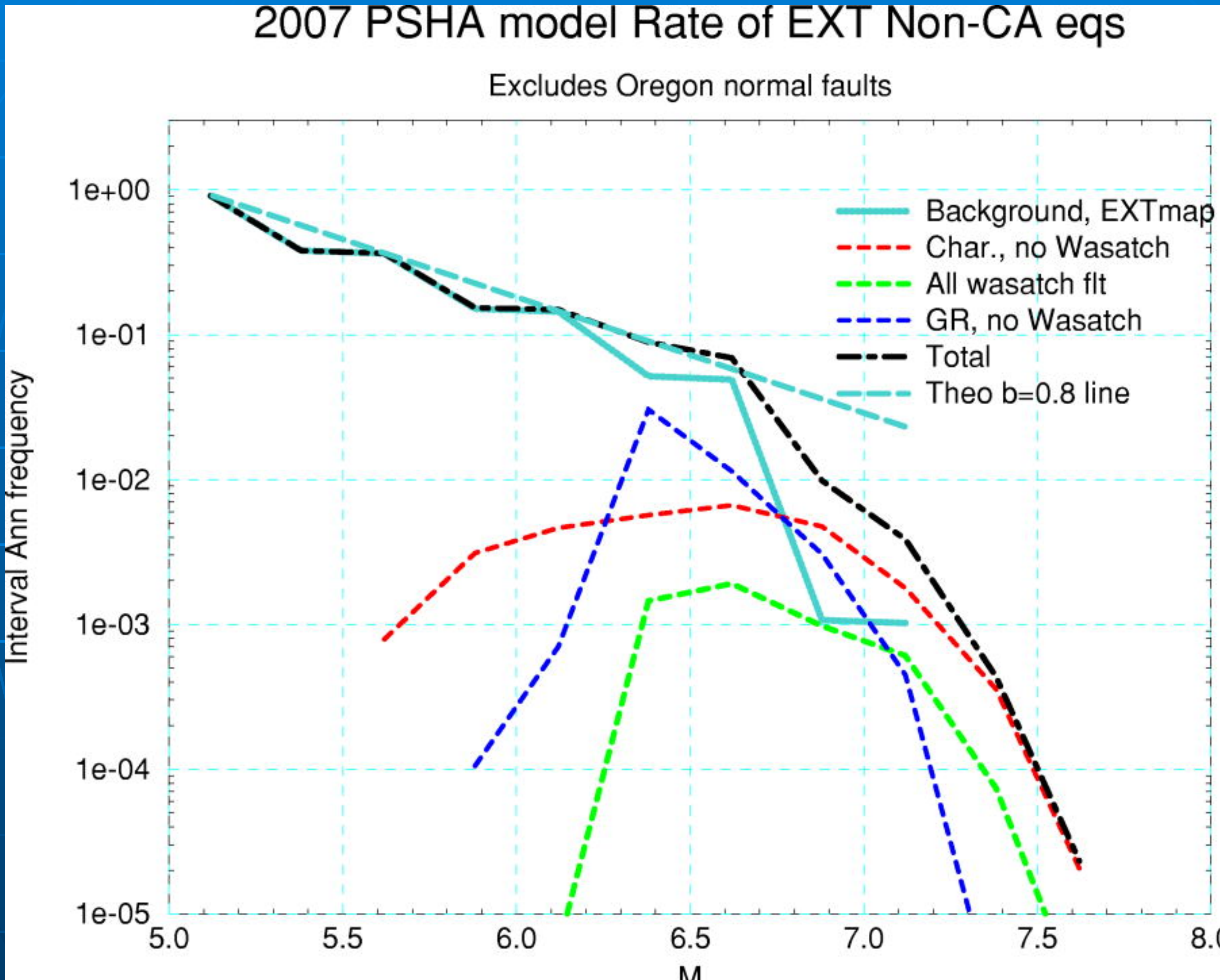
Proper Magnitude-Frequency Distributions (Gutenberg-Richter versus Characteristic Earthquake Models) for BRP Faults

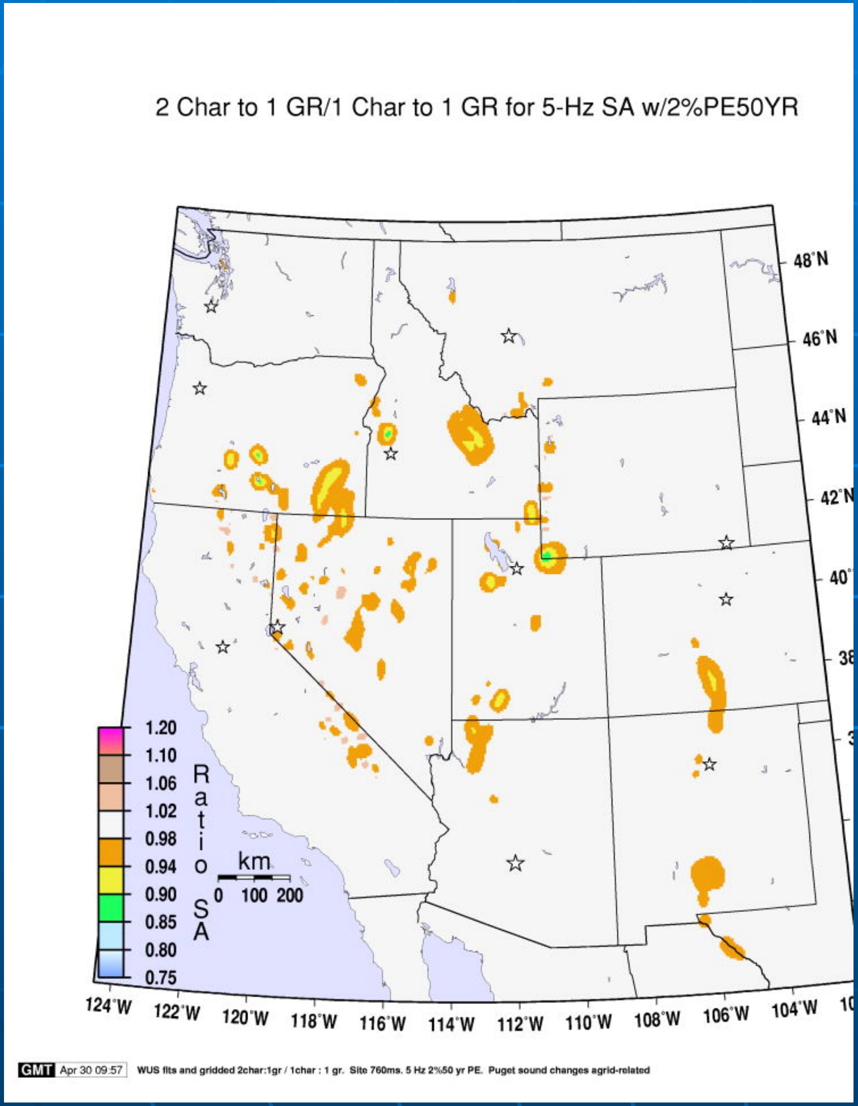
Short-Term Recommendations for the 2007 NSHMs

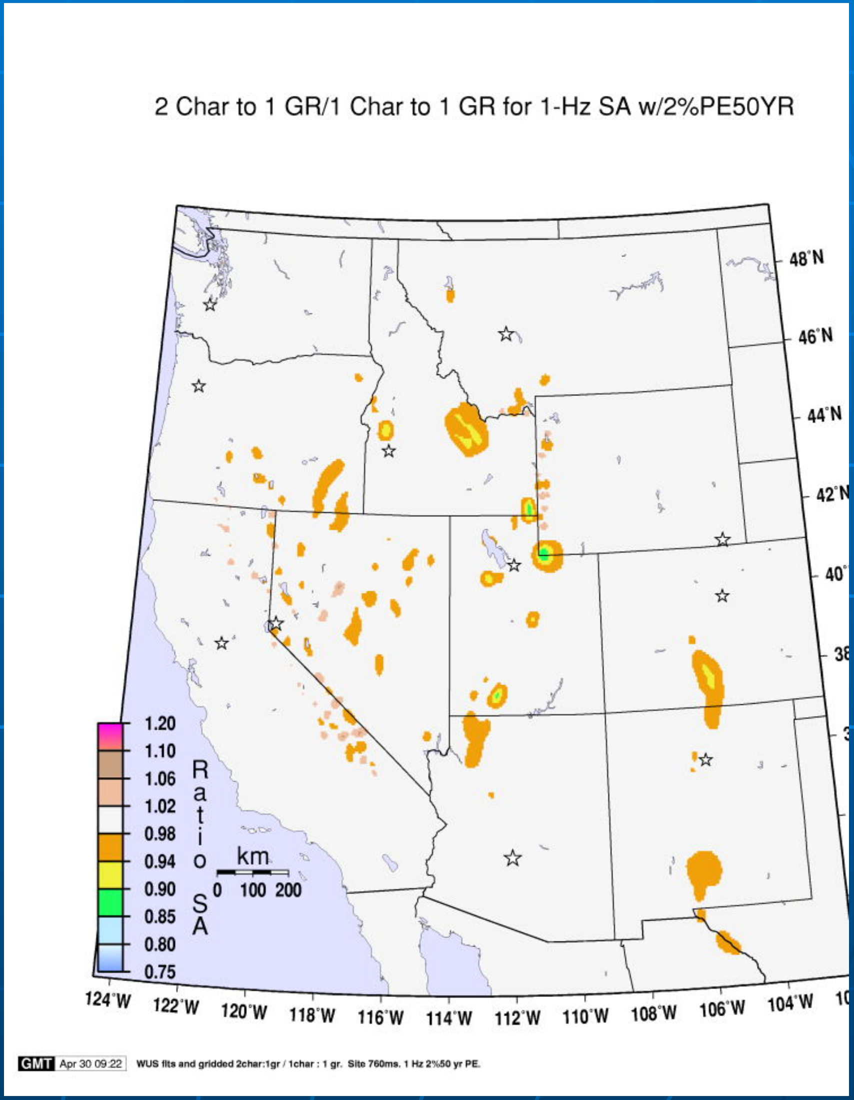
1. The USGS "floating exponential" model should be validated to the extent possible, or at least made consistent with the paleoseismic and historical earthquake record in the BRP. The USGS model should also be compared with traditional magnitude-frequency models currently used in state-of-the-practice PSHAs.
2. The USGS should use the same recurrence model and weights for all BRP faults unless there is a technical basis for deviating from this characterization.
3. Weights assigned to the maximum magnitude and "floating exponential" models used for the 2007 NSHMs should, at a minimum, have the same weights as those used in California (2/3 - 1/3) unless there is a technical basis for deviating from this characterization.
4. To avoid double-counting earthquakes in the range of M 6.5 to the characteristic earthquake magnitude, zones surrounding BRP faults should be removed from the areas included in the Gaussian smoothing of background seismicity.
5. The methodology used for constructing the NSHMs must be fully transparent. The USGS is urged to publish, if only as a short note, how recurrence modeling is performed for the NSHMs, especially for fault-specific sources.



2007 PSHA model Rate of EXT Non-CA eqs
Excludes Oregon normal faults
Cumulative Ann frequency
1e+00
1e-01
1e-02
1e-03
1e-04
1e-05
5.0
5.5
6.0
6.5
7.0
7.5
8.0
M
Background, EXTmap
Char., no Wasatch
All wasatch flt
GR, no Wasatch
Total


2007 PSHA model Rate of EXT Non-CA eqs
Excludes Oregon normal faults
Interval Ann frequency
1e+00
1e-01
1e-02
1e-03
1e-04
1e-05
5.0
5.5
6.0
6.5
7.0
7.5
8.0
M
Background, EXTmap
Char., no Wasatch
All wasatch flt
GR, no Wasatch
Total
Theo b=0.8 line

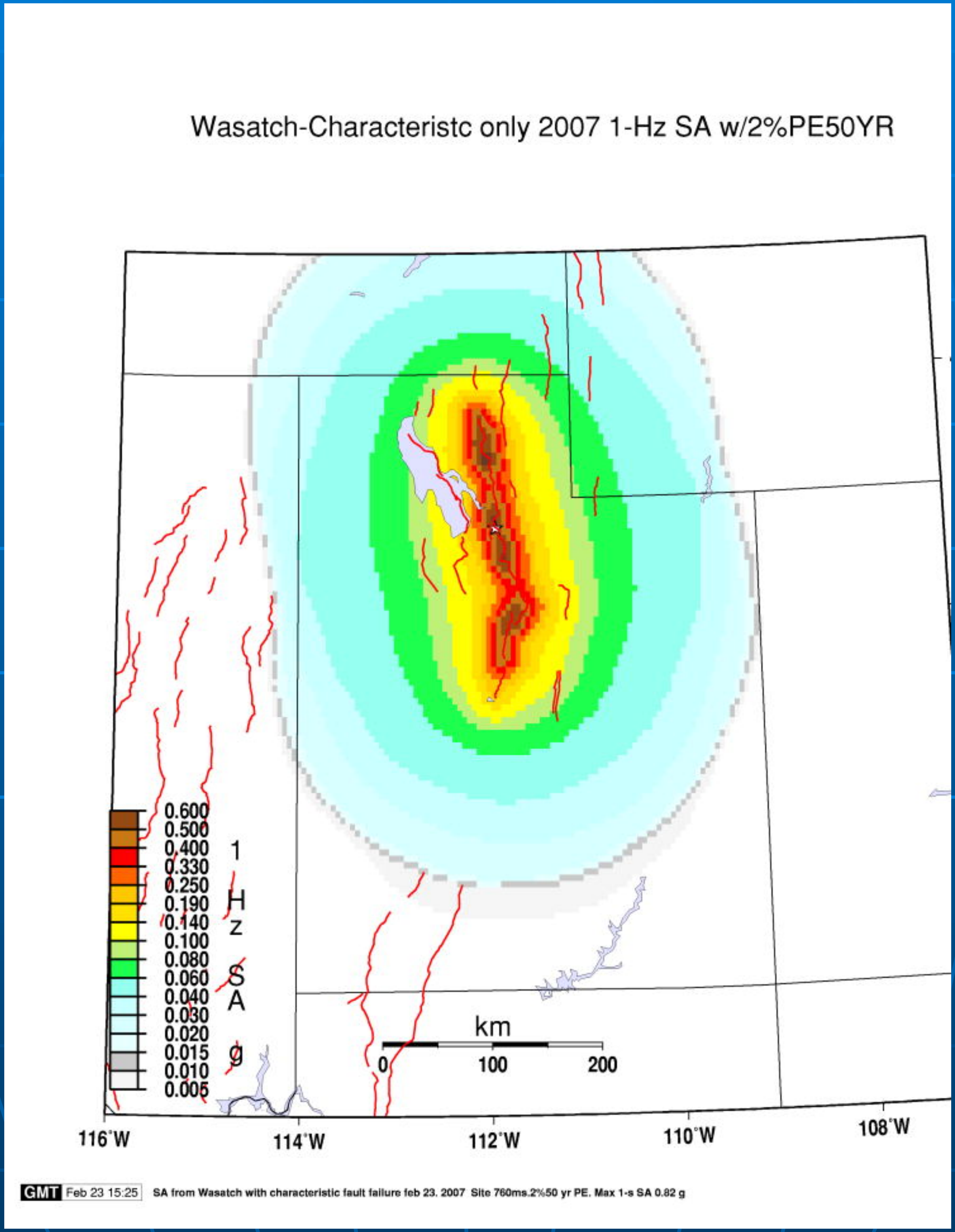

2 Char to 1 GR/1 Char to 1 GR for 5-Hz SA w/2%PE50YR
48°N
46°N
44°N
42°N
40°
1.20
1.10
1.06
1.02
0.98
0.94
0.90
0.85
0.80
0.75
Ratio SA
km
0 100 200
124°W 122°W 120°W 118°W 116°W 114°W 112°W 110°W 108°W 106°W 104°W
GMT Apr 30 09:57
WUS flts and gridded 2char:1gr / 1char : 1 gr. Site 760ms. 5 Hz 2%50 yr PE. Puget sound changes agrid-related


2 Char to 1 GR/1 Char to 1 GR for 1-Hz SA w/2%PE50YR
48°N
46°N
44°N
42°N
40°
1.20
1.10
1.06
1.02
0.98
0.94
0.90
0.85
0.80
0.75
Ratio SA
km
0 100 200
124°W 122°W 120°W 118°W 116°W 114°W 112°W 110°W 108°W 106°W 104°W
GMT Apr 30 09:22
WUS flts and gridded 2char:1gr / 1char : 1 gr. Site 760ms. 1 Hz 2%50 yr PE.

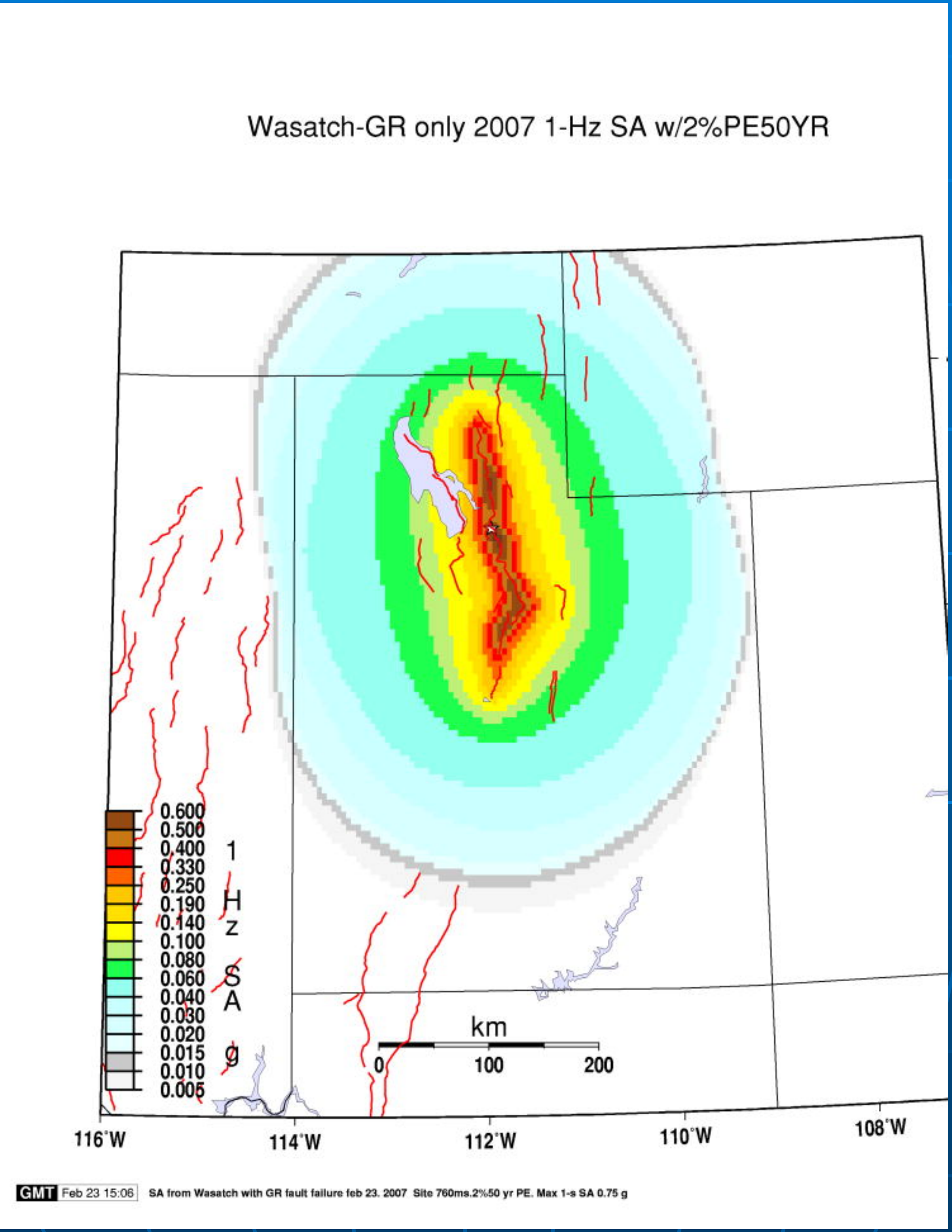
Short-Term Recommendations for the 2007 NSHMs Estimating Displacement and Length:

1. Include uncertainty in surface rupture length (SRL) and its consequences for magnitude.
2. Constrain the minimum magnitude assigned to surface-faulting earthquakes to M 6.5 to be consistent with the hazard set by background seismicity.
3. Use magnitude-displacement regressions to improve magnitude estimates where the magnitude from SRL appears inconsistent.
4. Have a working group look at the faults for which displacement data are available (thought to be ~20 in Nevada), and suggest a weighting between displacement and SRL estimates of magnitude to achieve a combined fault magnitude estimate.

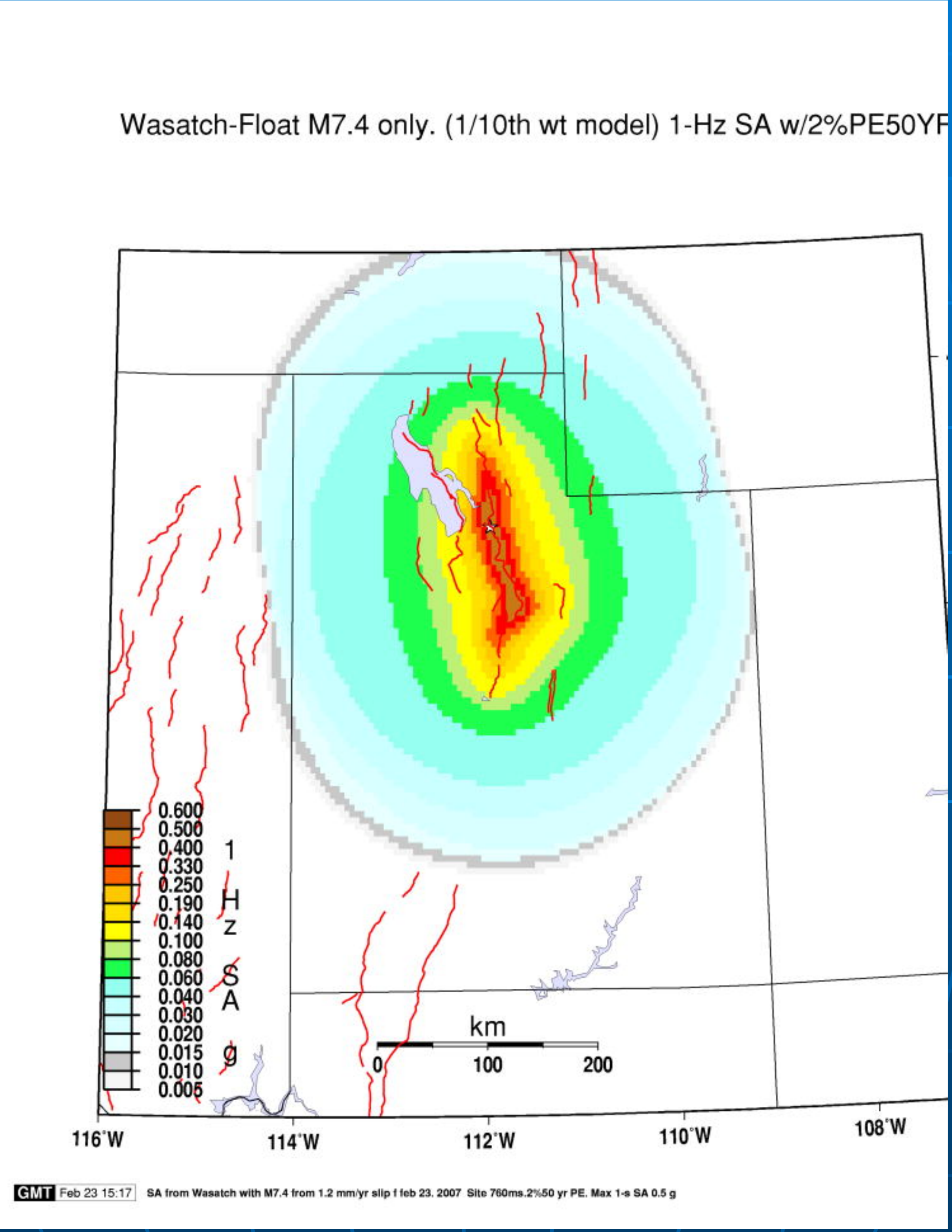
1. Hazard calculations for the NSHMs should consider the possibility of multi-segment ruptures on BRP faults.
2. For BRP faults for which single-segment-rupture models are being used to compute the hazard, the 2007 NSHMs should also use an unsegmented rupture model which accounts for the possibility of ruptures extending beyond segment boundaries. The unsegmented model should be given a relatively low weight.
3. The two faults that ruptured together in the 1959 Hebgen Lake earthquake should be treated as a single seismic source for the purpose of the 2007 NSHM hazard calculations.



Wasatch-Characteristc only 2007 1-Hz SA w/2%PE50YR
0.600
0.500
0.400
0.330
0.250
0.190
0.140
0.100
0.080
0.060
0.040
0.030
0.020
0.015
0.010
0.005
1 Hz SA g
km
0
100
200
116°W
114°W
112°W
110°W
108°W
GMT Feb 23 15:25
SA from Wasatch with characteristic fault failure feb 23. 2007 Site 760ms.2%50 yr PE. Max 1-s SA 0.82 g

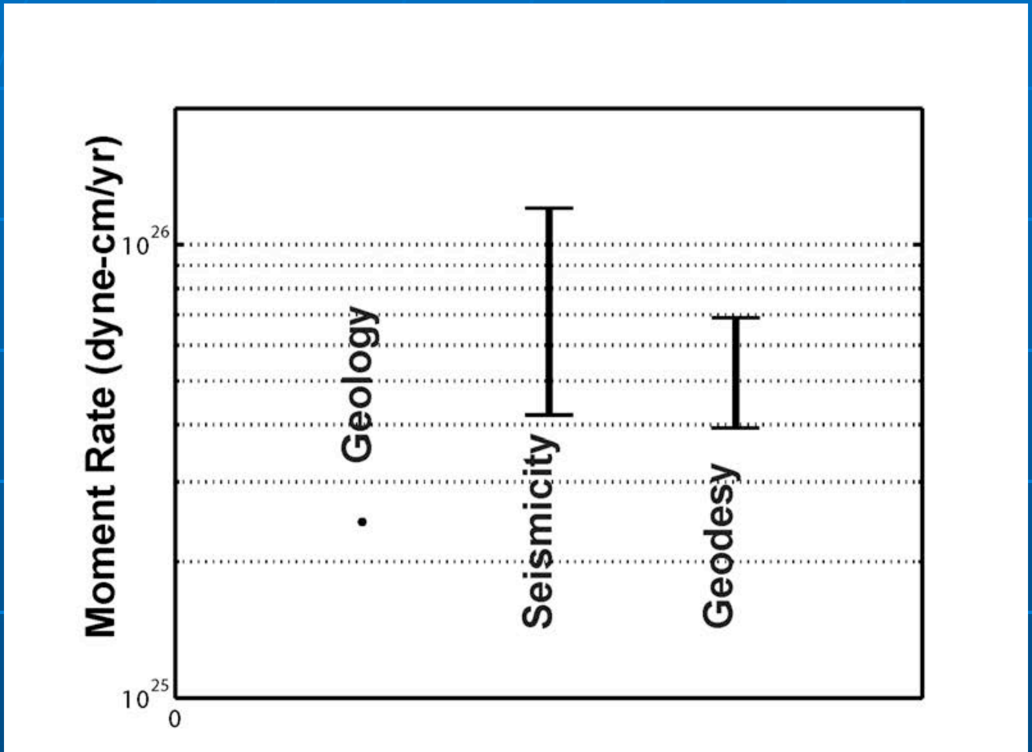


Wasatch-GR only 2007 1-Hz SA w/2%PE50YR
0.600
0.500
0.400
0.330
0.250
0.190
0.140
0.100
0.080
0.060
0.040
0.030
0.020
0.015
0.010
0.005
1 Hz SA g
km
0
100
200
116°W
114°W
112°W
110°W
108°W
GMT Feb 23 15:06
SA from Wasatch with GR fault failure feb 23. 2007 Site 760ms.2%50 yr PE. Max 1-s SA 0.75 g


Wasatch-Float M7.4 only. (1/10th wt model) 1-Hz SA w/2%PE50YR
0.600
0.500
0.400
0.330
0.250
0.190
0.140
0.100
0.080
0.060
0.040
0.030
0.020
0.015
0.010
0.005
1 Hz SA g
km
0
100
200
116°W
114°W
112°W
110°W
108°W
GMT Feb 23 15:17
SA from Wasatch with M7.4 from 1.2 mm/yr slip f feb 23. 2007 Site 760ms.2%50 yr PE. Max 1-s SA 0.5 g

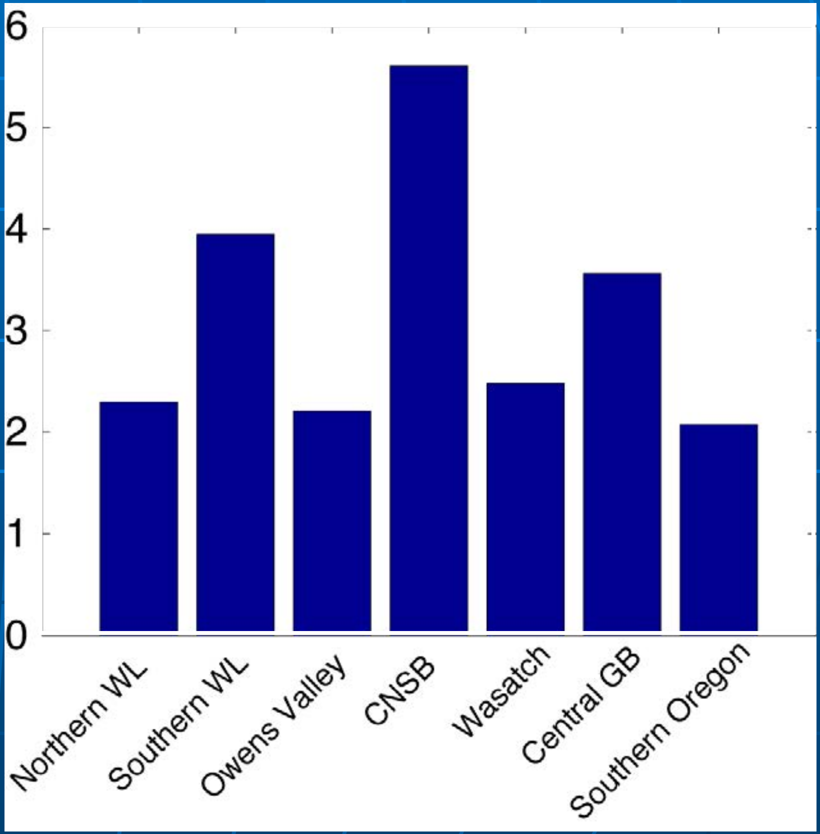
1. Convert vertical slip rates to extensional rates for consistency with GPS data. This involves resolving the question of dip of normal faults.
The NSHMs currently use a dip of 60°; the BRPEWG recommends using a dip of 50°±10°.
2. For the BRP, use the province-wide kinematic (GPS) boundary condition (12-14 mm/yr) as a constraint on the sum of geologic slip rates. Enhance the fault catalog used in the NSHMs if necessary to achieve the far-field rates.
3. Modify the boundaries of the geodetic zones in the western Great Basin used in the 1996 NSHMs to better reflect the areas of high strain depicted on the GPS-based strain-rate map.
4. Use the geodetic data as the total strain budget. Ideally, the moment rates from the faults, areal source zones, and GPS zones should add up to the full geodetic budget. This total should be comparable to the seismicity, which is a separate estimate of moment rate. Differences that exist between these individual moment sources should be fully accounted for in the 2007 NSHMs.
5. The USGS should test models to evaluate the effect of releasing geodetic strain as 80% coseismic and 20% aseismic.
6. The USGS should evaluate the impact on the NSHMs of partitioning geodetic strain on individual faults within a zone (assigning default slip rates) versus distributing the geodetic strain uniformly across the zone.

Geodesy Sees More Moment than Geology



Pancha et al., 2006

Ratio of Geodetic to Geologic Moment by Sub-Region



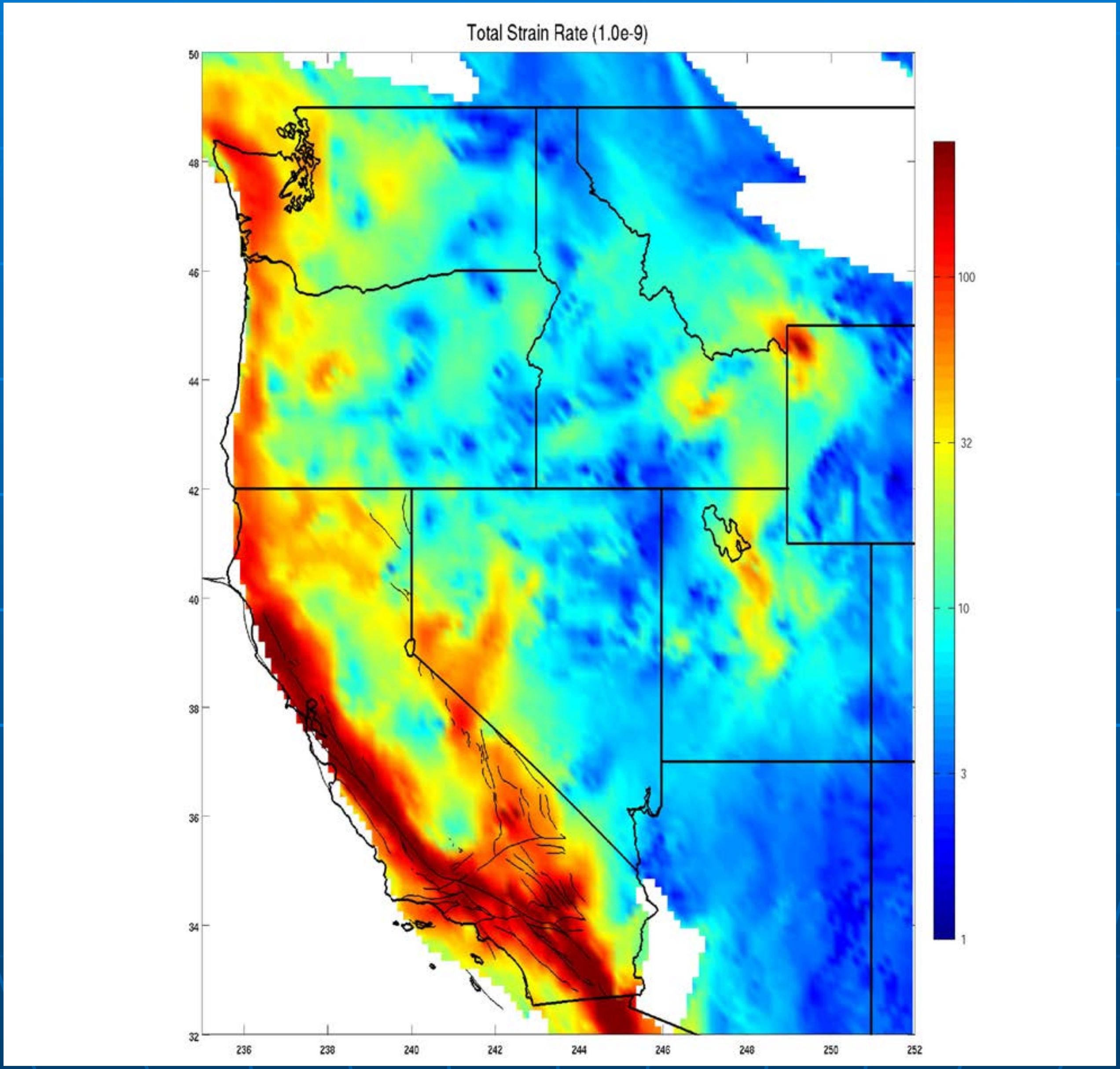
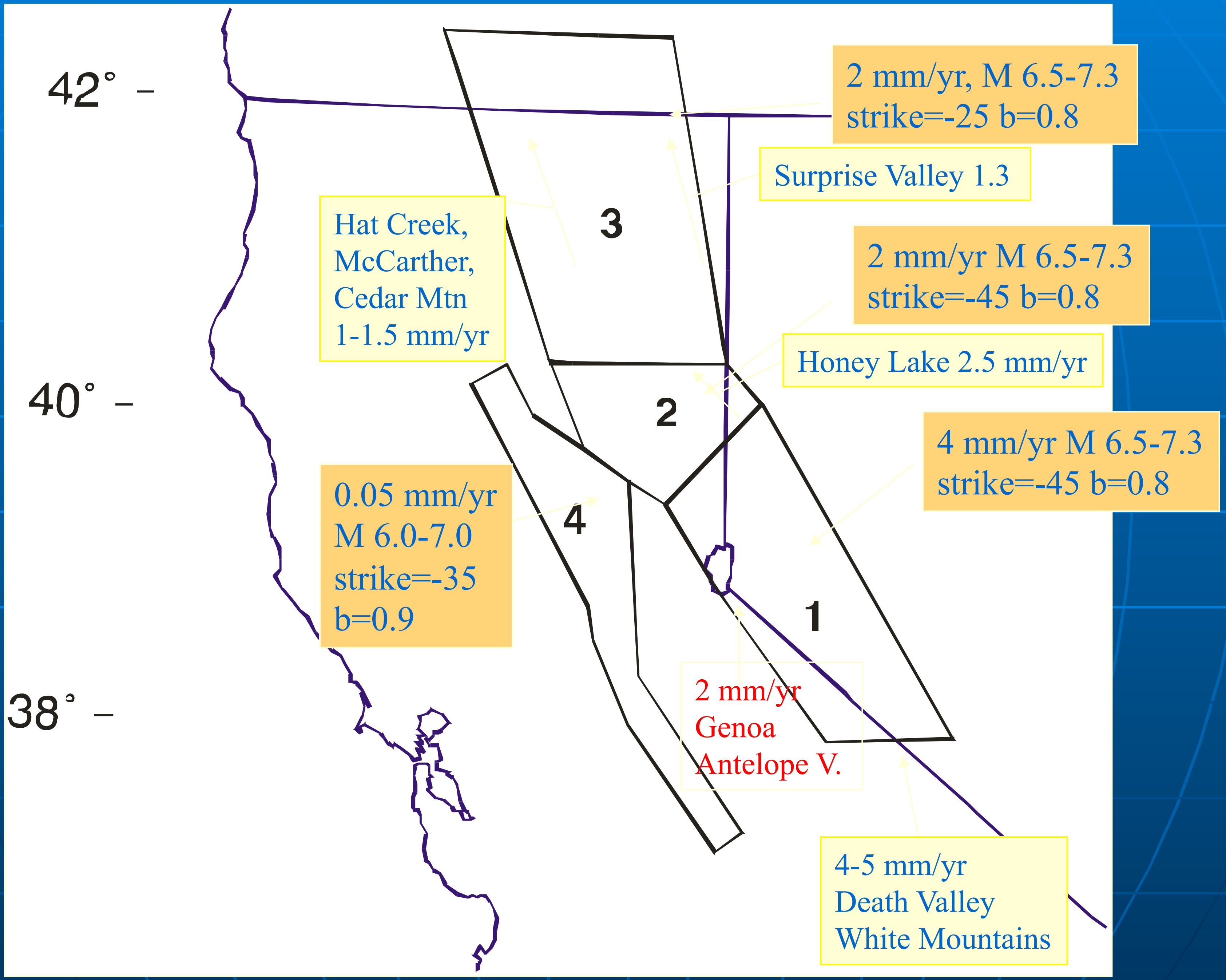
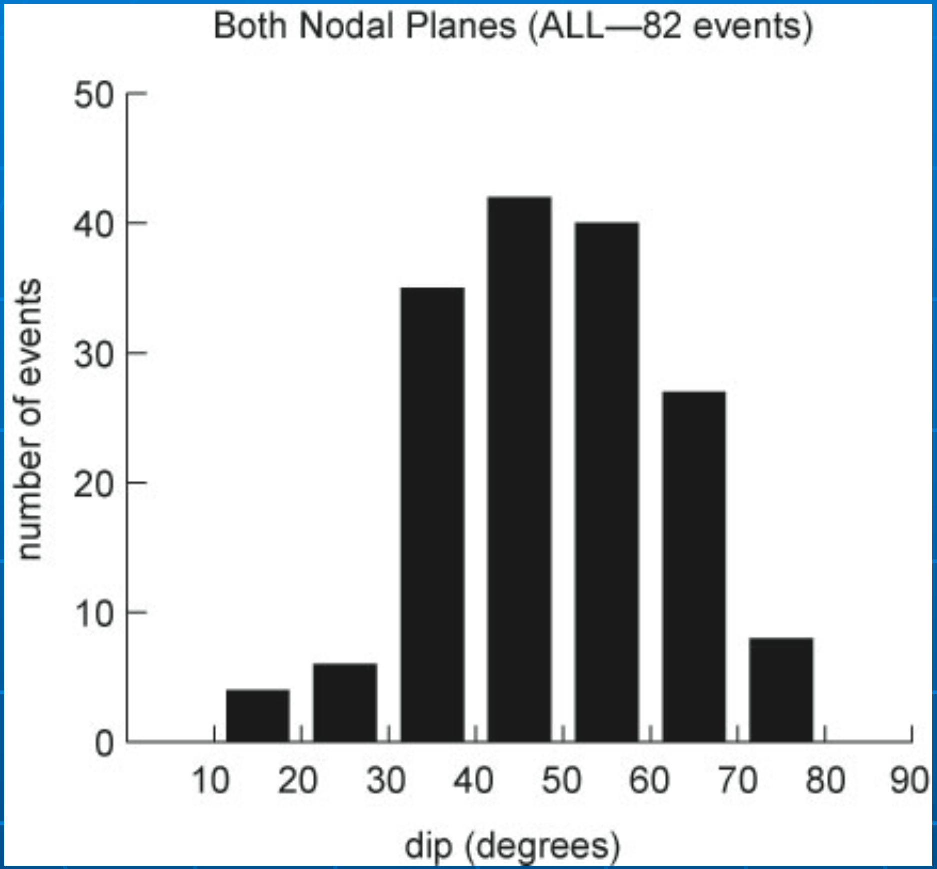


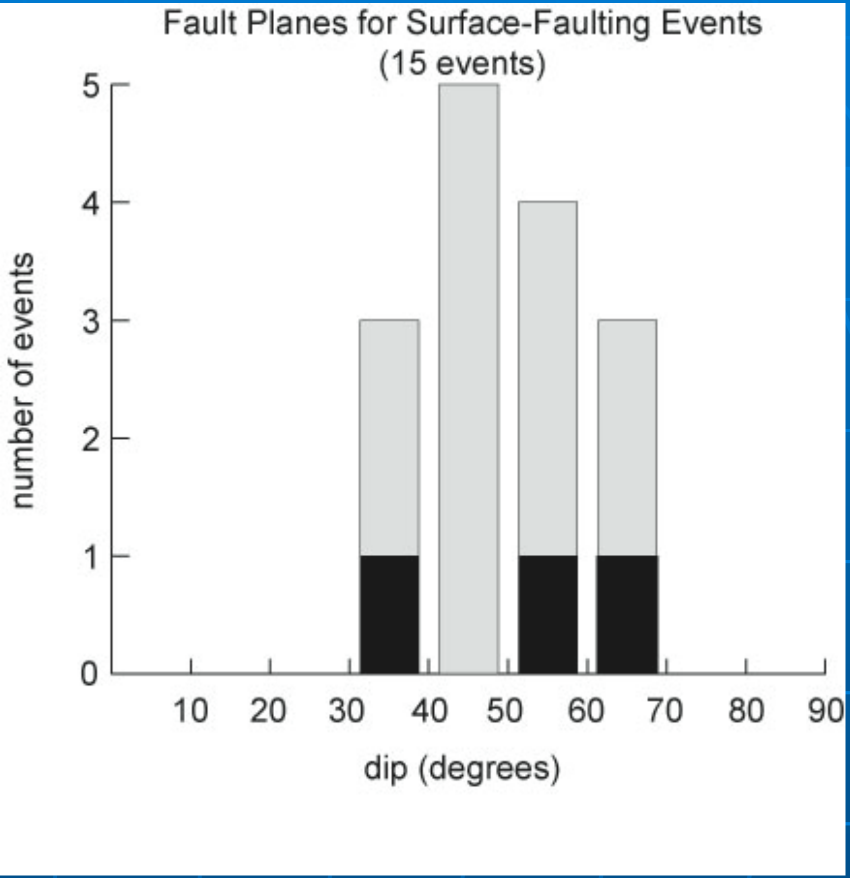
Figure 12: GPS strain data for the western U.S.

Zeng and Shen 2006

Geodetic based shear zones







(from Jackson, 2002)

Kathy Haller

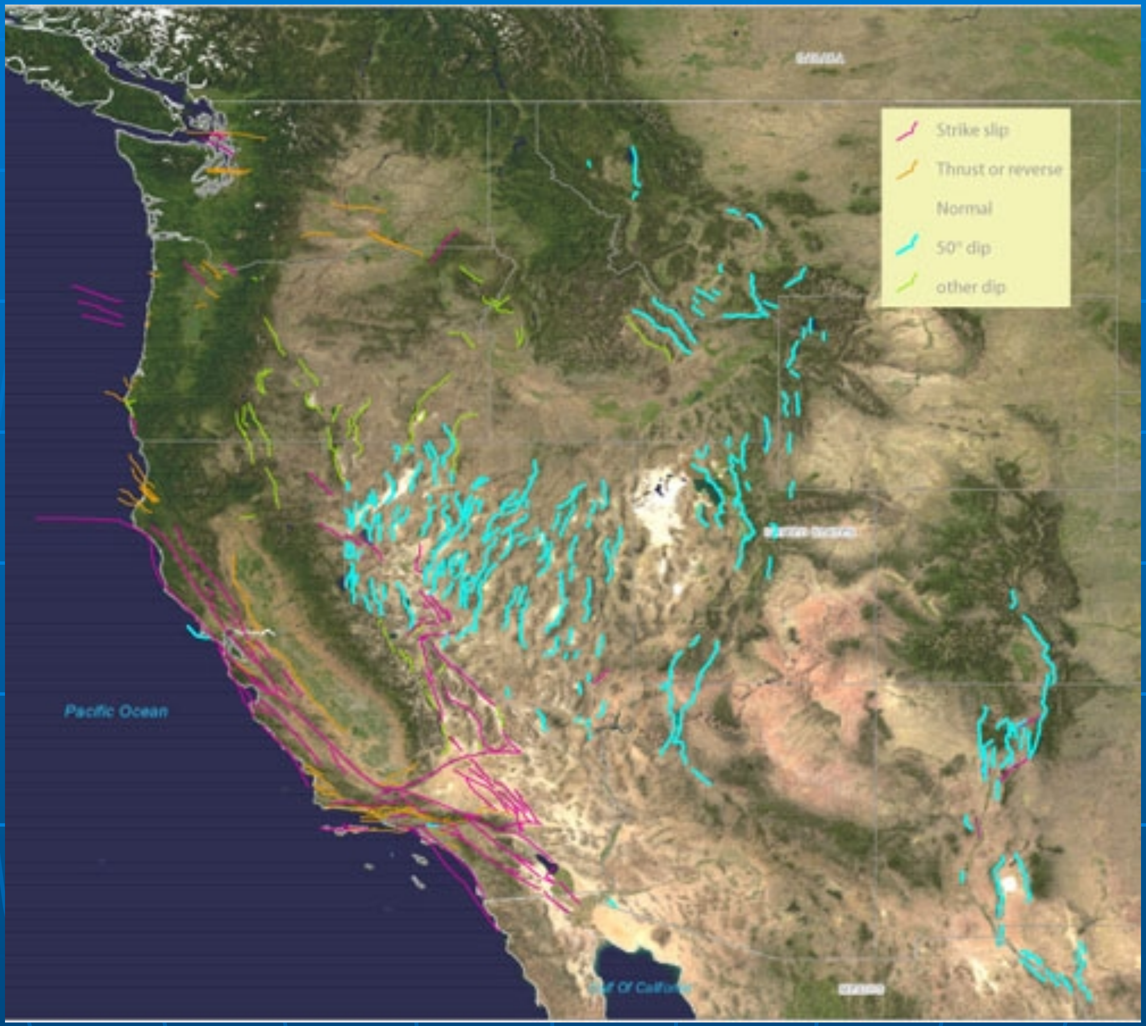
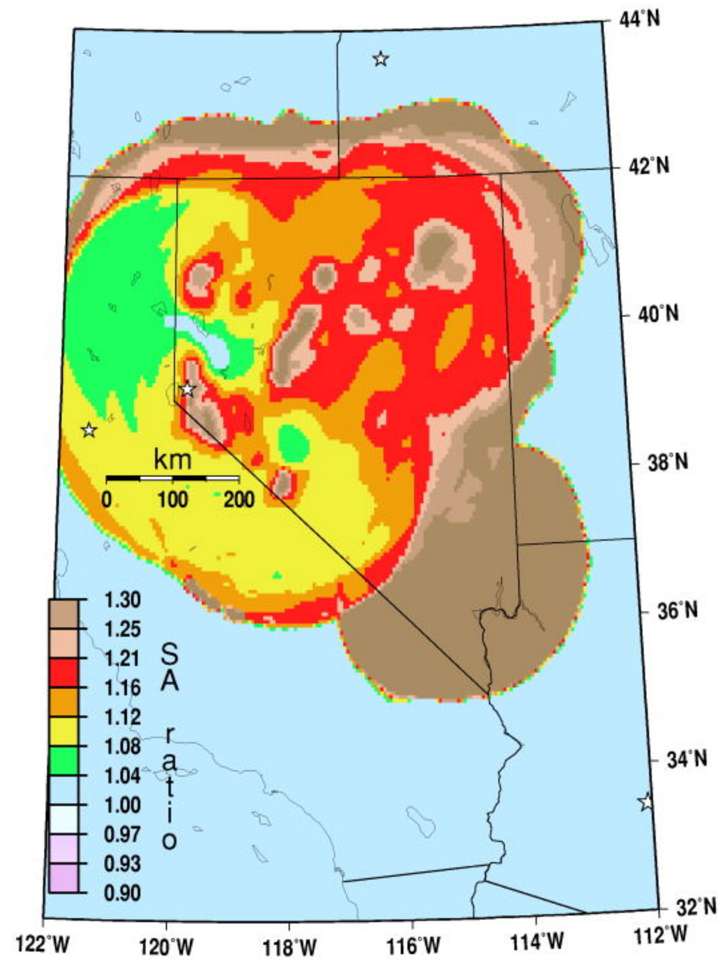


Figure 13: Faults in the western U.S. showing style of faulting

NV-Char 50d dip/60d dip, 1-Hz SA w/2%PE50Y. 760 m/s Rock



GMT May 2 15:57 PSHA nv-char ratio, numer uses 50d dipping flts, denom uses 60d dipping flts.. Site 760ms. 1 Hz 2%50 yr PE. NGA with epistemic gnd

California

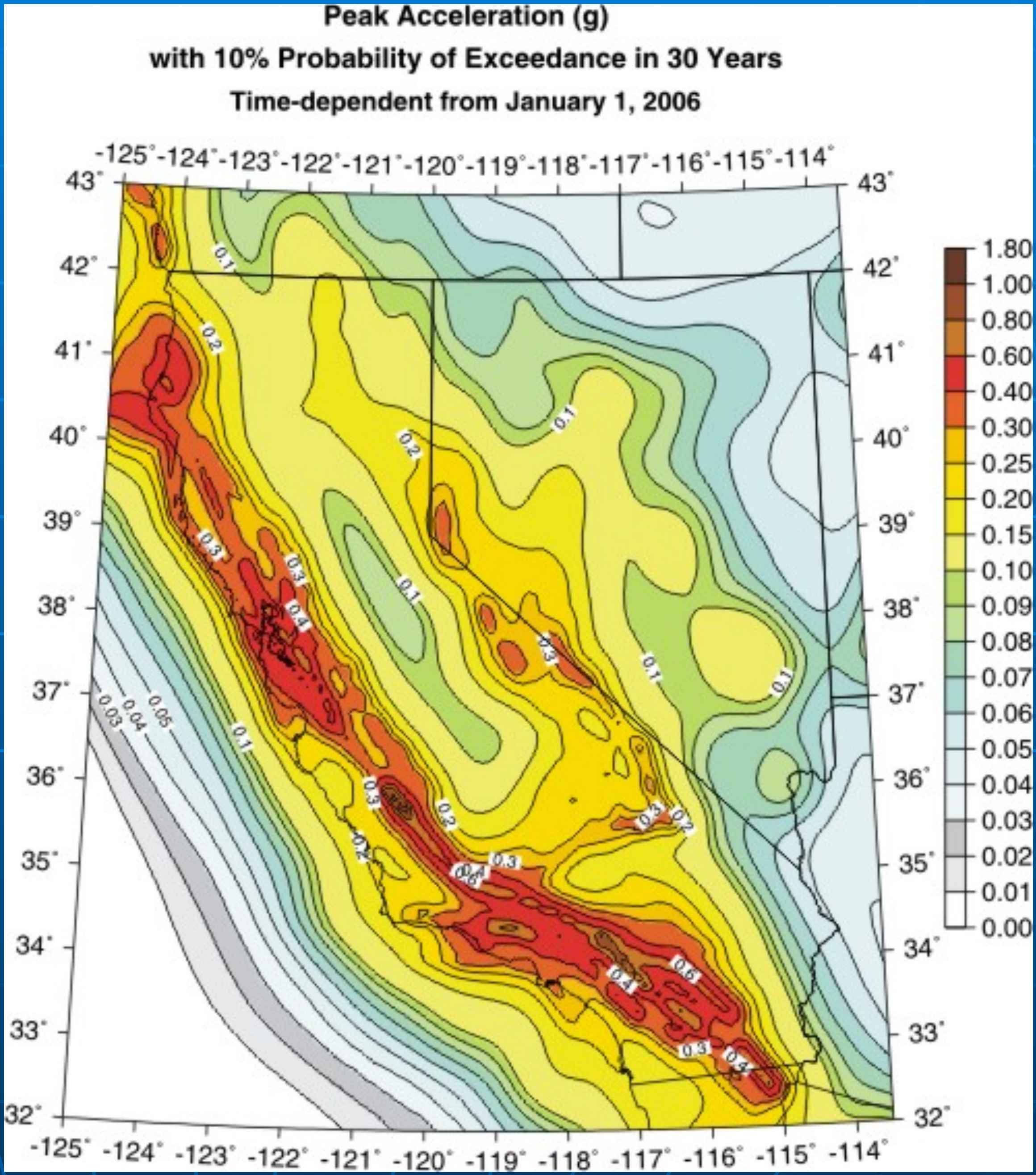
Working Group on California Earthquake Probabilities (2007)

Statewide Uniform California Earthquake Rate Model (changes to WGCEP 2002 model)

New fault models for San Andreas fault System

New analysis of gps strain data

Scientific Review Panel



WGCEP 2007 model

- 10% Mo reduction for Mo already considered in background, small earthquakes and aftershocks, coupling coefficient
- M-f bulge
- Difference in 2002 model and 2007 model partly caused by not using Wells and Coppersmith M-area relation
- New fault models for major faults (A-faults) cause increase in large magnitudes

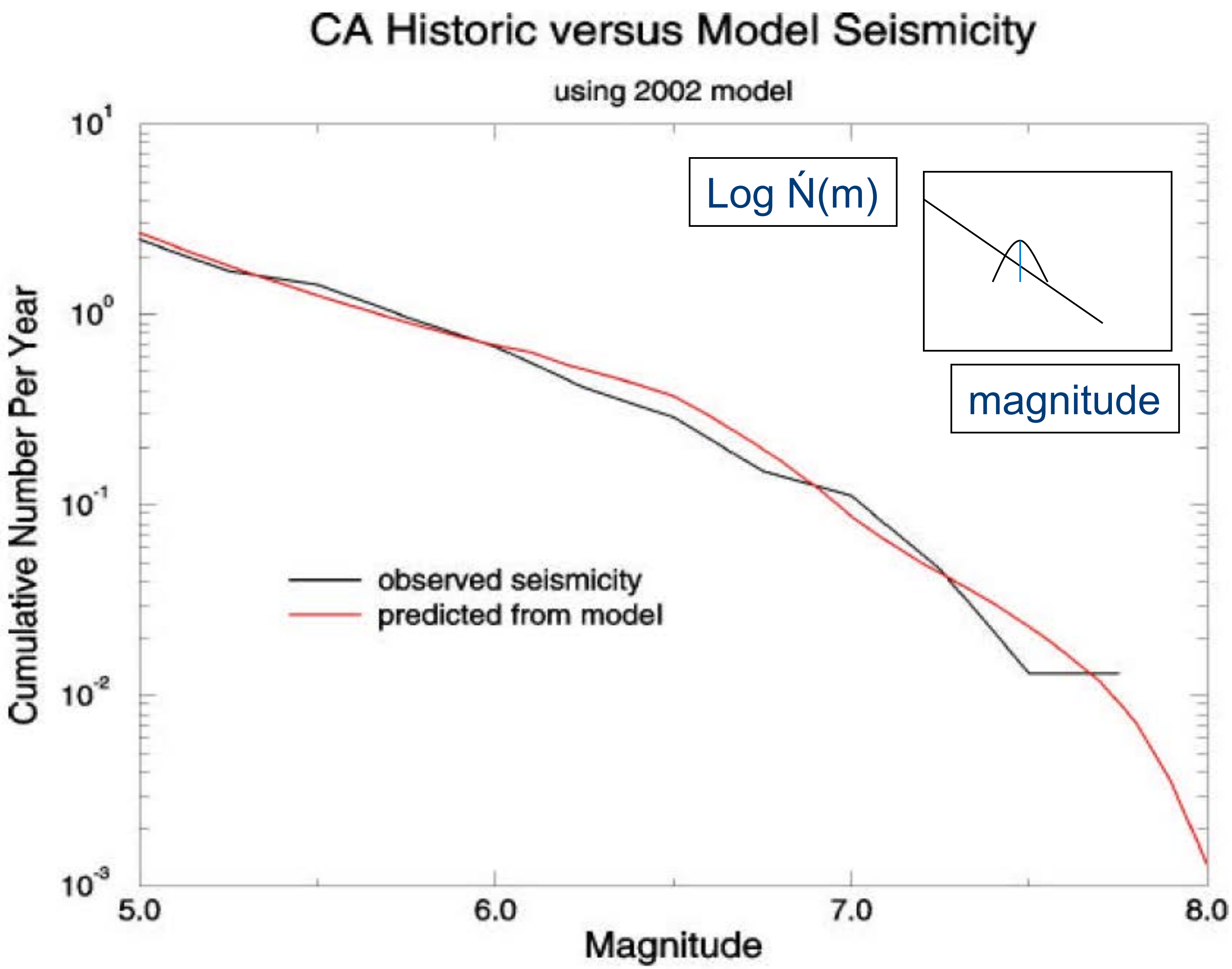
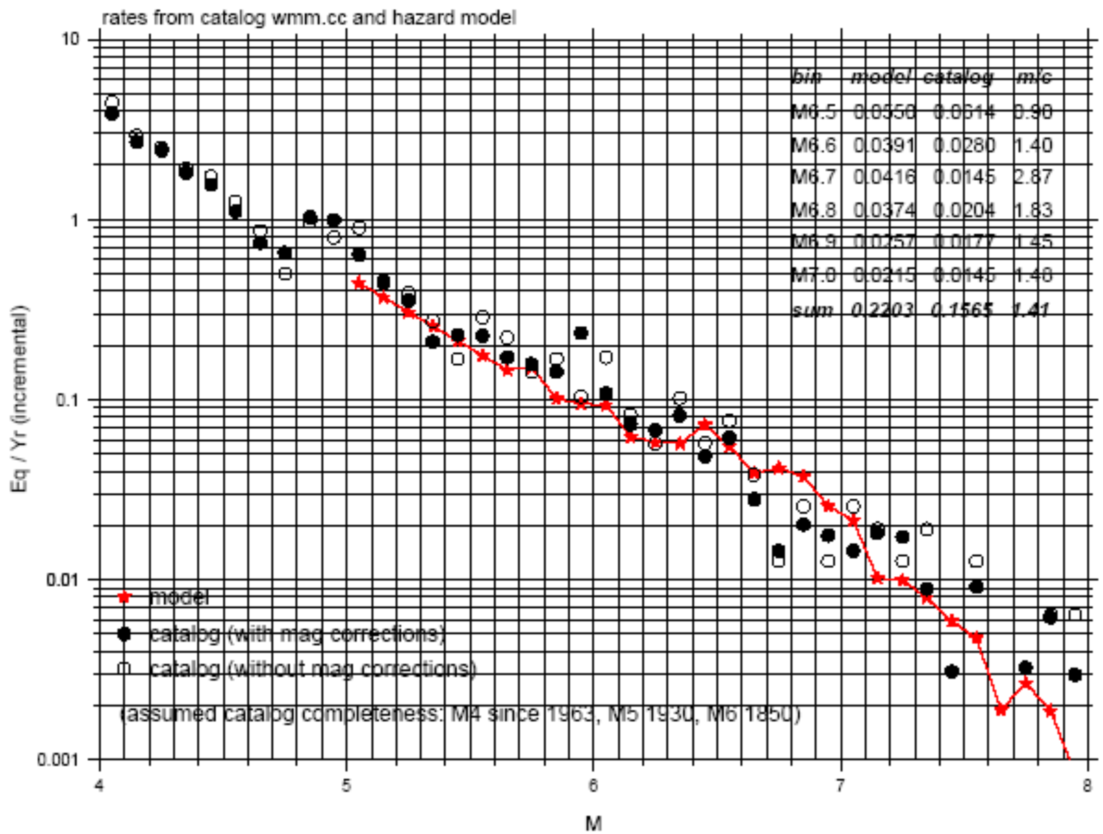
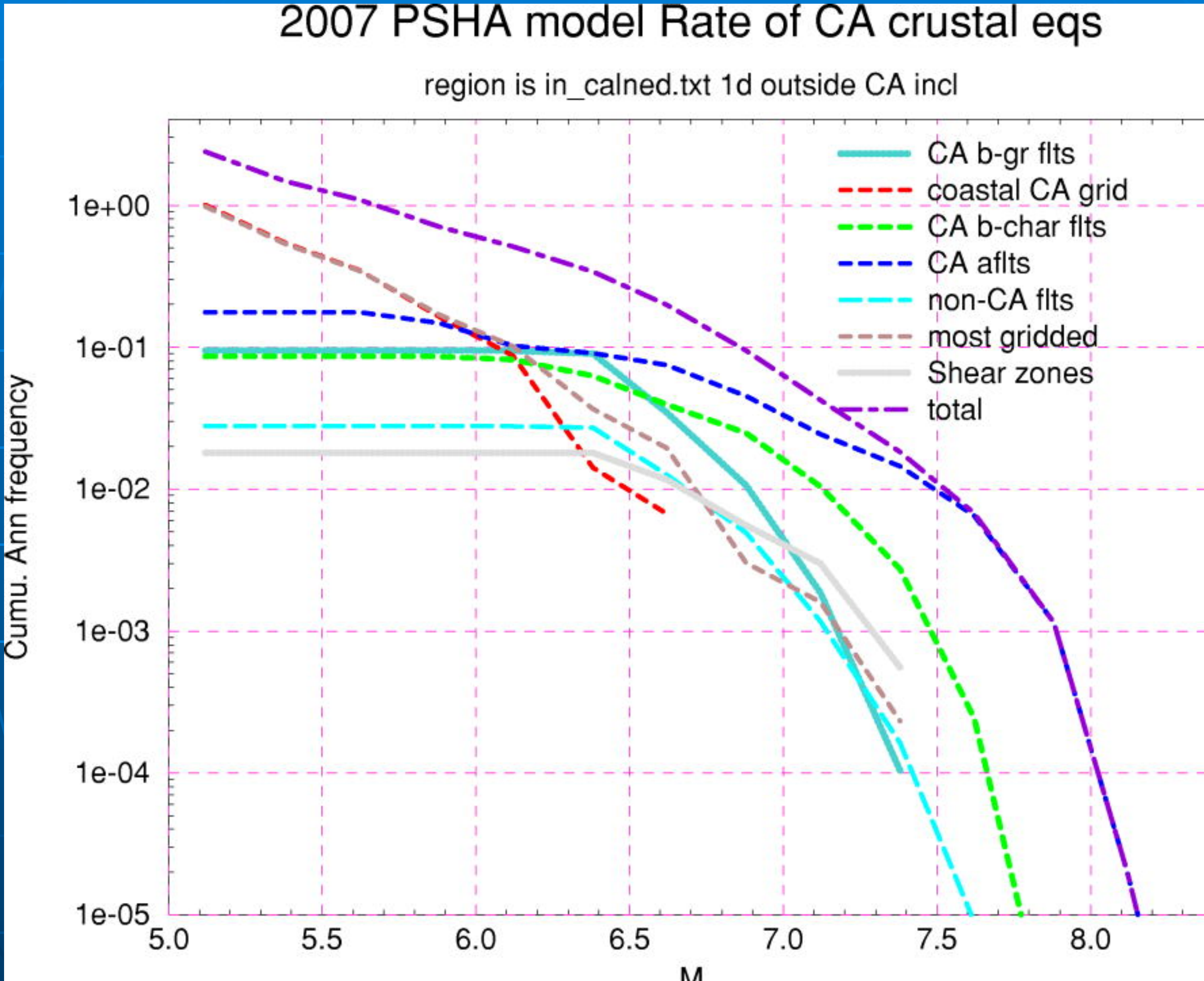
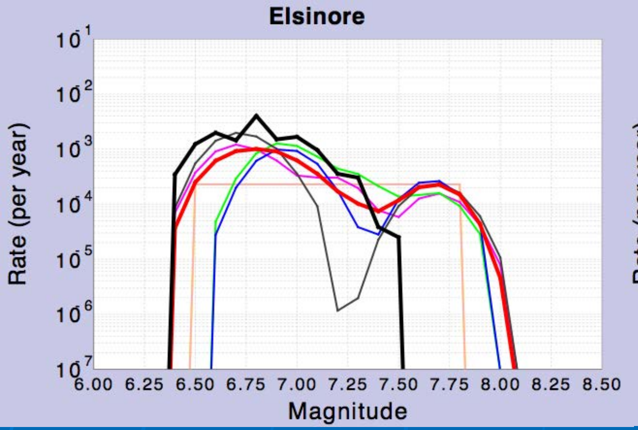


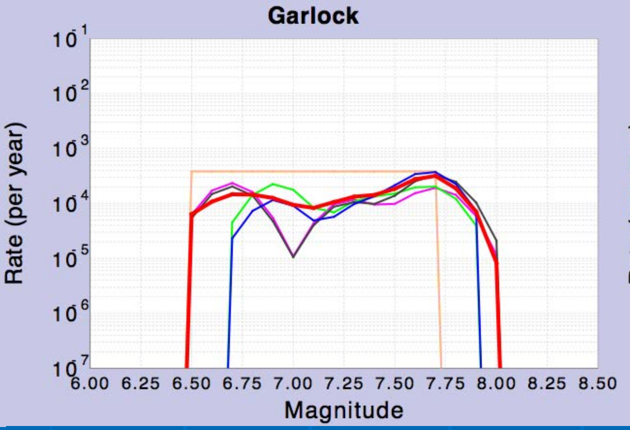
Figure 6. Comparison of predicted and historic seismicity rates for most of California.

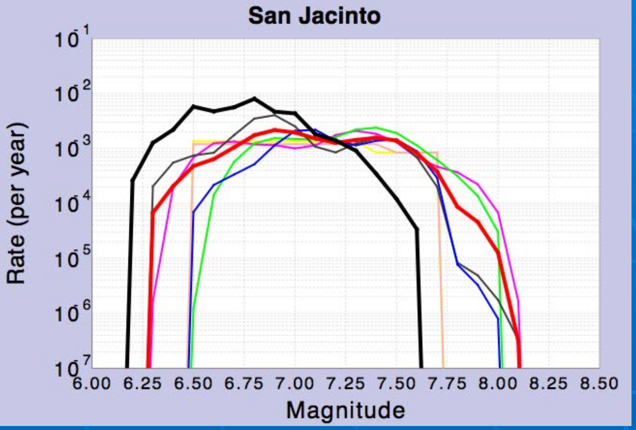


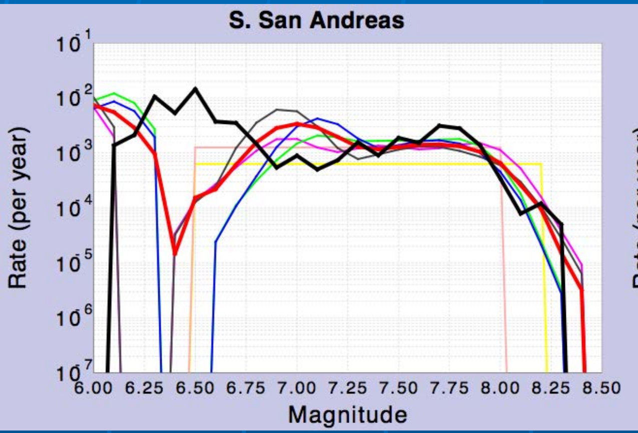
rates from catalog wmm.cc and hazard model
Eq / Yr (incremental)
M
bin model catalog m/c
M6.5 0.0550 0.0614 0.90
M6.6 0.0391 0.0280 1.40
M6.7 0.0416 0.0145 2.87
M6.8 0.0374 0.0204 1.83
M6.9 0.0257 0.0177 1.45
M7.0 0.0215 0.0145 1.40
sum 0.2203 0.1565 1.41
model
catalog (with mag corrections)
catalog (without mag corrections)
(assumed catalog completeness: M4 since 1963, M5 1930, M6 1850)

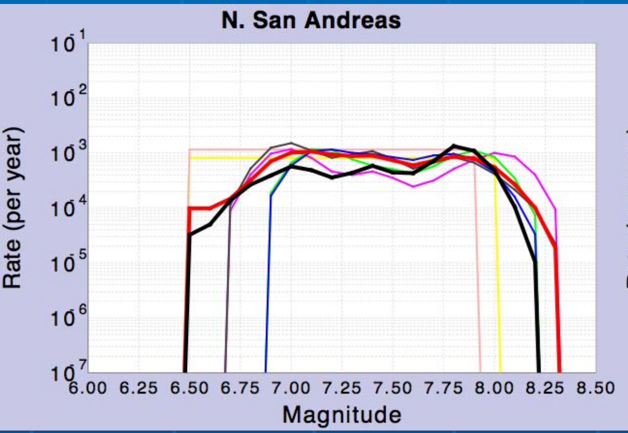

2007 PSHA model Rate of CA crustal eqs
region is in_calned.txt 1d outside CA incl
CA b-gr flts
coastal CA grid
CA b-char flts
CA aflts
non-CA flts
most gridded
Shear zones
total
Cumu. Ann frequency
1e+00
1e-01
1e-02
1e-03
1e-04
1e-05
5.0
5.5
6.0
6.5
7.0
7.5
8.0
M

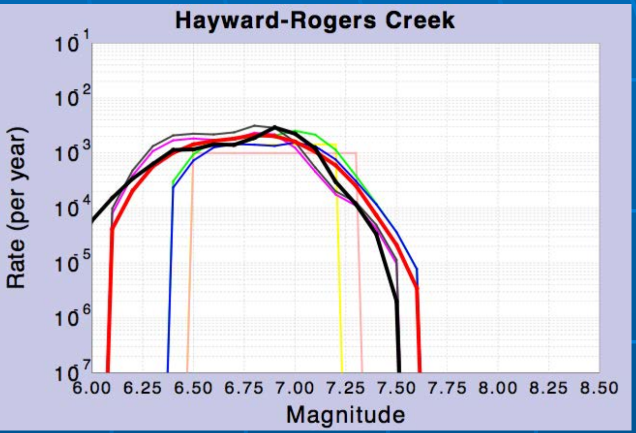


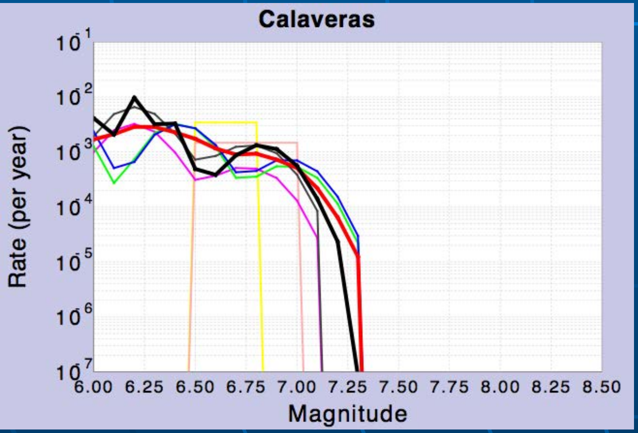








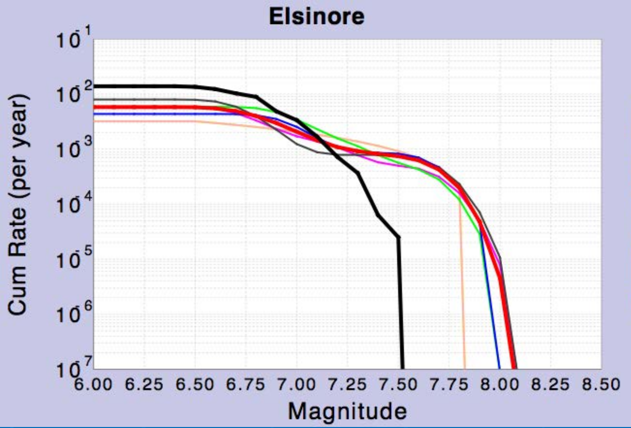


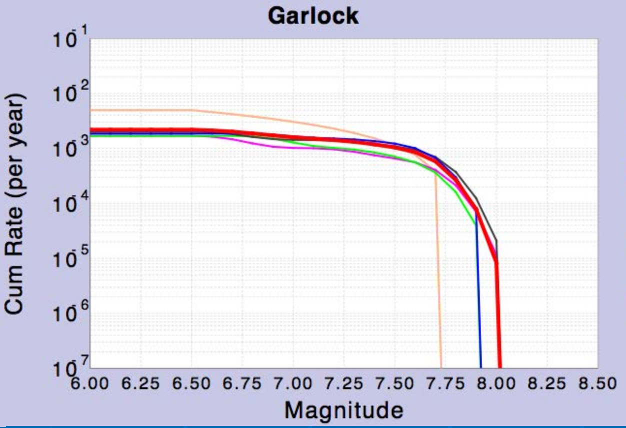


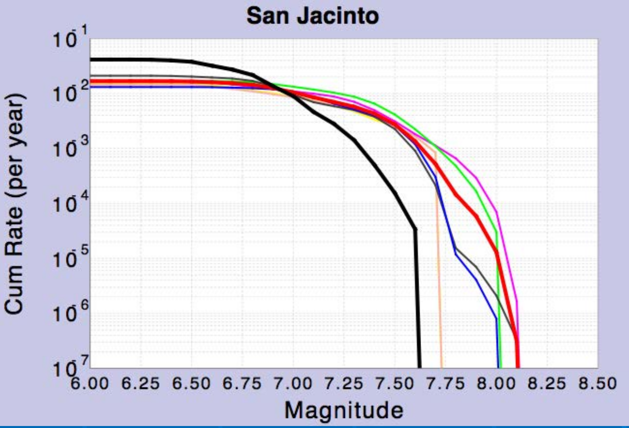
Incremental M-f distributions

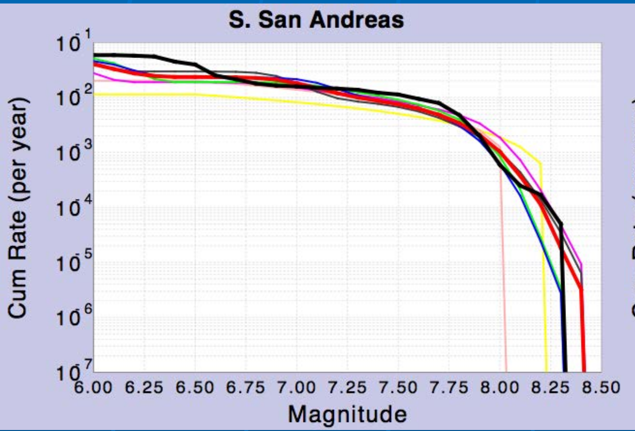
Bold red is WGCEP 2007 model

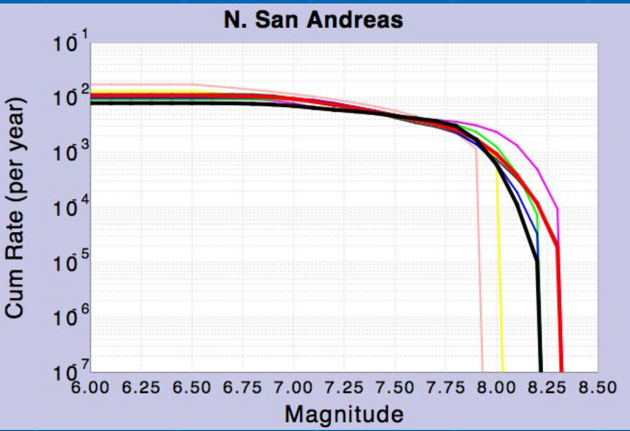
Bold black is UCERF 1.0 almost the same
As NSHM 2002 and WGCEP 2002.

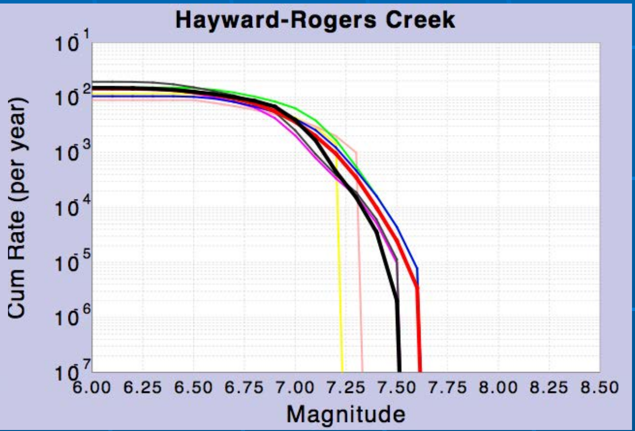


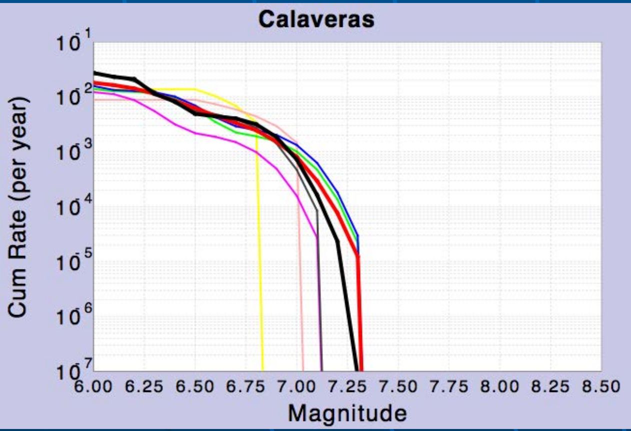












Cumulative M-f distributions

Bold red is WGCEP 2007 model

Bold black is UCERF 1.0 almost the same
As NSHM 2002 and WGCEP 2002.

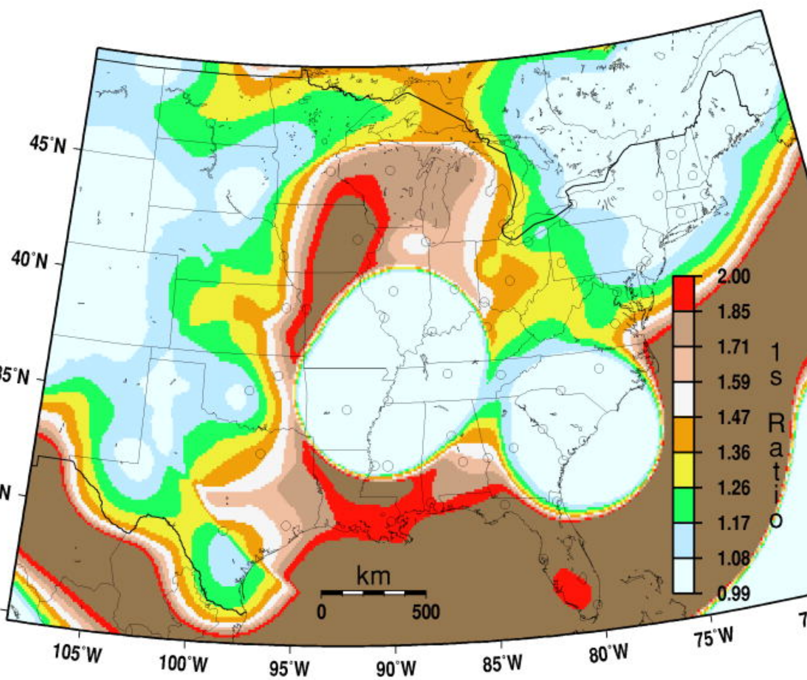
Comments from Paul Somerville

- Increase slab Mmax to 7.5
- Delete Sadigh et al. and Gregor et al. models from subduction attenuation relations, consider Zhao or Kanno relations instead
- Rupture areas too small, large gm’s

Comments from Jeff Kimball

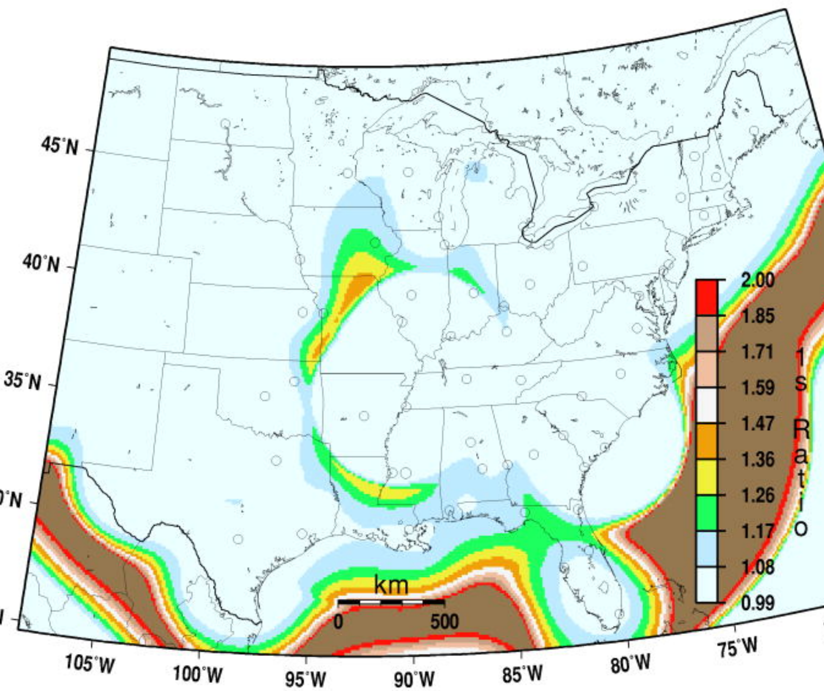
- 1000 km limit for CEUS gm's
- CEUS faults: char vs GR, lower bound magnitude
- Mmax logic tree: lower Mmax branch
- New Madrid hypothetical faults, geometry
- Clustered vs non-clustered weights
- Charleston source: include third zone
- CEUS attenuation: EPRI?, sigma,
- Puget lowland faults: EW striking?
- Pajarito fault: update recurrence
- NGA epistemic uncertainty figure
- Uncertainty bounds in 2002 model large, figure?
- Workshop participants passive, not active

CEUS 1s SA_Ratio 2%/50 1000km Rmax/400km Rmax



GMT May 1 13:20 CEUS SA 2% 50yr PE 1sec ratio 2007 model, simplified slightly. Denom uses Rmax=400 km. Dark brown high-side offscale

CEUS 0.2-s SA_Ratio 2%/50 1000km Rmax/400km Rmax



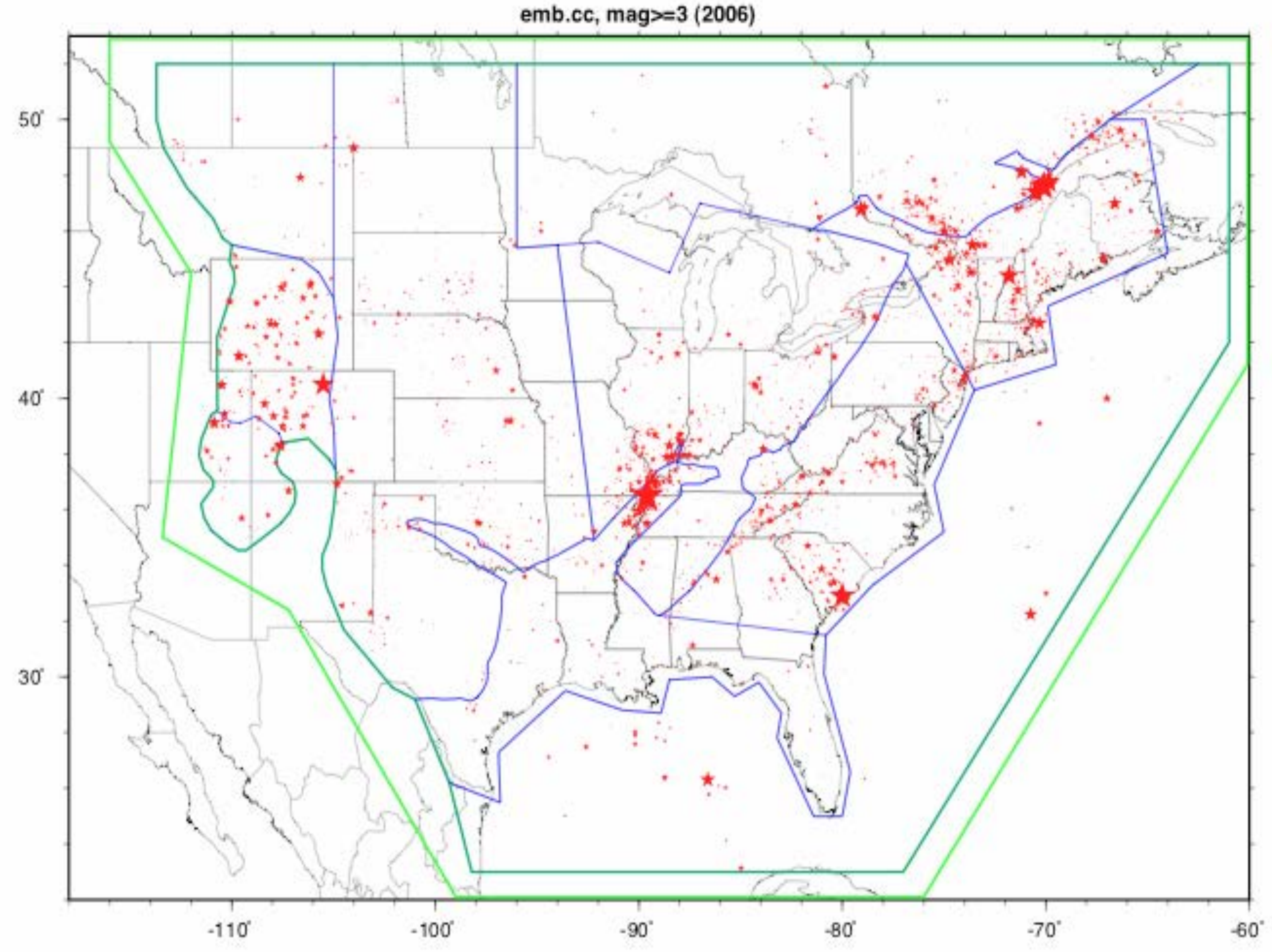
GMT May 1 13:25 CEUS SA 2% 50yr PE 5hz ratio 2007 model, simplified slightly. Denom uses Rmax=400 km. Dark brown high-side offscale

CENA Catalog: $m_{bLg} \geq 3$ since 1700

- For each source catalog
  - Reformat
  - Choose preferred magnitude & convert (some) to m_{bLg}
  - Guess magnitude error & rounding
- Combine source catalogs & sort chronologically
- Use preference rules to choose one entry for each earthquake
- Decluster (Gardner & Knopoff)
- Delete man-made events (e.g., KY,CO,UT mining)
- Estimate completeness & *b* value
- Compute 10^a grid

CENA Source Catalogs (in preference order)

- Special cases (mining, other non-eqs, etc.)
- SNM (Sanford etal): NM; m≥ ~3.0; 1963-1993
- NCEER91: CENA; m_{bLg}≥ ~2.5; 1627-1985
- USH (Stover&Coffman): US; m≥ ~4.5 or MMI≥ VI; 1568-1989
- SRA (Stover etal): 45 states (no CA,OR,WA); m≥ ~2.5; 1568-1989
- PDE: global; m ≥ ~2.5; 1960-2006
- DNAG: global; m ≥ ~3.0; 1534-1985



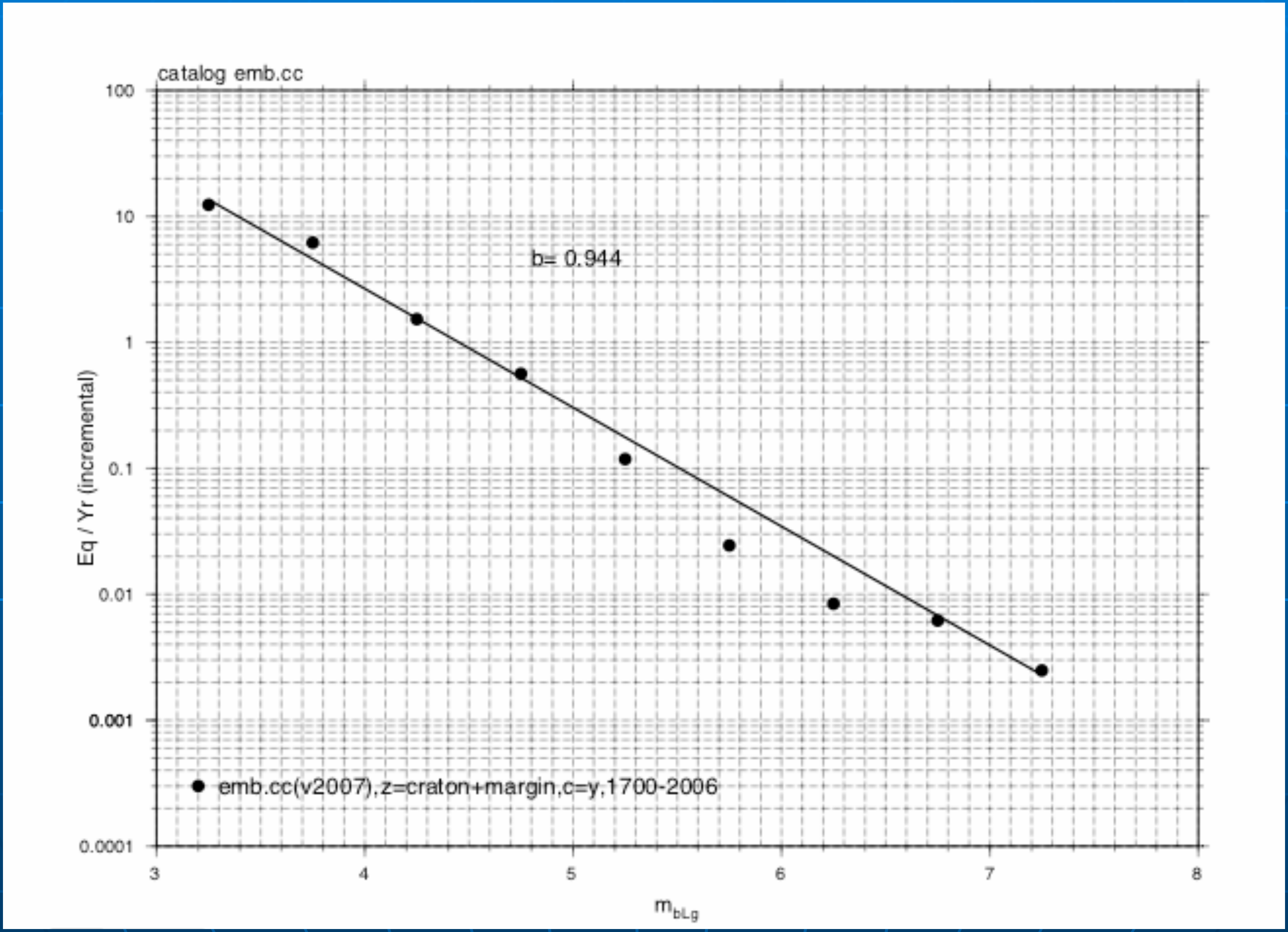
emb.cc, mag>=3 (2006)
50°
40°
30°
-110°
-100°
-90°
-80°
-70°
-60°

catalog1/catalog2= 14783/10133

# mainshocks=	3418
(SNM)=	23
(NCE)=	2380
(USH)=	28
(SRA)=	243
(PDE)=	654
(DNA)=	60
# foreshocks=	163
# aftershocks=	573

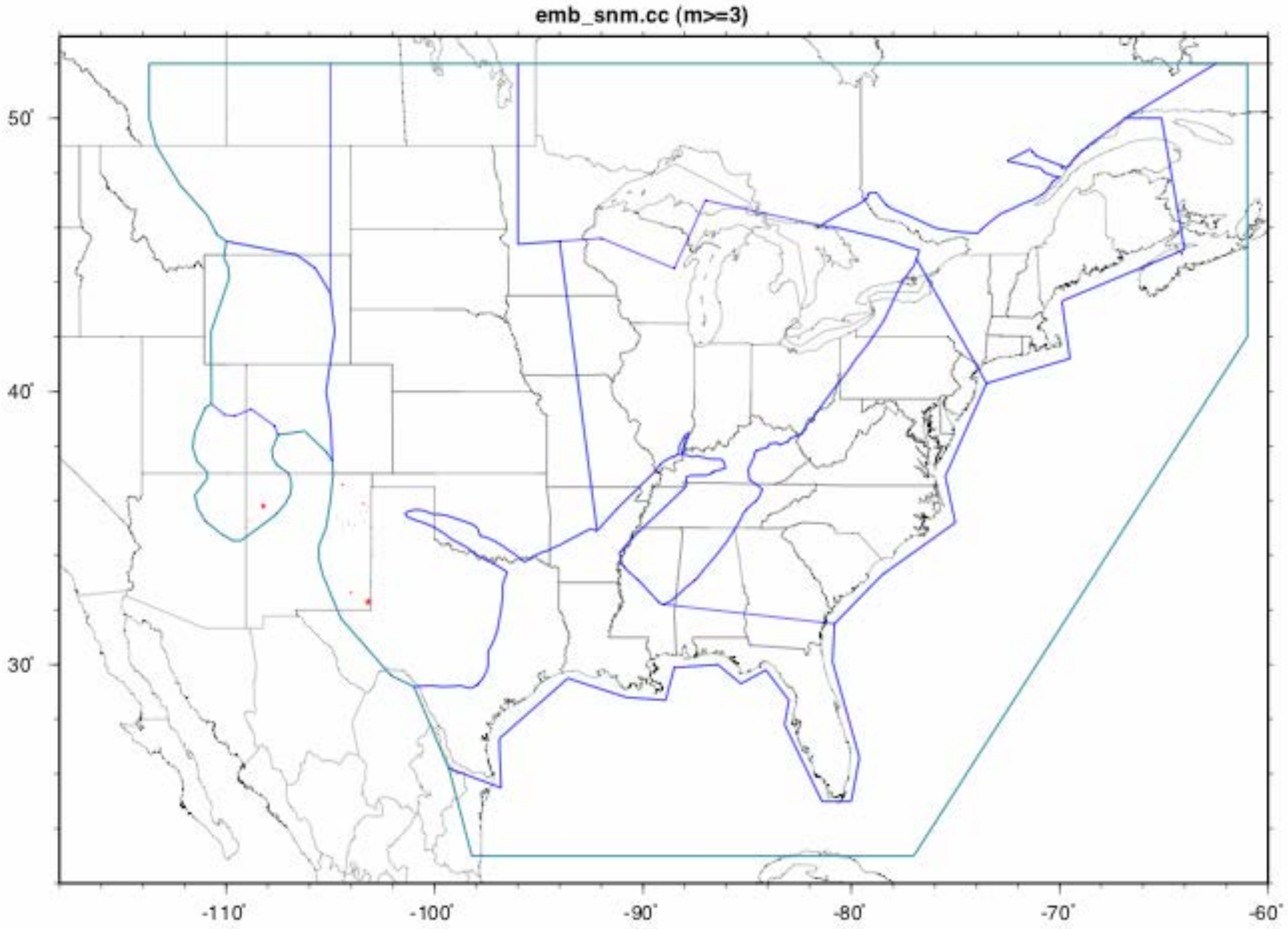
CENA Catalog: Changes Since 2002

- Extend through 2006 (primarily PDE)
- Incorporate J. Armbruster's updates to NCEER
- Choose preferred magnitude (instead of weighted combination of all)
- Guess magnitude error & rounding
  - used in two places in the hazard model:
    1. binned incremental regional rates for completeness & b-value calculation
    2. cell rates for 10^a calculation
  - Roughly follow CA guidelines
- We tried to get rid of DNAG, but couldn't do it

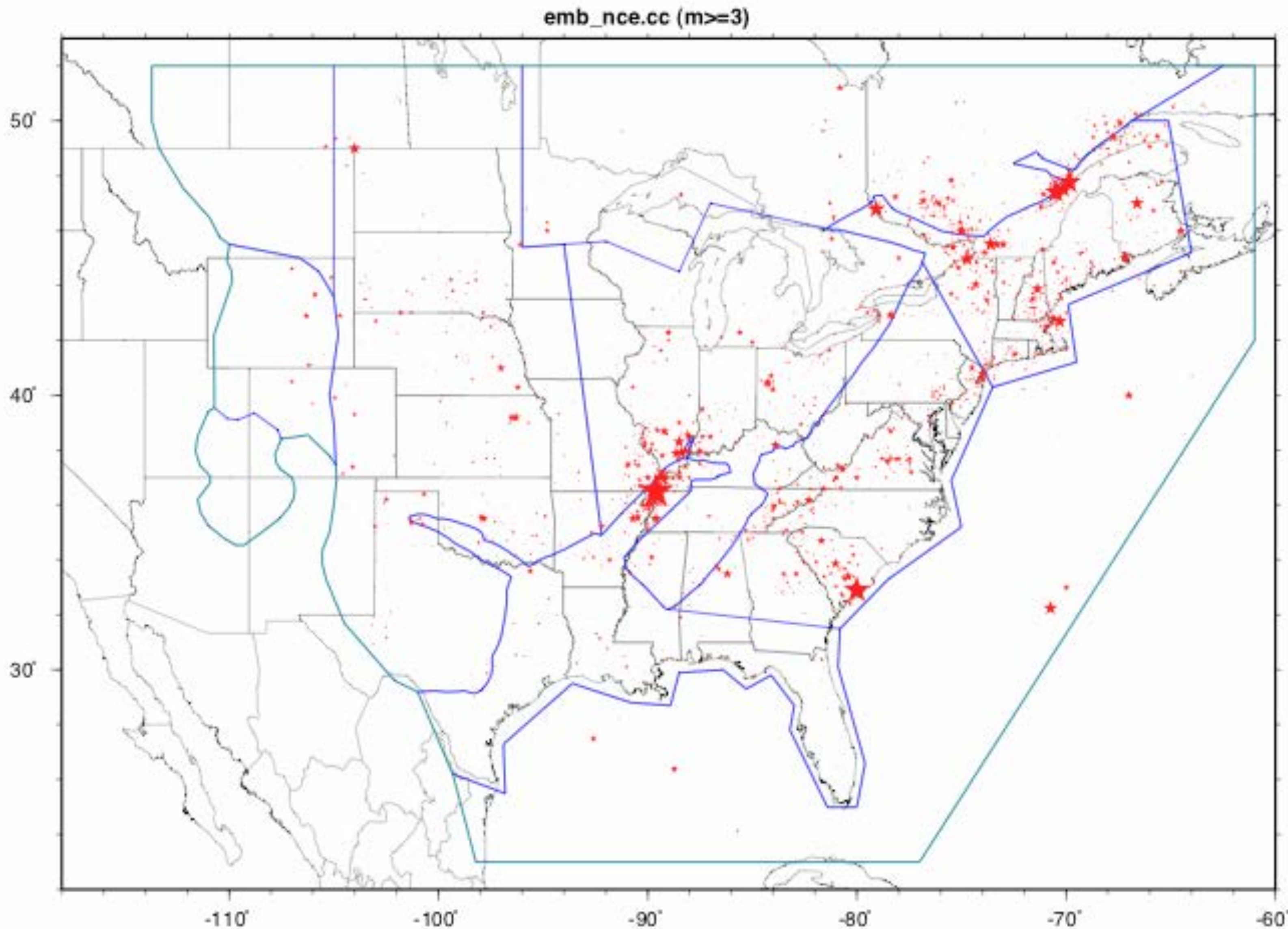


catalog emb.cc
b= 0.944
emb.cc(v2007),z=craton+margin,c=y,1700-2006
Eq / Yr (incremental)
100
10
1
0.1
0.01
0.001
0.0001
3
4
5
6
7
8
mbLg

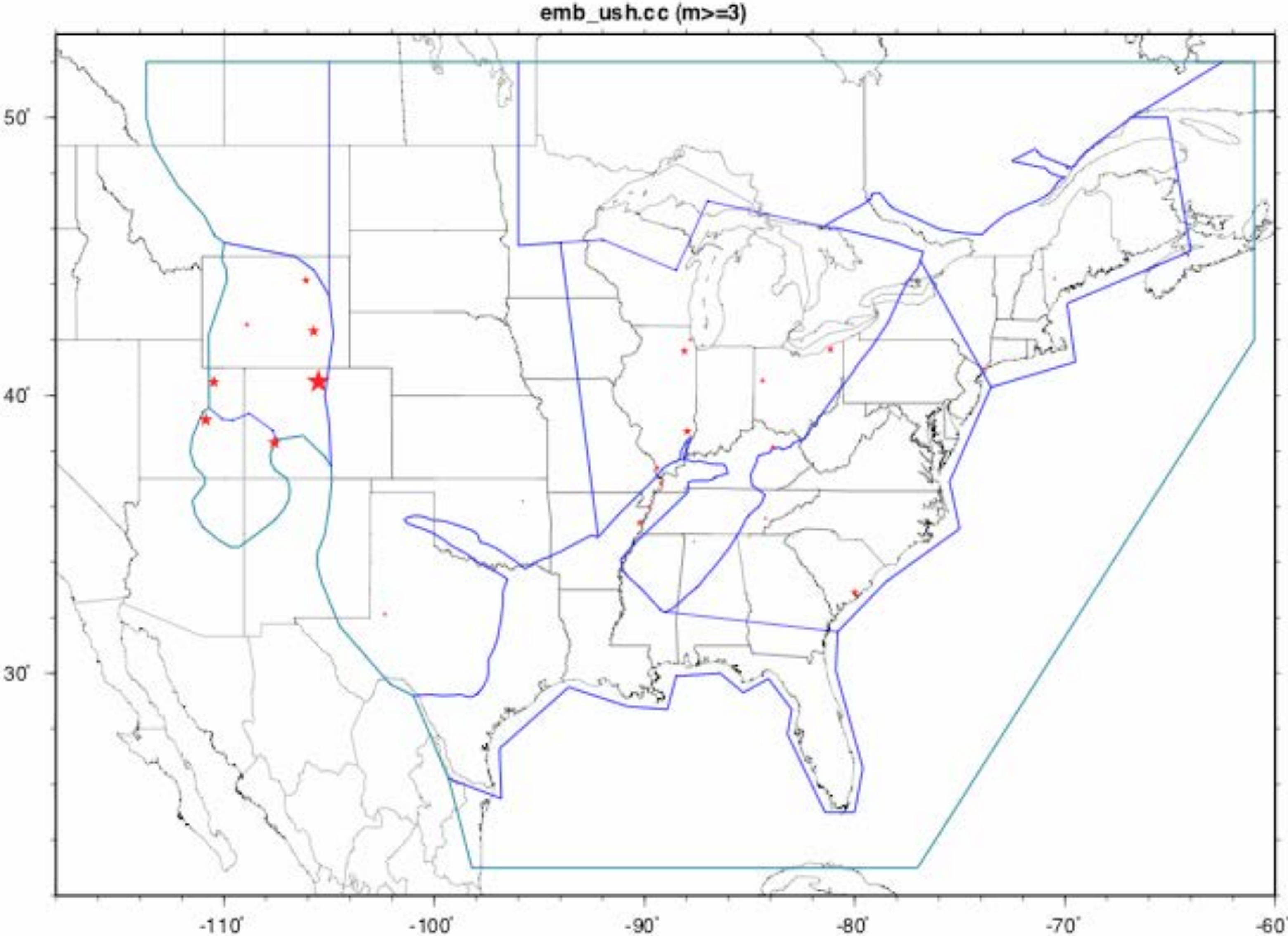
```
emb.cc(v2007),z=craton+margin,c=y
1700   3.0 3.5 4.0 4.5 5.0 5.5 6.0 6.5 7.0 7.5
00-24    2   0   0   0   0   0   0   0   0   0
25-49   18   0   0   1   2   1   0   0   0   0
50-74    6   2   1   1   0   1   0   0   0   0
75-99    8   2   2   1   0   0   0   0   0   0
00-24   18   5   3   1   1   0   0   0   1   0
25-49   25  14   6   4   2   0   0   0   0   0
50-74   66  25  13   5   4   0   1   0   0   0
75-99  141  75  25  12   6   0   0   1   0   0
00-24  121  71  22  12   4   1   0   0   0   0
25-49  208  97  38  19   3   2   1   1   0   0
50-74  306 154  60  18   3   0   0   0   0   0
75-99  428 194  59  16   7   1   1   0   0   0
00-06   81  55  24   6   4   0   0   0   0   0

b = 0.944 +/- 0.017
a_cumulative = 0.414E+01
 arc_m>=0(fn0) = 0.140E+05
 arc_m>=5(fn5) = 0.266E+00 +/-0.61E-02
```

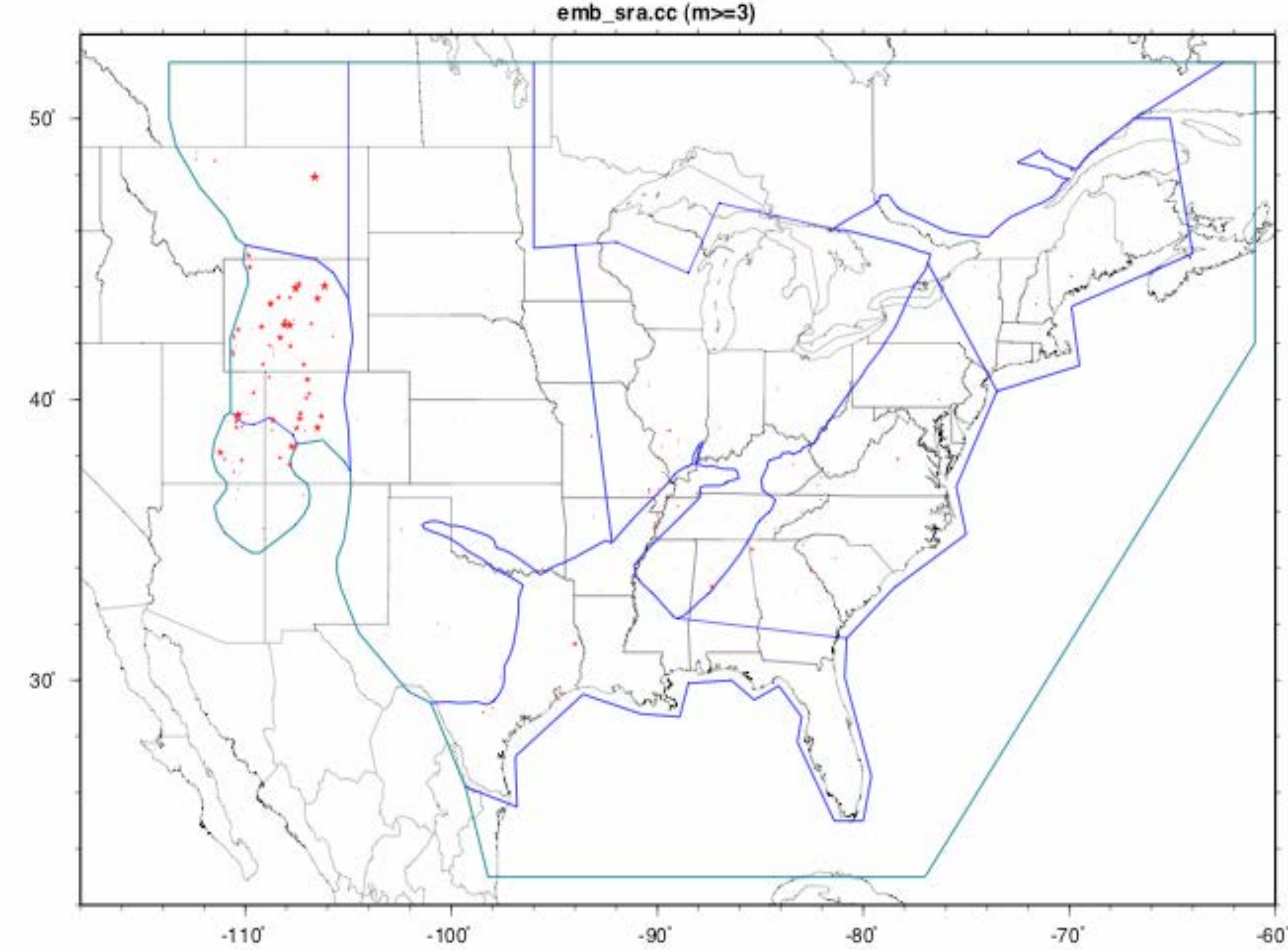


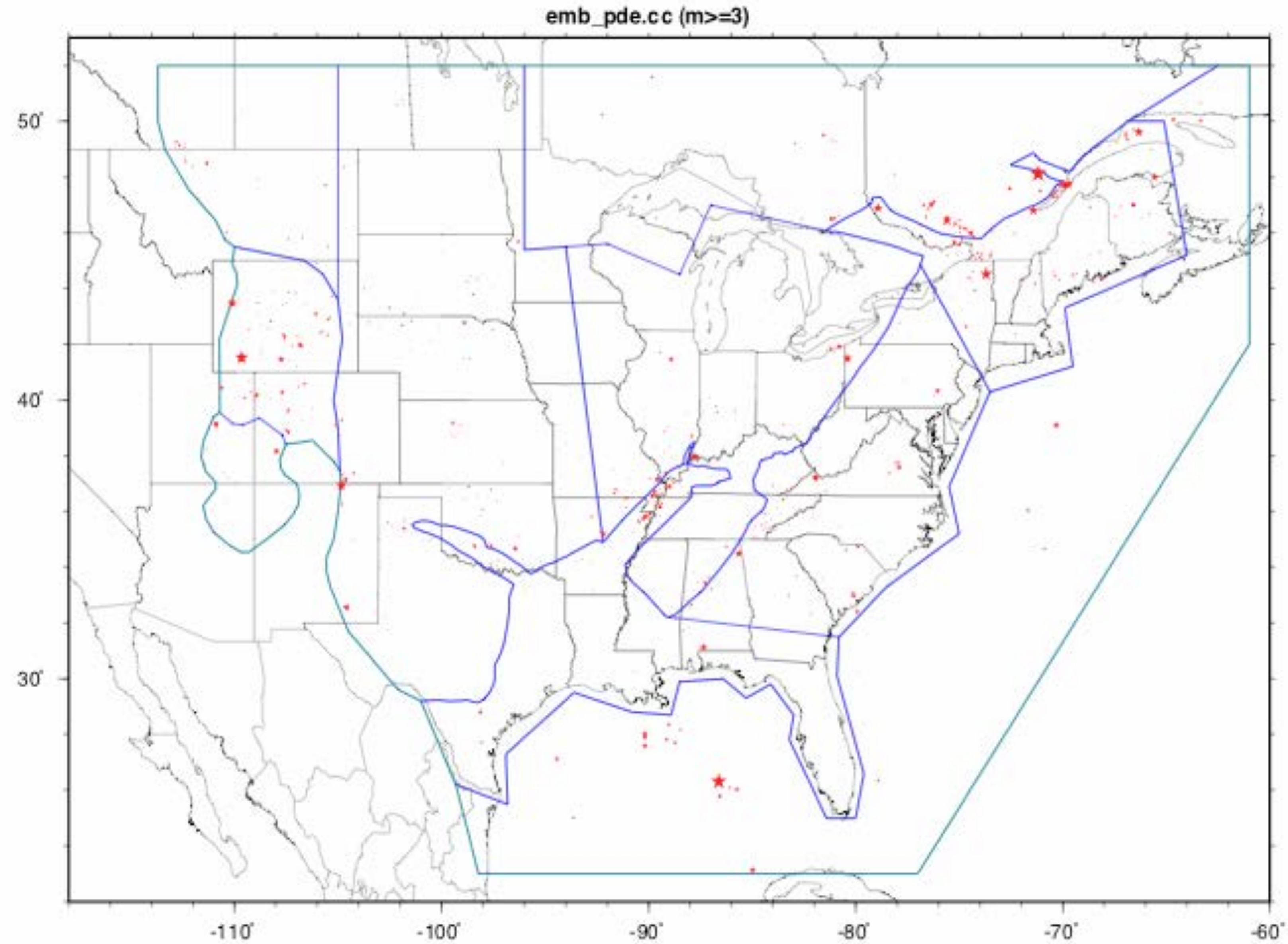
emb_snm.cc (m>=3)
50˚
40˚
30˚
-110˚
-100˚
-90˚
-80˚
-70˚
-60˚

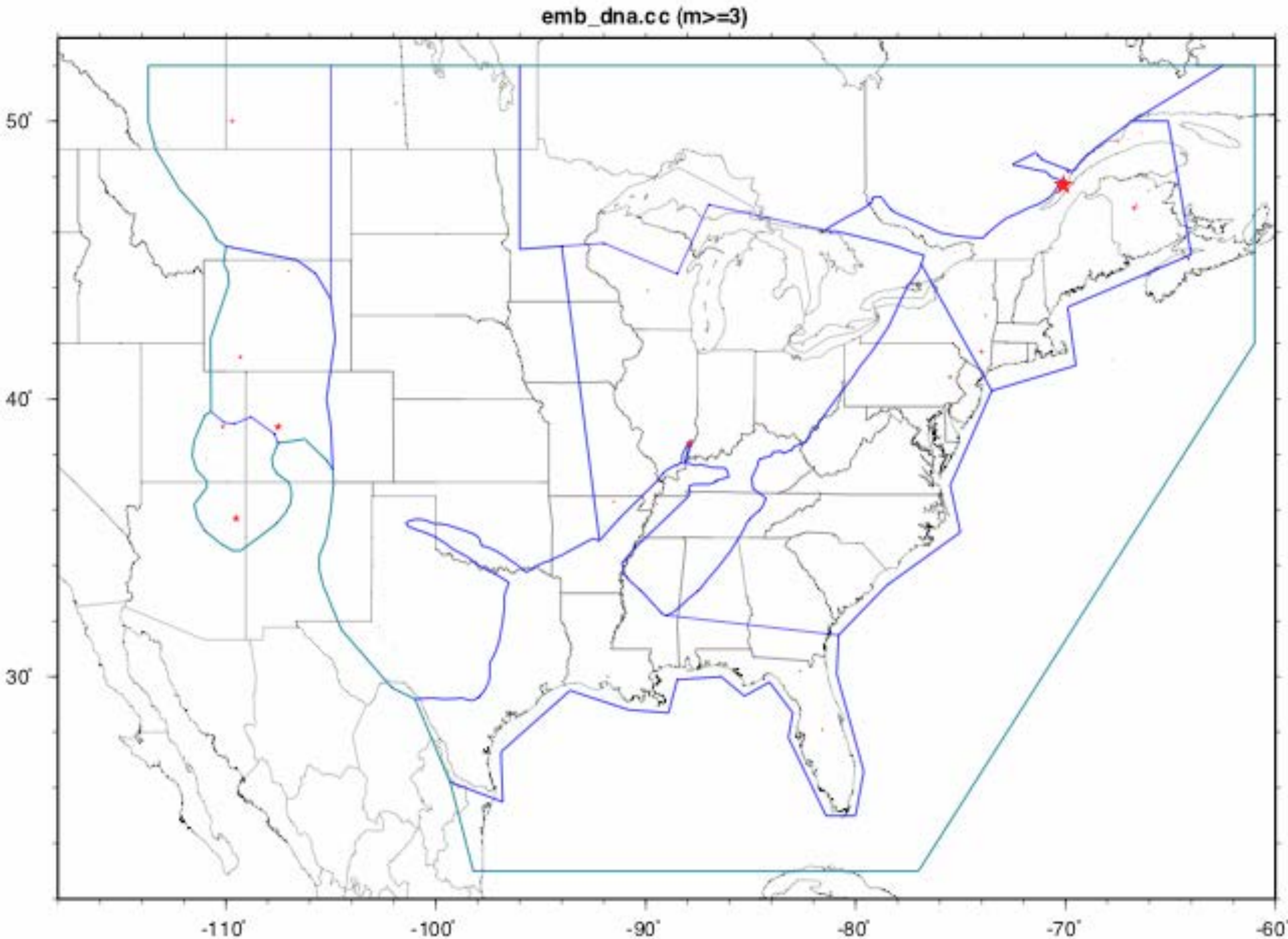


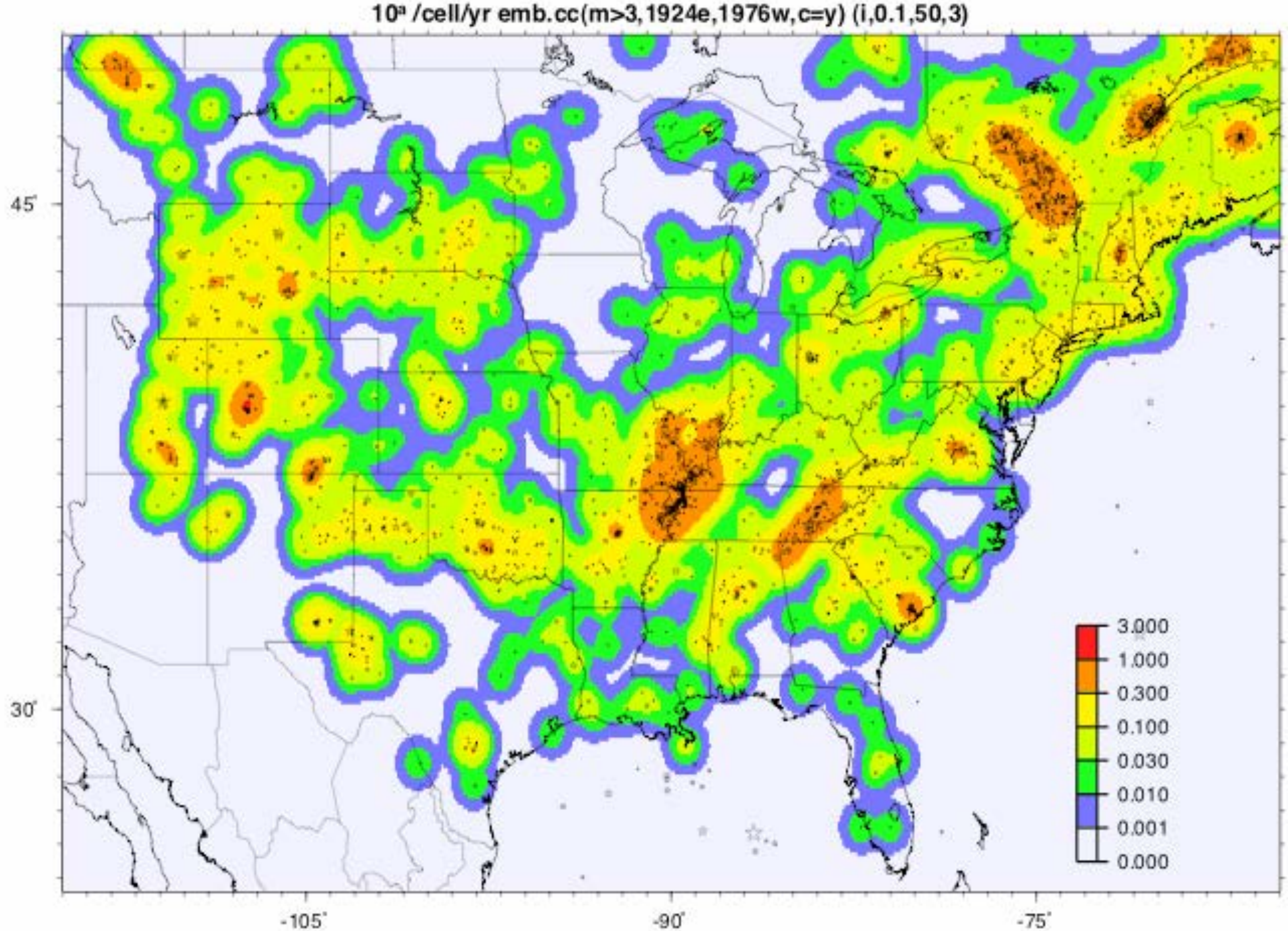
emb_nce.cc (m>=3)
50˚
40˚
30˚
-110˚
-100˚
-90˚
-80˚
-70˚
-60˚

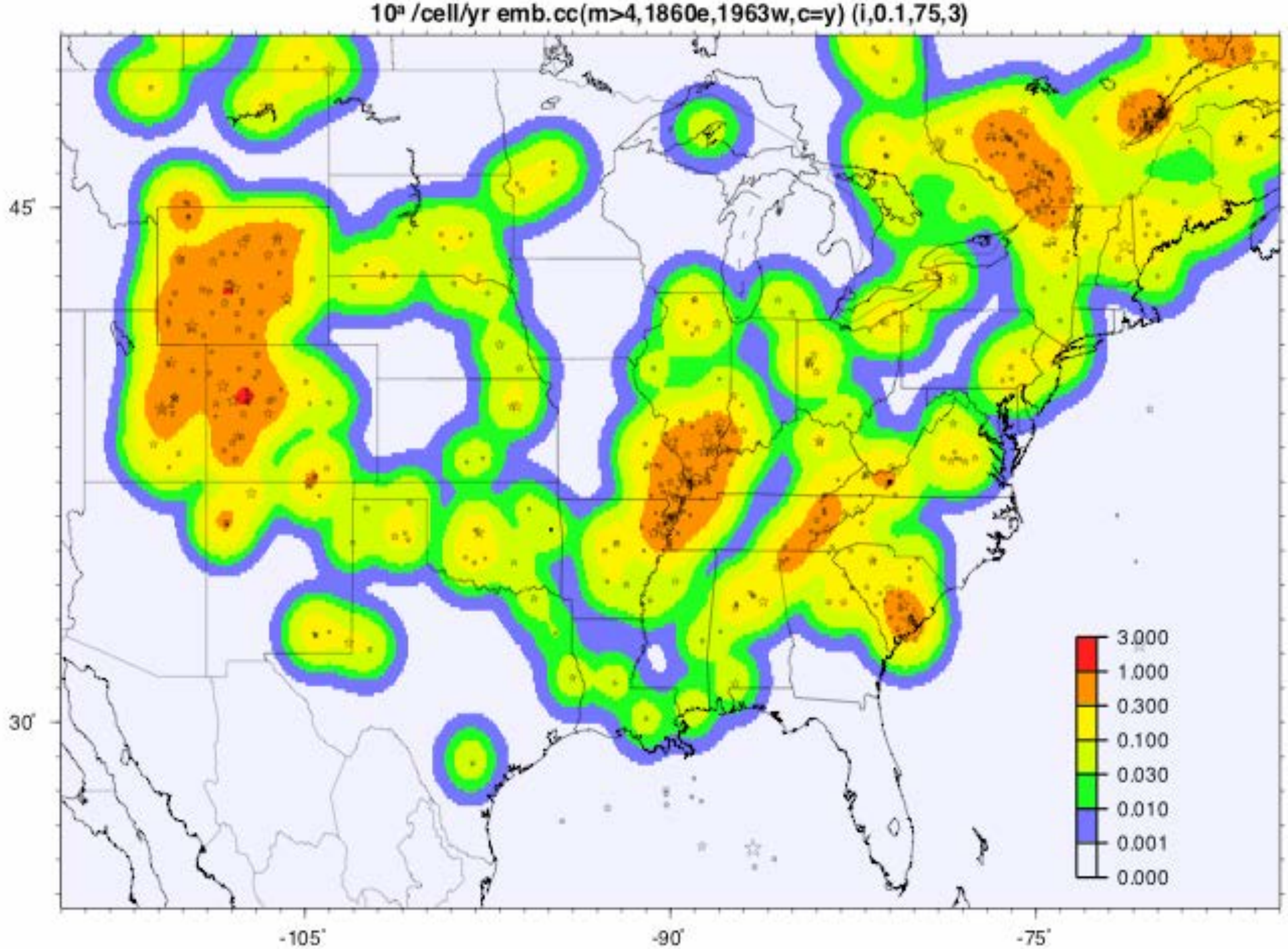

emb_ush.cc (m>=3)
50˚
40˚
30˚
-110˚
-100˚
-90˚
-80˚
-70˚
-60˚

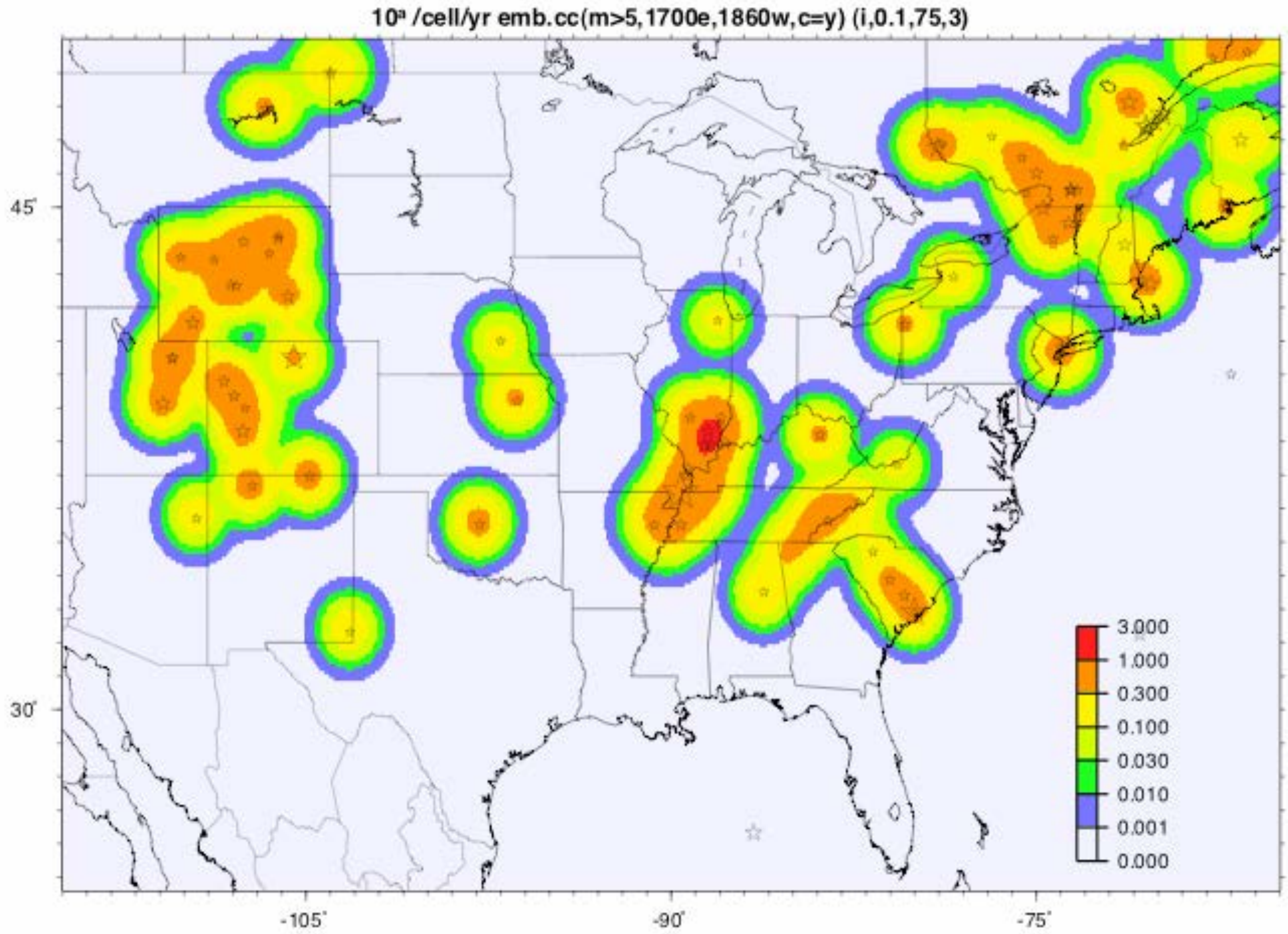

emb_sra.cc (m>=3)
50˚
40˚
30˚
-110˚
-100˚
-90˚
-80˚
-70˚
-60˚

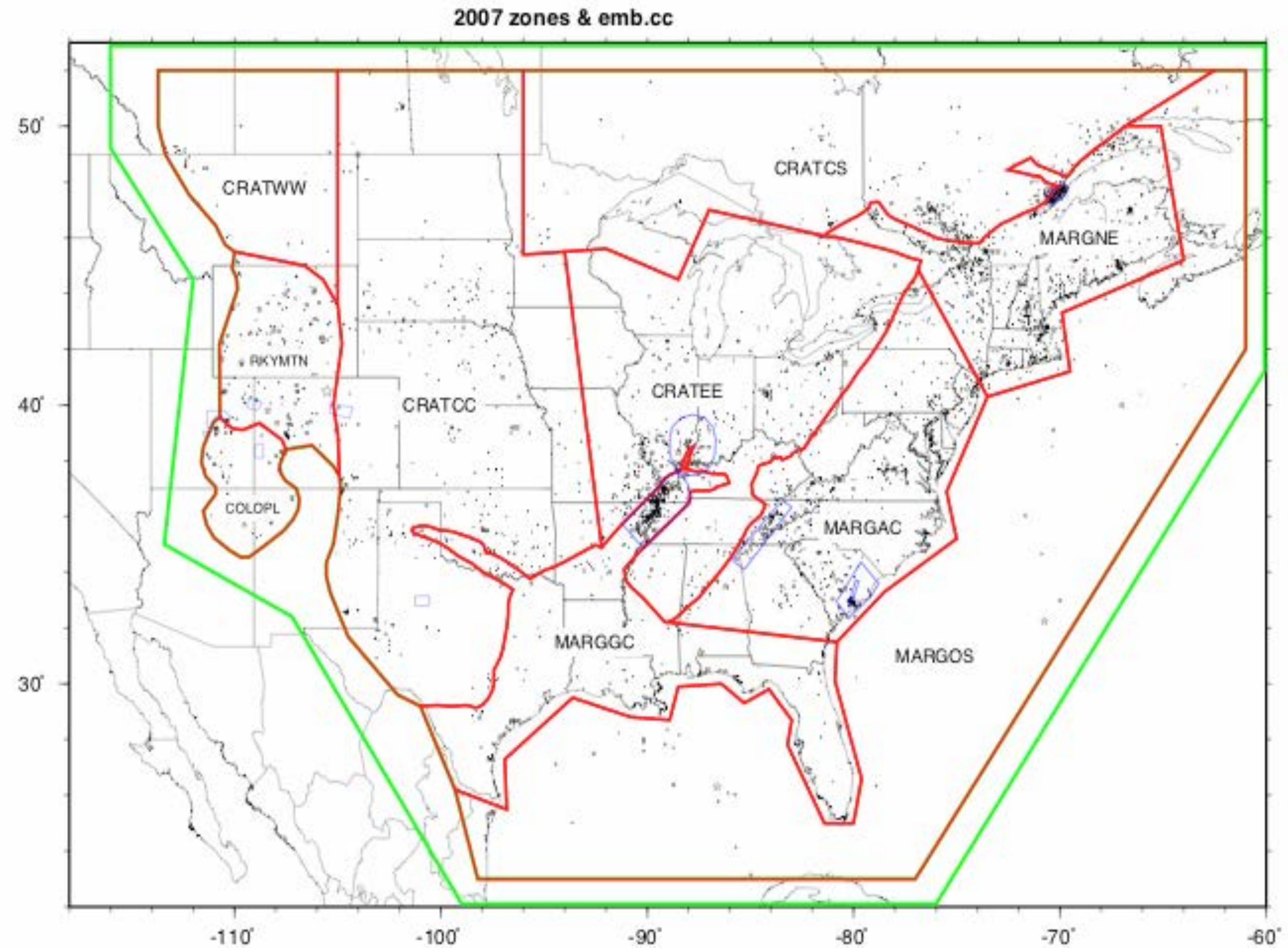

emb_pde.cc (m>=3)
50˚
40˚
30˚
-110˚
-100˚
-90˚
-80˚
-70˚
-60˚


emb_dna.cc (m>=3)
50˚
40˚
30˚
-110˚
-100˚
-90˚
-80˚
-70˚
-60˚


10ª /cell/yr emb.cc(m>3,1924e,1976w,c=y) (i,0.1,50,3)
45˚
30˚
-105˚
-90˚
-75˚
3.000
1.000
0.300
0.100
0.030
0.010
0.001
0.000


10a /cell/yr emb.cc(m>4,1860e,1963w,c=y) (i,0.1,75,3)
45°
30°
-105°
-90°
-75°
3.000
1.000
0.300
0.100
0.030
0.010
0.001
0.000


10ª /cell/yr emb.cc(m>5,1700e,1860w,c=y) (i,0.1,75,3)
45˚
30˚
-105˚
-90˚
-75˚
3.000
1.000
0.300
0.100
0.030
0.010
0.001
0.000



2007 zones & emb.cc
50°
40°
30°
-110°
-100°
-90°
-80°
-70°
-60°
CRATWW
CRATCS
MARGNE
RKYMTN
CRATCC
CRATEE
COLOPL
MARGAC
MARGGC
MARGOS

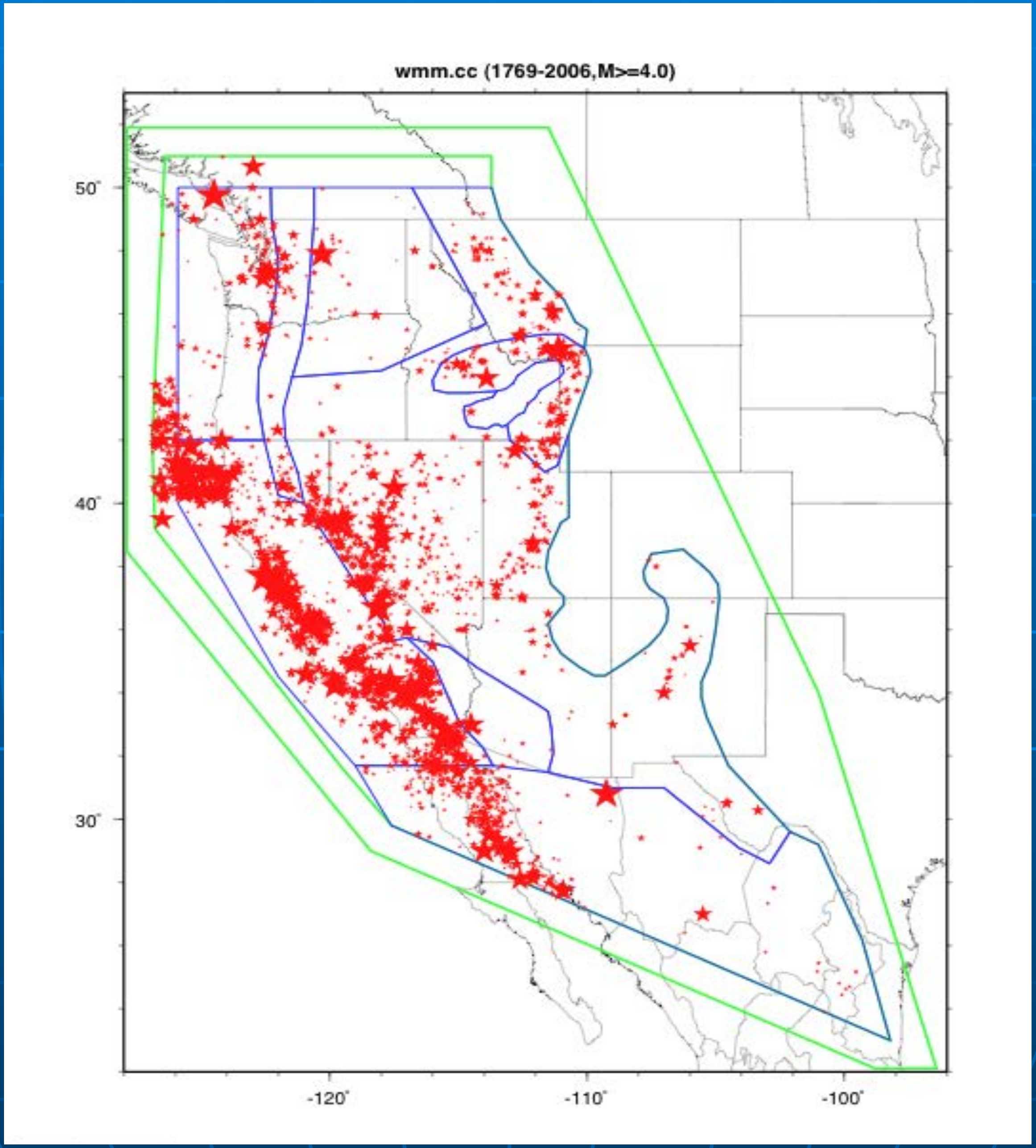
WNA Catalog: M >= 4 since 1850

- For each source catalog
  - Reformat
  - Choose preferred magnitude & convert to **M**
  - Estimate magnitude error & rounding
- Combine source catalogs & sort chronologically
- Use preference rules to choose one entry for each earthquake
- Decluster (Gardner & Knopoff)
- Delete man-made events (e.g., UT mining)
- Divide depth =< 35 & depth > 35
- Estimate completeness & *b* value
- Compute 10^a grid

WNA Source Catalogs (in preference order)

- Special cases (NTS, mining, other non-eqs, etc.)
- UNR (Pancha etal): IMW,PNW,CA; **M**≥ ~4.8; 1855-1999
- CGS: CA,NV,Mexico; m≥ 4; 1769-2006
- EVC (Engdahl&Villaseñor, IASPEI): global; m≥ ~5.5; 1900-2002
- USH (Stover&Coffman): US; m≥ ~4.5 or MMI≥ VI; 1769-1989
- SRA (Stover etal): 45 states (no CA,OR,WA); m≥ ~3.5; 1769-1989
- PDE: global; m ≥ ~3.2; 1960-2006
- DNAG: global; m ≥ ~3.5; 1808-1985

(UNR & CGS only in coastal CA)

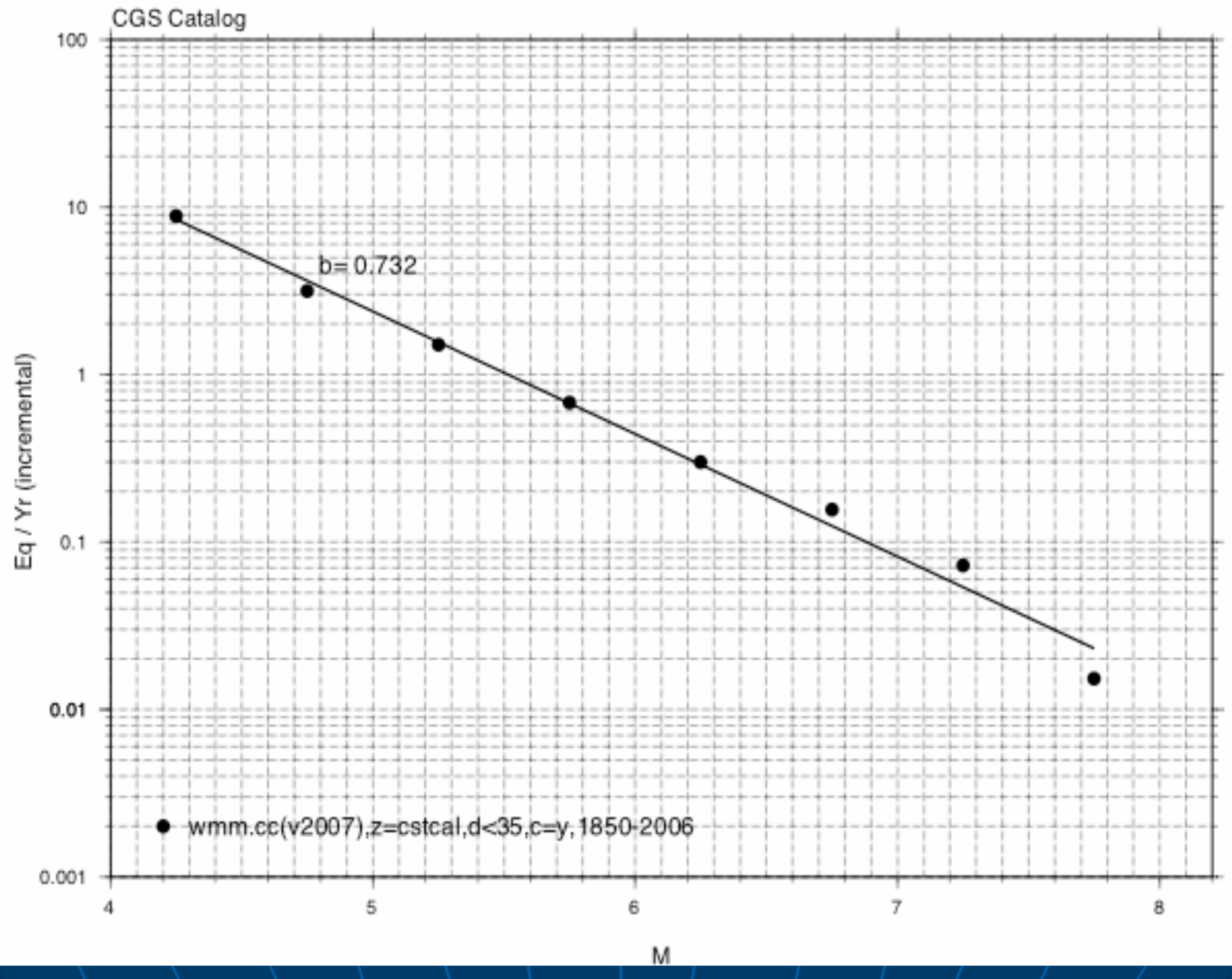

wmm.cc (1769-2006,M>=4.0)
50°
40°
30°
-120°
-110°
-100°

catalog1/catalog2= 37575/12395

# mainshocks=	3332
(UNR)=	356
(CGS)=	1920
(EVC)=	20
(USH)=	119
(SRA)=	163
(PDE)=	568
(DNA)=	186
# foreshocks=	721
# aftershocks=	4057

WNA Catalog: Changes Since 2002

- Extend through 2006 (primarily CGS & PDE)
- New source catalogs: UNR, EVC, modified CGS
- New magnitude-conversion rules (e.g., Sipkin for m_b, Utsu for M_s & m_L)
- Choose preferred magnitude (instead of weighted combination of all)
- Estimate magnitude error & rounding
  - used in two places in the hazard model:
    1. binned incremental regional rates for completeness & b-value calculation
    2. cell rates for 10^a calculation
  - California (K.Felzer's work with the CGS catalog)
    - statistics on amplitudes when possible
    - general rules otherwise: 0.111 since 1972, 0.222 since 1932, 0.333
    - rounding: observatory practice ~1900-1940
  - Rest of WNA: follow CA guidelines
- We tried to get rid of DNAG, but couldn't do it


CGS Catalog
100
10
1
0.1
0.01
0.001
Eq / Yr (incremental)
b= 0.732
wmm.cc(v2007),z=cstcal,d<35,c=y,1850-2006
4
5
6
7
8
M

wmm.cc(v2007),z=cstcal,d<35,c=y

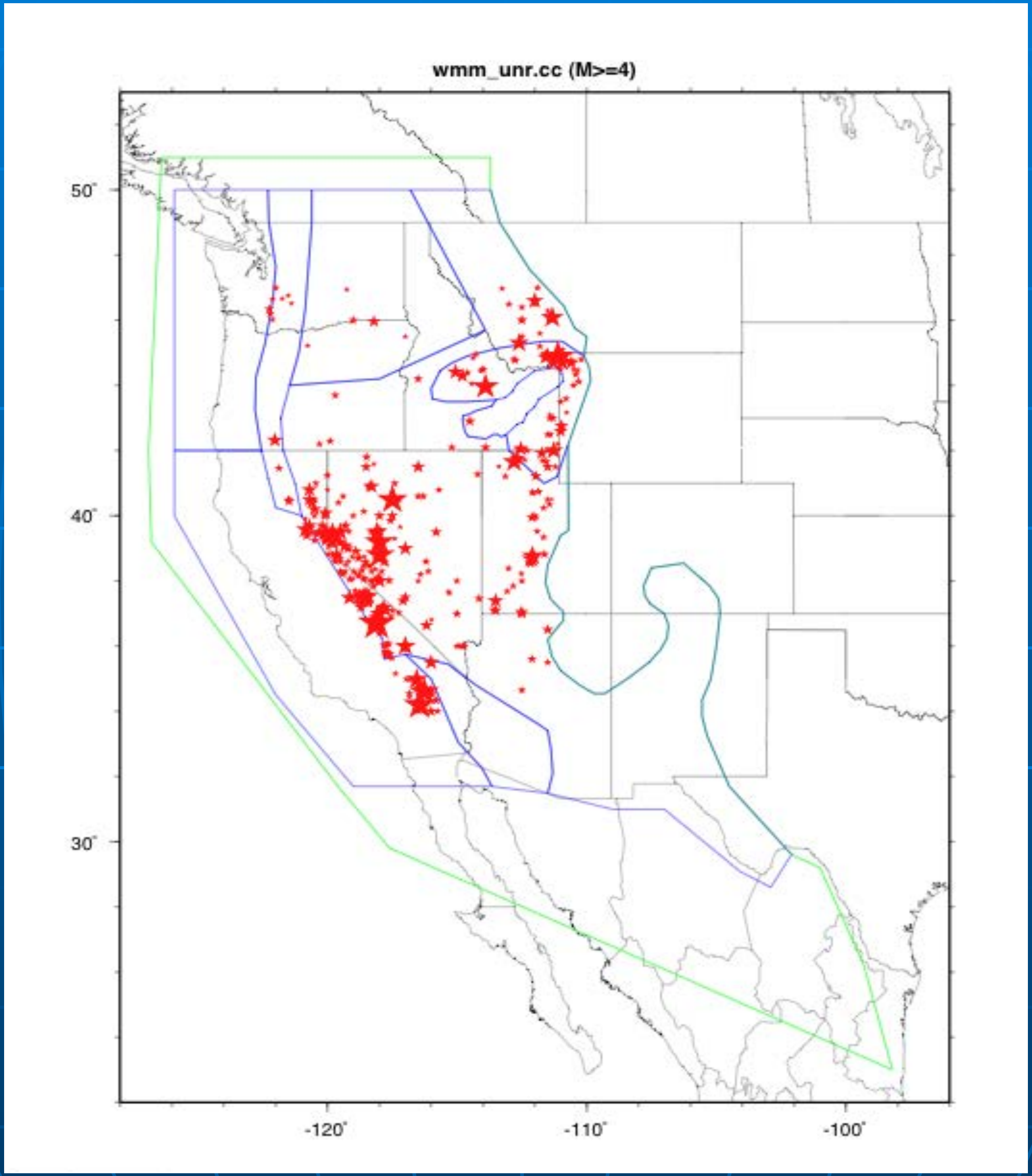
1800	4.00	4.50	5.00	5.50	6.00	6.50	7.00	7.50
00-09	0	0	2	2	1	0	0	0
10-19	0	0	0	0	0	0	1	0
20-29	0	0	1	1	1	0	0	0
30-39	0	0	0	0	1	0	1	0
40-49	0	0	0	0	0	0	0	0
50-59	0	0	2	5	4	0	0	1
60-69	1	2	1	3	3	1	0	0
70-79	1	0	0	2	2	1	0	0
80-89	3	0	2	10	3	0	0	0
90-99	0	0	0	4	8	4	1	0
00-09	6	3	2	7	5	0	0	1
10-19	9	4	2	9	4	2	0	0
20-29	8	7	5	5	3	1	3	0
30-39	73	30	11	7	3	1	0	0
40-49	64	36	15	6	1	3	0	0
50-59	94	37	11	6	3	2	0	0
60-69	88	38	12	6	1	1	0	0
70-79	92	31	20	5	1	3	0	0
80-89	92	28	16	8	6	2	1	0
90-99	99	25	10	6	0	1	4	0
00-06	78	18	13	4	0	1	0	0

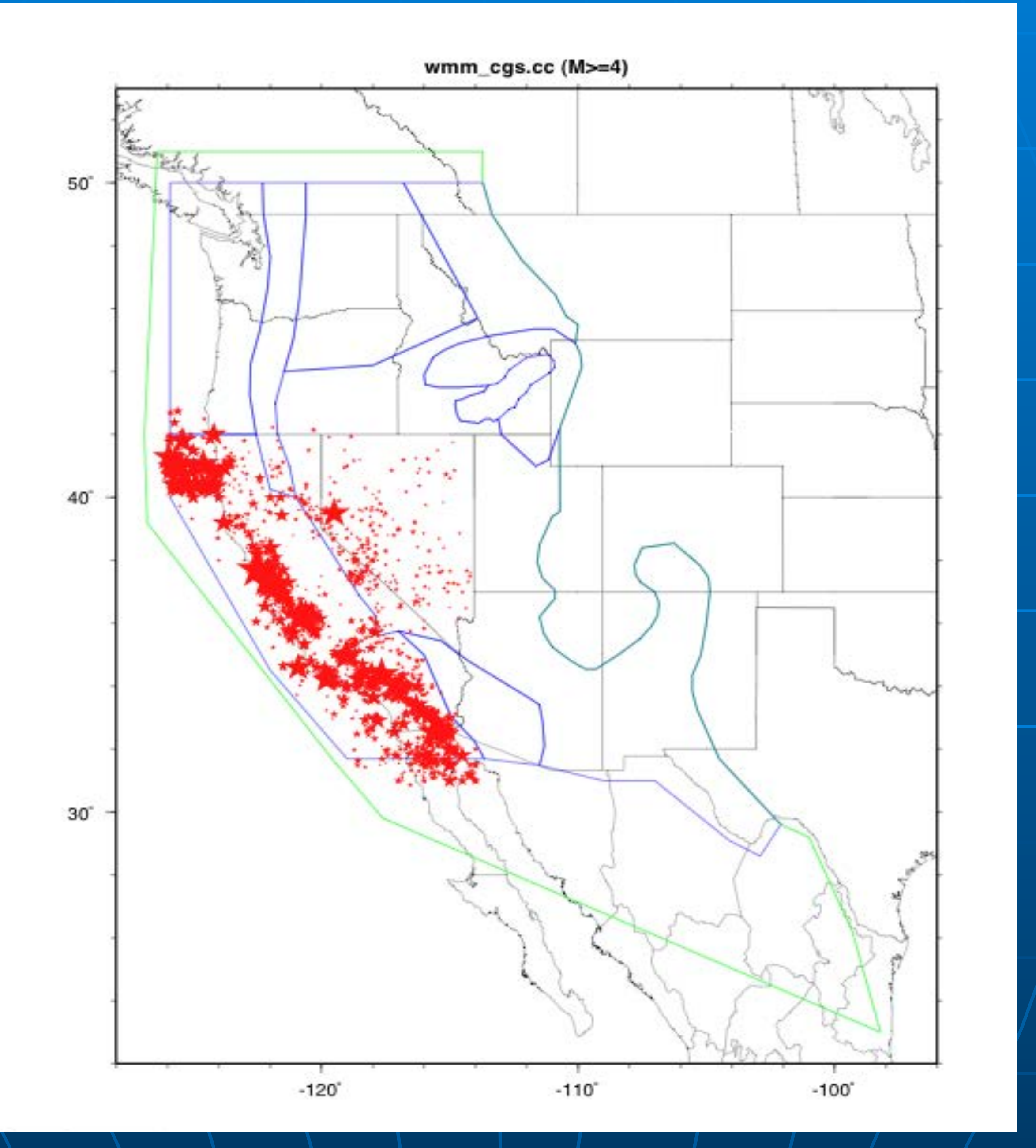
b = 0.732 +/- 0.019

a_cumulative = 0.410E+01

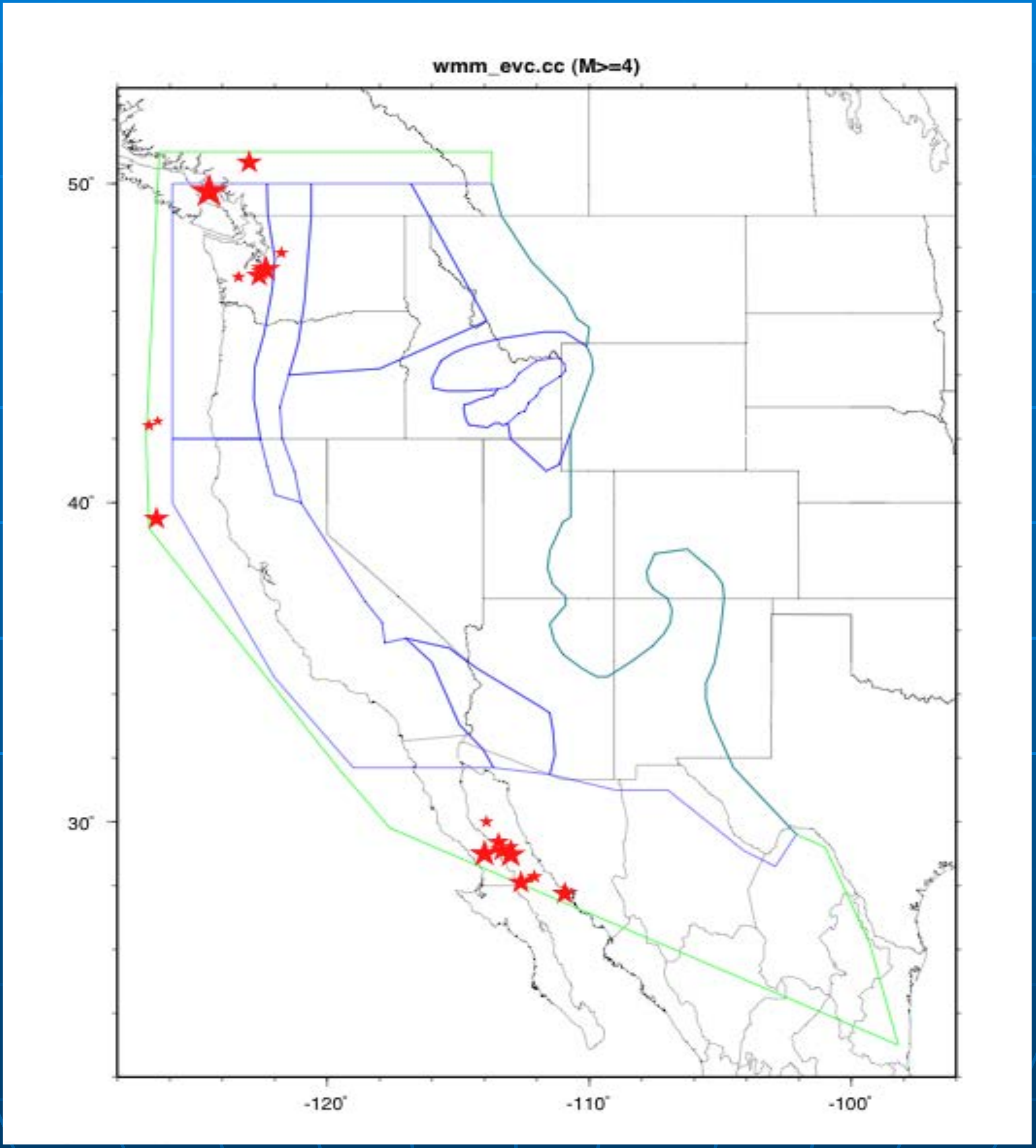
arc_m>=0(fn0) = 0.125E+05

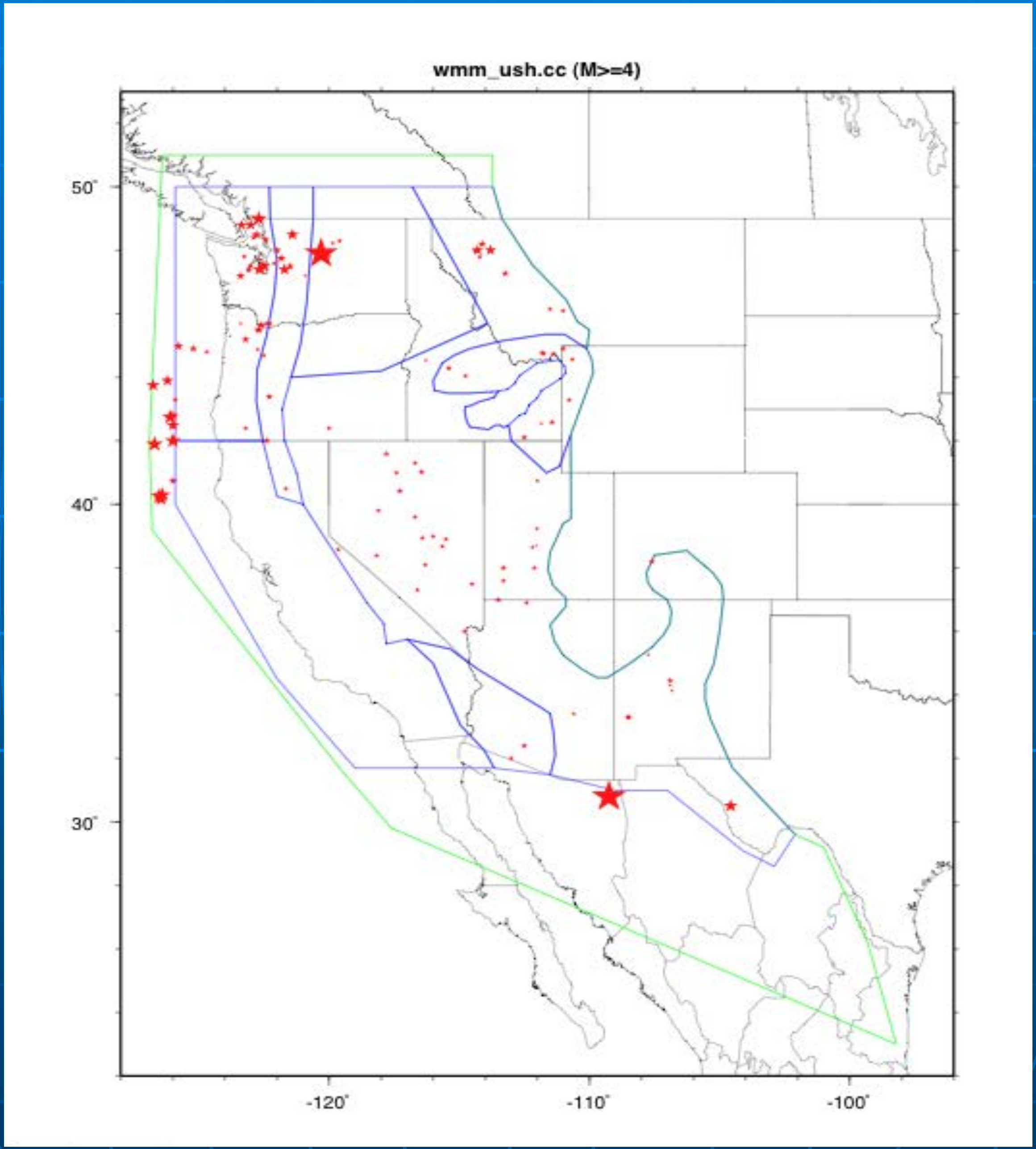
arc_m>=5(fn5) = 0.275E+01 +/-0.81E-01

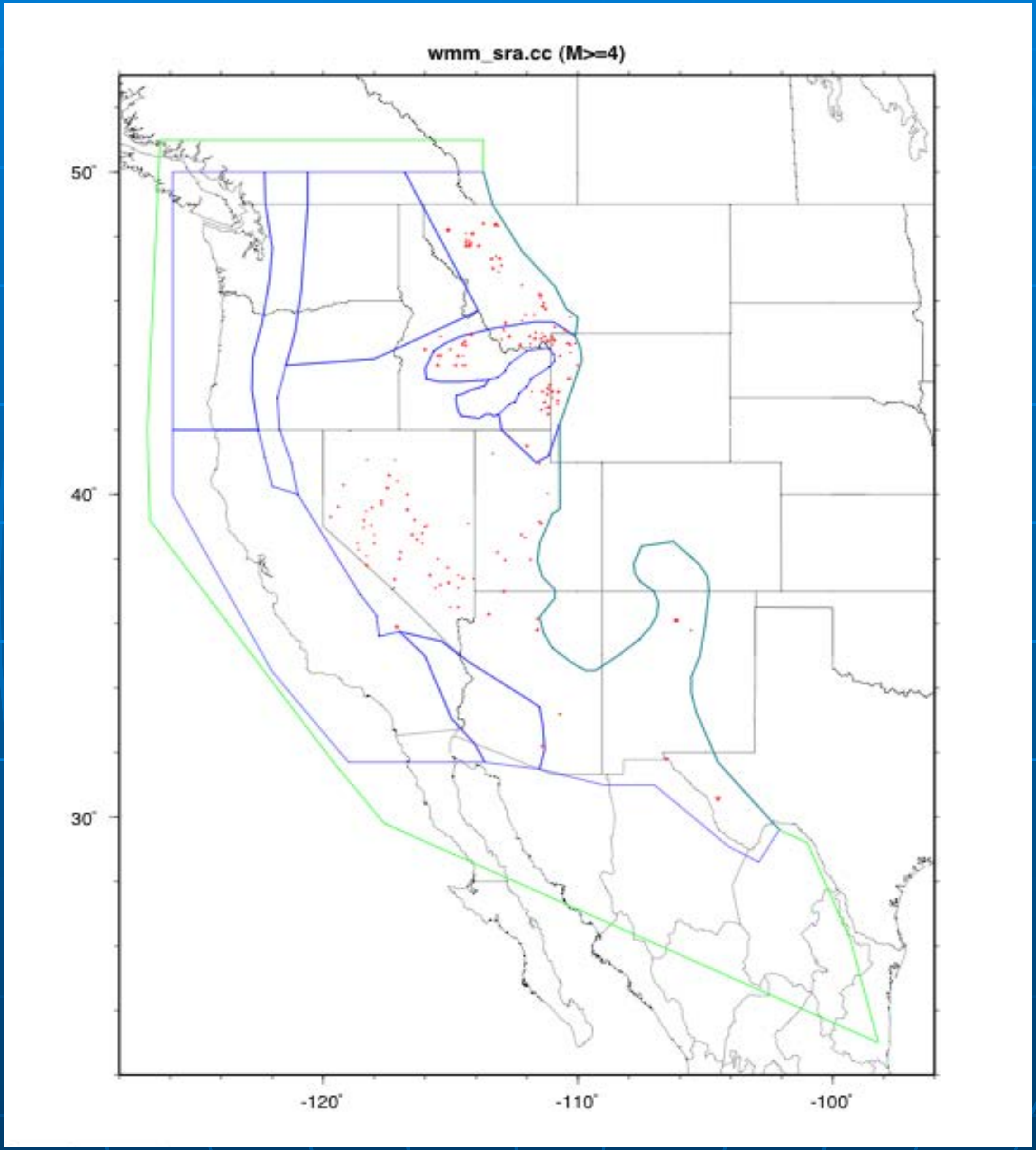

wmm_unr.cc (M>=4)
50°
40°
30°
-120°
-110°
-100°

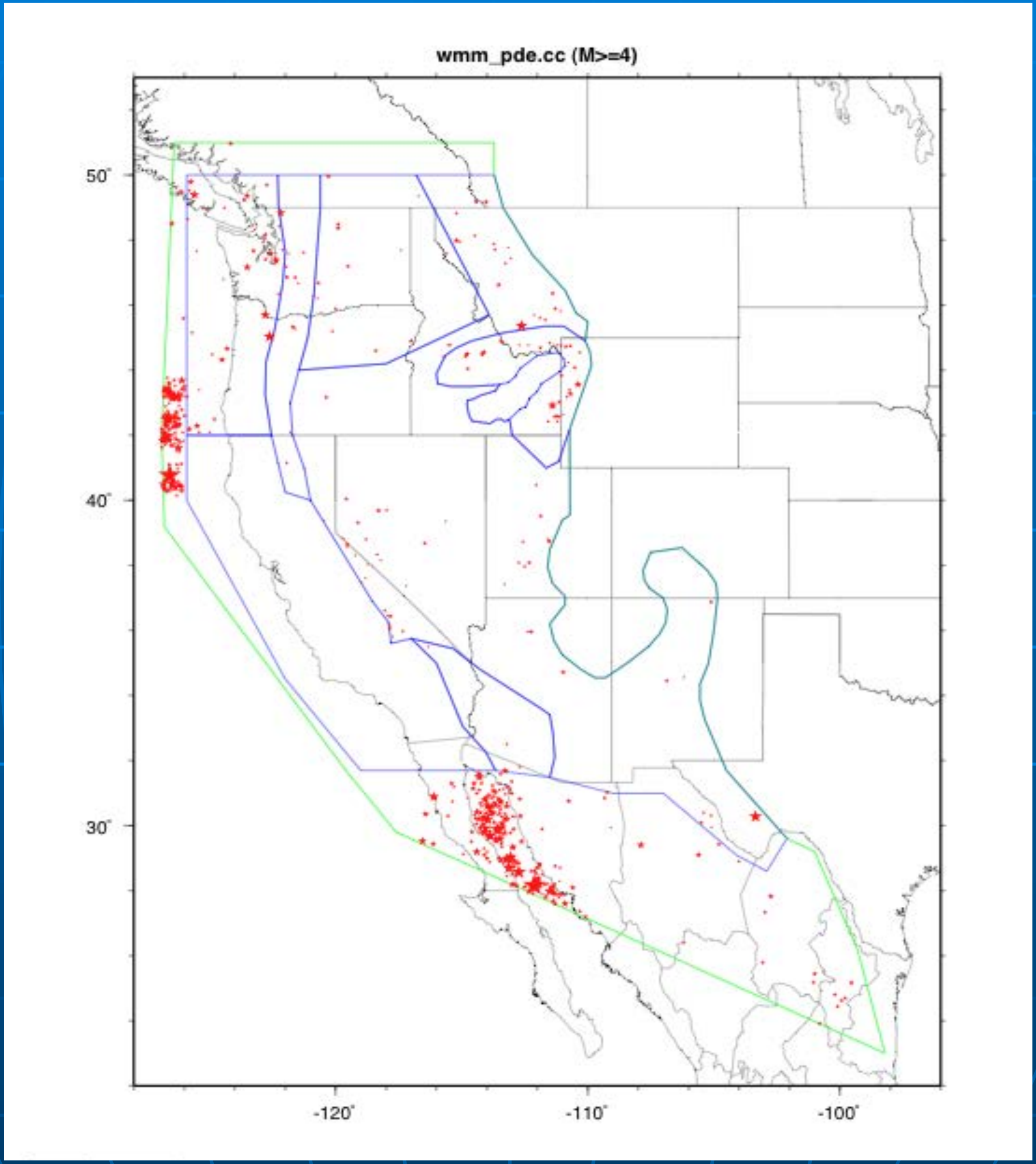


wmm_cgs.cc (M>=4)
50˚
40˚
30˚
-120˚
-110˚
-100˚

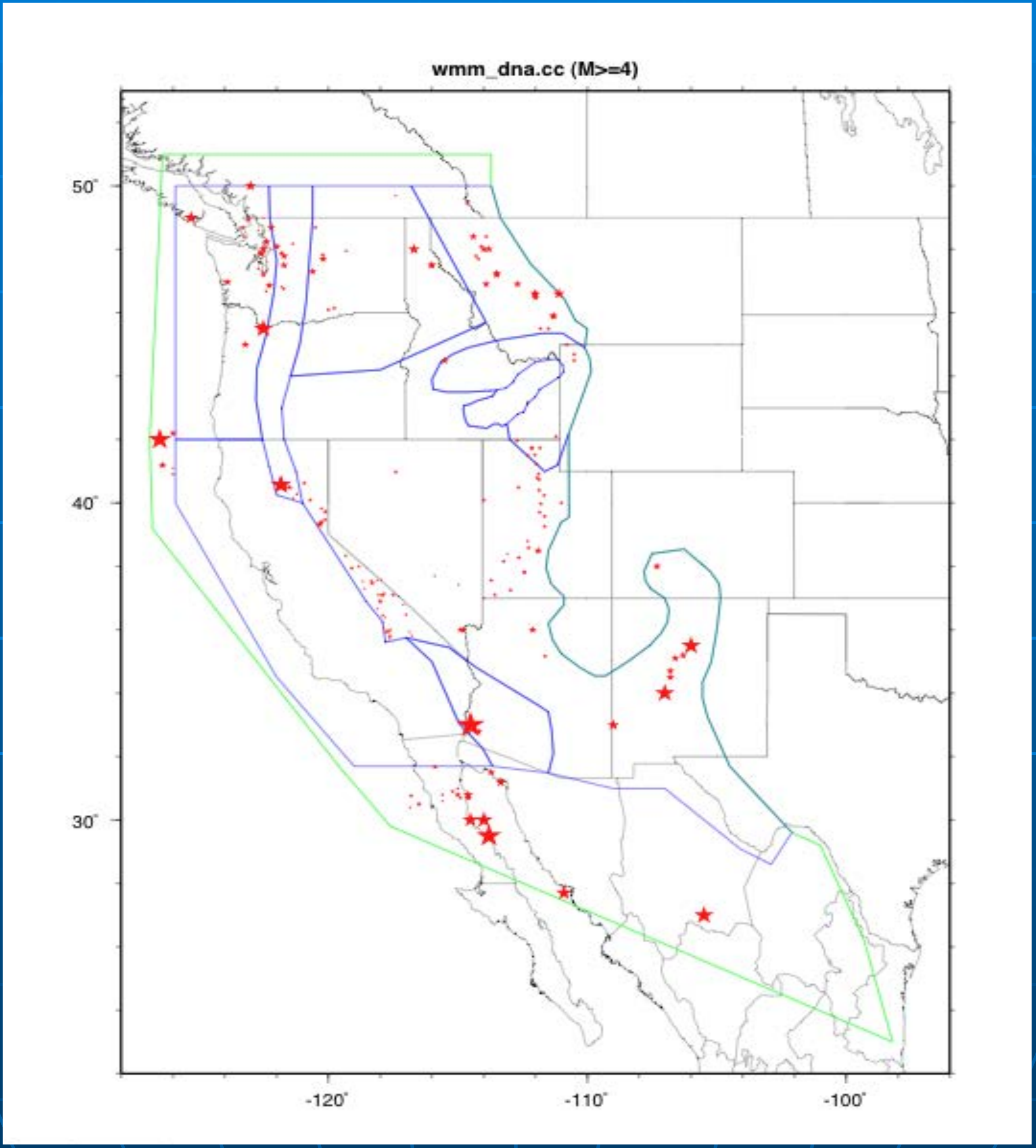

wmm_evc.cc (M>=4)
50°
40°
30°
-120°
-110°
-100°


wmm_ush.cc (M>=4)
50°
40°
30°
-120°
-110°
-100°

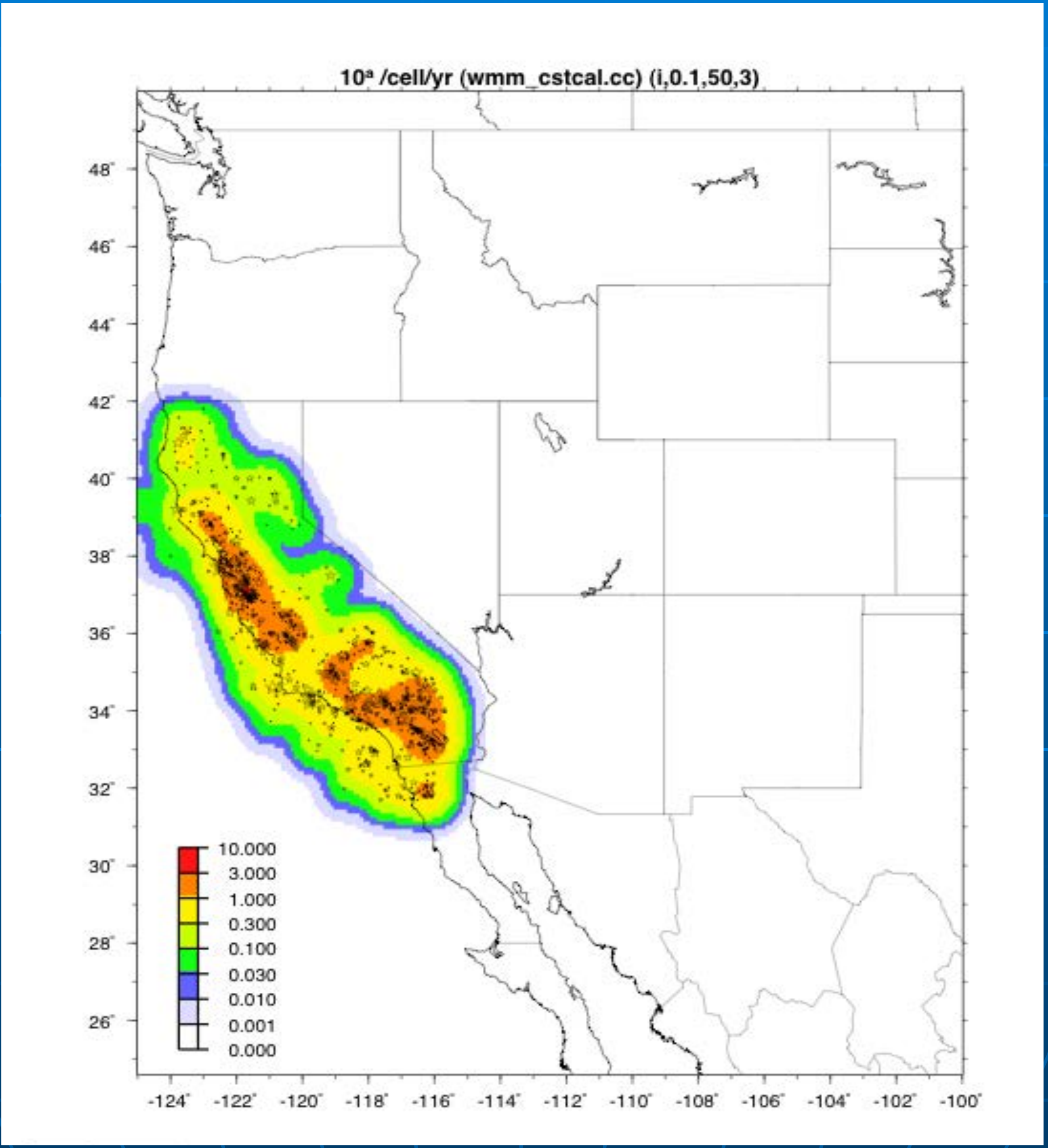

wmm_sra.cc (M>=4)
50°
40°
30°
-120°
-110°
-100°



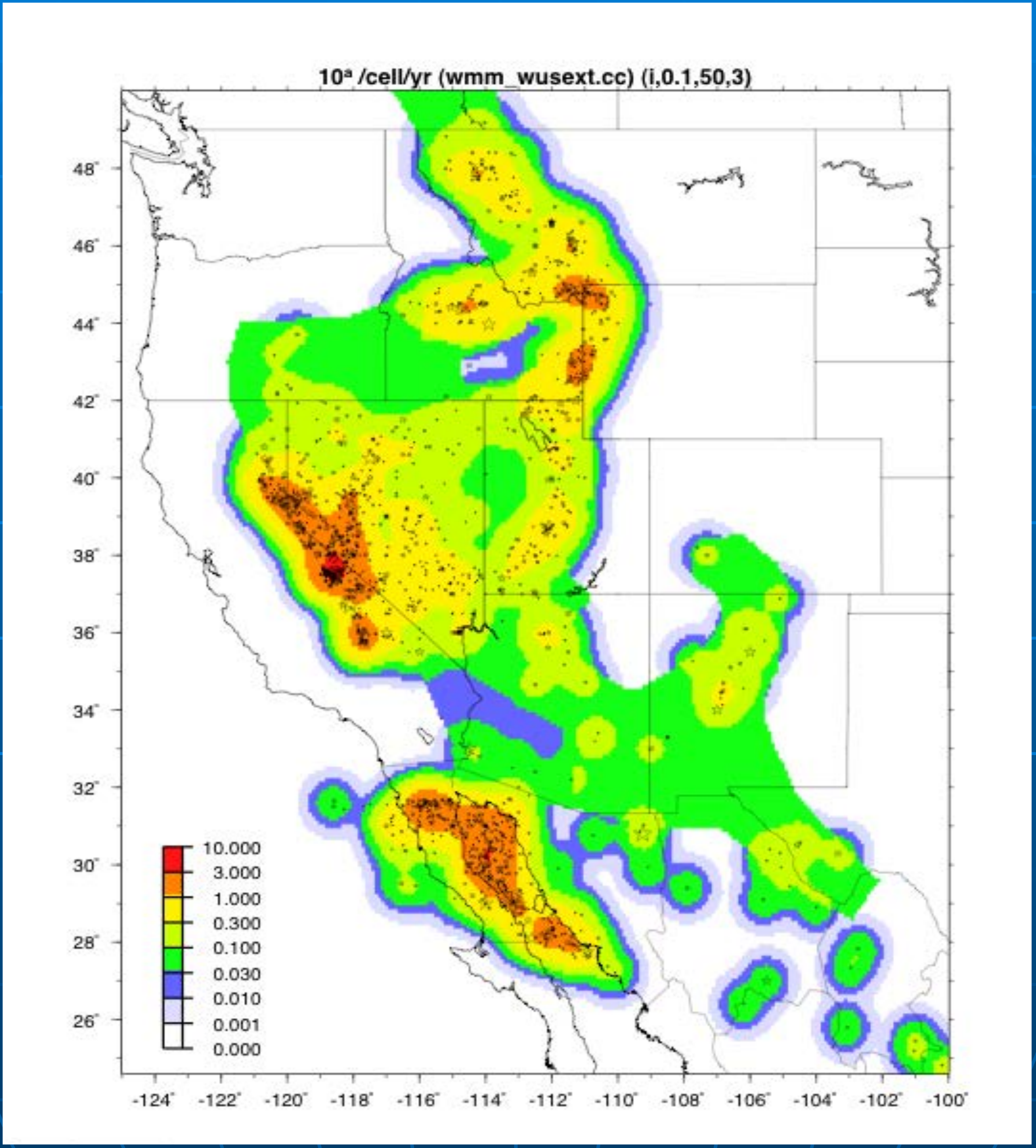
wmm_pde.cc (M>=4)
50˚
40˚
30˚
-120˚
-110˚
-100˚



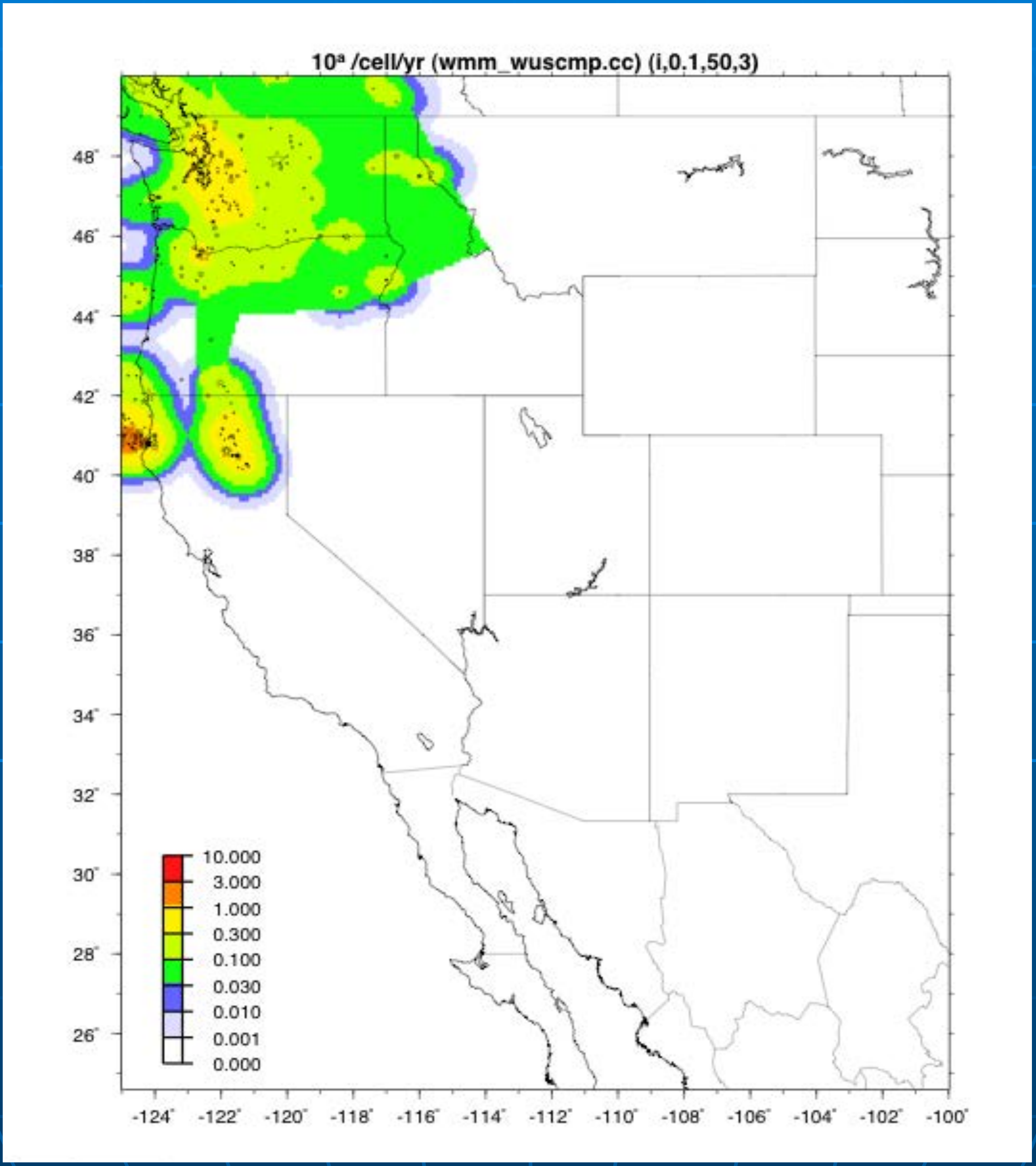
wmm_dna.cc (M>=4)
50°
40°
30°
-120°
-110°
-100°



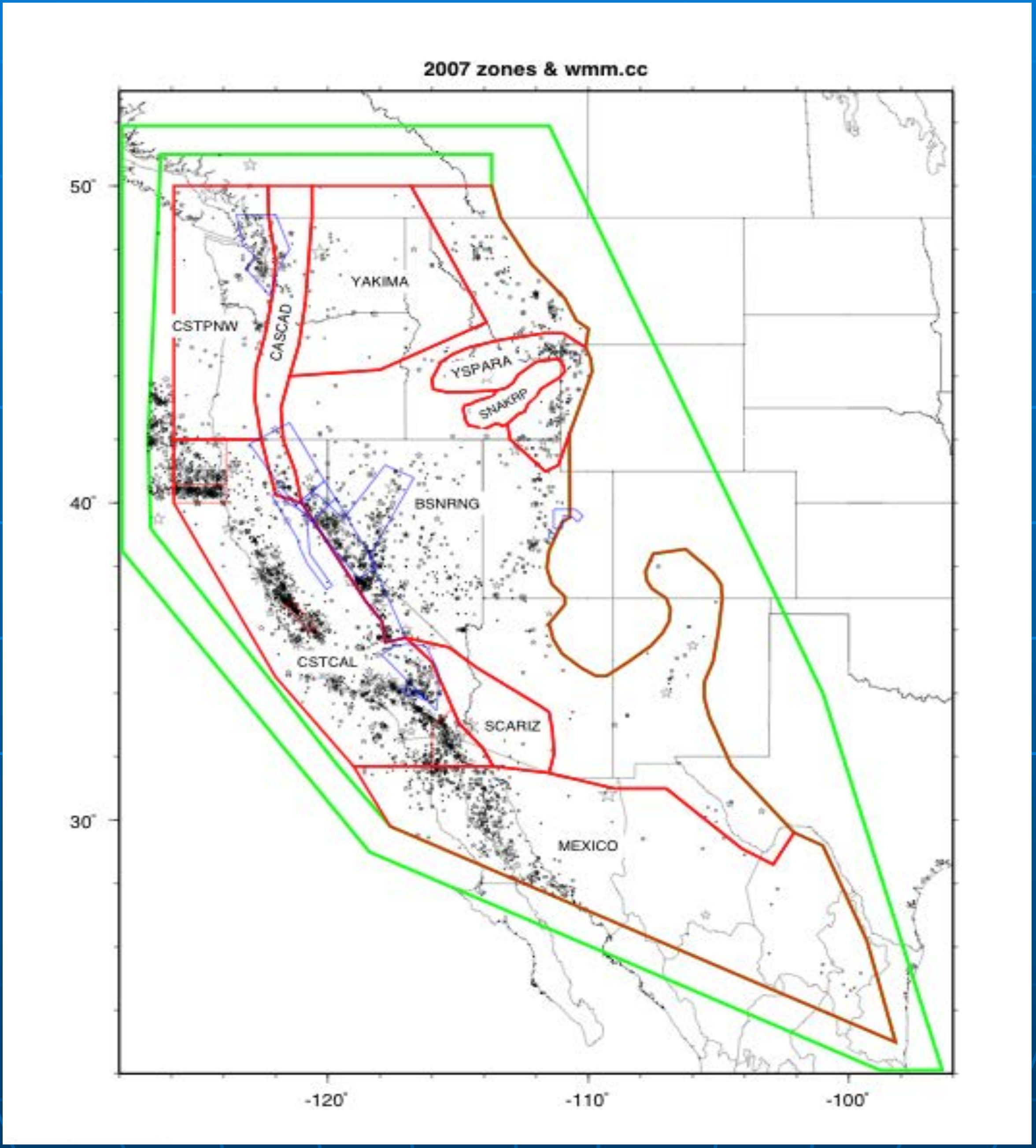
10ª /cell/yr (wmm_cstcal.cc) (i,0.1,50,3)
48°
46°
44°
42°
40°
38°
36°
34°
32°
30°
28°
26°
-124°
-122°
-120°
-118°
-116°
-114°
-112°
-110°
-108°
-106°
-104°
-102°
-100°
10.000
3.000
1.000
0.300
0.100
0.030
0.010
0.001
0.000

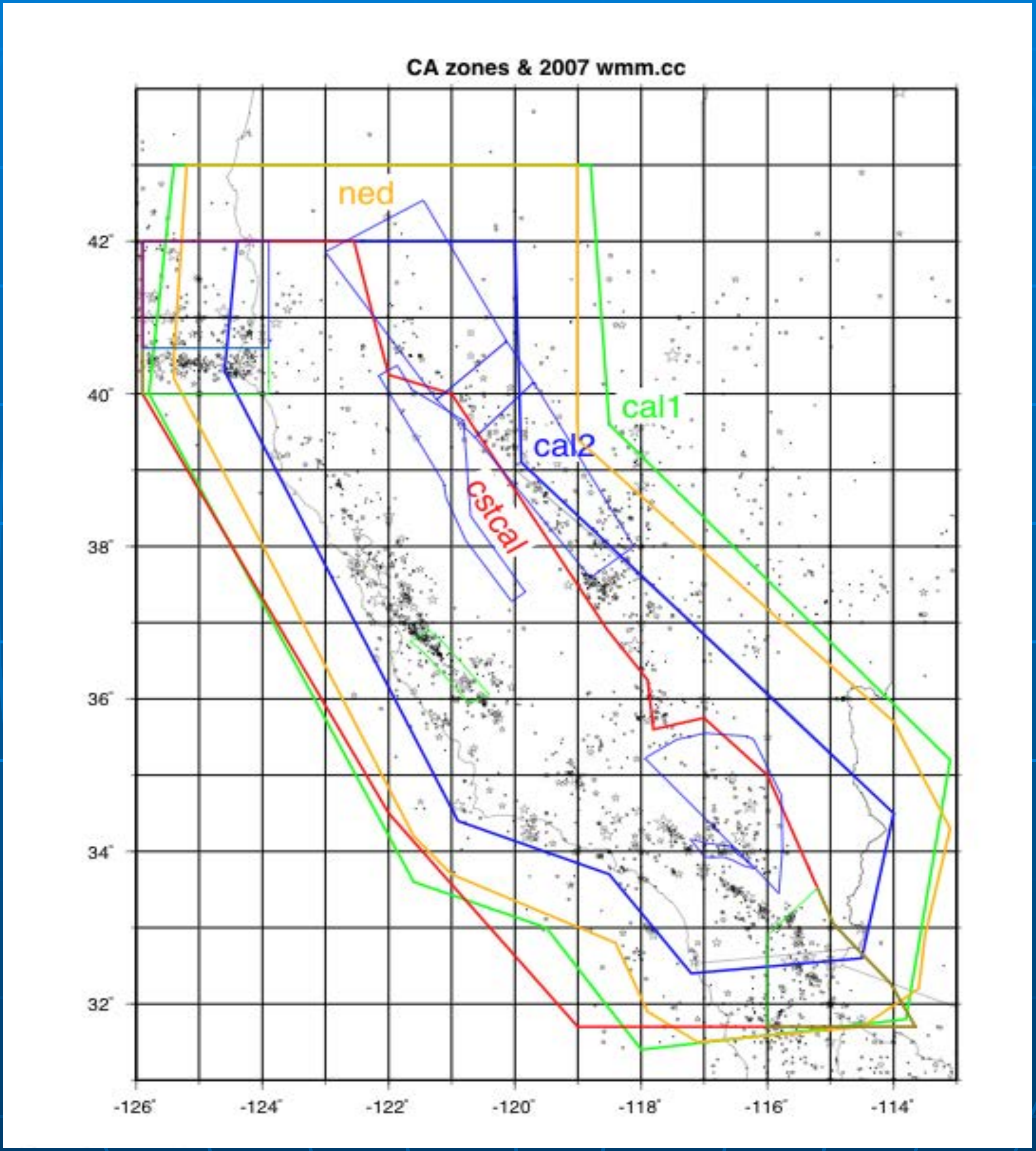


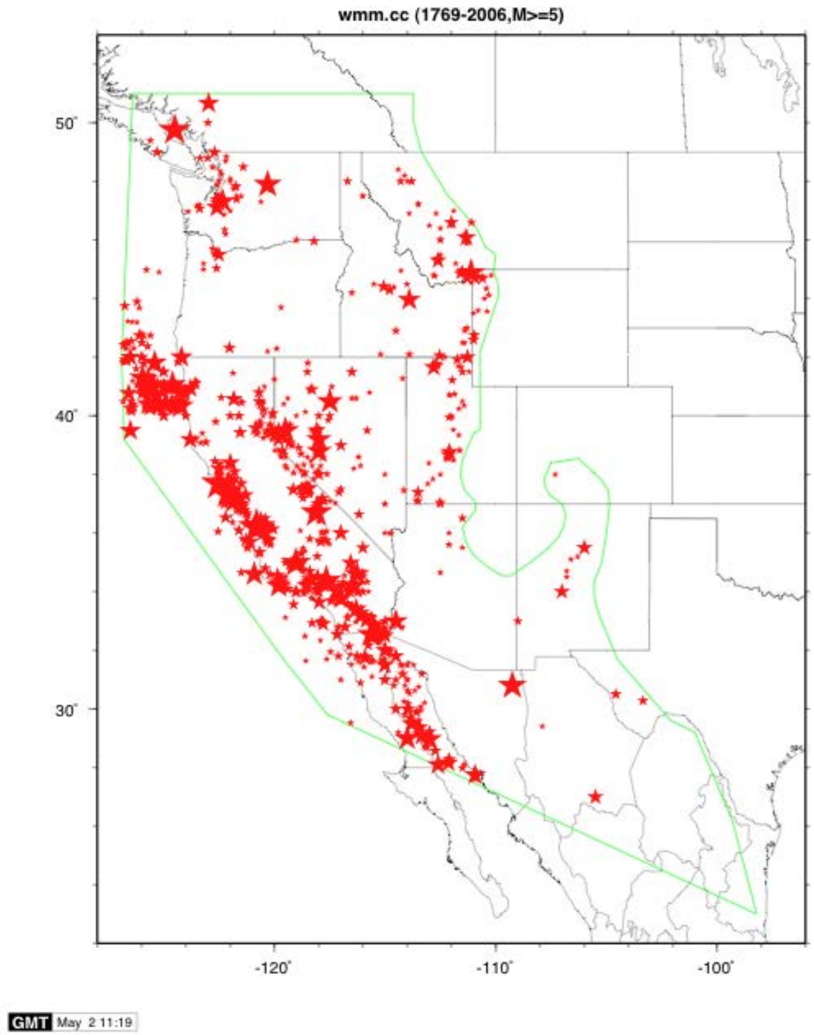
10ᵃ /cell/yr (wmm_wusext.cc) (i,0.1,50,3)
48°
46°
44°
42°
40°
38°
36°
34°
32°
30°
28°
26°
-124°
-122°
-120°
-118°
-116°
-114°
-112°
-110°
-108°
-106°
-104°
-102°
-100°
10.000
3.000
1.000
0.300
0.100
0.030
0.010
0.001
0.000

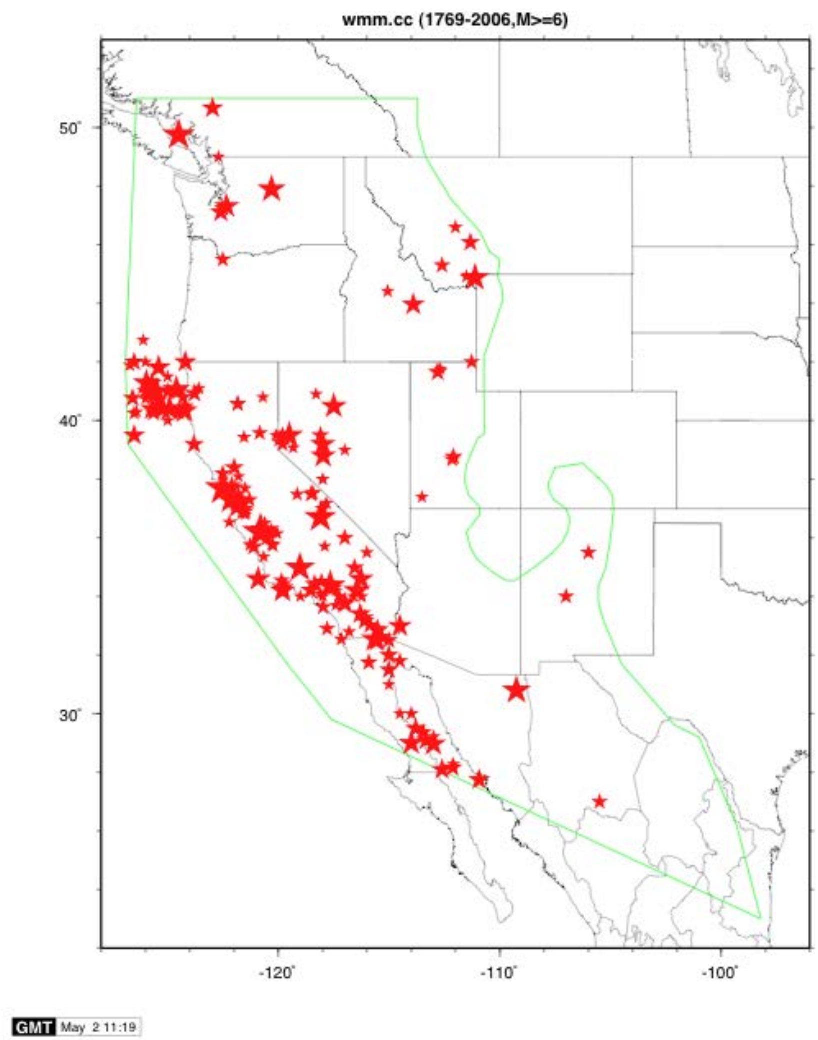


10ª /cell/yr (wmm_wuscmp.cc) (i,0.1,50,3)
48˚
46˚
44˚
42˚
40˚
38˚
36˚
34˚
32˚
30˚
28˚
26˚
-124˚
-122˚
-120˚
-118˚
-116˚
-114˚
-112˚
-110˚
-108˚
-106˚
-104˚
-102˚
-100˚
10.000
3.000
1.000
0.300
0.100
0.030
0.010
0.001
0.000

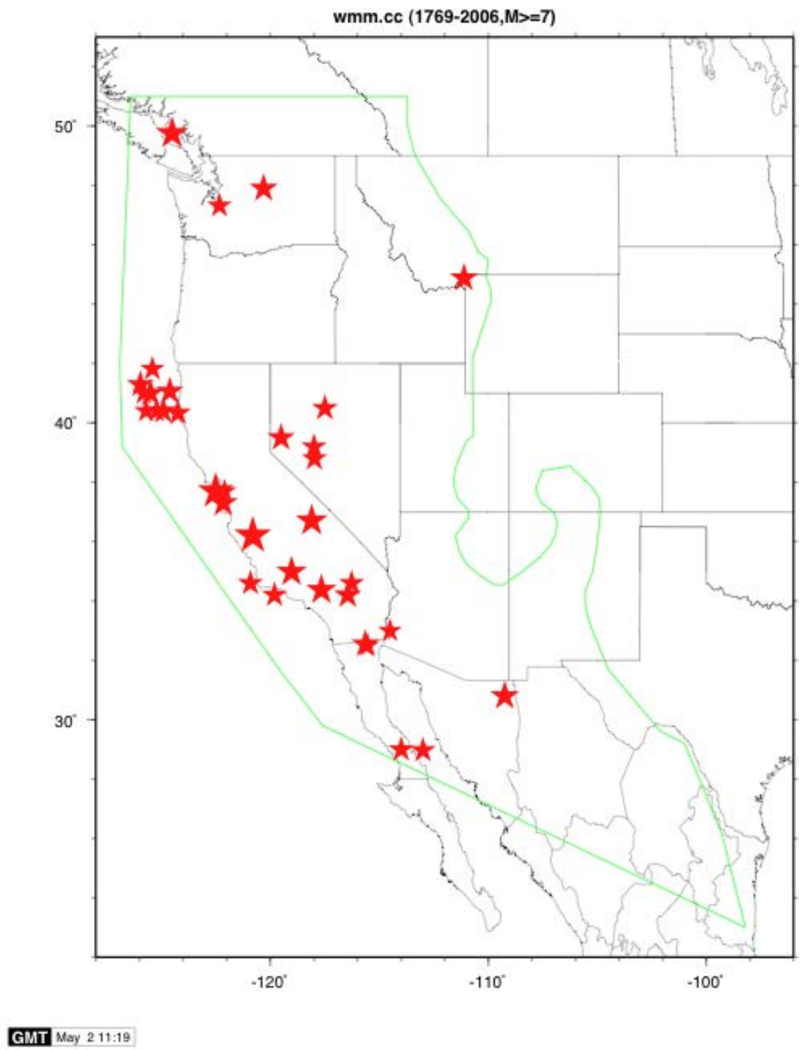

2007 zones & wmm.cc
50°
40°
30°
-120°
-110°
-100°
YAKIMA
CSTPNW
CASCAD
YSPARA
SNAKRP
BSNRNG
CSTCAL
SCARIZ
MEXICO


CA zones & 2007 wmm.cc
ned
cal1
cal2
cstcal
42°
40°
38°
36°
34°
32°
-126°
-124°
-122°
-120°
-118°
-116°
-114°


wmm.cc (1769-2006,M>=5)
50°
40°
30°
-120°
-110°
-100°
GMT May 2 11:19

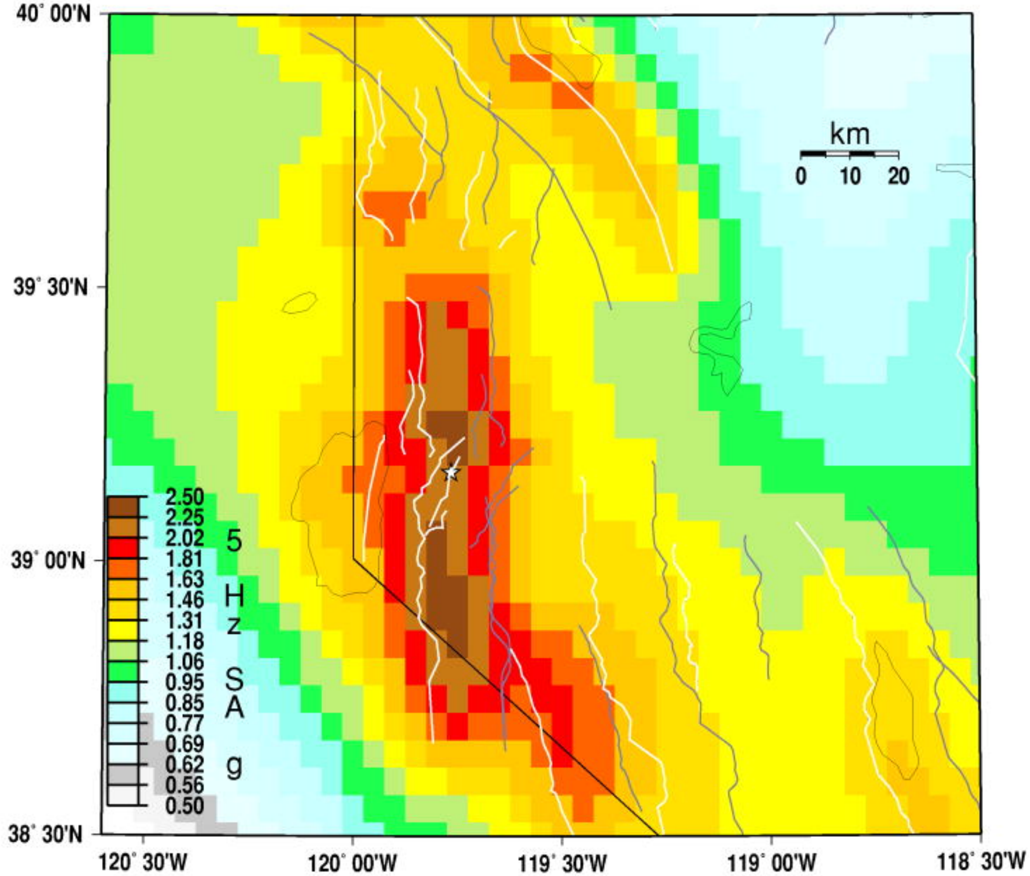


wmm.cc (1769-2006,M>=6)
50˚
40˚
30˚
-120˚
-110˚
-100˚
GMT May 2 11:19

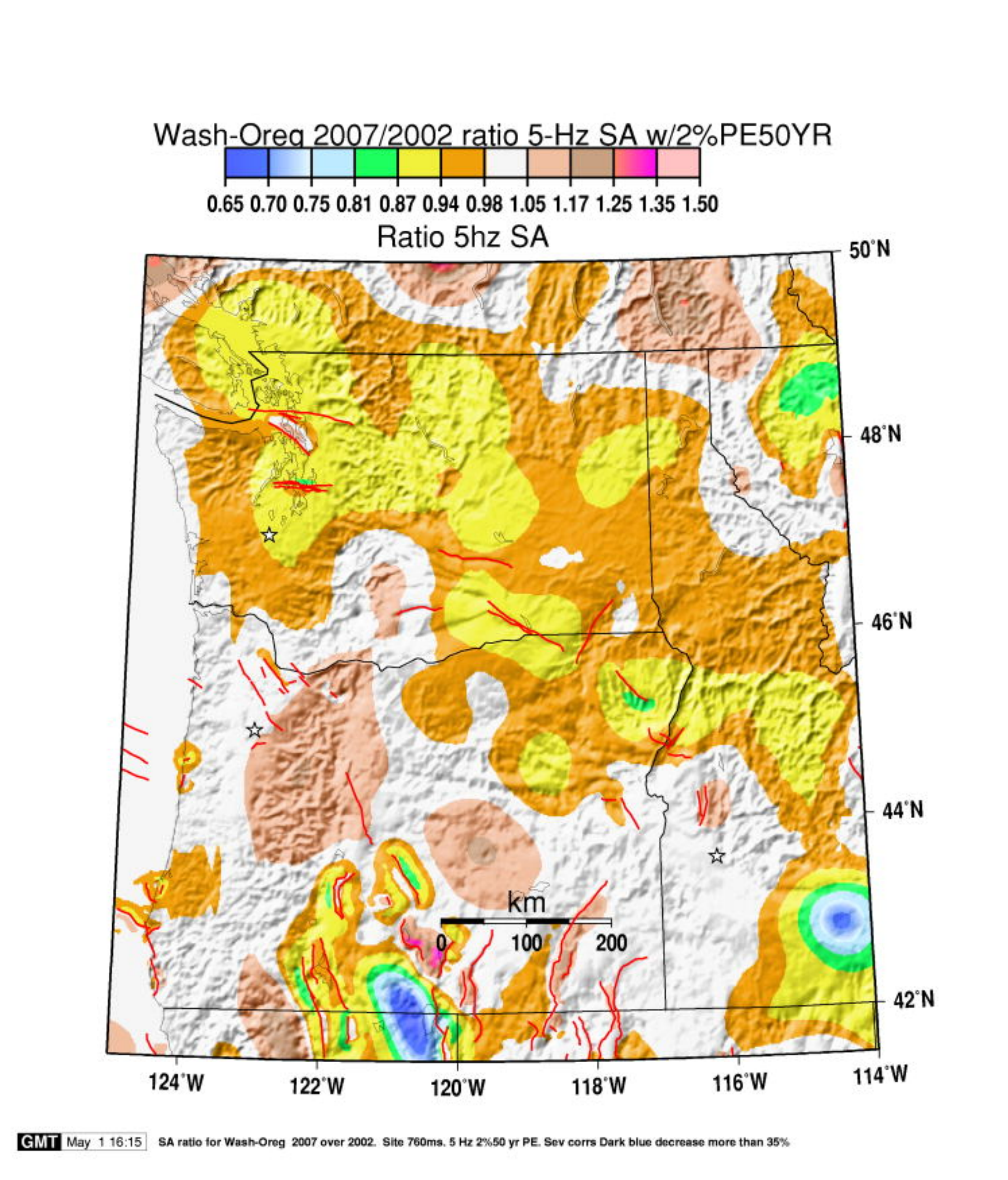


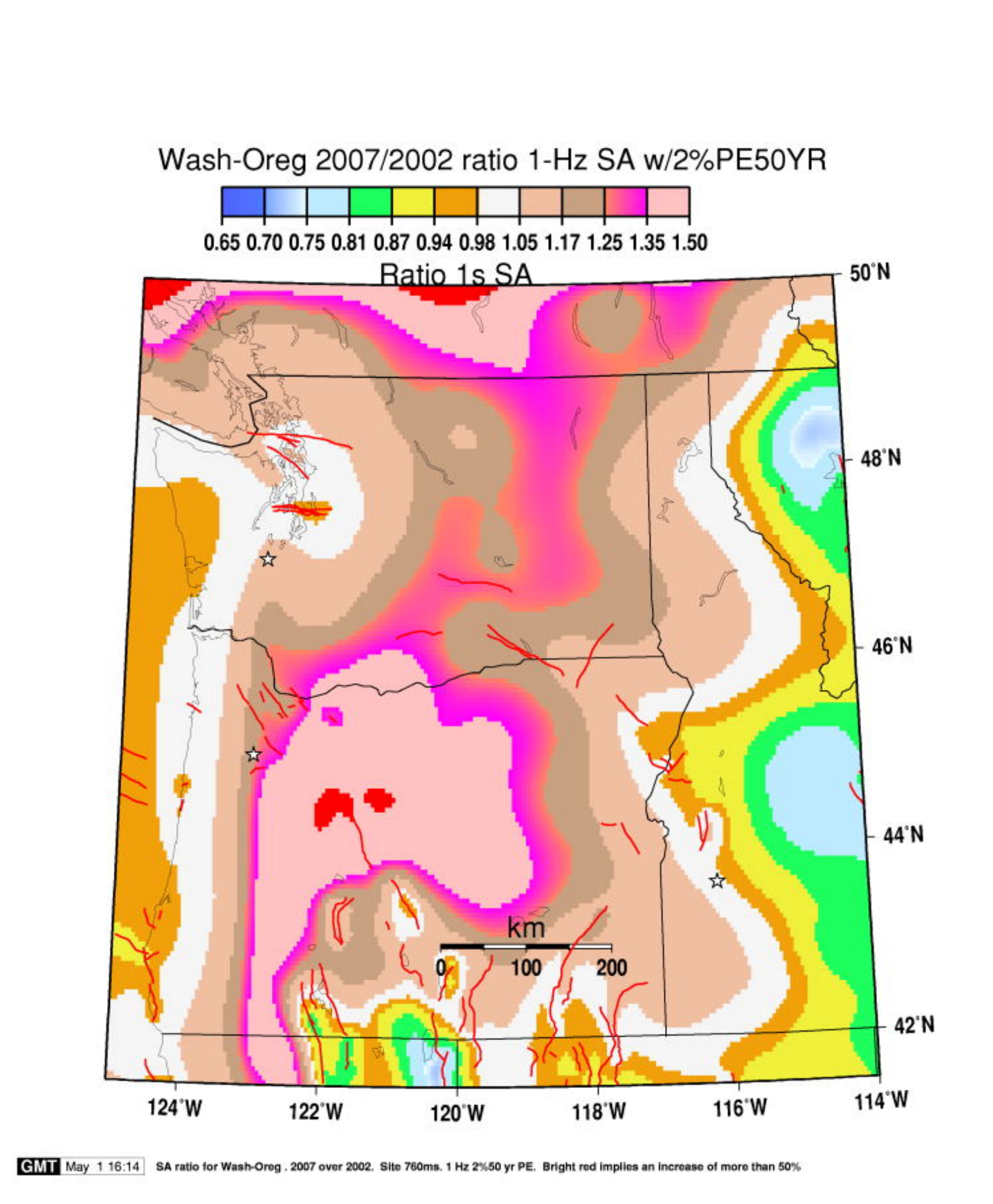
wmm.cc (1769-2006,M>=7)
50°
40°
30°
-120°
-110°
-100°
GMT May 2 11:19

W Nev 2007 5-Hz SA w/2%PE50YR



GMT Apr 25 16:14 SA for Western Nevada. Site Vs30 760ms. 5 Hz 2%50 yr PE.


Wash-Oreg 2007/2002 ratio 5-Hz SA w/2%PE50YR
0.65 0.70 0.75 0.81 0.87 0.94 0.98 1.05 1.17 1.25 1.35 1.50
Ratio 5hz SA
50°N
48°N
46°N
44°N
42°N
km
0
100
200
124°W
122°W
120°W
118°W
116°W
114°W
GMT May 1 16:15
SA ratio for Wash-Oreg 2007 over 2002. Site 760ms. 5 Hz 2%50 yr PE. Sev corrs Dark blue decrease more than 35%


Wash-Oreg 2007/2002 ratio 1-Hz SA w/2%PE50YR
0.65 0.70 0.75 0.81 0.87 0.94 0.98 1.05 1.17 1.25 1.35 1.50
Ratio 1s SA
50°N
48°N
46°N
44°N
42°N
km
0
100
200
124°W
122°W
120°W
118°W
116°W
114°W
GMT May 1 16:14
SA ratio for Wash-Oreg . 2007 over 2002. Site 760ms. 1 Hz 2%50 yr PE. Bright red implies an increase of more than 50%