Scientific Research on the Cascadia Subduction Zone that Will Help Improve Seismic Hazard Maps, Building Codes, and Other Risk-Mitigation Measures

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GeoPrisms-Earthscope Science Workshop for Cascadia
Portland, Oregon; April 6, 2012

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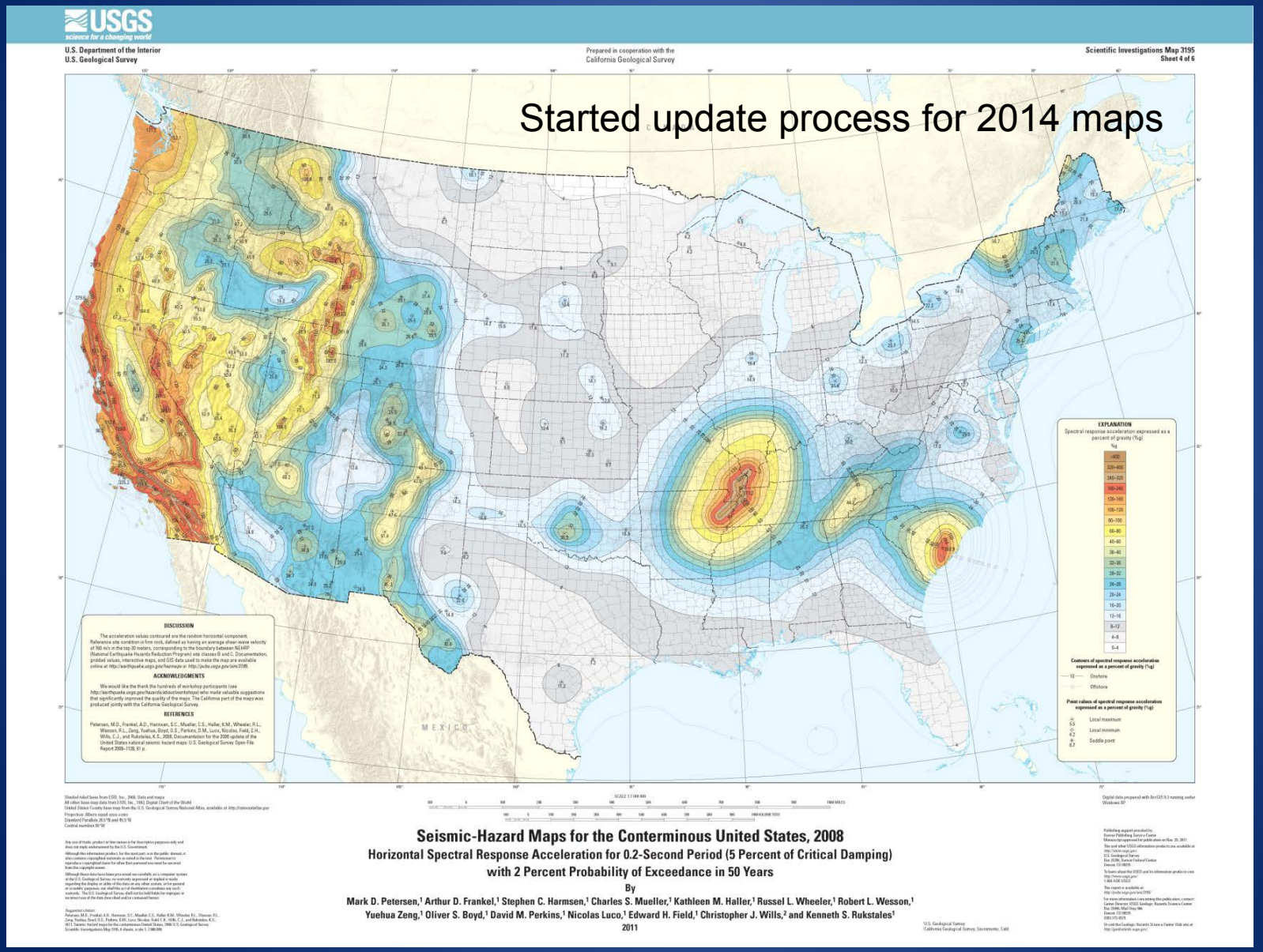
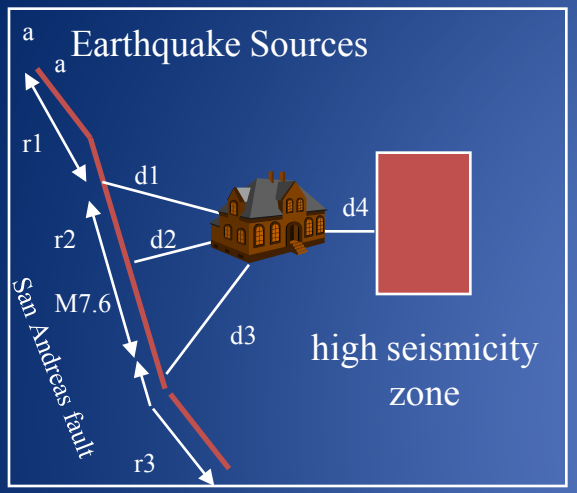
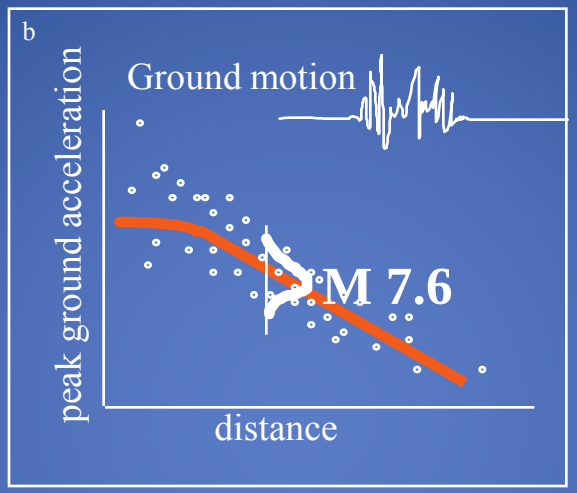
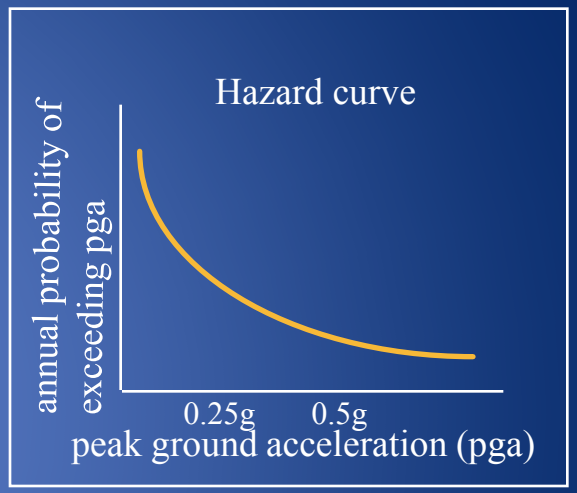
National seismic hazard maps are the basis of design maps used in International Building Code and International Residential Code for new buildings in 50 states



Probabilistic Seismic Hazard Assessment







Specify recurrence rates of earthquakes for each source that can affect site of Interest

Time independent or time dependent

Ground-Motion Prediction Equations tell you median ground motions that each potential earthquake will produce at site, and variability

Derived from strong-motion data (WUS) or models (CEUS)

Hazard curve: describes probability of having ground motions ≥ a certain intensity

We use mean hazard curves from logic trees with alternative models

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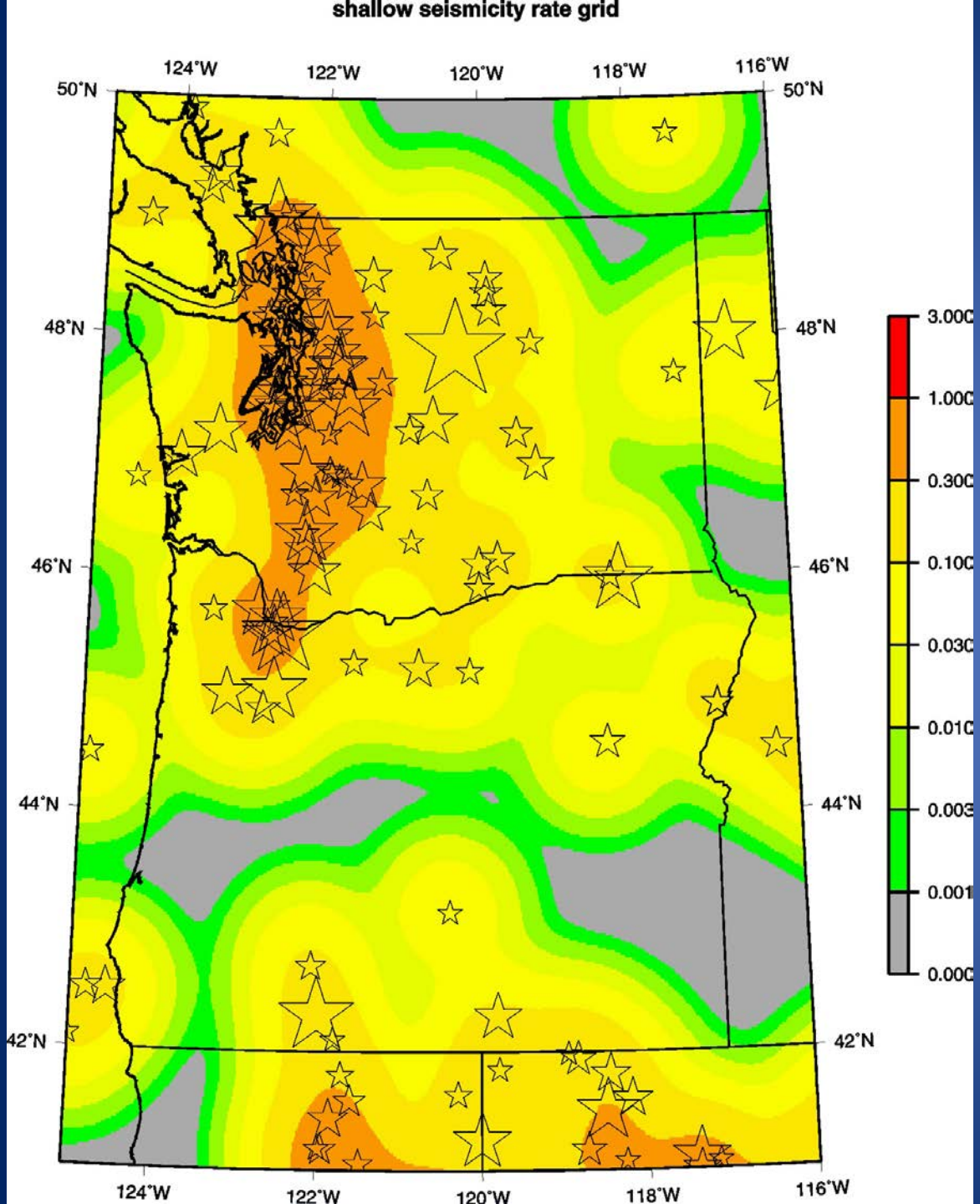

Figure from C. Mueller

M ≥ 4.0 since 1963
M≥ 5.0 since 1930
M≥ 6.0 since 1850

< 35 km deep
Maximum likelihood a-values on grid; used Gaussian smoothing function with correlation distance of 50 km.
Use this grid to calculate hazard from M5-7 earthquakes; also use background zones for floor of hazard

Also use seismicity rate grid for deep earthquakes > 35 km

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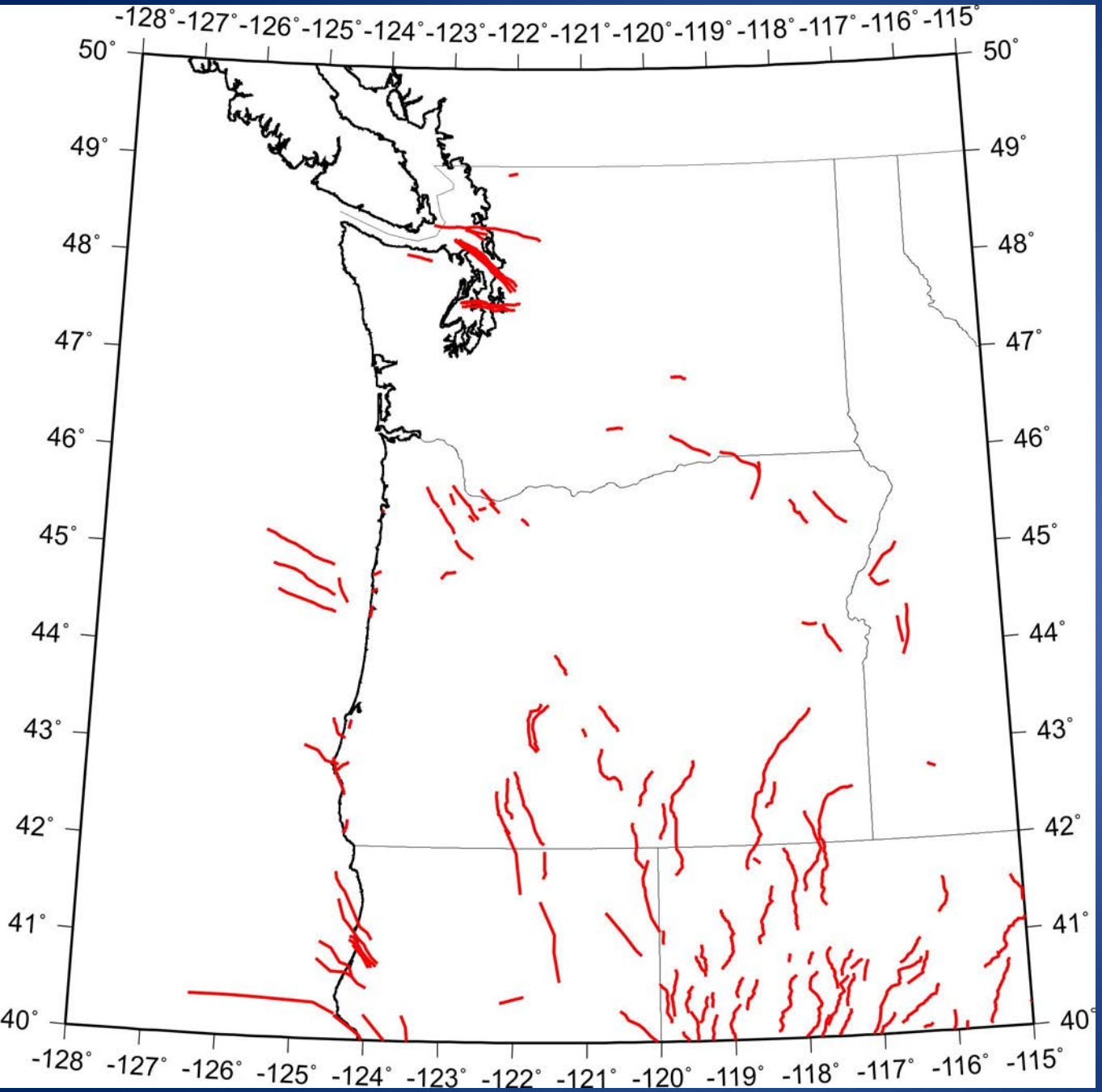

Used Quaternary faults with slip rate determinations and/or paleo-earthquake chronologies

We have an advisory panel to provide recommendations on faults to add or revise (B. Sherrod)

We use combination Of characteristic and Gutenberg-Richter models to go from slip rate to recurrence rate

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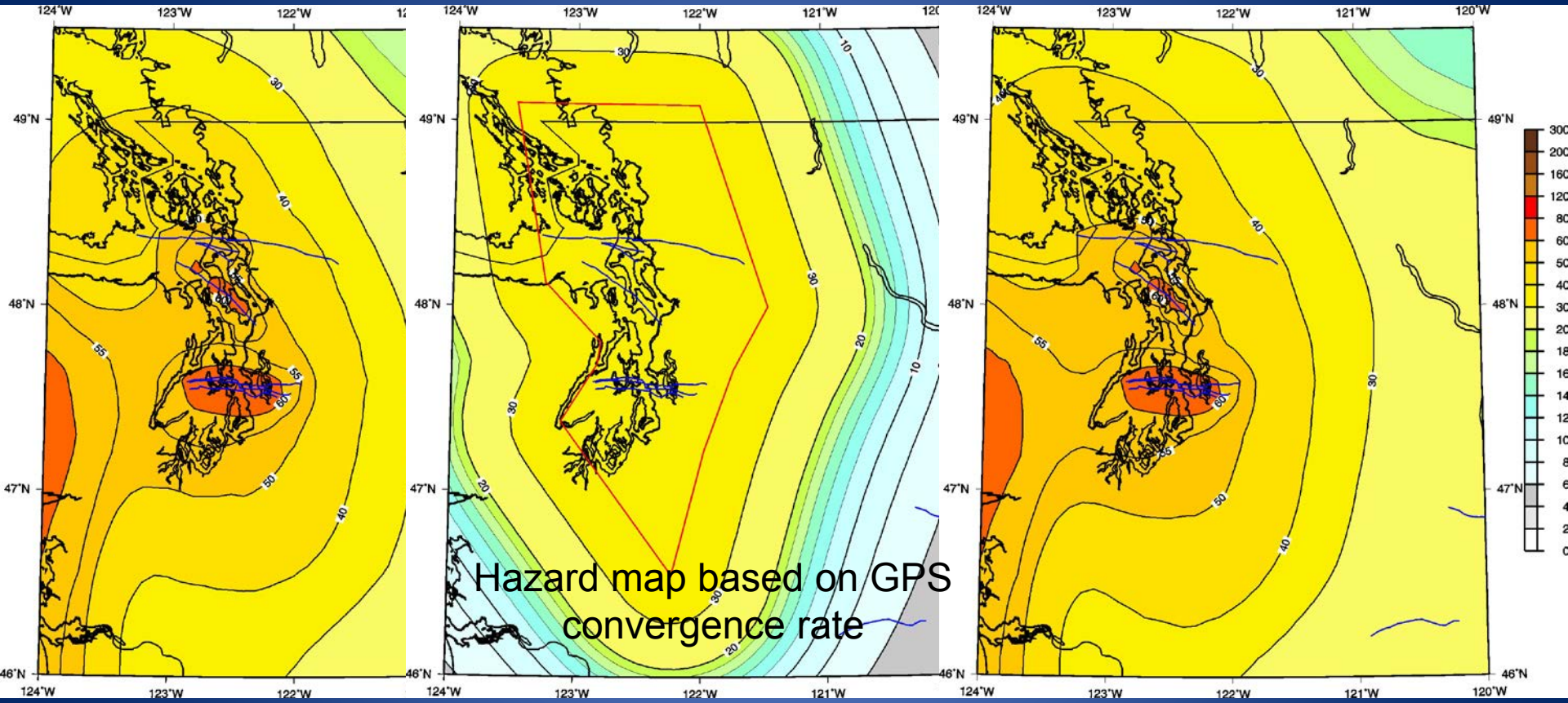
Puget Sound: Effect of including areal source zone accommodating 3 mm/yr N-S convergence measured by GPS (in addition to convergence from faults used in hazard maps)



PGA (%g) with 2% P.E. in 50 Years

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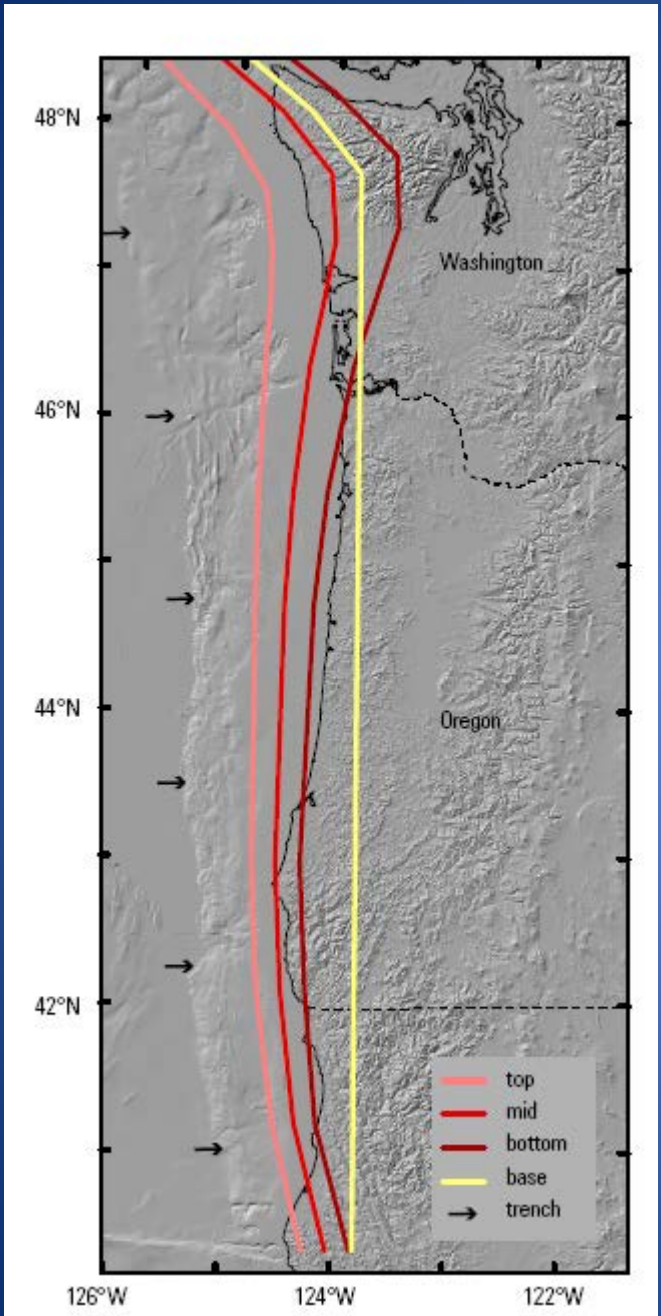

Great earthquakes on Cascadia Subduction Zone have been included in NSHM's since 1996, with rates based on paleoseismic studies (e.g., Atwater, 1992)
500 year average recurrence M8.8-9.2 (0.67 prob)

M8.0-8.7 filling zone with 500 yr Recurrence (0.33 prob)

Figure shows different models for Down-dip edge of rupture used in 2002 and 2008 maps

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What we need to know most about Cascadia great earthquakes

- Recurrence rates, rupture zones, and magnitudes of great earthquakes based on onshore and offshore paleoseismic observations
- Down-dip edge of rupture of great earthquakes inferred from GPS and uplift data, ETS, thermal modeling, paleo-slip, structural characteristics
- Ground motions expected for great earthquakes

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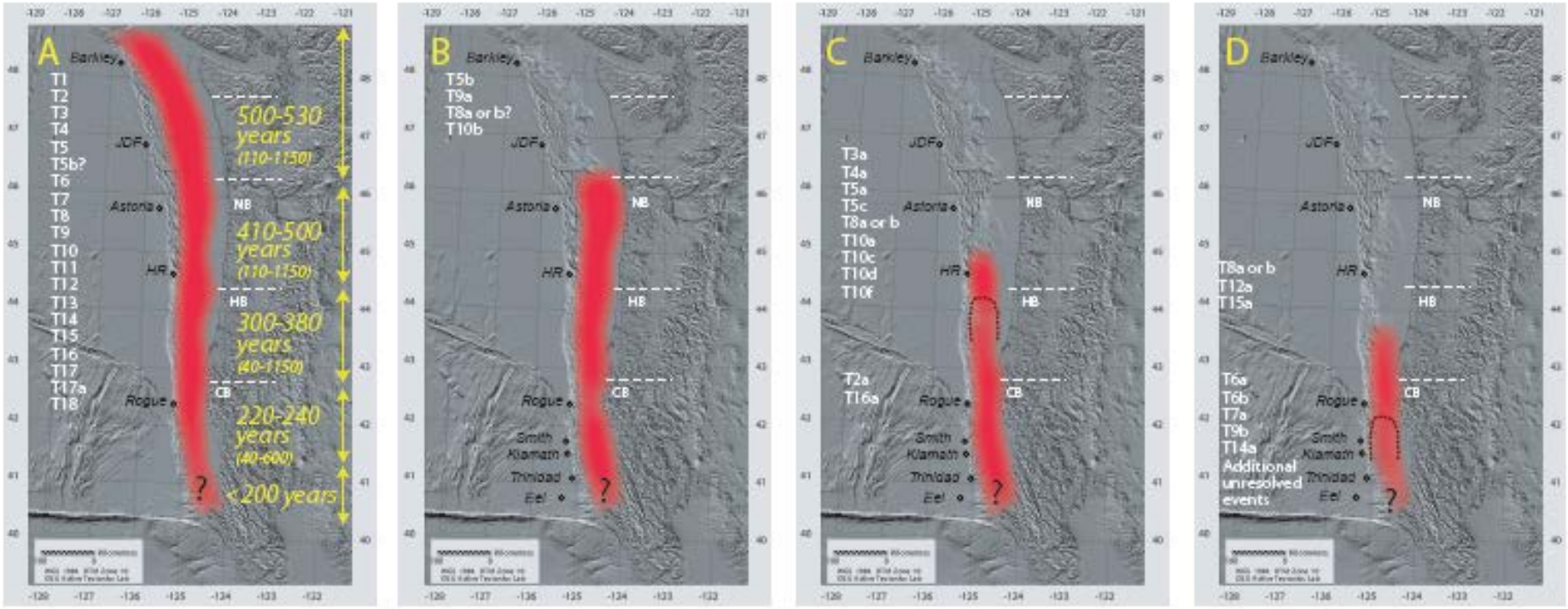
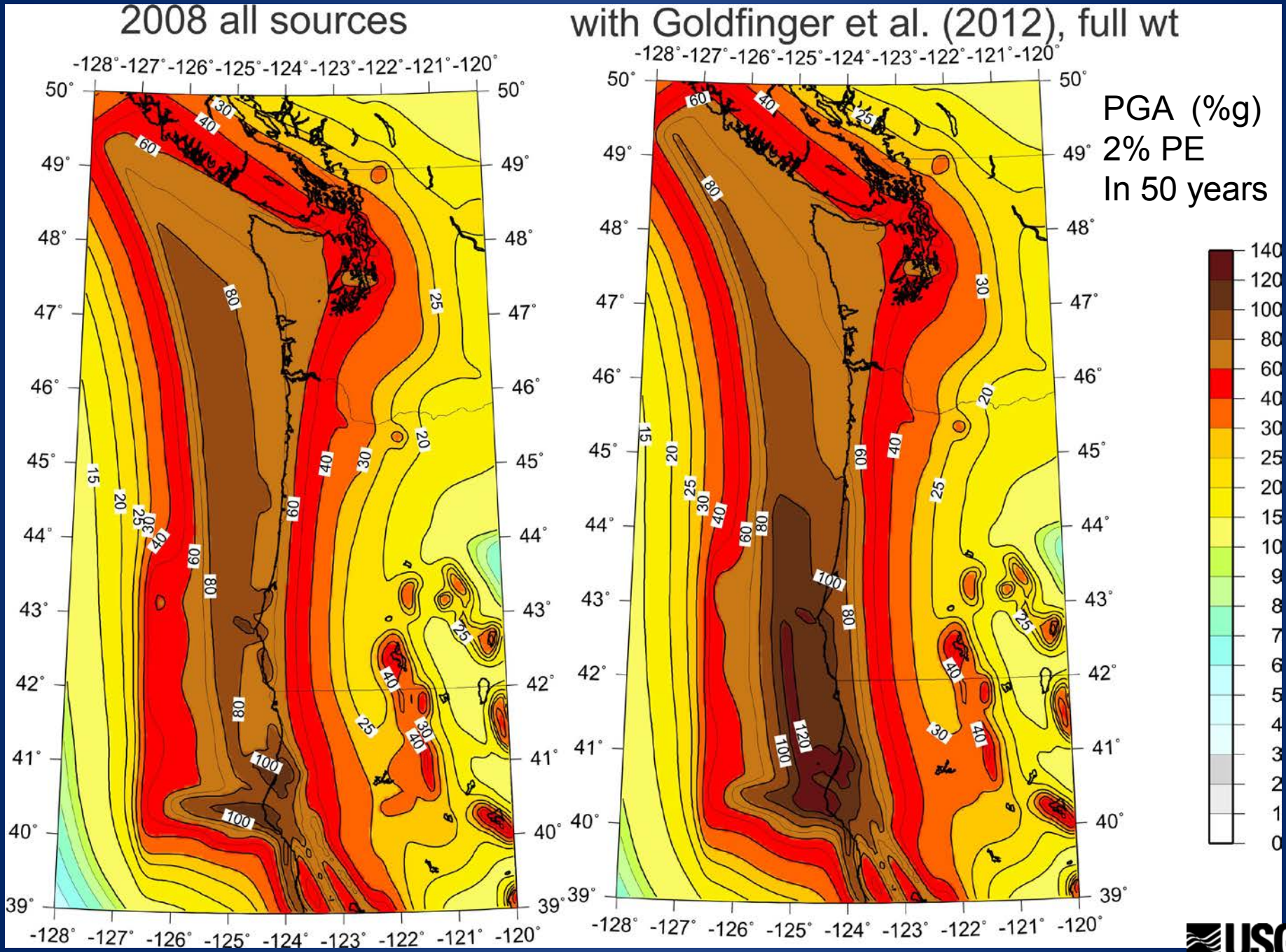


Figure from Goldfinger et al. (2012); great earthquake ruptures inferred from turbidites over past 10,000 years

We convened workshop at Oregon State University on Nov 18-19, 2010 to evaluate turbidite data for constraining recurrence models for CSZ

See Frankel (2011) USGS Open-File Report 2011-1310 for summary


2008 all sources
with Goldfinger et al. (2012), full wt
PGA (%g)
2% PE
In 50 years
-128° -127° -126° -125° -124° -123° -122° -121° -120°
50° 49° 48° 47° 46° 45° 44° 43° 42° 41° 40° 39°
140 120 100 80 60 40 30 25 20 15 10 9 8 7 6 5 4 3 2 1 0
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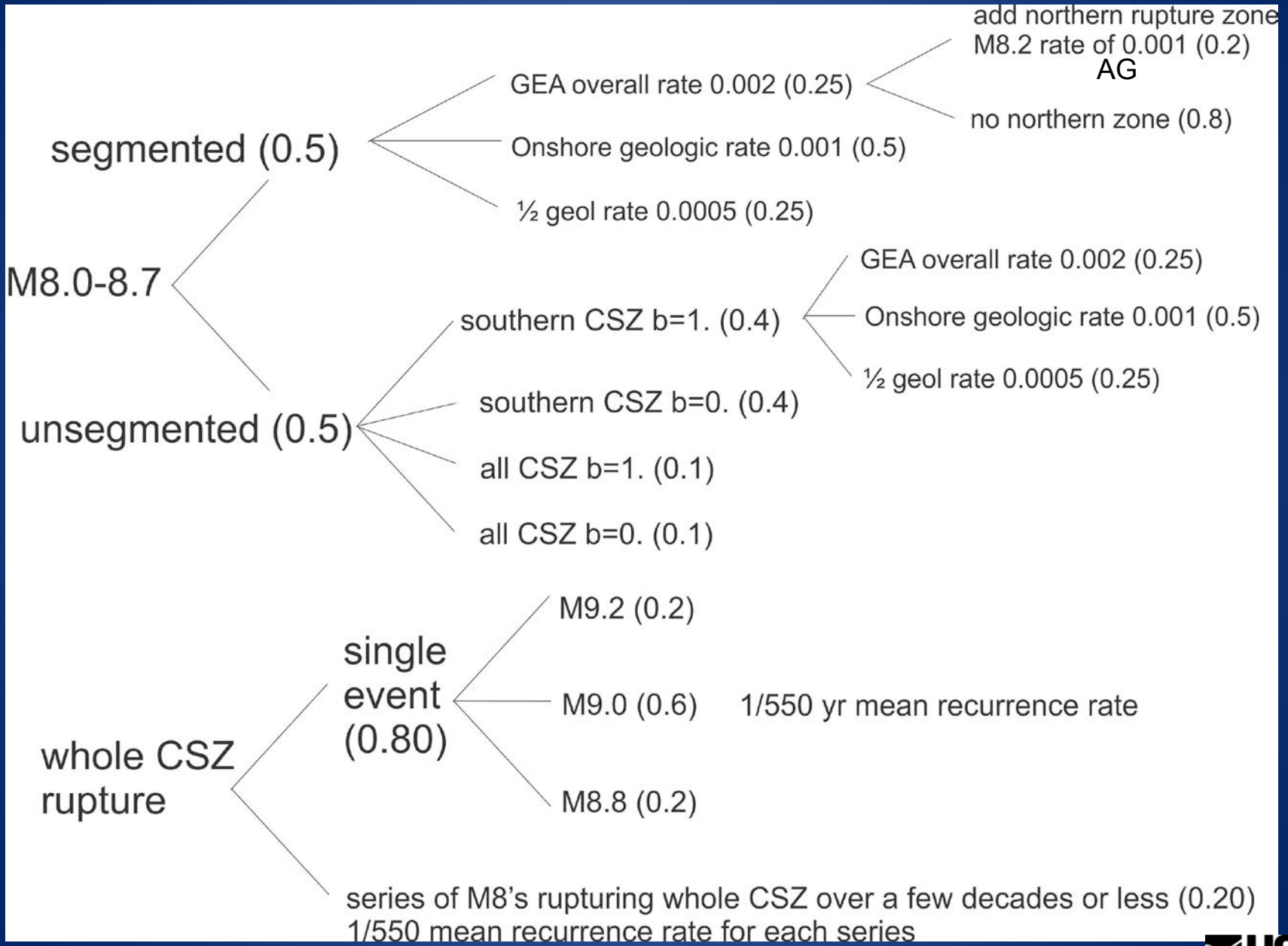
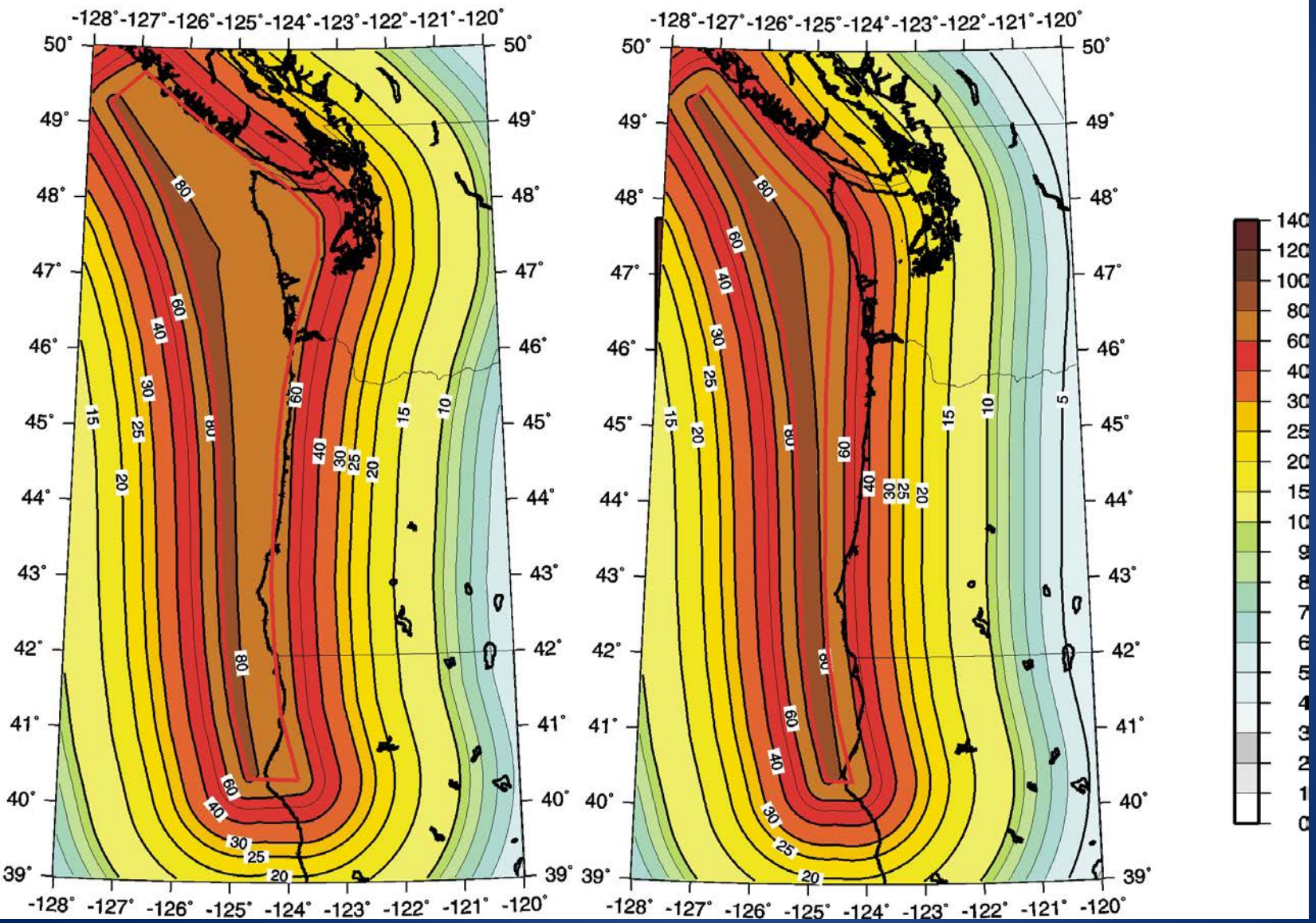
Proposed Logic Tree for CSZ great earthquake recurrence; weights in parentheses

GEA = Goldfinger et al. (2012) AG= Atwater and Griggs (2012)



Peak Ground Acceleration (%g) for 2% Probability of Exceedance in 50 Years



Ground-motion Prediction Equations use nearest distance of rupture to site

What coseismic slip does this correspond to?

1m or 2m?

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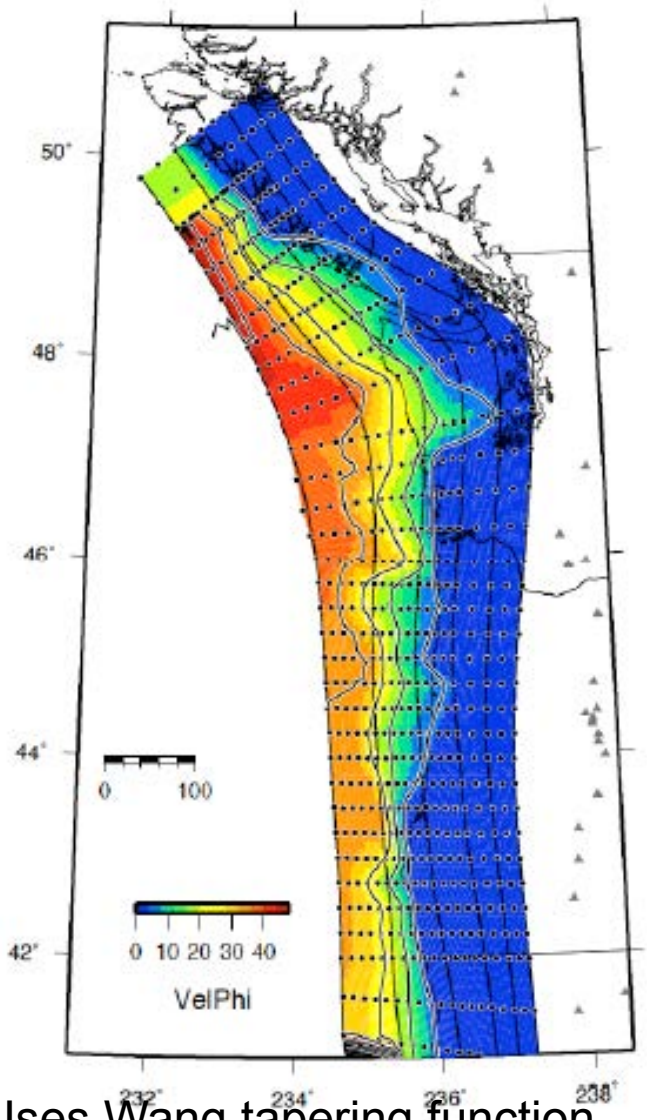
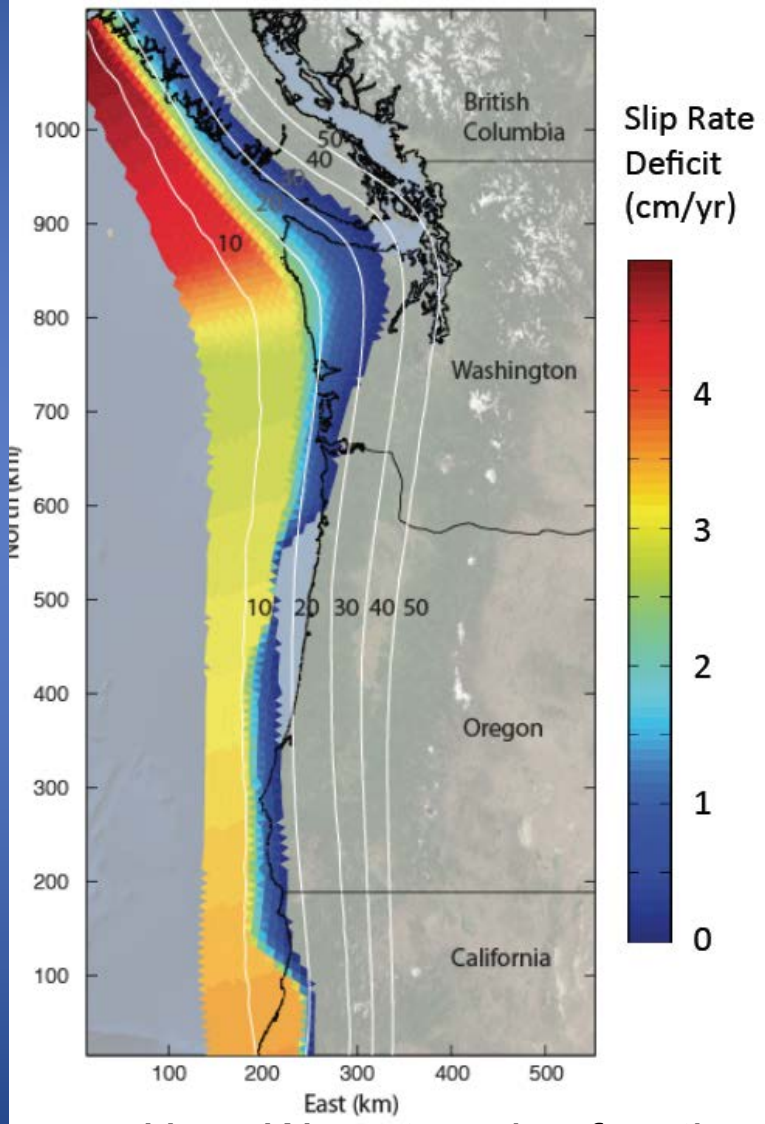
December 2011 workshop participants gave high weight to studies using GPS and uplift data to constrain down-dip edge of rupture

McCaffrey and King (2011)



Uses Wang tapering function

Schmidt et al. (2011)



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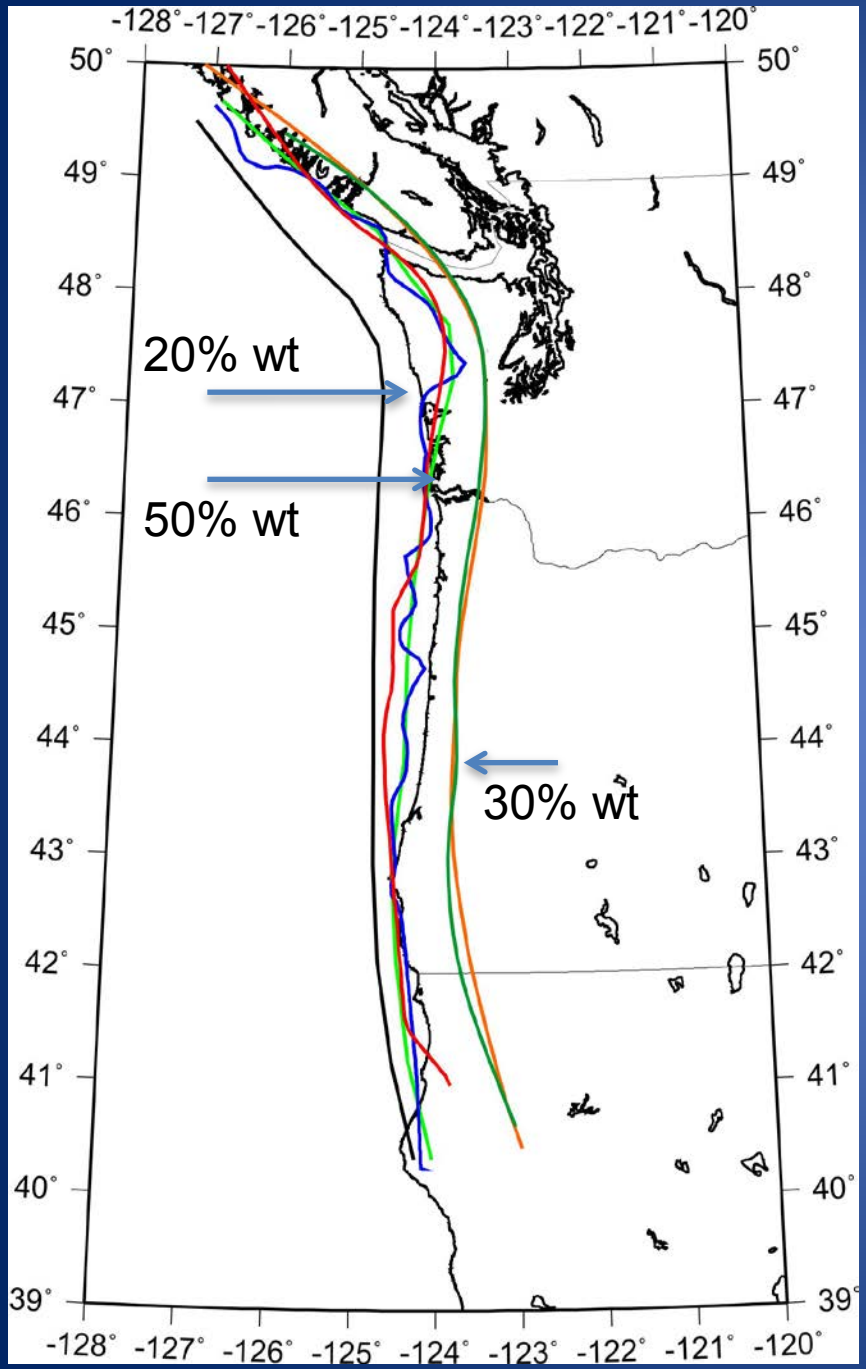

Trial logic tree for down-dip edge of rupture

Light Green: average of McCaffrey and King (blue) and Schmidt et al. (red) contour for 1cm/yr locking; 50% wt

30% wt: Use average of:
Dark Green: Top of tremor from Gomberg et al. (2010)
Orange: Top of tremor from A. Wech (provided by McCrory and Blair)

Black: base of locked zone from Flück, Hyndman, and Wang (1997)
Assign 20% weight to midpoint with 1 cm/yr locking contour

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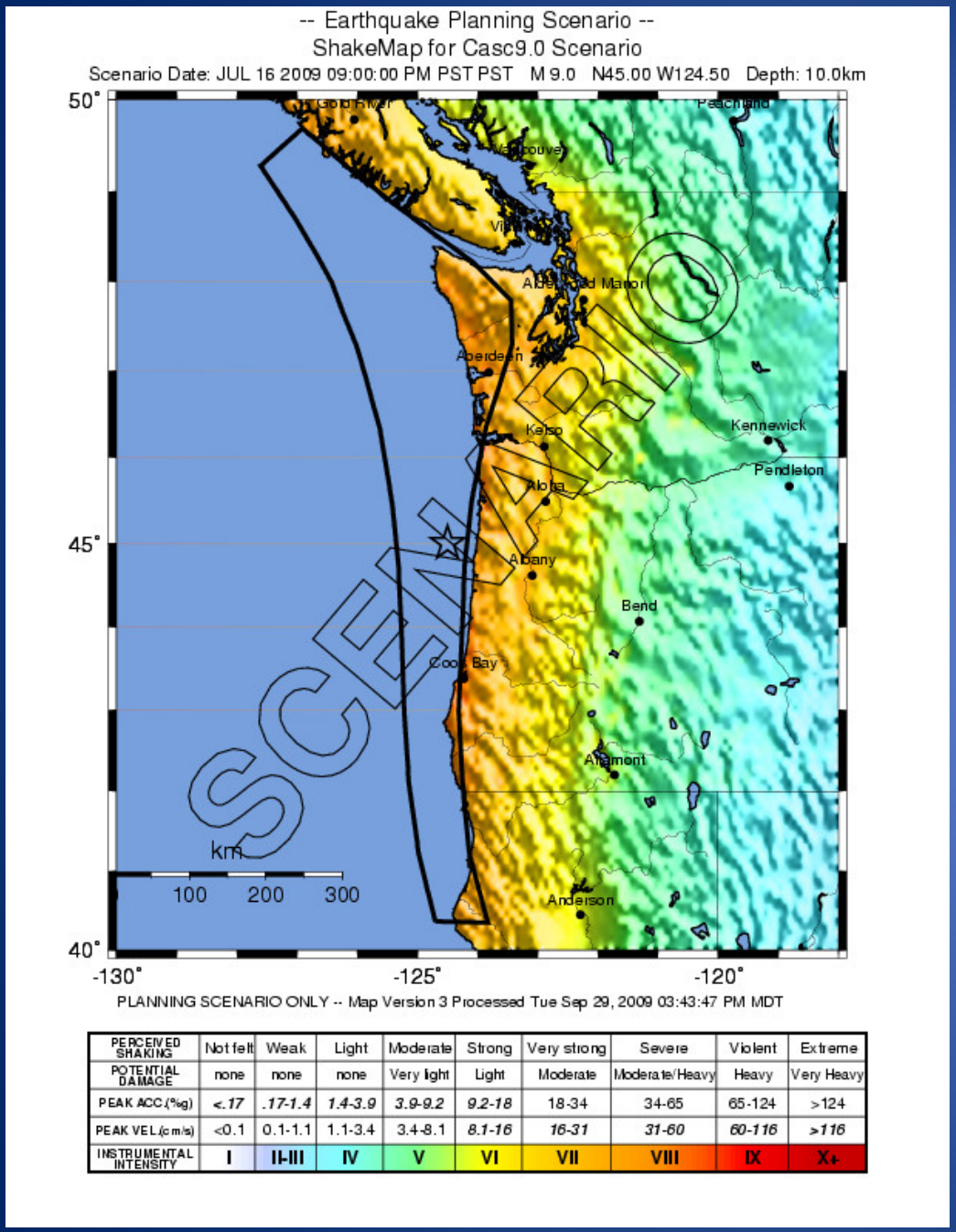
Estimating Ground Motions from Great Earthquakes on the Cascadia Subduction Zone Earthquakes:

Source and path issues



PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	*<.17*	*.17-1.4*	*1.4-3.9*	*3.9-9.2*	*9.2-18*	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	*8.1-16*	*16-31*	*31-60*	*60-116*	*>116*
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Scenario ground motions for M9.0 earthquake based on ground-motion prediction equations of Zhao et al. (2006), Atkinson and Boore (2003), and Youngs et al. (1997), based on strong-motion recordings from various subduction zones.

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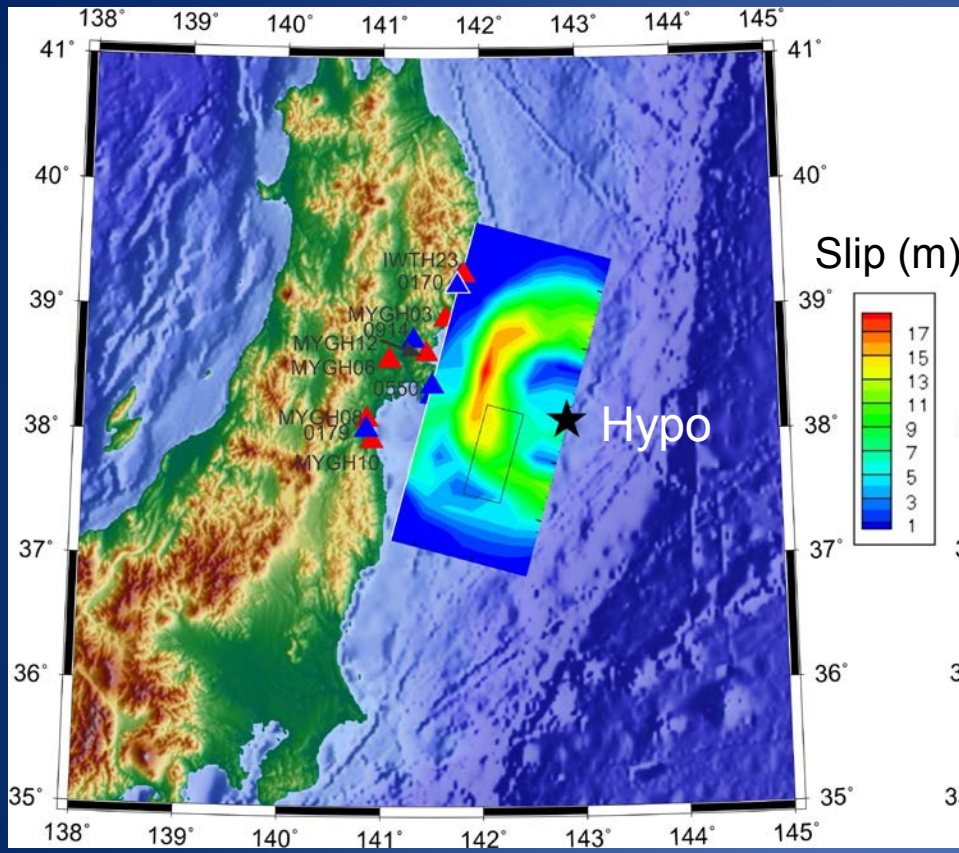
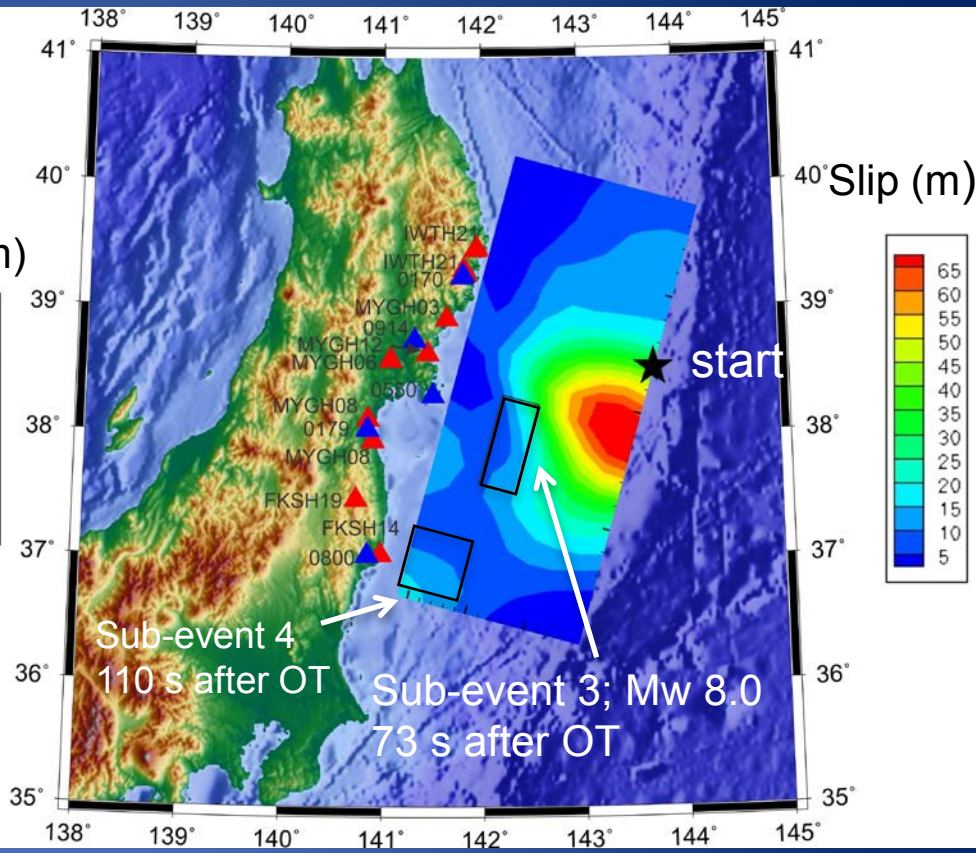
Tohoku earthquake: Results of inversions of velocity waveforms from strong-motion records (0-0.2 Hz) and 1 sps GPS displacement waveforms (Frankel, in review)

Sub-event 1; Mw 8.5

Sub-event 2; Mw 9.05, starts 35 s later





Sub-event 1 ruptures downdip and to north; generates low (< 0.2 Hz) and high frequency ground motions

As sub-event 2 ruptures down dip and to south, high-frequency sub-events 3 and 4 occur (d=40 km). Sub-event 2 only generates low frequencies (< 0.2 Hz) at shallow depths (< 30 km), has rise time of slip of about 40 sec.

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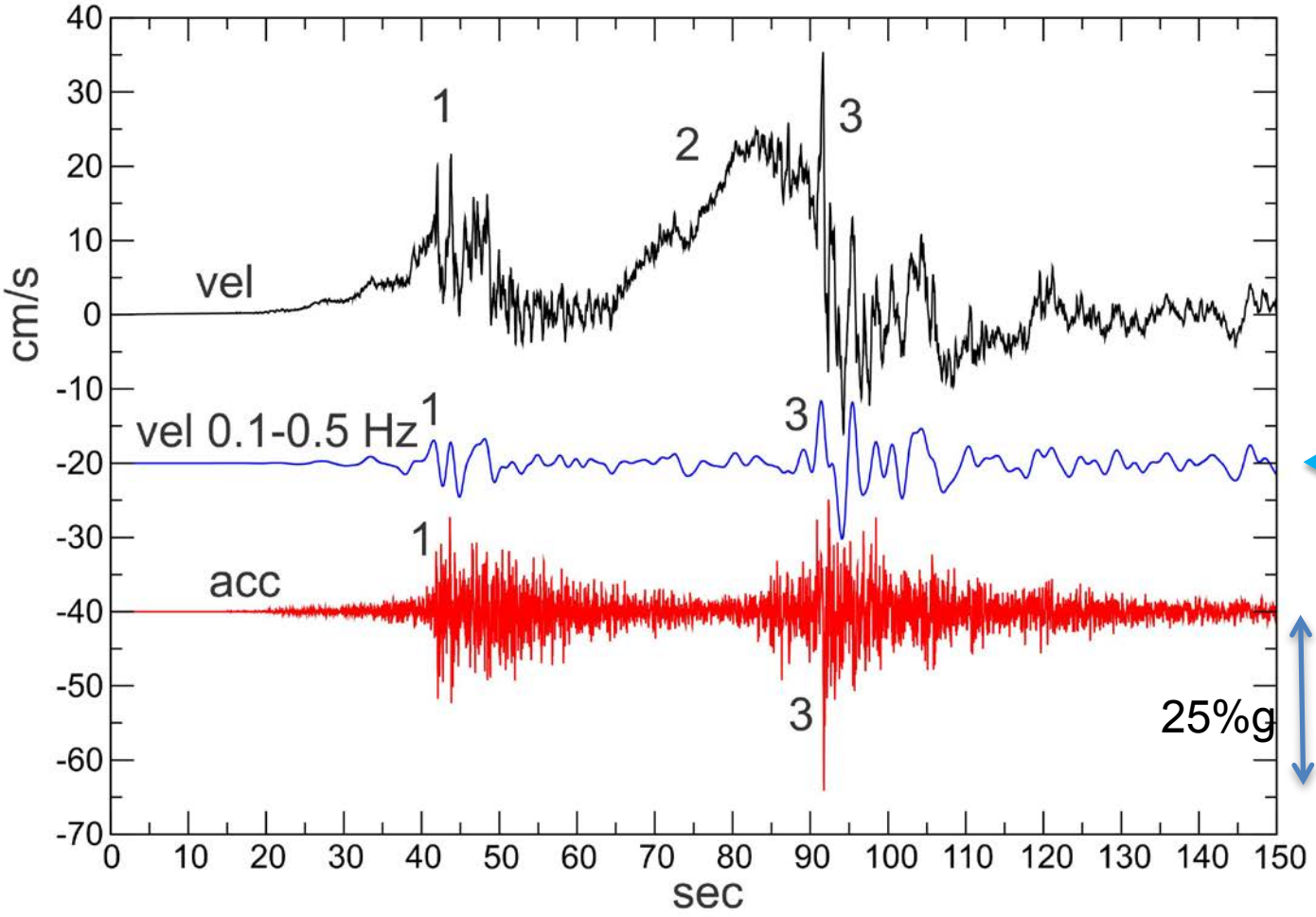
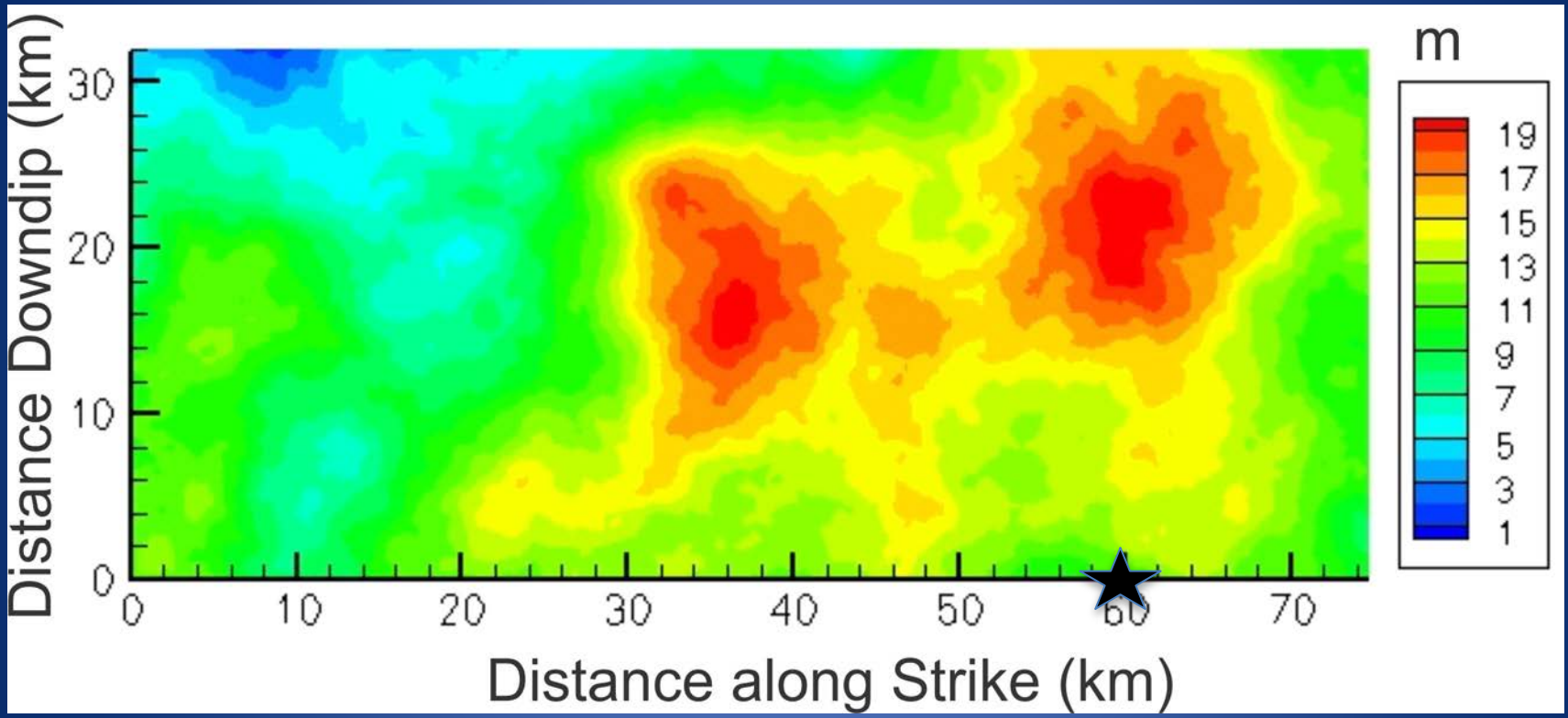
MYGH12 EW

From borehole accel.recording



Buildings 20-100 stories are most affected by motions at these frequencies

Slip used to model sub-event 3 using synthetics from a plane-layered velocity model
Mw 8.0, slip velocity 15 m/s, ave Vr= 3.0 km/s



Compare the 15 m/s slip velocity to the 2.7 m/s slip velocity used for modeling crustal earthquakes and NGA (Frankel, 2009; 100 bars). Implies stress drop for sub-event 3 is about 560 bars

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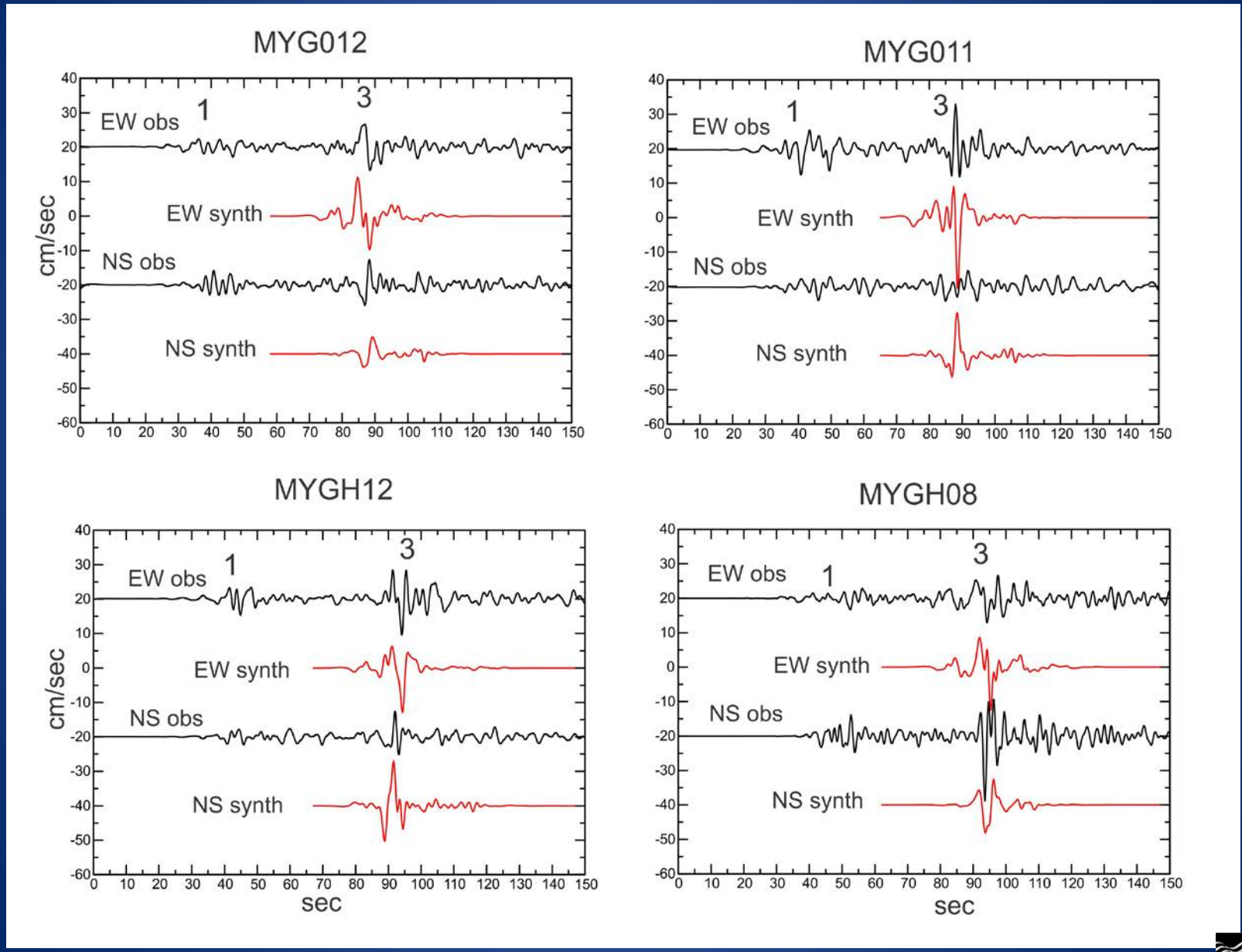
Observed and synthetic seismograms for sub-event 3 filtered at 0.1-0.5 Hz (surface recordings). Synthetics based on Mw 8.0; stress drop of 560 bars, source dimension of 75 km x 30 km, ave. depth 45 km.



From Wu et al. 2008 JGR: 1978 (M7.4) and 2005 (M7.3) Myagi-Oki earthquakes

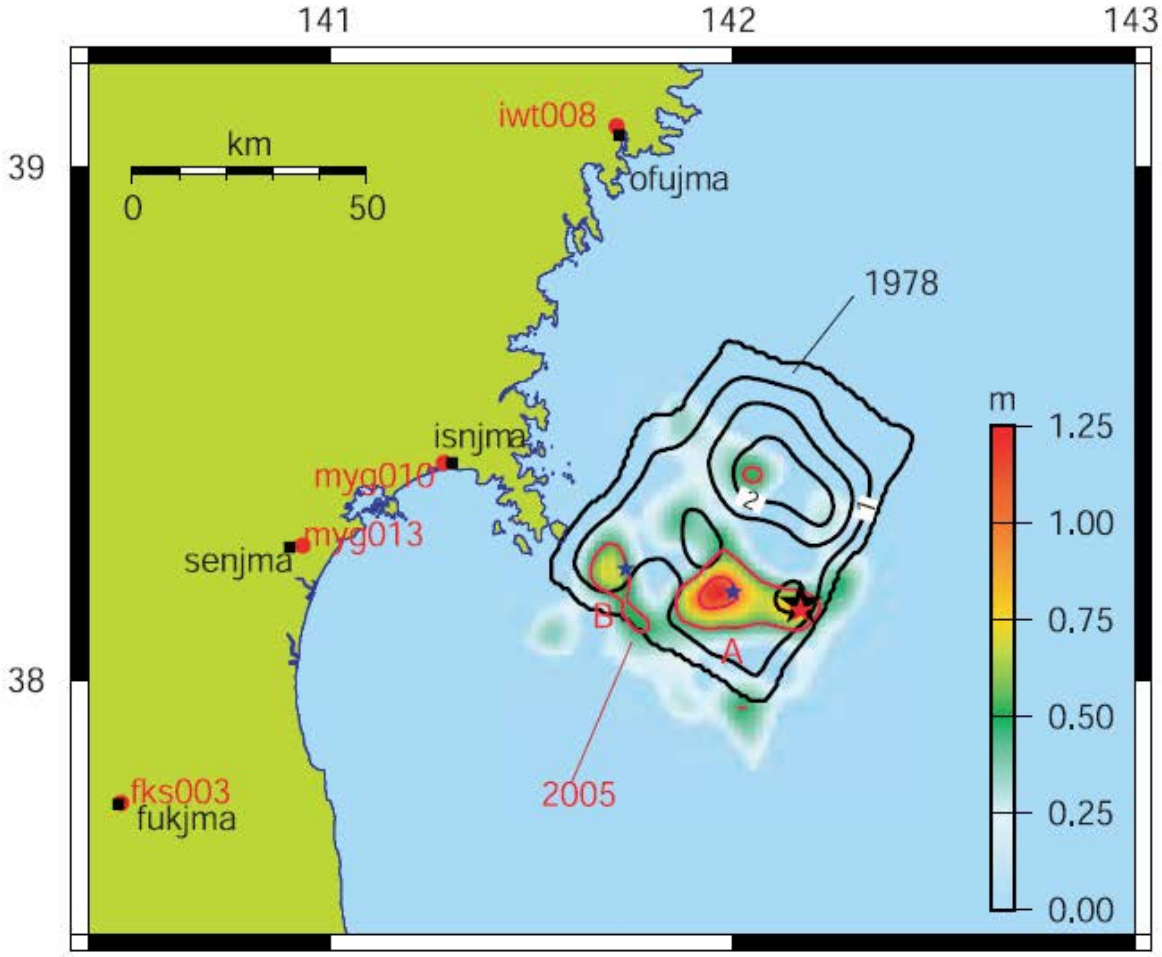
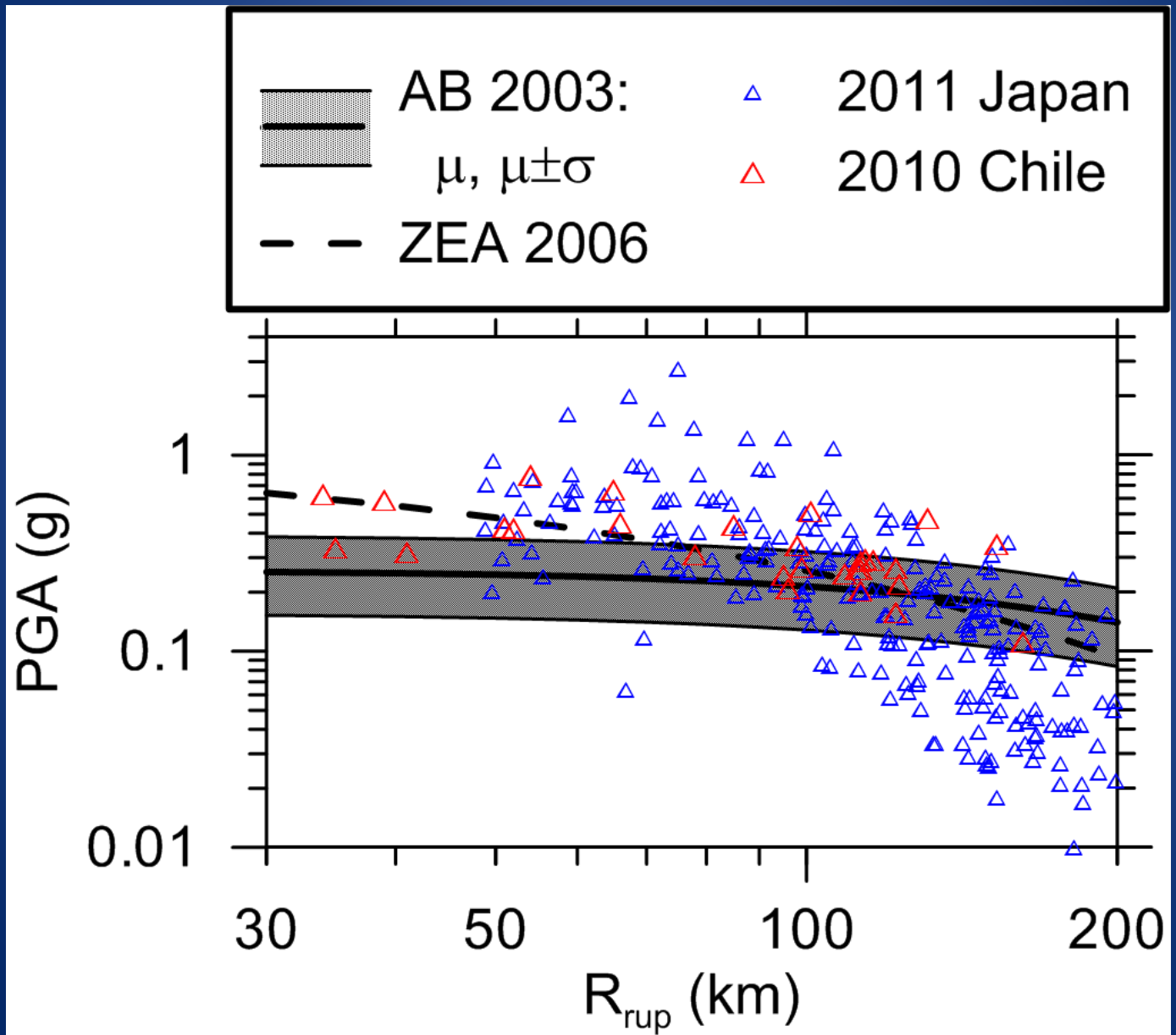


Figure 5. Slip distributions of the Miyagi-oki earthquakes. The black contour lines and color contours represent the slip distributions of the 1978 and 2005 events, respectively. The epicenters of the two events are marked by black (1978) and red (2005) stars, respectively; note that because of the similar locations of the two epicenters, the black star is almost completely obscured by the red one. The seismograms in Figure 3 were observed at the four pairs of stations shown on the map (black squares for the 1978 event and red circles for the 2005 event).

Slide from Jonathan Stewart

Distance Scaling



From Phillips et al. (in press), Q tomography based on recordings of earthquakes from Earthscope Transportable Array

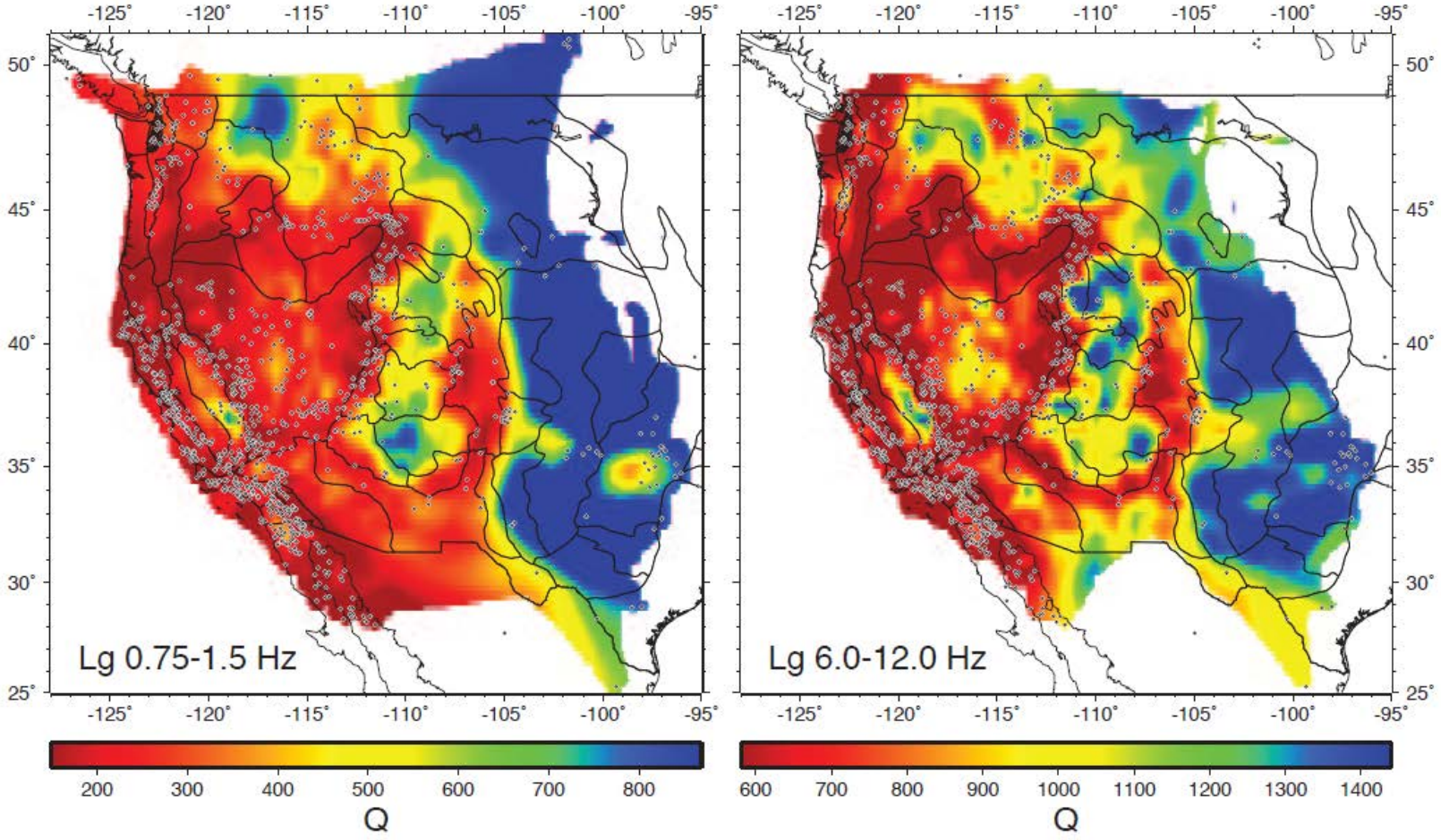


Figure 6. Q for two frequency bands. Results for the 0.75-1.5 Hz band are shown on the left and for the 6-12 Hz band on the right. Color bars differ, we see roughly twice the Q variation at low

Some Research Priorities for Improved Seismic Hazard Assessment for the CSZ

- Confirm that mud-silt turbidites are caused by shaking from M8 earthquakes in southern CSZ
- More onshore studies of tsunami deposits, liquefaction and coastal subsidence to identify M8 quakes, including studies of lake deposits caused by shaking; also useful for constraining down-dip edge
- Paleoseismology on crustal faults: improve our fault inventory; determine earthquake chronologies and slip rates
- Use GPS to look at regional strain; reconcile with observed seismicity rates and fault slip rates
- Ocean-bottom transducers for GPS: better resolve coupling, identify asperities
- Any way to quantify hazard from deep earthquakes under Portland and SW Oregon?

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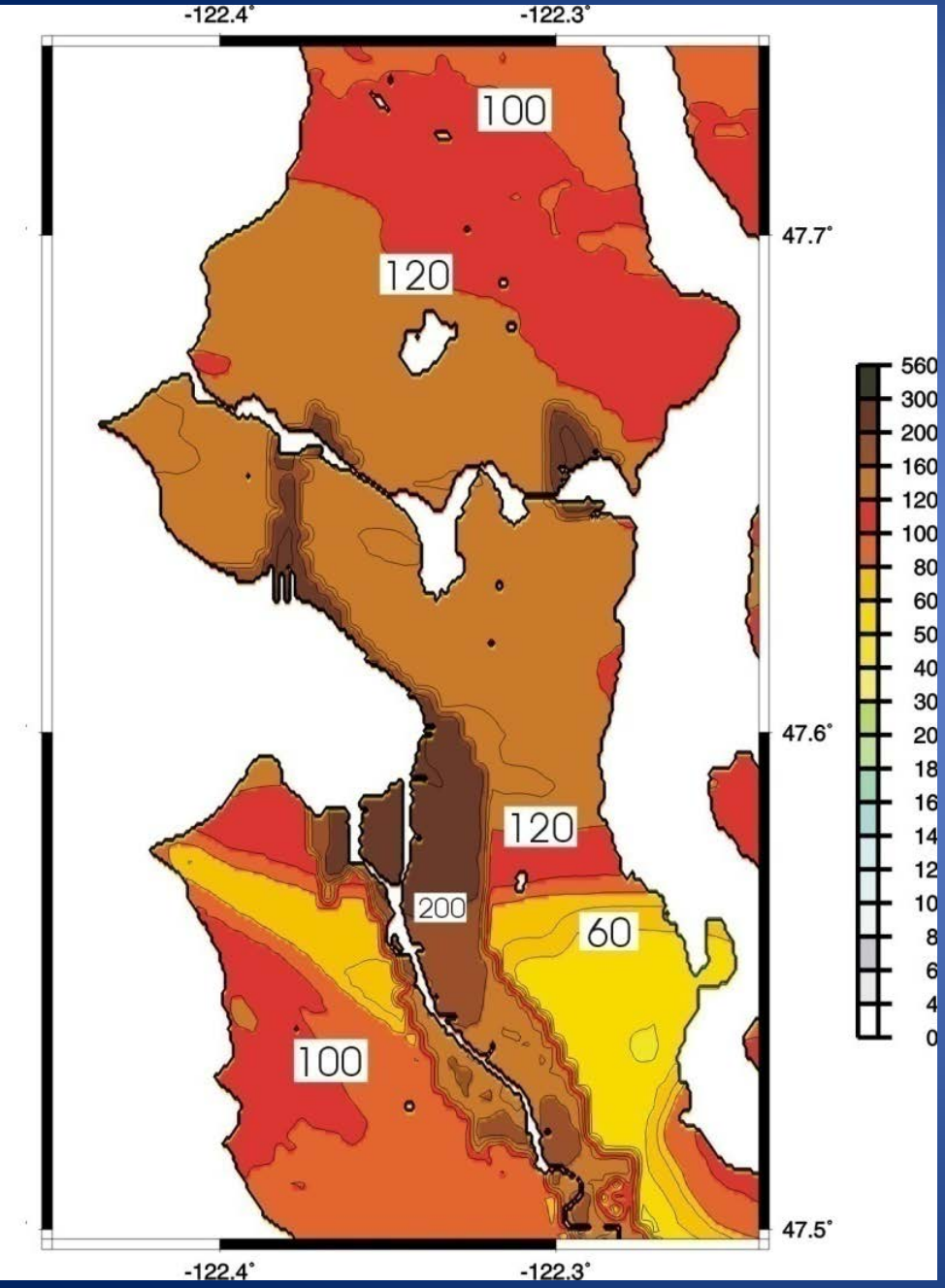
Research needed on ground motions from CSZ great earthquakes

- Improve 3D velocity and Q models needed for making accurate synthetics (especially S-waves and surface waves): top 60 km and especially top 2 km for sedimentary basins that urban areas are located on. More detailed Q tomography would be useful for comparing paths across Cascades and along forearc
- Better understand depth-dependence of high-frequency seismic-wave generation on the subduction interface; better understand scaling of rise times and asperity dimensions with magnitude
- Ultimate goals: Make broadband synthetic seismograms (0-20 Hz) for M8-9 Cascadia earthquakes, including rupture directivity, 3D basin effects, nonlinear site response; use directly in hazard maps

1 Hz S.A. (%g) with 2% Chance of Being Exceeded in 50 Years; this is the period that would most affect a 10 story building



Seattle urban
seismic hazard map
with soil conditions, basin effects,
and rupture directivity

Combines results of 3D ground-motion simulations of 541 scenarios
(Seattle fault,
Cascadia subduction zone, random shallow and deep earthquakes)

USGS Open-File Report
2007-1175

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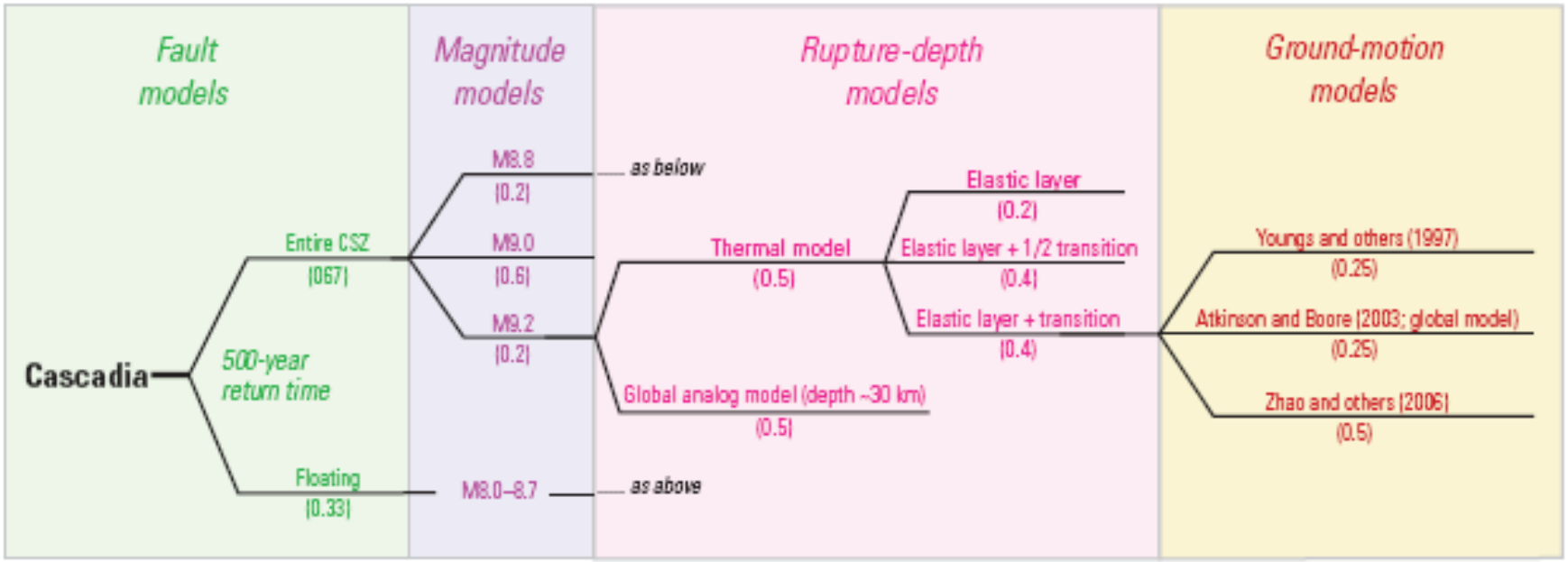

Figure 20. Logic tree for Cascadia subduction zone (CSZ). Parameters in this figure include some aleatory variability as well as depicted epistemic uncertainty. Additional aleatory variability shown in table K-1 in Appendix K.

From 2008 NSHM Documentation (Petersen et al., 2008)

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Ground-motion prediction equations for subduction-zone earthquakes use nearest distance between rupture surface and site

- Often based on inversion of strong-motion or teleseismic records
- Tohoku earthquake illustrates that high-frequency energy may be generated in areas closer to coast than areas of high slip
- What amount of slip correlates with “edge” of rupture for use in GMPE’s? 10% of peak slip?

Annual rate of exceeding ground motion u_0

$$= \sum_{M} \sum_{D}$$

Recurrence rate for magnitude M at distance D

X

Probability that earthquake with magnitude M at distance D will produce ground motion $\geq u_0$ at site

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