Workshop for the Update of the Pacific Northwest Portion of the National Seismic Hazard Maps

March 28-29, 2006

Art Frankel

USGS

From Science to Mitigation of Risk

Earth Science Information

Seismological: earthquake monitoring (catalogs), ground-motion studies (ANSS+ portable arrays)

Geological: paleoseismology (on-land, offshore), fault studies, geologic mapping

Geophysical: crustal deformation (GPS), seismic reflection and refraction, potential field studies, borehole studies

Quantitative Assessment Of Hazard

Probabilistic seismic hazard assessment: USGS national seismic hazard maps

Site-specific studies

Urban seismic hazard maps

Scenario ground motion maps

Mitigation of Earthquake Risk

Seismic provisions in building codes

Design standards for bridges

Land-use planning

Loss estimation

Earthquake insurance

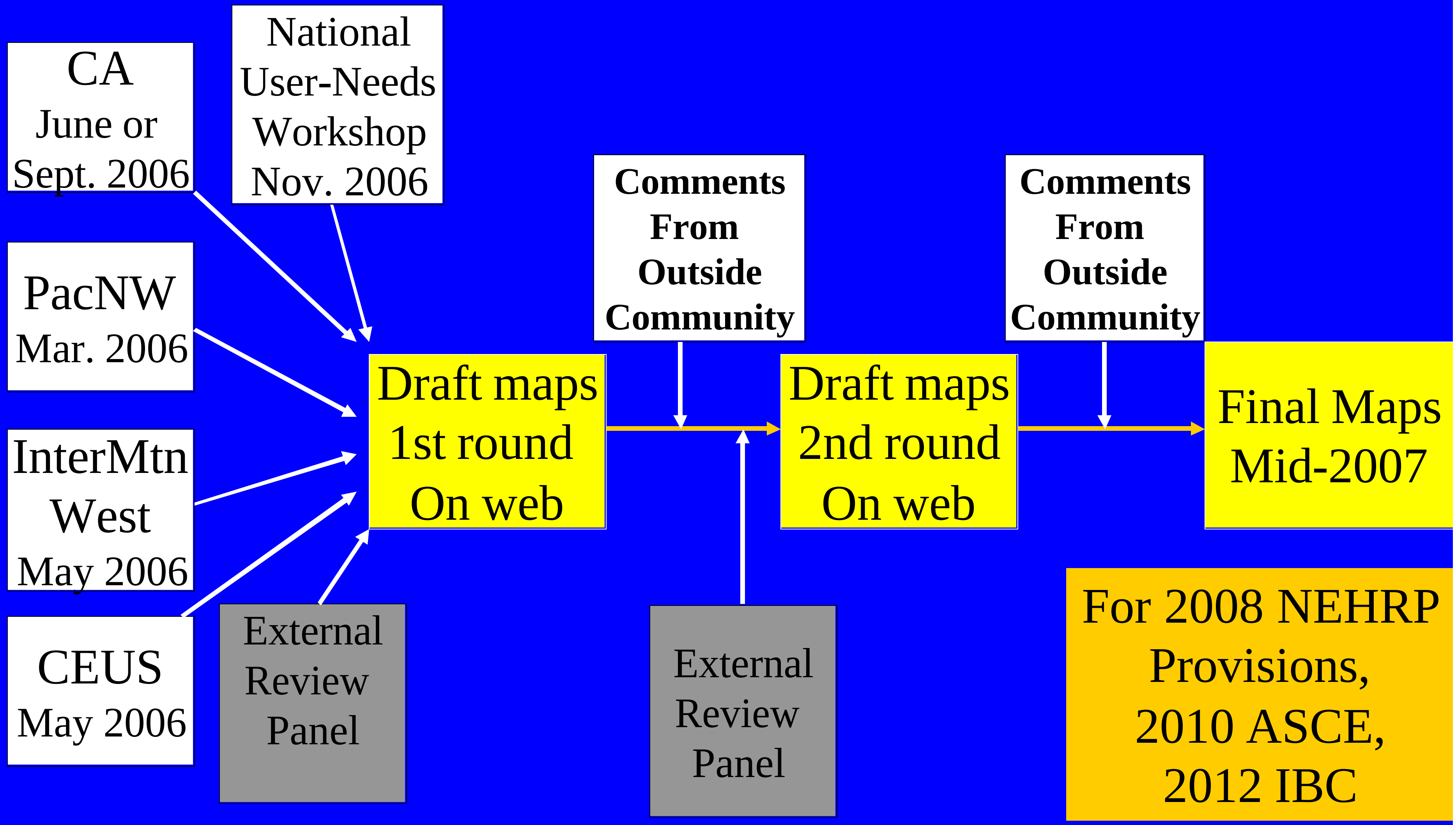
Emergency management

The national seismic hazard maps are the basis of seismic design maps in the International Building Code (used in 47 states) and International Residential Code (used in 45 states).

The maps have a variety of other applications, including:

- new AASHTO design guidelines for bridges
- EPA regulations on landfills
- Loss estimation using HAZUS
- Inputs used for determination of earthquake insurance premiums
- Inputs used for scenarios (e.g., emergency management)

Process for 2007 Maps



CA
June or
Sept. 2006

National
User-Needs
Workshop
Nov. 2006

PacNW
Mar. 2006

InterMtn
West
May 2006

CEUS
May 2006

External
Review
Panel

Draft maps
1st round
On web

**Comments
From
Outside
Community**

External
Review
Panel

Draft maps
2nd round
On web

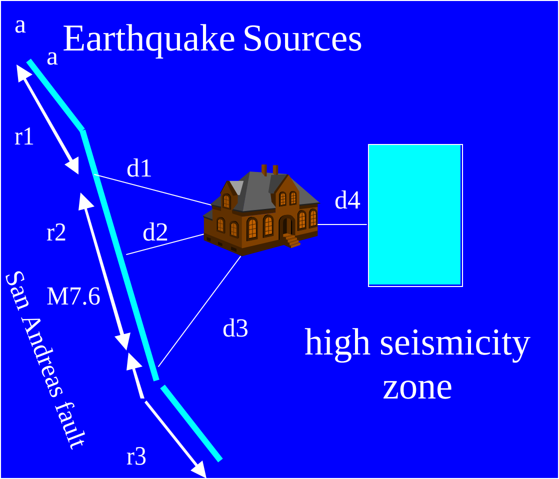
**Comments
From
Outside
Community**

Final Maps
Mid-2007

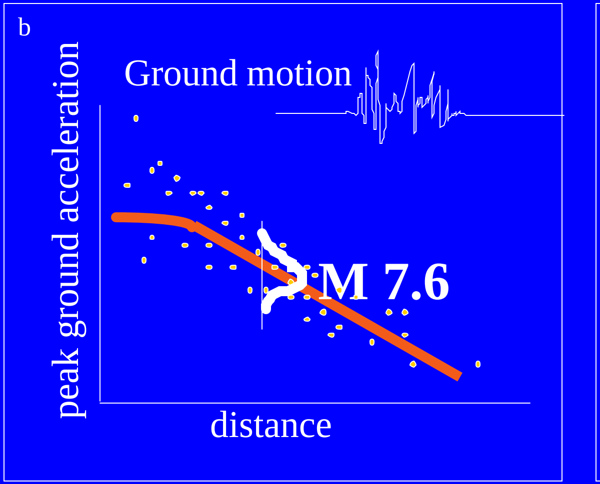
For 2008 NEHRP
Provisions,
2010 ASCE,
2012 IBC

eqhazmaps.usgs.gov

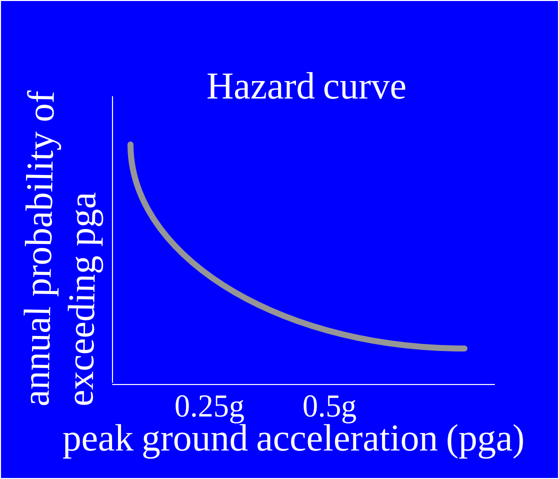
Hazard Methodology Example



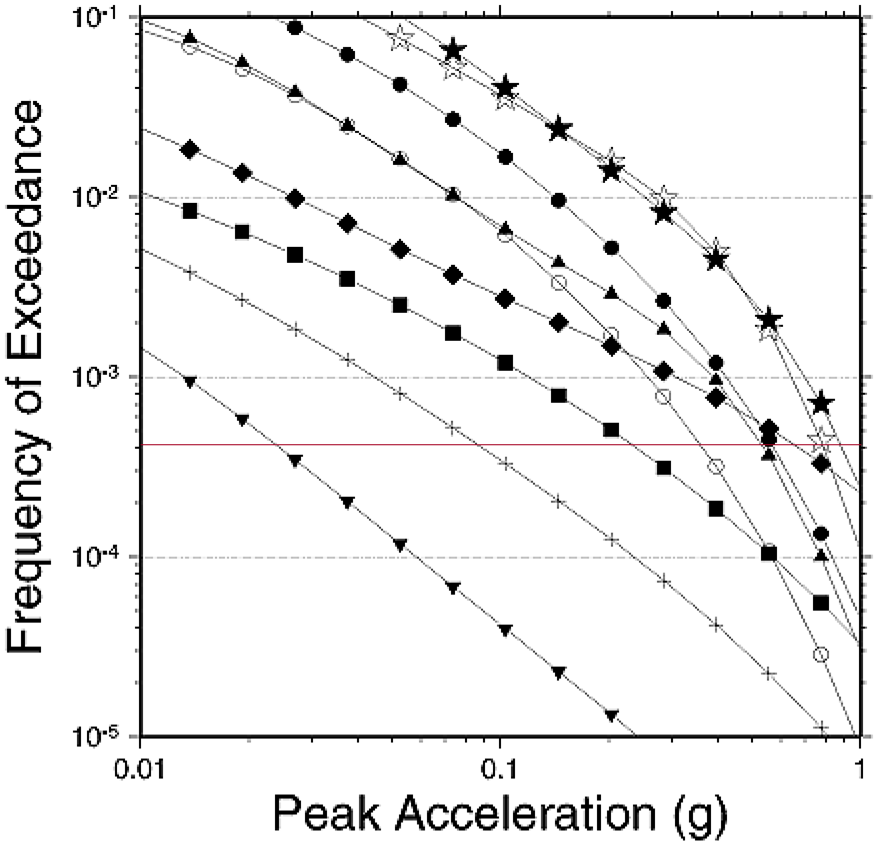
Specify recurrence rates of earthquakes for each source that can affect site of interest



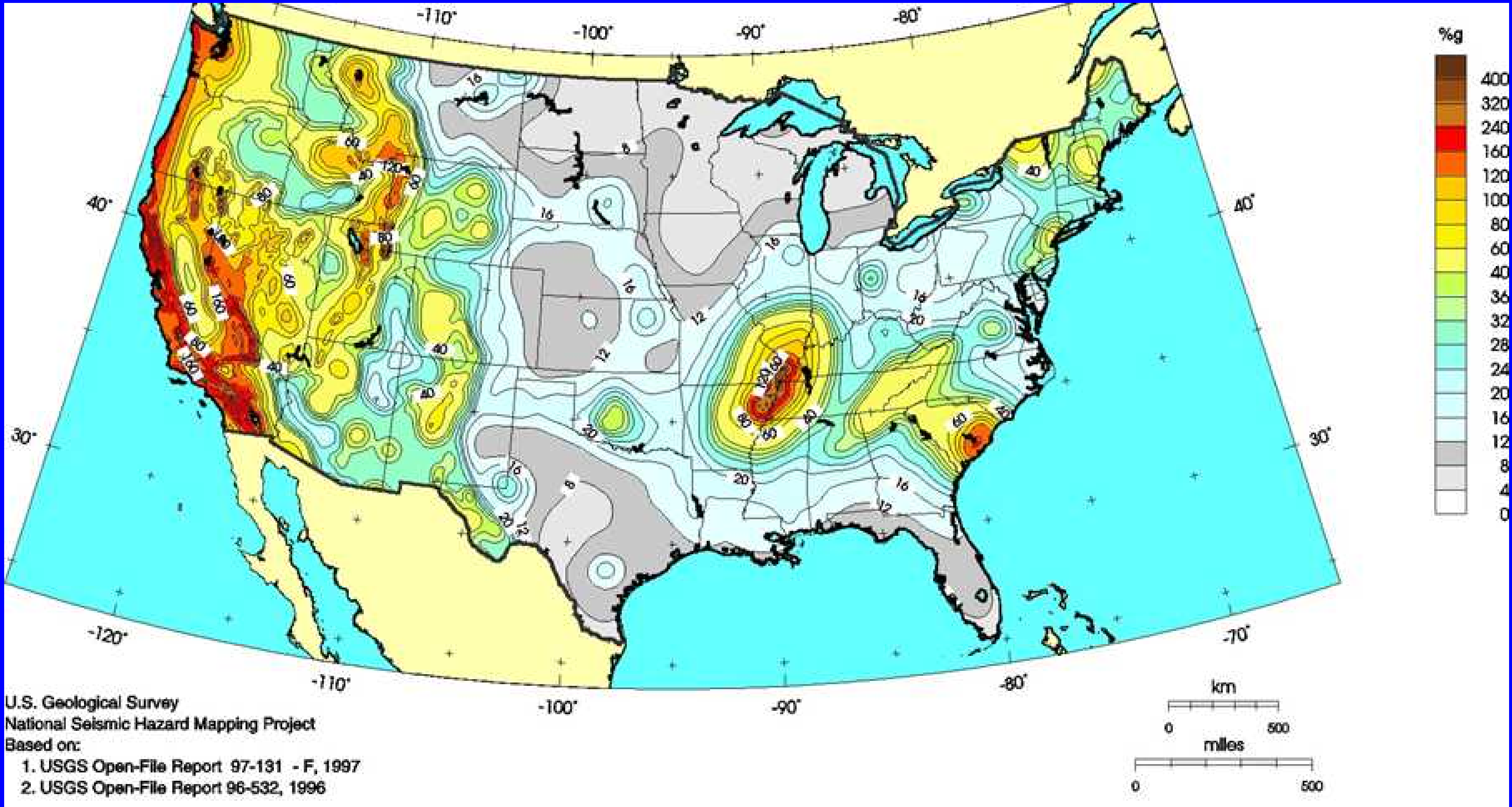
Attenuation relations tell you median ground motions that each potential earthquake will produce at site, and variability



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



Line shows 2% Prob. of Exceedance in 50 year; Approx. 2500 yr return time



U.S. Geological Survey
National Seismic Hazard Mapping Project
Based on:
1. USGS Open-File Report 97-131 - F, 1997
2. USGS Open-File Report 96-532, 1996

Horizontal Spectral Response Acceleration (%g) for 0.2 Sec Period (5% of Critical Damping)
With 2% Probability of Exceedance in 50 Years
Firm Rock - 760 m/sec shear wave velocity

This map is used in building codes in 45 states

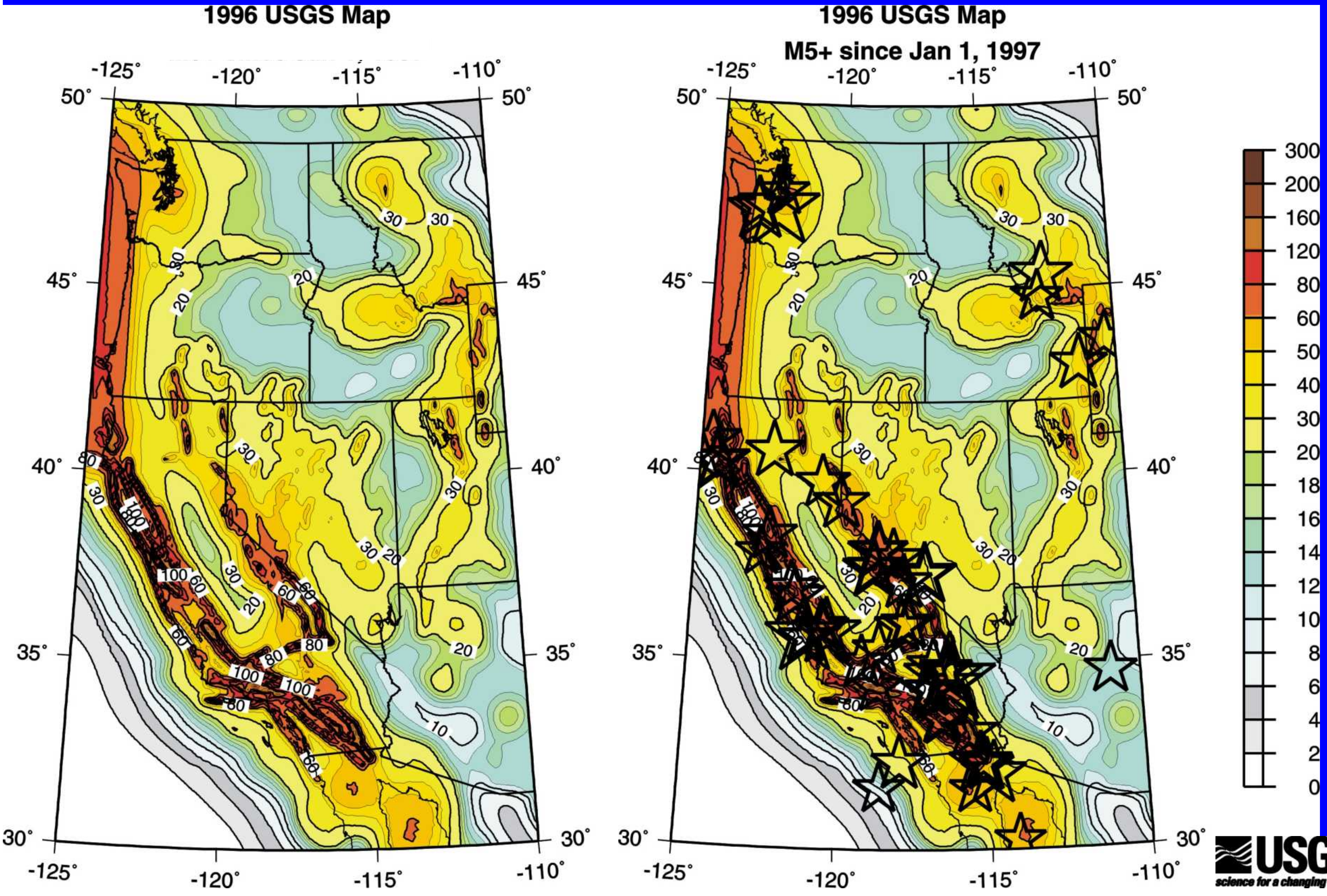
USGS
science for a changing world

- The national seismic hazard maps represent an average estimate of seismic hazard using alternative models of fault parameters, seismicity, and attenuation relations; they are not worst-case maps
- Website with hazard maps, lookup by lat-lon, input data, deaggregations, documentation: eqhazmaps.usgs.gov

USGS
science for a changing world

PGA (%g) with 2% PE in 50 yr

62 events



1996 USGS Map

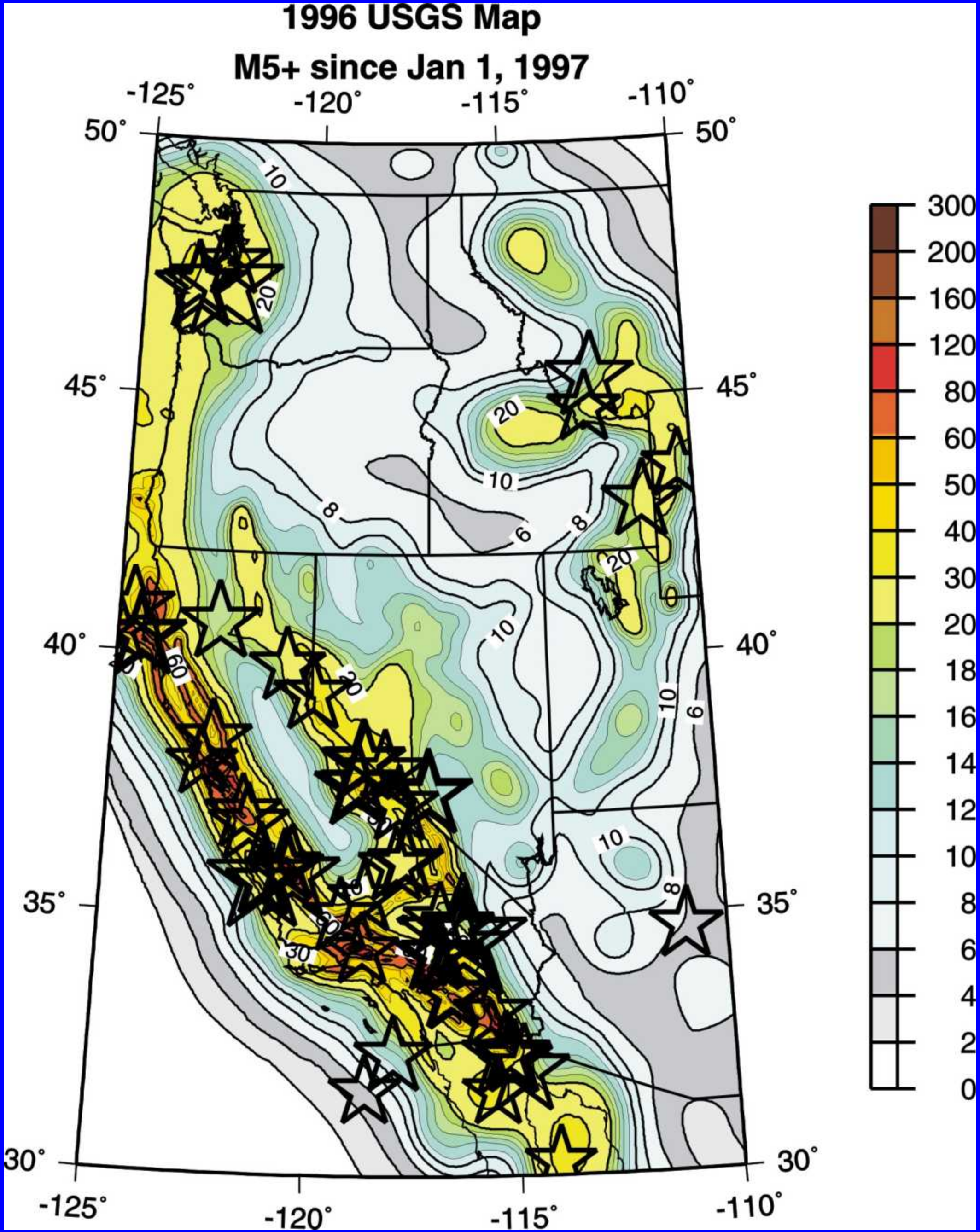
1996 USGS Map

M5+ since Jan 1, 1997

USGS

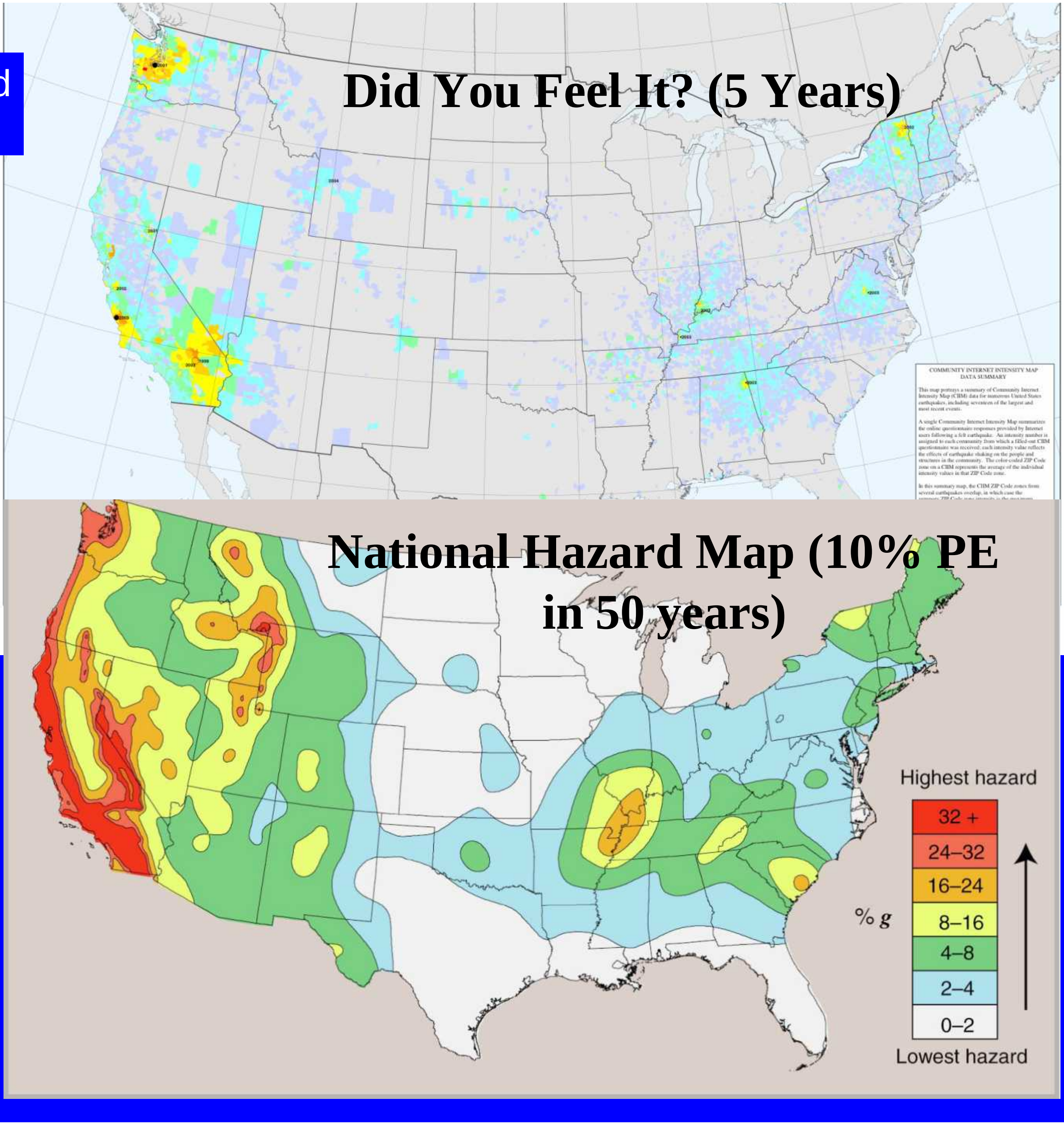
science for a changing world

PGA (%g)
With 10% PE
In 50 years



Slide composed by D. Wald

yellow=
MMI 6



Did You Feel It? (5 Years)

COMMUNITY INTERNET INTENSITY MAP
DATA SUMMARY

This map portrays a summary of Community Internet Intensity Map (CIIM) data for numerous United States earthquakes, including seventeen of the largest and most recent events.

A single Community Internet Intensity Map summarizes the online questionnaire responses provided by Internet users following a felt earthquake. An intensity number is assigned to each community from which a filled-out CIIM questionnaire was received; each intensity value reflects the effects of earthquake shaking on the people and structures in the community. The color-coded ZIP Code zone on a CIIM represents the average of the individual intensity values in that ZIP Code zone.

In this summary map, the CIIM ZIP Code zones from several earthquakes overlap, in which case the

National Hazard Map (10% PE in 50 years)

Direct Inputs to Hazard Maps

- Earthquake catalogs (instrumental and historic)
- Fault data (geologic slip rates, dates of past events from trenching, fault geometry, etc.)
- Effects of prehistoric earthquakes: paleoliquefaction (New Madrid, Charleston, Wabash Valley), subsidence and uplift (Cascadia, Seattle flt), turbidites (Cascadia)
- Geodetic data (NV-CA, Puget Lowland)
- Ground-motion attenuation relations

Components of Seismic Hazard Maps for Pacific Northwest

5.0<=M<=7.0

Spatially-smoothed shallow seismicity (h<35 km)
- M4+ since 1963
- M5+ since 1930
- M6+ since 1850

Spatially-smoothed deeper seismicity (h>= 35 km)
- M4+ since 1963
- M5+ since 1940

Background source zones in eastern WA and OR

Puget Lowland areal zone seismicity rate from rate of M>=5.0 since 1928; Mmax 7.3 [also from GPS]

M>=6.0

Crustal faults:
0.5 wt characteristic
0.5 wt truncated Gutenberg-Richter with Mmin=6.5

For 6.0 <= M <=6.5
full weight characteristic

Cascadia subduction zone:
0.5 wt M8.3 eqs fill zone every 500 years
0.5 wt M9.0 eq every 500 years

Mmax for gridded seismicity adjusted so there is no overlap with faults

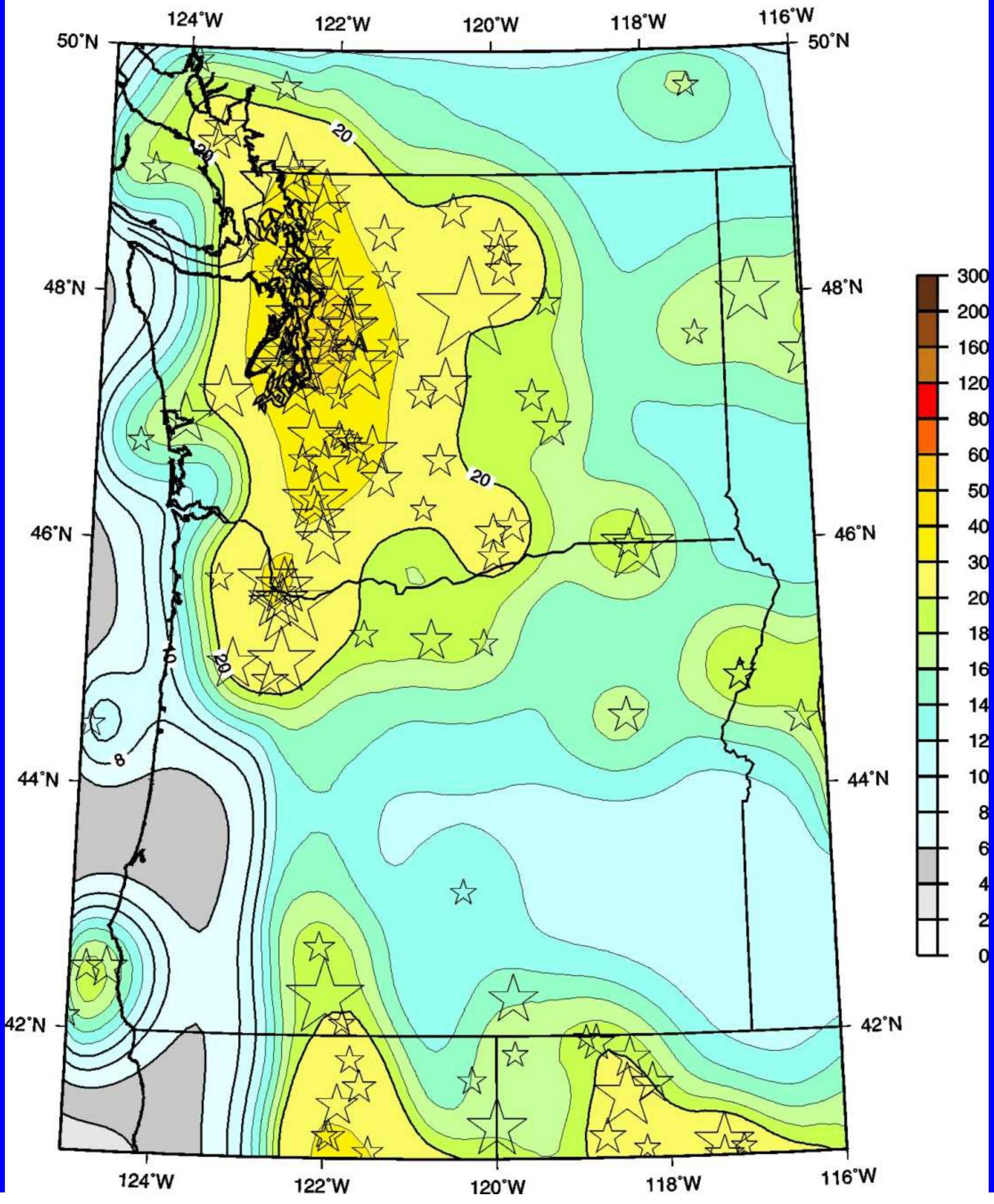
Some issues for workshop

- What faults should be added to the maps? Need info on slip rate or earthquake recurrence rate
- What changes should be made for faults already in maps?
- Should the treatment of GPS results be changed?
- What changes should be made in the frequency-magnitude distribution and rupture geometry for great Cascadia subduction zone (CSZ) earthquakes?
- How do we develop time-dependent models for CSZ? Also needed for California Earthquake Authority effort (USGS-SCEC)
- Should changes be made in treatment of deep, intraslab earthquakes?
- What new ground-motion attenuation relations should be used in the maps, such as the Next-Generation of Attenuation (NGA) relations being developed for PEER and new subduction-zone relations?
- Quantifying Uncertainties
- Discussion of engineering issues

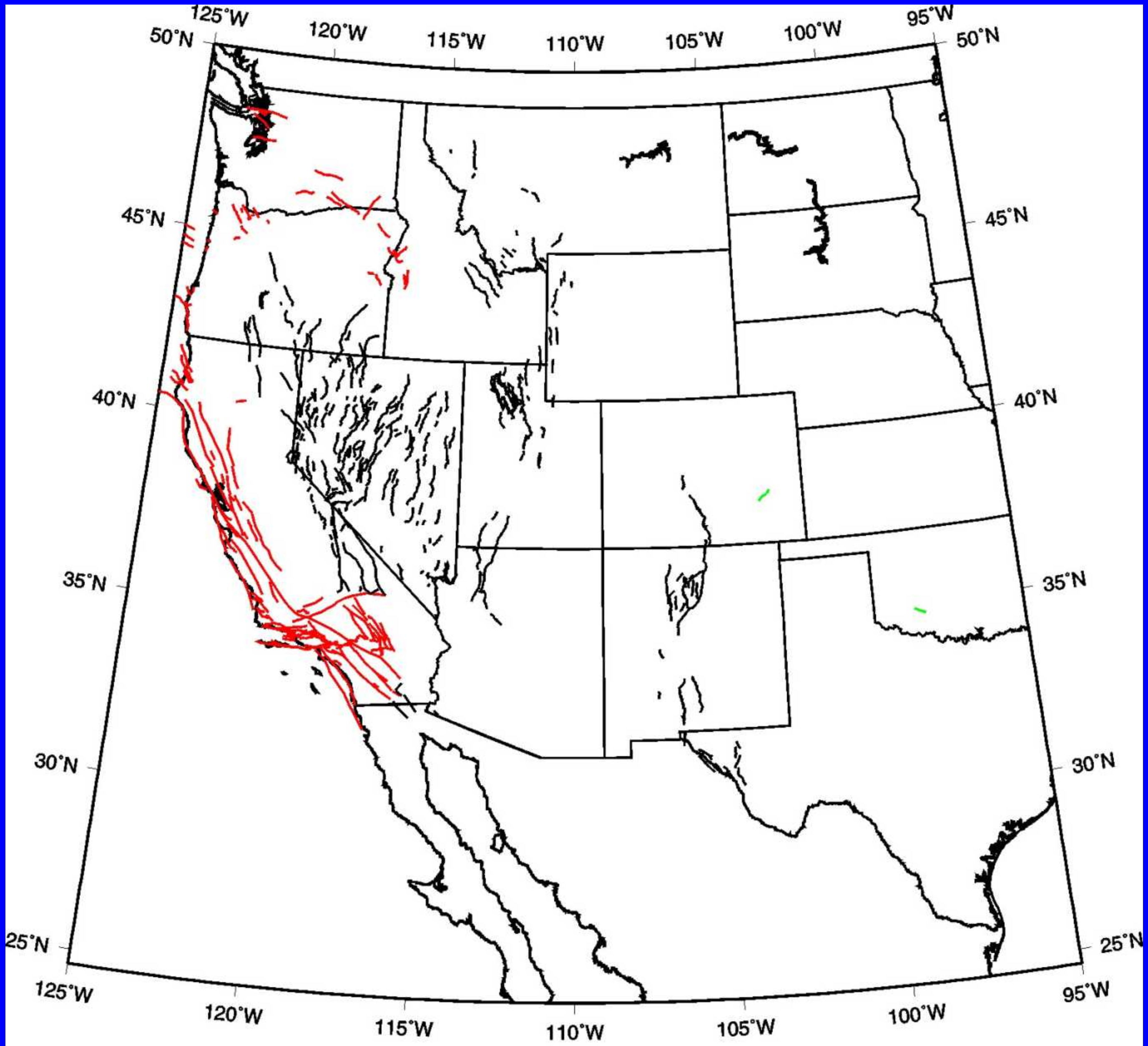
Working Group on Washington-Oregon Faults for the National Seismic Hazard Maps

- Provide recommendations to NSHMP about faults to add to the hazard maps, parameters to use for the added faults, and fault parameters to revise.
- Ian Madin, Mark Molinari, Brian Sherrod, Tim Walsh

Peak Accel. (%g) with 2% Probability of Exceedance in 50 Years
shallow seismicity and background zones only



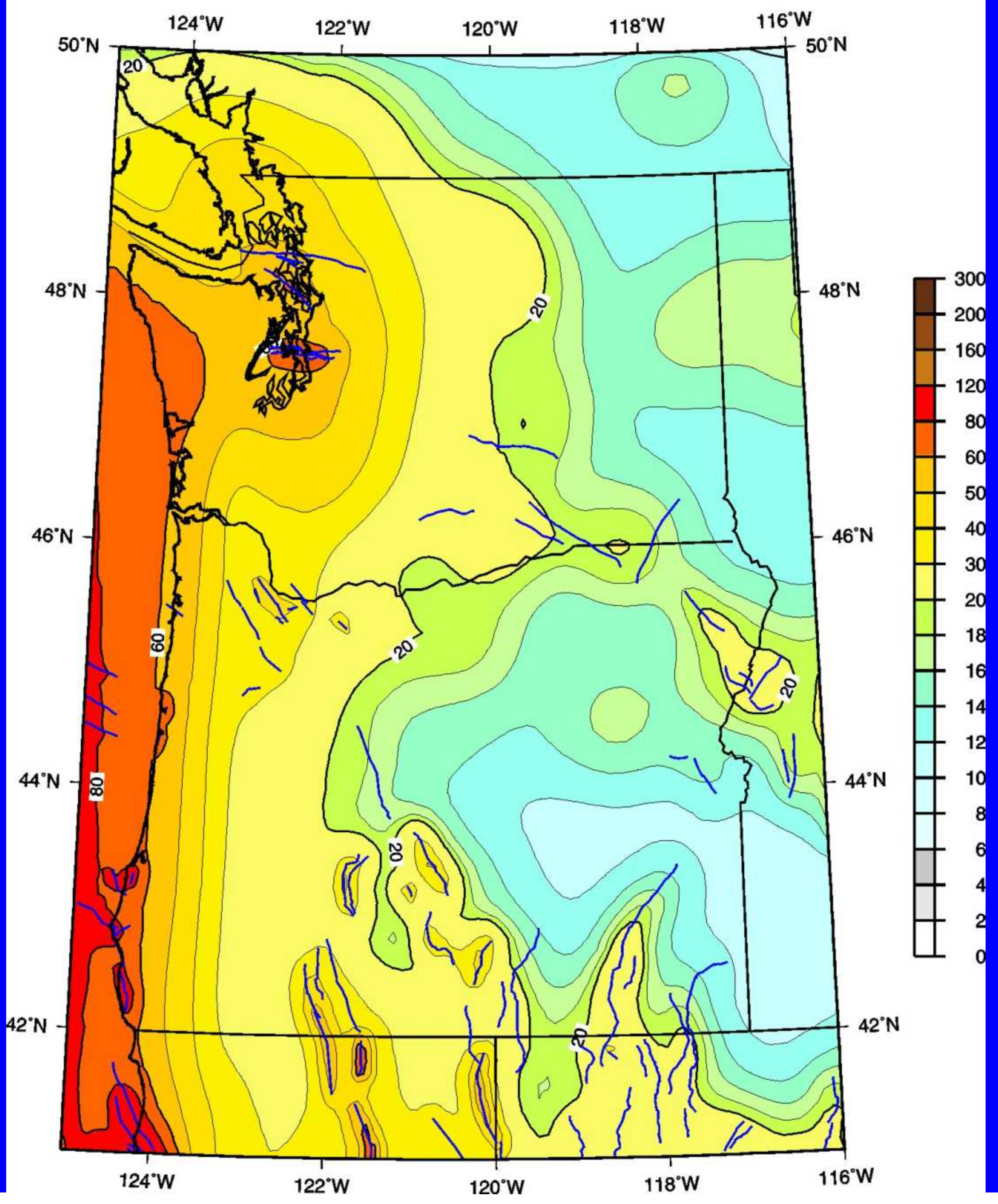
Crustal faults used in 2002 national maps



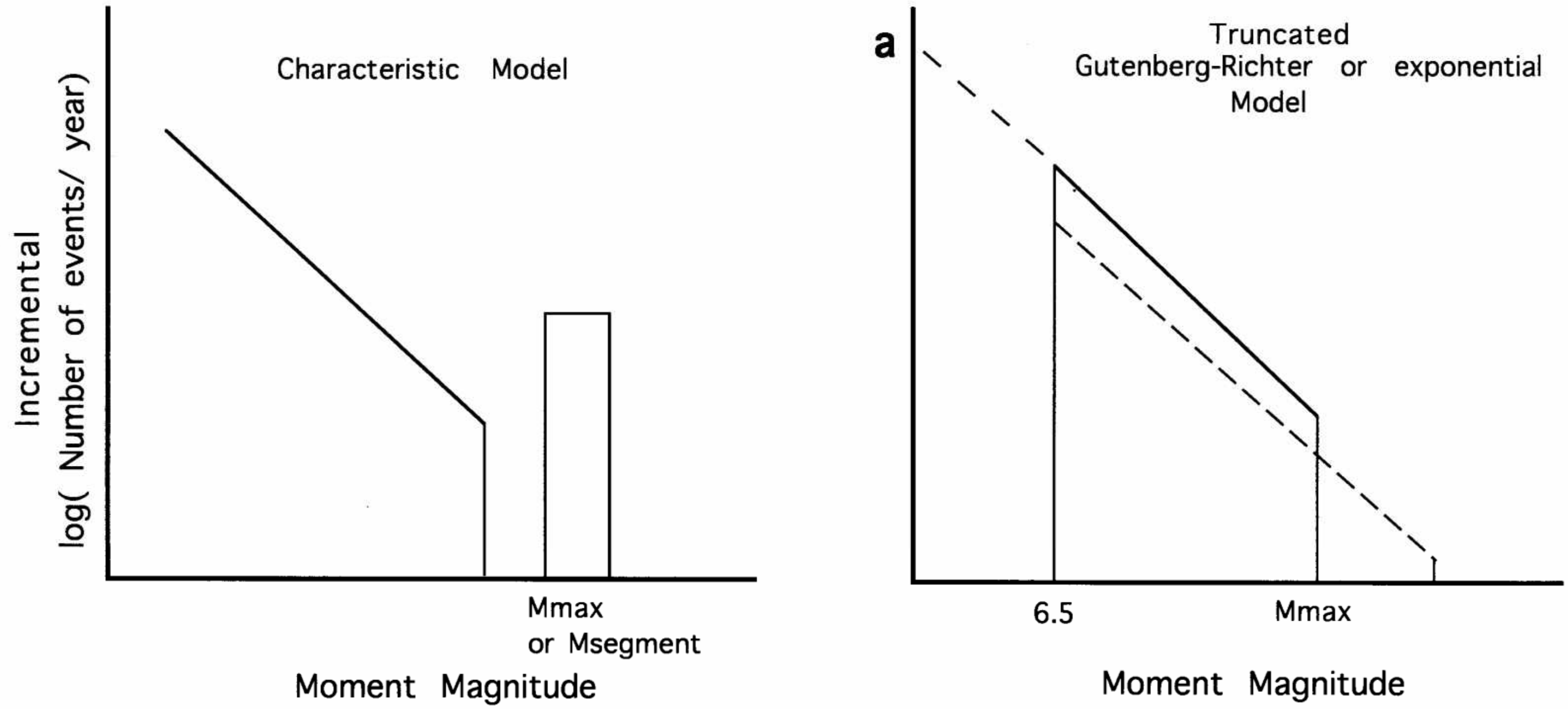
USGS
science for a changing world

Peak Accel. (%g) with 2% Probability of Exceedance in 50 Years

USGS Map, Oct. 2002

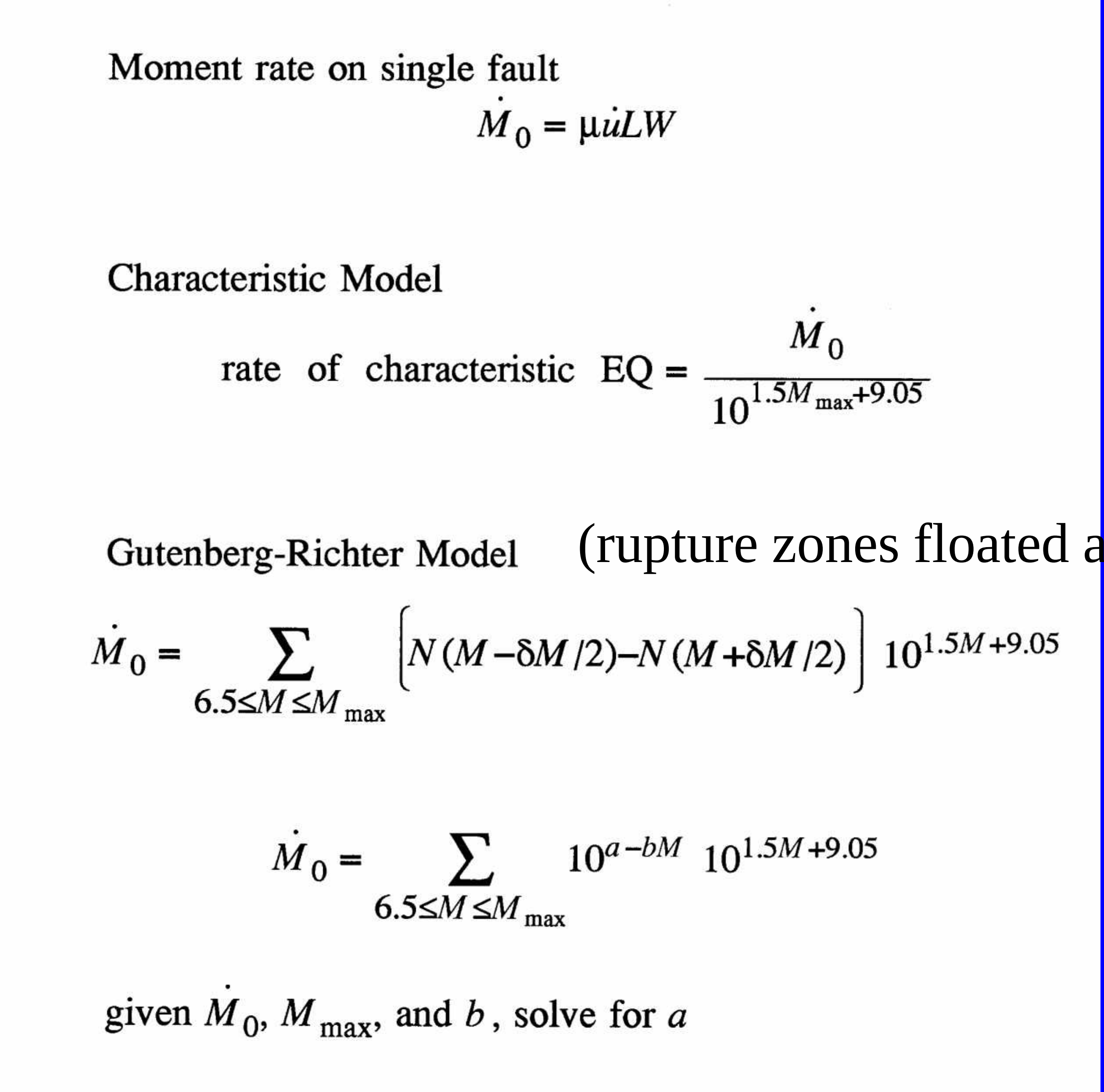


Recurrence Models For a Single Fault Zone



Characteristic earthquake completely ruptures entire length of mapped fault

Float rupture zones along fault



Moment rate on single fault

$$\dot{M}_0 = \mu \dot{u} L W$$

Characteristic Model

$$\text{rate of characteristic EQ} = \frac{\dot{M}_0}{10^{1.5M_{\max}+9.05}}$$

Gutenberg-Richter Model (rupture zones floated along fault)

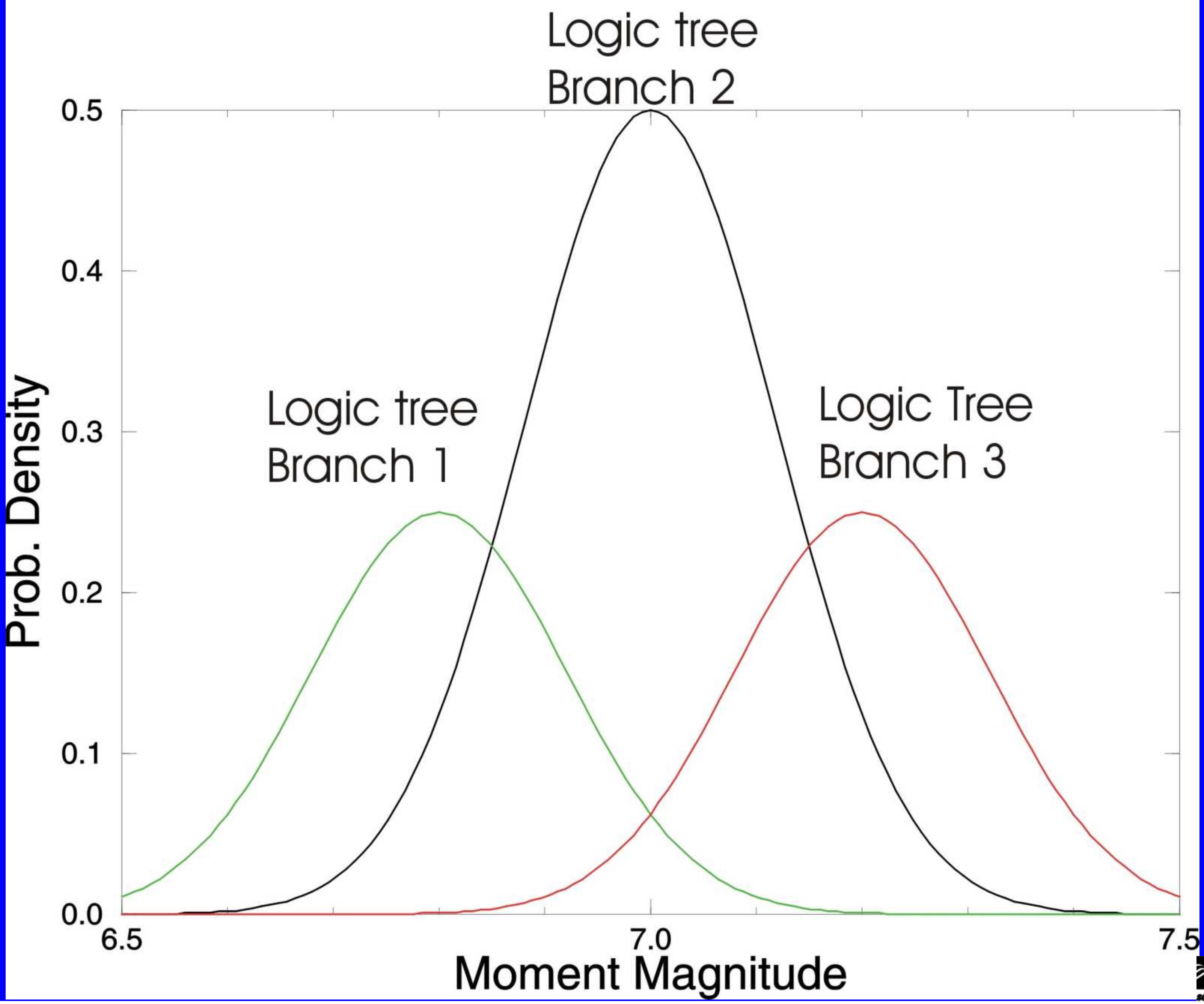
$$\dot{M}_0 = \sum_{6.5 \le M \le M_{\max}} \left[N(M - \delta M/2) - N(M + \delta M/2) \right] 10^{1.5M+9.05}$$

$$\dot{M}_0 = \sum_{6.5 \le M \le M_{\max}} 10^{a-bM} \, 10^{1.5M+9.05}$$

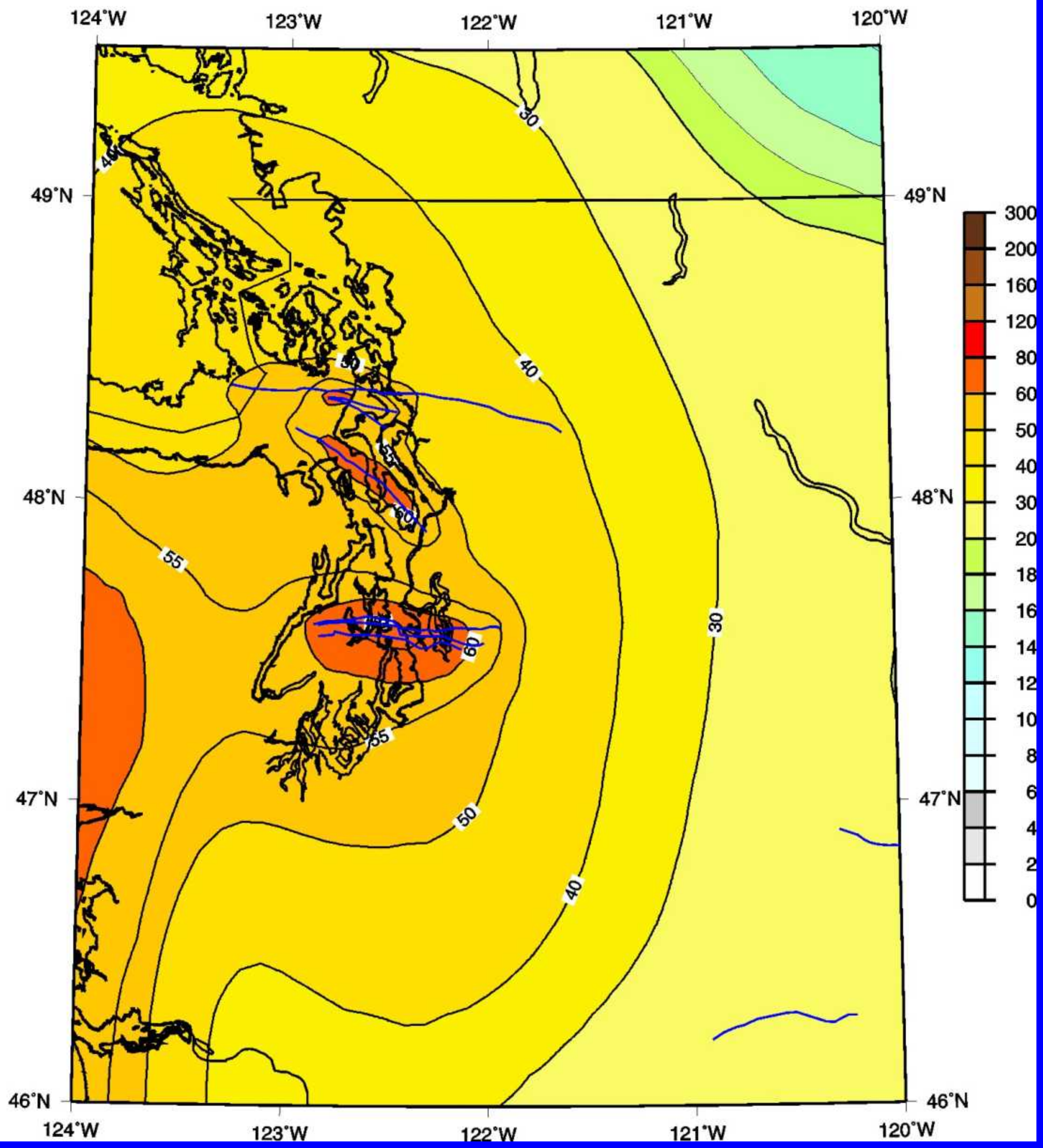
given $\dot{M}_0$, $M_{\max}$, and b, solve for a

Characteristic magnitude (Mmax here) derived from surface fault length using Wells and Coppersmith 1994

Epistemic and Aleatory Uncertainty for Mchar

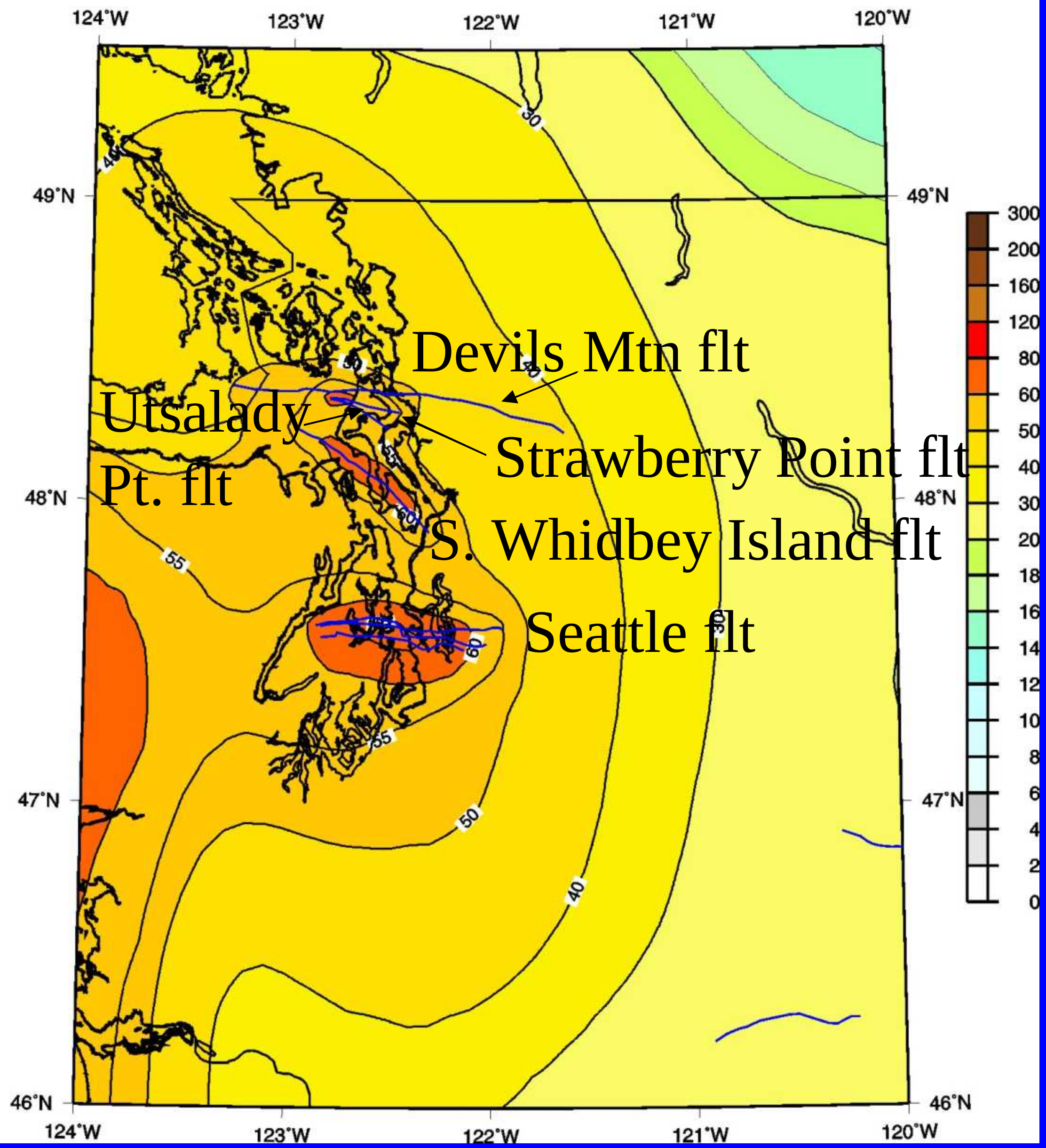


From 2002 USGS National Seismic Hazard Map
PGA (%g) with 2% Prob. Of Exceedance in 50 Years



USGS
science for a changing world

From 2002 USGS National Seismic Hazard Map
PGA (%g) with 2% Prob. Of Exceedance in 50 Years



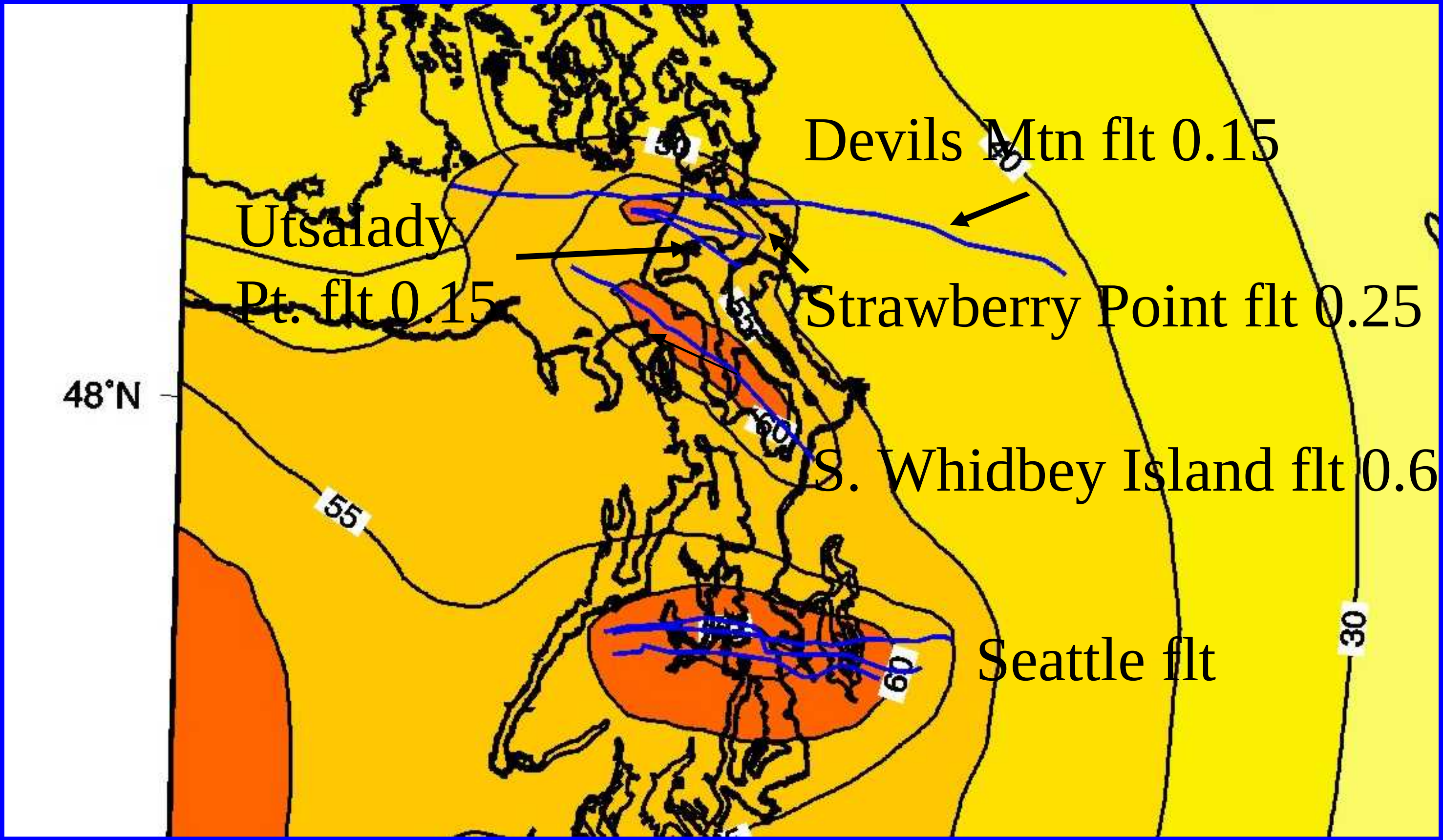
Devils Mtn flt

Utsalady Pt. flt

Strawberry Point flt

S. Whidbey Island flt

Seattle flt



Devils Mtn flt 0.15

Utsalady
Pt. flt 0.15

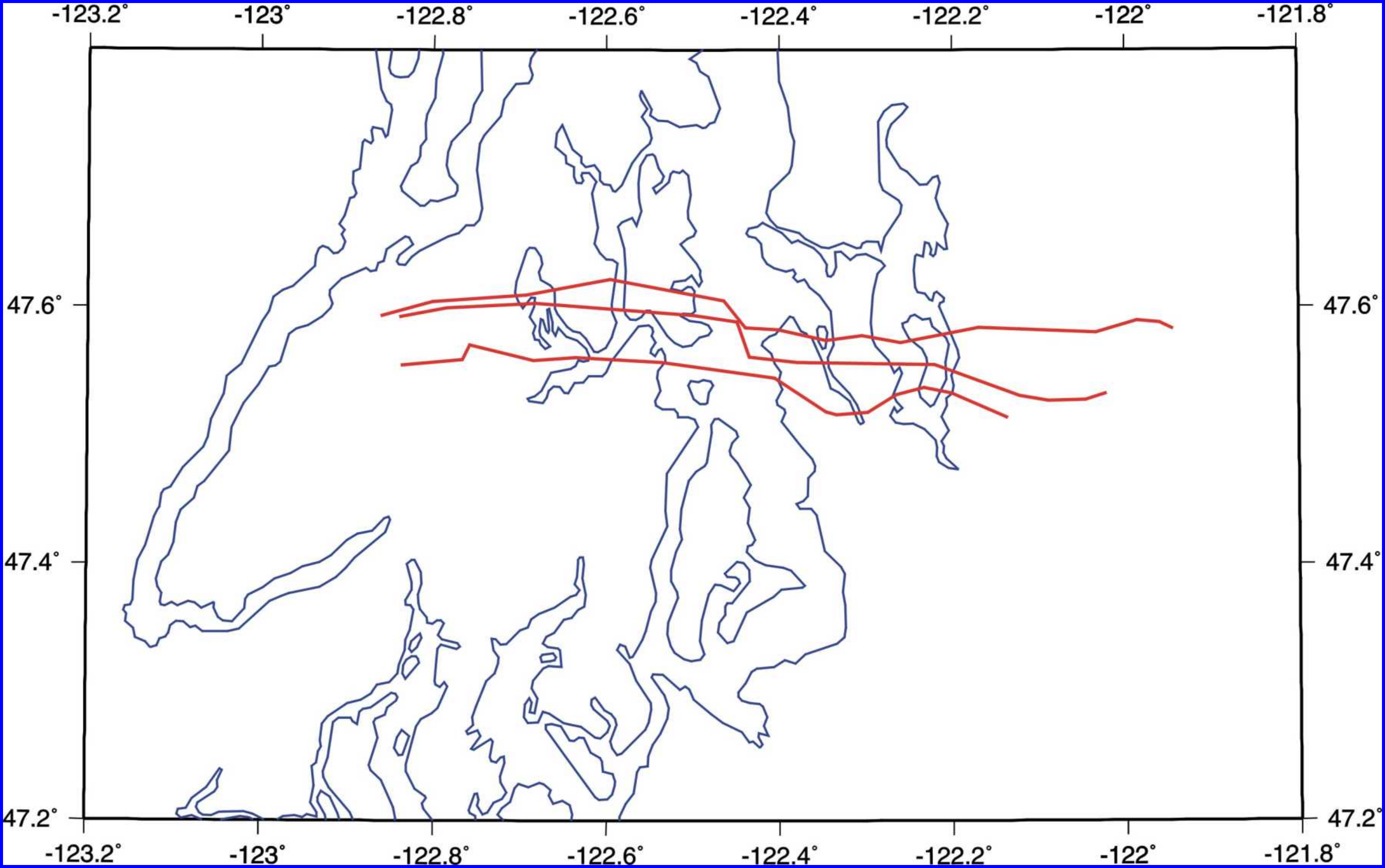
Strawberry Point flt 0.25

S. Whidbey Island flt 0.6

Seattle flt

Mean slip rates in mm/yr

3 traces of Seattle fault zone used in 2002 maps from Blakely et al. 2002



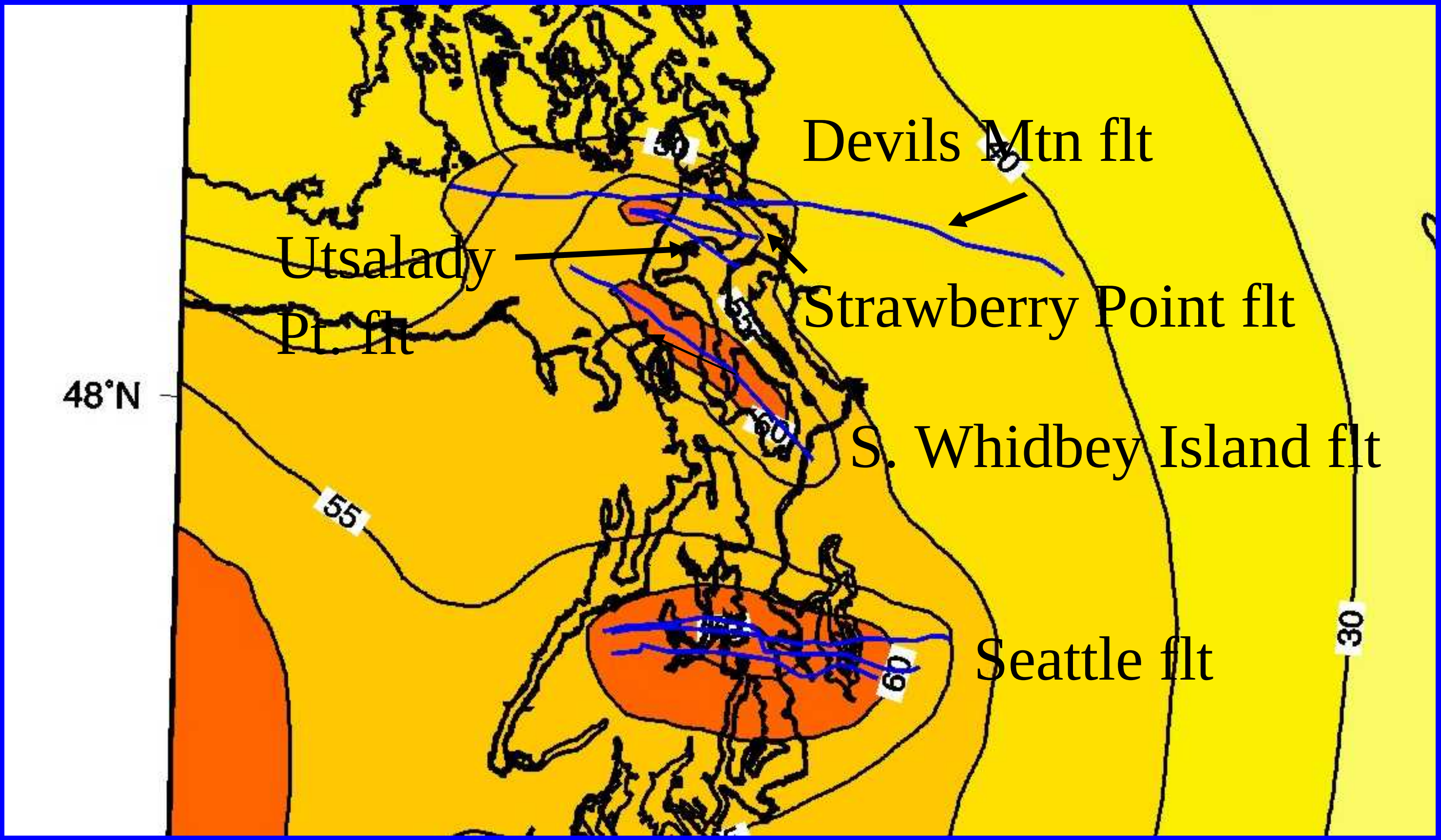
Seattle Fault
(treatment in 2002 maps)

- 0.5 wt for characteristic model (northern, frontal fault only) M7.2, 5000 yr recurrence
- 0.5 weight for truncated Gutenberg-Richter from M6.5-M7.2, M 6.5 1000 years, distributed over 3 traces, floating rupture zones along strike
- 45 degree dip, width=21 km, fault reaches surface
- M7.2 derived from Wells and Coppersmith 1994, given length of 71 km
- Used attenuation relations for thrust/reverse faulting

USGS
science for a changing world

South Whidbey Island Fault (treatment in 1996 and 2002 maps)

- Used slip rate of 0.6 mm/yr (Johnson et al. 1996)
- 0.5 wt Mchar= 7.2 (fault length 63 km), recurrence time of 3100 yr
- 0.5 wt truncated GR, M6.5-7.2, M 6.5 recurrence time of 930 yr
- Fault dip of 60 degrees, width= 17.3 km
- Used attenuation relations for strike-slip faulting



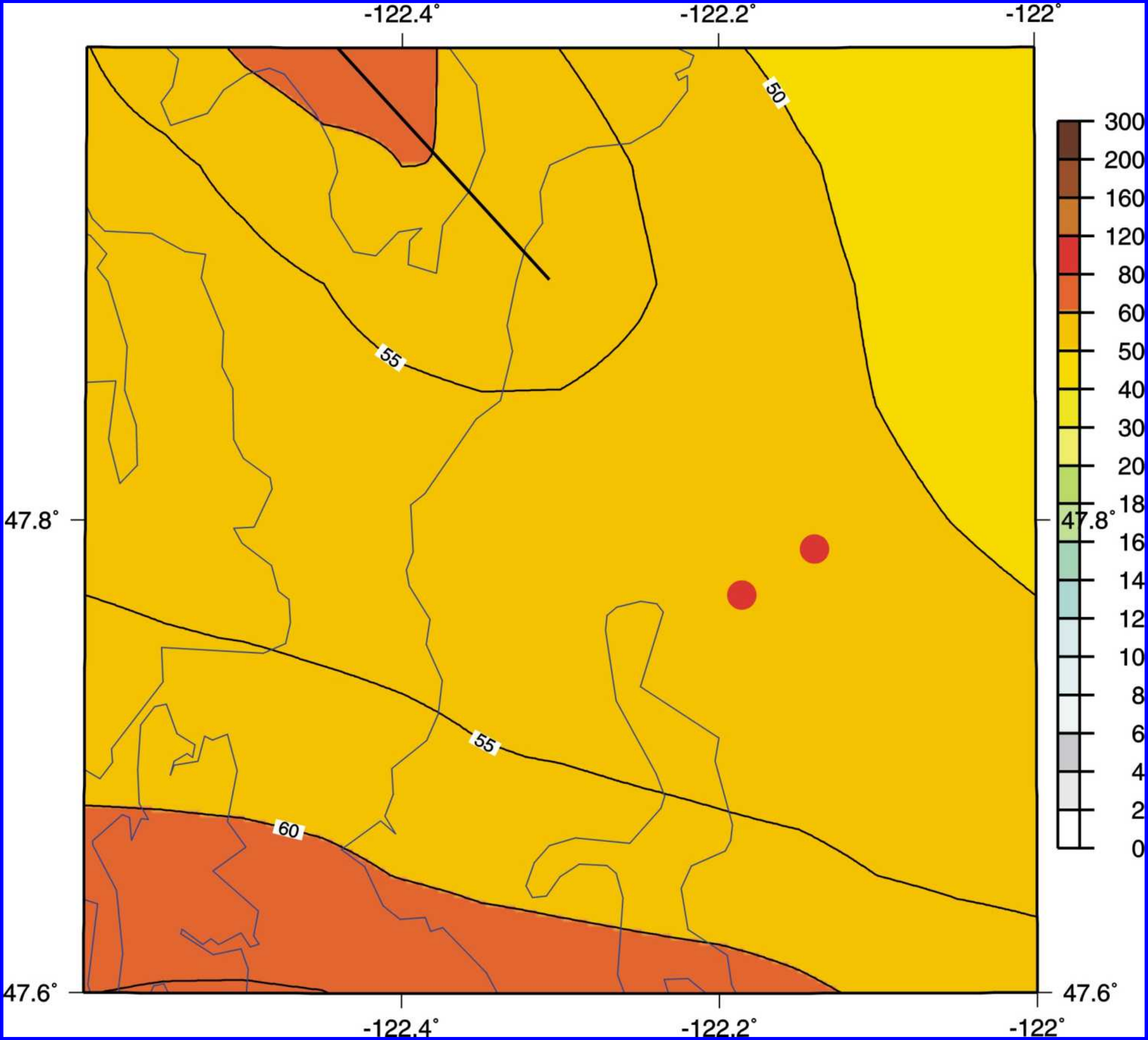
Devils Mtn flt

Utsalady Pt. flt

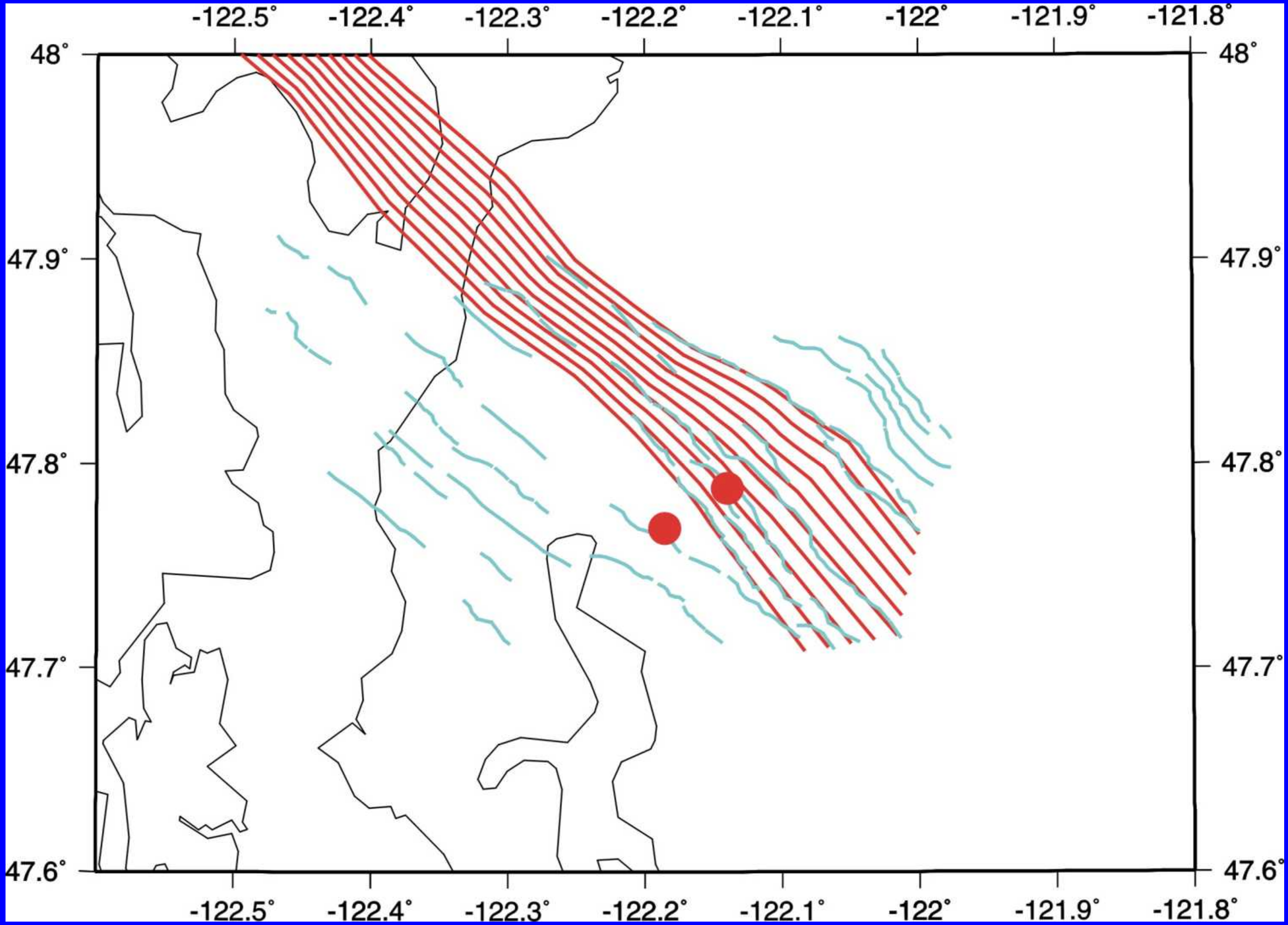
Strawberry Point flt

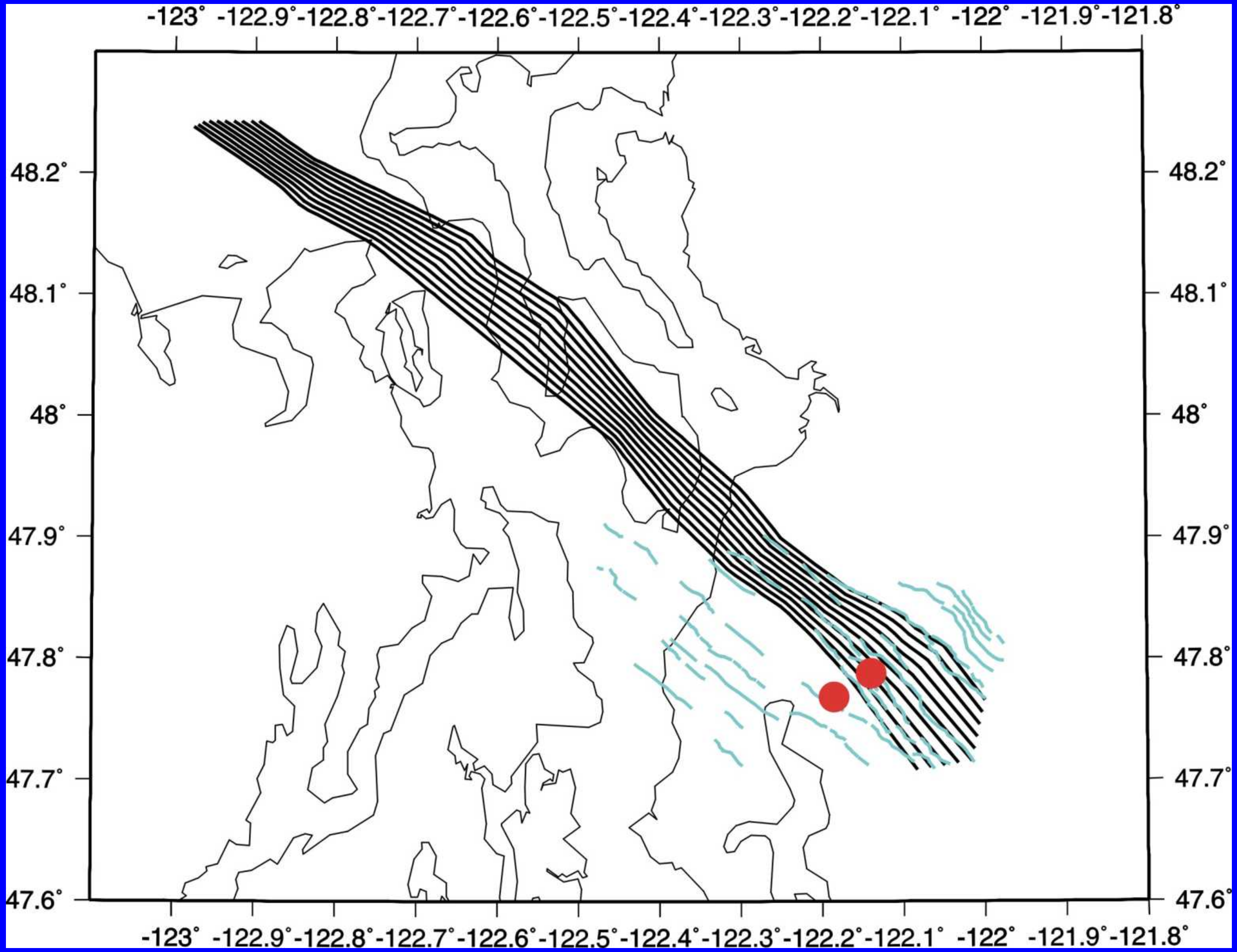
S. Whidbey Island flt

Seattle flt



USGS science for a changing world


-122.5°
-122.4°
-122.3°
-122.2°
-122.1°
-122°
-121.9°
-121.8°
48°
47.9°
47.8°
47.7°
47.6°


-123°
-122.9°
-122.8°
-122.7°
-122.6°
-122.5°
-122.4°
-122.3°
-122.2°
-122.1°
-122°
-121.9°
-121.8°
48.2°
48.1°
48°
47.9°
47.8°
47.7°
47.6°

- Change dip from 60° to 45° and seismogenic thickness from 15 km to 20 km

$$\text{slip rate on fault plane} = \frac{\text{uplift rate}}{\text{sin (dip)}}$$

$$\text{fault width} = \frac{\text{seismogenic thickness}}{\text{sin (dip)}}$$

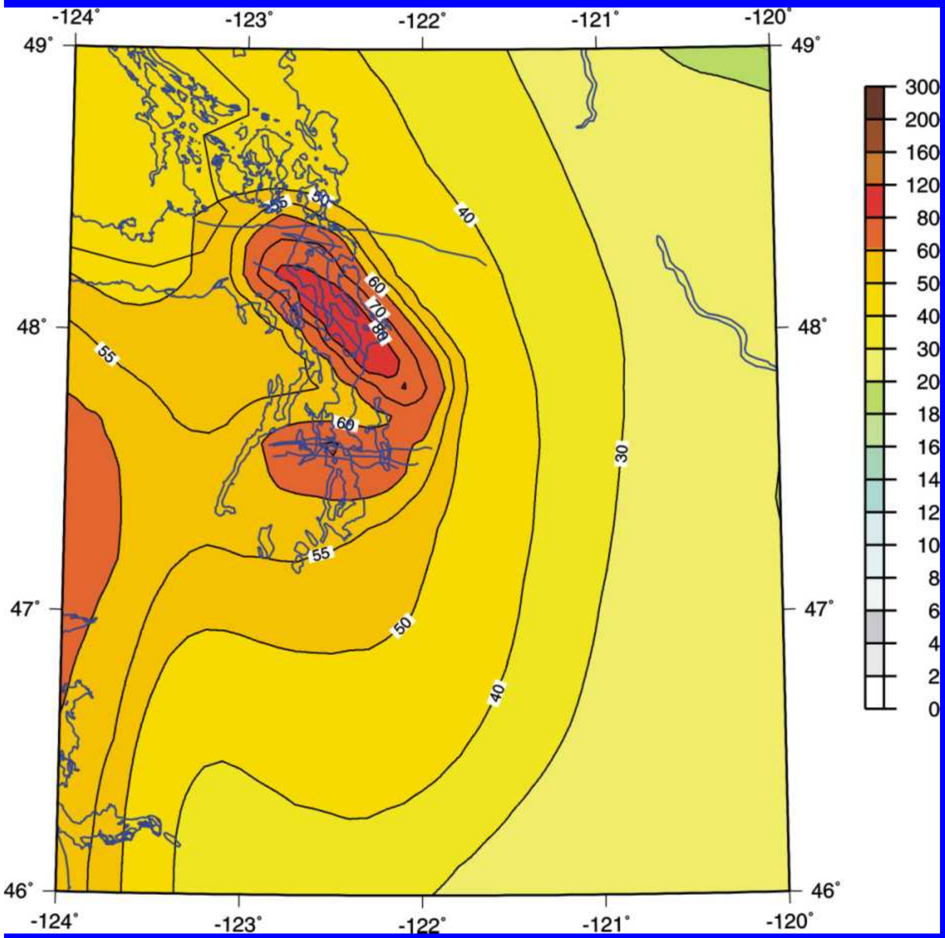
$$\text{rate of char. eqs} = \frac{\text{moment rate}}{\text{char. moment}} = \frac{\text{shear modulus} * \text{length} * \text{width} * \text{slip rate}}{\text{char. moment}}$$

This increases estimate of rate of char. earthquakes by factor of two, if the uplift rate and characteristic moment are unchanged

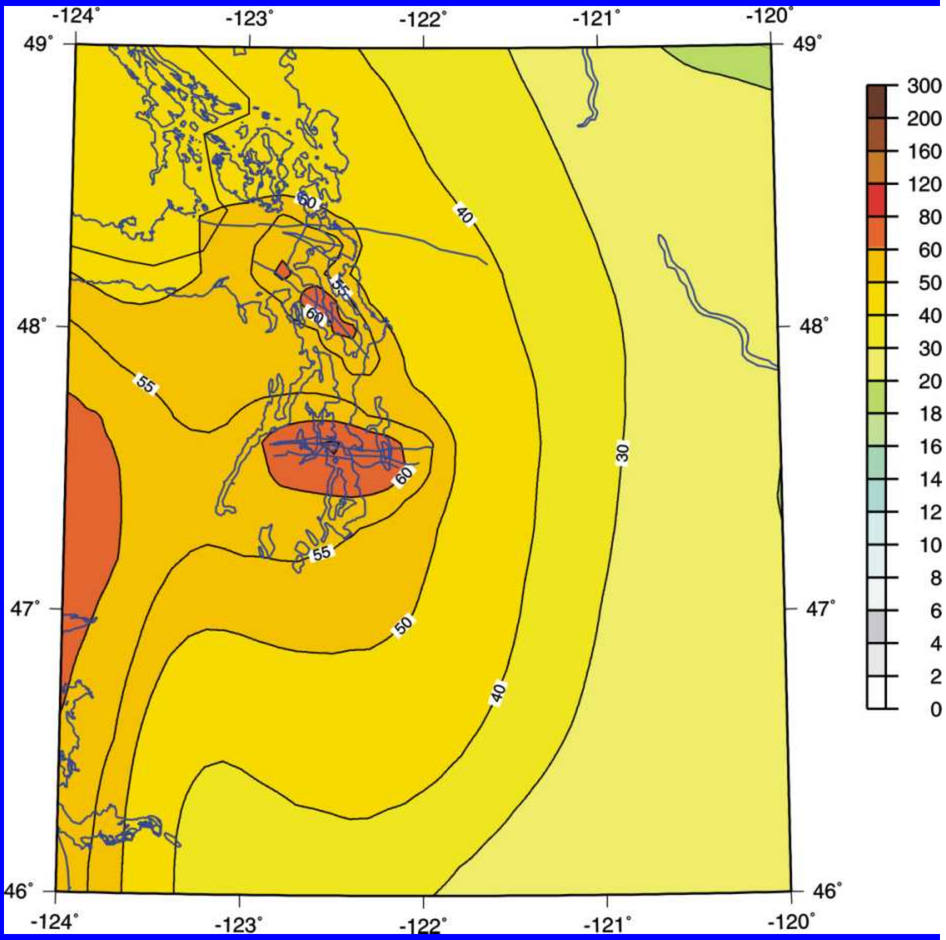
Results of using proposed SWIF parameters

- 0.6 mm/yr uplift rate, 45º dip, 20 km seism. thickness; 86 km length gives M7.3 (was M7.2): Tchar= 1700 yr, M 6.5 400 yr
- For 0.5 mm/yr strike slip component (derived assuming pure north-south convergence): Tchar= 2900 yr, M 6.5 680 yr
- For ½ wt.(pure reverse faulting), ½ wt (reverse + strike slip): Tchar= 1300 yr, M 6.5 310 yr [much shorter times than used for the Seattle fault]

- Note: trenching finds 2-5 earthquakes during Holocene (T= 2000-5000 yr), in limited sample
- Use reverse faulting term in attenuation relation for reverse faulting model



With revised SWIF parameters,
including possible strike-slip component



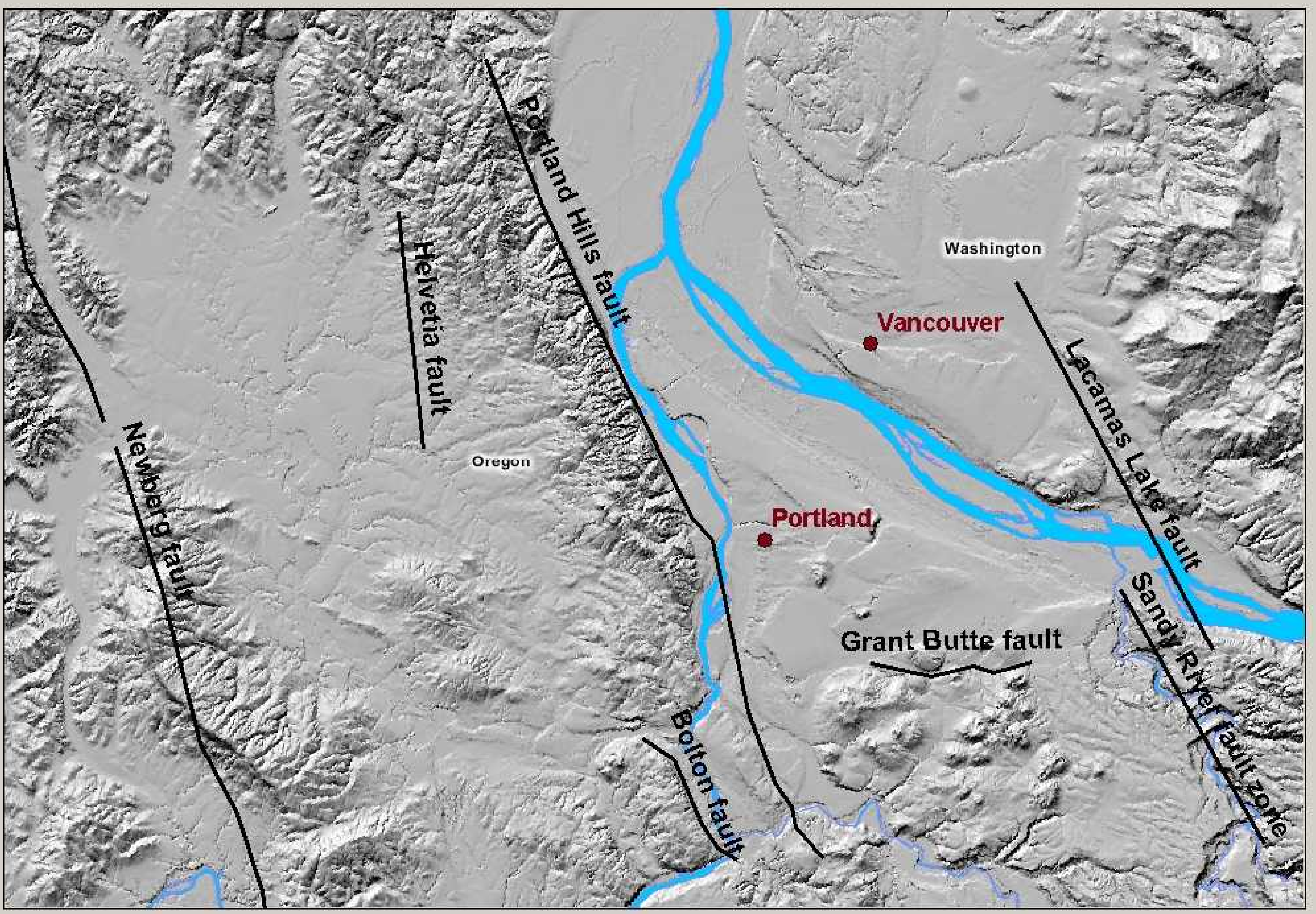
2002 map

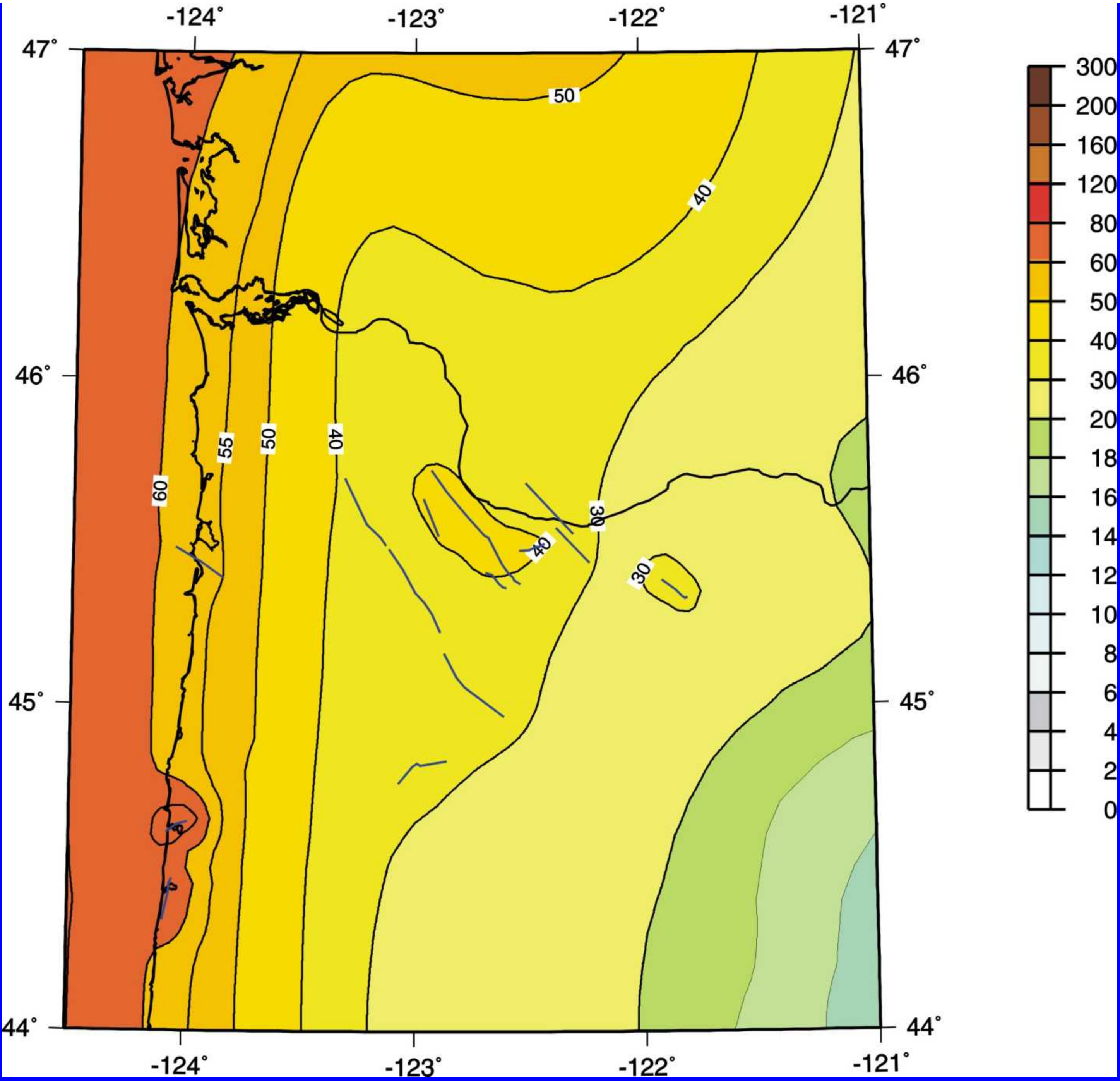
Caveat

- By revising parameters (e.g., seismogenic thickness, adding assumed strike-slip component, dip) for one fault without changing others, one can derive an incorrect view of the relative hazard of that fault compared to other faults, given the geologic data on those faults.

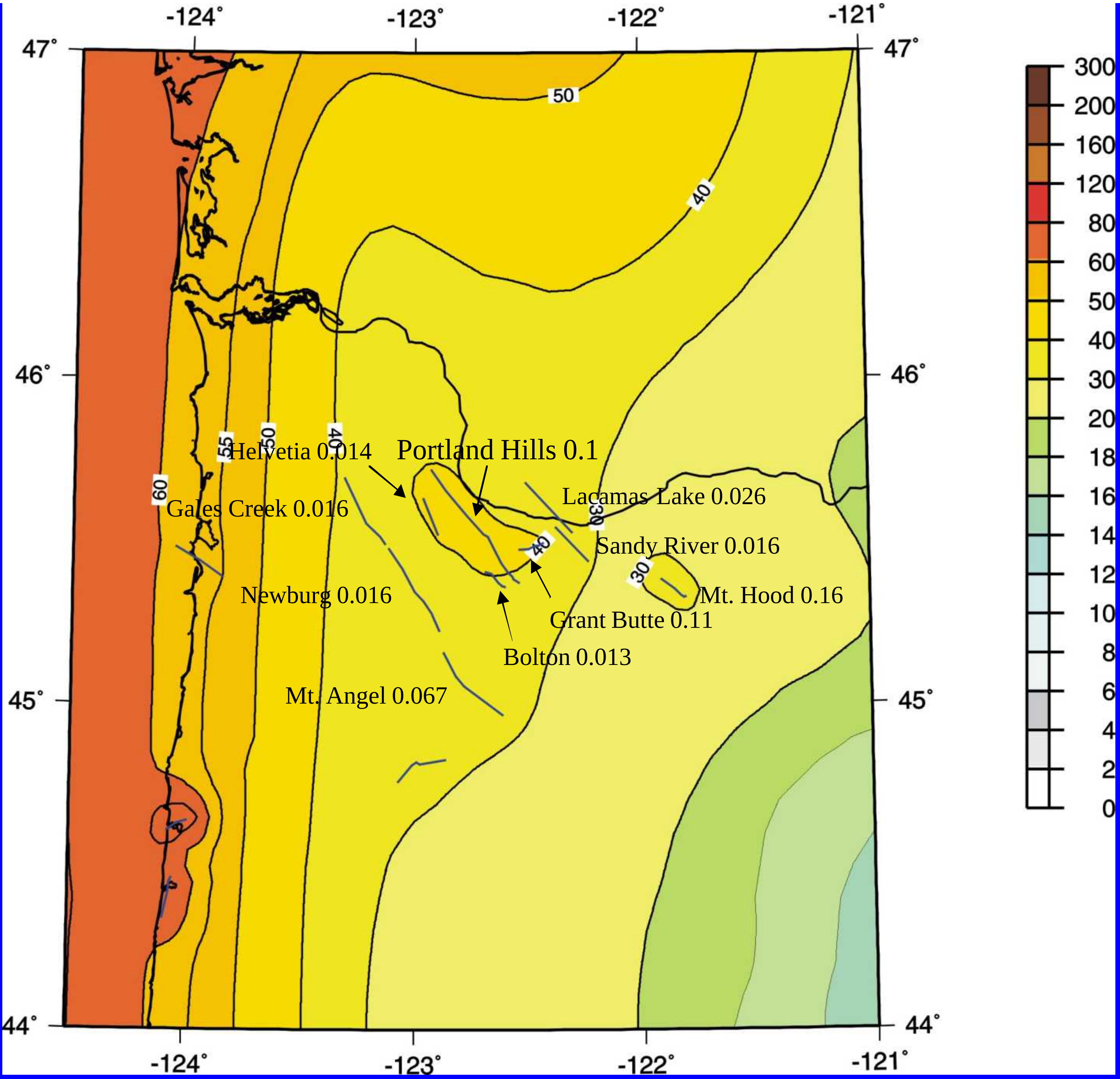
Portland area faults

Faults used in 2002 maps





PGA (%g)
with 2% PE
in 50 years



PGA (%g) with 2% PE in 50 years

Mean slip rates in mm/yr

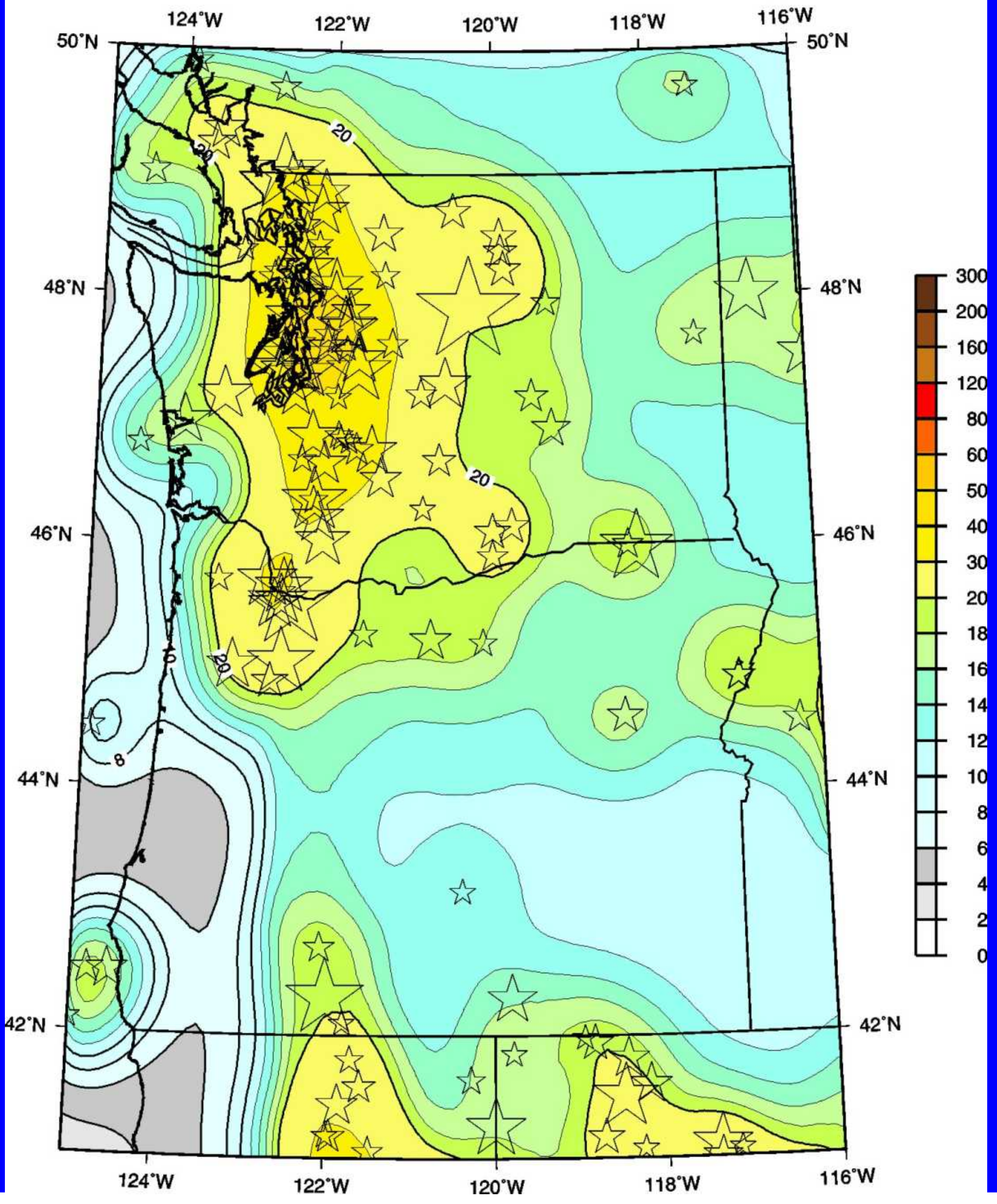
Portland Hills fault
(treatment in 1996 and 2002 maps)

- 0.1 mm/yr vertical slip rate (from 1995 Geomatrix report for ODOT, cited as I.P. Madin, pers. comm., Pleistocene vertical uplift rate)
- 0.5 wt Char. M7.0, recurrence time 12,000 yr (50 km fault length)
- 0.5 wt truncated GR M6.5-7.0, M 6.5 every 5000 years
- 60 degree dip, 17.3 km width
- Used attenuation relations for reverse faulting

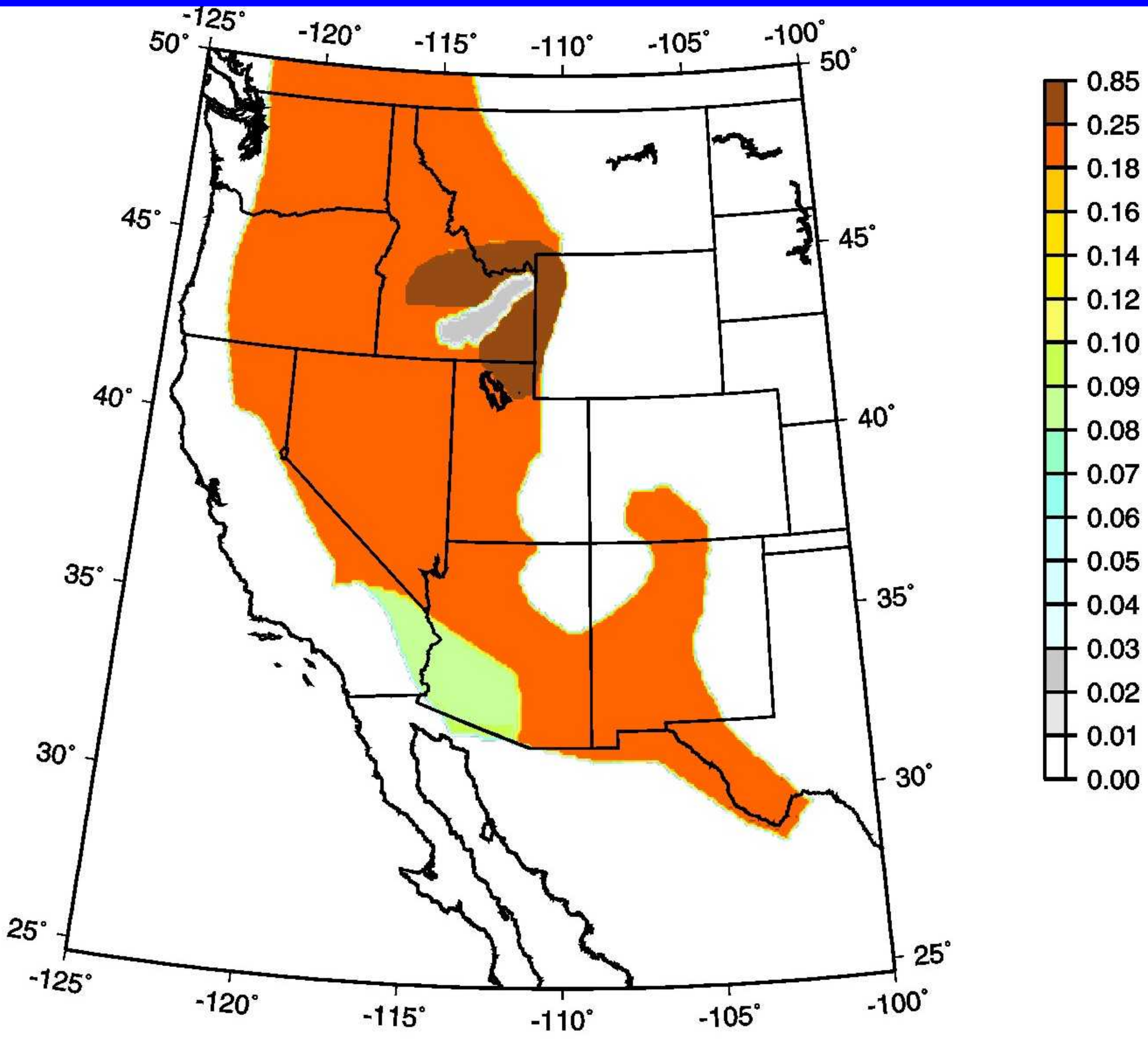
Eastern WA and OR

Peak Accel. (%g) with 2% Probability of Exceedance in 50 Years

shallow seismicity and background zones only

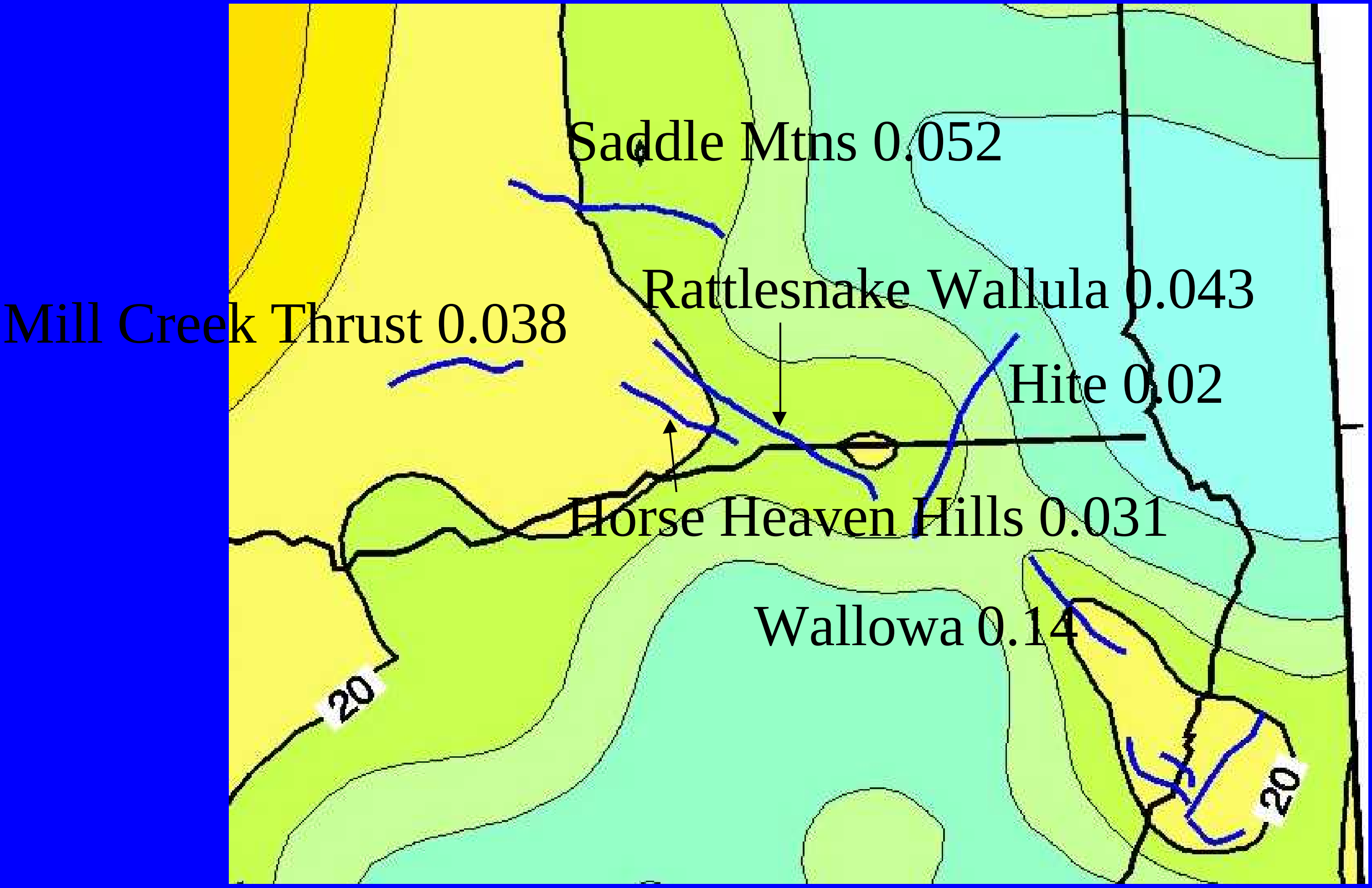


USGS
science for a changing world



. Map showing seismicity rates for background zones in WUS.

USGS
science for a changing world



Saddle Mtns 0.052

Rattlesnake Wallula 0.043

Mill Creek Thrust 0.038

Hite 0.02

Horse Heaven Hills 0.031

Wallowa 0.14

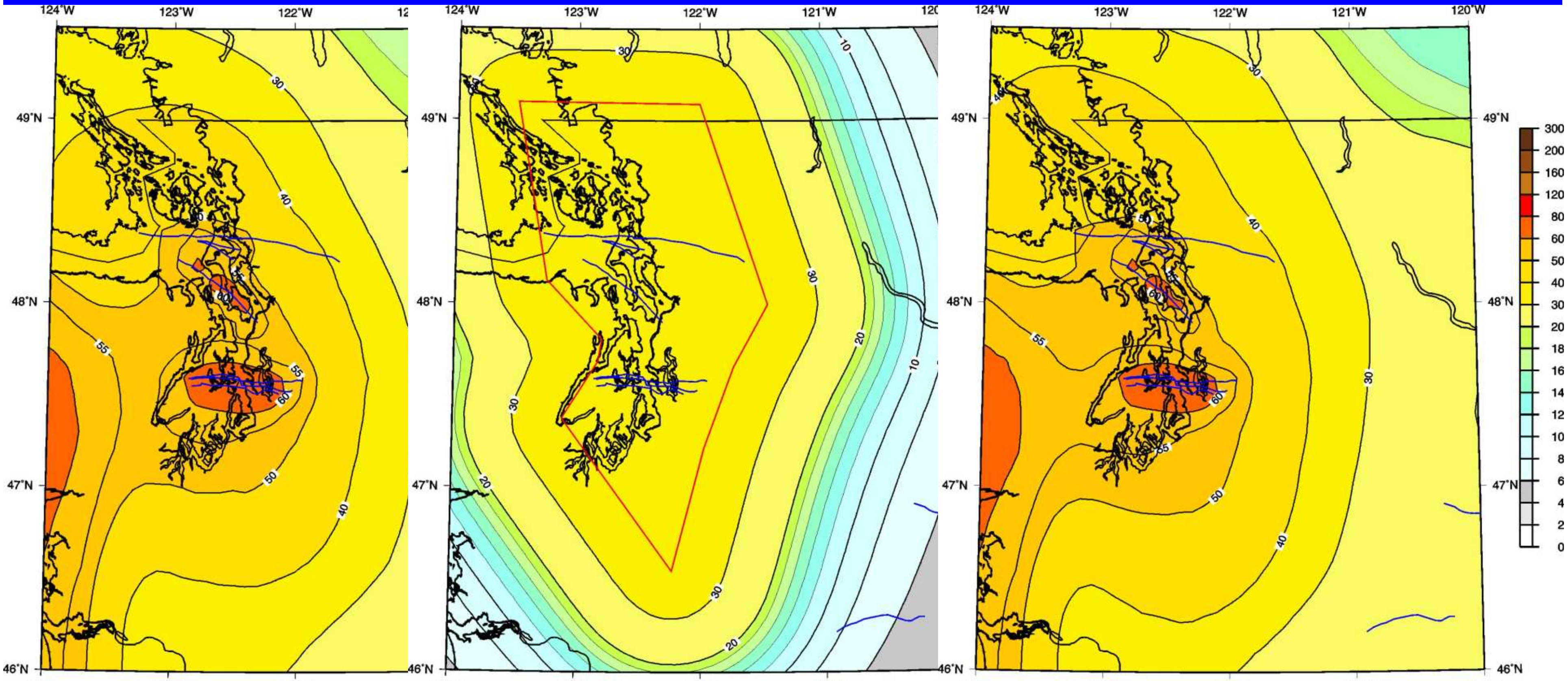
Mean slip rates in mm/yr

Comparison of hazard estimates for Hanford (all values in *g*)

	Geomatrix 1996, stiff soil sites	USGS 2002 rock sites	USGS 2002 adjusted to stiff soil sites
PGA 2000 yr	0.21-0.26	0.20	0.28
PGA 10,000 yr	0.37-0.48	0.36	0.41
5 Hz S.A. 2000 yr	0.46-0.58	0.41	0.57
5 Hz S.A. 10,000 yr	0.87-1.1	0.84	0.97
1 Hz S.A. 2000 year	0.23-0.26	0.13	0.31
1 Hz S.A. 10,000 yr	0.43-0.50	0.26	0.49

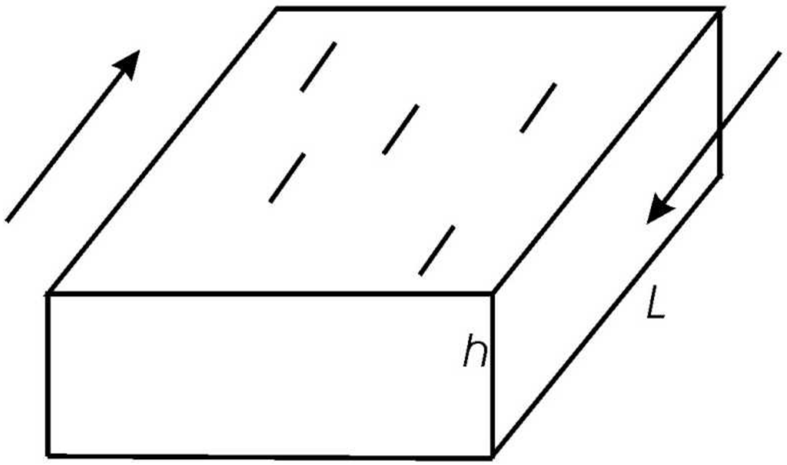
Using GPS info to get regional moment rate and seismicity rate

Puget Sound: Effect of including areal source zone accommodating 3 mm/yr N-S convergence measured by GPS



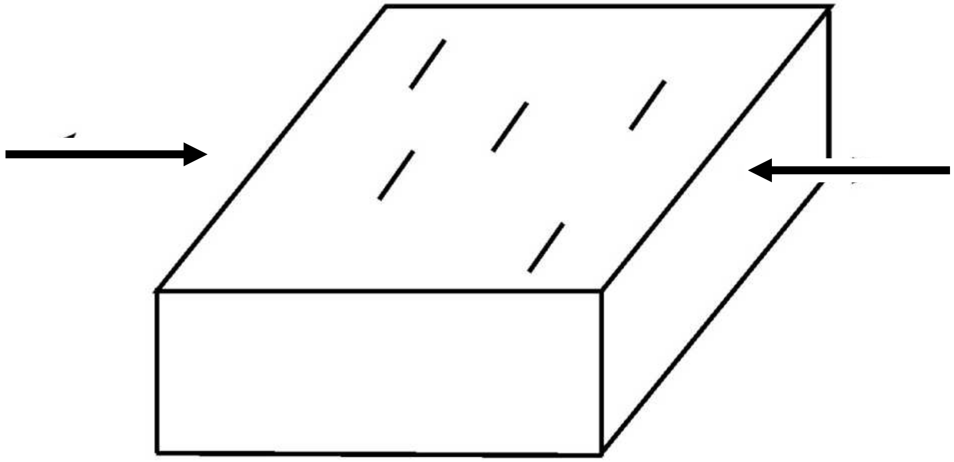
PGA (%g) with 2% P.E. in 50 Years

From Kostrov (1974), Anderson (1979)



For shear on vertical faults

$$\dot{M}_0 = \mu h L \dot{u}$$



convergence on 45 deg. dipping faults

$$\dot{M}_0 \cong 2\mu h L \dot{u}$$

Assumptions used in converting convergence rate to earthquake moment rate

- Convergence rate of 3 mm/yr [faults in our model take up additional convergence]
- Seismogenic thickness of 20 km
- Mmax of 7.3
- b-value of 0.8
- East-west striking faults, dipping at 45º
- Convergence is entirely taken up by earthquake slip
- Used specific areal zone
- Found that derived a-value is consistent with observed rate of M 5.0 earthquakes since 1928 (13 events, 0.18 /yr).
- Change b-value to 0.9, M 5.0 rate increases by 30%
- Change Mmax to 7.4, M 5.0 rate decreases by 10%

USGS
science for a changing world

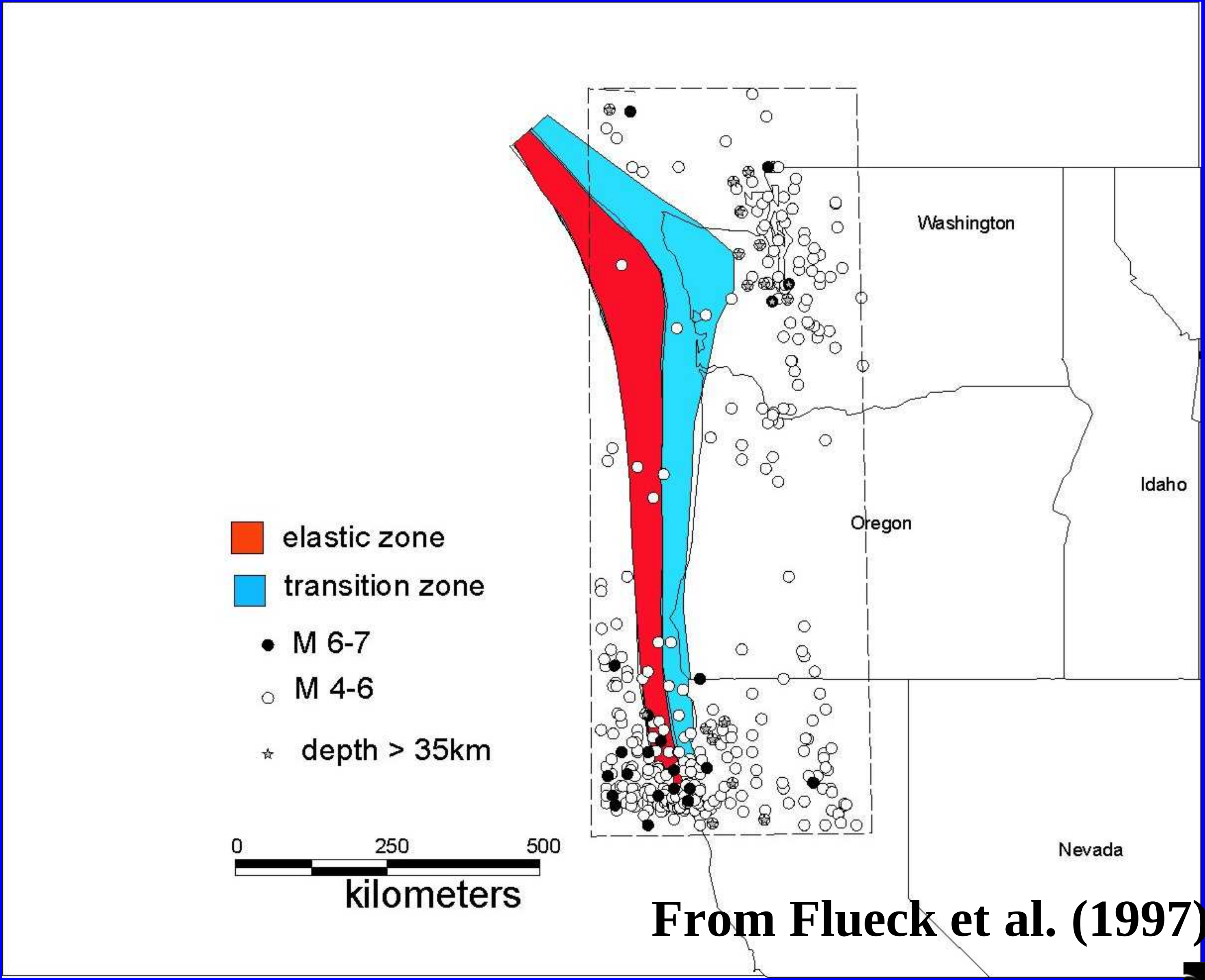
Cascadia subduction zone

- Half weight M9.0 rupturing entire CSZ on average 500 years
- Half weight M8.3 earthquakes filling entire CSZ on average 500 years

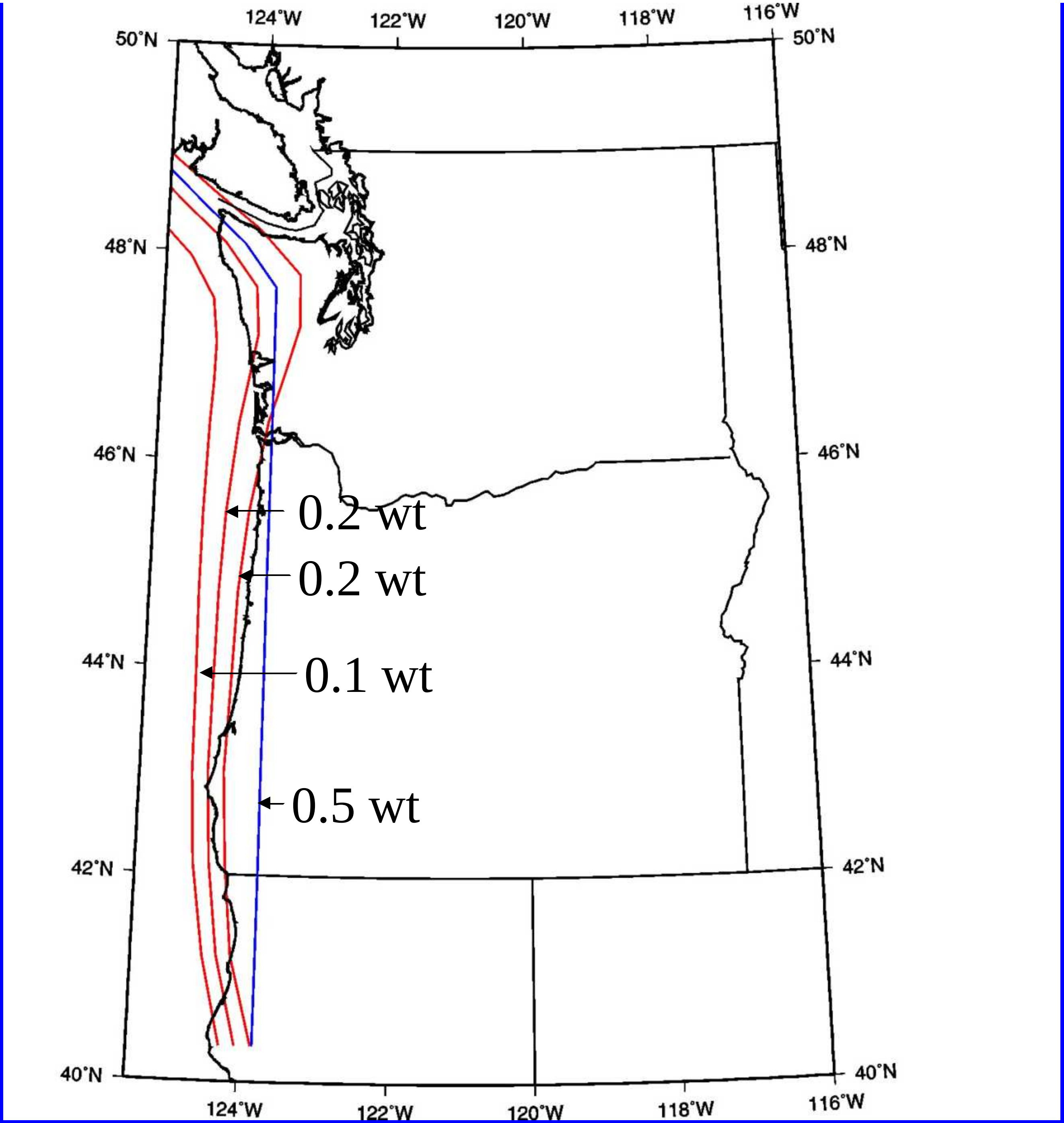
Components for Frequency-magnitude distribution for Cascadia subduction zone

- M9’s rupturing whole zone
- Cascade of M8’s rupturing whole zone
- Isolated M8’s
- Other events M5-7 (e.g., Petrolia EQ)

Possible configurations for rupture zone of great Cascadia Earthquakes



From Flueck et al. (1997)

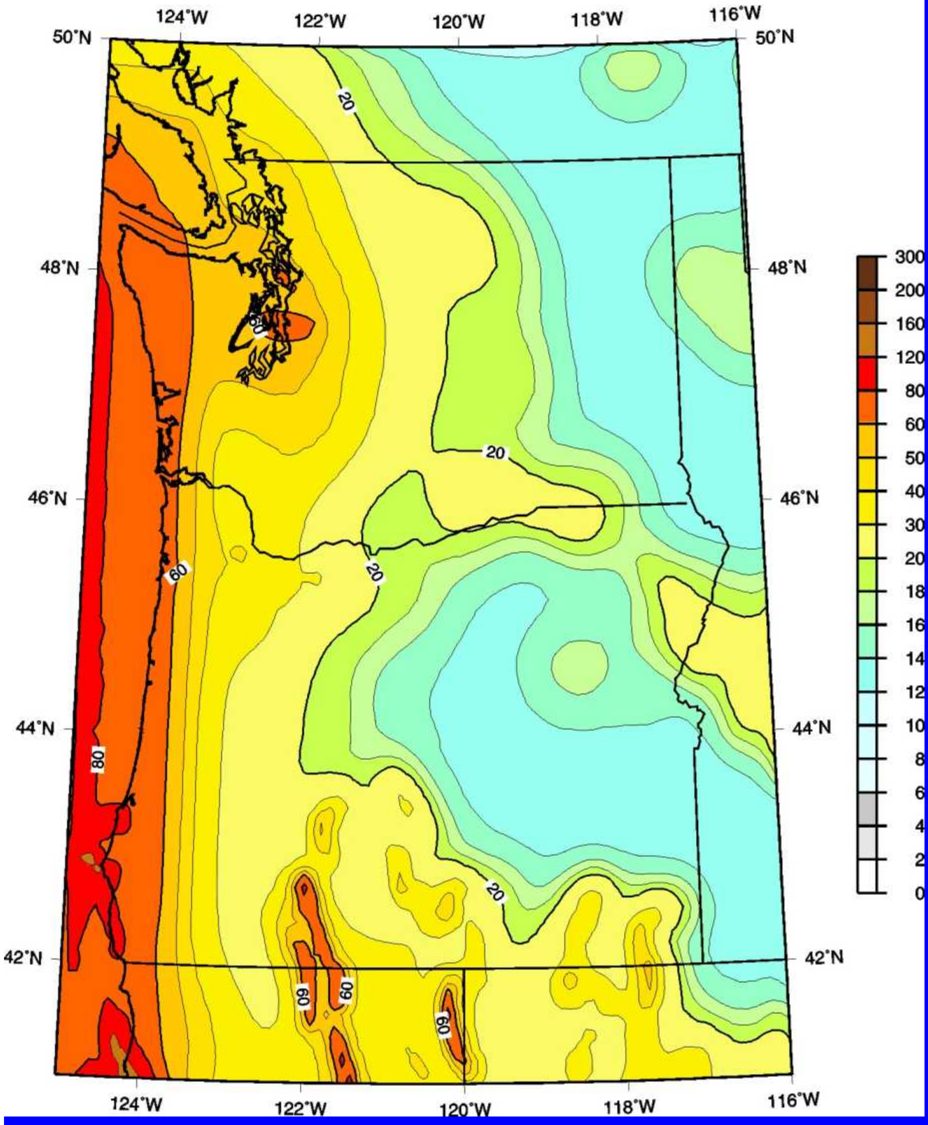


0.2 wt

0.2 wt

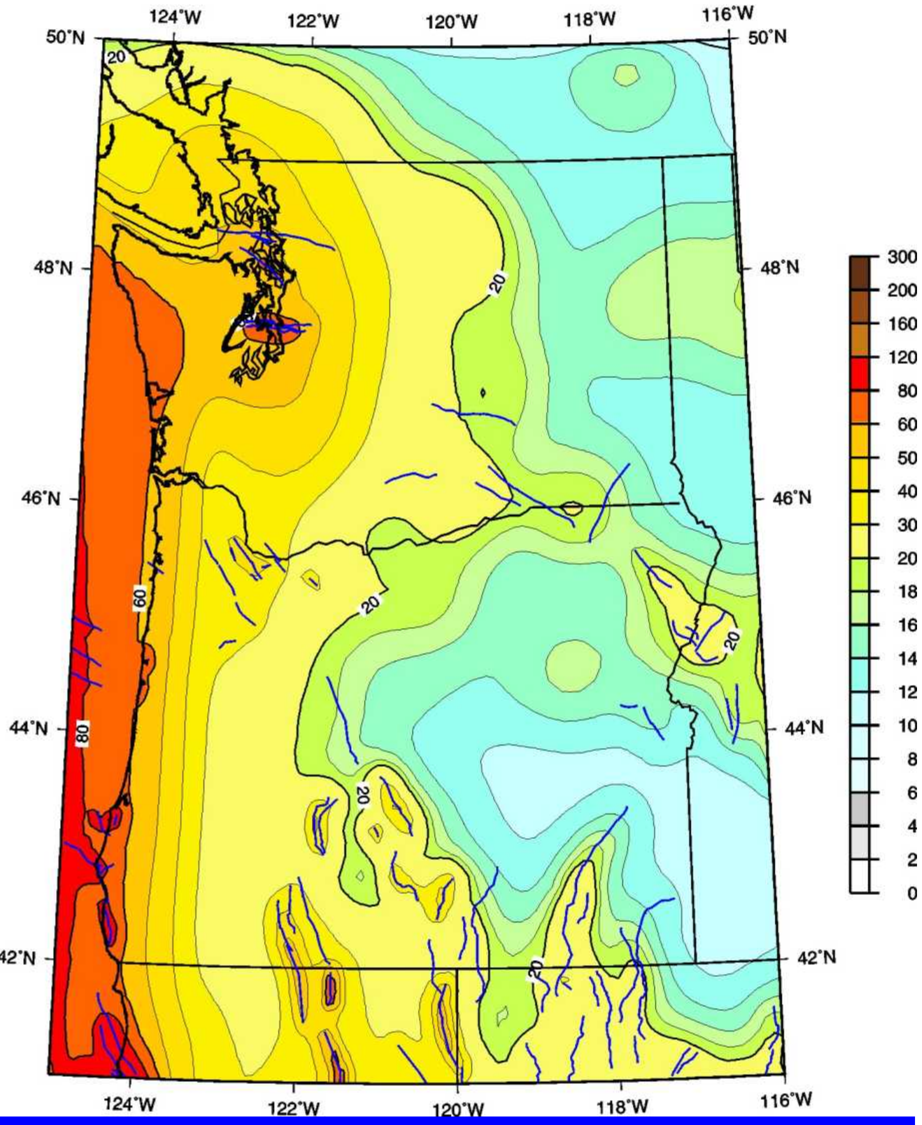
0.1 wt

0.5 wt



Peak Accel. (%g) with 2% Probability of Exceedance in 50 Years

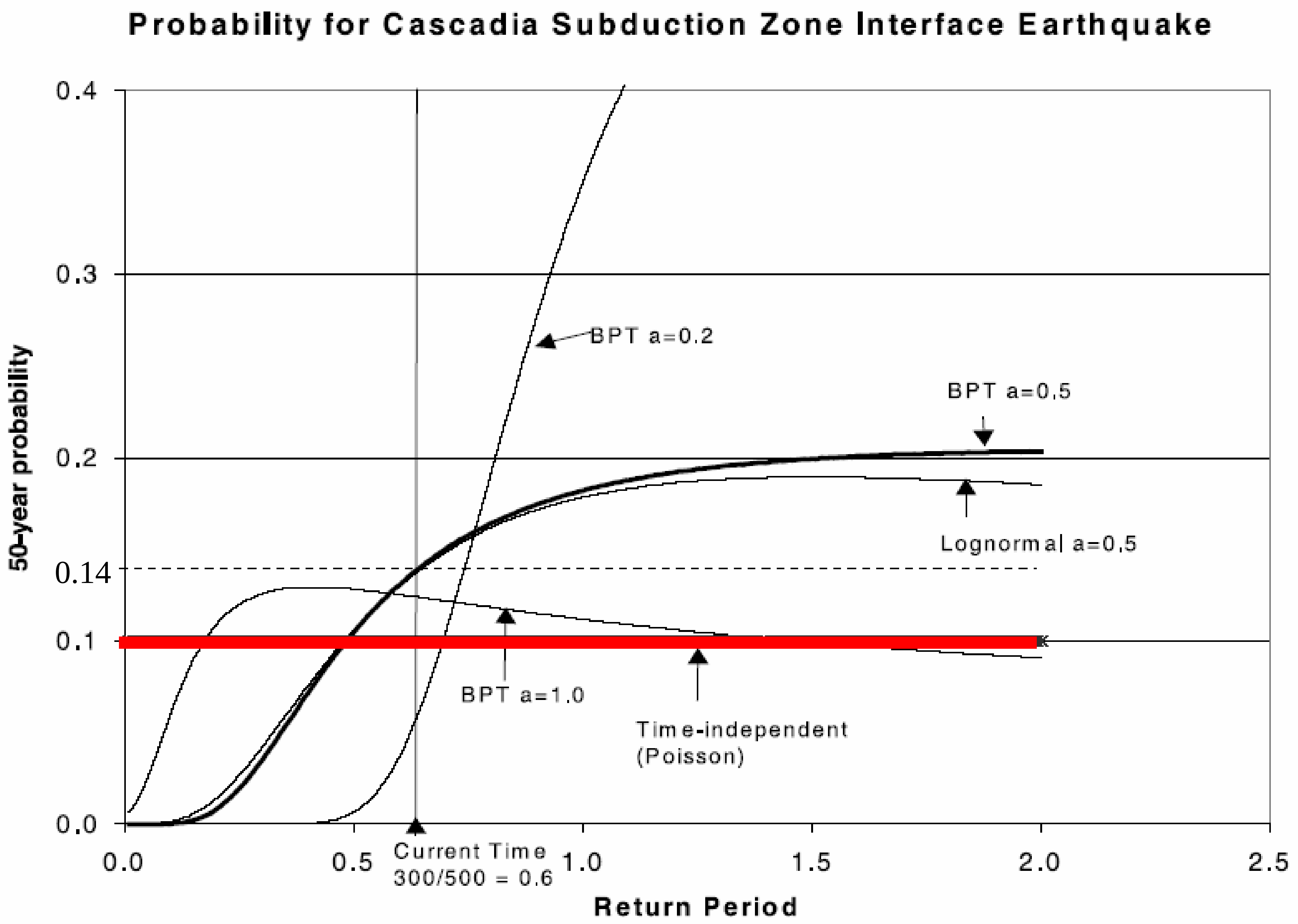
1996 USGS Map



Peak Accel. (%g) with 2% Probability of Exceedance in 50 Years

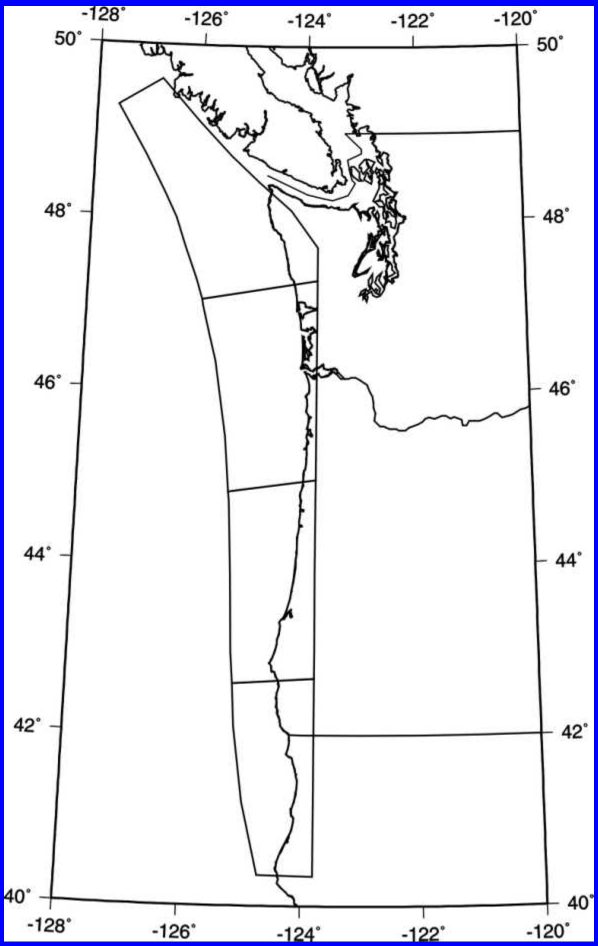
USGS Map, Oct. 2002

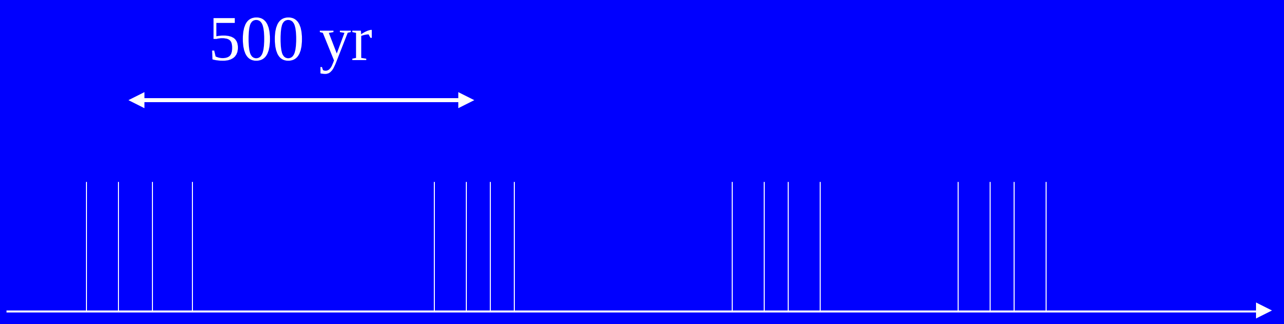
USGS
science for a changing world



from Petersen et al. (2002)

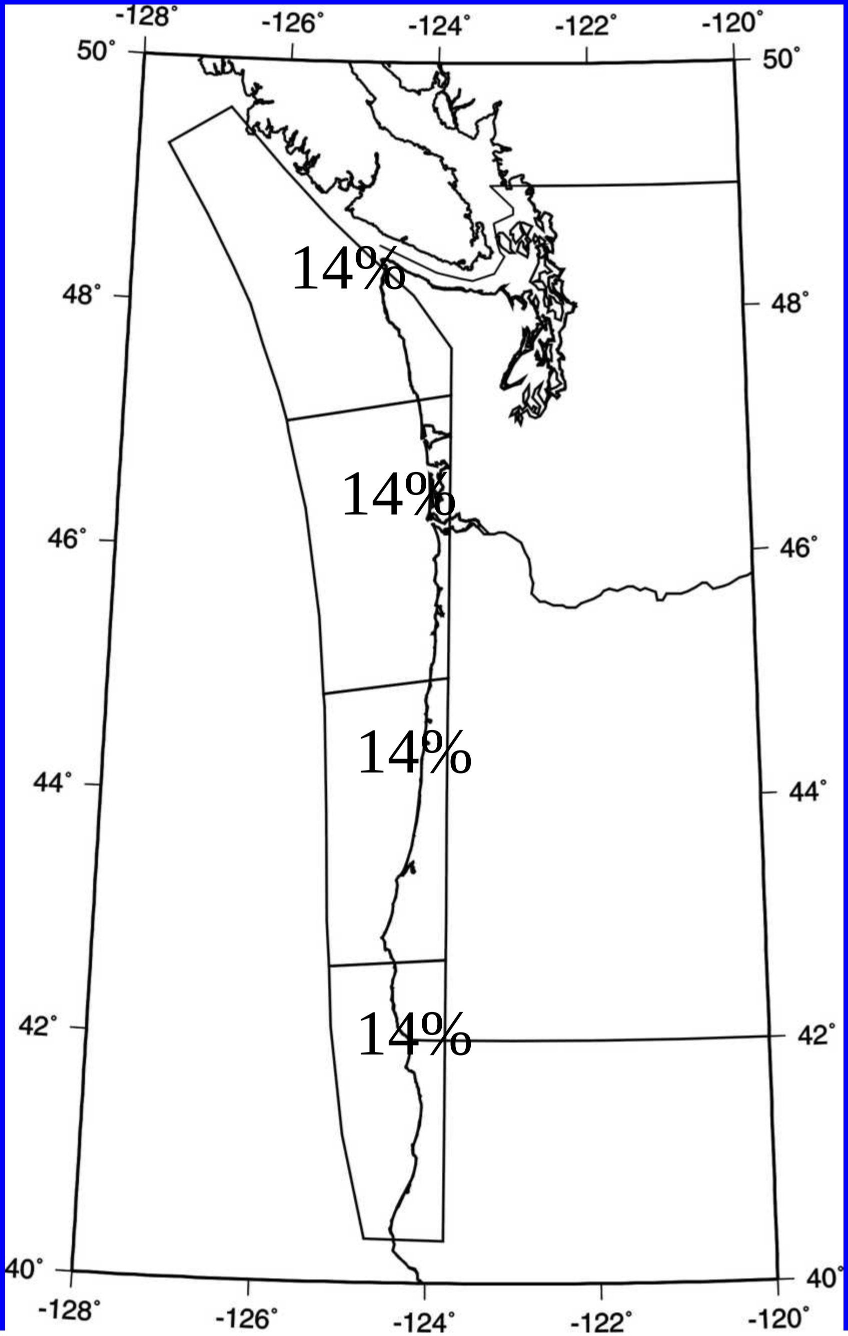
Cluster of M8's
rupturing whole CSZ




500 yr

time

50 year probabilities



For tightly clustered M8.3's: time-dependent probability of any segment is approximately the time-dependent probability for a M9

Since these are not independent earthquakes, you cannot just add the frequencies of exceeding a specified ground motion for each segment

First find 50-year probabilities of exceeding specified ground motions at each site for rupture of each segment: P_1, P_2, P_3, P_4.

Then find the probability of having one or more ground motion exceedances in 50 years at each site (union of P_1, P_2, P_3, P_4)
[after Toro and Silva, 2001]

probability of one or more exceedances of $u_0 =$

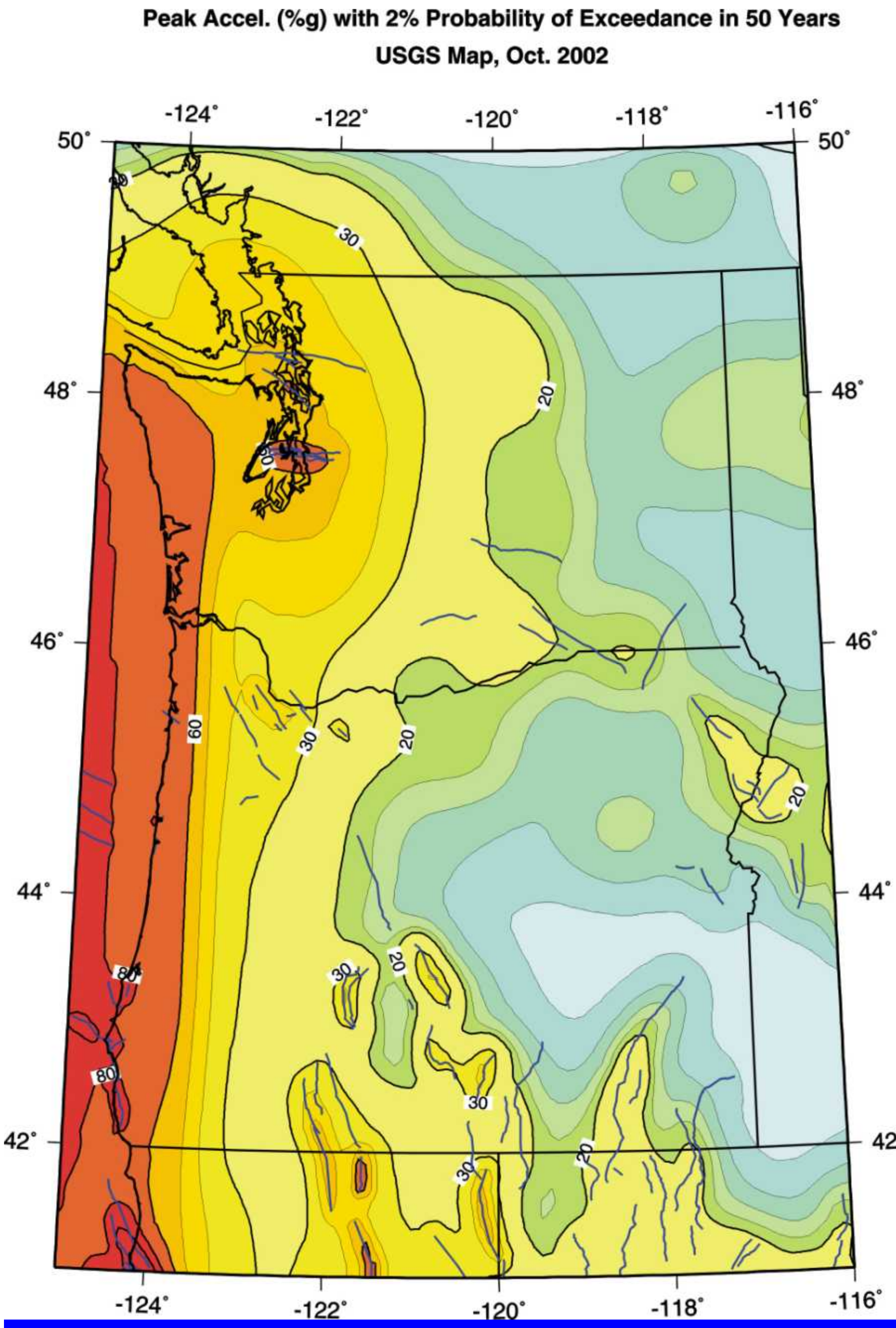
$$P_1 + P_2 + P_3 + P_4 - P_1P_2 - P_2P_3$$

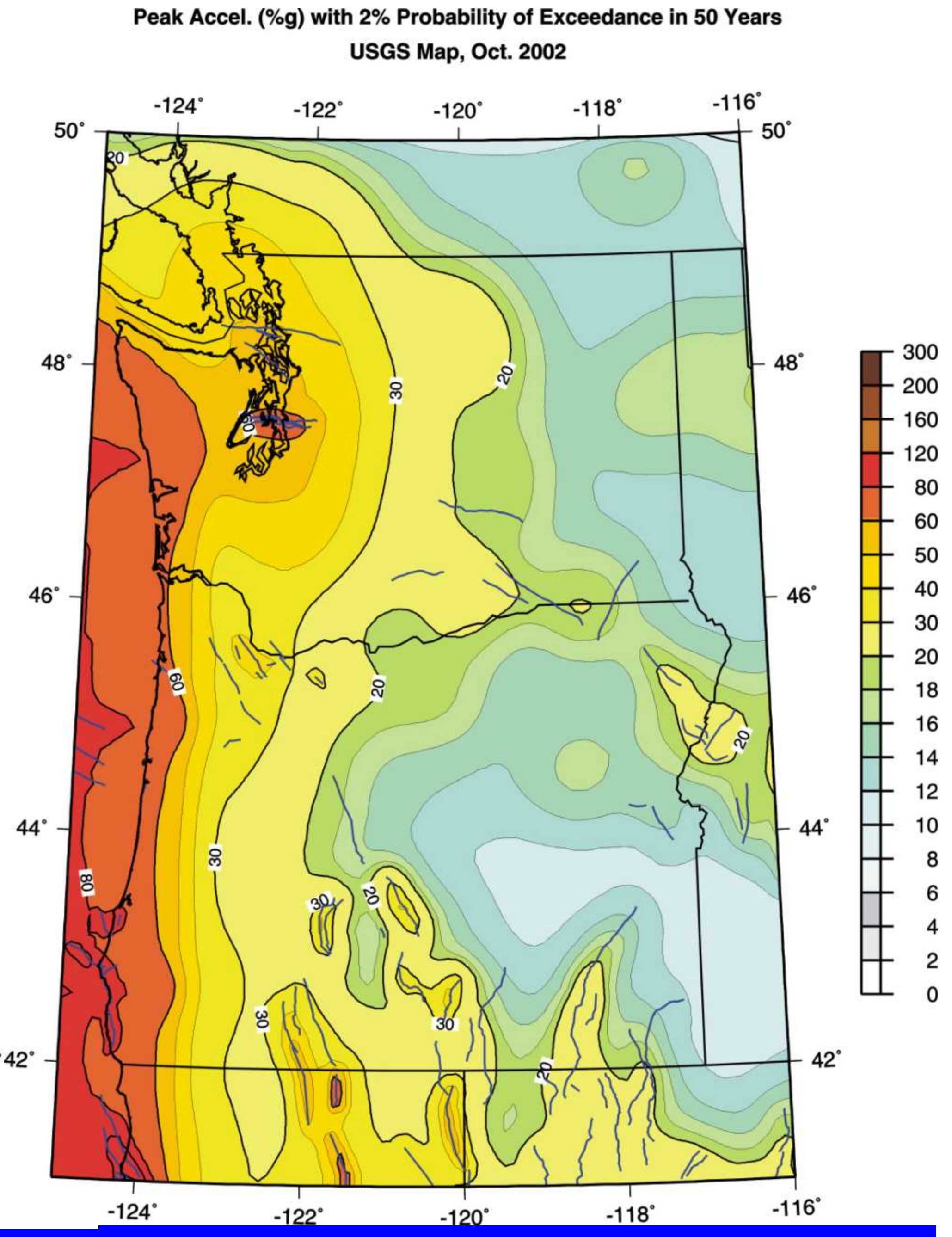
$$-P_3P_4 - P_1P_3 - P_1P_4 - P_2P_4$$

$$+P_1P_2P_3 + P_1P_3P_4 + P_1P_2P_4 + P_2P_3P_4$$

$$-P_1P_2P_3P_4$$

where P_i is the probability of earthquake on segment i producing ground motion greater than u_0

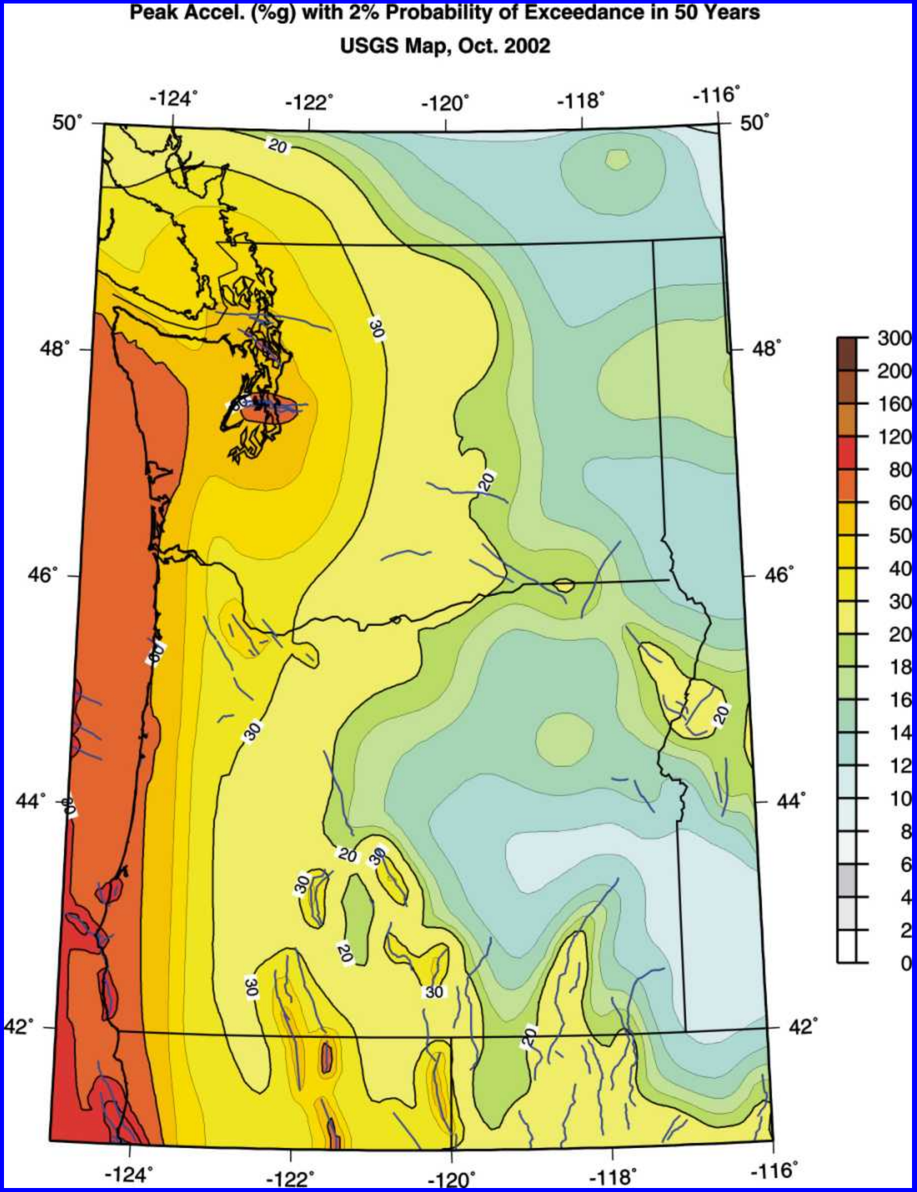

Peak Accel. (%g) with 2% Probability of Exceedance in 50 Years
USGS Map, Oct. 2002


Peak Accel. (%g) with 2% Probability of Exceedance in 50 Years
USGS Map, Oct. 2002

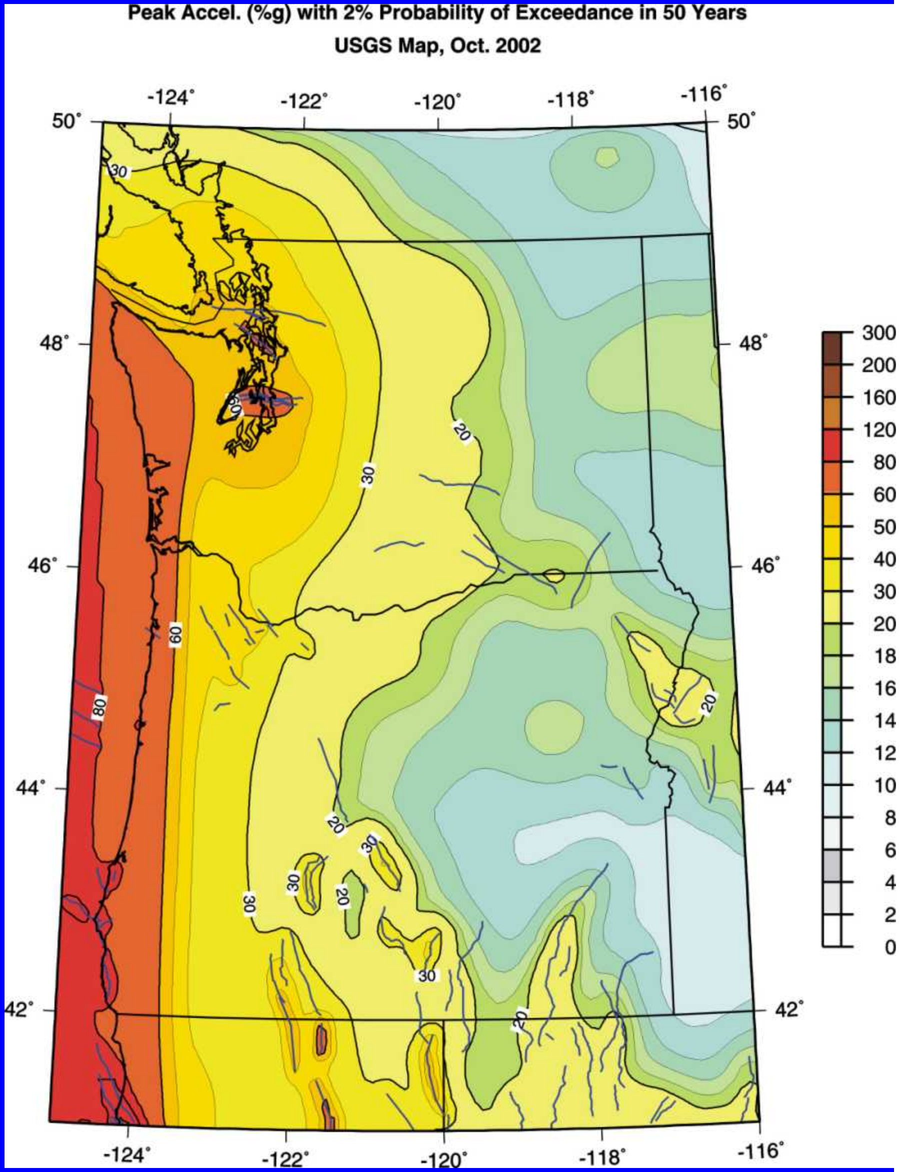
Time independent M8.3's

Clustered M8.3's

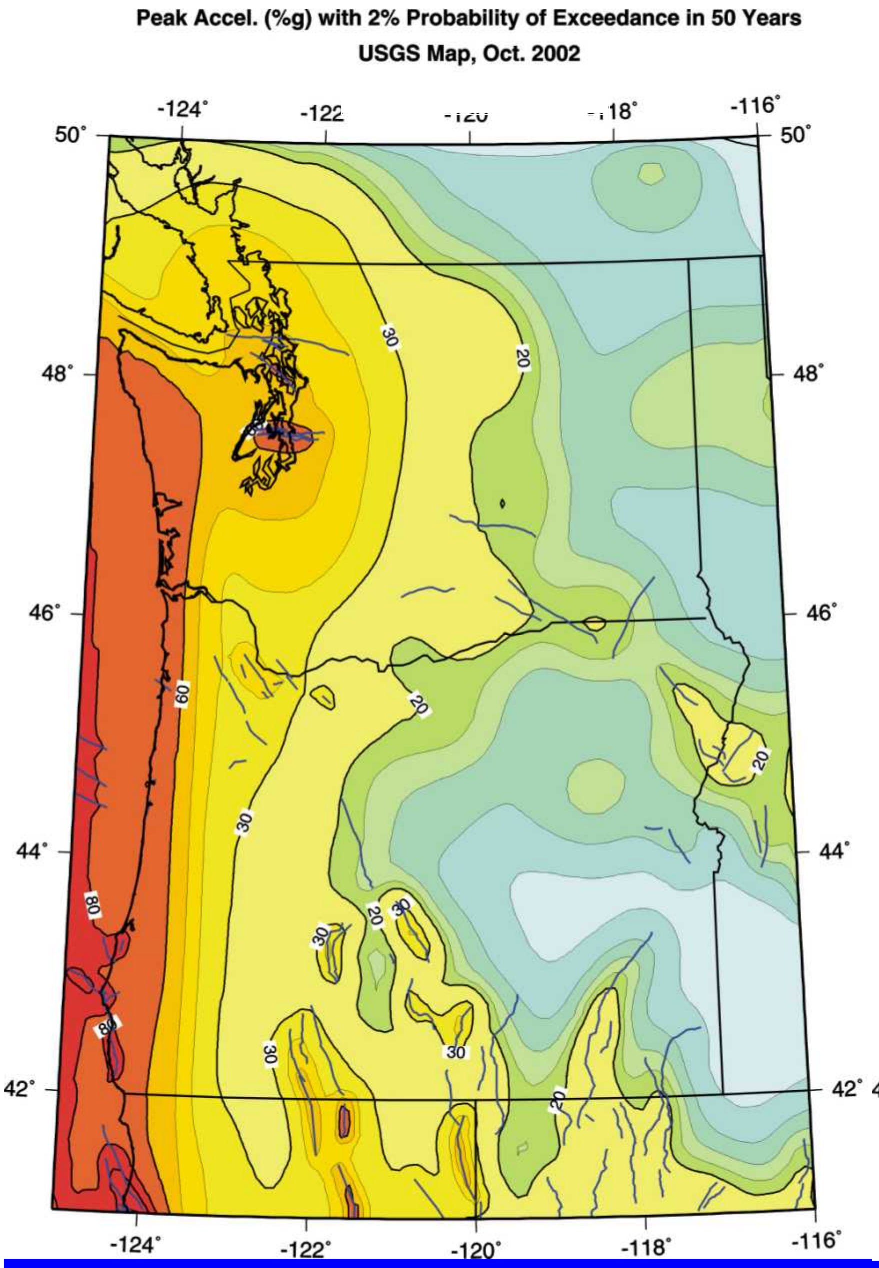
USGS
science for a changing world



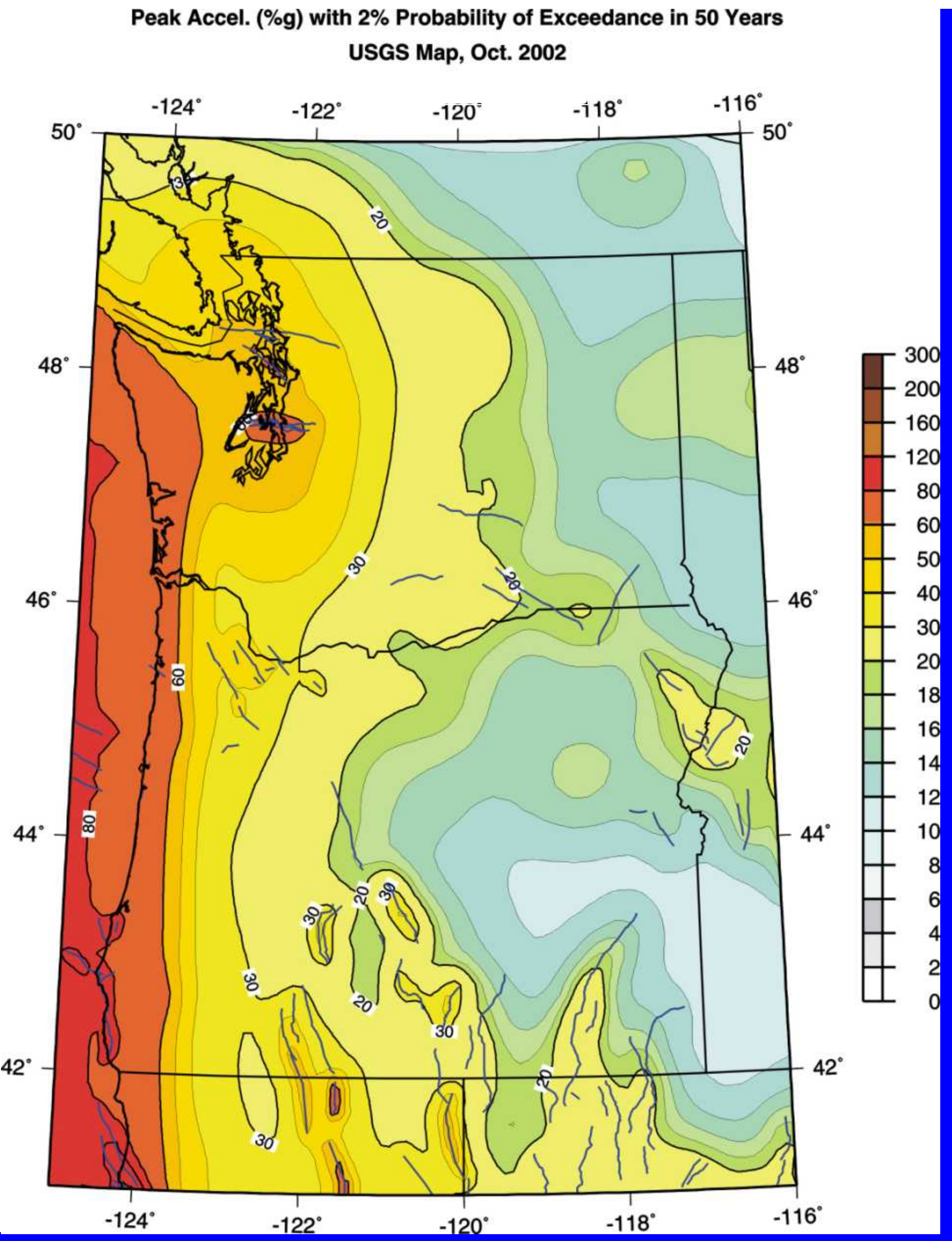
Time independent M9



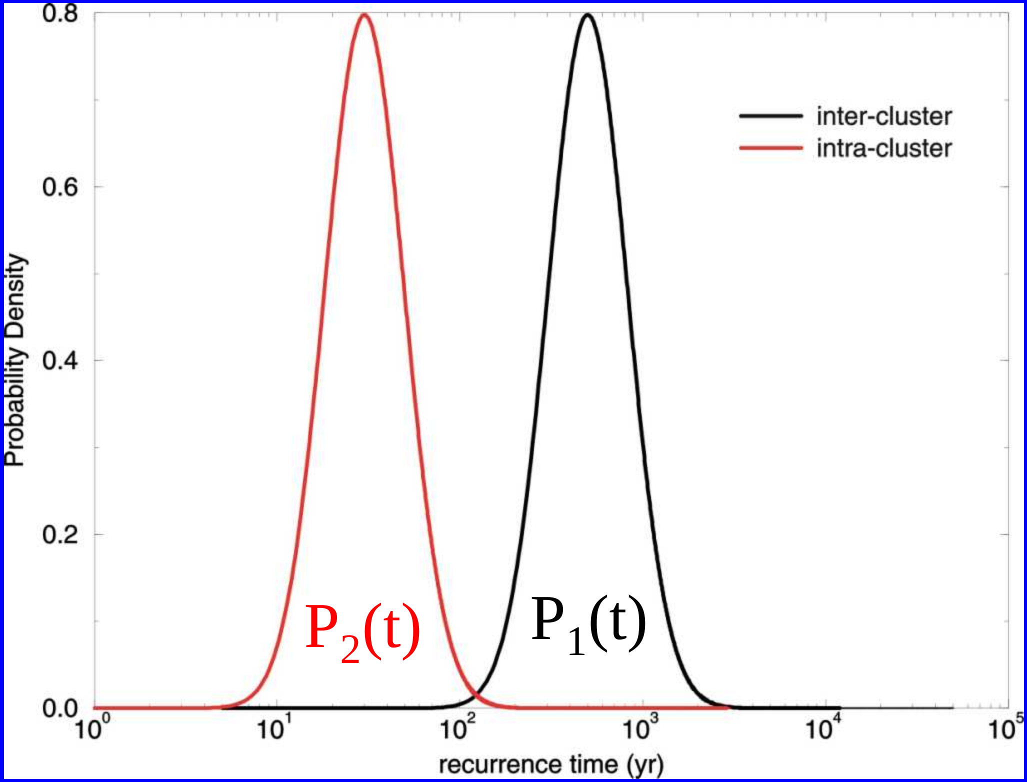
Time-dependent M9



Time independent



With time dependent M8 and M9 equal weight



For intra-cluster median of 1 year and inter-cluster median of 500 yr, get 14% probability for next 50 yr, for each segment (assume COV's of 0.5)

For intra-cluster median of 20 years and inter-cluster median of 500 yr, get 9% probability for next 50 yr, for each segment (assume COV's of 0.5)

Probability of segment rupture in next Δt years:

$$\frac{1}{n}\,\frac{\int_{t_e}^{t_e+\Delta t} P_1(t)\,dt}{\int_{t_e}^{\infty} P_1(t)\,dt} + \frac{n-1}{n}\,\frac{\int_{t_e}^{t_e+\Delta t}\int_{0}^{\Delta t-t_1} P_2(t_2)\,P_1(t_1)\,dt_2\,dt_1}{\int_{t_e}^{\infty} P_1(t)\,dt}$$

n is number of rupture segments, t_e is time since last earthquake