Subduction Zone Ground Motion Models

Subduction ground motion prediction equations

Subduction interface (2008)

- Atkinson and Boore (GLOBAL) (0.25)
- Youngs et al. (0.25)
- Zhao et al. (0.5)

Subduction interface (2014)

- (new) Atkinson and Macias
- (old-replace?) Atkinson-Boore
- (new) BC Hydro
- (old) Youngs et al.
- Zhao et al. with magnitude saturation

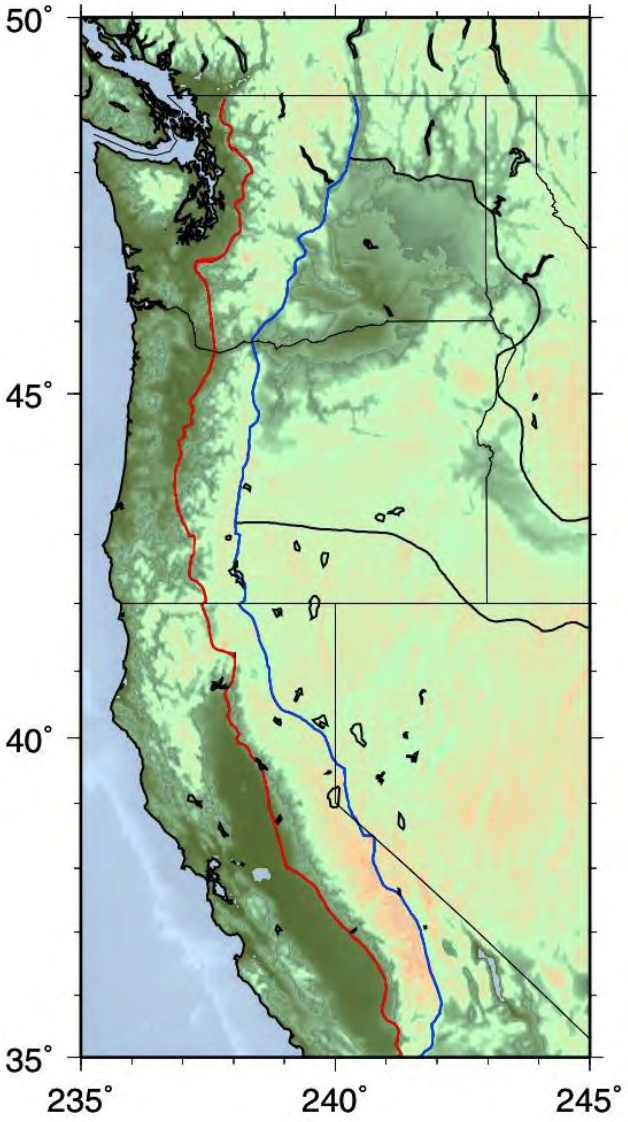
Intraslab (2008)

- Atkinson-Boore, global, 0.25)
- Atkinson-Boore, Cascadia 0.25)
- Youngs et al. (0.5)

Intraslab (2014)

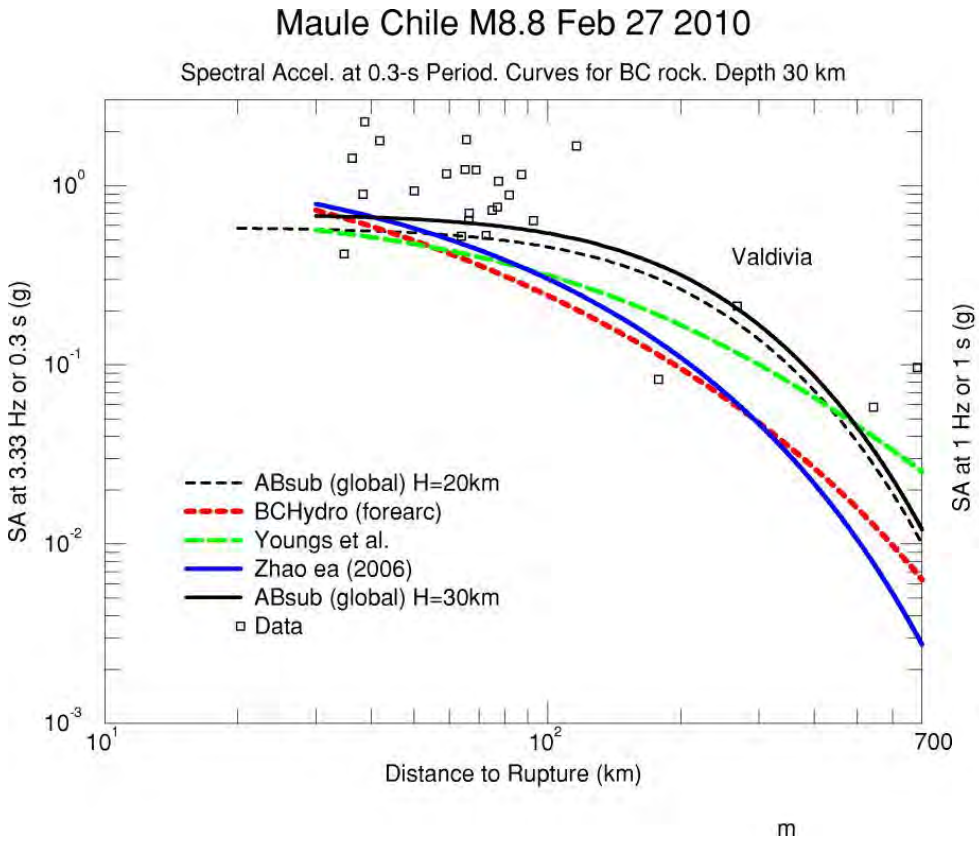
- (new) Zhao et al.
- (new) BC Hydro
- (old) Atkinson-Boore (global)
- (old) Atkinson-Boore (Cascadia)

Tectonic boundaries for GMPE's



1. Tectonic boundaries – red eastern boundary of forearc, blue western boundary of backarc
2. How do these boundaries relate to BC Hydro and Ghofrani and Atkinson backarc definitions?

Interface ground motions: 0.3 s and 1 s M 8.8 Maule Chile data



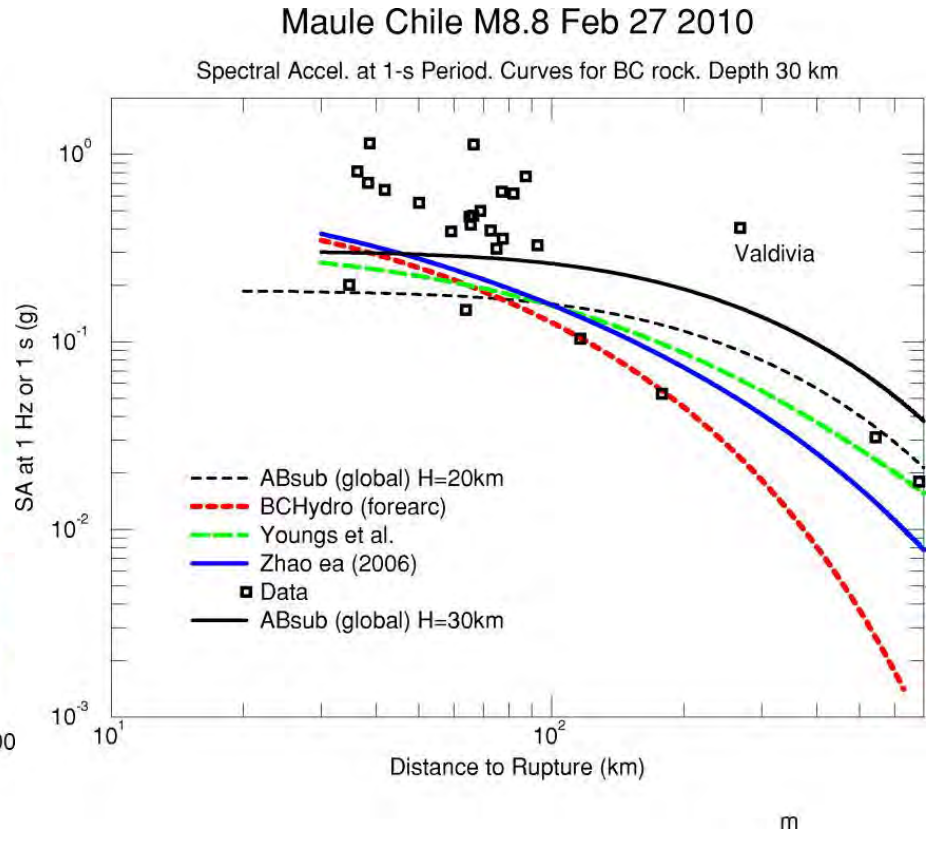
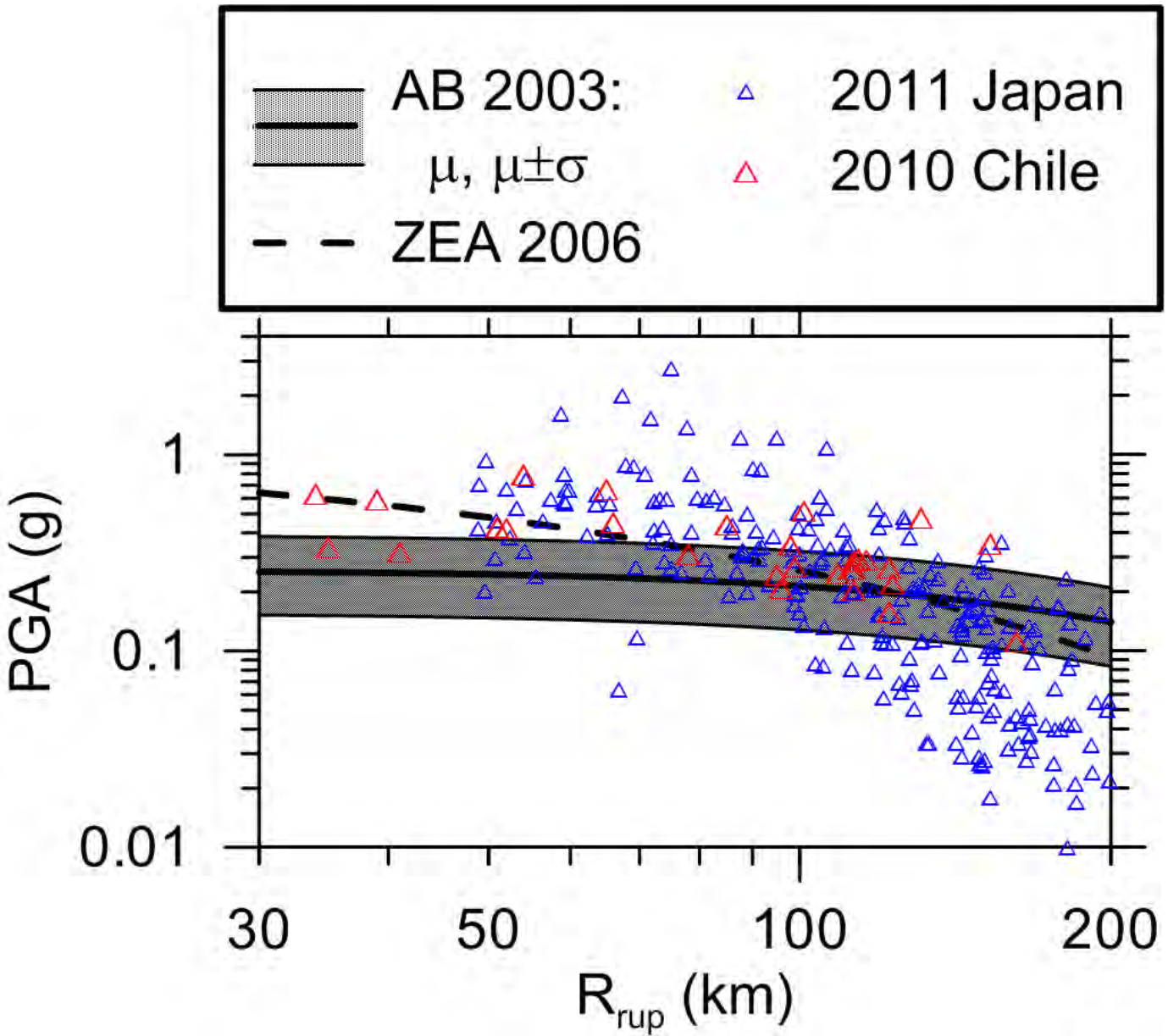


Figure from Jonathan Stewart, UCLA

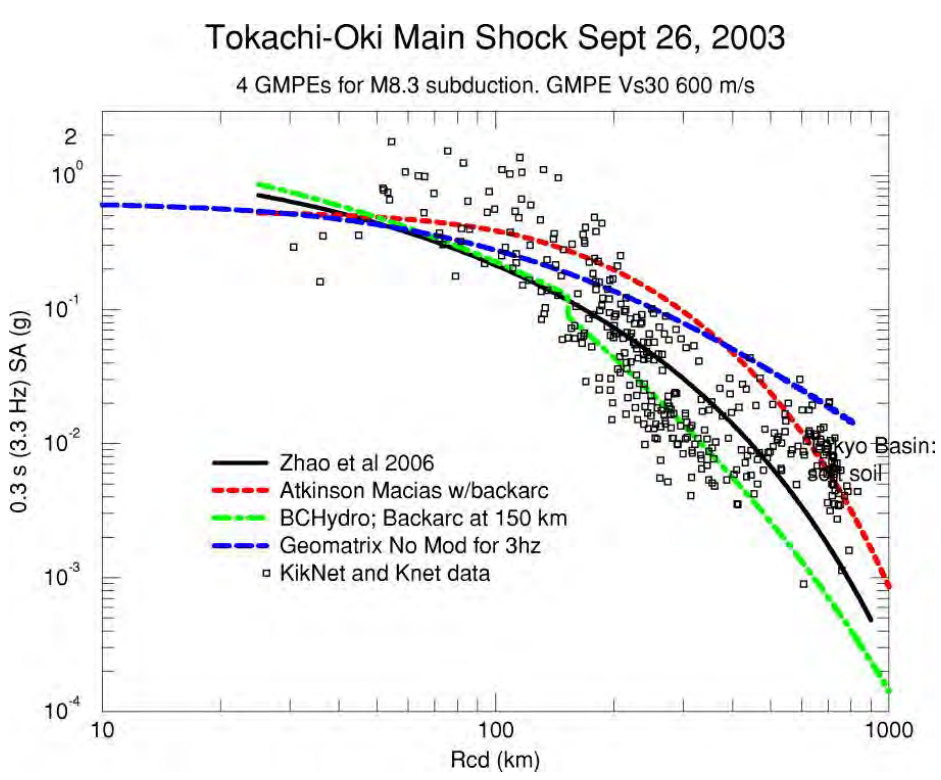
Distance Scaling

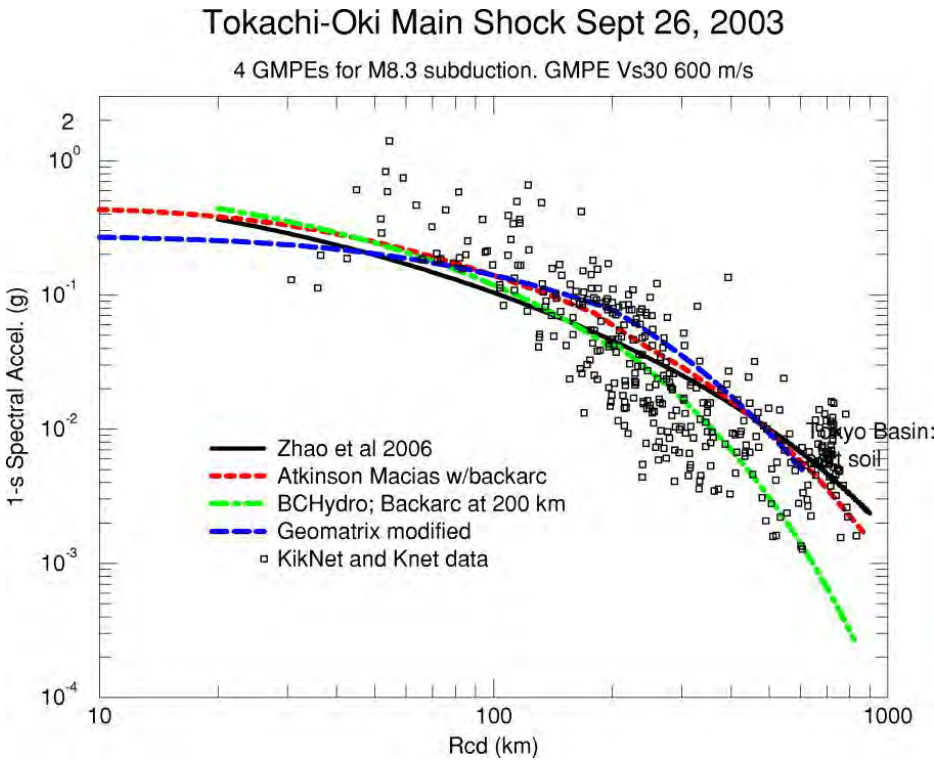


High PGA's for Tohoku EQ are partly caused by site amplification (thin soil over hard rock); This type of site is not typical for the PacNW.

However, it is found in the Portland Hills area.

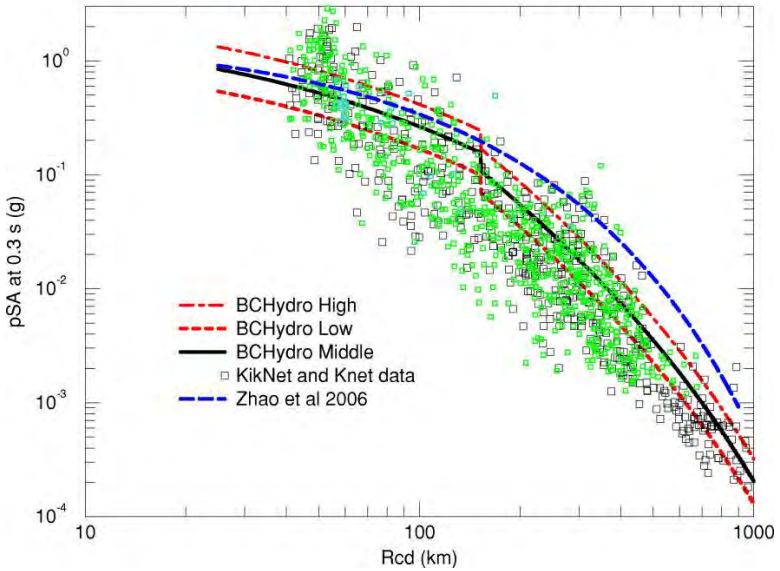
Interface ground motions: 0.3 s and 1 s
M 8.3 Tokachi-Oki Japan data





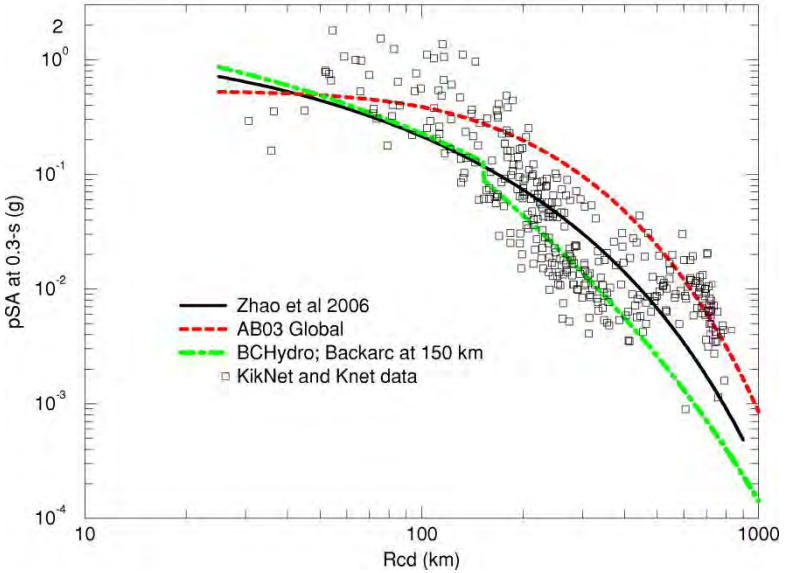
Tohoku Main Shock Mar 11 2011

GMPEs for M9 subduction. GMPE Vs30 760 m/s. Z 25 km.



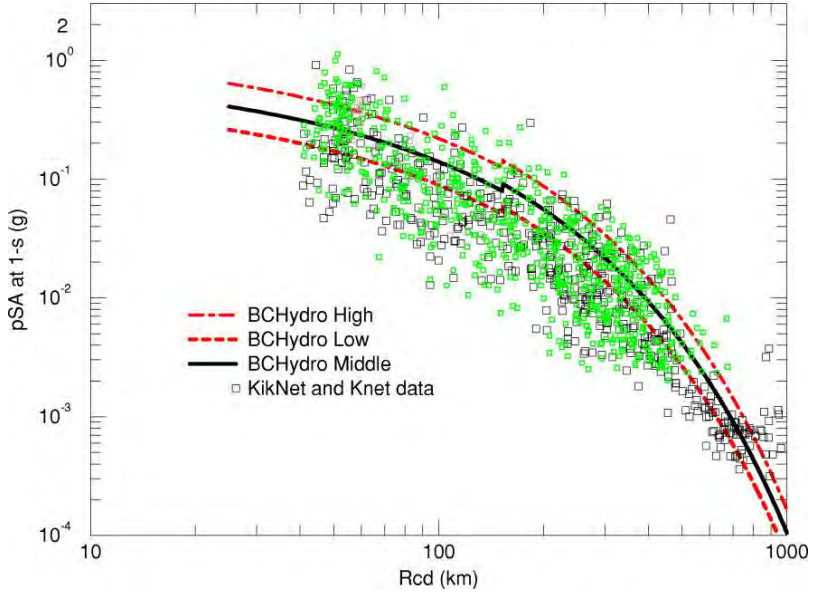
Tokachi-Oki Main Shock Sept 26, 2003

3 GMPEs for M8.3 subduction. Site Vs30 600 m/s



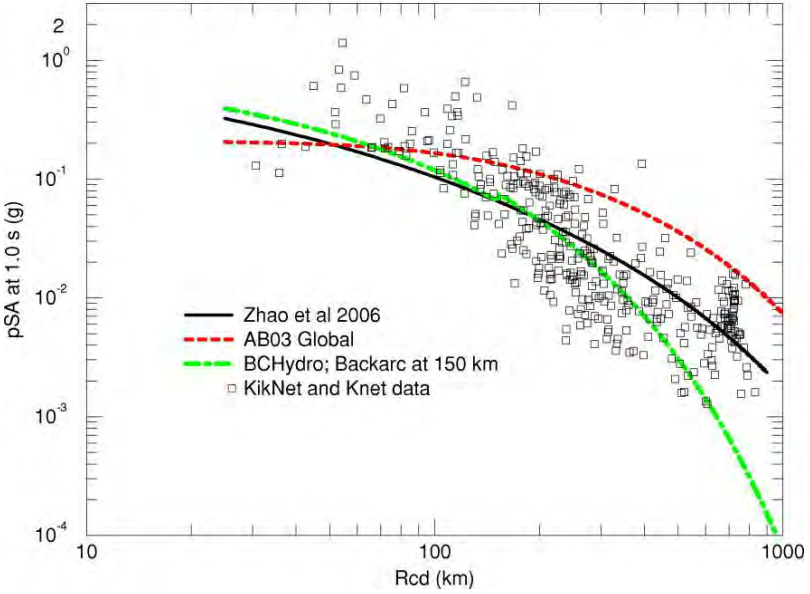
Tohoku Main Shock Mar 11 2011

BCHydro GMPE for M9 subduction. GMPE Vs30 760 m/s. Z 25 km.

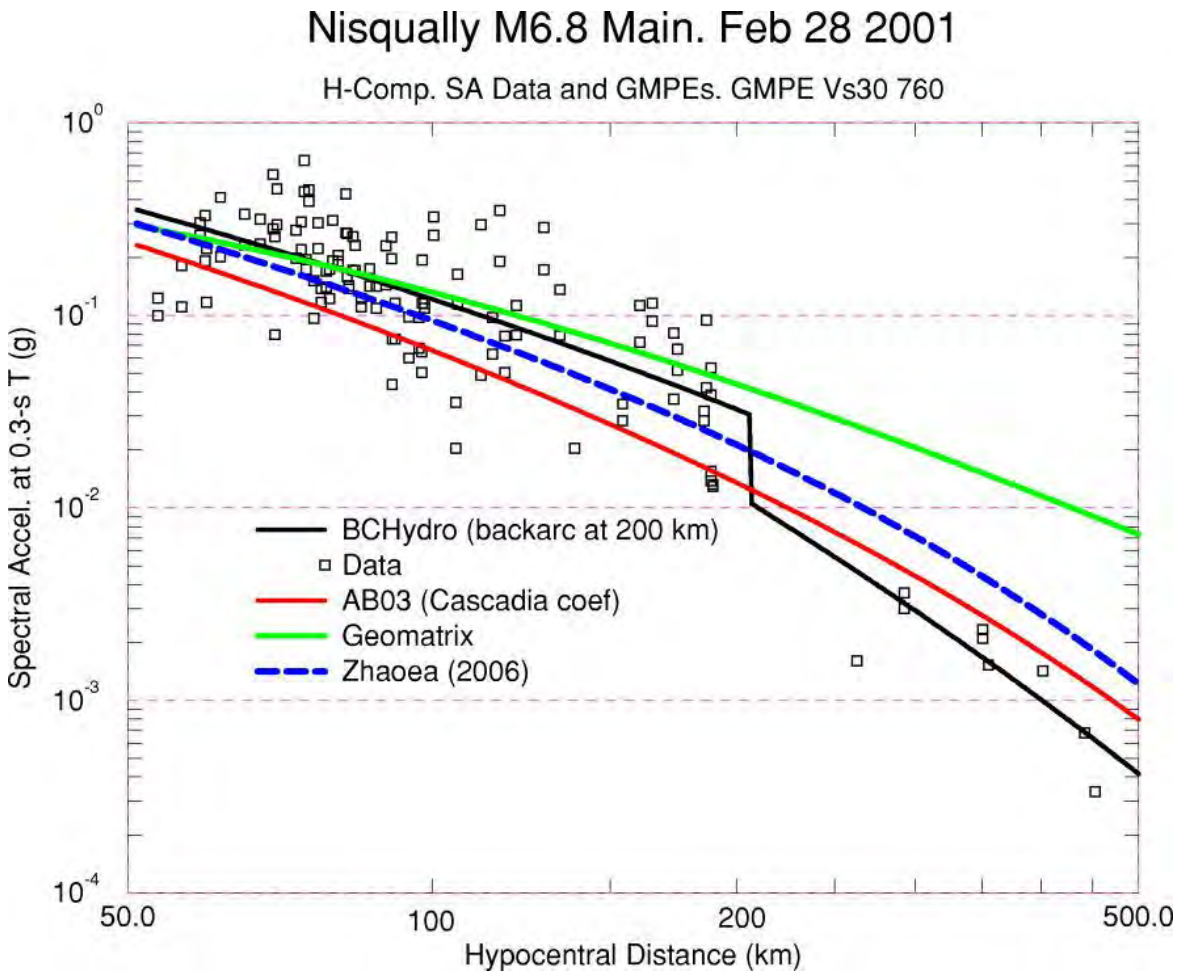


Tokachi-Oki Main Shock Sept 26, 2003

3 GMPEs for M8.3 subduction. Site Vs30 600 m/s



Comparison between Nisqually deep data



Sensitivity Studies for Interface and Intraslab earthquakes

Ground motion prediction equations

Subduction interface (2008)

- Atkinson and Boore (GLOBAL) (0.25) Atkinson and Boore (2003) used a global subduction dataset containing 1200 horizontal-component spectra compiled for earthquakes through 2001. They found that the Cascade region of northwest U.S. and southwest Canada and the area surrounding Japan showed regional variations. Site classification for NEHRP categories.
- Youngs et al. (0.25) Youngs and others (1997) used a global subduction dataset containing 350 horizontal-component response spectra compiled for earthquakes through 1989, by adding data to a version of the subduction database compiled by Crouse (1991). Youngs et al (1997) developed their attenuation relationship for subduction zone interface and intraslab earthquakes of moment magnitude M 5 and greater and for distances of 10 to 500 km. In addition, they simulated ground motions from large interface earthquakes to determine the appropriateness of their model for moment magnitude and distance between the site and the rupture (R_{rup}) that were not well represented in their dataset. Specifically, they simulated earthquakes with Mw > 8 for interface earthquakes and R_{rup} less than 30 km, as well as distances greater than 300 km, for both interface and intraslab earthquakes. They provide regression coefficients for rock and soil site classes.
- Zhao et al. (0.5) Zhao et al (2006) used a global dataset containing 4726 horizontal-component spectra. Records from the Japan region made up the majority at 4518 records. In this dataset 1285 were from crustal events, 1508 were from interface events, and 1725 were from intraslab events. The magnitude distribution varies between Mw 5 and 8, with most earthquakes having magnitudes less than 6.0. The focal depth distribution for the interface events ranges fairly evenly between 15 and 50 km. The intraslab events have distances that are distributed less evenly between 20 and 125 km, with most events occurring between 45 and 80 km. Zhao and others (2006) consider four site classes SC I, II, III, and IV which they claim are similar to rock, hard soil, medium soil, and soft soil, respectively.

Subduction interface (2014)

- (new) Atkinson and Macias, M 7.5-9 in Cascadia, simulation based with calibration from M 8.1 Tokachi-Oki earthquake.
- Atkinson-Boore
- (new) BC Hydro,
- Youngs et al.
- (new) Zhao et al. w saturation

Subduction interface 1hz

2008 model

New

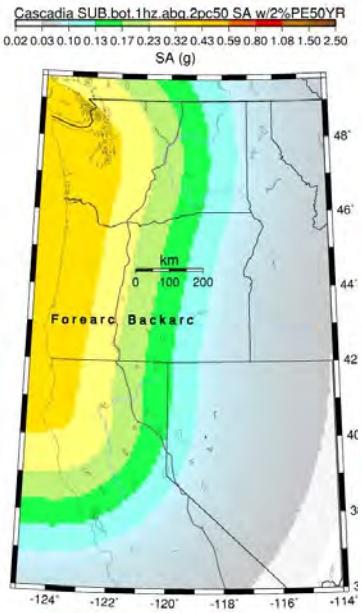
A-B (Global)

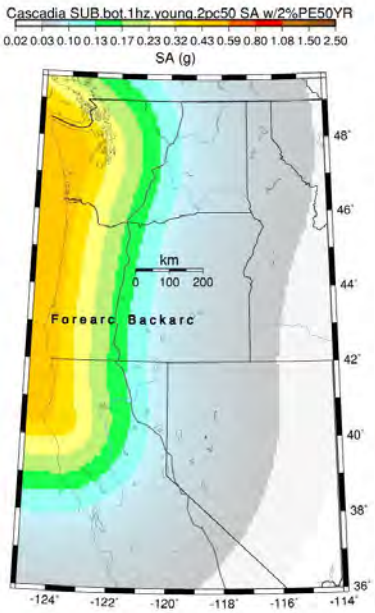
Youngs et al.

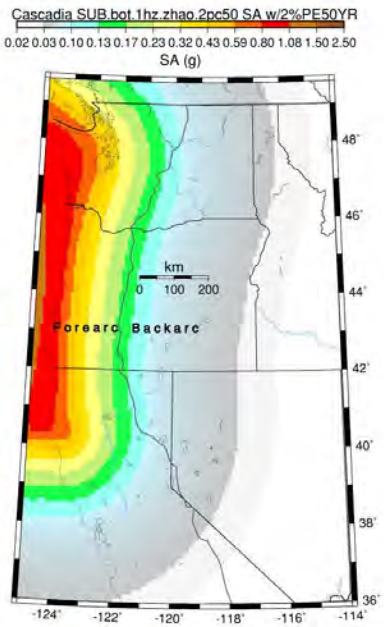
Zhao et al.

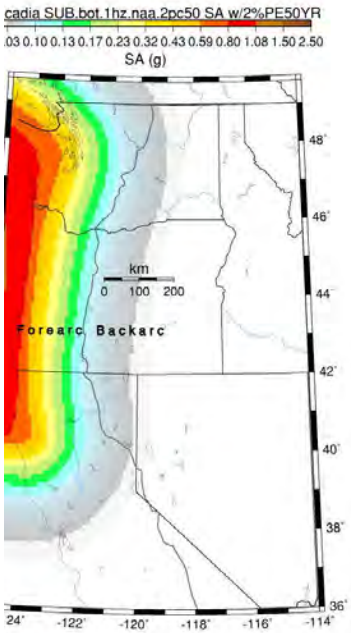
BC Hydro

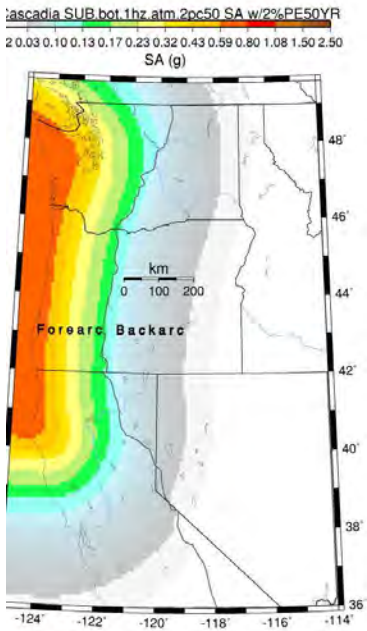
Atkinson-Macias

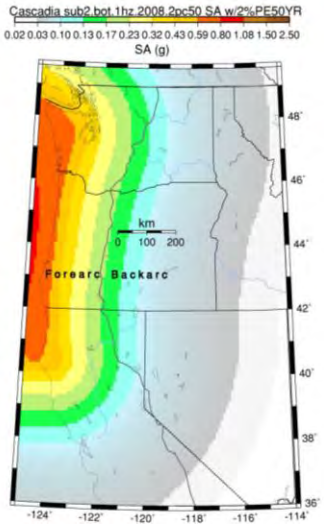


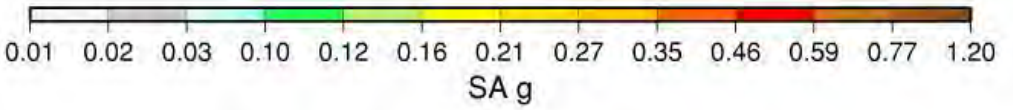










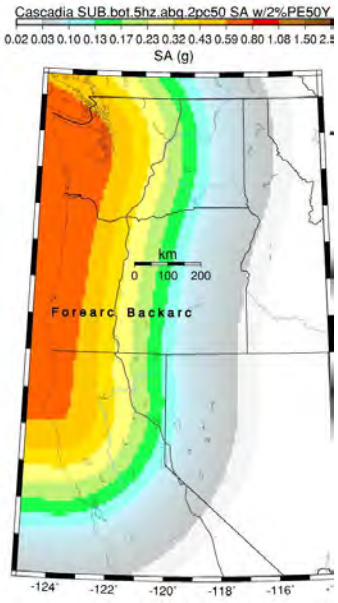


Subduction interface 5 hz

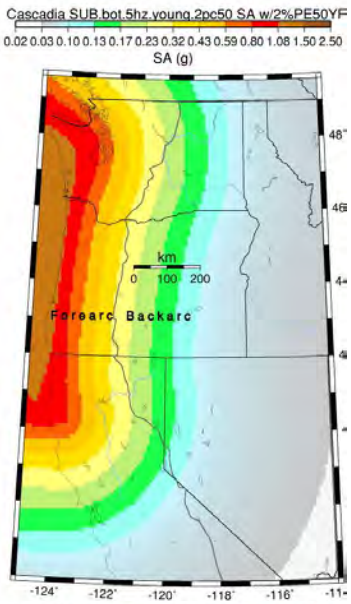
2008 model

New

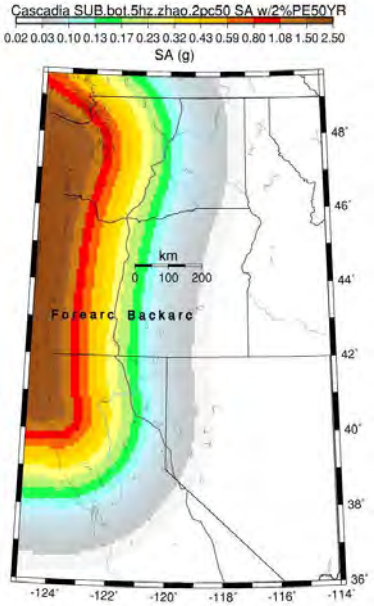
A-B (Global)



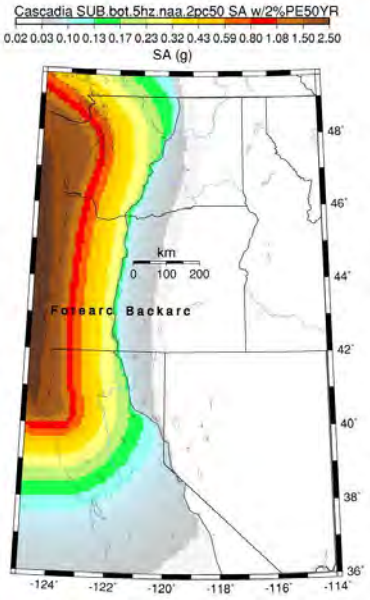
Youngs et al.



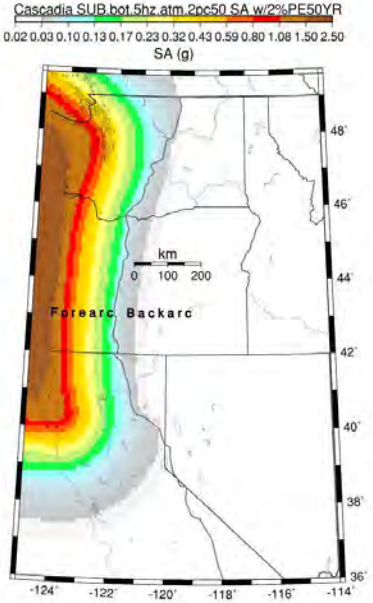
Zhao et al.

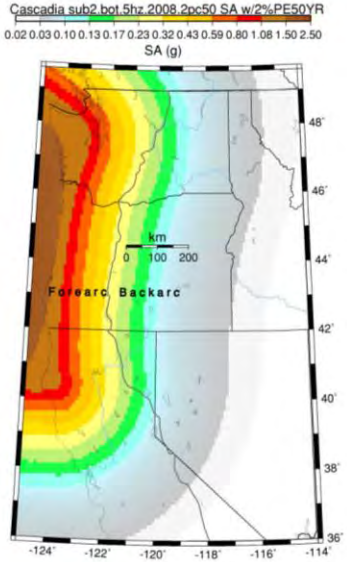


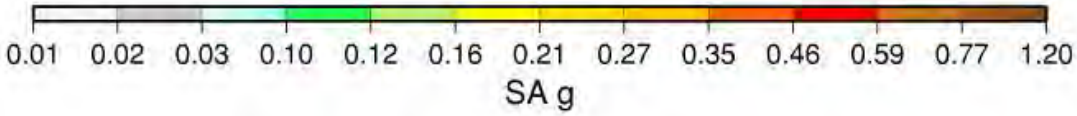
BC Hydro



Atkinson-Macias

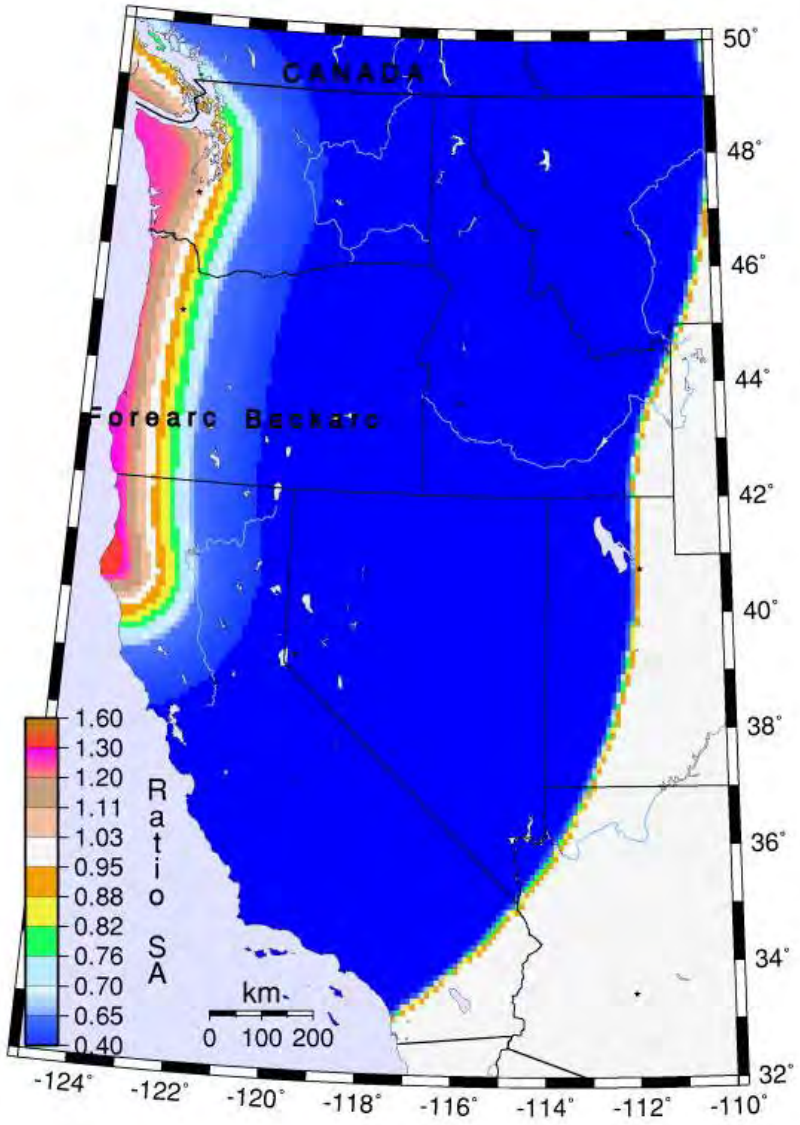






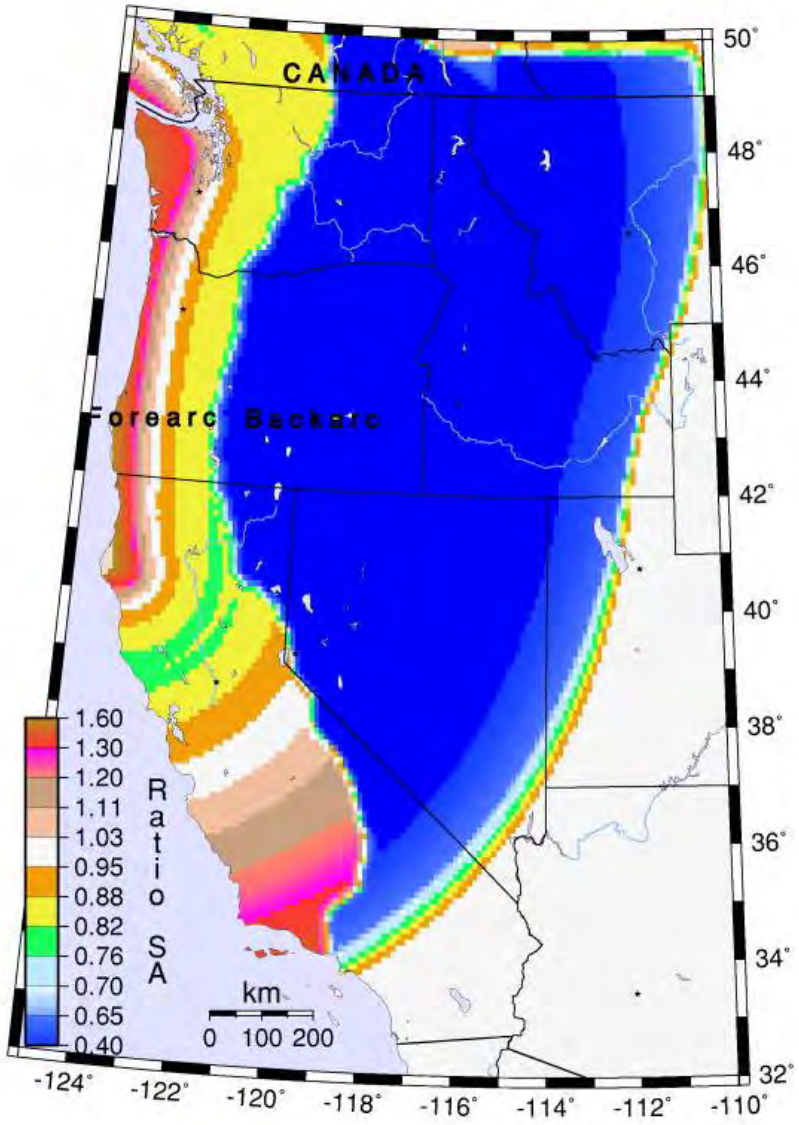
Comparison of BC Hydro to 2008 maps

Cascadia casc.naa_o_2008.1hz ratio SA w/2%PE50YR



GMT 2012 Nov 21 09:47:12 Spectral acceleration ratios from casc.naa_o_2008.1hz. BC rock site condition.

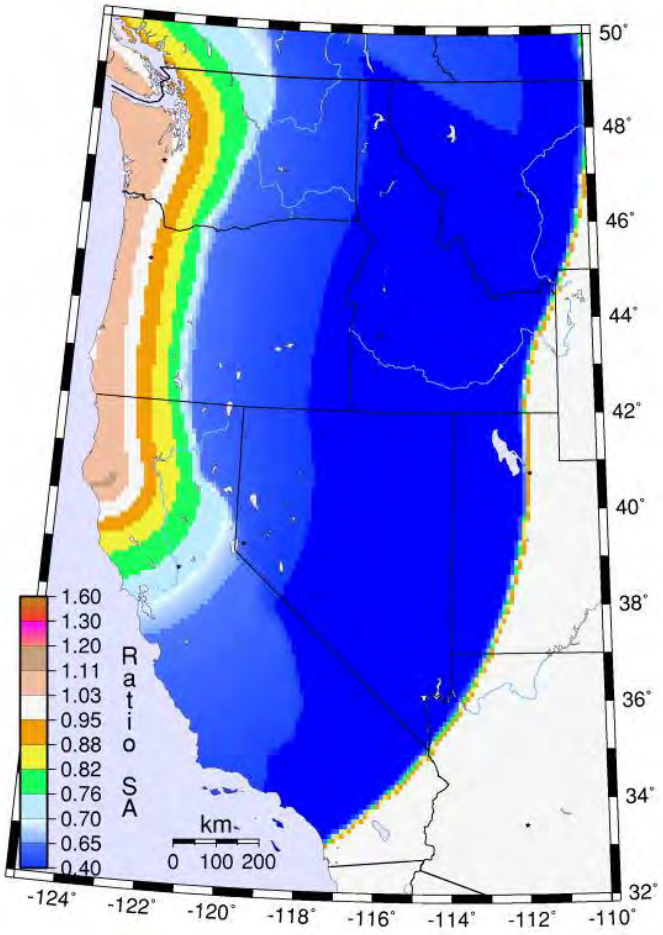
Cascadia casc.naa_o_2008.5hz ratio SA w/2%PE50YR



2012 Nov 21 09:45:08 Spectral acceleration ratios from casc.naa_o_2008.5hz. BC rock site condition.

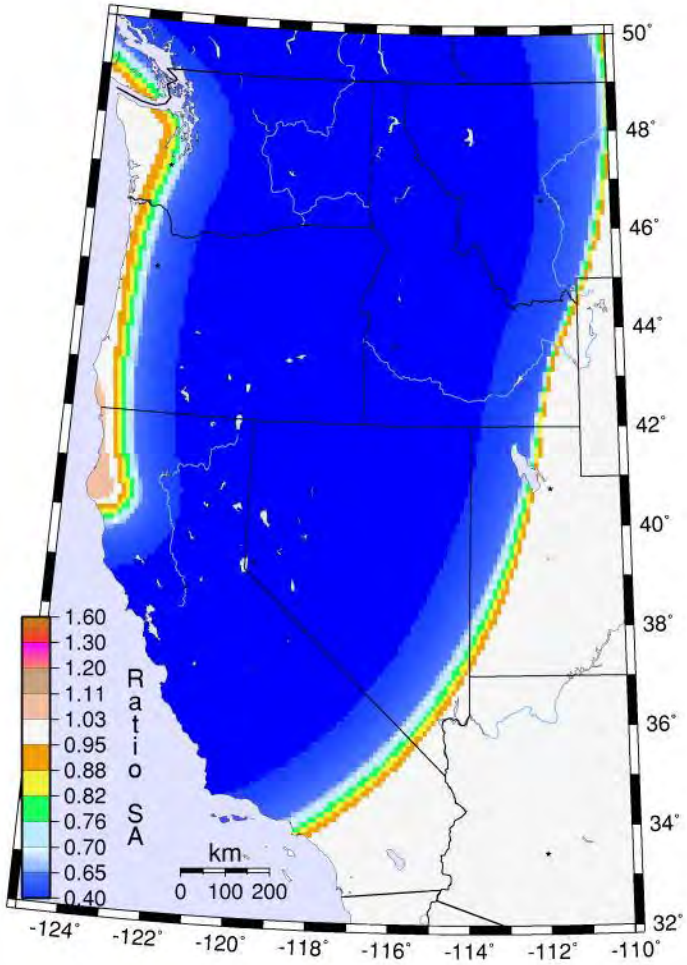
Comparison of Atkinson and Macias to 2008 maps

Cascadia casc.AtM_o_2008.1hz ratio SA w/2%PE50YR



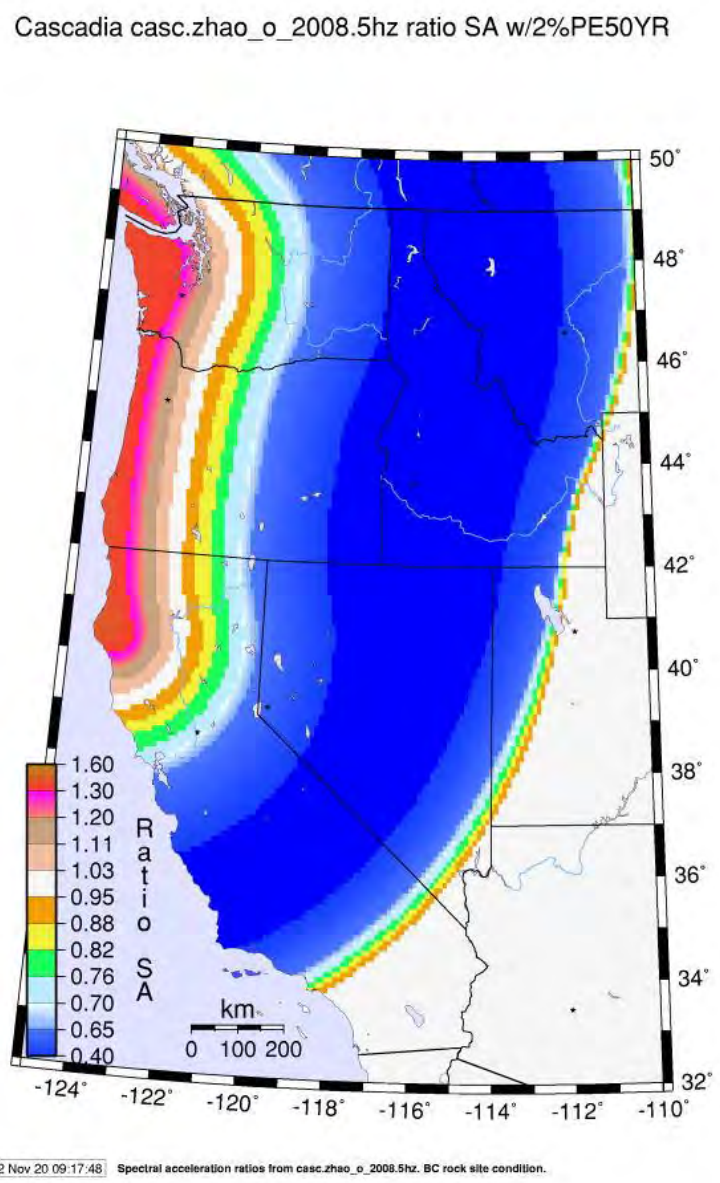
GMT 2012 Nov 20 09:21:08 Spectral acceleration ratios from casc.AtM_o_2008.1hz. BC rock site condition.

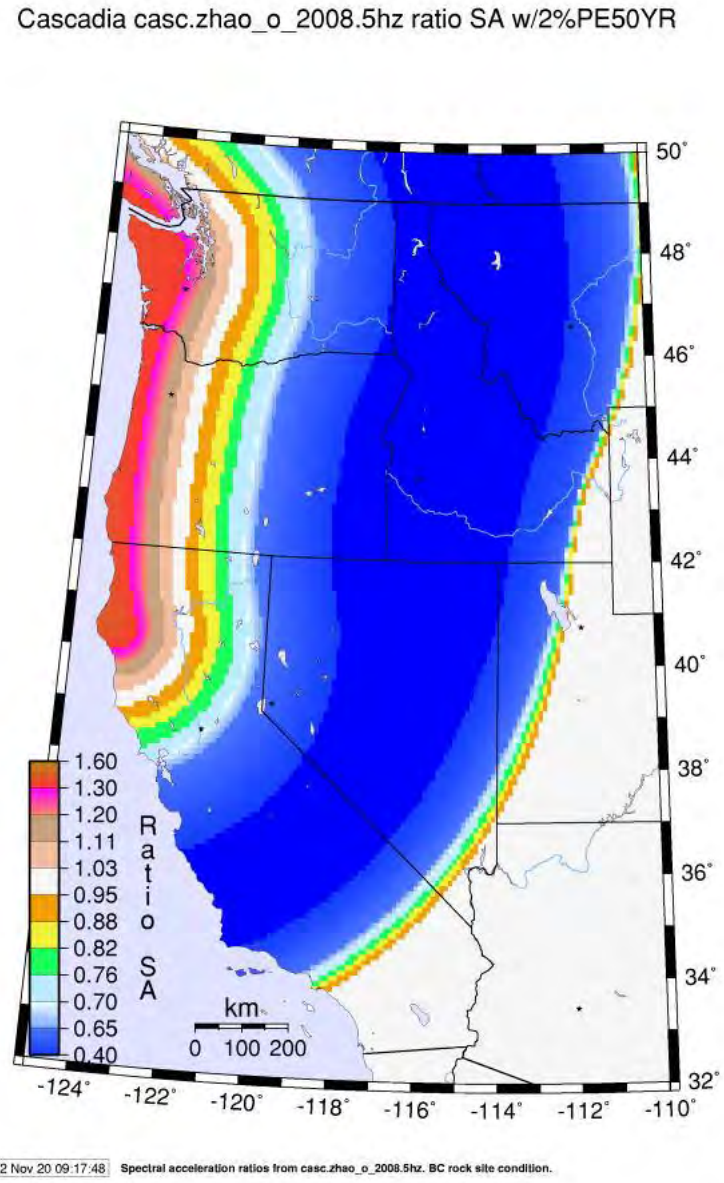
Cascadia casc.AtM_o_2008.5hz ratio SA w/2%PE50YR



GMT 2012 Nov 20 09:22:59 Spectral acceleration ratios from casc.AtM_o_2008.5hz. BC rock site condition.

Comparison of Zhao et al. to 2008 maps





Ground motion prediction equations (intraslab)

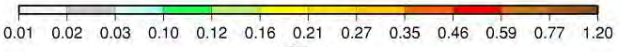
Intraslab (2008)

- Atkinson-Boore, global, 0.25)
- Atkinson-Boore, Cascadia 0.25)
- Youngs et al. (0.5)

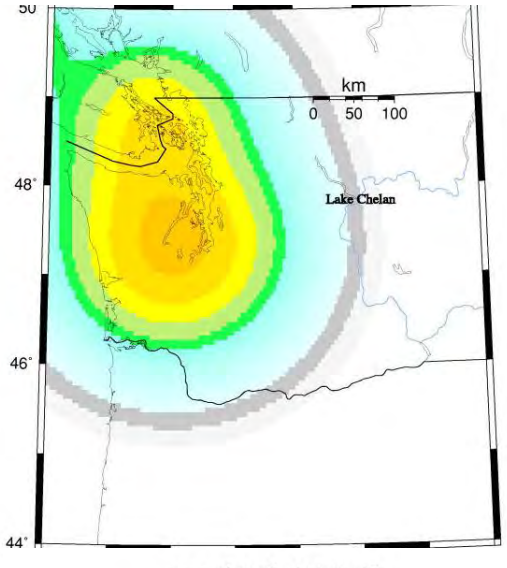
Intraslab (2014)

- (new) Zhao et al.
- (new) BC Hydro
- (old) Atkinson-Boore (global)
- (old) Atkinson-Boore (Cascadia)

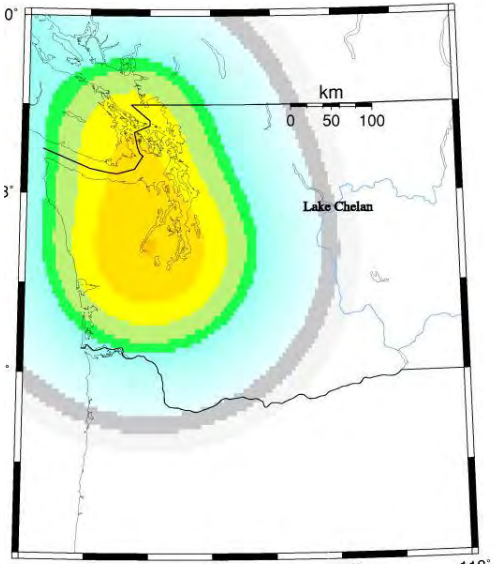
Deep earthquakes 1 hz, 2% in 50



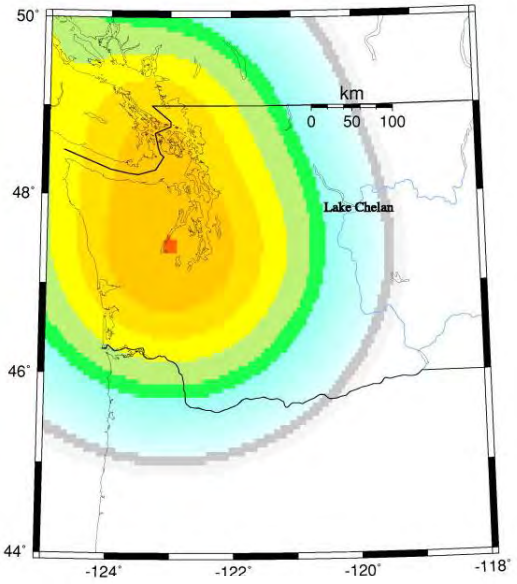
Atkinson and Boore (Cascadia)
0.25



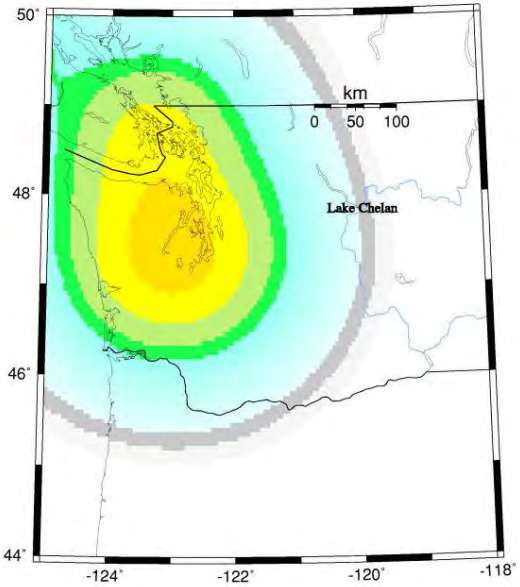
Atkinson and Boore (Global)
0.25



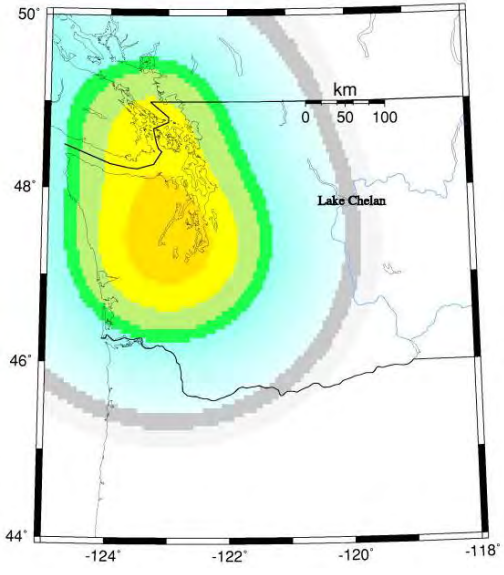
Youngs et al.
0.5



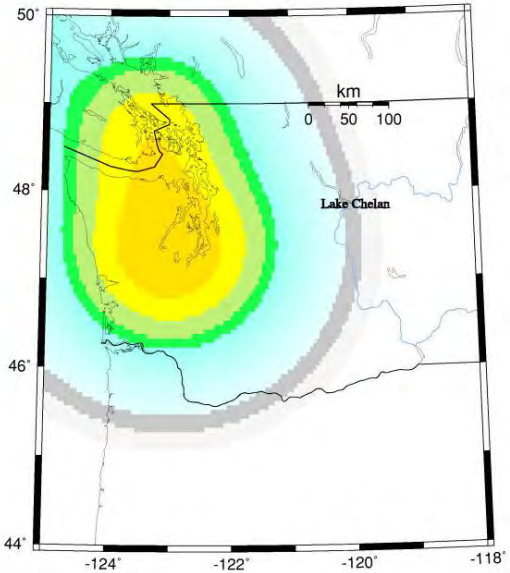
BC Hydro



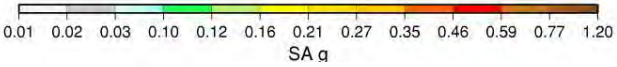
Zhao et al.



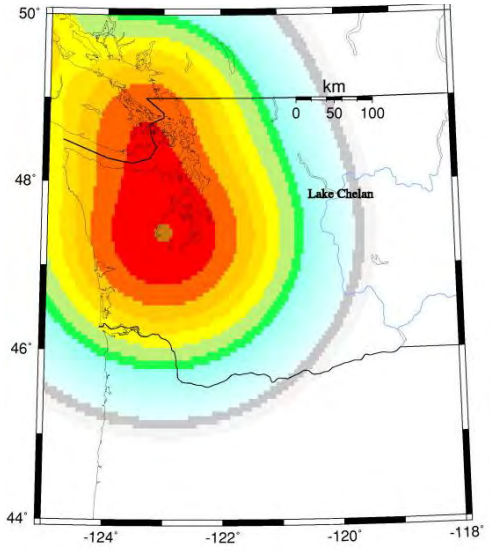
2008



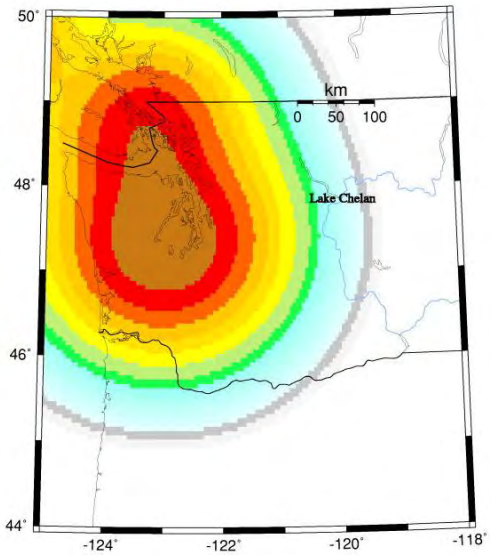
Deep earthquakes 5 hz, 2% in 50



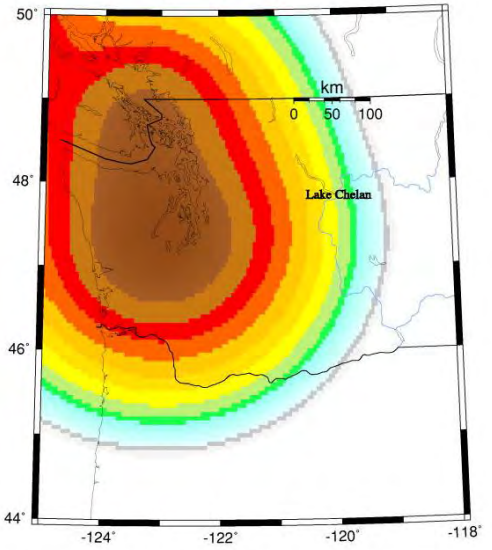
Atkinson and Boore (Cascadia)
0.25



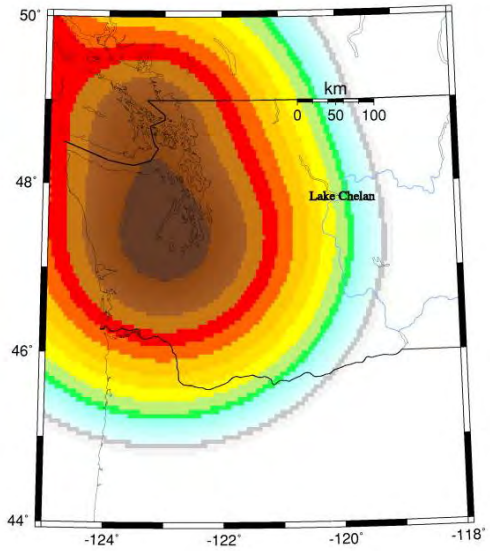
Atkinson and Boore (Global)
0.25



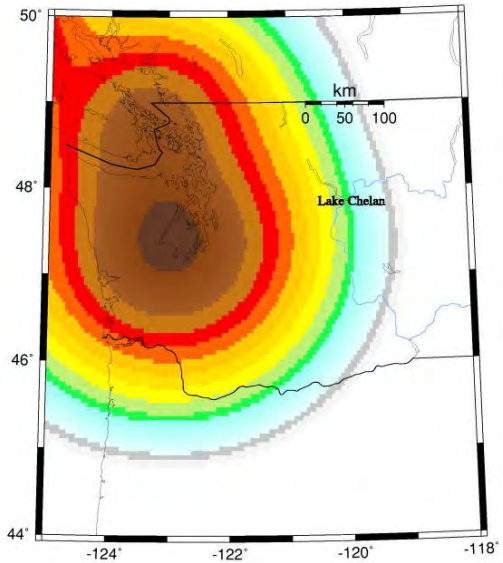
Youngs et al.
0.5



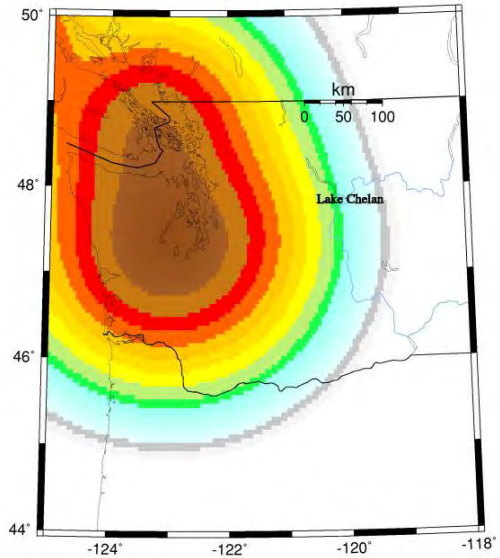
BC Hydro-new



Zhao et al.- new



2008



Conclusions

- New ground motion- Subduction Interface models typically higher in-close but decay much faster with distance
- Small changes in intraslab earthquake models
- Weighting?

Weighting of Subduction Interface and Intraslab Equations

Subduction interface 1hz

2008 model

New

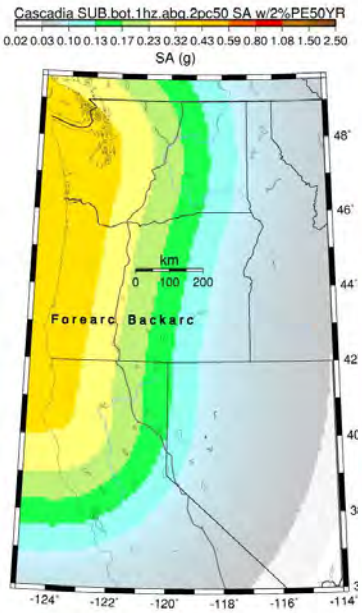
A-B (Global)

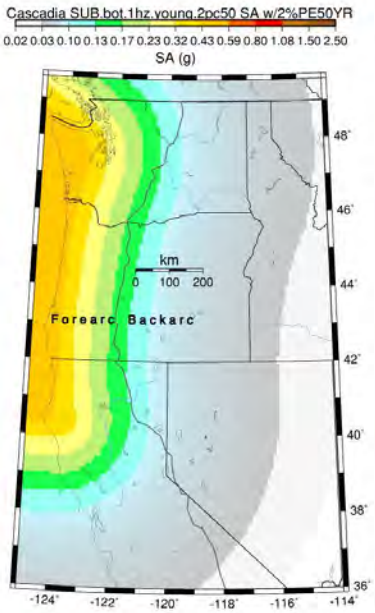
Youngs et al.

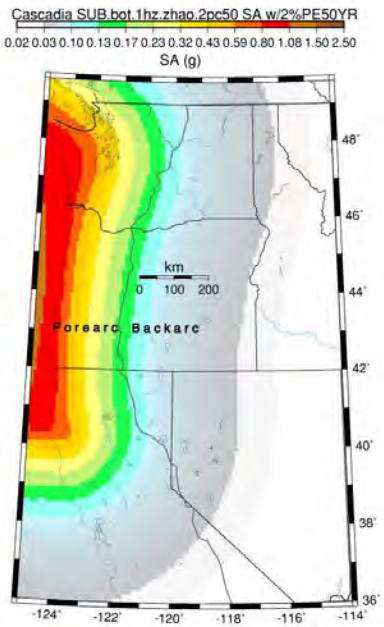
Zhao et al.

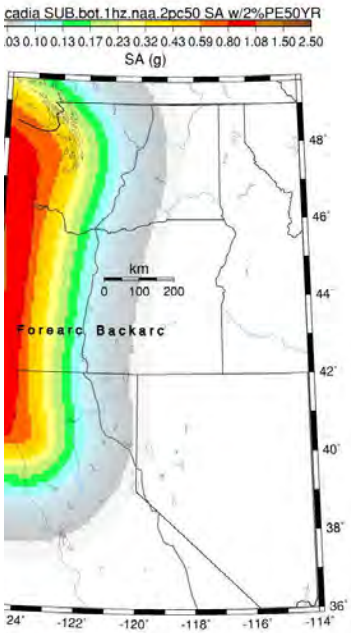
BC Hydro

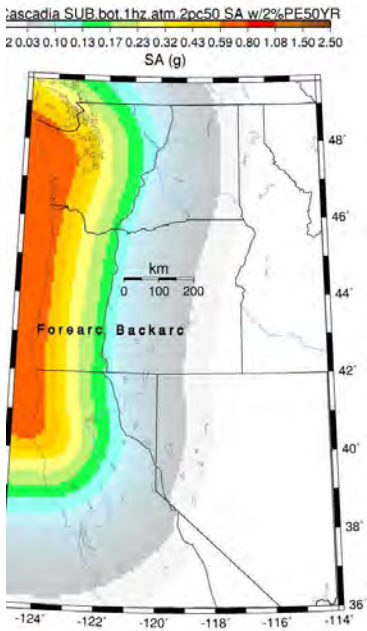
Atkinson-Macias

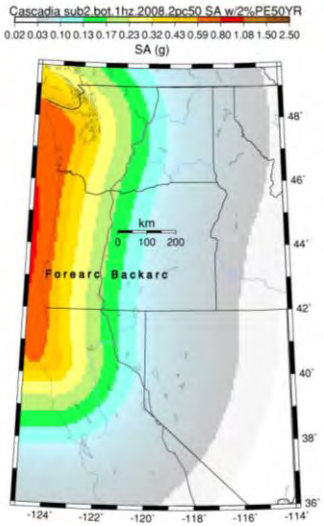


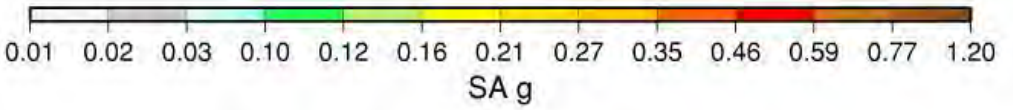










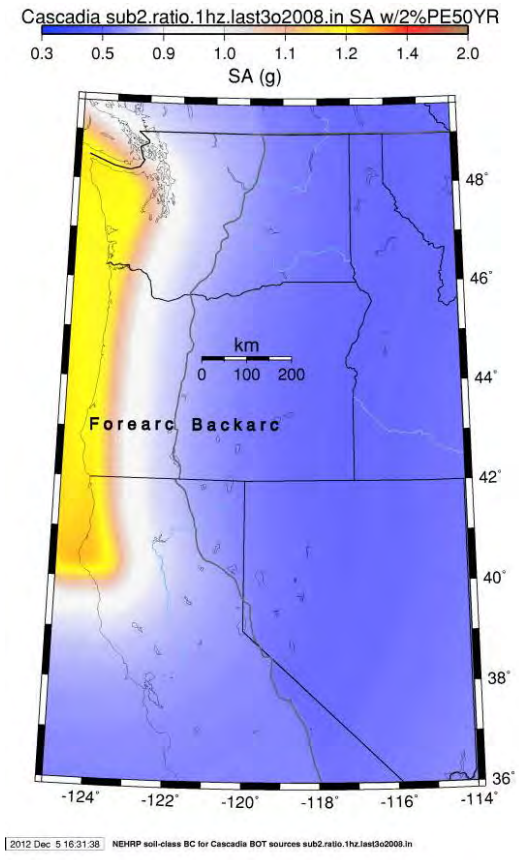


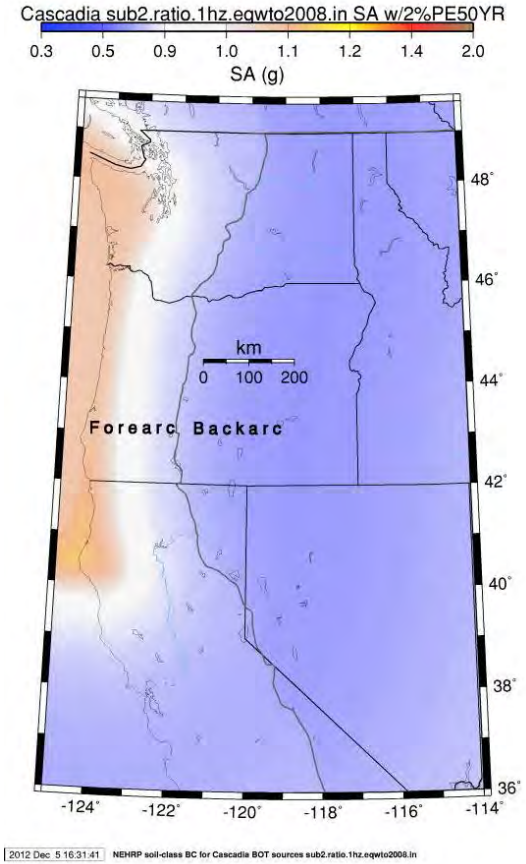
Potential Weighting, 1 hz, 2% in 50 Weighted models over 2008 model

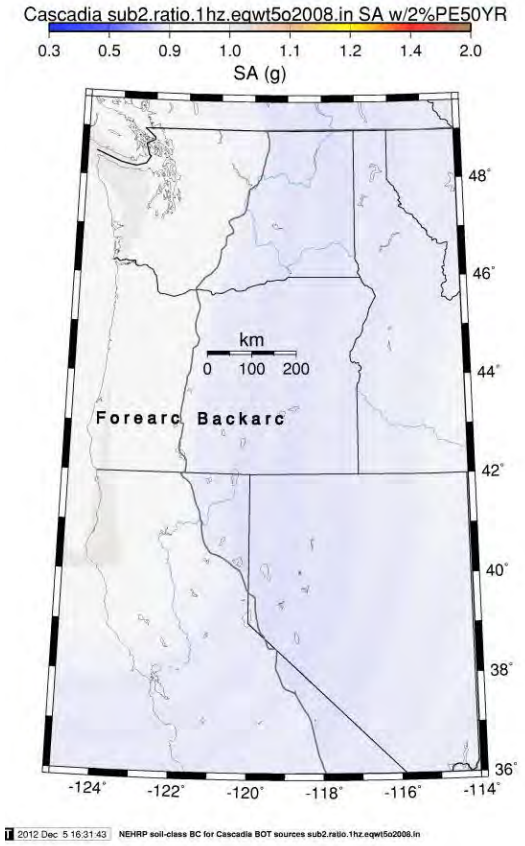
AM	0.33
BCHydro	0.33
Zhao	0.33

AM	0.25
BCHydro	0.25
Zhao	0.25
Youngs	0.25

AM	0.20
BCHydro	0.20
Zhao	0.20
Youngs	0.20
AB	0.20





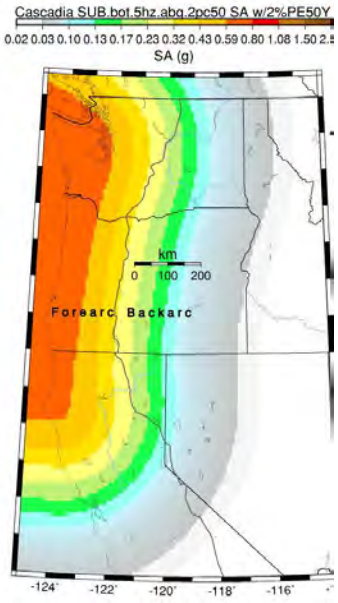


Subduction interface 5 hz

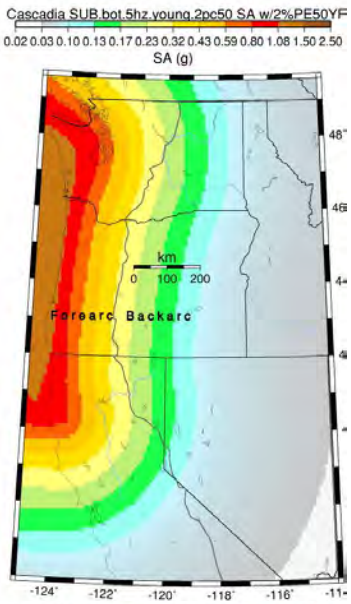
2008 model

New

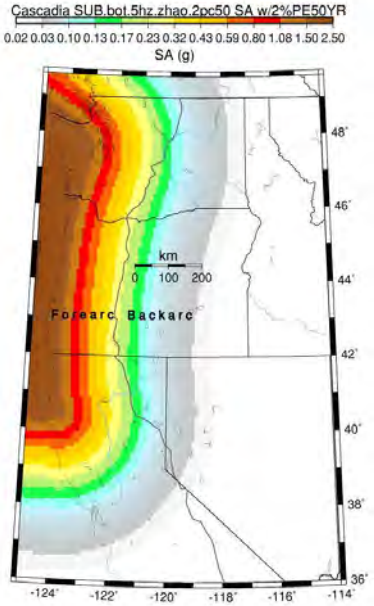
A-B (Global)



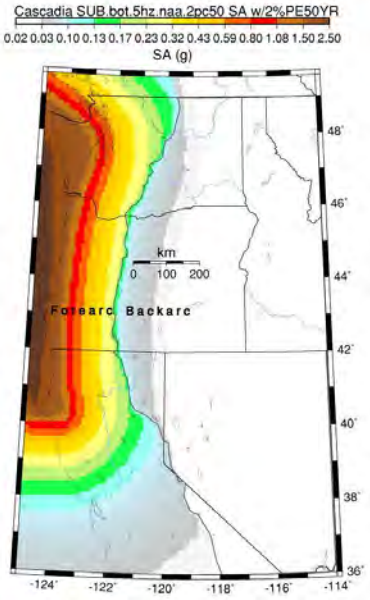
Youngs et al.



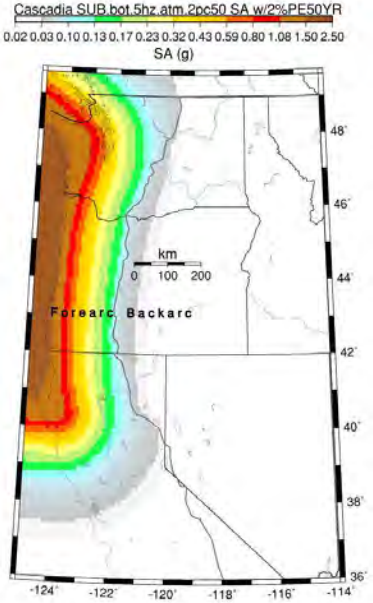
Zhao et al.

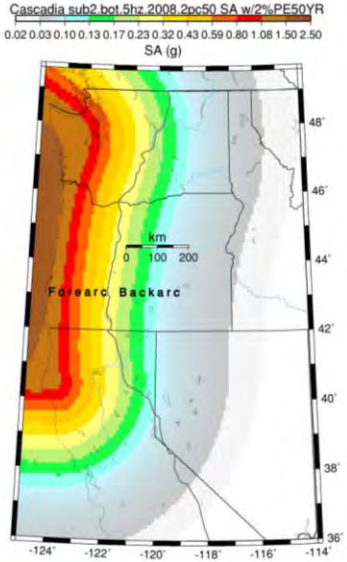


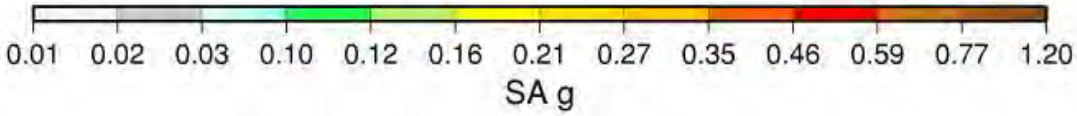
BC Hydro



Atkinson-Macias





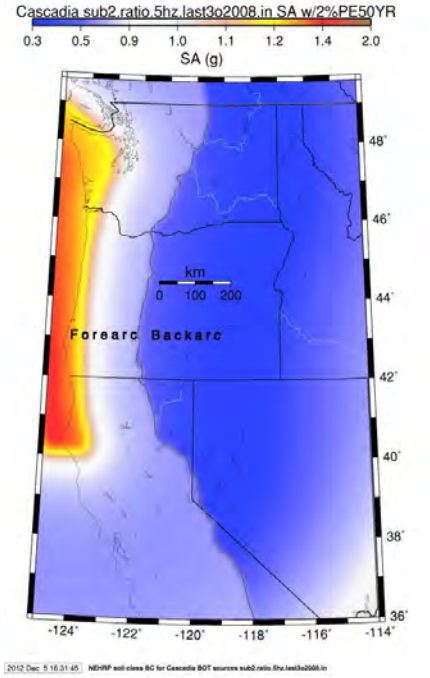


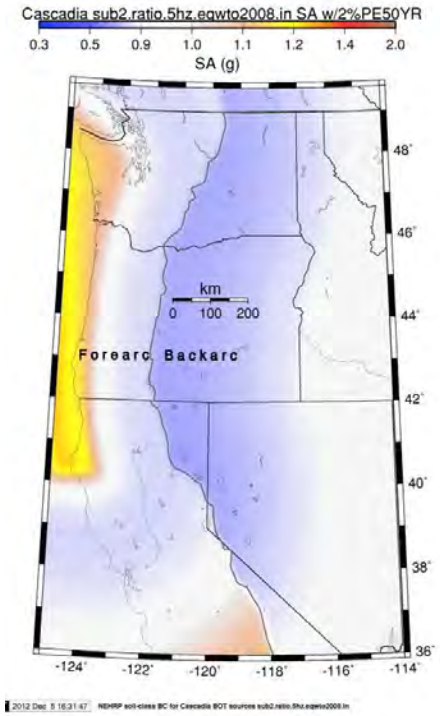
Potential Weighting (5 hz, 2% in 50) Weighted models over 2008 model

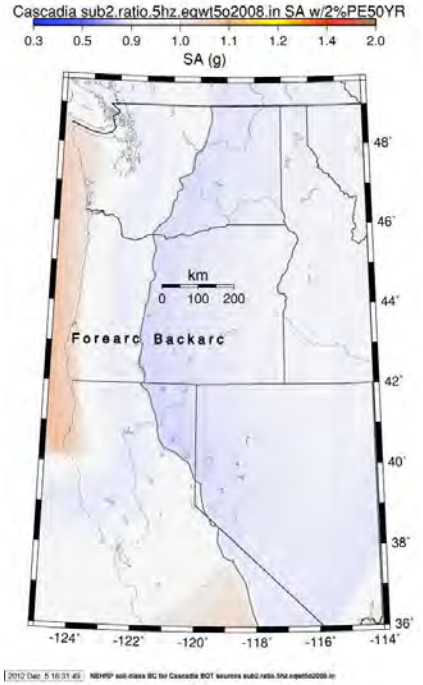
AM	0.33
BCHydro	0.33
Zhao	0.33

AM	0.25
BCHydro	0.25
Zhao	0.25
Youngs	0.25

AM	0.20
BCHydro	0.20
Zhao	0.20
Youngs	0.20
AB	0.20



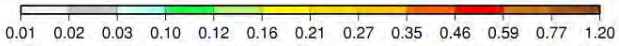




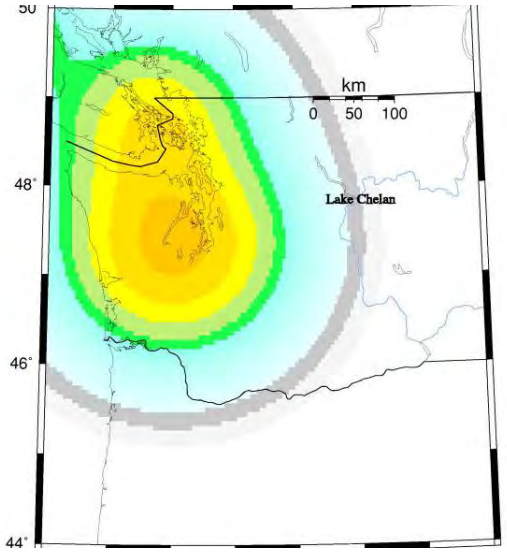
Discussion (Interface GMPEs)

- What are some reasonable criteria to weight the different models? (amount of data considered, fall-off with distance, M scaling, scope of study - SSHAC)
- Which models should be considered for the 2014 update?

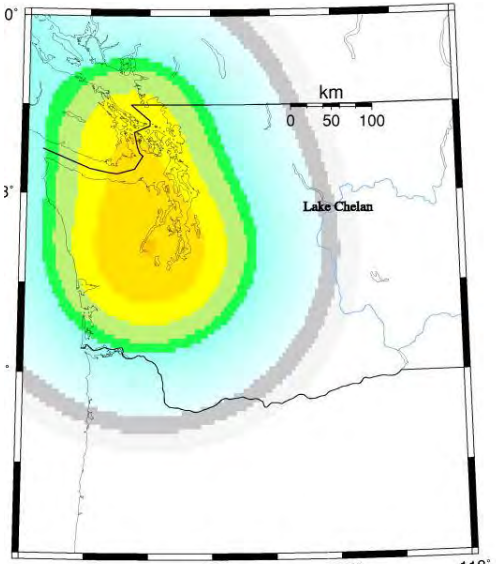
Deep earthquakes 1 hz, 2% in 50



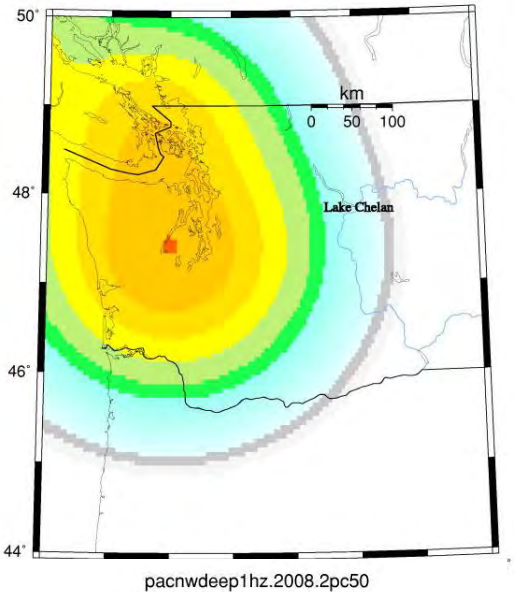
Atkinson and Boore (Cascadia)
0.25



Atkinson and Boore (Global)
0.25

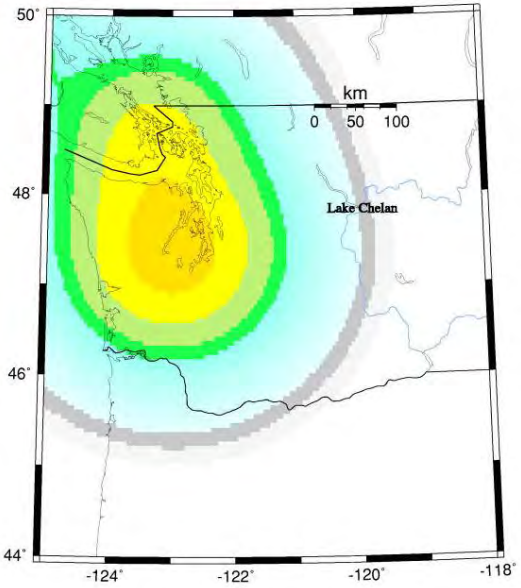


Youngs et al.
0.5

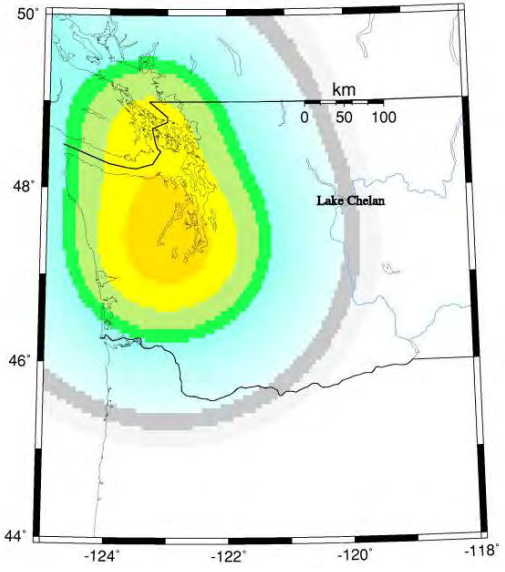


pacnwdeep1hz.2008.2pc50

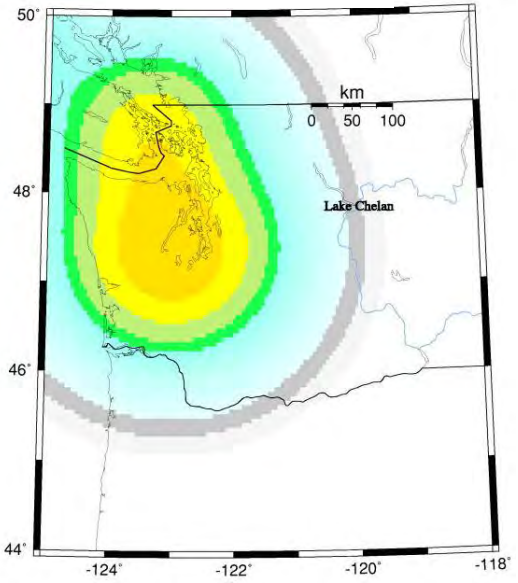
BC Hydro



Zhao et al.



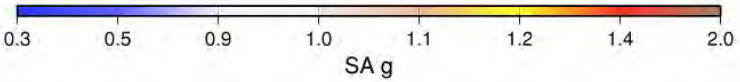
2008 model



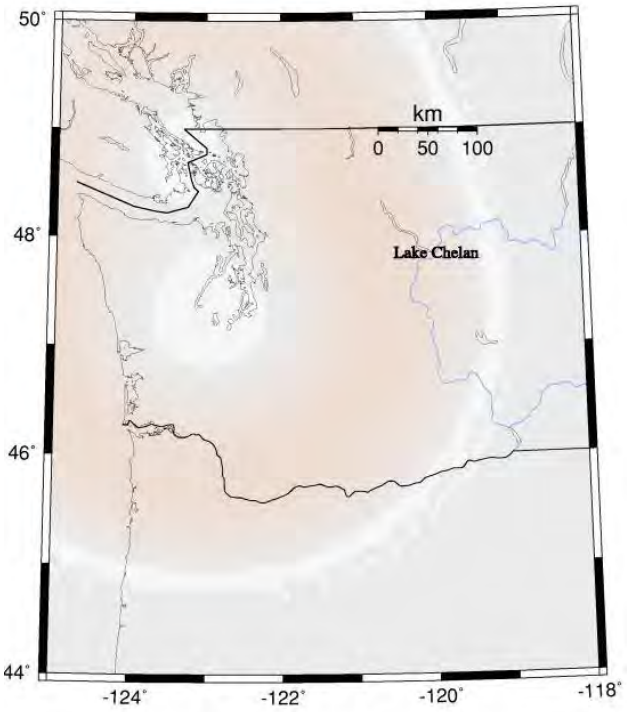
Deep earthquakes 1 hz, 2% in 50

BCHydro	0.25
Zhao	0.25
AB (glo)	0.25
AB (cas)	0.25

BCHydro	0.33
Zhao	0.33
AB (glo)	0.17
AB (cas)	0.17



pacnwdeep.ratio.1hz.eqw4o2008.in



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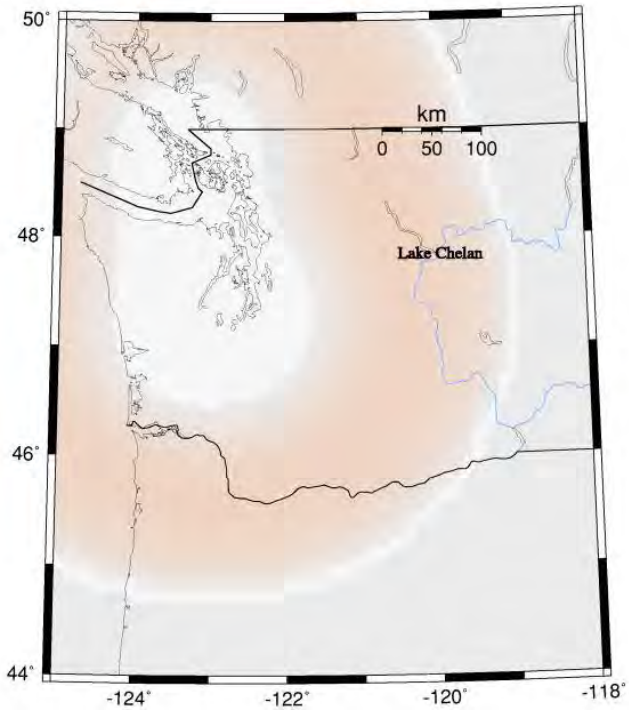
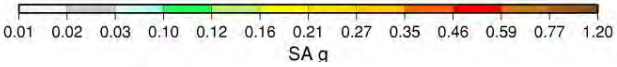
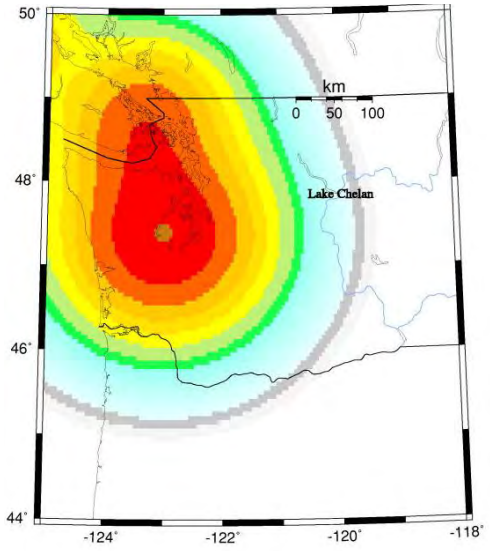


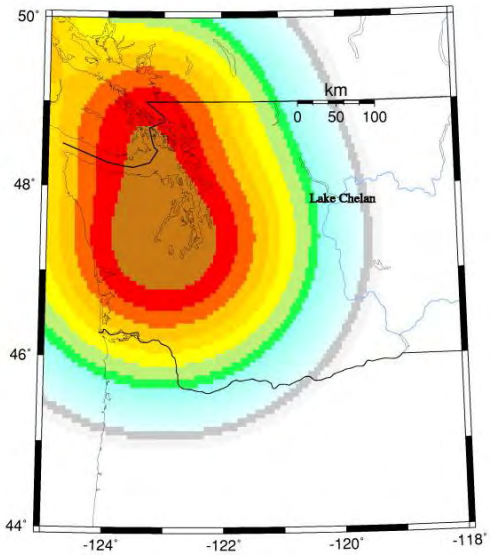
Deep earthquakes 5 hz, 2% in 50



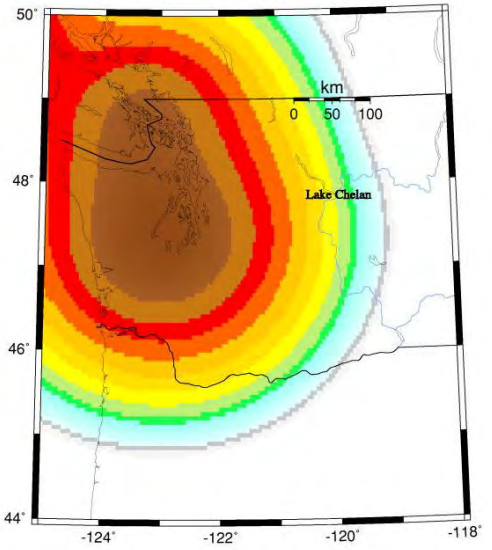
Atkinson and Boore (Cascadia)
0.25



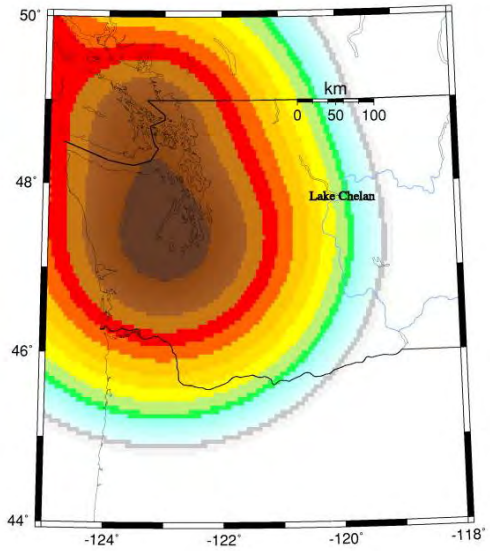
Atkinson and Boore (Global)
0.25



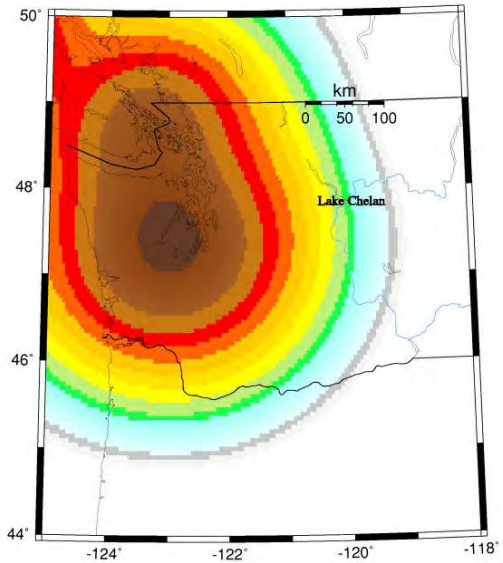
Youngs et al.
0.5



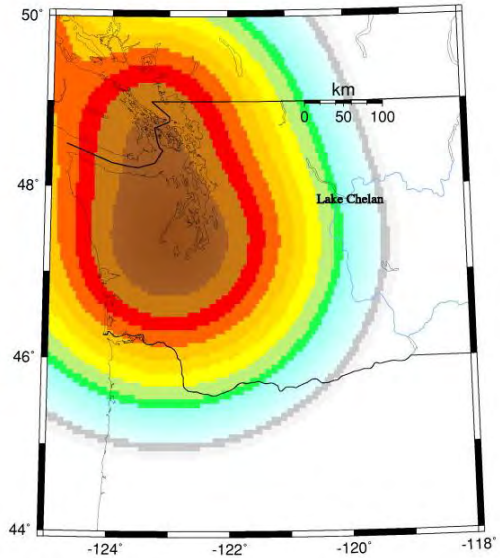
BC Hydro-new



Zhao et al.- new



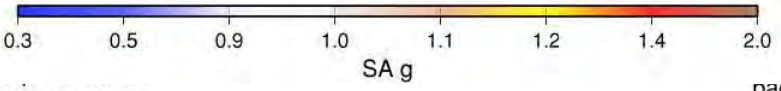
2008



Deep earthquakes 5 hz, 2% in 50

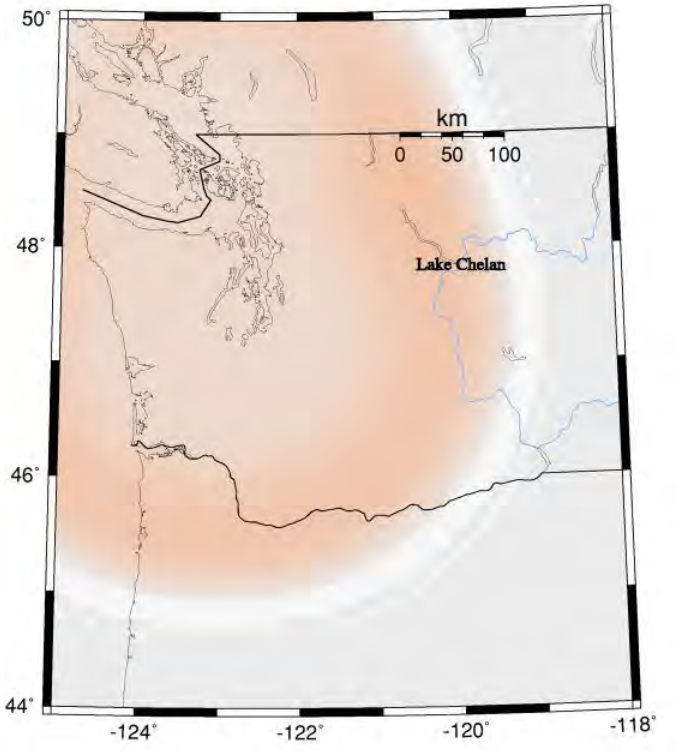
BCHydro	0.25
Zhao	0.25
AB (glo)	0.25
AB (cas)	0.25

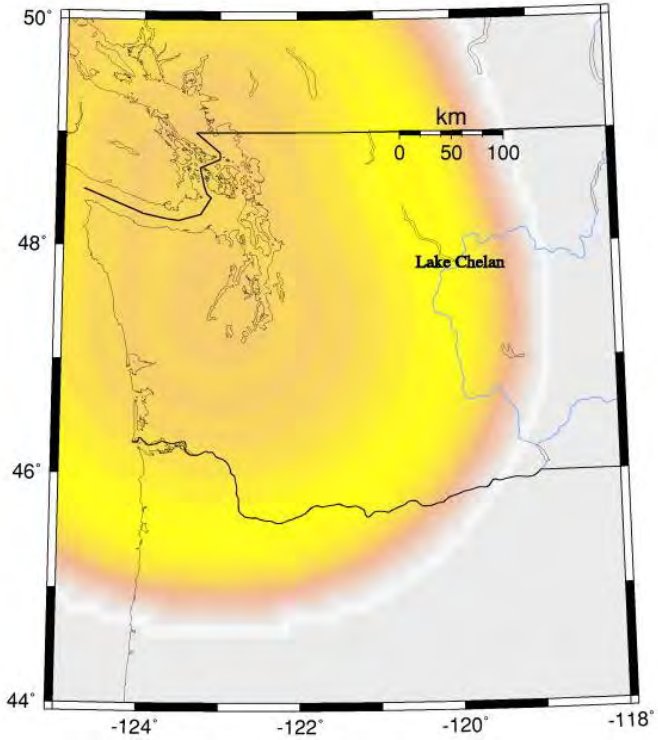
BCHydro	0.33
Zhao	0.33
AB (glo)	0.17
AB (cas)	0.17



pacnwdeep.ratic

pacnwdeep.ratio.5hz.lowwtabo2008.in

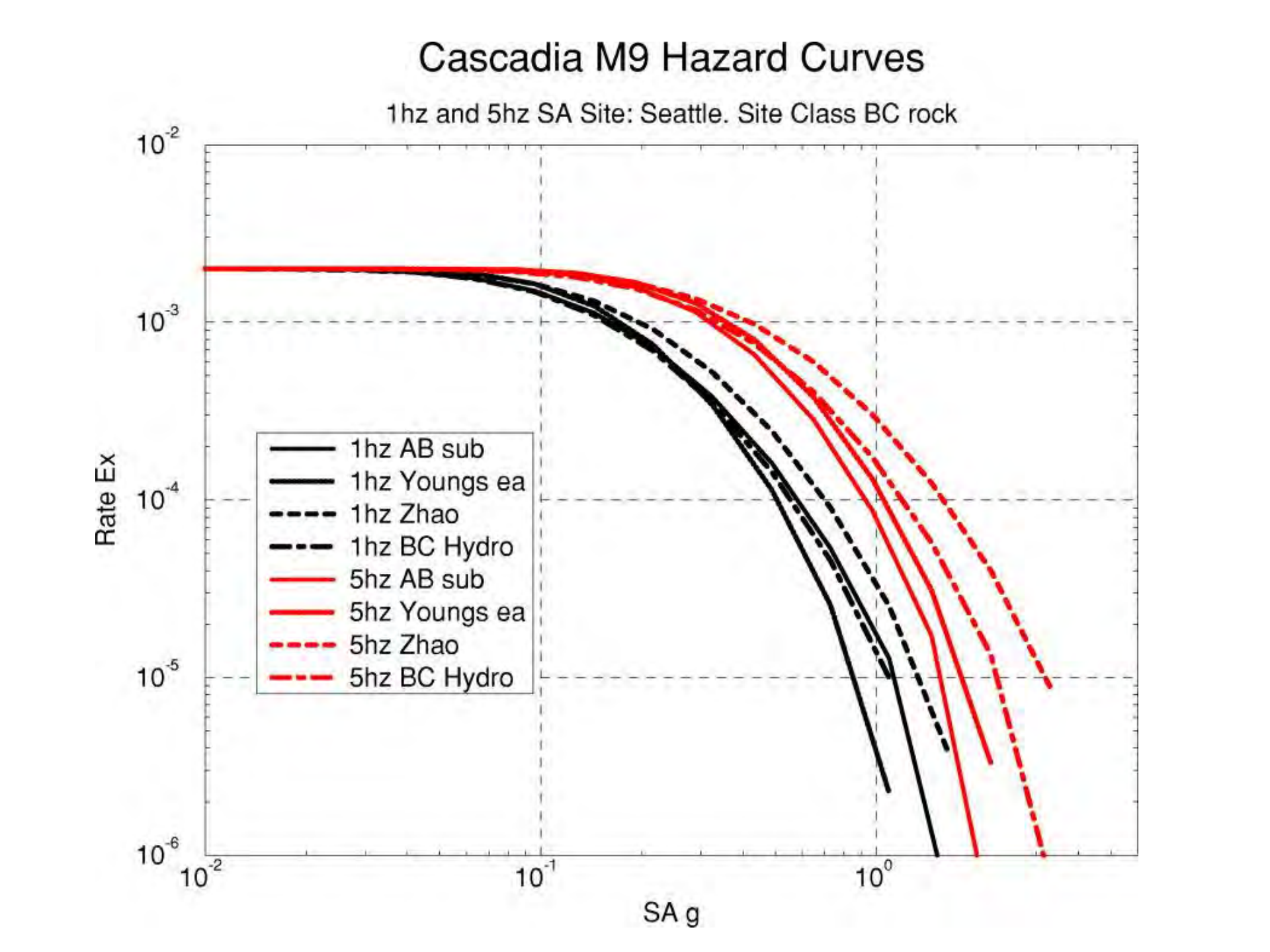


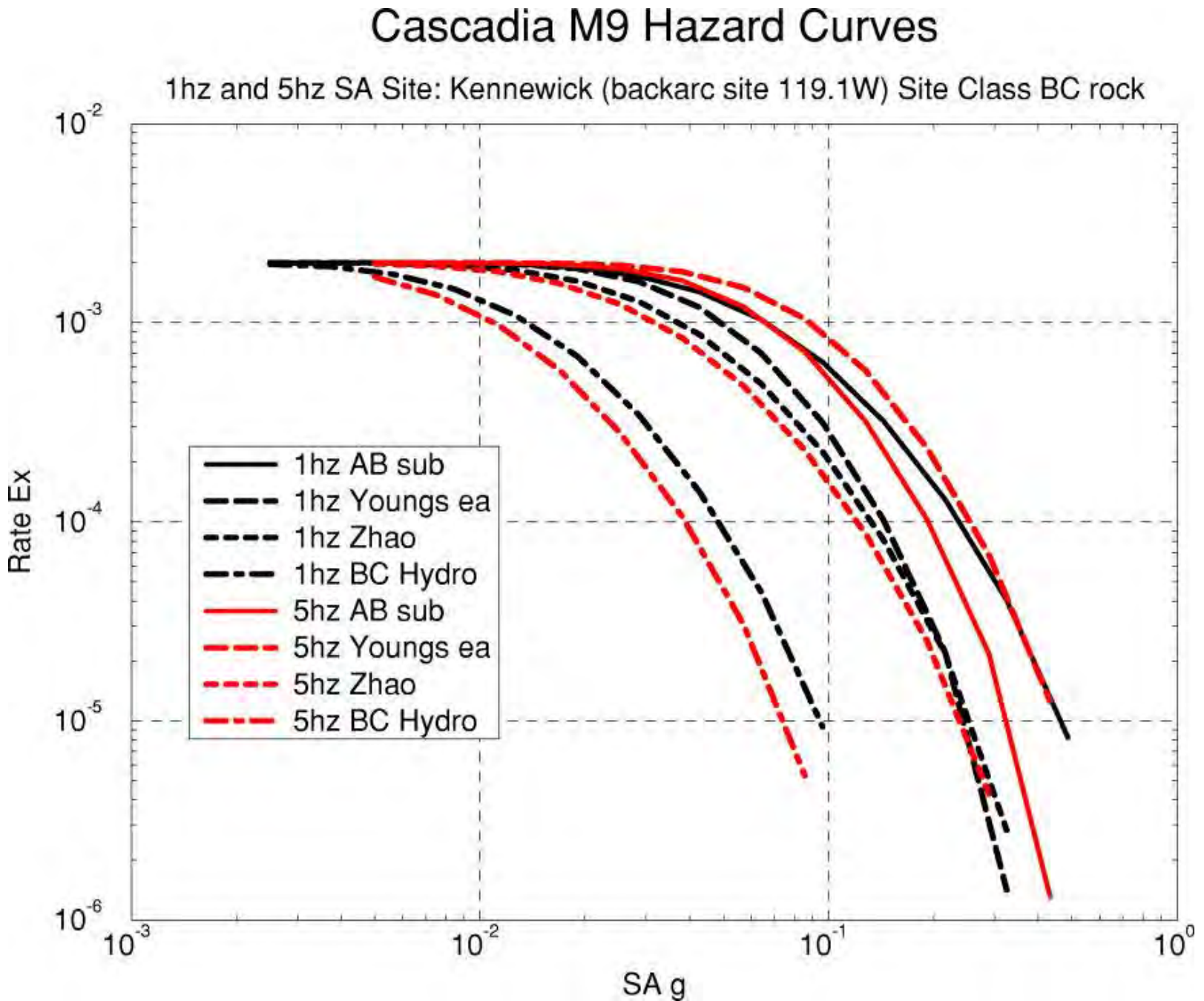


Discussion

- What are some reasonable criteria to weight the different models? (amount of data considered, fall-off with distance, Magnitude scaling, scope of study)
- Which models should be considered for the 2014 update?

Miscellaneous


Cascadia M9 Hazard Curves
1hz and 5hz SA Site: Seattle. Site Class BC rock
Rate Ex
SA g
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-2}
10^{-1}
10^{0}
1hz AB sub
1hz Youngs ea
1hz Zhao
1hz BC Hydro
5hz AB sub
5hz Youngs ea
5hz Zhao
5hz BC Hydro


Cascadia M9 Hazard Curves
1hz and 5hz SA Site: Kennewick (backarc site 119.1W) Site Class BC rock
Rate Ex
SA g
10-2
10-3
10-4
10-5
10-6
10-3
10-2
10-1
100
1hz AB sub
1hz Youngs ea
1hz Zhao
1hz BC Hydro
5hz AB sub
5hz Youngs ea
5hz Zhao
5hz BC Hydro

Questions: New Subduction Zone GM models

- Atkinson and Macias
  - Should we use the Atkinson and Macias in place of the Atkinson and Boore
  - A-M does not have a back-arc term but we used the Ghofrani and Atkinson (2011) anelastic attenuation term (c). Should we use this for other GMPEs?
  - Should we use backarc-forearc for deep earthquake GMPEs?
  - What depth of rupture should we assume for Atkinson and Macias equations?

Questions: New Subduction Zone GM models

- BC Hydro
  - How should we define the fore-arc and back-arc boundary? Should we model this as a transitional boundary?
  - Should we use backarc-forearc for deep earthquake GMPEs?
  - Will this GMPE be published before 2014? Addo et al.?
  - How should we use the epistemic branches? (high, middle, and low median)
  - What depth of rupture should we assume for BCHydro equations?

Questions: New Subduction interface models for Zhao et al 2006 (modified by Zhau and Xu, 2012)

- Should we apply the magnitude-scaling rate to the 2006 model (especially for periods > 0.5s) even though the relation depends on Japan data and no other global data?
- Which of the three functions of magnitude (linear, bilinear, and curved) should we use?
- Should we use the equation for site class (SC-I, rock Vs30>600 m/s) conditions if we want to make a map with Vs30=760 m/s or should we do something else?
- What depths should we apply to the equation?

WUS GM models (preliminary)

- Boore et al. : gm for 1 hz are 30% higher than in NGAWI near faults, this is similar to Boore et al. 1997, Why?
- Abrahamson and Silva.
- Campbell and Bozorgnia (How do suggest we apply the basin term? We use 2 km. How should we define the hypocentral depth? Should there be a hypocentral depth distribution? Should this be a function of M? Right now, we use 8 km below top of fault or 12 km, whichever is less. Should we allow for shallow hypocenters (1km- Mogul swarm)?
- Chiou and Youngs (gm for 1 hz are 30% higher than in NGAWI, this is similar to Sadigh et al. model, Why did we bounce back?) How do we apply the basin term, z1, or the depth to Vs=1.0 km/s? We use 40 m depth for rock of 1.0 km/s to characterize the z1 term when Vs30=760 . You recommended using this term in 2008. What do you recommend for the next version?
- Idriss
- Graizer and Kalkan (2 models, one unpublished, when will it be published?) How do we apply the basin term? We use 1 km in our preliminary calculations but we know that for all sites in the WUS this is highly variable. The GK GMPE uses linear site amplification (not a function of gm) why do you think this is appropriate? Are you using rcd, in the software you sent it only uses an unspecified x-term? Should the Q factor vary spatially?- we use Q=435 which is what you recommended for CA. Is this appropriate for the rest of the WUS? You treat normal slip events the same as strike-slip events, is this appropriate?
- All: Zhao and Lu indicate that the magnitude scaling rates among NGA I models for earthquakes M>7 are alarmingly large. The MSRs vary by a factor of 2-3. Is that still the case? Is this reasonable?

List of questions (WUS, crustal)

- Idriss:
- 1. Do you have an updated sigma equation SE=1.28+0.05lnT-0.08M? The sigmas are quite large, why?
- 2. What do we do for distances greater than 150 km?,
- 3. What do we do for Vs30 less than 450 m/s?
- 4. Is the linear site response reasonable (the site response is not a function of ground motion)?
- 5. Normal slip events are treated same as strike-slip events, is this reasonable?

Questions: CEUS GM models

- Atkinson and Boore (2006-prime and 2008-prime)
  - Should we remove the AB 06 model? Yes, from paper?
  - The kappa and geometric spreading are correlated in the model. Should we let kappa (hard rock to 760 m/s) vary in each model as a logic tree branch? geographically?
  - In 2008 we used stress drop values of 140 and 200 bars. You assume in 2006' that the stress is constant for a given magnitude. Do you think that we should vary stress drop in your new GMPEs?
  - Would you recommend that we apply your amplification factors for different soils to other GMPEs? Would you recommend that we make maps for Vs30 other than 760m/s in the CEUS using your amplification factors? What factors would you recommend for the Gulf Coast?

Questions CEUS GM models (Toro)

- Should we use your Gulf Coast model in place of the Toro (2002) model we used in 2008 for Mid-continent? How would we define the mid-continent?

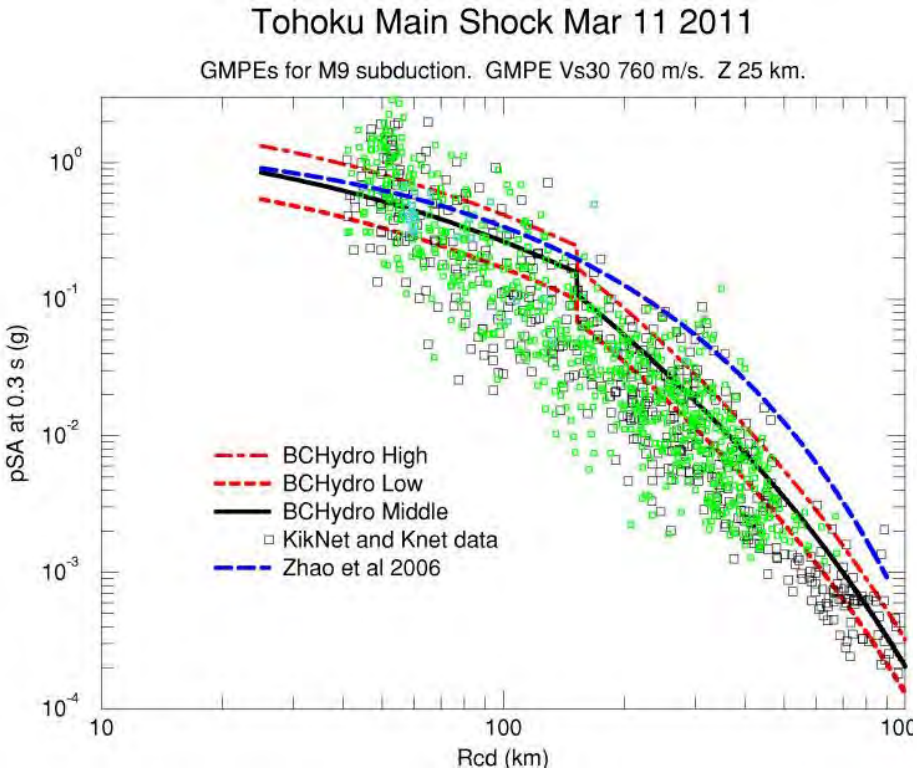
Questions: CEUS GM models

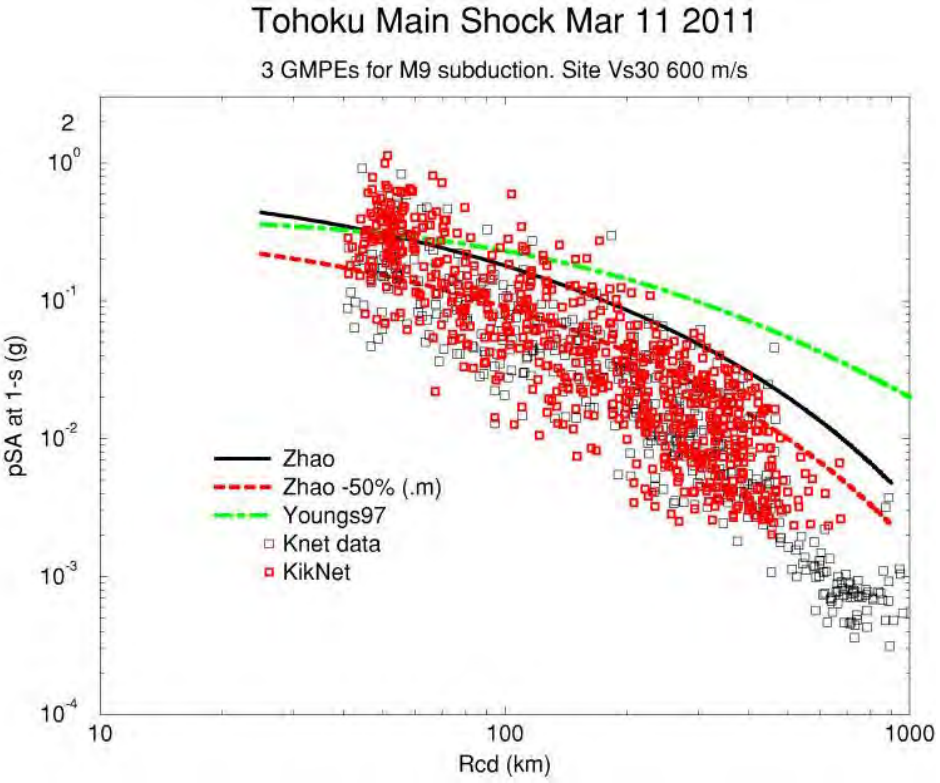
- Pezeshk
  - In the new hybrid models you choose to apply R-1.3. Why did you change the geometric spreading from the earlier Tavakoli and Pezeshk model?
  - Should we abandon the use of Tavakoli and Pezeshk from the 2014 model?
  - How can we modify your model for soil amplification, especially 760 m/s – in 2008 we used Kappa 0.01 s? What do you recommend for kappa of your latest GMPE?

Questions for EPRI

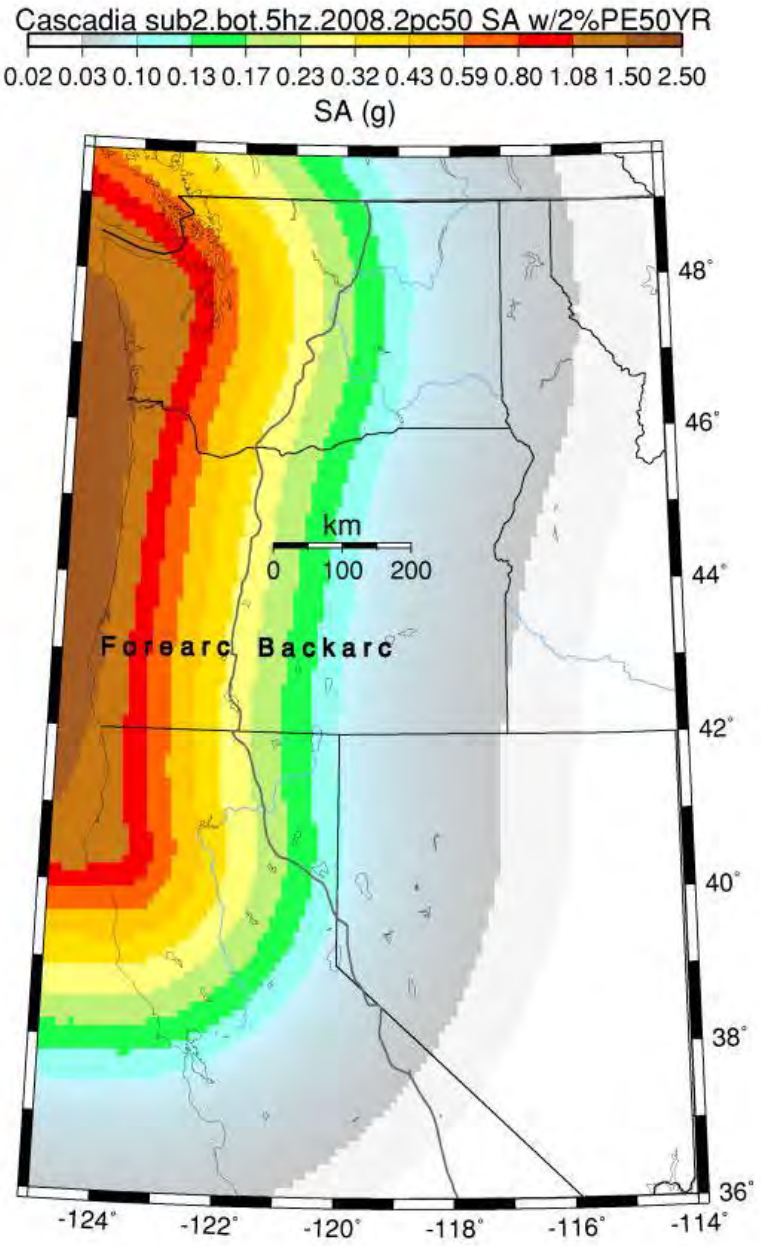
- Why does the highest weighted cluster (#2) which is mostly AB not fit the data better than the other GMPEs?
- What seismological principles were applied? How has this changed since EPRI 04?

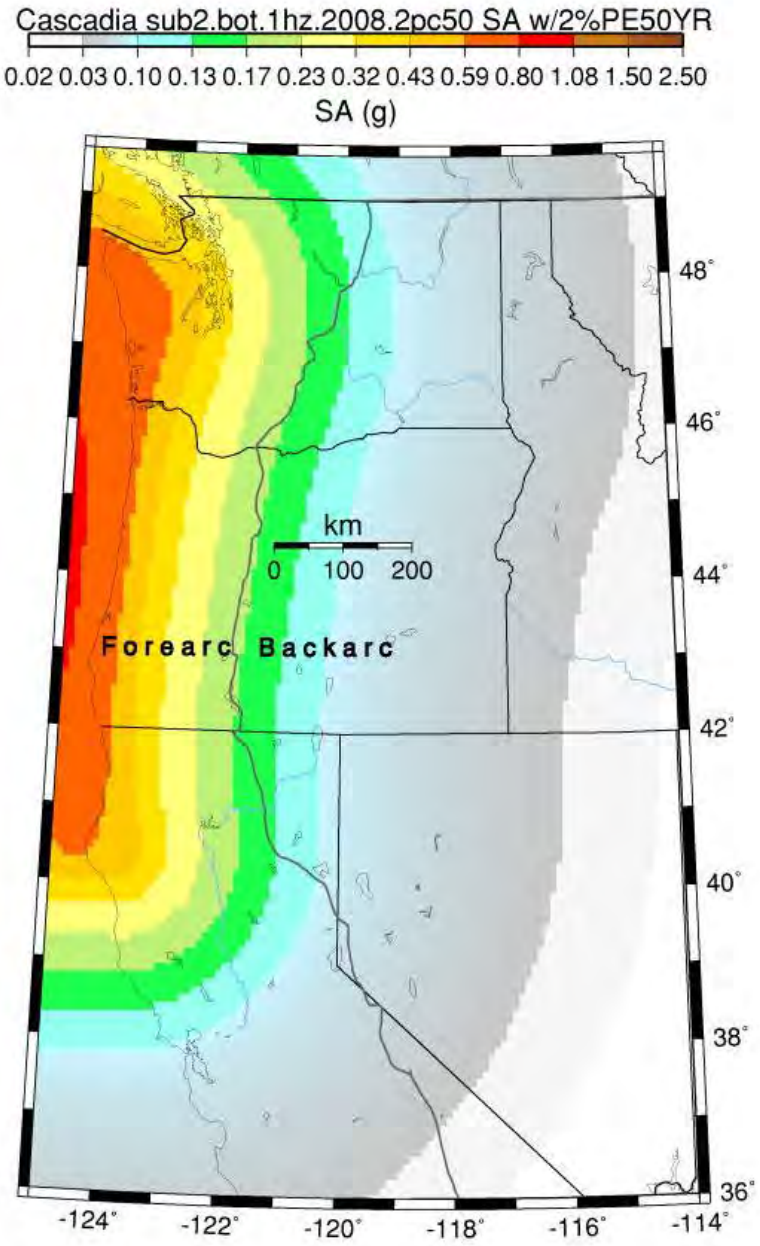
Ground motion comparisons (0.3 s and 1 s)





Potential Weights





Tohoku ground motions (3s) with BCHYDRO and AM