Ground-motion prediction equations (GMPEs) for 2015 national maps in Canada

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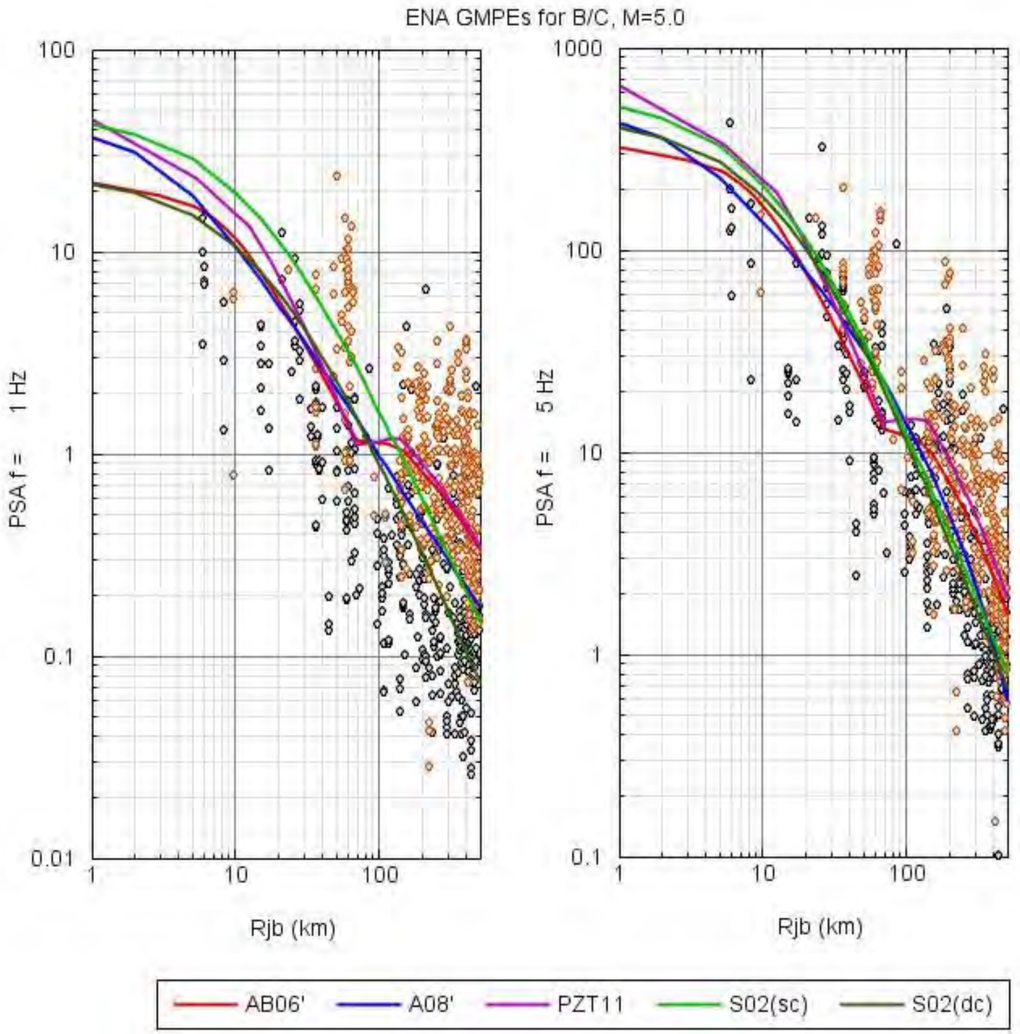
Comments subdivided by topic

- General approach
- GMPEs for eastern Canada rock sites
- Scaling of backbone GMPEs for hazard assessment
- Comments on subduction GMPEs for in-slab and interface (importance of considering site effects when using global GMPEs)

Common Principles Applied

- Alternative published or peer-reviewed GMPEs are useful to define representative equations and assess their uncertainty
- But uncertainty is not necessarily well captured by simply weighting alternative GMPEs
- A better alternative is to use alternative GMPEs and their data constraints to guide selection of a “representative” or base-model GMPE and bounding (low, high) equations; this offers greater flexibility than use of alternative GMPEs
- adopt a 3-suite model (middle, high, low) for each type of event, all for B/C site conditions: this represents the epistemic uncertainty – the amount of epistemic uncertainty is greater for regions/event types with less data and less knowledge
- Aleatory (random scatter) uncertainty represented by a single frequency-dependent model for all regions/event types (pre-print, Atkinson, 2012 SRL)
- 2015 NBCC seismic hazard mapping presented today (www.seismotoolbox.ca, Misc Resources, for details)

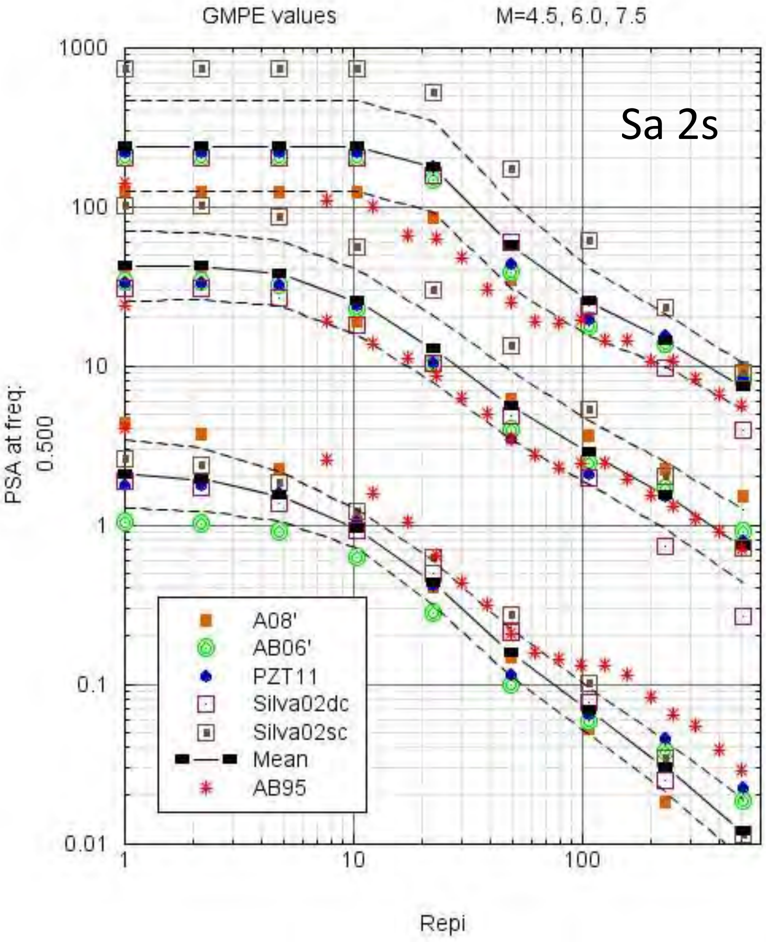
Proposed ENA GMPEs

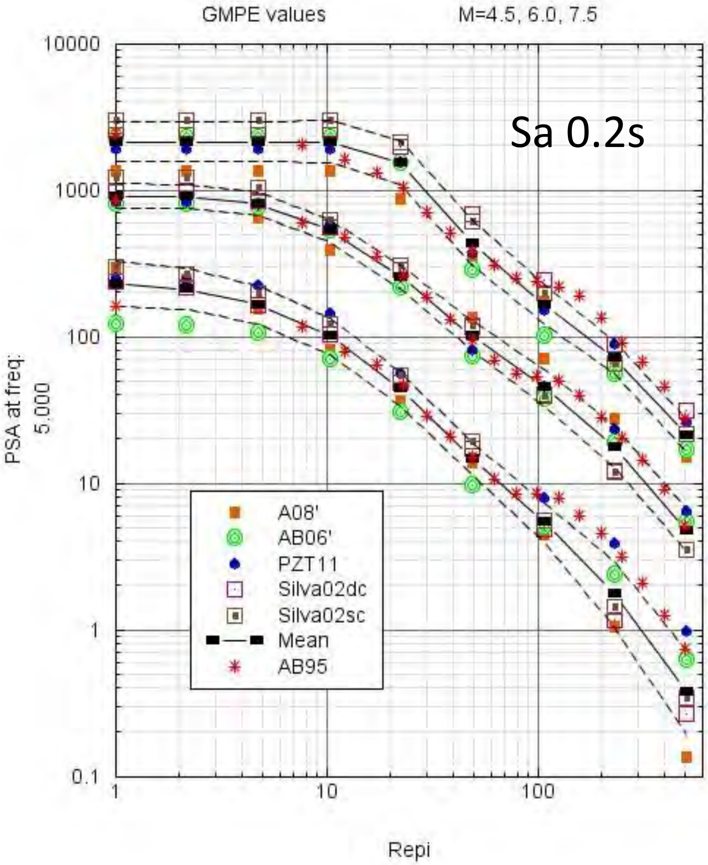


- ***GMPEs** from Atkinson and Boore' (2006); Atkinson' (2008); Pezeshk et al. (2011); Silva (2002) (single/double corner)*
- ***M**4.5-5.0 data in black, **M**5.0-5.5 data in orange. All data converted to B/C.*
- *Large scatter misleading as data cover an entire magnitude unit and a range of site conditions*

ENA GMPEs – construct "representative" GMPE and initial uncertainty bounds

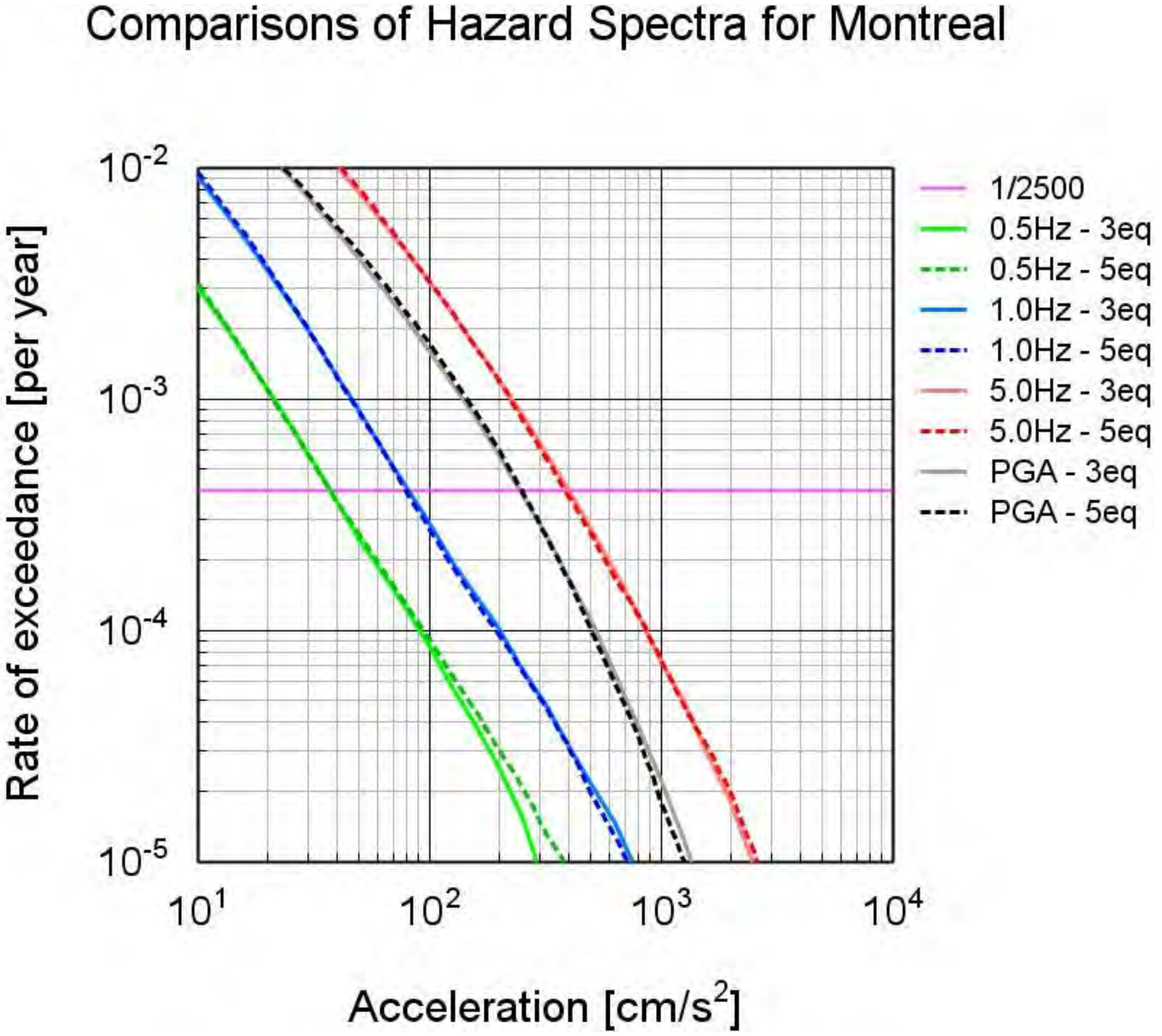
- Taken as mean +/- std.dev. of the 5 equations
- Given in table format
- Uncertainty revisited in comparison to other event types (for consistency)
- Weights 0.5, 0.25, 0.25 (mid, lower, upper)





Tests of scaled backbone approach

- Tests of results for scaled backbone vs. direct use of alternative GMPEs made for cities in eastern Canada
- Compare direct use of the 5 alternative ENA GMPEs with our 3-model representative suite (as comprised of mean motion, +, - std.dev. Of the 5)



Sensitivity to direct use of alternatives tested: differences <10% if same GMPEs used in both approaches – what matters is what GMPEs are included (this sensitivity well known)

Other event types: (Interface, Inslab, Western Crustal, Offshore)

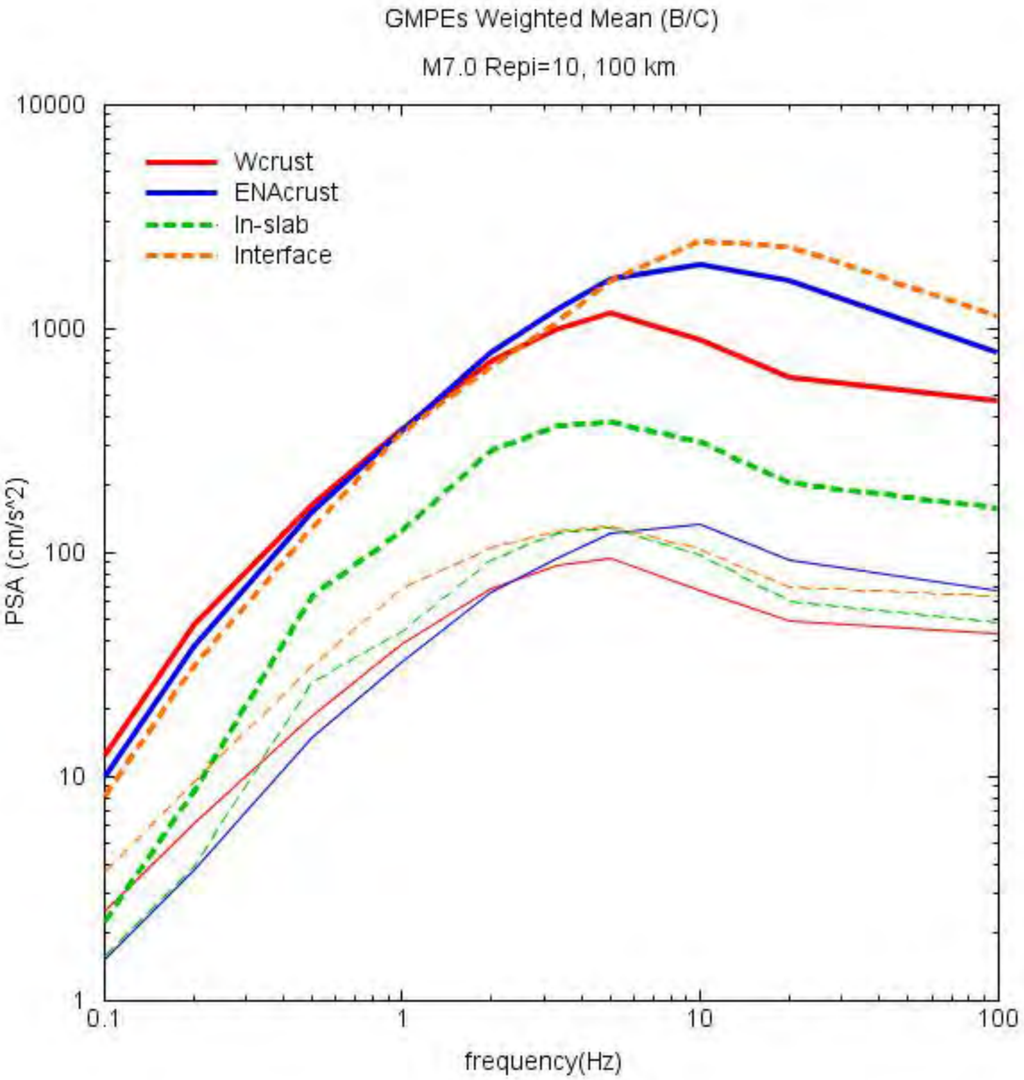
- Same overall approach (3-eqn suite) was followed for other event types
- However in other regions a "representative" GMPE was selected, based on evaluation of alternative GMPEs against each other, and against the most relevant data (e.g. Nisqually for in-slab; Tohoku, modified for site conditions, for interface)
- Important issue for subduction GMPEs is correction of Japanese GMPEs for Japan-specific generic site conditions (discuss later)

Comparison of spectra for GMPEs for different event types – M7 at epicentral distances near 10km, 100km

Solid lines are crustal events (WNA, ENA).

Dashed lines are subduction events.

Heavy lines at 10 km, thin lines at 100 km.



Considerations in evaluation of epistemic uncertainty – how wide should the spread of upper and lower GMPEs be about the representative or middle GMPE?

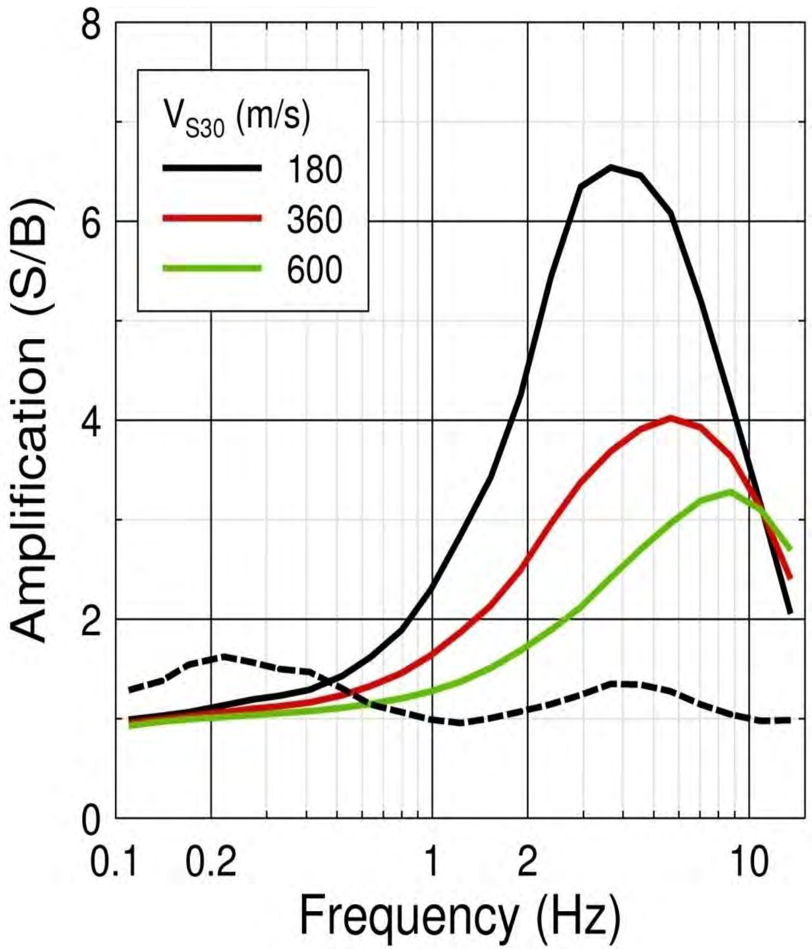
- After initial definition of 3-model suite for each region, we re-evaluate the epistemic uncertainty to ensure consistency between regions
- Start with western crustal GMPEs as the basis, as these are most easily quantified in terms of their epistemic uncertainty (based on both comparisons between alternative GMPEs and the constraints that data provide on those GMPEs)
- Adjust the uncertainty bounds (as a function of magnitude/distance) for other GMPEs relative to those for western crustal GMPEs
- Other GMPEs should have epistemic uncertainty that is generally larger than that for western crustal GMPEs

Summary

- Representative GMPEs defined from a suite of published GMPEs for each region
- All GMPEs defined for B/C site conditions; adjustments made as needed for consistency
- Epistemic uncertainty represented by a middle, lower and upper bound GMPE for each region
- Tested the backbone approach in comparison to alternative GMPEs
- Epistemic uncertainty is larger in regions with poor data
- Epistemic uncertainty is larger at close distances and for large magnitudes
- Common model for aleatory uncertainty (random scatter)
- Proposed GMPEs strike a balance between simplicity and capturing major epistemic uncertainties

Modifications suggested to subduction GMPEs based mostly on Japan data

- Most recent subduction GMPEs dominated by plentiful Japanese data
- Typical site conditions shallow soil over hard rock
- Typical amplifications of >5 at frequencies of 5 to 10 Hz (as seen in studies of Tohoku and other events)
- Expected site amplification in Cascadia is greater at low frequency, less at high frequency (except for shallow soil site conditions)
- Japan-dominated GMPEs should be adjusted for site conditions before application to Cascadia



Avg. Site Amps in Japan - from Ghofrani et al., 2012

Example:

Response spectral amplitudes versus distance for ***M****6.8 Nisqually (Cascadia) and Geiyo (Japan) in-slab events.*

From Atkinson and Casey (2003, BSSA).

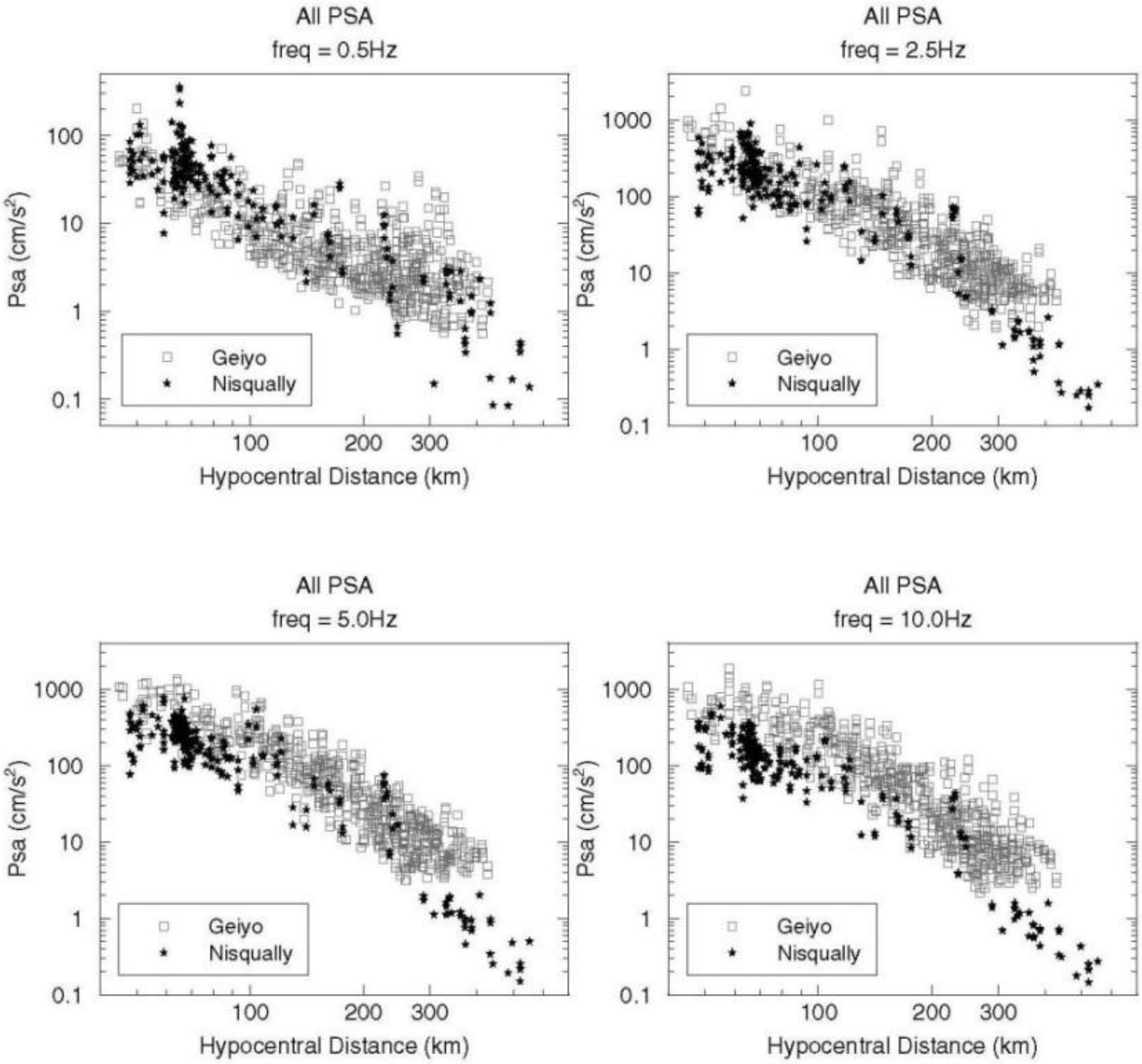


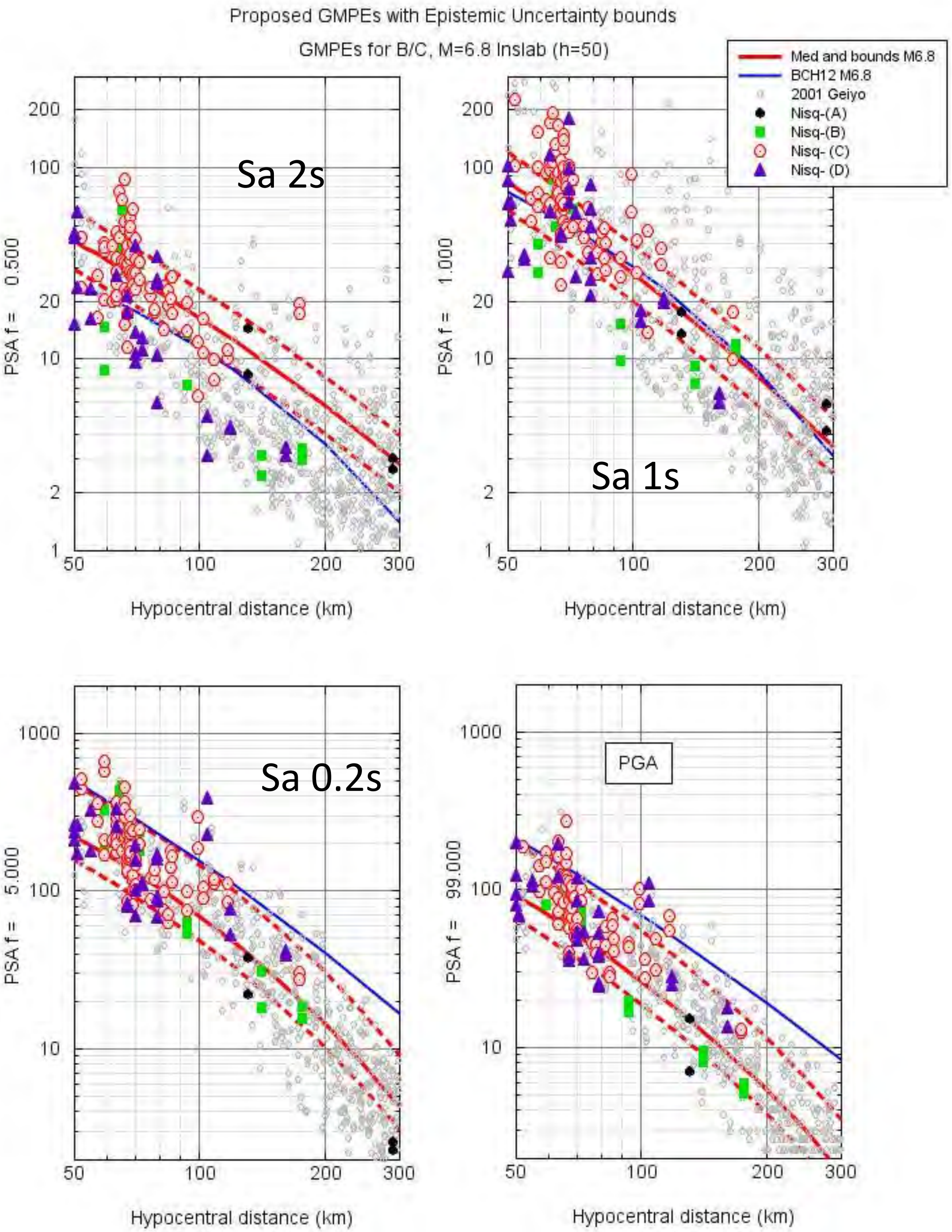
Figure 2. Response spectral amplitudes versus hypocentral distance for the Geiyo (gray boxes) and Nisqually (black stars) events at frequencies of 0.5, 2.5, 5.0, and 10.0 Hz (all data).

Atkinson&Casey factors based on QW calcs for typical profiles. Atkinson&Boore factors based on regression residuals for Cascadia and Japan relative to global GMPE.

Table:		**Cascadia/Japan site factors:**	
Freq.(Hz)	Atkinson &Casey(03)	Atkinson &Boore (03)	Recommended Cascadia Multiplicative Factor (log)
0.2			1 (0.000 log units)
0.33		1.23	1.20 (0.079 log units)
0.5	1.47	1.55	1.51 (0.179)
1	1.08	1.00	1.04 (0.017)
2.5	1.16	0.83	1.00 (0.000)
3.33			0.81 (-0.091)
5	0.71	0.50	0.60 (-0.222)
10	0.53	0.35	0.44 (-0.357)
25		0.35	0.44 (-0.357)
PGA		0.45	0.50 (-0.301)
PGV			1.00 (0.000)

Proposed in-slab GMPEs

- Use Zhao et al., 2006, corrected to Cascadia site conditions
- Define epistemic uncertainty as ~0.15 log10 units, based on inspection of plot of other credible GMPEs (slightly larger than crustal value of ~0.1 log units)
- In-slab GMPEs of Zhao need to be capped at large M (>7.5) but this does not affect Cascadia

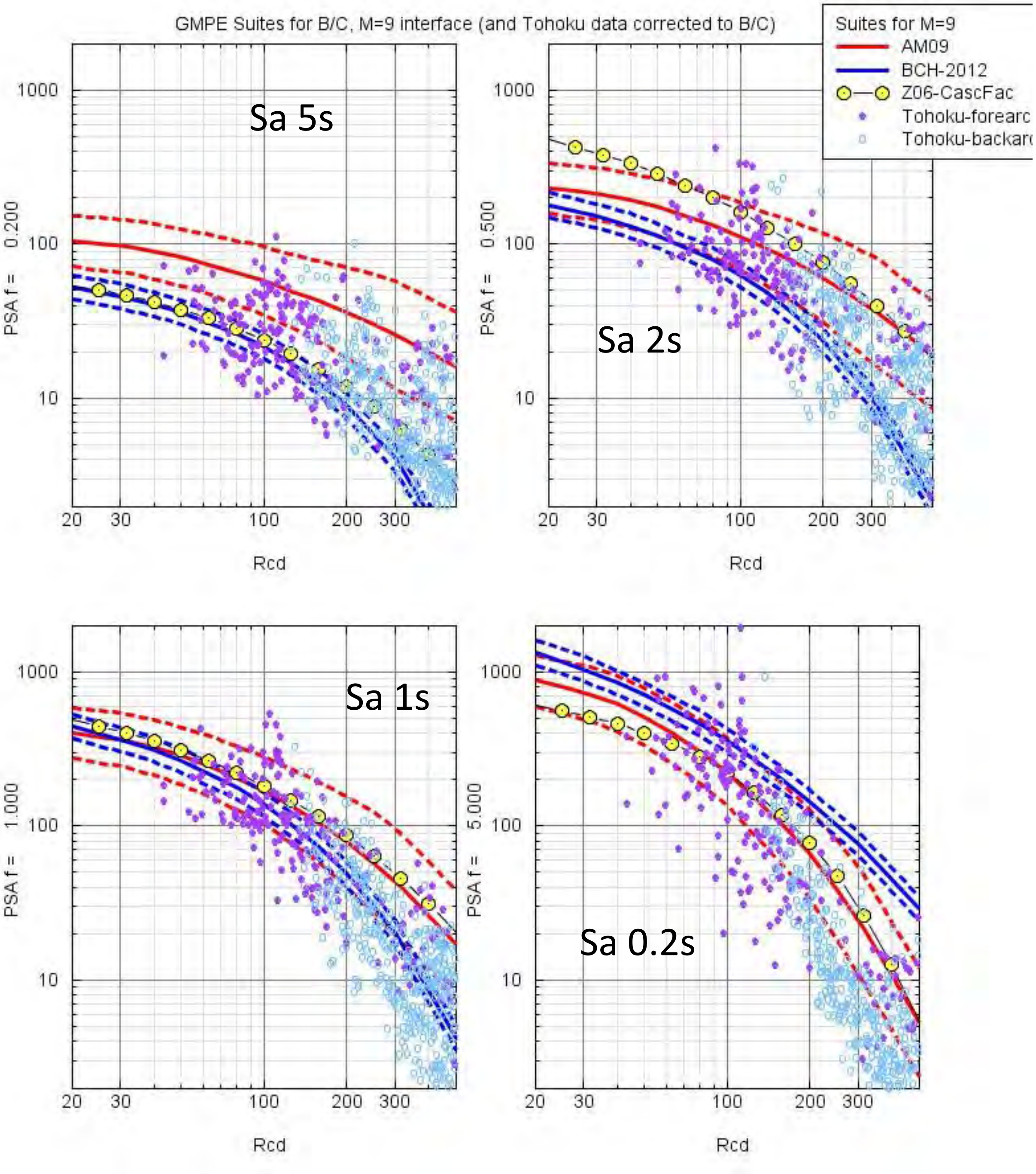


Inslab suite based on Zhao et al. (2006) +/- 0.15 units (red lines). Compared to M6.8 Nisqually data + M6.8 Geiyo, all corrected to B/C. BC Hydro, 2012 also shown.

Based on this comparison, we elected to put more weight on low branch at long periods, more weight on high branch at short periods.

Interface GMPEs

- Great new data from Tohoku
- Tohoku data provide more support for the importance of considering representative site effects in evaluating GMPEs
- We evaluated pre-Tohoku GMPEs, adjusted to Cascadia site conditions as per the in-slab equations
- Consider epistemic uncertainty should be larger than for in-slab (used 0.20 log units based on range of GMPEs and data issues)



Interface GMPEs for M9 Cascadia. Backbone is Atkinson and Macias (2009) –Cascadia GMPE based on simulations, calibrated using M8.3 Tokachi-Oki (AM09). Zhao et al., 2006 and BC Hydro, 2012 also shown.

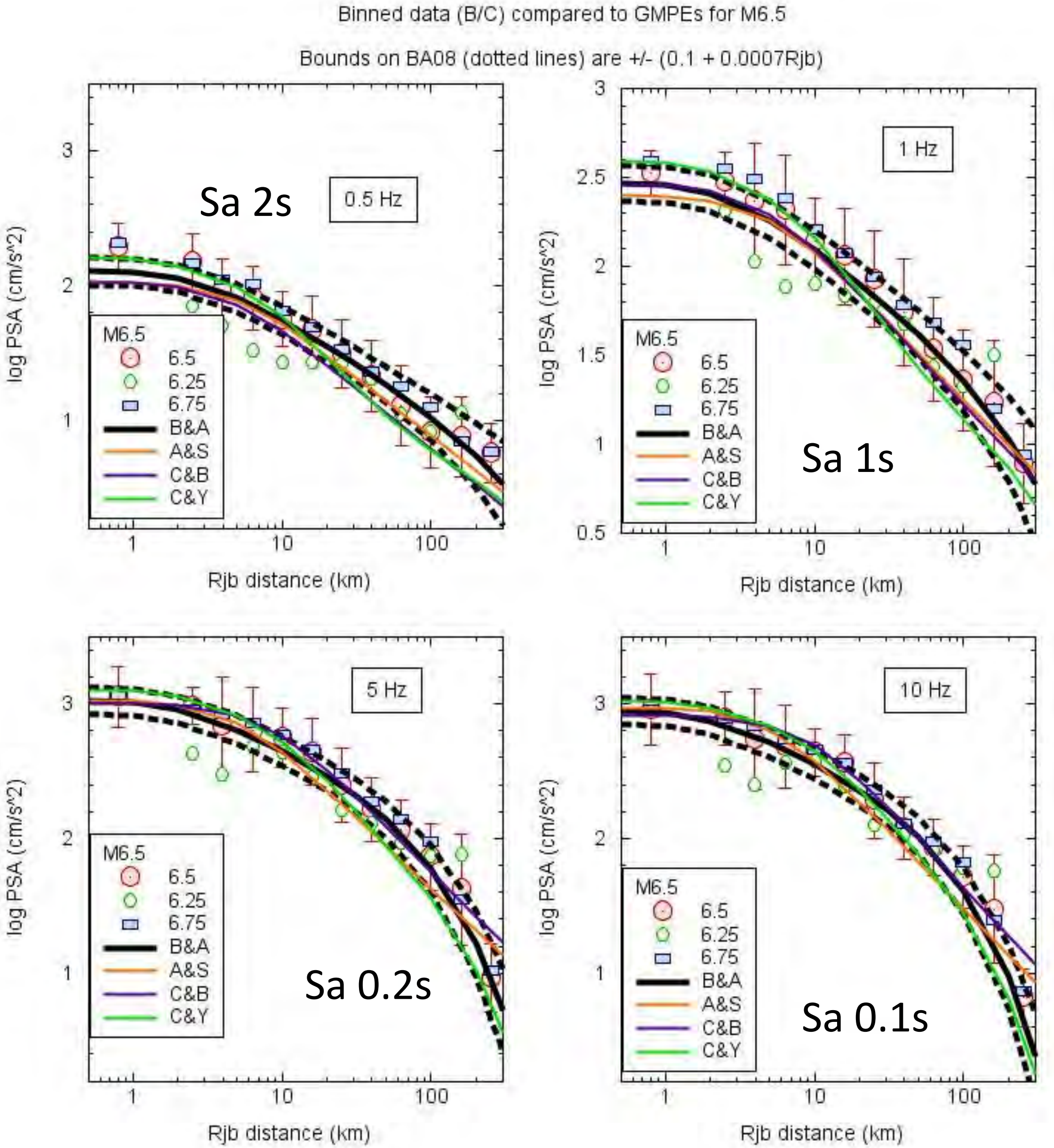
Tohoku motions (B/C) superimposed (fore-arc, back-arc).

Based on this comparison, we placed more weight on lower curve at long periods, more weight on upper curve at short periods

Crustal GMPEs

- Extra slides if needed for discussion

Western crustal GMPEs - based on PEER-NGA eqns (B/C site)



Binned data (B/C) compared to GMPEs for M6.5

Bounds on BA08 (dotted lines) are +/- (0.1 + 0.0007Rjb)

Solid lines show NGA equations. Dashed black lines are BA08 ± bounds

Symbols show mean data amplitudes for 0.5 unit magnitude bins; error bars show standard deviation for central magnitude bin.

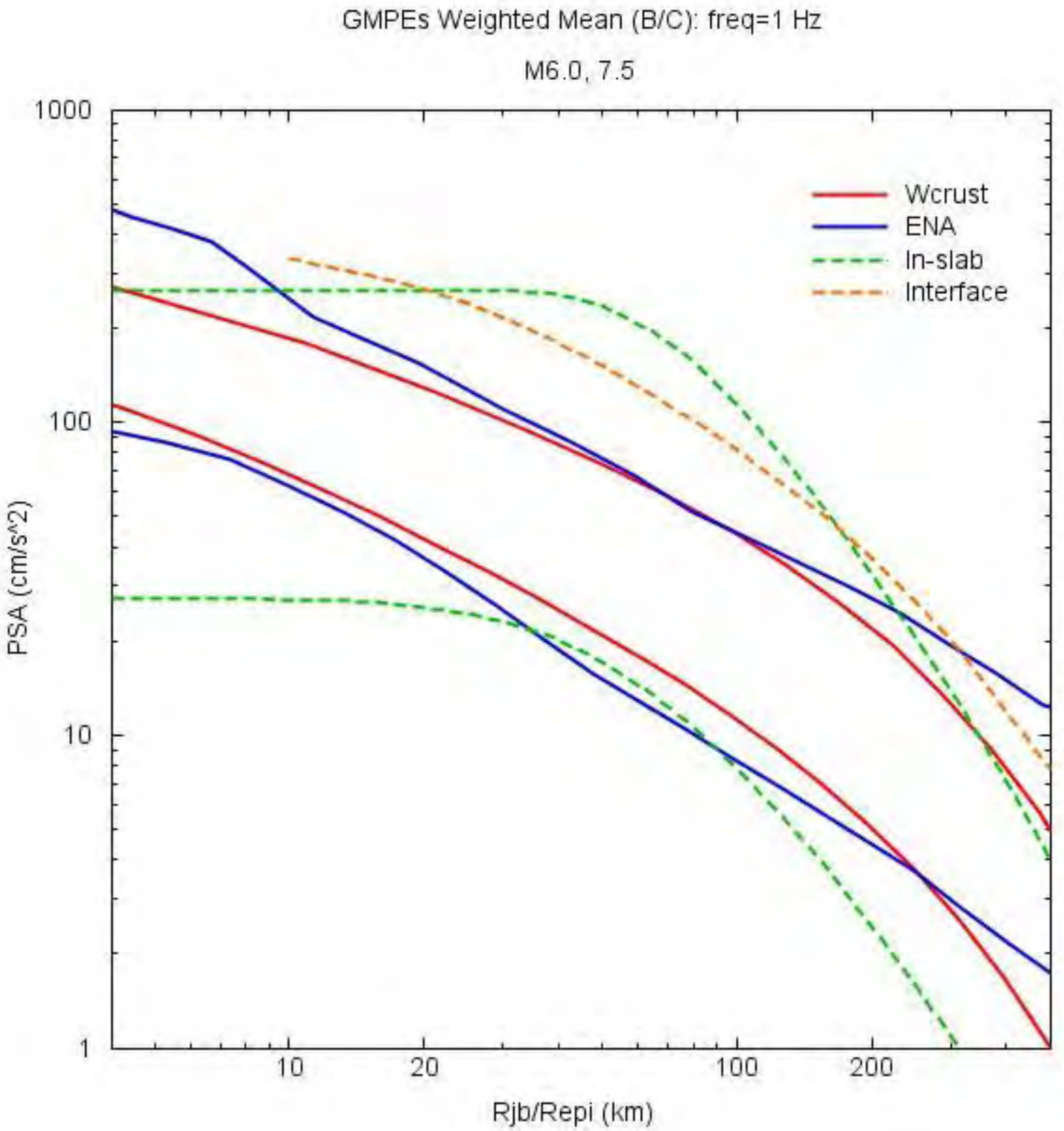
BA08' GMPEs can be used as representative (fewest parameters), with uncertainty defined based on the other NGA eqns and the data constraints

Compare attenuation for GMPEs for different event types – 1 Hz

Solid lines are crustal events (WNA, ENA).

Dashed lines are subduction events.

Interface considered only for M>7



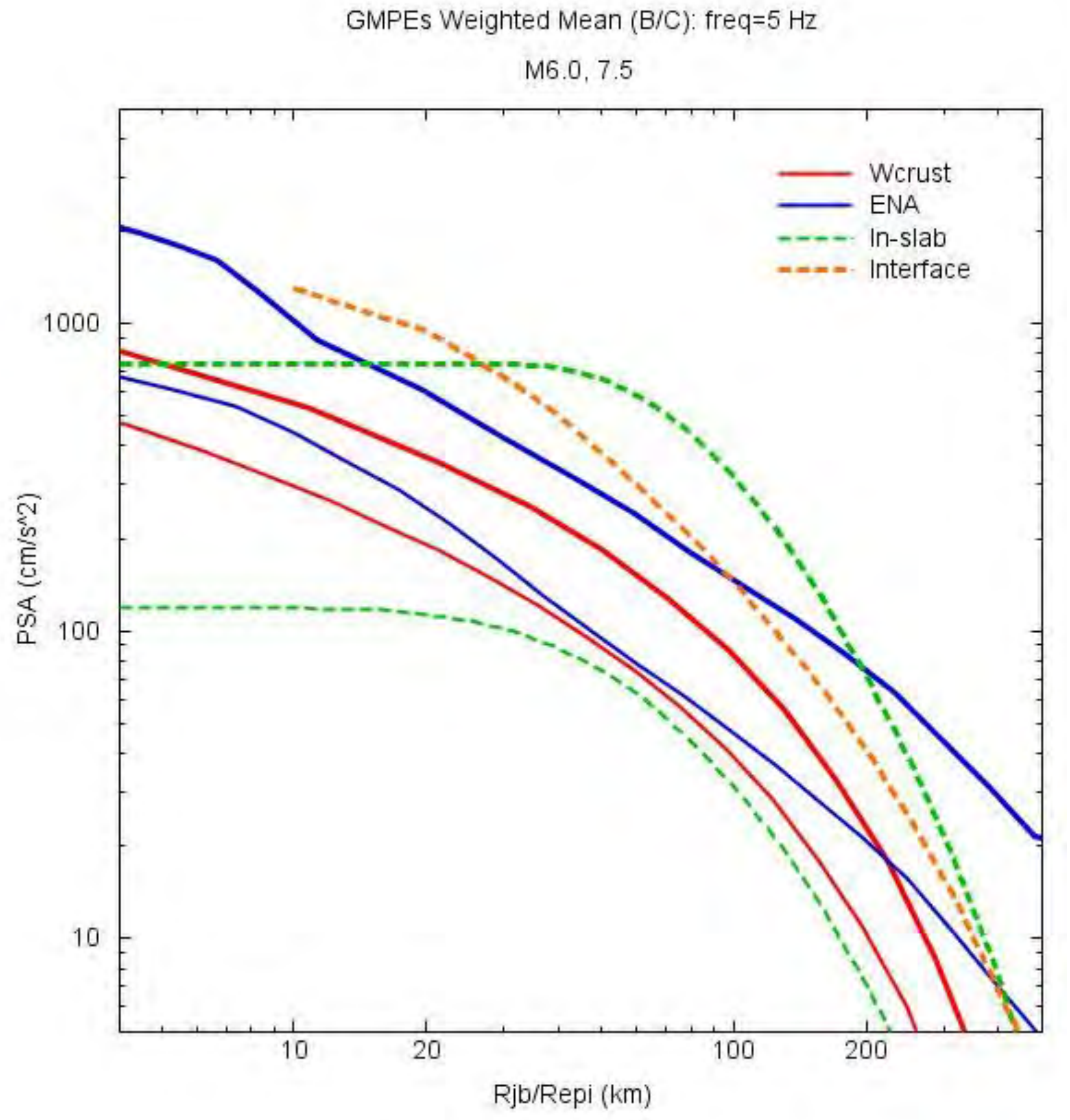
Compare attenuation for GMPEs for different event types – 5 Hz

Solid lines are crustal events (WNA, ENA).

Dashed lines are subduction events.

Heavy lines for M7.5.

Interface considered only for M>7



Comparison spectra for GMPEs for different event types – M8.5 at epicentral distances near 10km, 100km

Solid lines are crustal events (WNA).

Dashed lines are subduction events (interface).

Heavy lines at 10 km, thin lines at 100 km.