PACIFIC EARTHQUAKE ENGINEERING
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Update of the BC Hydro Subduction Ground-Motion Model using the NGA-Subduction Dataset

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ABSTRACT

An update to the BCHydro ground-motion model for subduction earthquakes has been developed using the 2018 PEER NGA-SUB dataset. The selected subset includes over 70,000 recordings from 1880 earthquakes. The update modifies the BCHydro model to include regional terms for the V_{S30} scaling, large distance (linear R) scaling, and constant terms, which is consistent with the regionalization approach used in the NGA-W2 ground-motion models. A total of six regions were considered: Cascadia, Central America, Japan, New Zealand, South America, and Taiwan. Region-independent terms are used for the small-magnitude scaling, geometrical spreading, depth to top of rupture (Z_{TOR}) scaling, and slab/interface scaling. The break in the magnitude scaling at large magnitudes for slab earthquakes is based on thickness of the slab and is subduction-zone dependent. The magnitude scaling for large magnitudes is constrained based on finite-fault simulations as given in the 2016 BCHydro model. Nonlinear site response is also constrained to be the same as the 2016 BCHydro model. The sparse ground-motion data from Cascadia show a factor of 2–3 lower ground motions than for other regions. Without a sound physical basis for this large reduction, the Cascadia model is adjusted to be consistent with the average from all regions for the center range of the data: **M** = 6.5, R = 100 km, V_{S30} = 400 m/sec. Epistemic uncertainty is included using the scaled backbone approach, with high and low models based on the range of average ground motions for the different regions. For the Cascadia region, the ground-motion model is considered applicable to distance up to 1000 km, magnitudes of 5.0 to 9.5, and periods from 0 to 10 sec. The intended use of this update is to provide an improved ground-motion model for consideration for use in the development of updated U.S. national hazard maps. This update ground-motion model will be superseded by the NGA-SUB ground-motion model when they are completed.

ACKNOWLEDGMENTS

This updated ground-motion model is the result of collaboration by the NGA-SUB developer group. The work was partially supported by both funding and in-kind support from FM Global, Pacific Gas & Electric Company, and Caltrans. Many members of the NGA-SUB developer group have participated without financial support from the Pacific Earthquake Engineering Research Center (PEER), provided in-kind contributions of the expertise.

Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect those of the sponsoring agencies, PEER, or the Regents of the University of California, Berkeley.

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1 Introduction

The U.S. Geological Survey (USGS) is in the process of reviewing and updating the seismic source characterization and ground-motion characterization models used in the national seismic hazard mapping project. To give the USGS adequate time to review the new models, any new models for consideration need to be provided to the USGS in the June 2018 time frame. Currently, the NGA-SUB project is developing new ground-motion prediction equations (GMPEs) for subduction zones based on a greatly expanded dataset and additional finite-fault numerical simulations. The full set of NGA-SUB GMPEs with improved model parametrization will not be completed in time for consideration by the USGS in the next round of updates of the national seismic hazard maps. To meet the USGS review time requirements, the NGA-SUB developers decided to develop a simplified GMPE that is an update of the 2016 BCHydro GMPE [Abrahamson et al. 2016]. This updated BCHydro GMPE uses the expanded dataset to regionalize V_{S30}, linear R, and constant terms in the GMPE, similar to the approach used by the NGA-W2 GMPEs. This approach provides an improved model that includes region-specific terms for Cascadia.

2 Dataset Selection

The NGA subduction (NGA-SUB) database includes recordings from seven different regions: Alaska, Cascadia, Central America, Japan, New Zealand, South America, and Taiwan as described by Kishida et al. [2018]. The full dataset includes over 70,000 3-component recordings. The June 12, 2018, version of the NGA-SUB dataset was used for this study. Given the large size of the NGA-SUB dataset, QA of the meta data and time histories set is still ongoing at the time of this study. Therefore, for the current study, the parts of the dataset that show questionable scaling and which are still under review were exc---luded. The main selection criteria used for selecting the subset of data for use in this study can be grouped into three main headings: selection by region, selection criteria for earthquakes, and selection criteria for recordings for each region.

2.1 DATASET SELECTION BY REGION

A preliminary analysis of the June 12, 2018, version of the dataset showed that the distance scaling of the recordings from earthquakes in the Alaska region are unusual. For example, the distance scaling of PGA for **M** > 6 earthquakes in Alaska is shown in Figure 2.1. The large scatter (factor of 100) and lack of attenuation with distance indicate that this dataset may include some errors in the distances or time histories. Therefore, the recordings in the Alaska dataset were excluded from this analysis.

An analysis of distance scaling from Taiwan earthquakes also showed unusually large scatter for the smaller magnitude earthquakes. The metadata for some of the smaller magnitude Taiwanese events in the June 12, 2018, version of the dataset are incorrect. For this study, rather than determine which of the earthquakes have meta data errors, all of the Taiwanese earthquakes with **M** < 5.5 have excluded. A second issue for the Taiwan data is the data from the "TW" network. The ground motions from the TW network appear to be biased to much lower values than the other networks. As an example, Figure 2.2 compares the ground motions from the CWB and TW networks. Given the apparent bias from the TW network, all of the recordings from this network have been excluded. The TW network represents about 10% of the recordings in Taiwan dataset.

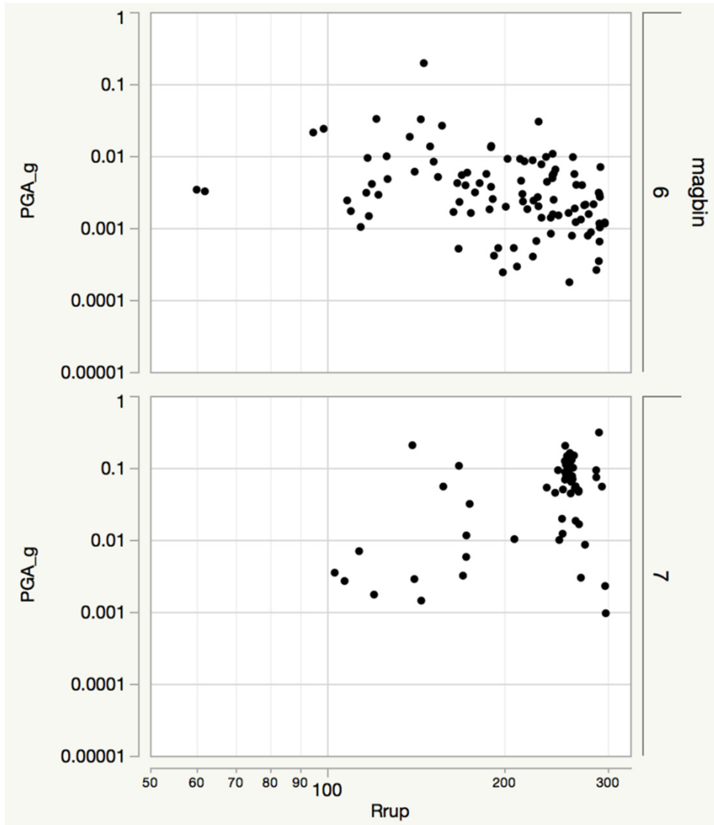

Figure 2.1 **Distribution of PGA with rupture distance for the Mw > 6 events in the Alaska database.**

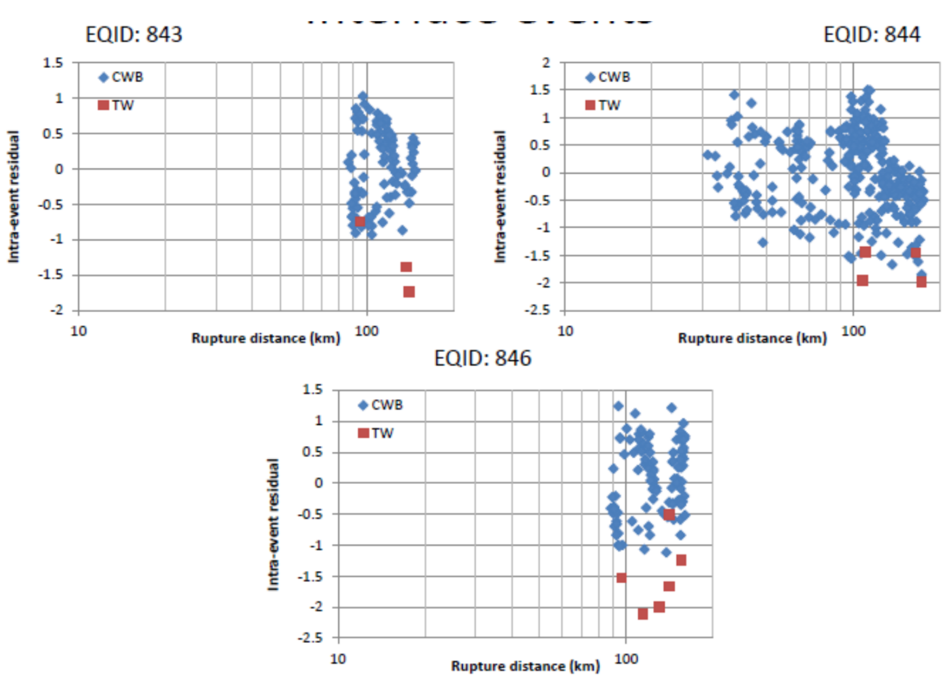

Figure 2.2 **Distribution of the residuals from preliminary analysis for interface events in Taiwan dataset that includes data from TW and CWB networks .**

2.2 SELECTION CRITERIA FOR EARTHQUAKES

The ground-motion model is developed for two event types: interface and slab earthquakes. The NGA-SUB dataset includes six event classifications shown in Table 2.1. For interface events, only class 0 events were used. For slab events, both class 1 and class 5 (event from lower part of a double seismic zone) were used. To avoid potential event classification issues, the unusually shallow intra-slab events ($Z_{TOR} < 20$ km) and unusually deep interface events ($Z_{TOR} > 50$ km) have been excluded.

For all earthquakes, the minimum magnitude of 5 was used, which is consistent with the 2016 BCHydro model. The minimum of 3 recordings per event (after all of the selection criteria have been met) is applied; the number of recordings per event is set at 3.

Table 2.1 Event classes.

Event class index	Event class description
0	Subduction interface
1	Subduction intraslab event
2	Shallow crustal/overriding
3	Mantle
4	Outer rise event
5	Intraslab, lower double seismc zone
-999	Unknown
-888	Interface event with small confidence
-777	Intraslab event with small confidence
-666	Shallow crustal/overriding events with small confidence
-444	Outer rise event with small confidence

2.3 SELECTION CRITERIA FOR RECORDINGS

To avoid potential bias in the ground motions, the following selection criteria are applied:

- Remove recordings with multiple event flag equal to 1 (time history that include more than one earthquake)
- Remove recordings with late *P*-trigger
- Remove recordings that have missing data in magnitude, distance and V_{S30} fields
- Remove stations with GMX first letter N, Z, and F (non-free-field stations)
- Remove downhole recordings with instrument depth >2 m

The distance scaling can be strongly influenced by wave propagation from earthquakes in the forearc to stations in the backarc. Ground-motion data from the Japan region show much faster attenuation for backarc stations; however, a preliminary analysis of the data in the Cascadia region show no difference between the attenuation for stations located in the forearc from those located in the backarc (Figure 2.2). Therefore, for application to Cascadia, the ground-motion model is developed only for stations located in the forearc. All recordings in the backarc have been removed.

To capture the large-distance scaling in Cascadia, data out to a distance of 1000 km from the Cascadia region have been included. For other regions, the distance is limited to 300 km as the main use of the global data is to constrain the magnitude scaling, short-distance scaling, and depth scaling. The large-distance slope of the recordings from the Tohoku earthquake is quite different than the others; see Figure 2.3. This difference can affect the event terms in the regression, leading to smaller event terms. To have the event terms representative of the Tohoku ground motions in the 100-km range, the recordings from the Tohoku earthquake with R_{rup} > 200 km have been eliminated.

The data includes an estimate of the maximum distance, R_{max}, for which the dataset is not affected by censoring of the ground motions. The recordings with $R_{rup} > R_{max}$ have been removed. This criterion mainly affects the Taiwan dataset. Finally, a small number of outlier recordings and events, identified by visual inspection, were removed.

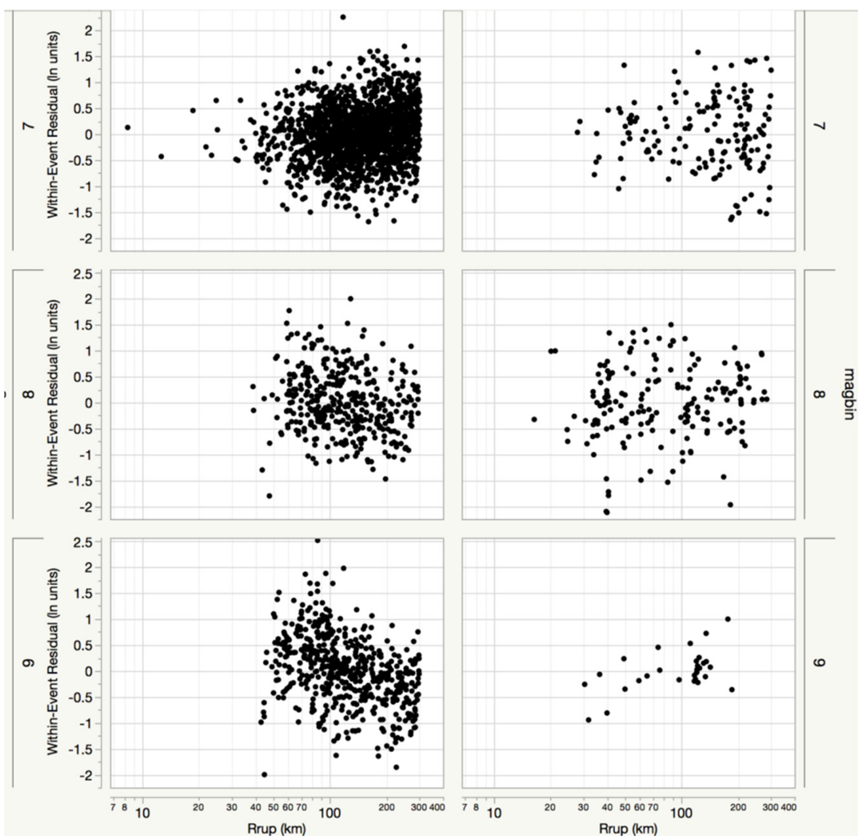

Figure 2.3 Distribution of the residuals from preliminary analysis with rupture distance (left: data from Japan, right: data from South America).

Regional distribution of the recordings used in the regression is given in Table 2.2. As defined in the NGA-West2 database, the response spectral values for the selected recordings are only used in the regression analysis for spectral frequencies greater than 1.25 times the high-pass corner frequency used in the record processing. This requirement produces a dataset that varies as a function of period. The period dependence of the number of earthquakes and number of recordings used in the regression analysis is shown in Figure 2.4, which shows a slight drop in the number of recordings and earthquakes between 5–6 sec. The magnitude-distance distributions are shown in Figure 2.5.

Table 2.2 Distribution of the selected earthquakes and recordings.

Number	Region	Number of earthquakes	Number of recordings
1	Alaska	0	0
2	Cascadia	4	155
3	Central America	12	78
4	Japan	73	4953
5	New Zealand	34	541
6	South America	47	636
7	Taiwan	11	1792
	Total	181	8073
	Total in NGA-SUB	**1,880**	**71,343**

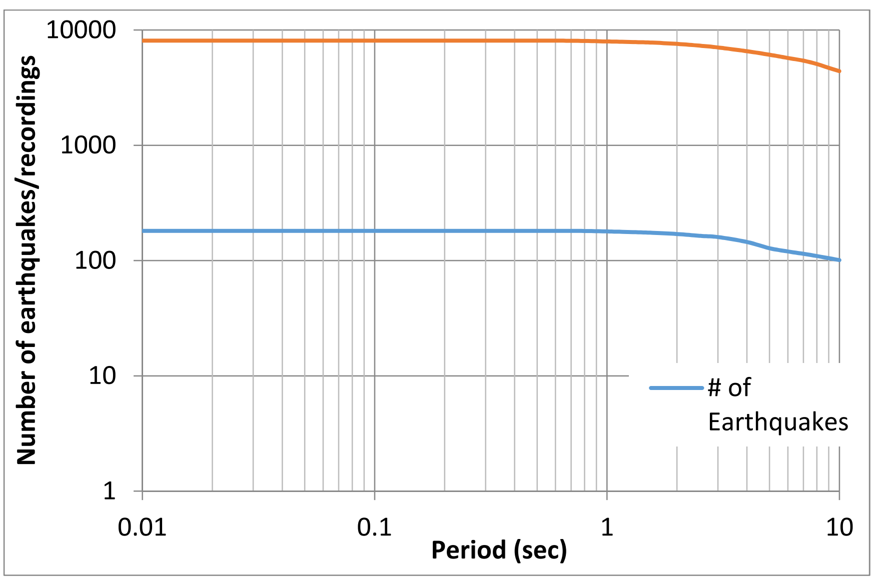

Figure 2.4 Number of earthquakes and number of recordings in the selected subset by period.

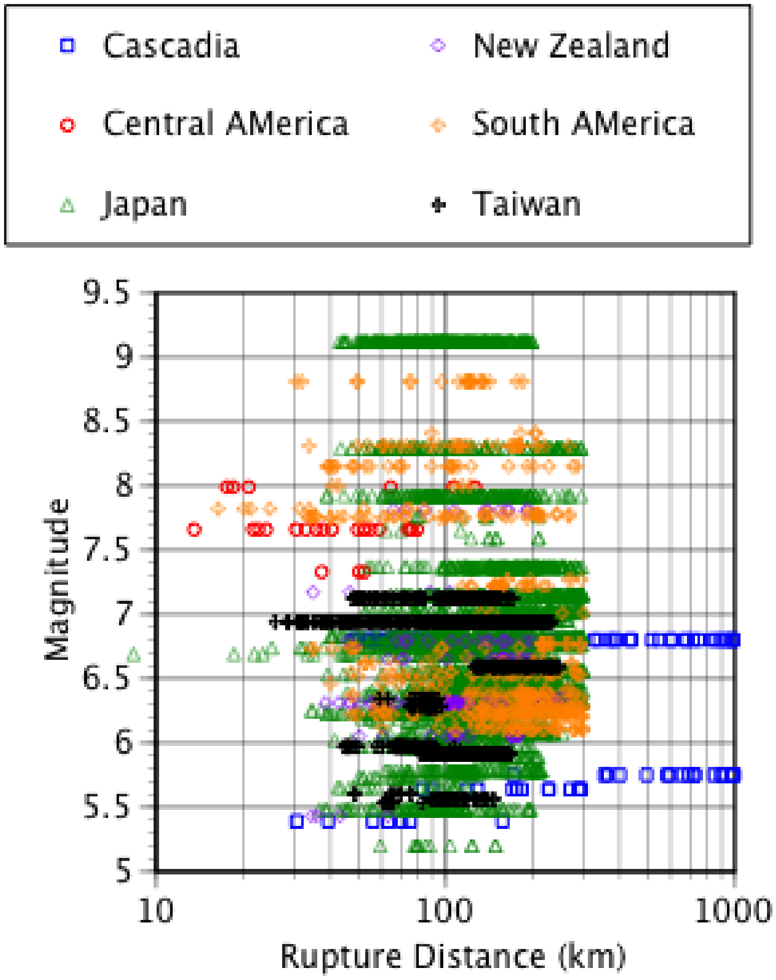

Figure 2.5 **Magnitude-distance distributions for the final subset (*T* = 6 sec).**

3 Regression Analysis

3.1 FUNCTIONAL FORM

The functional form for the GMPE is based on the functional form used in the 2016 BCHydro model. The base model is given by:

$$\ln\left[\mathrm{PSA}\left(g\right)\right] = a_1 + a_4\Delta C_1\left[a_2 + a_{14}F + a_3\left(M-7.8\right)\right]\ln\left\{R_{rup} + C_4\exp\left[\left(M-6\right)a_9\right]\right\}$$
$$+a_6R_{rup} + a_{10}F + f_{\mathrm{mag}}\left(M,F\right) + f_{Z_{\mathrm{TOR}}}\left(Z_{\mathrm{TOR}}\right) + f_{\mathrm{site}}\left(\mathrm{PGA}_{1000}, V_{S30}\right)$$

where

M = moment magnitude

R_{rup} = rupture distance in km

F = event type (0 for interface and 1 for intraslab)

Z_{TOR} = depth of the top of rupture (km)

PGA_{1000} = median peak horizontal acceleration for V_{S30} = 1000 m/sec

ΔC_1 = difference between the C_1 for slab and interface

The magnitude scaling is given by:

$$f_{\mathrm{mag}}\left(M,F\right) = \begin{cases} a_4\left(M-C_1\right) + a_{13}\left(10-M\right)^2 & \text{for } M \le C_1 \\ a_5\left(M-C_1\right) + a_{13}\left(10-M\right)^2 & \text{for } M > C_1 \end{cases}$$

The nonlinear site response scaling is given by:

$$f_{\mathrm{site}}\left(\mathrm{PGA}_{1000}, V_{S30}\right) = \begin{cases} a_{12}\ln\left(\frac{V_S^*}{V_{\mathrm{lin}}}\right) - b\,\ln\left(\mathrm{PGA}_{1000} + c\right) b\,\ln\left[\mathrm{PGA}_{1000} + c\left(\frac{V_S^*}{V_{\mathrm{lin}}}\right)^n\right] & \text{for } V_{S30} < V_{\mathrm{lin}} \\ \left(a_{12} + b\,n\right)\ln\left(\frac{V_S^*}{V_{\mathrm{lin}}}\right) & \text{for } V_{S30} \ge V_{\mathrm{lin}} \end{cases}$$

where

$$V_S^* = \begin{cases} 1000 & \text{for } V_{S30} > 1000 \text{ m/sec} \\ V_{S30} & \text{for } V_{S30} \le 1000 \text{ m/sec} \end{cases}$$

The BCHydro model used a quadratic magnitude scaling with a break in the scaling for large magnitudes (**M** >7.6 to **M**8.0 for interface and **M** >7.5 for the slab). The slope of the large-magnitude scaling was constrained based on finite-fault simulations by Gregor et al. [2006] and Atkinson and Macias [2008] for interface earthquakes. For the updated BCHydro model, this constraint on the large magnitude scaling is maintained, but the break points are re-evaluated. The break in the magnitude scaling for interface earthquakes are given in Table 3.1. The break in the magnitude scaling for slab events is based on the slab thickness as described by Archuleta and Ji [2018]. For Cascadia, $C_1 = 7.2$ for slab events.

The BCHydro model used linear scaling with Z_{TOR} without a limit on the depth range for the scaling. A preliminary analysis showed that the Z_{TOR} scaling does not apply for depth greater than about 100 km. Therefore, the Z_{TOR} scaling was modified to apply only to a maximum depth of 100 km. The Z_{TOR} scaling is given by:

$$f_{Z_{\mathrm{TOR}}}\left(Z_{\mathrm{TOR}},F\right)=\begin{cases}\theta_{11}\left(Z_{\mathrm{TOR}}-60\right)F & \text{for } Z_{\mathrm{TOR}}\le 100\text{ km}\\ \theta_{11}\left(100-60\right)F & \text{for } Z_{\mathrm{TOR}}>100\text{ km}\end{cases}$$

There are regional coefficients for the three regional terms. The indexes for these coefficients are listed in Table 3.1.

Table 3.1 Region-specific parameters.

Term	Region	Regression coefficient
Change in V_{S30} scaling	Cascadia	a_{18}
	Central America	a_{19} = 0 (fixed at global value)
	Japan	a_{20}
	New Zealand	a_{21}
	South America	a_{22}
	Taiwan	a_{23}
Change in Linear R term	Cascadia	a_{25}
	Central America	a_{26}
	Japan	a_{27}
	New Zealand	a_{28}
	South America	a_{29}
	Taiwan	a_{30}
Constant	Cascadia	a_{32}
	Central America	a_{33}
	Japan	a_{34}
	New Zealand	a_{35}
	South America	a_{36}
	Taiwan	a_{37}

3.2 REGRESSION ANALYSIS

The random-effects model was used for the regression analysis following the procedure described by Abrahamson and Youngs [1992]. The regression is performed in a number of steps to arrive at a smooth model. The coefficients are smoothed to either lead to smooth spectra or to constrain the model to be consistent with basic seismological constraints. Table 3.2 lists the parameters that were regressed in each step and those which were smoothed and fixed following each step.

The large-magnitude scaling was constrained to be equal to the BCHydro scaling. In all steps, the magnitude dependent geometrical spreading term (a_3), the linear magnitude scaling terms for large magnitude events (a_5), the magnitude dependent finite-fault effect term (a_9), and the quadratic magnitude term (a_8) are set to the values given in 2016 BCHydro model. In the first run, the global geometrical spreading term (a_2) and the global linear V_{S30} scaling term (a_{12}) are smoothed; see Figures 3.1 and 3.2.

In the second run, the additional global geometrical spreading term for slab events (a_{14}) has been smoothed based on the smoothed geometrical spreading term in the previous step. Similarly, linear magnitude term for small-to-moderate magnitude events (a_4) has been smoothed in Step 3; see Figure 3.3. In step 4, the global large distance scaling parameter (a_6) has been smoothed; see Figure 3.4. In the same step, the Z_{TOR} scaling (a_{11}) has been smoothed and held fixed for the next steps.

The next set of runs included estimation of the regional terms for the linear V_{S30} terms for Cascadia (a_{18}) and other regions (a_{19}-a_{23}), large-distance scaling parameters for Cascadia (a_{25}) and other regions (a_{26}-a_{30}), and the constant terms for Cascadia (a_{31}) and other regions (a_{33}-a_{37}). The regional terms for Cascadia, a_{18} and a_{25}, have been smoothed. Other regional parameters were not smoothed because they are not intended to be used.

The values of the smoothed coefficients for the median ground motion are given in the following chapter; see Table 4.1.

3.3 RESIDUALS

The between-event residuals are shown as a function of magnitude in Figures 3.9 and 3.10 for six spectral periods: PGA, T = 0.1 sec, T = 0.2 sec, T = 0.5 sec, T = 1 sec, and T = 3 sec. Note that there is no clear trend in magnitude, indicating that the magnitude scaling is reasonable. A key issue is the extrapolation to the **M**9 range. The event terms for the two largest earthquakes (Maule and Tohoku) are shown in Figure 3.11. The event terms are reasonably balanced between these two events, indicating that the selected break points in the interface magnitude scaling are reasonable.

The within-event residuals for the same six spectral periods are shown by region in Figures 3.12, 3.13, and 3.14. In each case, the residuals are shown as functions of the magnitude, distance, V_{S30}, and PGA_{1000}. Figure 3.12 shows the residuals for the Cascadia region; Figure 3.13 shows the residuals for the Japan region; and Figure 3.14 shows the residuals for the other regions. Overall, there is not a strong trend in the residuals as functions of the four parameters.

Table 3.2 Estimated and constrained parameters at each step of regression

Step	Estimated parameters	Parameters held fixed	Parameters smoothed after run
1	a_1 (global constant), a_2 (geometrical spreading, GS), a_4 (linear magnitude for **M**<c_1), a_6 (global linear R), a_{10} (additional global constant for slab events), a_{11} (Z_{TOR}), a_{12} (global linear V_{S30}), a_{14} (additional global GS for slab events)	a_3 (mag dep GS), a_5 (linear magnitude for **M**>c_1), a_9 (magnitude dependent H), a_8 (quadratic magnitude)	a_2, a_{12}
2	a_1, a_4, a_6, a_{10}, a_{11}, a_{14}, a_{45}	a_3, a_5, a_9, a_8, a_2, a_{12}	a_{14}
3	a_1, a_4, a_6, a_{10}, a_{11}, a_{45}	a_3, a_5, a_9, a_8, a_1, a_{12}, a_{14}	a_4
4	a_1, a_6, a_{10}, a_{11}	a_3, a_5, a_9, a_8, a_1, a_{12}, a_{14}, a_4	a_6, a_{11}
5	a_{10}, regional V_{S30}: a_{18}, a_{20}, a_{21}, a_{22}, a_{23}, regional R: a_{25}, a_{26}, a_{27}, a_{28}, a_{29}, a_{30}, regional const: a_{32}, a_{33}, a_{34}, a_{35}, a_{36}, a_{37}	a_3, a_5, a_9, a_8, a_1, a_{12}, a_{14}, a_6, a_{11} $a_1 = 0$	a_{18}, a_{25}
7	a_{10}, a_{18} (delta linear V_{S30} term for Cascadia), a_{25} (delta linear R terms for Cascadia), a_{31} (constant term for Cascadia)		a_{10}

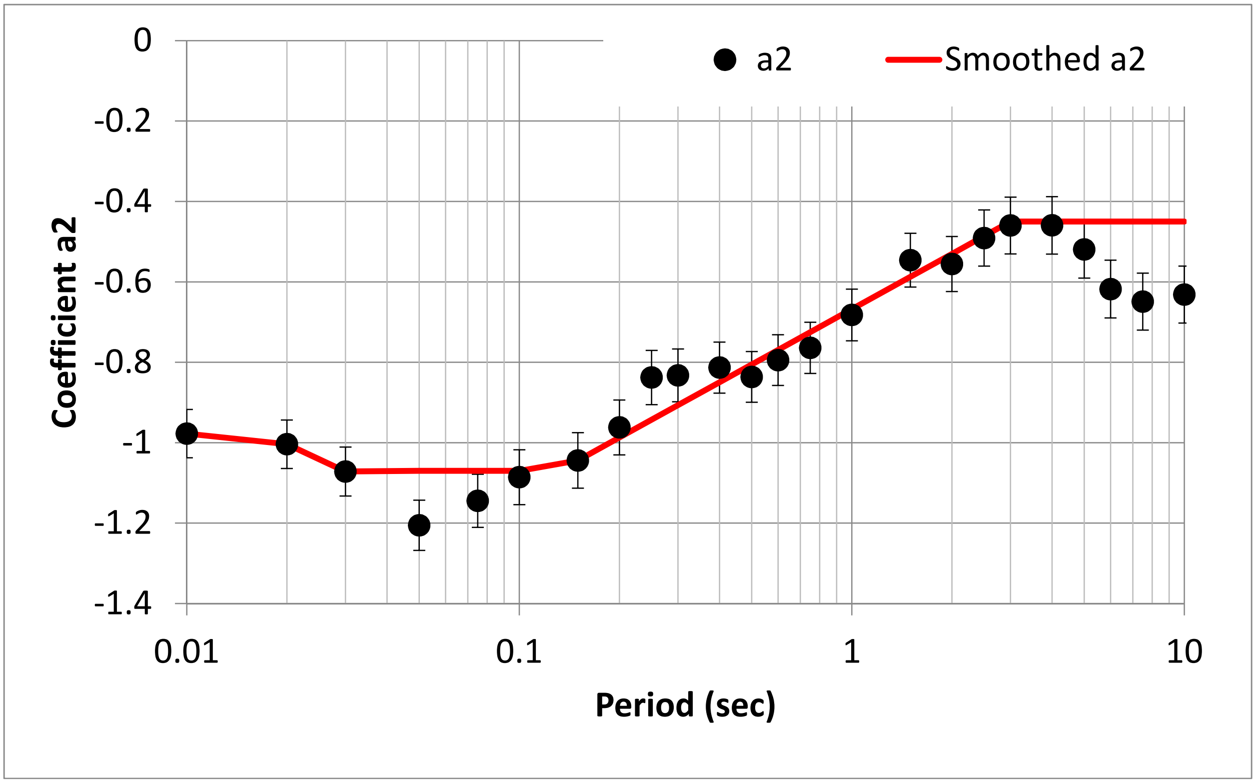

Figure 3.1 Smoothing of coefficient a_2 (global geometrical spreading for interface).

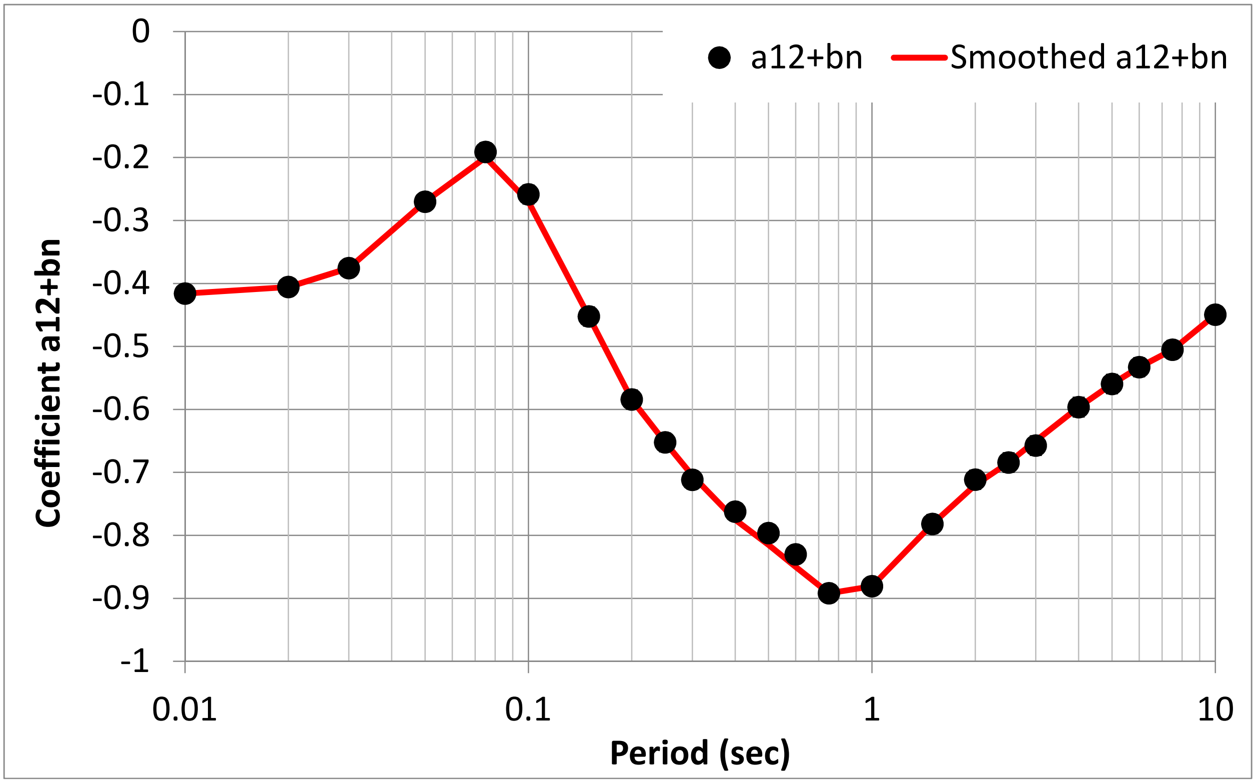

Figure 3.2 Smoothing of coefficient a_{12} (global V_{S30} scaling).

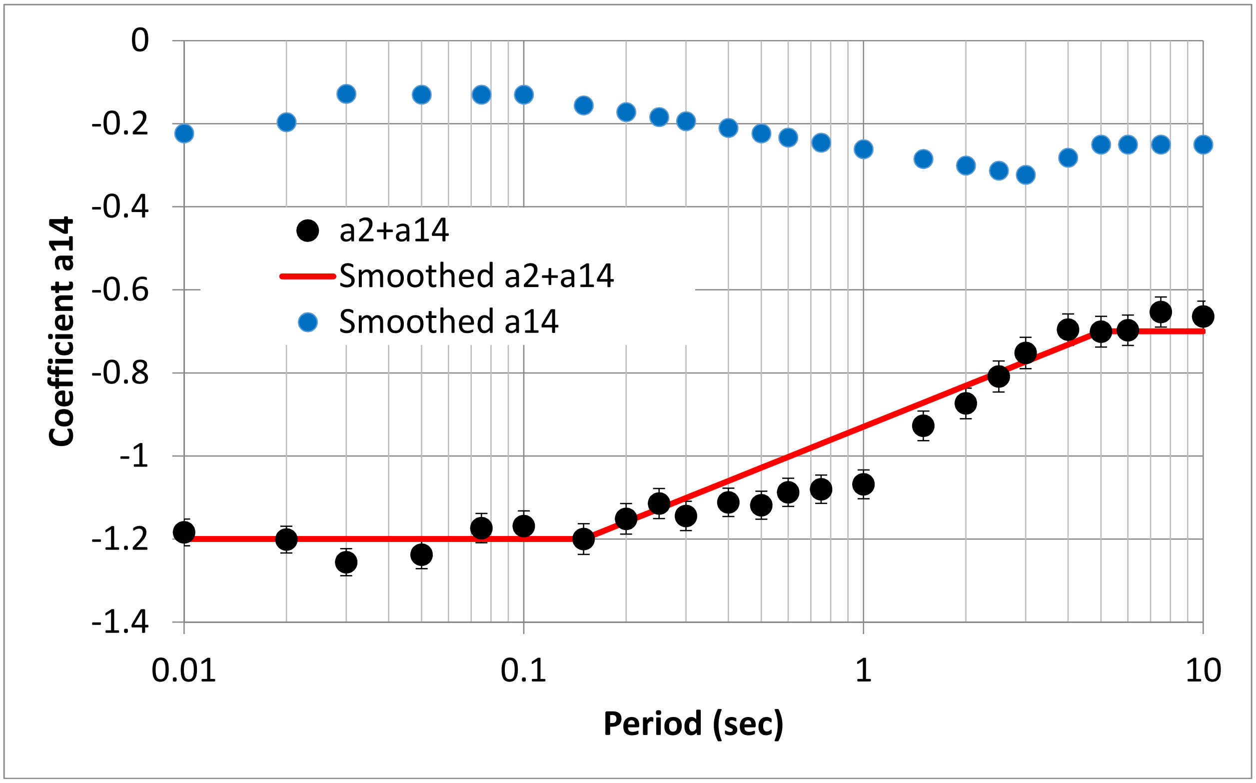

Figure 3.3 Smoothing of coefficient a_{14} (global additional geometrical spreading for slab).

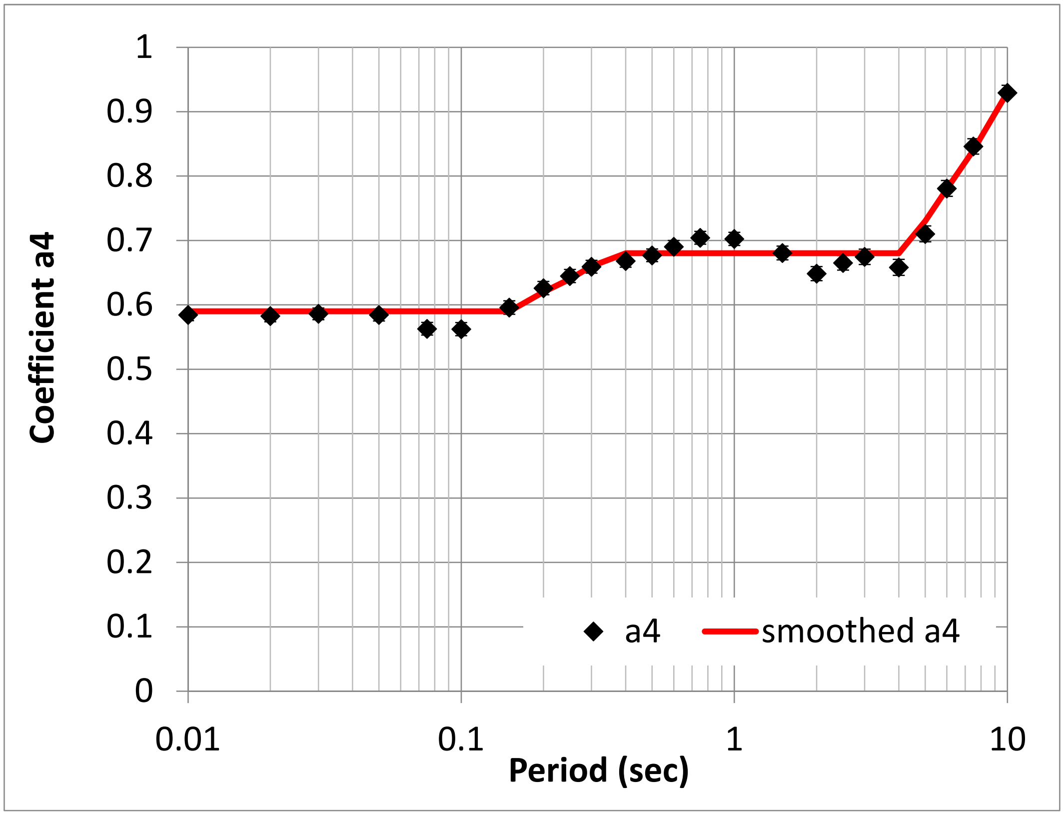

Figure 3.4 **Smoothing of coefficient a_4 (global small magnitude scaling).**

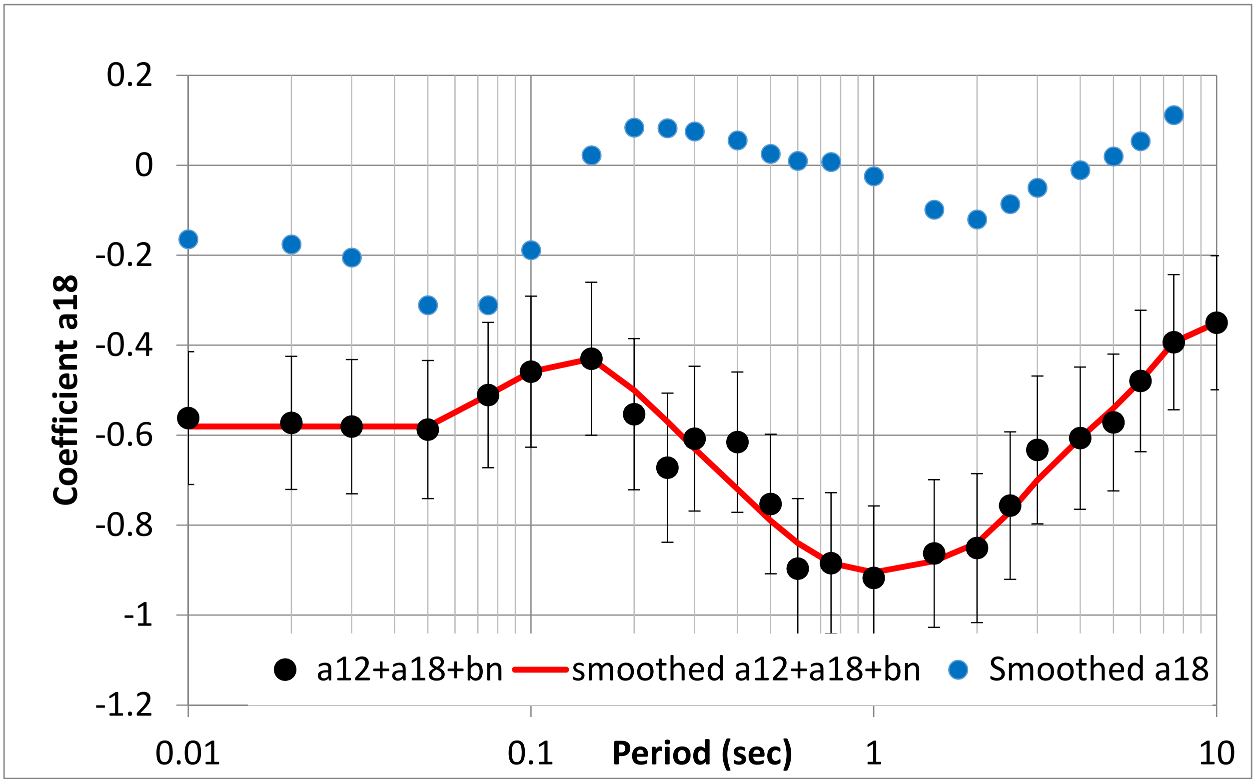

Figure 3.5 Smoothing of coefficient a_{18} (Cascadia VS30 scaling).

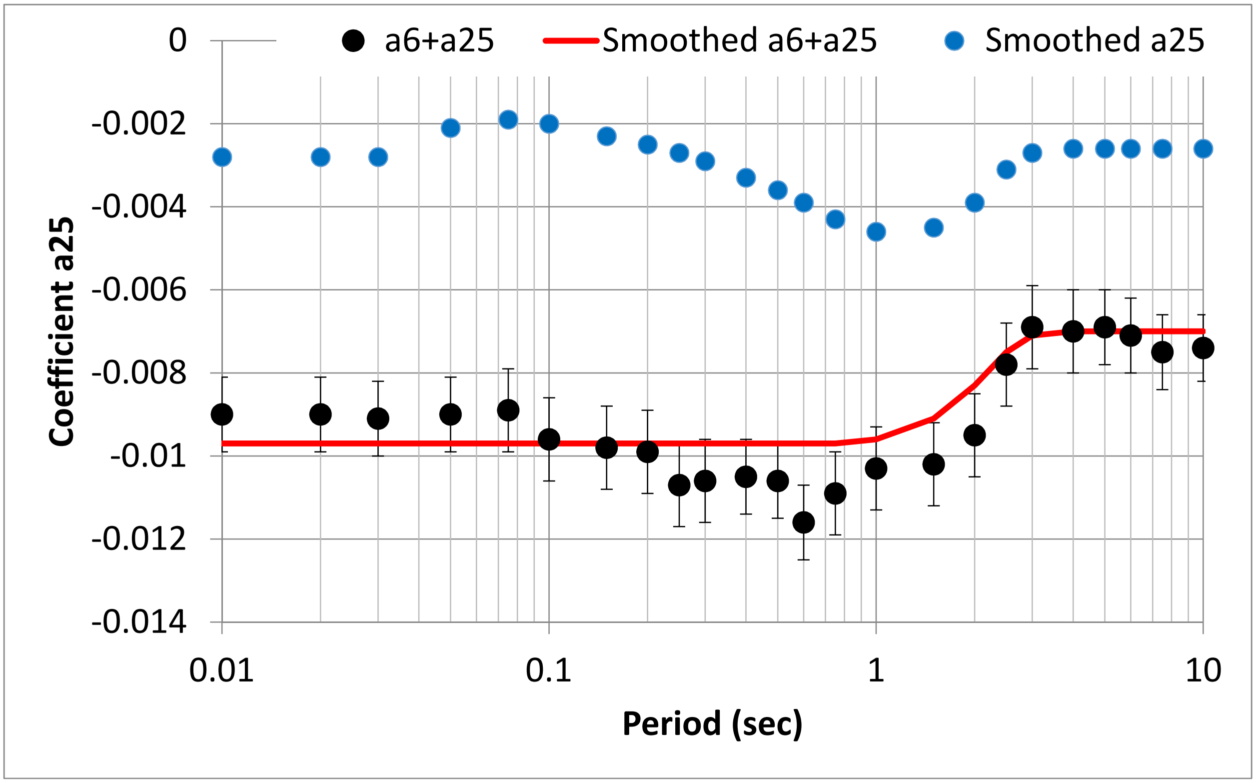

Figure 3.6 Smoothing of coefficient a_{25} (Cascadia linear R scaling).

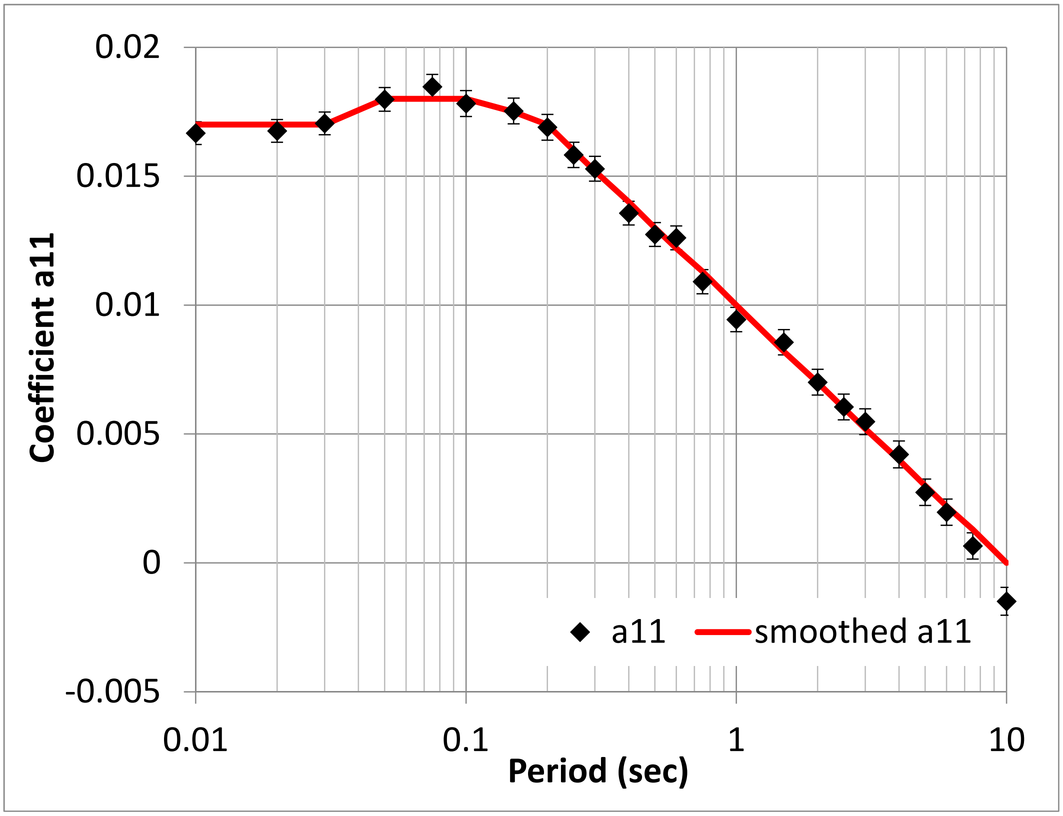

Figure 3.7 Smoothing of coefficient a_{11} (global Z_{TOR} scaling for slab).

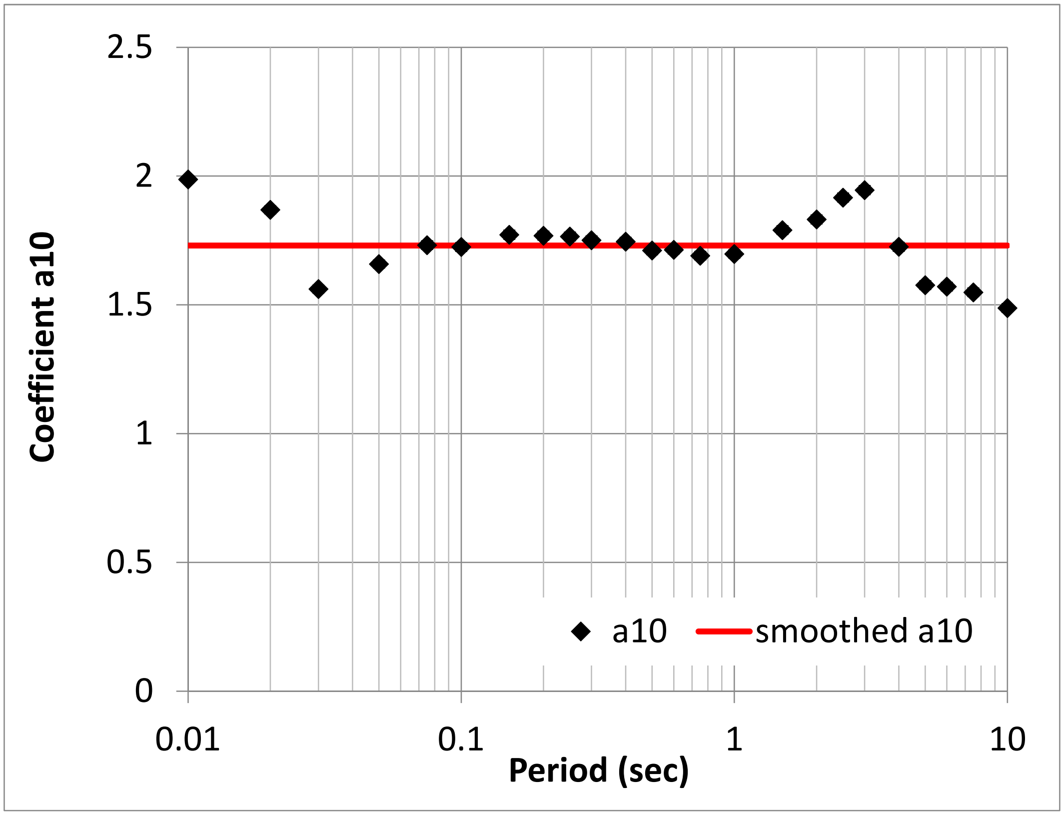

Figure 3.8 Smoothing of coefficient a_{10} (global slab constant term).

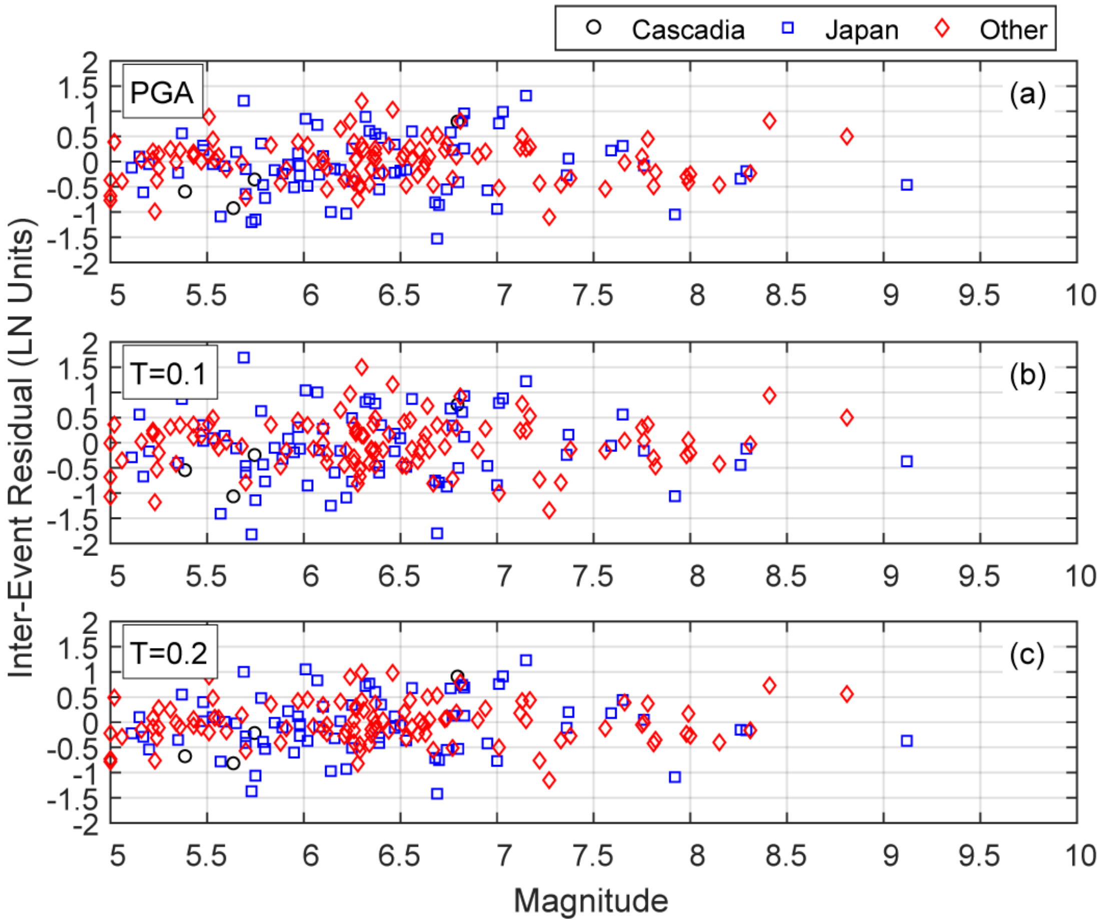

Figure 3.9 Between-event residuals: (a) PGA, (b) *T* = 0.1 sec, and (c) *T* = 0.2 sec.

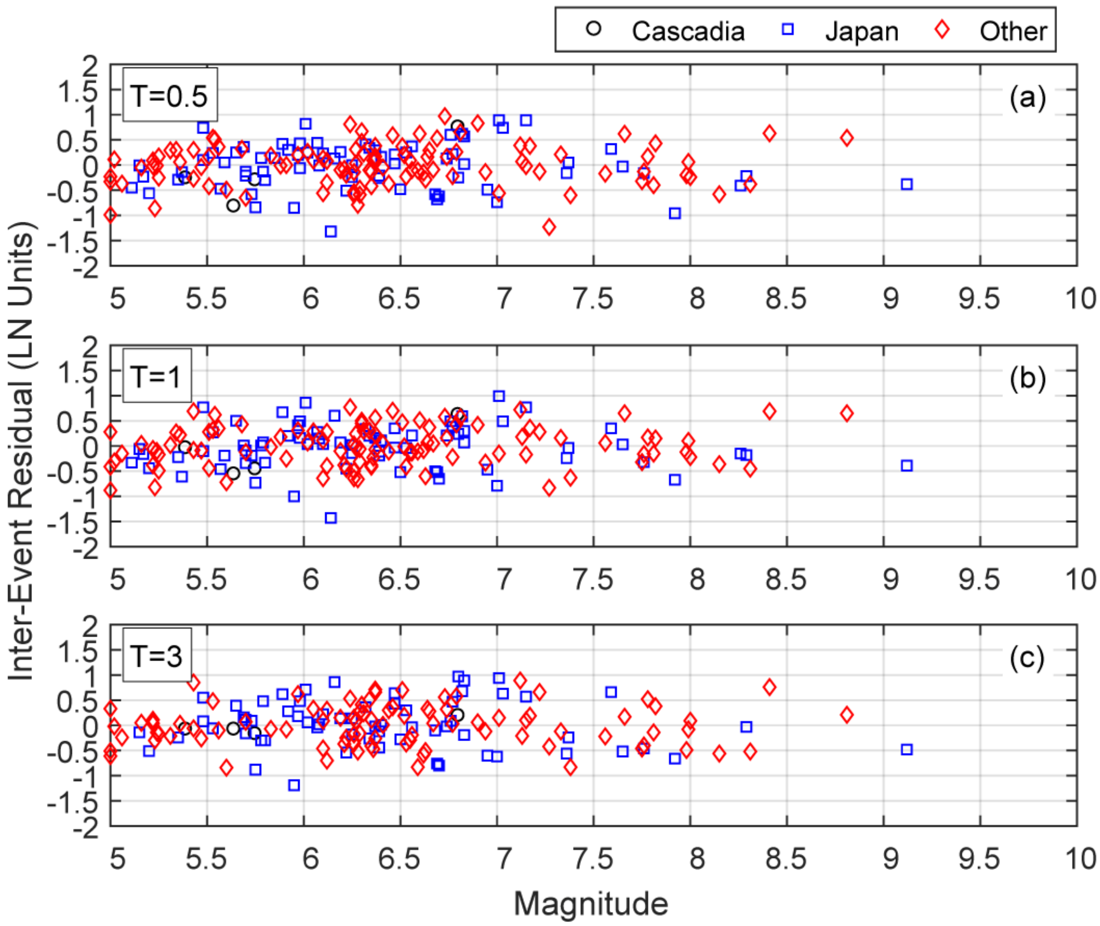

Figure 3.10 **Between-event residuals: (a) *T* = 0.5 sec, (b) *T* = 1 sec, and (c) *T* = 3 sec.**

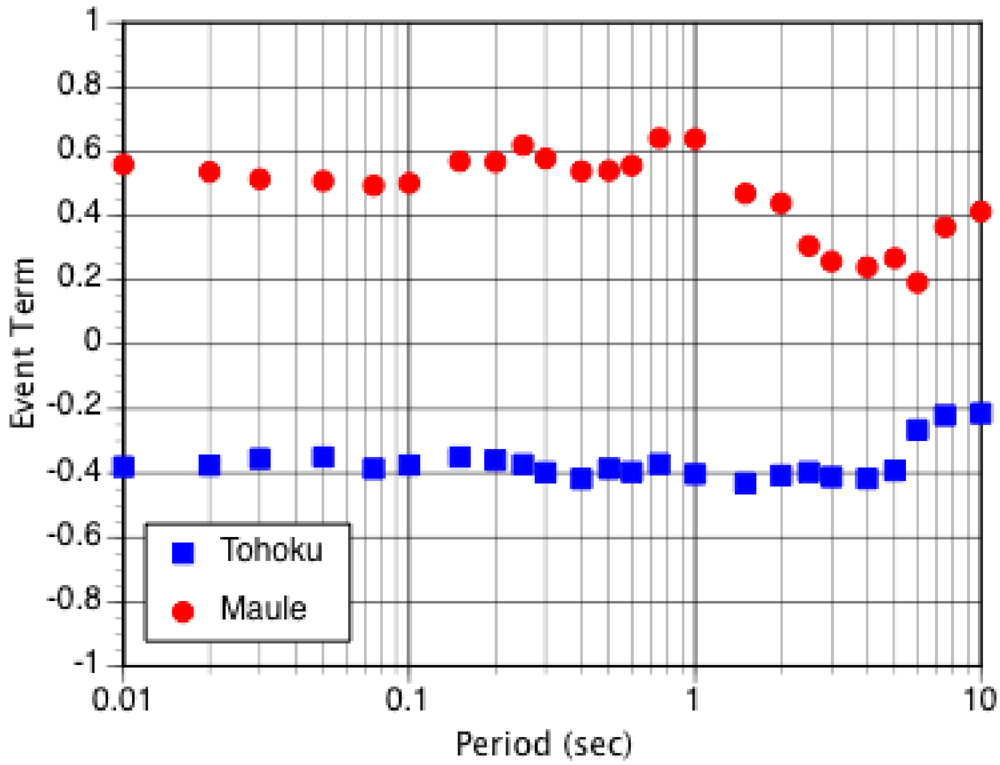

Figure 3.11 Between-event residuals for the largest events: Tohoku and Maule, Chile.

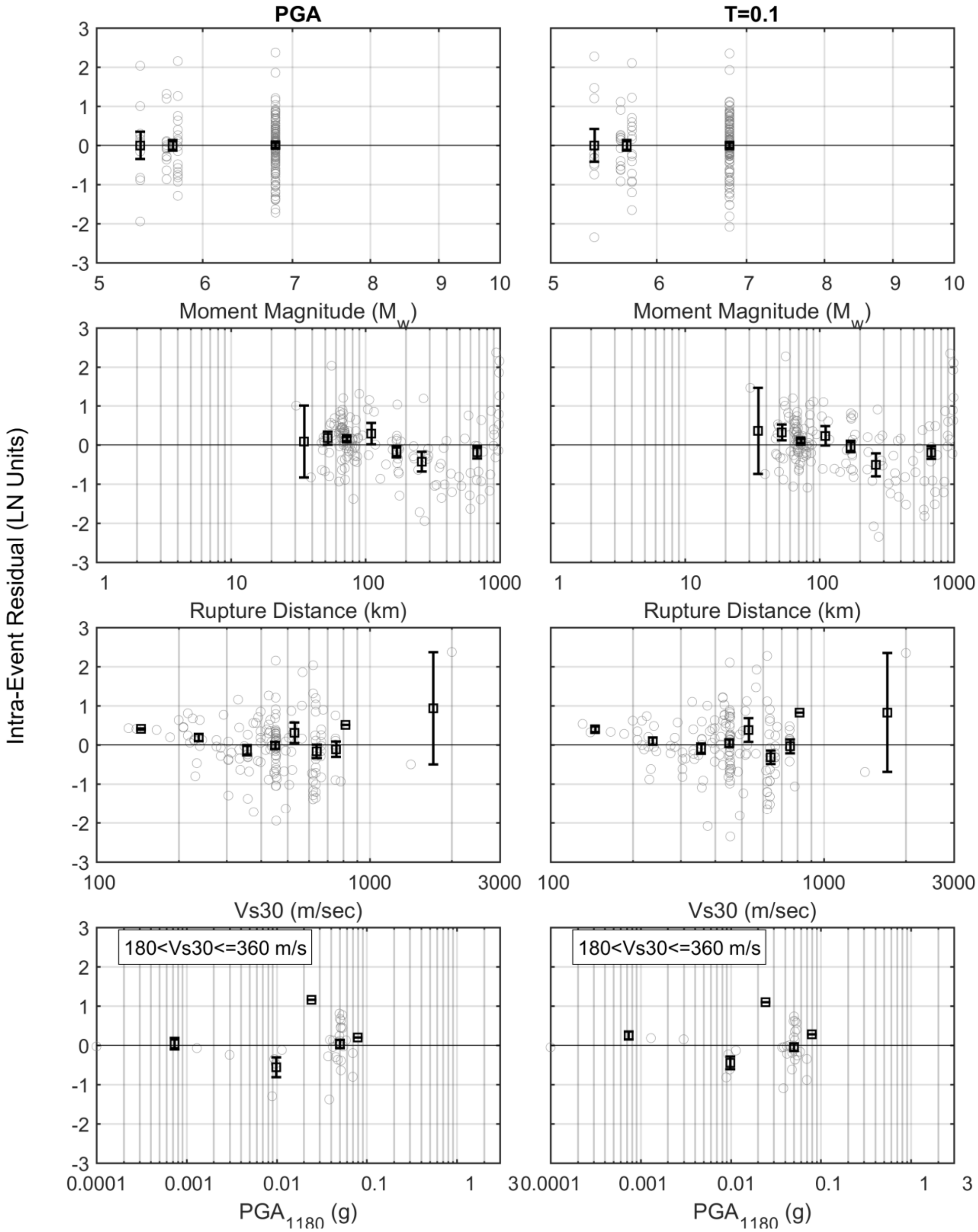

Figure 3.12(a) Within-event residuals for Cascadia: PGA and *T* = 0.1 sec.

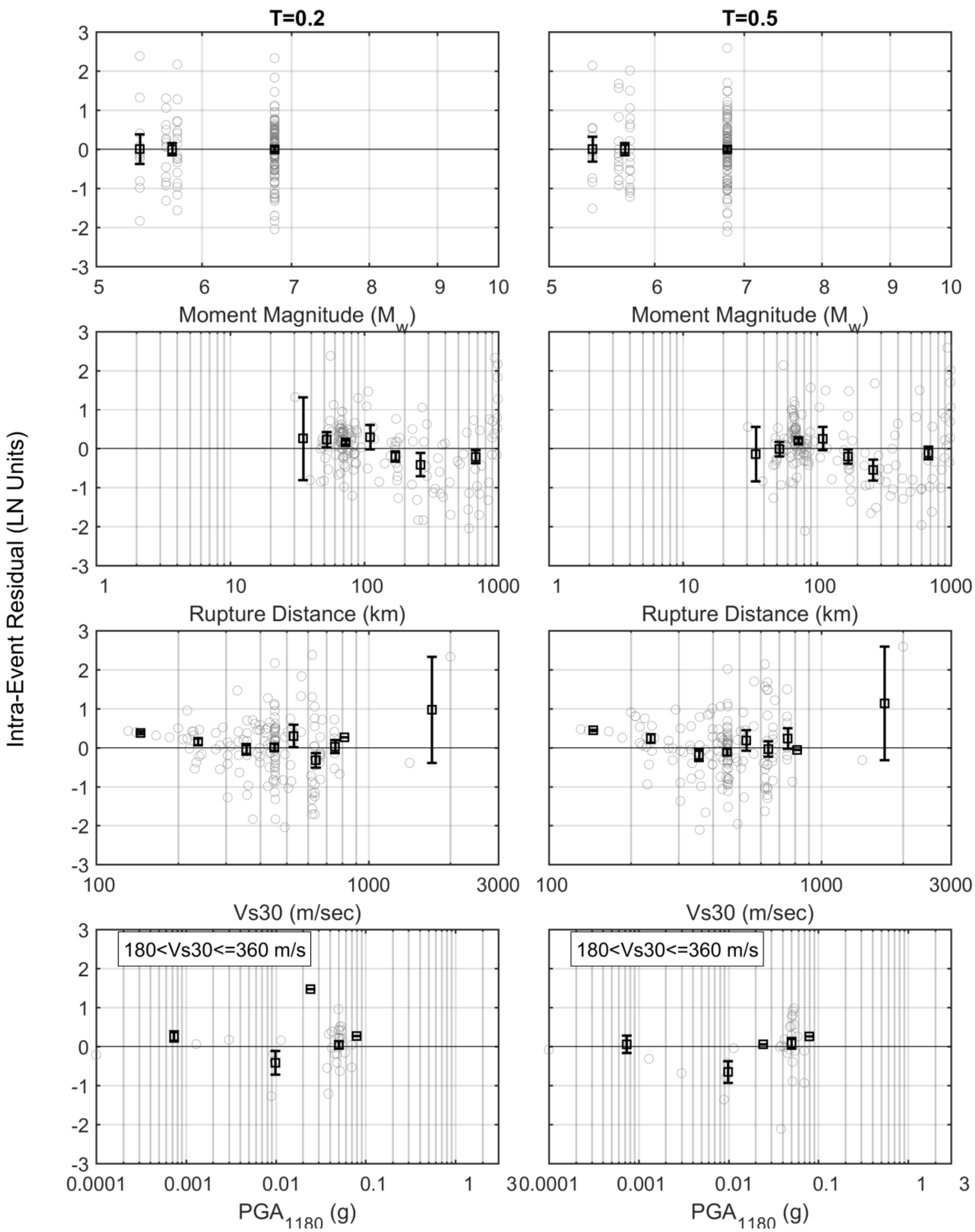

Figure 3.12(b) Within-event residuals for Cascadia: *T* = 0.2 sec and *T* = 0.5 sec.

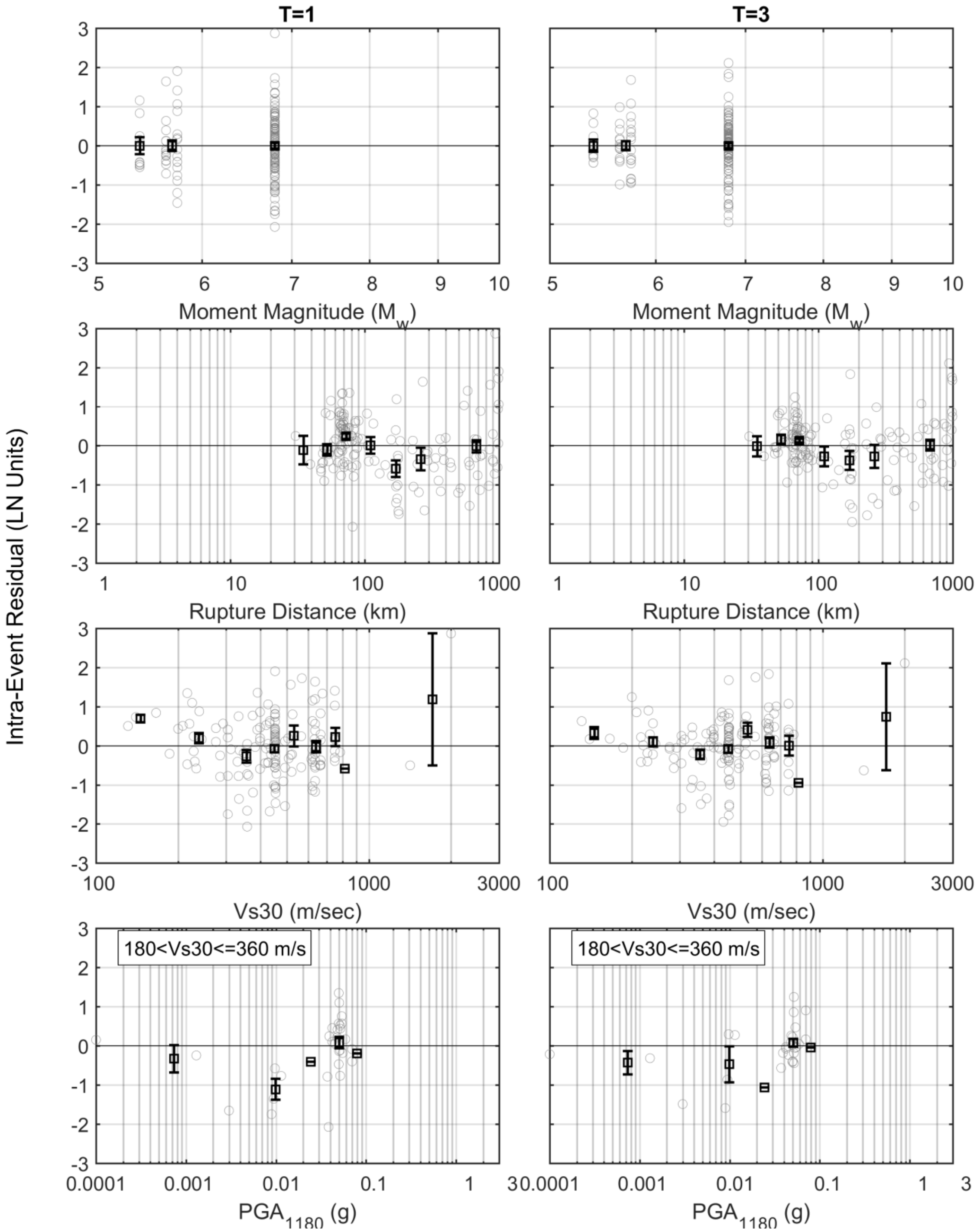

Figure 3.12(c) Within-event residuals for Cascadia: *T* = 1 sec and *T* = 3 sec.

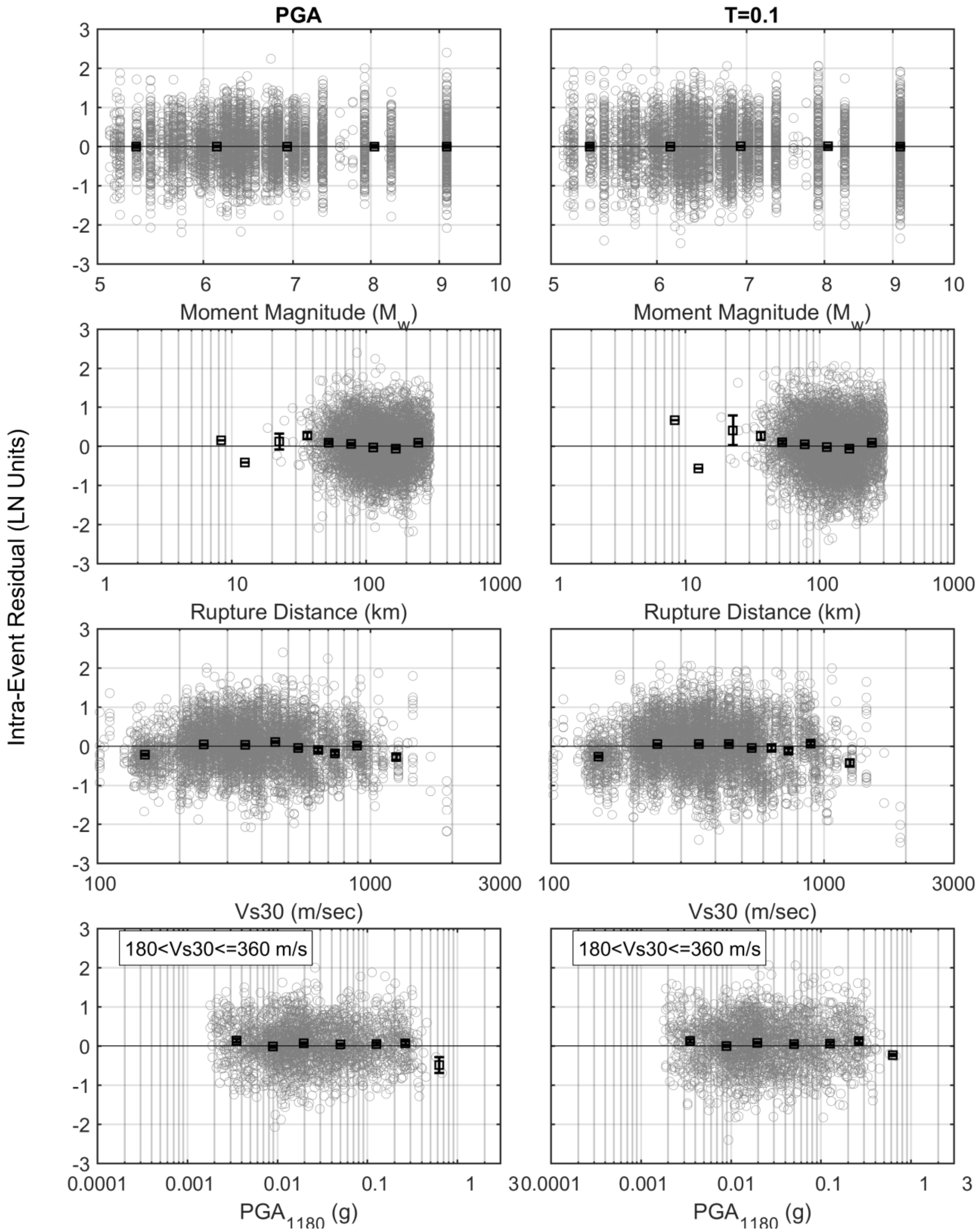

Figure 3.13(a) Within-event residuals for Japan: PGA and *T* = 0.1 sec.

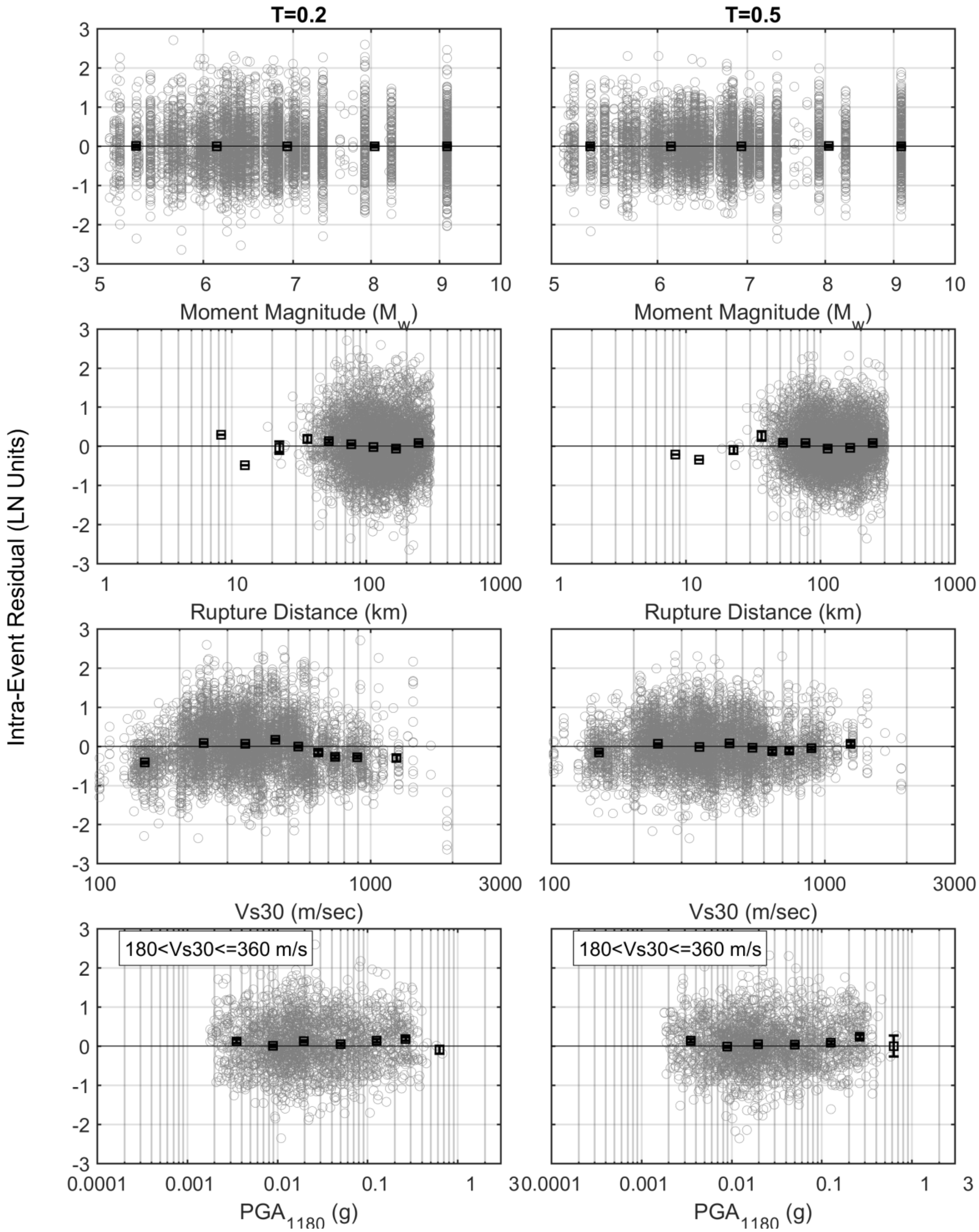

Figure 3.13(b) Within-event residuals for Japan: *T* = 0.2 sec and *T* = 0.5 sec.

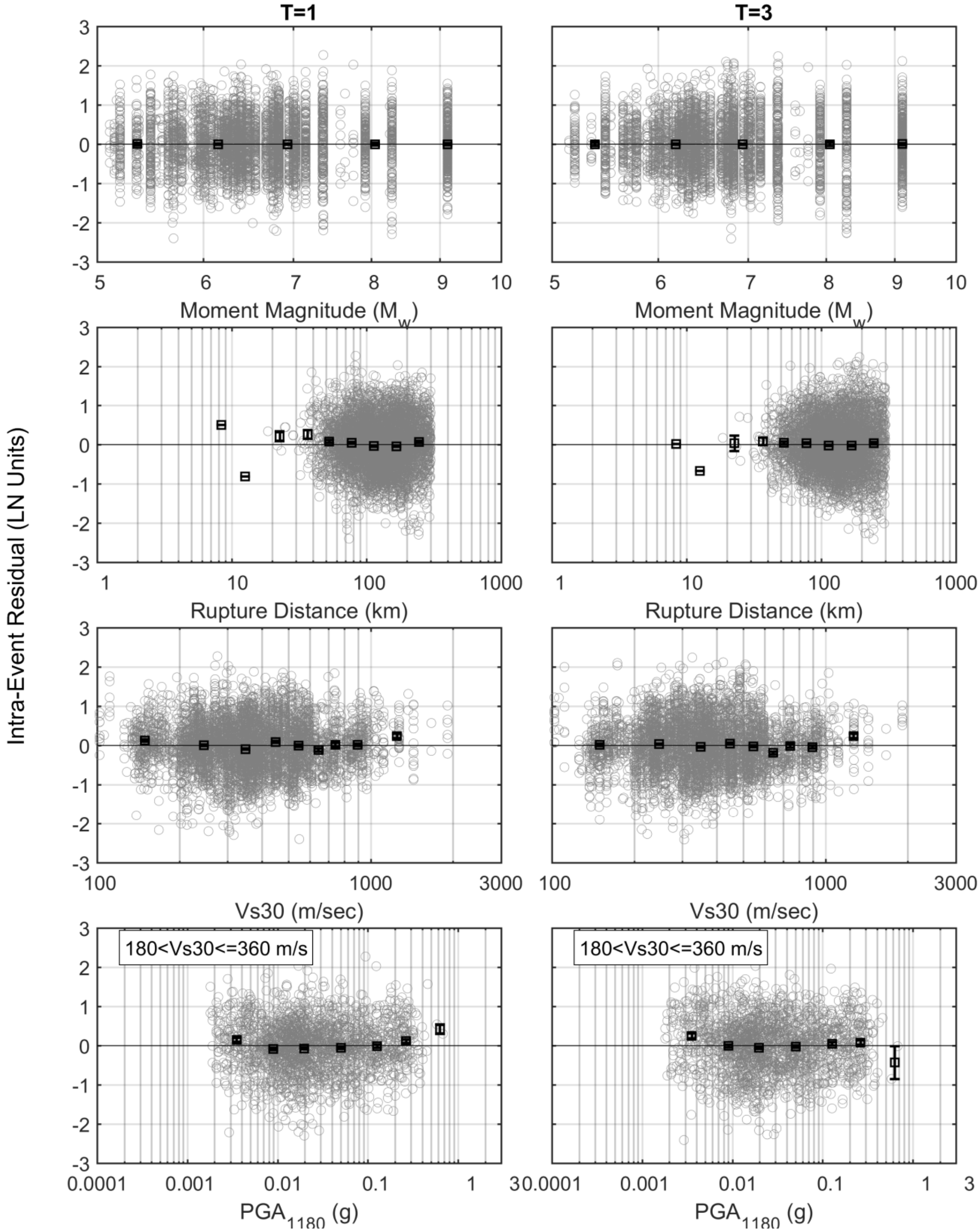

Figure 3.13(c) Within-event residuals for Japan: *T* = 1 sec and *T* = 3 sec.

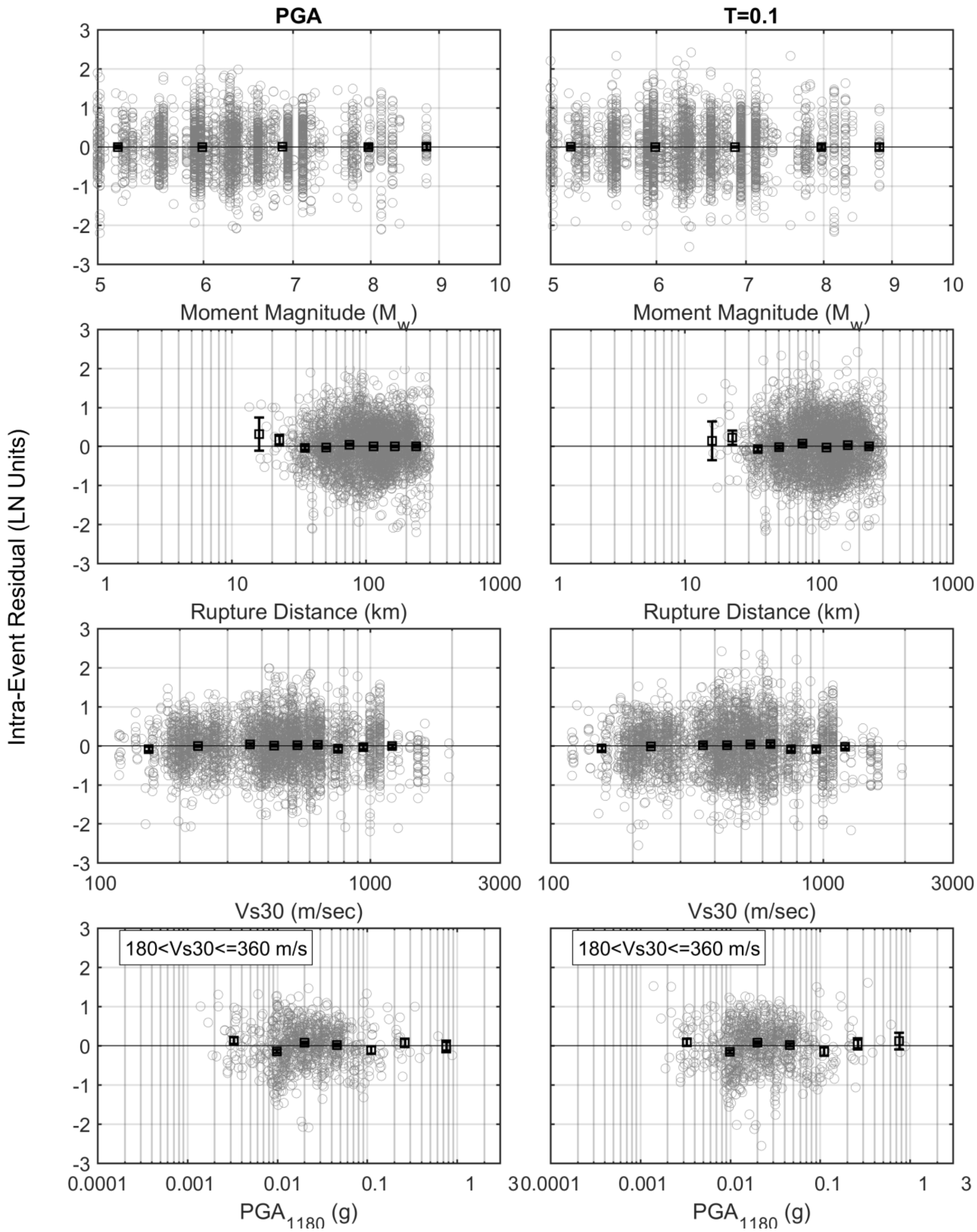

Figure 3.14(a) Within-event residuals for other regions: PGA and *T* = 0.1 sec.

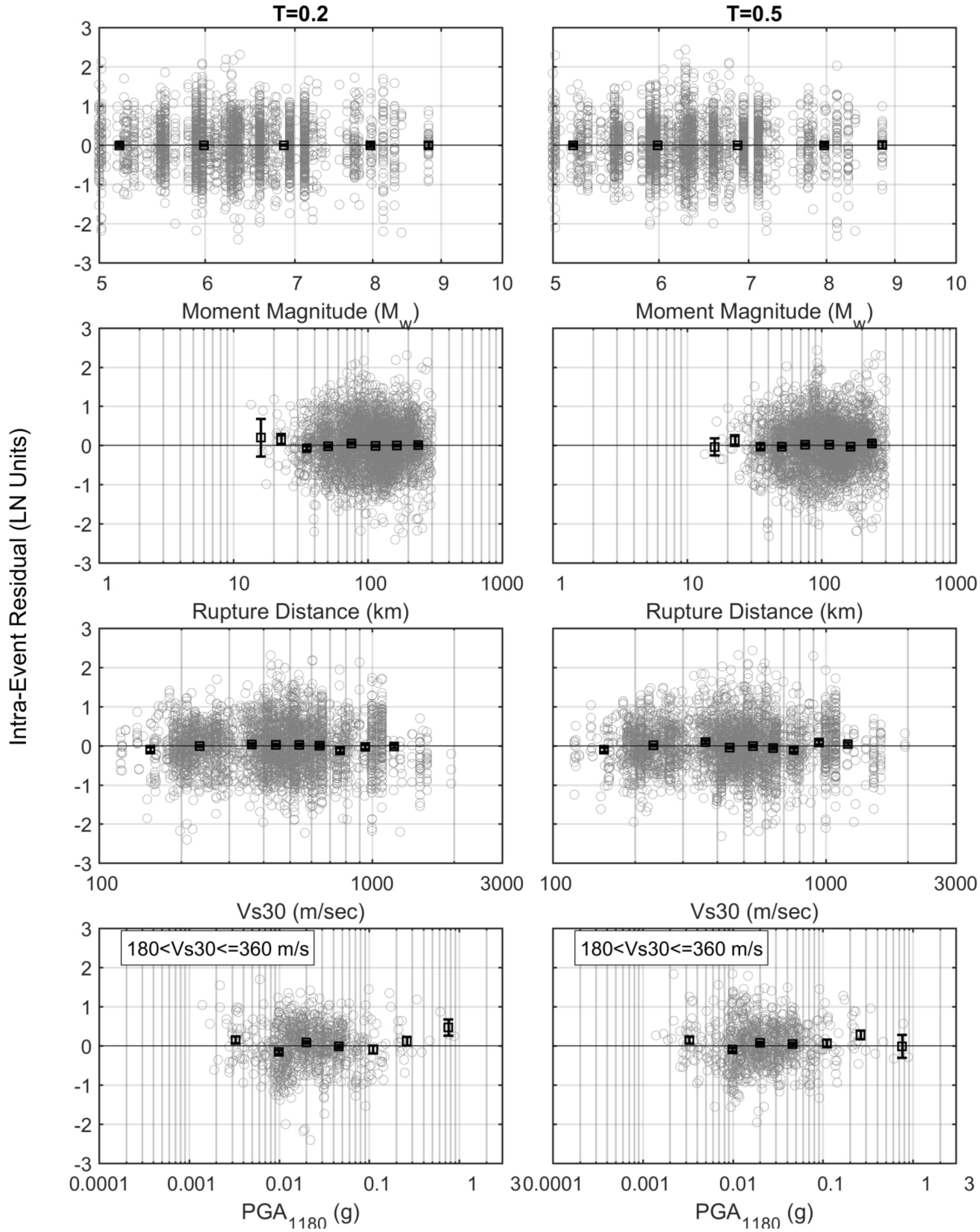

Figure 3.14(b) Within-event residuals for other regions: *T* = 0.2 sec and *T* = 0.5 sec.

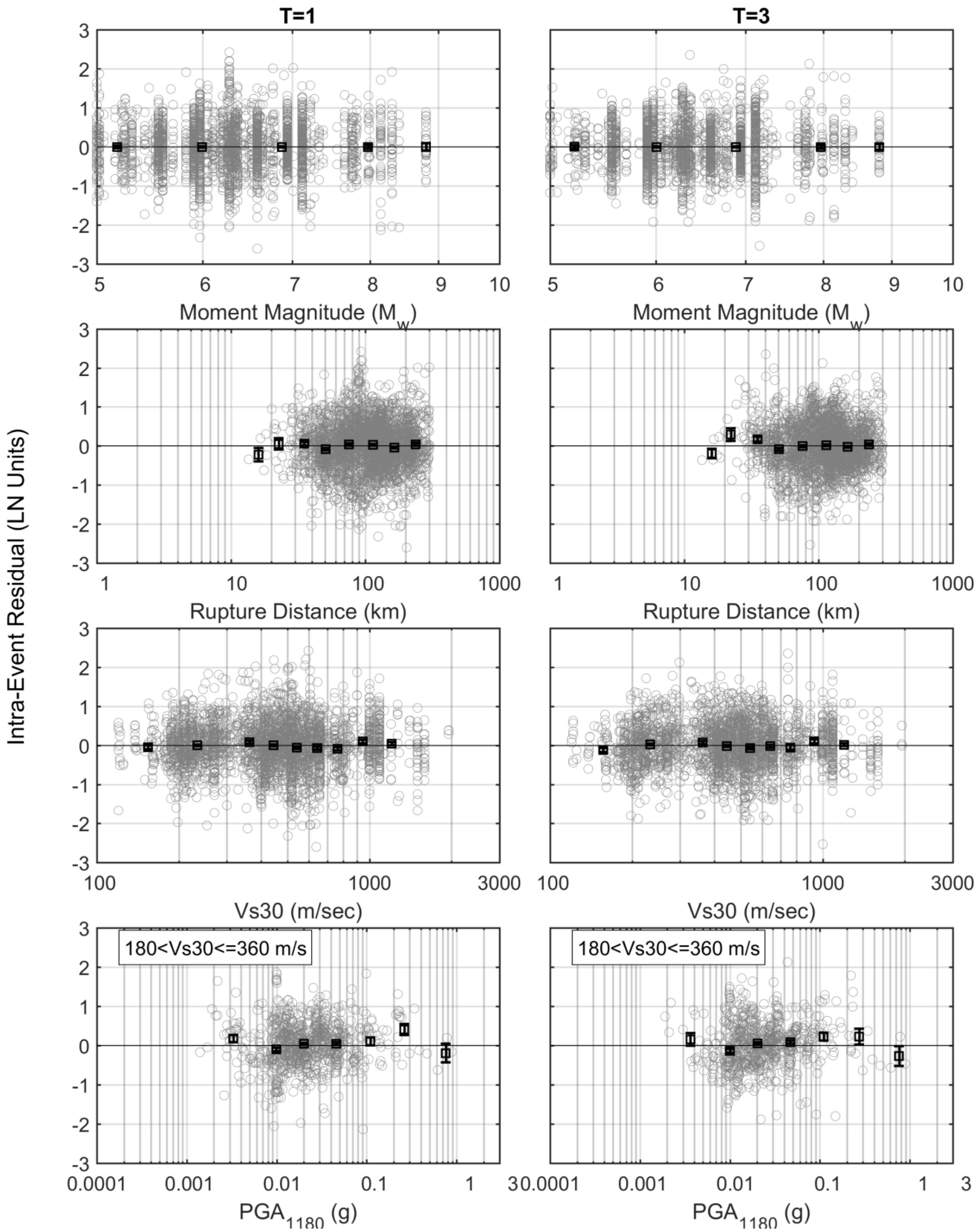

Figure 3.14(c) Within-event residuals for other regions: *T* = 1 sec and *T* = 3 sec.

4 Model Results

4.1 ADJUSTING THE CASCADIA MODEL

There are only four earthquakes in the Cascadia region in the selected subset. Of these four events, three have very low ground motions at short periods, leading to a median that is 2–3 times smaller than for other regions. The Cascadia median spectrum for a **M**6.5 slab and interface earthquakes at a distance of 100 km is compared to the median spectra for other regions in Figures 4.1 and 4.2, respectively. Other Cascadia earthquakes with **M** < 5, which are not in the selected subset, also show very low short-period ground motions. Of the four earthquakes classified as the Cascadia region, two are from Washington and two are from northern California. The largest earthquake of the four is the **M**6.8 Nisqually event. The ground motions from this earthquake are much higher than the other three events.

Without a sound physical basis for the large reduction in the short-period ground motions in Cascadia as compared to other regions, and the observation that the short-period Nisqually ground-motion amplitudes are similar to other regions, the NGA-SUB developers judged that the reduction in the short-period ground motions for the small earthquakes in Cascadia should not be incorporated into the updated BCHydro ground-motion model. Therefore, the Cascadia model is adjusted so that the ground-motions for an earthquake scenario near the center of the data (**M**6.5, R = 100 km, V_{S30} = 400 m/sec) was consistent with the average over all regions.

The median ground motion for the average scenario is computed for each region using the region-specific terms. The log ratio of the median for each region to the median for Cascadia is shown in Figure 4.3 for slab events and in Figure 4.4 for interface events. For the slab events, the median is computed for all six regions, and the adjustment is based on the average term over the six regions. That is: the low Cascadia ground motions are included in the average region term for the slab. For the interface events, the adjustment is based on the average term over only four regions: Central America, Japan, New Zealand, and Japan. There is not enough data from Cascadia or Taiwan to constrain an interface model; therefore, they are not included in the regional average. The adjustments to the Cascadia constant term are shown in Figure 4.5. The adjustment terms are smoothed based on the sum of the regional Cascadia constant term and the adjustment terms. The resulting smoothed adjustment term (keeping the Cascadia constant terms unsmoothed) are shown in Figure 4.5.

The adjusted Cascadia slab model is compared to the median from Nisqually data in Figure 4.6. The Nisqually data are adjusted to a V_{S30} of 400 m/sec using the V_{S30} scaling for Cascadia, and the median of the data in distance range of 70 to 120 km is shown. The adjusted Cascadia slab model is shown along with the 16th and 84th percentile range from the standard deviation of the event terms. This figure shows that the average from the Nisqually data are not inconsistent with the adjusted Cascadia model.

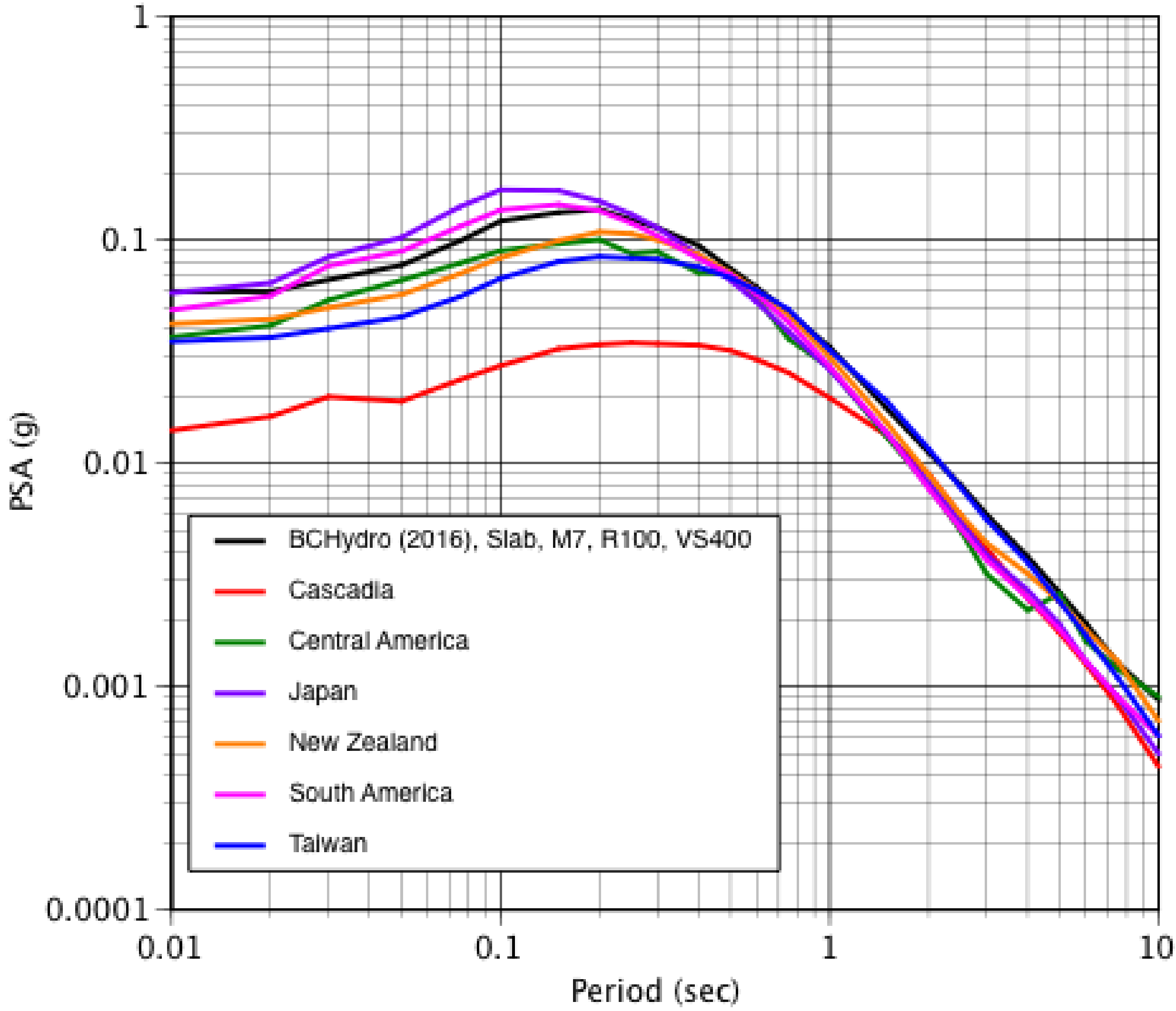

Figure 4.1 **Median spectra for different regions for slab, M7, Z_{TOR} = 50 km, R_{rup} = 100 km, and V_{S30}=400 m/sec.**

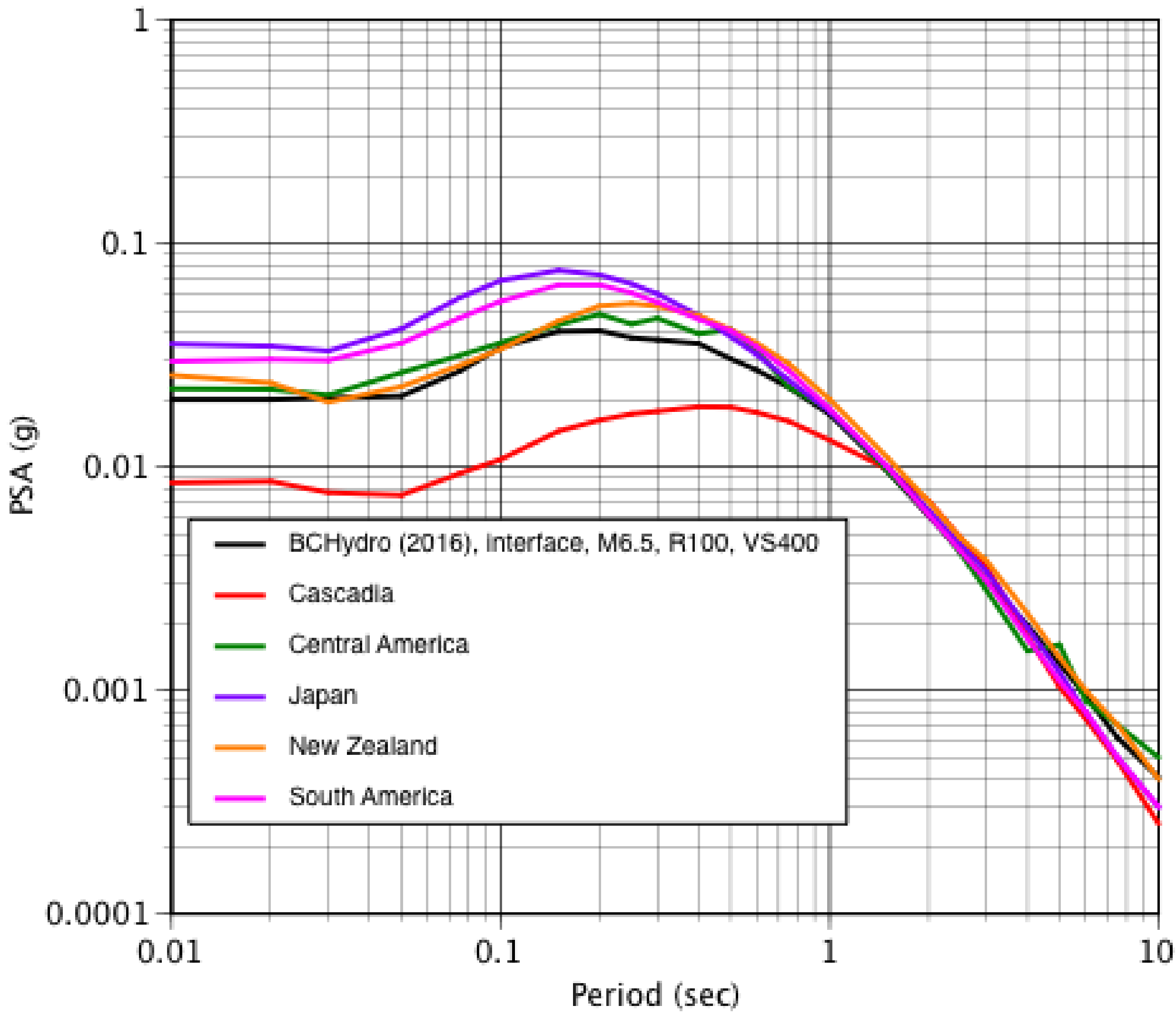

Figure 4.2 **Median spectra for different regions for interface, M7, Z_{TOR} = 20 km, R_{rup} = 100 km, and V_{S30}=400 m/sec.**

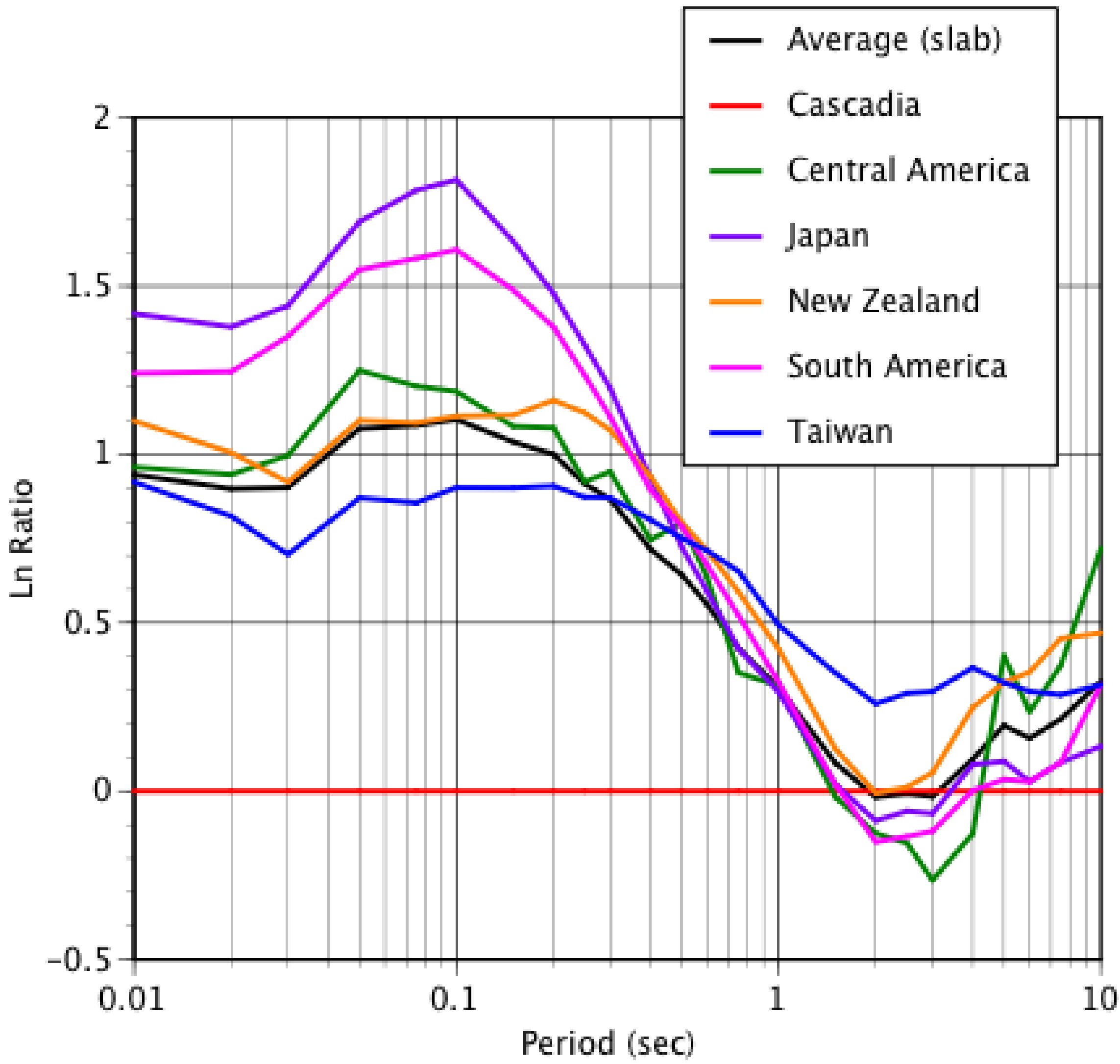

Figure 4.3 Adjustment to the constant term for Cascadia for slab earthquakes.

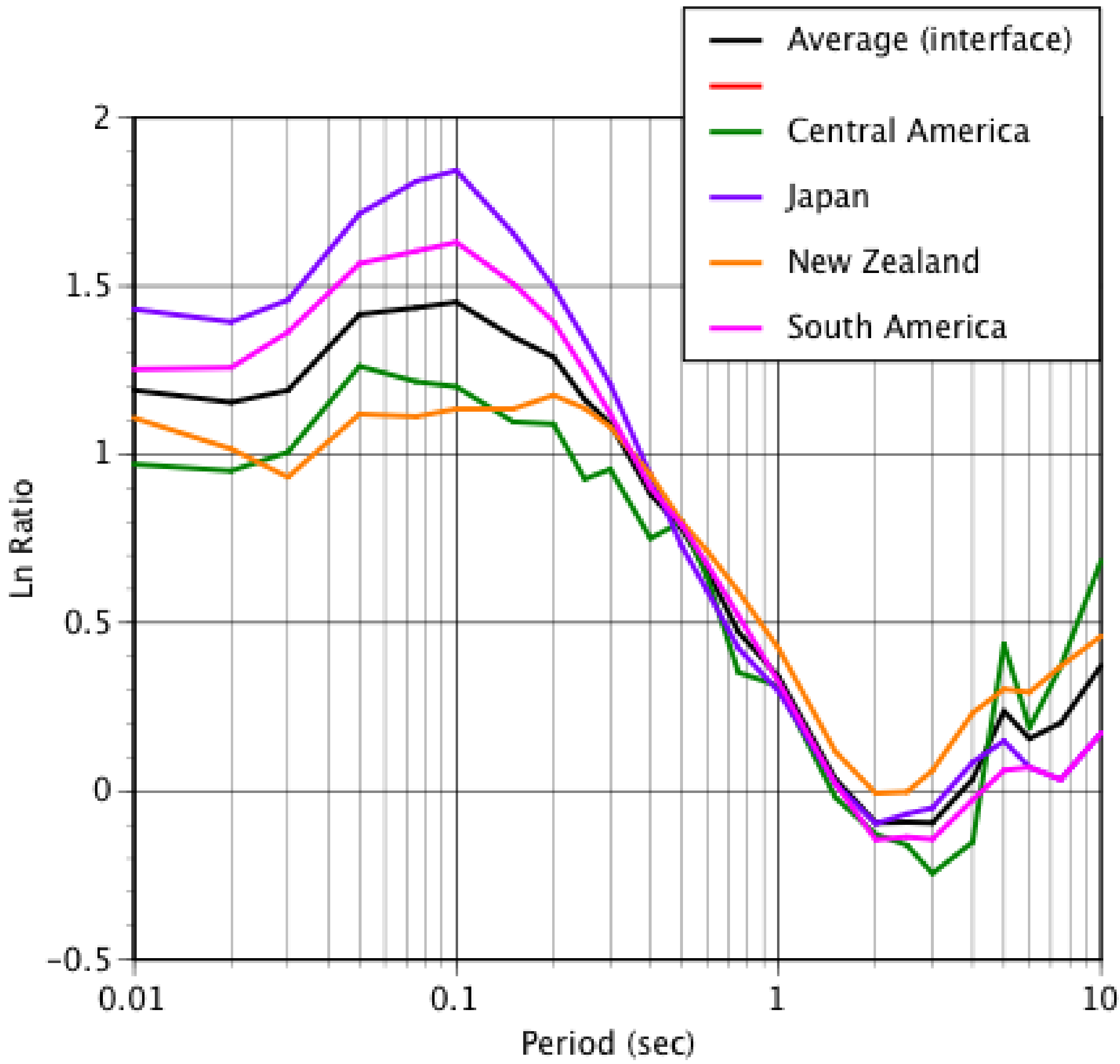

Figure 4.4 Adjustment to the constant term for Cascadia for interface earthquakes.

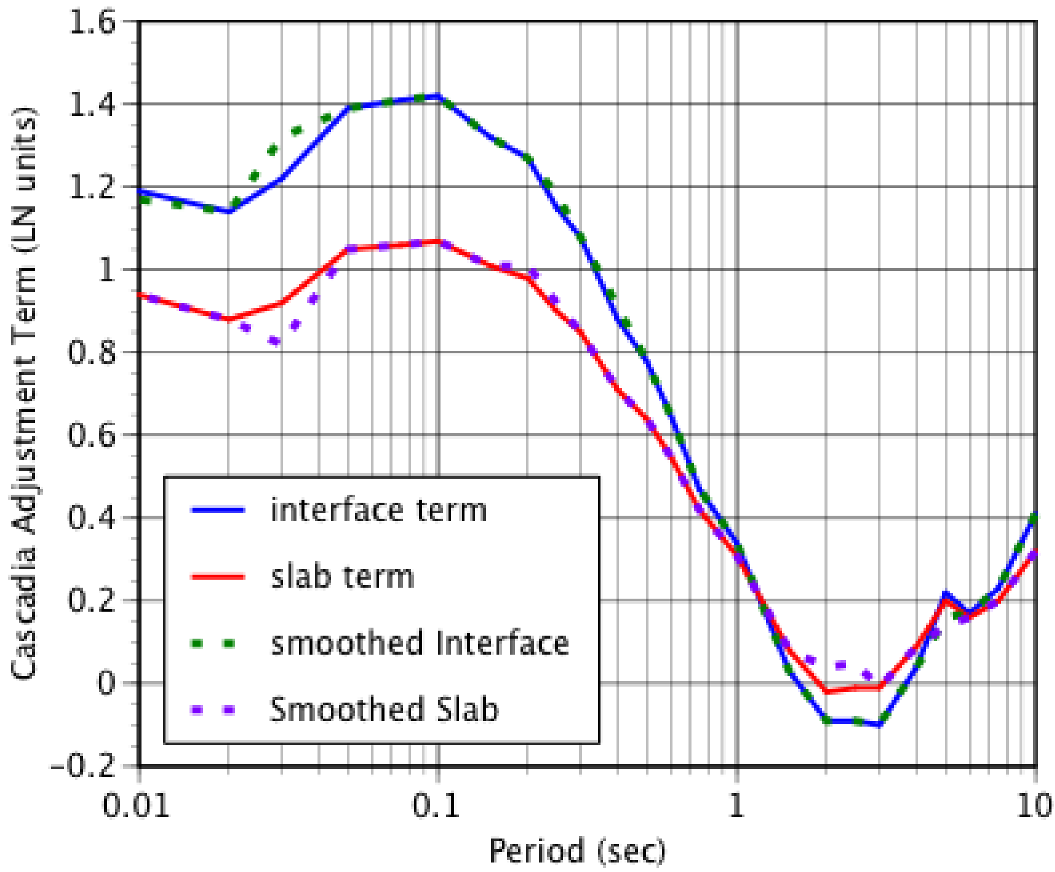

Figure 4.5 Adjustment to the constant term for Cascadia.

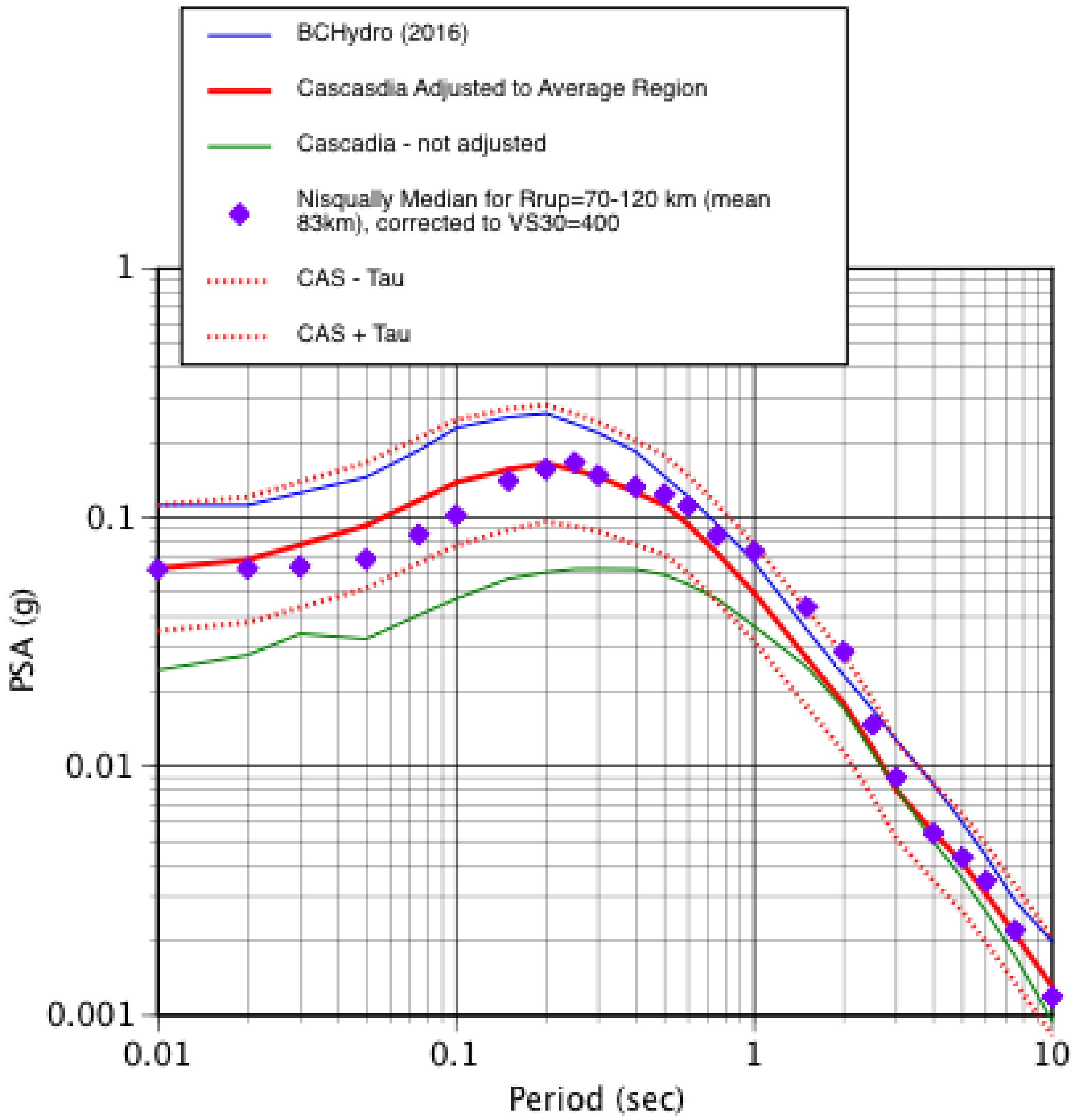

Figure 4.6 **Median attenuation comparison for PGA for M9, V_{S30} = 760 m/sec.**

4.2 MODEL COEFFICIENTS

The model coefficients for the adjusted Cascadia ground-motion model are listed in Tables 4.1, 4.2, and 4.3.

Table 4.1 Period-independent coefficients.

Coefficient	Period-independent values
n	1.18
c	1.88
C_4	10 km
a_3	-0.10
a_5	0.0
a_9	0.40
a_{10}	1.73

Table 4.2 Period-dependent coefficients for the Cascadia model.

Period (sec)	a_1	a_2	a_4	a_6	a_{11}	a_{12}	a_{13}	a_{14}
0.01	2.027	-1.044	0.59	-0.00520	0.0170	0.818	-0.0135	-0.223
0.02	2.043	-1.044	0.59	-0.00520	0.0170	0.857	-0.0135	-0.196
0.03	2.072	-1.08	0.59	-0.00520	0.0170	0.921	-0.0135	-0.128
0.05	2.130	-1.11	0.59	-0.00540	0.0180	1.007	-0.0138	-0.130
0.075	2.445	-1.11	0.59	-0.00570	0.0180	1.225	-0.0142	-0.130
0.1	2.689	-1.11	0.59	-0.00590	0.0180	1.457	-0.0145	-0.130
0.15	2.992	-1.084	0.59	-0.00620	0.0175	1.849	-0.0153	-0.156
0.2	2.929	-1.027	0.62	-0.00630	0.0170	2.082	-0.0162	-0.172
0.25	2.861	-0.983	0.64	-0.00632	0.0160	2.240	-0.0172	-0.184
0.3	2.802	-0.947	0.66	-0.00632	0.0152	2.341	-0.0183	-0.194
0.4	2.705	-0.89	0.68	-0.00625	0.0140	2.415	-0.0206	-0.210
0.5	2.561	-0.845	0.68	-0.00610	0.0130	2.359	-0.0231	-0.223
0.6	2.389	-0.809	0.68	-0.00590	0.0122	2.227	-0.0256	-0.233
0.75	2.093	-0.76	0.68	-0.00563	0.0113	1.949	-0.0296	-0.245
1.0	1.636	-0.698	0.68	-0.00525	0.0100	1.402	-0.0363	-0.261
1.5	0.994	-0.612	0.68	-0.00460	0.0082	0.329	-0.0493	-0.285
2.0	0.422	-0.55	0.68	-0.00400	0.0070	-0.487	-0.061	-0.301
2.5	-0.151	-0.501	0.68	-0.00350	0.0060	-0.770	-0.0711	-0.313
3.0	-0.600	-0.46	0.68	-0.00320	0.0052	-0.700	-0.0798	-0.323
4.0	-1.247	-0.455	0.68	-0.00280	0.0040	-0.607	-0.0935	-0.282
5.0	-1.732	-0.45	0.73	-0.00255	0.0030	-0.540	-0.098	-0.250
6.0	-2.009	-0.45	0.78	-0.00240	0.0022	-0.479	-0.098	-0.250
7.5	-2.385	-0.45	0.84	-0.00220	0.0013	-0.393	-0.098	-0.250
10.0	-2.937	-0.45	0.93	-0.00200	0.0000	-0.350	-0.098	-0.250

Table 4.3 Period-dependent coefficients for the Cascadia model.

Period (sec)	V_{lin}	*b*	C_1 interface	C_1 slab	Adjustment term for interface	Adjustment term for slab
0.01	865.1	-1.186	8.2	7.2	1.17	0.94
0.02	865.1	-1.219	8.2	7.2	1.14	0.88
0.03	907.8	-1.273	8.2	7.2	1.32	0.82
0.05	1053.5	-1.346	8.2	7.2	1.39	1.05
0.075	1085.7	-1.471	8.2	7.2	1.41	1.06
0.1	1032.5	-1.624	8.2	7.2	1.42	1.07
0.15	877.6	-1.931	8.2	7.2	1.32	1.01
0.2	748.2	-2.188	8.2	7.2	1.27	1.01
0.25	654.3	-2.381	8.2	7.2	1.18	0.92
0.3	587.1	-2.518	8.2	7.2	1.08	0.85
0.4	503	-2.657	8.2	7.2	0.91	0.71
0.5	456.6	-2.669	8.2	7.2	0.78	0.64
0.6	430.3	-2.599	8.2	7.2	0.65	0.55
0.75	410.5	-2.401	8.15	7.2	0.47	0.42
1.0	400	-1.955	8.1	7.2	0.34	0.31
1.5	400	-1.025	8.05	7.2	0.03	0.08
2.0	400	-0.299	8	7.2	-0.09	0.04
2.5	400	0	7.95	7.2	-0.09	0.05
3.0	400	0	7.9	7.2	-0.10	-0.01
4.0	400	0	7.85	7.2	0.04	0.09
5.0	400	0	7.8	7.2	0.16	0.14
6.0	400	0	7.8	7.2	0.17	0.16
7.5	400	0	7.8	7.2	0.23	0.20
10.0	400	0	7.8	7.2	0.41	0.32

4.3 EPISTEMIC UNCERTAINTY

The epistemic uncertainty is modelled using the scaled backbone approach. The scale factor for the scaled backbone model is based on the range of average ground motions between the different regions. The range is shown in Figures 4.7 and 4.8 for slab events and interface events, respectively. The recommended high and low epistemic uncertainty range is shown by the heavy black lines in these figures. Preliminary results using random effects for the constant scale factor between regions leads to a standard deviation consistent with this range if a three-point distribution (±1.65 sigma) is used. The epistemic uncertainty is listed in Table 4.4.

This epistemic uncertainty is a minimum uncertainty that only reflects the epistemic uncertainty in the adjustment factor applied to the Cascadia model. It does not capture the epistemic uncertainty in the magnitude and distance scaling. Other published ground-motion models can be used to capture the alternative magnitude and distance scaling.

Table 4.4 Epistemic uncertainty in the adjustment term (in LN units).

Period (sec)	Interface Low	Interface High	Slab Low	Slab High
0.01	-0.3	0.3	-0.5	0.5
0.02	-0.3	0.3	-0.5	0.5
0.03	-0.3	0.3	-0.5	0.5
0.05	-0.3	0.3	-0.5	0.5
0.075	-0.3	0.3	-0.5	0.5
0.1	-0.3	0.3	-0.5	0.5
0.15	-0.3	0.3	-0.5	0.5
0.2	-0.3	0.3	-0.5	0.5
0.25	-0.3	0.3	-0.46	0.46
0.3	-0.3	0.3	-0.42	0.42
0.4	-0.3	0.3	-0.38	0.38
0.5	-0.3	0.3	-0.34	0.34
0.6	-0.3	0.3	-0.3	0.3
0.75	-0.3	0.3	-0.3	0.3
1.0	-0.3	0.3	-0.3	0.3
1.5	-0.3	0.3	-0.3	0.3
2.0	-0.3	0.3	-0.3	0.3
2.5	-0.3	0.3	-0.3	0.3
3.0	-0.3	0.3	-0.3	0.3
4.0	-0.3	0.3	-0.3	0.3
5.0	-0.3	0.3	-0.3	0.3
6.0	-0.3	0.3	-0.3	0.3
7.5	-0.3	0.3	-0.5	0.5
10.0	-0.3	0.3	-0.5	0.5

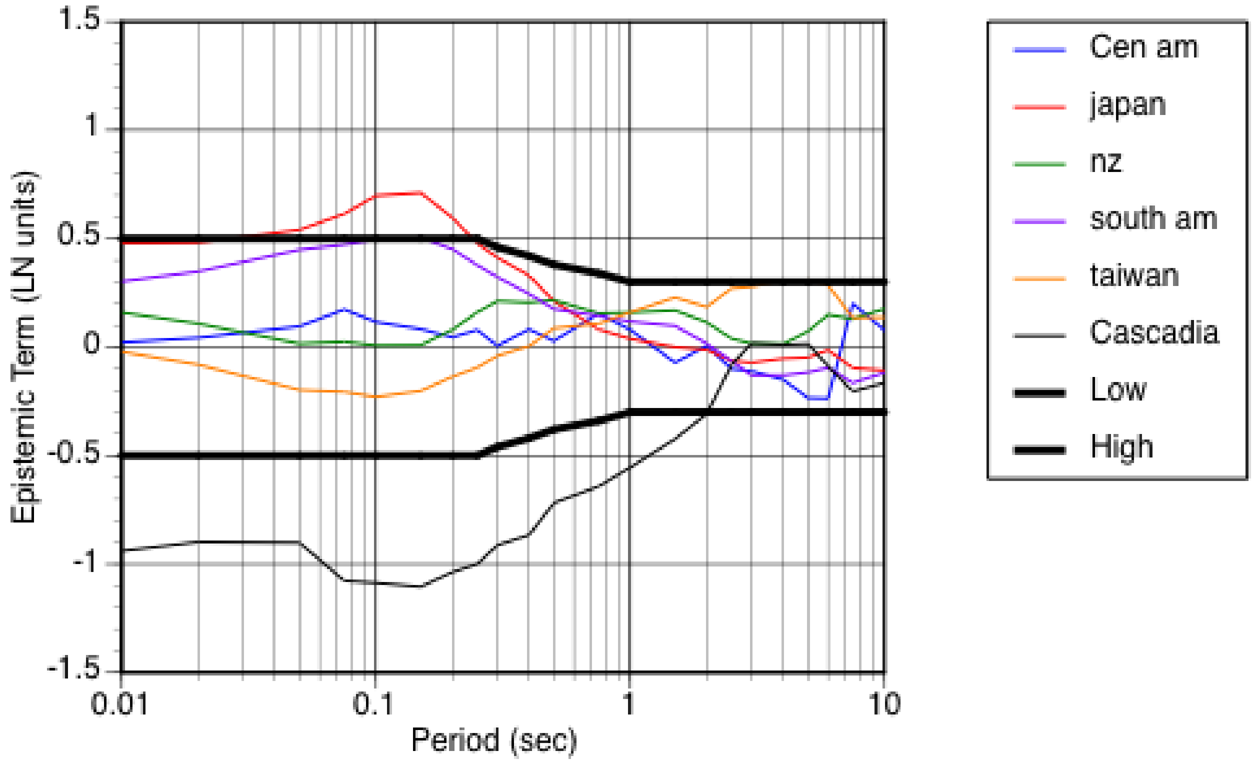

Figure 4.7 Recommended epistemic uncertainty in the Cascadia adjustment term for slab earthquakes.

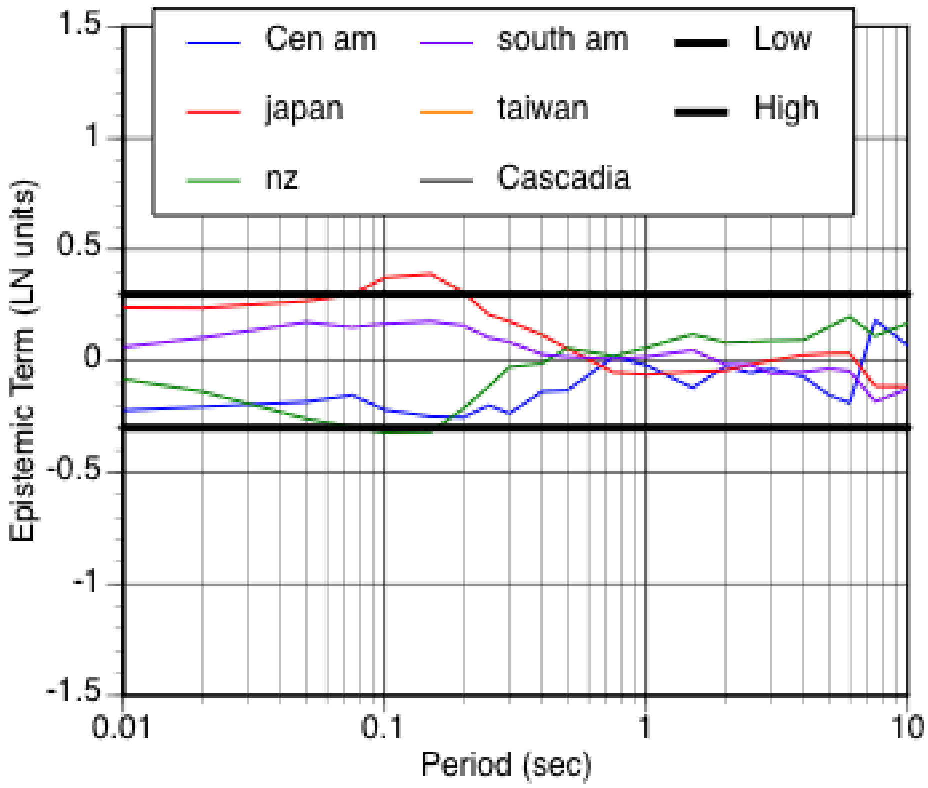

Figure 4.8 **Recommended epistemic uncertainty in the Cascadia adjustment term for interface earthquakes.**

4.4 MEDIAN MODEL COMPARISONS

The updated BCHydro model is compared with current GMPEs for subduction earthquakes in this section. Figures 4.9 to 4.12 compare the distance scaling for **M**9 interface earthquakes for four spectral periods. Figures 4.13 to 4.16 compare the distance scaling for **M**7 slab earthquakes. For both interface and slab events, the distance scaling of the updated BCHydro model is similar to the scaling of the Zhao et al. model [2006] (for Japan). Compared to the 2016 BCHydro model, the updated model has steeper distance scaling at short periods (PGA), similar distance scaling at intermediate periods ($T = 1$ sec), and flatter distance scaling at long periods ($T = 3$).

Figures 4.17 to 4.20 compare the response spectra for **M**8 and **M**9 interface earthquakes at distances of 75 and 300 km. At 75 km distance, the spectral shape of the updated BCHydro model is similar to the 2016 BCHydro model; however, at 300 km distance, the spectral content is very different, with the updated model showing a shift to longer spectral periods.

Figures 4.21 to 4.24 compare the response spectra for **M**6.5 and **M**7.5 slab earthquakes at distances of 75 and 300 km. At both 75 km and 300 km distance, the spectral shape of the updated BCHydro model is similar to the 2016 BCHydro model at long periods, but show lower short-period ground motions.

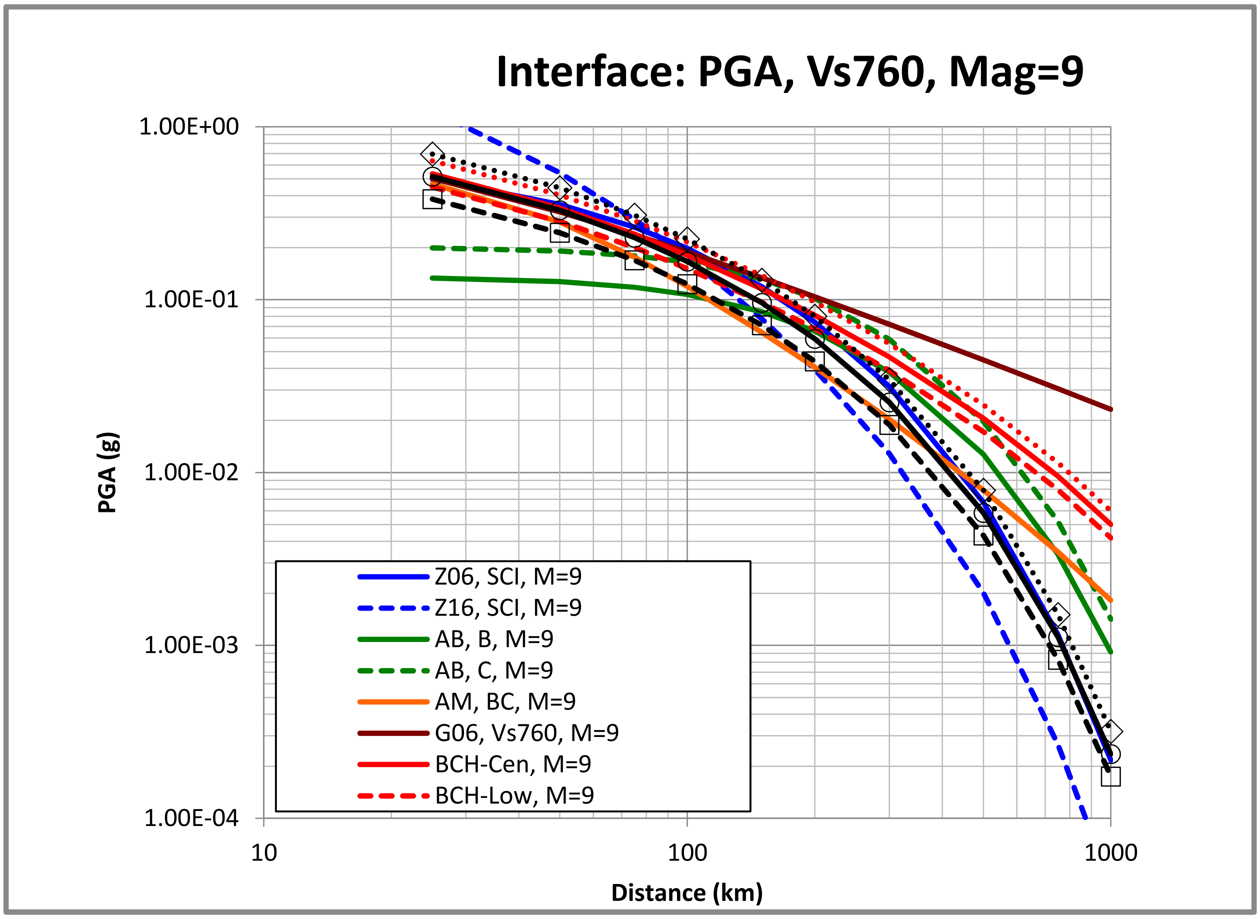

Figure 4.9 Median attenuation comparison for PGA for M9, V_{S30} = 760 m/sec.

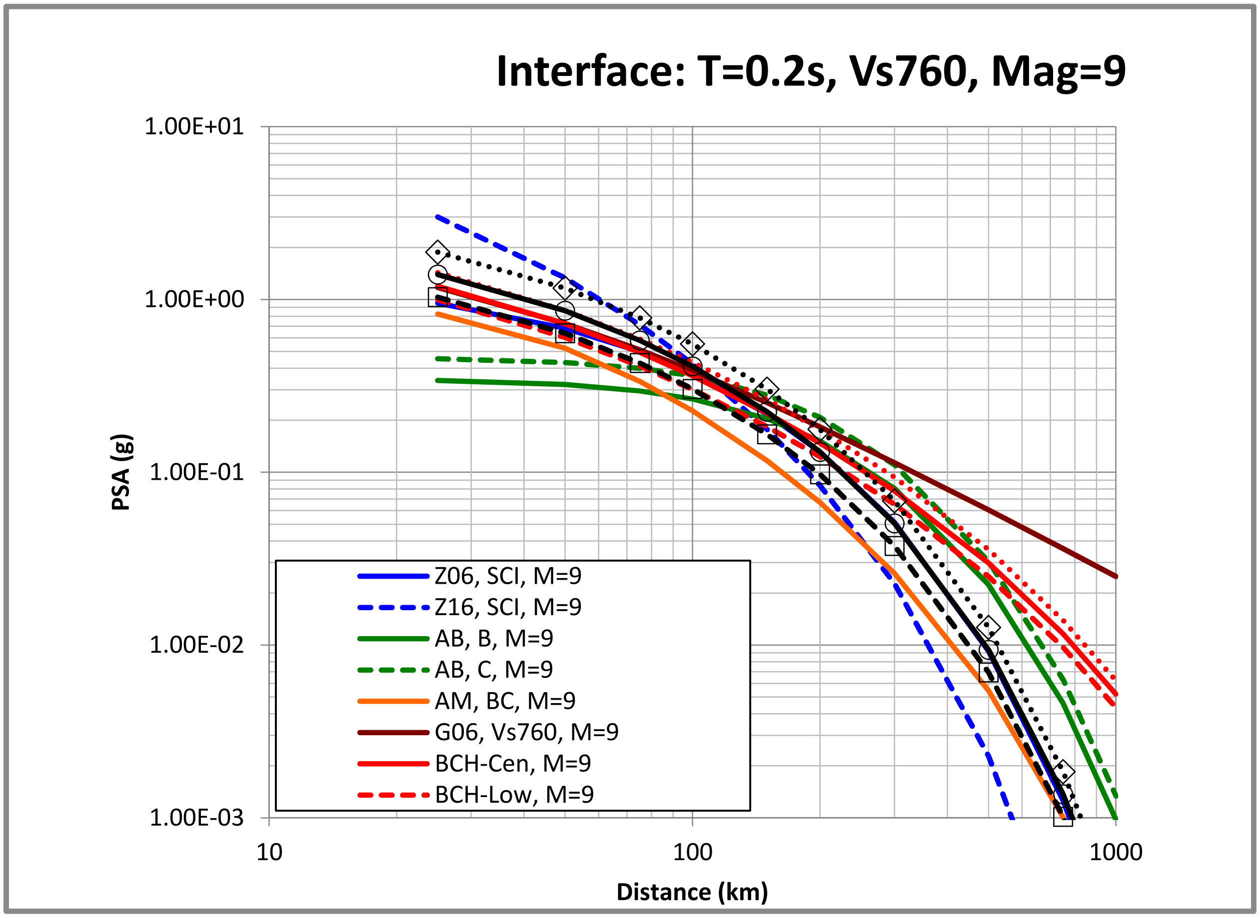

Figure 4.10 Median attenuation comparison for T = 0.2 sec for M9, V_{S30} = 760 m/sec.

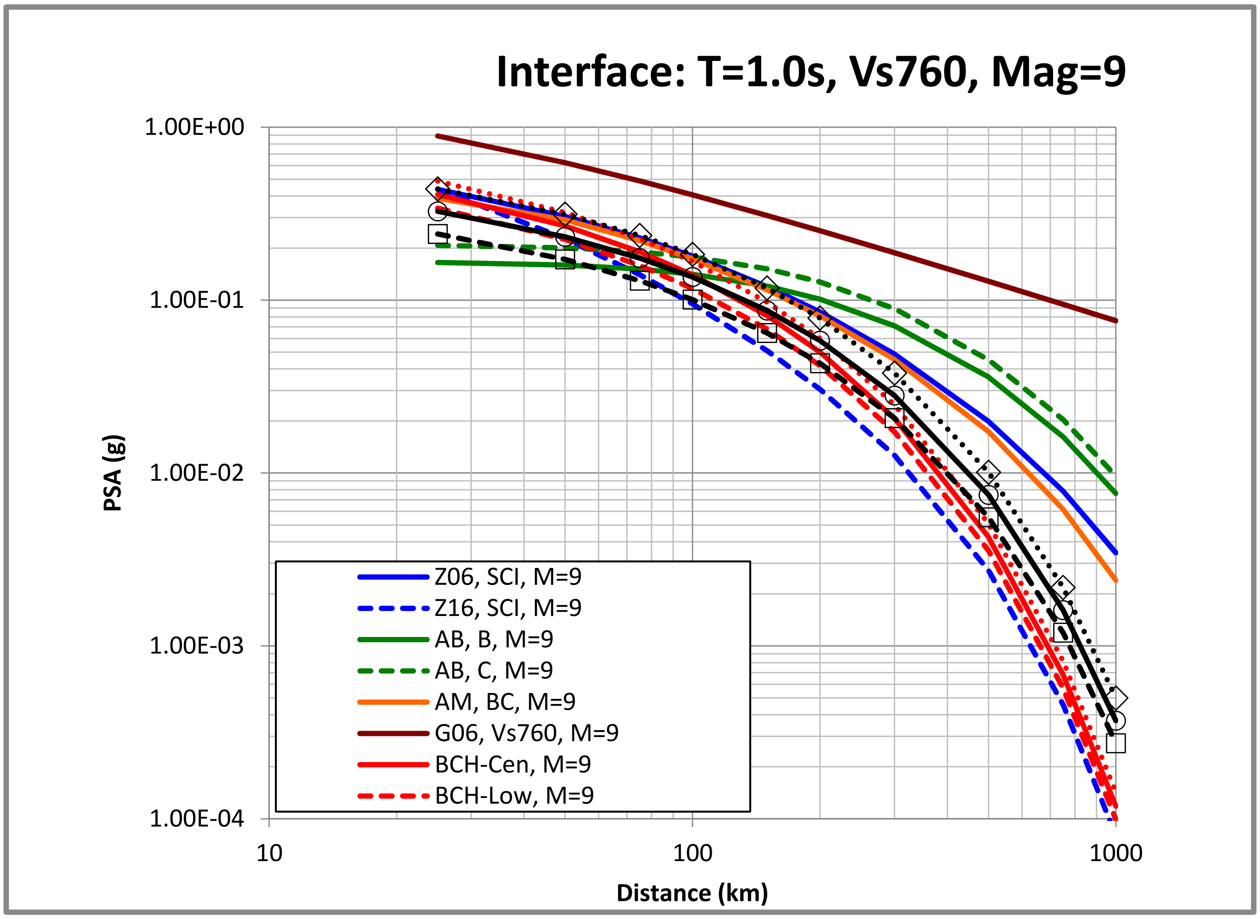

Figure 4.11 Median attenuation comparison for *T* = 1 sec, for M9, V_{S30} = 760 m/sec.

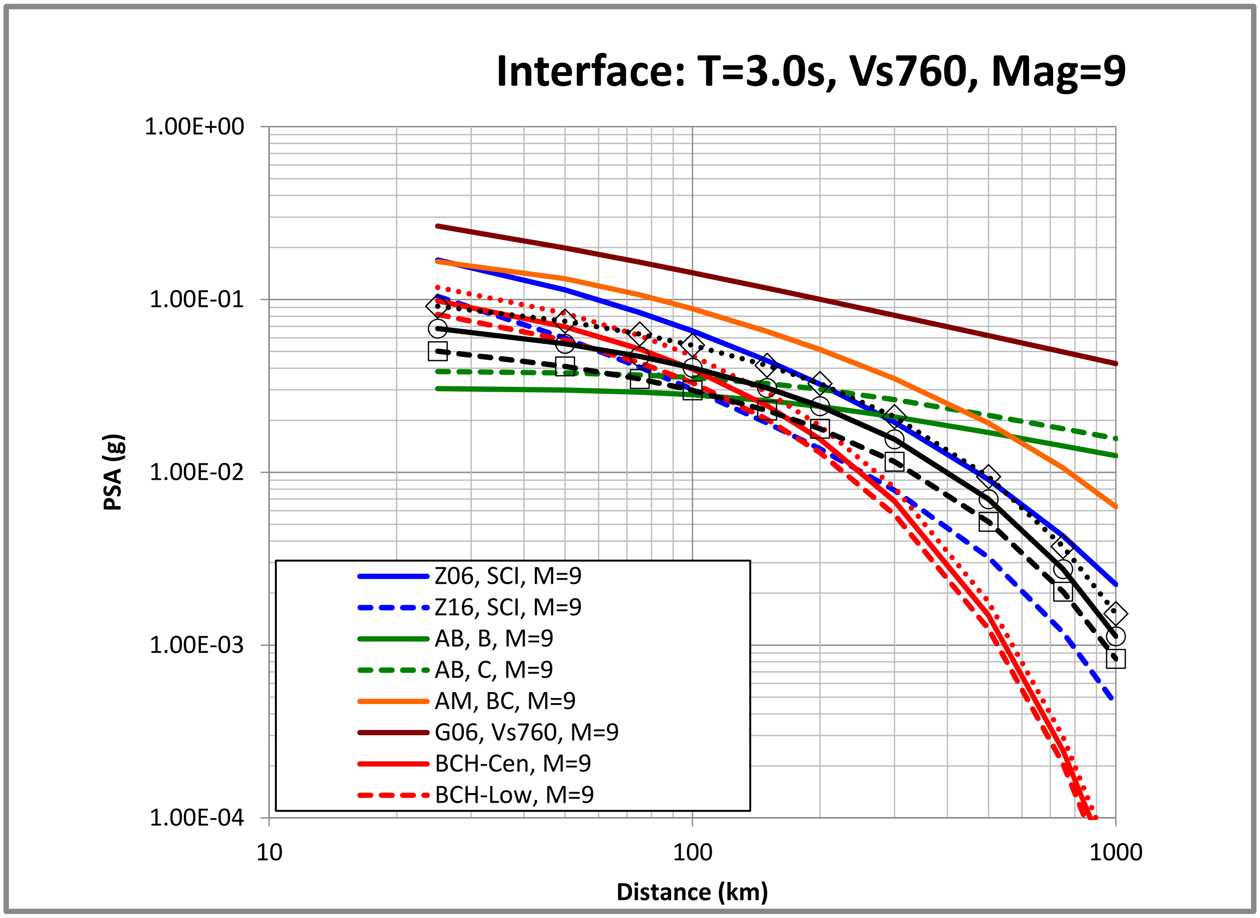

Figure 4.12 Median attenuation comparison for *T* = 3 sec, for M9, V_{S30} = 760 m/sec.

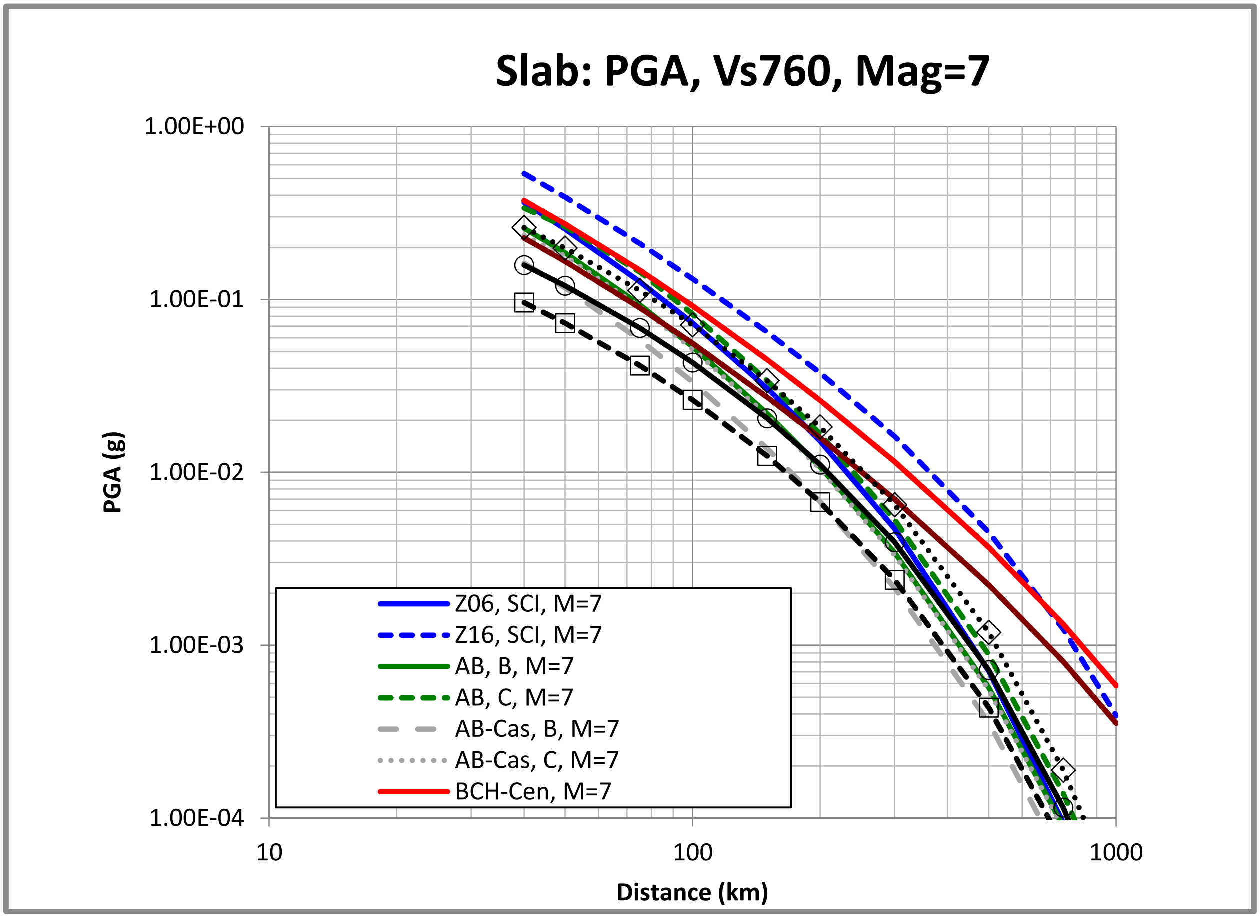

Figure 4.13 Median attenuation comparison for slab events, PGA, for M7, V_{S30} = 760 m/sec.

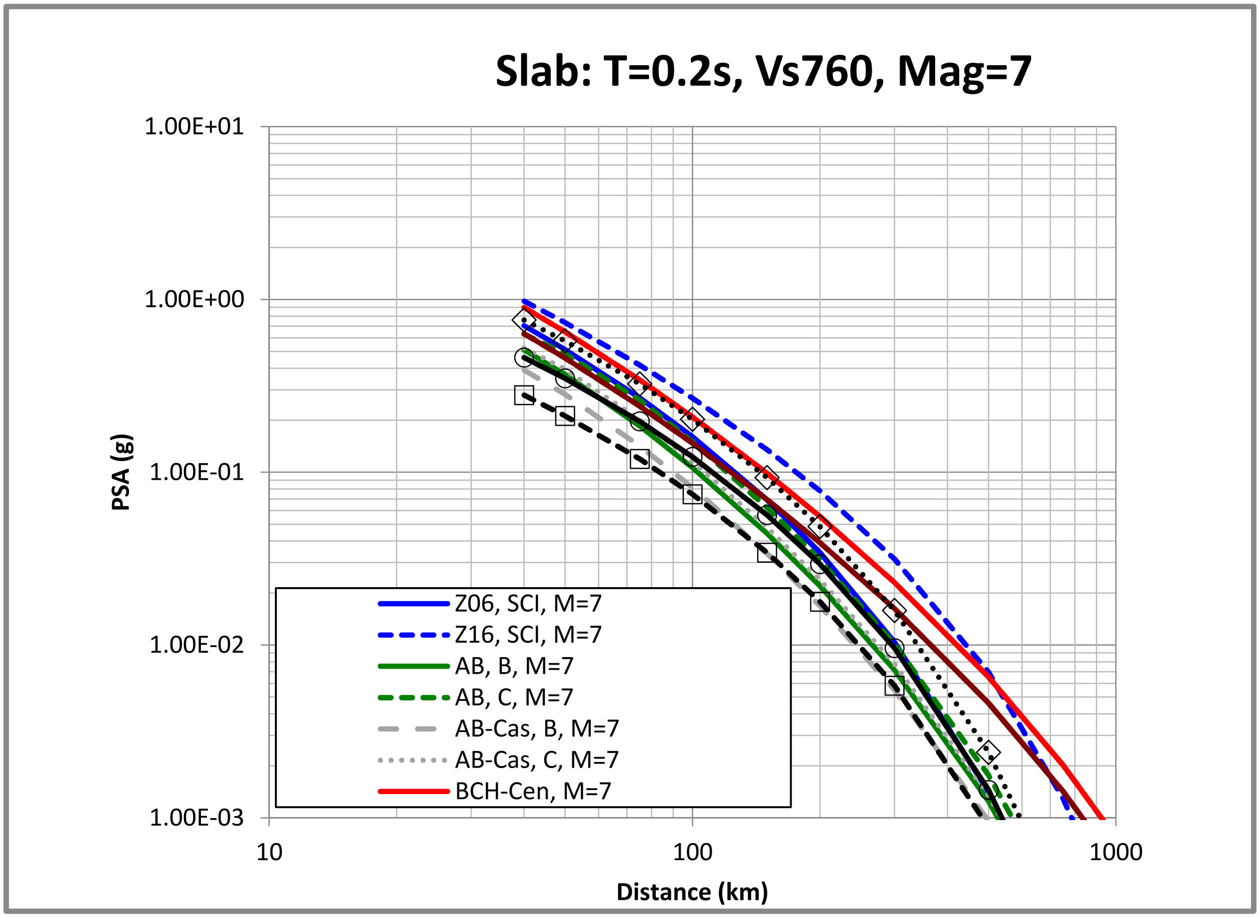

Figure 4.14 Median attenuation comparison for slab events, T = 0.2, for M7, V_{S30} = 760 m/sec.

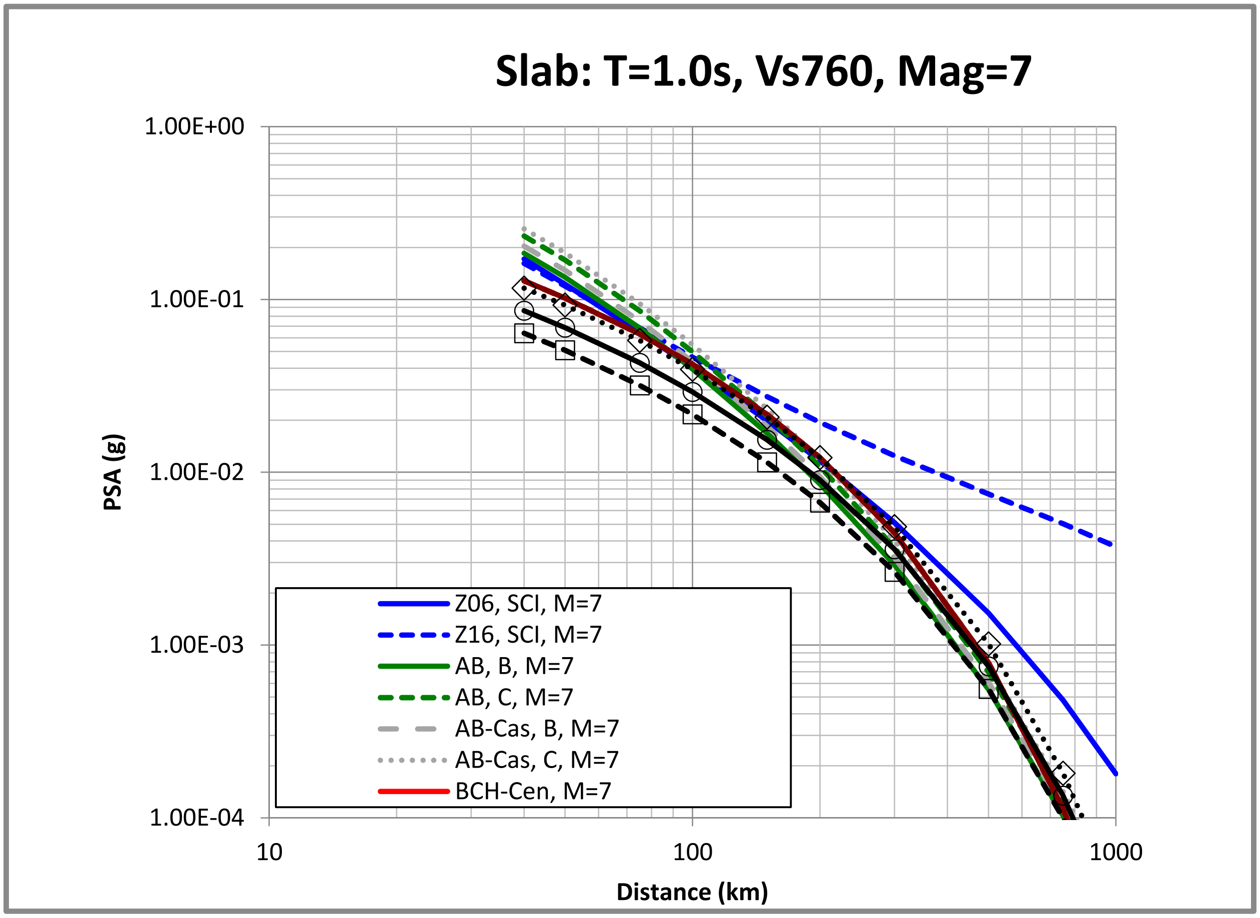

Figure 4.15 Median attenuation comparison for slab events, *T* = 1, for M7, V_{S30} = 760 m/sec.

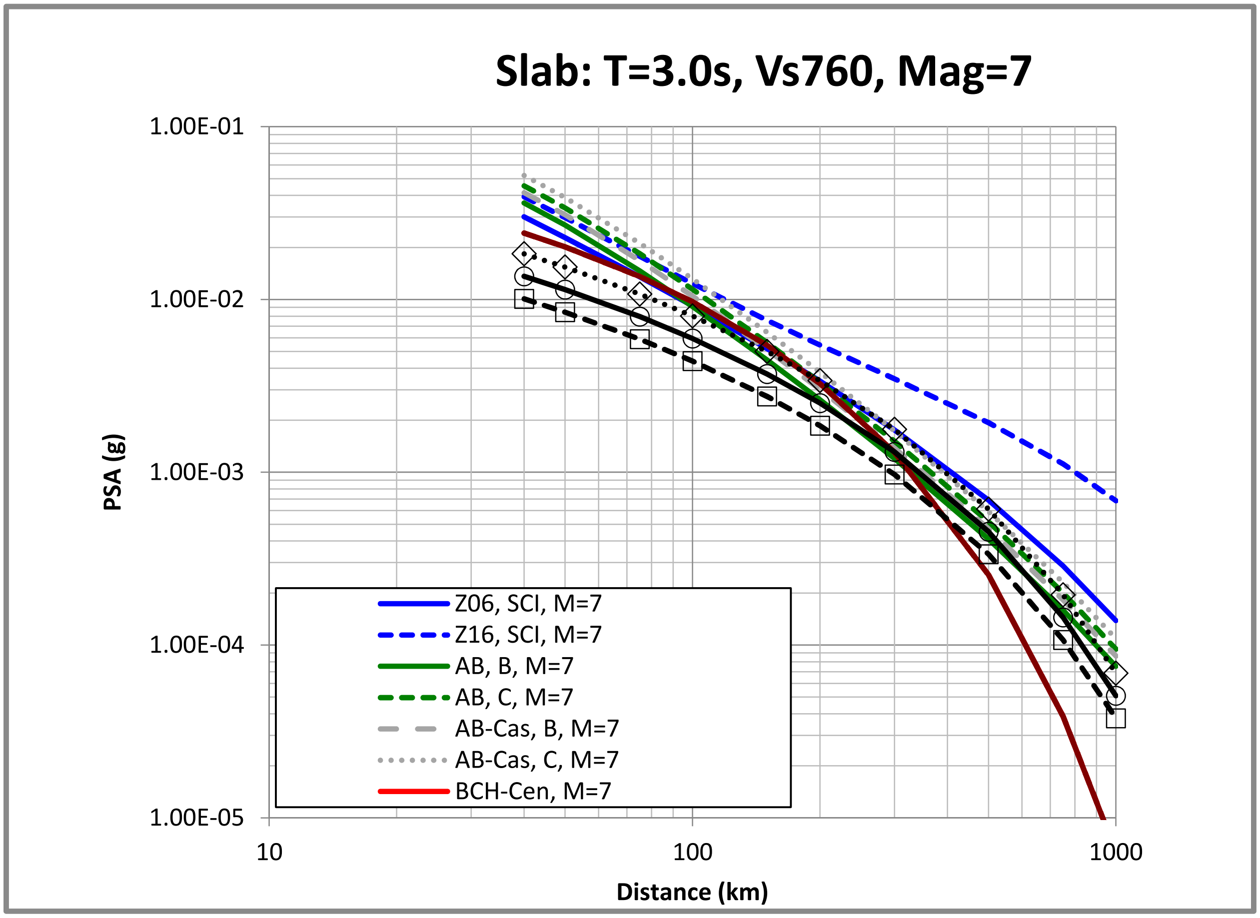

Figure 4.16 Median attenuation comparison for slab events, T = 3, for M7, V_{S30} = 760 m/sec.

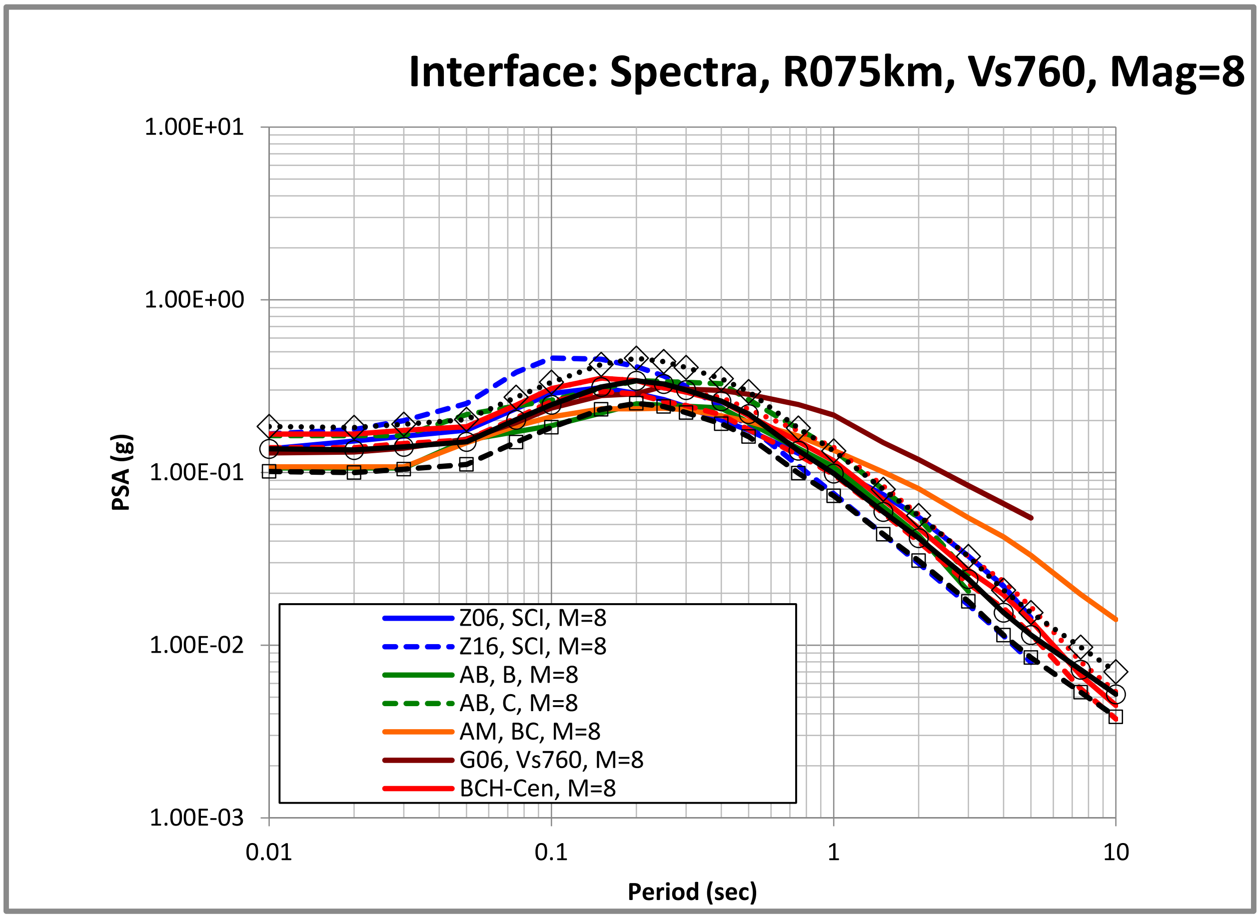

Figure 4.17 Median spectrum comparison for interface events, R_{rup} = 75 km, for M8, V_{S30} = 760 m/sec.

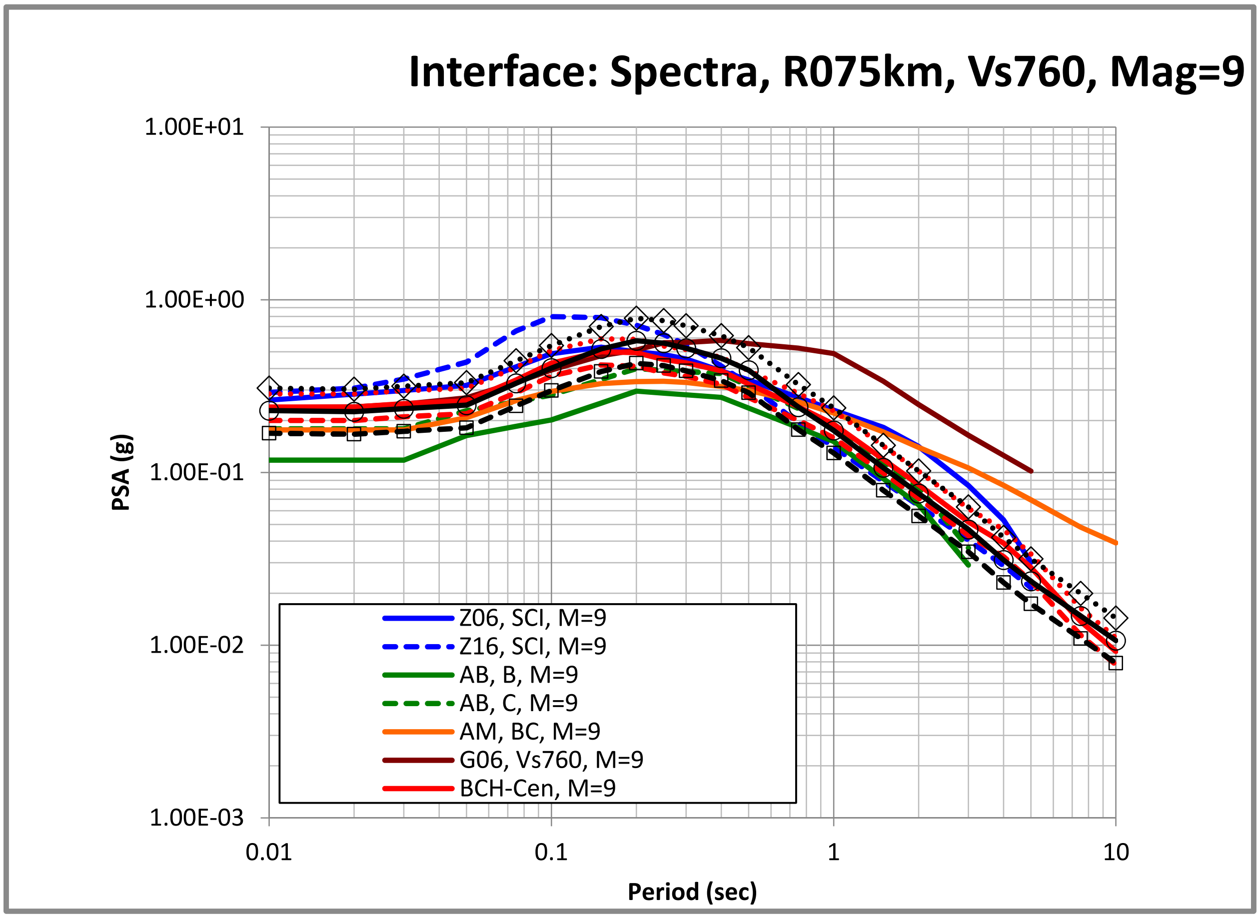

Figure 4.18 Median spectrum comparison for interface events, R_{rup} = 75 km, for M9, V_{S30} = 760 m/sec.

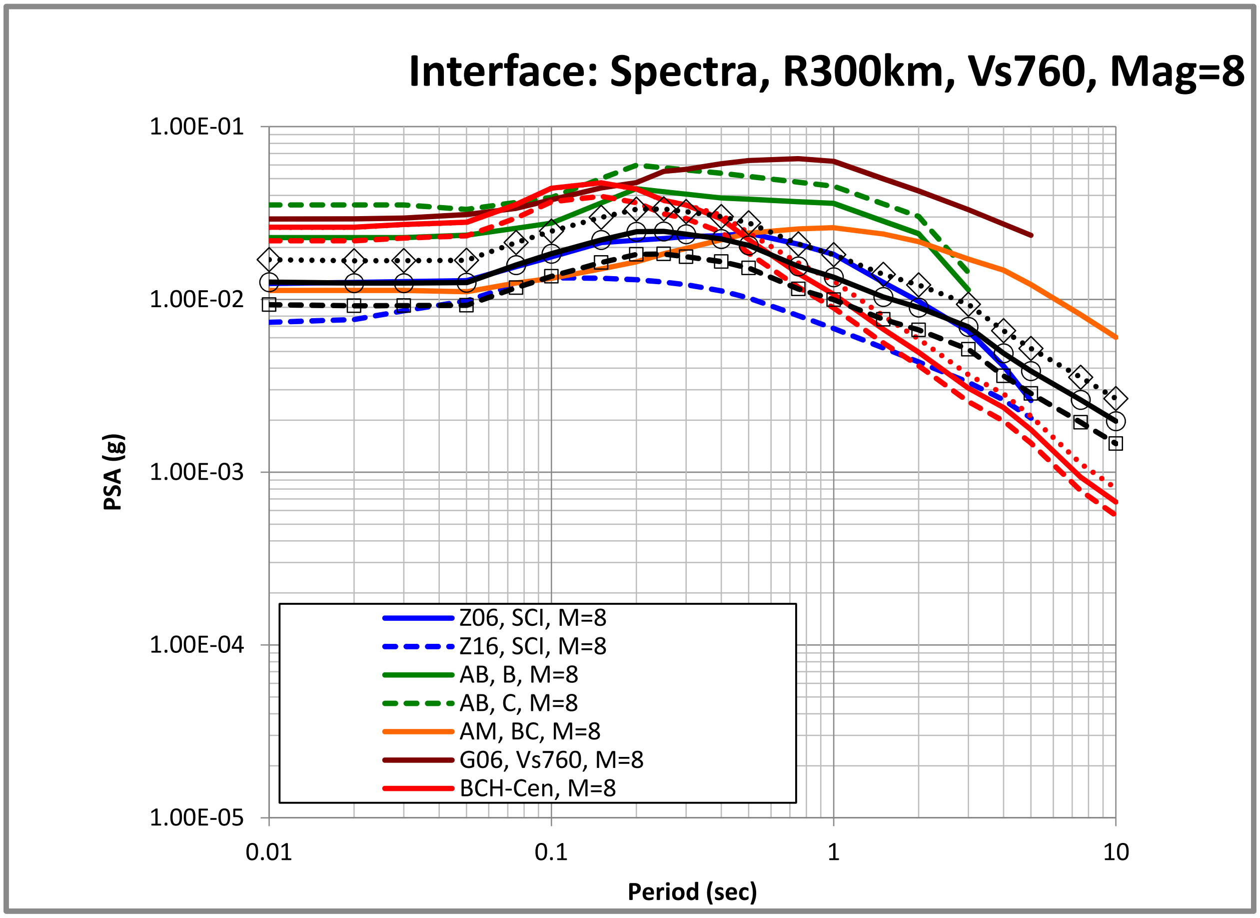

Figure 4.19 Median spectrum comparison for interface events, R_{rup}= 300 km, for M8, V_{S30} = 760 m/sec.

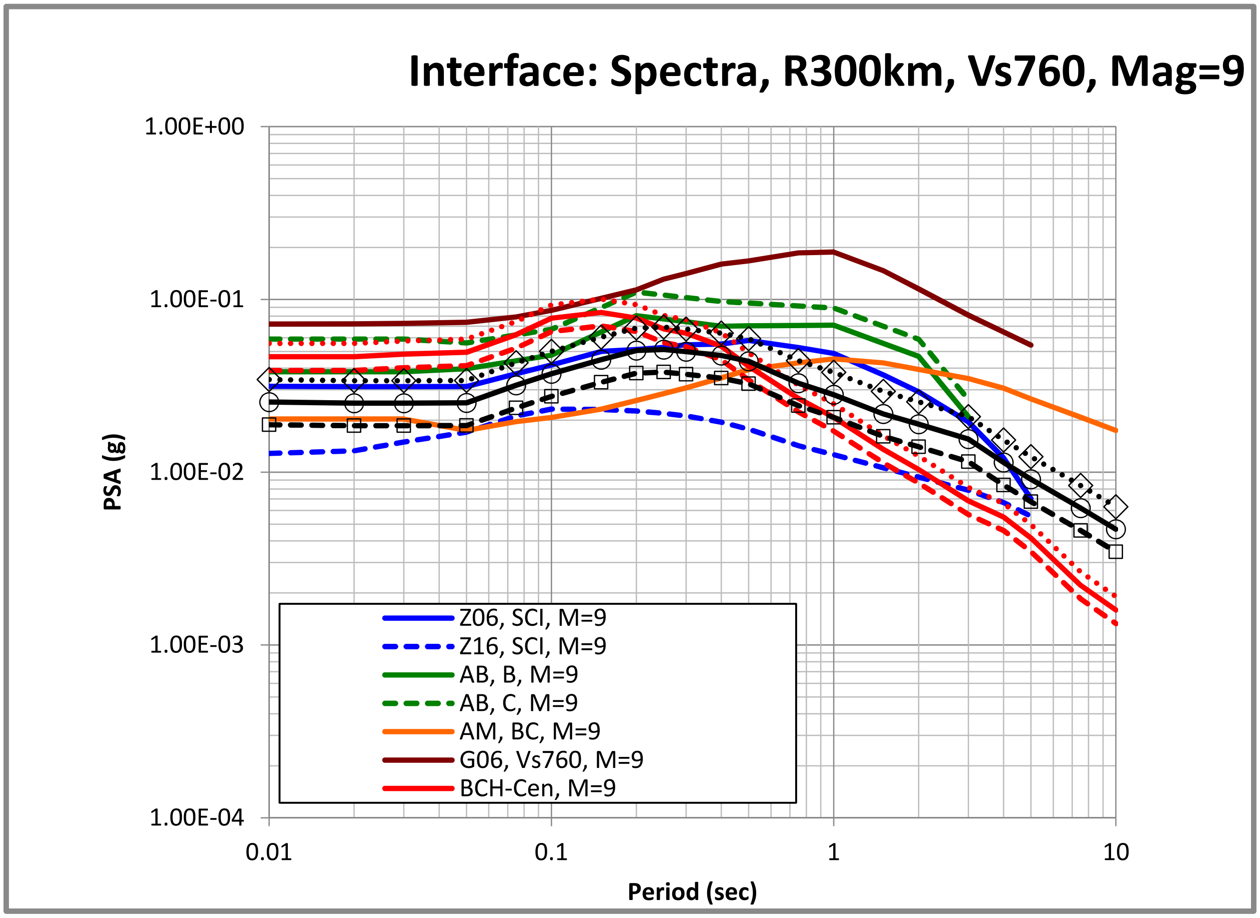

Figure 4.20 **Median spectrum comparison for interface events, R_{rup} = 300 km, for M9, V_{S30} = 760 m/sec.**

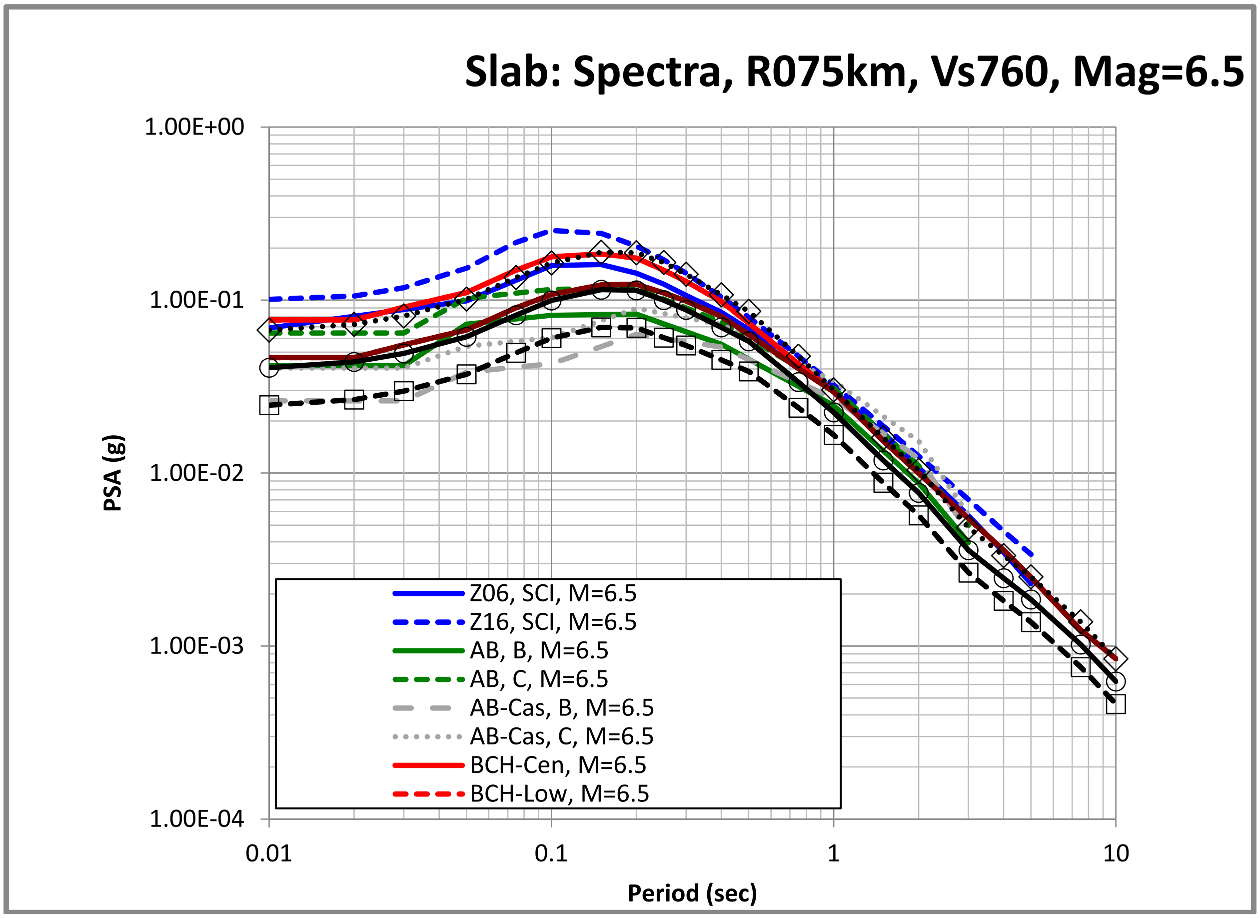

Figure 4.21 **Median spectrum comparison for slab events, R_{rup}=75 km, for M6.5, V_{S30} = 760 m/sec.**

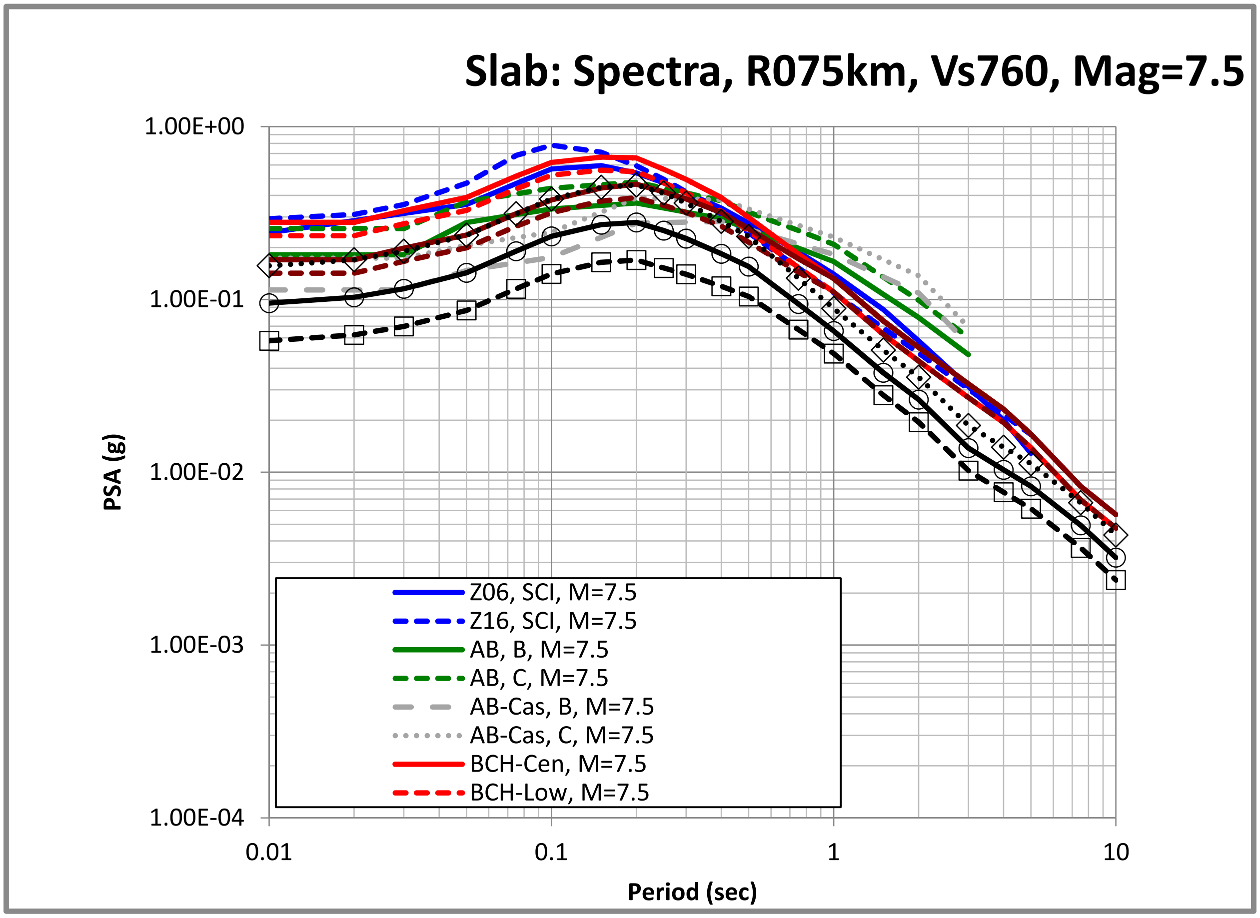

Figure 4.22 Median spectrum comparison for slab events, R_{rup} = 75 km, for M7.5, V_{S30} = 760 m/sec.

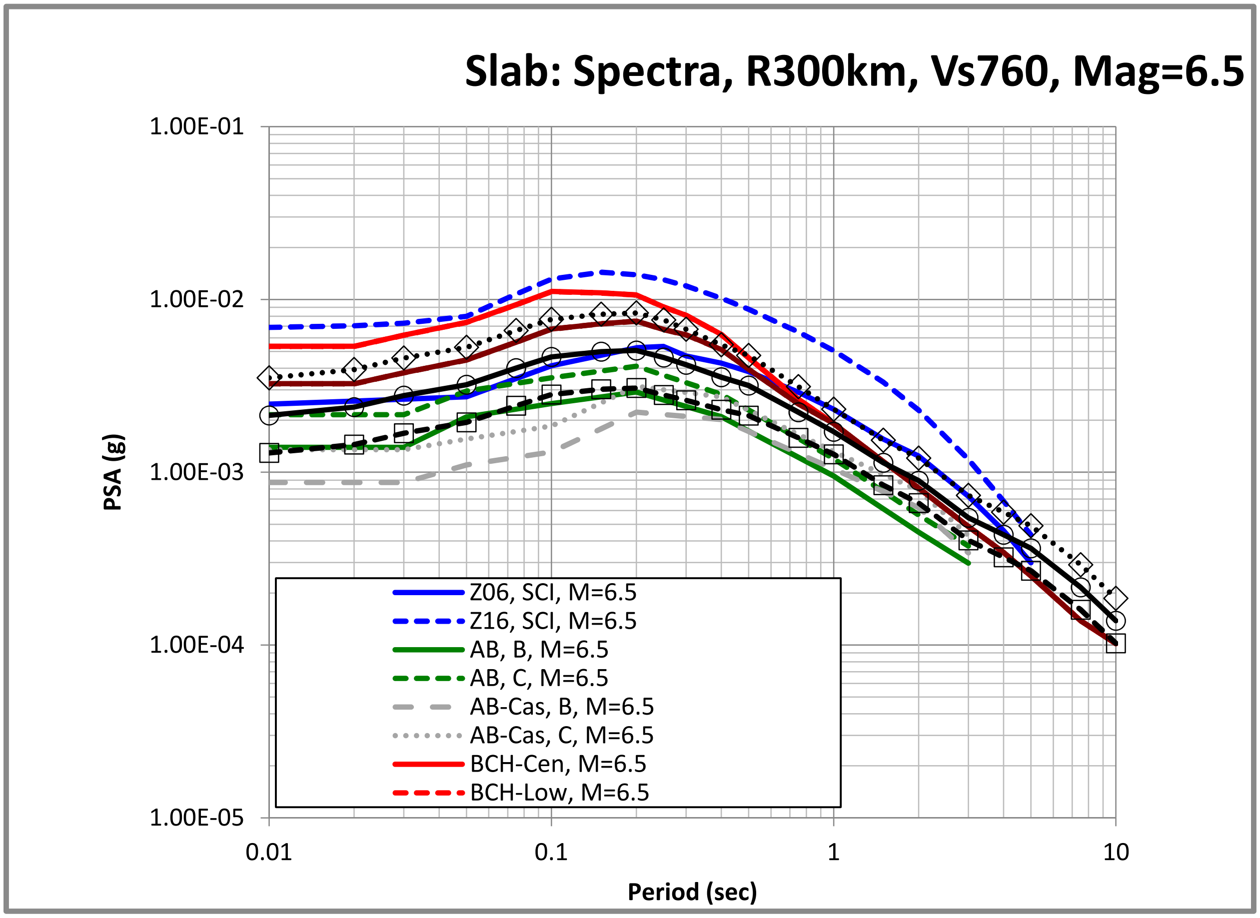

Figure 4.23 **Median spectrum comparison for slab events, R_{rup} = 300 km, for M6.5, V_{S30} = 760 m/sec.**

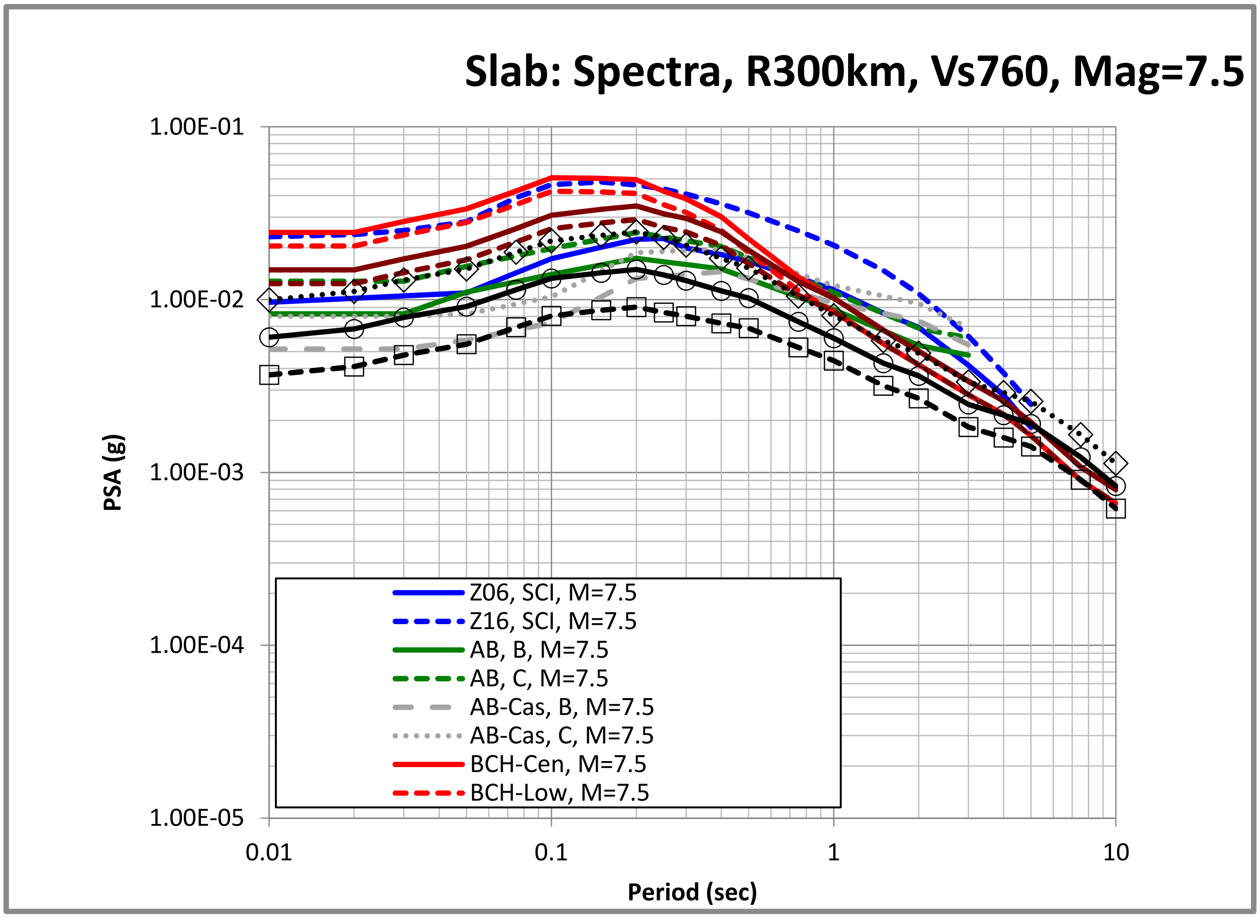

Figure 4.24 **Median spectrum comparison for slab events, R_{rup} = 300 km, for M7.5, V_{S30} = 760 m/sec.**

4.5 STANDARD DEVIATION

The standard deviation of the within-event residuals (phi) and the between-event residuals (tau) from the regression is shown in Figure 4.25. A check of the magnitude dependence of the phi and tau did not show a need for a magnitude-dependent model. A simple model with a period-independent and magnitude-independent phi is used. For tau, there is a magnitude dependence that is modeled. To avoid unusual shapes in the spectrum at different epsilon levels, the phi and tau are smoothed, as shown in Figure 4.25. The smoothed aleatory terms are listed in Table 4.5.

Table 4.5 Aleatory variability terms (in LN units)

Period (sec)	phi	tau
0.01	0.62	0.58
0.02	0.62	0.58
0.03	0.62	0.58
0.05	0.62	0.58
0.075	0.62	0.58
0.1	0.62	0.58
0.15	0.62	0.56
0.2	0.62	0.54
0.25	0.62	0.52
0.3	0.62	0.505
0.4	0.62	0.48
0.5	0.62	0.46
0.6	0.62	0.45
0.75	0.62	0.45
1.0	0.62	0.45
1.5	0.62	0.45
2.0	0.62	0.45
2.5	0.62	0.45
3.0	0.62	0.45
4.0	0.62	0.45
5.0	0.62	0.45
6.0	0.62	0.45
7.5	0.62	0.45
10.0	0.62	0.45

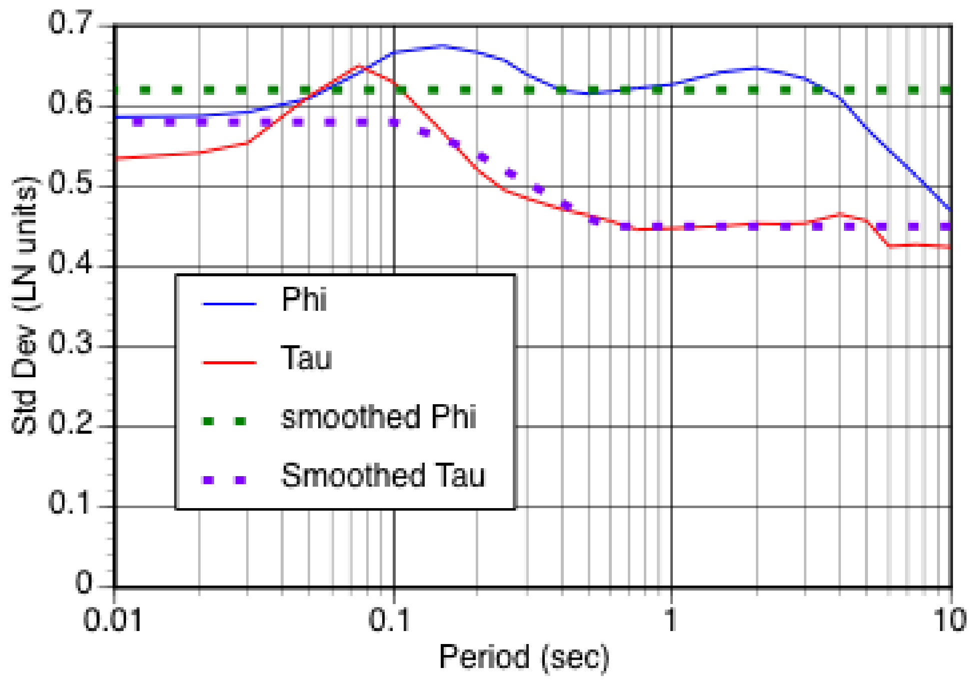

Figure 4.25 Smoothed phi and tau models.

5 Conclusions and Future Work

The updated BCHydro model is based on the expanded and improved NGA-SUB dataset and it includes the first order regional differences in the ground-motion scaling in terms of the V_{S30} scaling, linear R scaling, and a constant term. Due to these two changes, the model represents in an improvement over the 2016 BCHydro GMPE. The Updated BCHydro GMPE is intended for application to the Cascadia region as part of the updates to the national hazard maps. The ongoing NGA-SUB project will develop a suite of subduction GMPEs in the near future. These NGA-SUB GMPEs will supersede this BCHydro updated GMPE.

5.1 FUTURE WORK

In developing this update, there are several technical issues identified that should be addressed as part of the completion of the NGA-SUB project. These issues are listed below.

- The magnitude scaling below the magnitude break point was modeled using the same scaling for interface and slab earthquakes. The event terms show that for the **M**5 to **M**6 range, the magnitude scaling for slab event is stronger than for interface events. The basis for using either the same magnitude scaling or different magnitude scaling for interface and slab events should be revisited.
- The slab thickness was used to set the magnitude break for the slab scaling. Another approach would be to use the slab thickness to scale the difference between slab and interface events (the a_{10} term). The best use of the slab thickness to constrain the scaling of the slab ground motion needs further evaluation.
- Basin effects were not included in the updated BCHydro model. The similarity or difference between basin scaling for different regions needs to be evaluated before developing a basin term.

REFERENCES

Abrahamson N.A., Gregor N., Addo K. (2016). BC Hydro ground motion prediction equations for subduction earthquakes, *Earthq. Spectra*, 32: 23–44.

Abrahamson N.A., Youngs R.R. (1992). A stable algorithm for regression analyses using the random effects model, *Bull. Seismol. Soc. Am*., 82: 505–510.

Archuleta R., Ji C. (2018). Scaling of PGA and PGV deduced from numerical simulations of intraslab earthquakes, . PEER Report, in preparation, Pacific Earthquake Engineering Research Center, University of California, Berkeley, CA.

Atkinson G.M., Macias M. (2009). Predicted ground motions for great interface earthquakes in the Cascadia subduction zone, *Bull. Seismol. Soc. Am*., 99(3): 1552–1578.

Gregor N.J., Silva W.J., Wong I.G., Youngs R.R. (2002). Ground-motion attenuation relationships for Cascadia subduction zone megathrust earthquakes, *Bull. Seismol. Soc. Am*., 92: 1923–1932. doi:10.1785/0120000260.

Kishida T., Contreras V., Bozorgnia Y., Abrahamson N.A., Ahdi S.K., Ancheta T.D., Boore D.M., Campbell K.W., Chiou B., Darragh R., Gregor N., Kuehn N., Kwak D.Y., Kwok A.O., Lin P., Magistrale H., Mazzoni S., Muin S., Midorikawa S., Si H., Silva W.J., Stewart J.P., Wooddell K.E., Youngs R.R. (2018). NGA-Sub ground-motion database, *Proceedings*, *11NCEE*, Los Angeles, CA.

Zhao J.X., Zhang J., Asano A., Ohno Y., Oouchi T., Takahashi T., Ogawa H., Irikura K., Thio H.K., Somerville P.G., Fukushima Y., Fukushima Y. (2006). Attenuation relations of strong ground motion in Japan using site classification based on predominant period, *Bull. Seismol. Soc. Am.,* 96(3): 898–913.

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