Hybrid Broadband Ground Motion Simulations of Porters Pass Earthquakes

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1. Background and Introduction

We present ground motion simulations of the Porters Pass (PP) fault in the Canterbury region of New Zealand; a major active source near Christchurch city. The active segment of the PP fault has an inferred length of 82 km and a mostly strike-slip sense of movement. The PP fault slip makes up approximately 10% of the total 37 mm/yr margin-parallel plate motion and also comprises a significant proportion of the total strain budget in regional tectonics. Given that the closest segment of the fault is less than 45 km from Christchurch city, the PP fault is crucial for accurate earthquake hazard assessment for this major population centre.

We have employed the hybrid simulation methodology of Graves and Pitarka (2010, 2015), which combines low (f<1 Hz) and high (f>1 Hz) frequencies into a broadband spectrum. We have used validations from three moderate magnitude events (M_w4.6 Sept 04, 2010; M_w4.6 Nov 06, 2010; M_w4.9 Apr 29, 2011) to build confidence for the $M_w > 7$ PP simulations. Thus far, our simulations include multiple rupture scenarios which test the impacts of hypocentre location and the finite-fault stochastic rupture representation of the source itself. In particular, we have identified the need to use location-specific 1D V_s/V_p models for the high frequency part of the simulations to better match observations.

2. Porters Pass simulations

The $M_w = 7.2$ Porters Pass simulations are shown in Figure 1 below. Here we have shown ground velocity snapshots for the hypothetical $M_w = 7.2$ event with three rupture scenarios in which the hypocenter (denoted by star) is placed at the South-West, central and North-East locations along the strike of the PP fault.

The PP fault is displayed as the solid black line and the dashed box represents the surface boundaries of the 3D velocity model used in the finite-difference algorithm for the visco-elastic wave equation.

The ground velocity snapshots qualitatively show that the Christchurch city is subjected to the largest magnitude shaking when the hypocenter is located on the South-West of the PP fault. The underlying reason is the cumulative impact of rupture directivity-basin coupling in this case which is not as significant when the hypocenter is placed at the centre of the fault. For the other scenario rupture directivity points away from the city.

We can also see the impact of basin-induced surface waves. Furthermore, we have checked and concluded that the effects of stochastic rupture representation itself are secondary to rupture directivity.

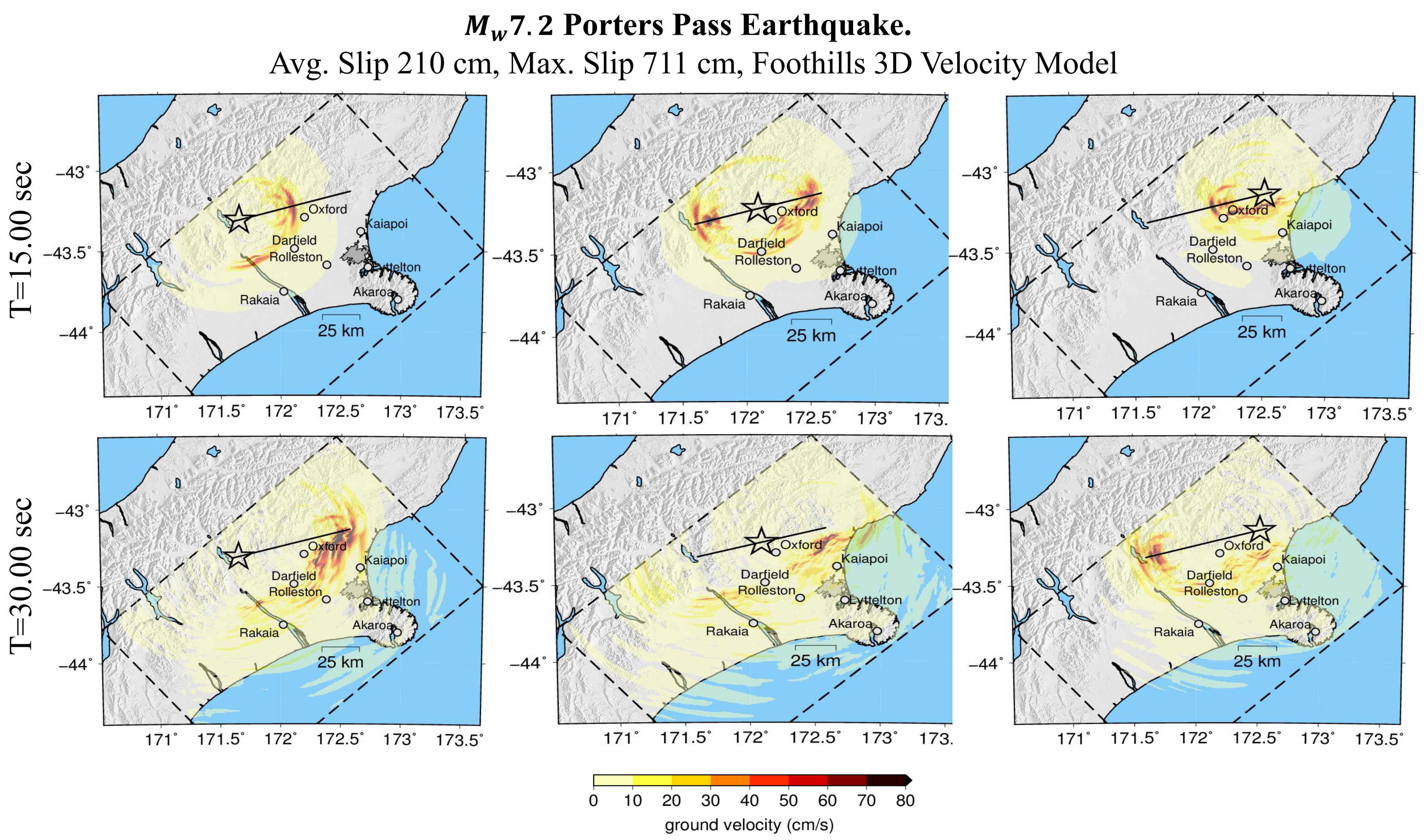

Figure 1: Ground velocity snapshots at t=15 and t=30 secs after the rupture initiates. Black line is the Porters Pass fault and star the hypocenter location.

3. Porters Pass adjacent validation events

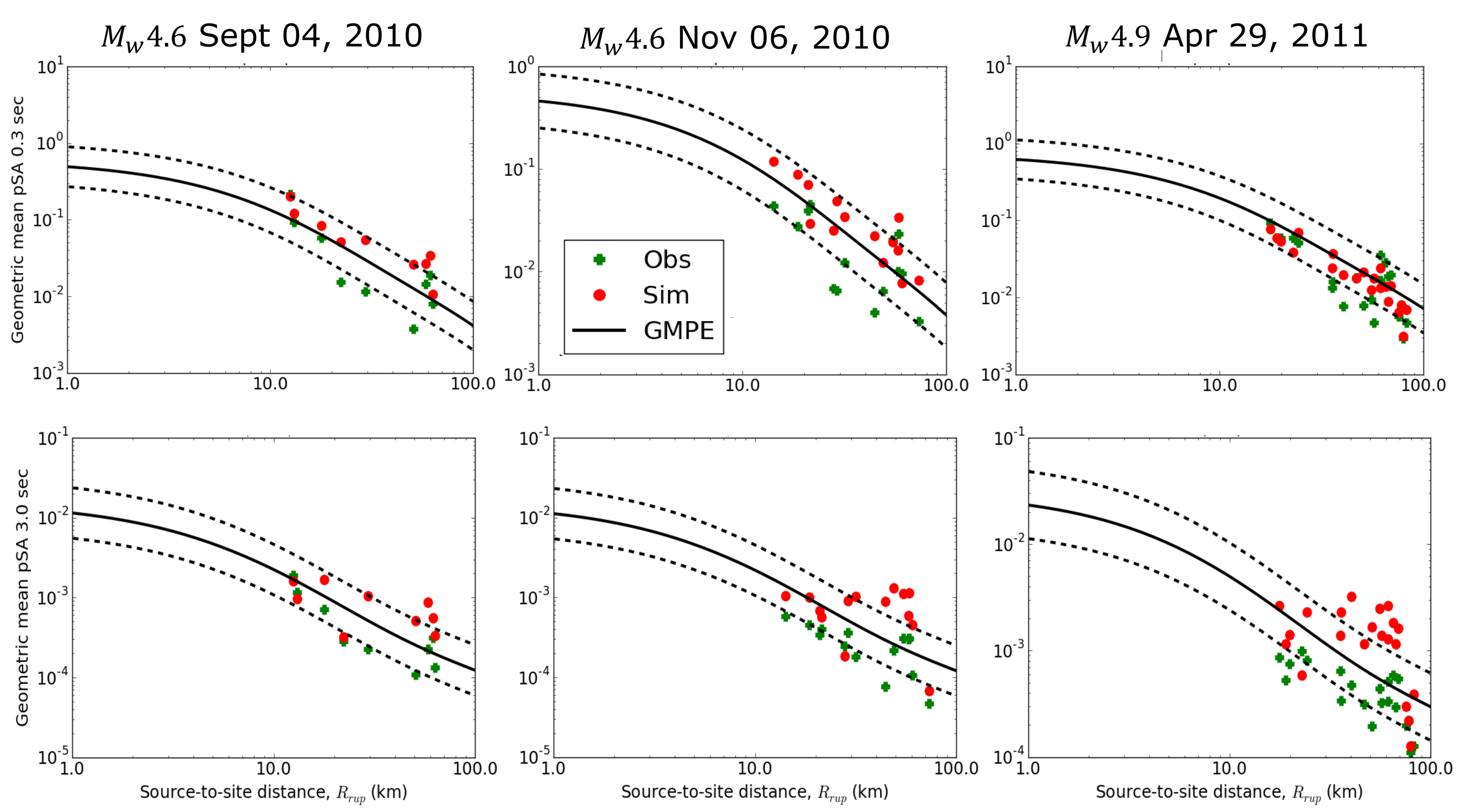

Figure 2: Simulated pseudo spectral acceleration for a single degree of freedom oscillator are compared to those from observations and GMPE predictions.

Previous studies of the Canterbury earthquake sequence were of events that where located in the Canterbury Basin and the Banks Peninsula. To build confidence in our $M_w > 7$ PP simulation we first validated the 3D velocity model using three historical events (M_w4.6 Sept 04, 2010; M_w4.6 Nov 06, 2010; M_w4.9 Apr 29, 2011) in the foothills of the Canterbury Alps.

Figure 2 shows the observed and simulated pseudo spectral acceleration for $T = 0.3\,sec$ and $T = 3.0\,sec$ that lie in the high and low frequency parts of the broadband spectrum respectively.

In general we observe good agreement between observations, simulations and the GMPE predictions (although more rigorous validation is on going). The Sep 04, 2010 and Nov 06, 2010 events show the simulated high frequencies have larger amplitude. In contrast the Apr 29, 2011 event shows the simulated low frequency amplitudes show little difference from observations.

4. Analyses: Non-ergodic within- and between-event residuals

A comparison of our three moderate magnitude events to results from a previous study carried out by Razafindrakoto et al. (2016) for ten of the major Canterbury earthquake sequence is shown in Figure 3. Here the solid black line illustrates the total between-event residual, the three validation events residuals are shown in blue and the residuals for the ten events from the Canterbury earthquake sequence are in red.

- The individual between-event residuals show simulated amplitudes are substantially over predicted for two of the validation events.
- The site-to-site effects for the SPFS station, located on the Canterbury Alps, is characteristically different from that at the PPHS station located in the Christchurch city--part of the basin. See Figure 4 (b) for station locations.

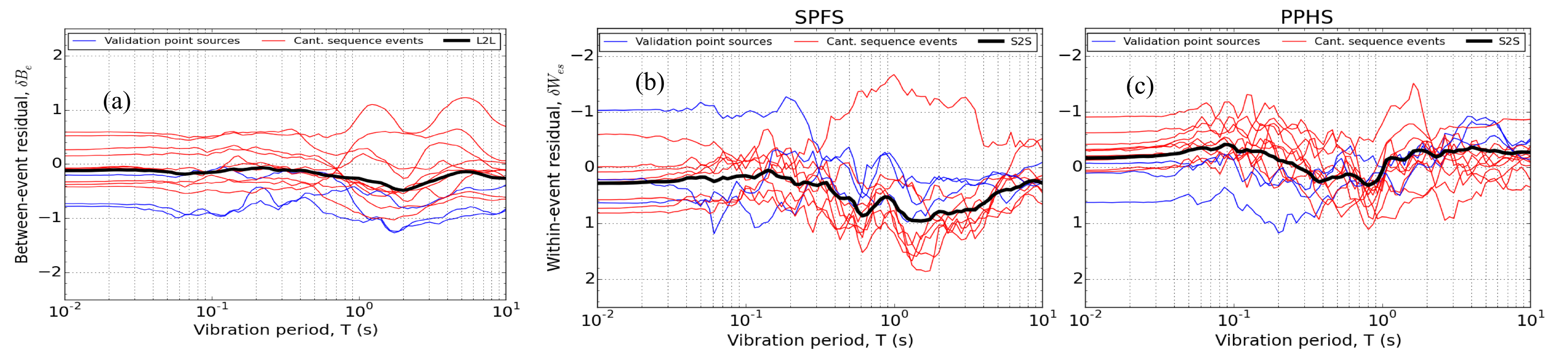

Figure 3: (a) Between-event residuals and (b), (c) within-event residuals which illustrate site-to-site effects. A single velocity model (Canterbury 1D) is used for HF simulations.

5. Location-specific high frequency 1D velocity model

We are investigating to check if location-specific 1D velocity models used for the high frequency part of the hybrid simulations can result in improvements. Figure 4 (a) shows the velocity model profiles (from the Canterbury velocity model, Lee et al. (2016)) at strong motion stations and the regional velocity profile. The brown colored lines in 4 (b) demarcate the velocity region into Alps foothills, Canterbury Basin and the Banks Peninsula volcanics.

- Repeated simulations for the three validation events with region-specific 1D velocity models results in improved residuals for the high frequency part. This can been seen by comparing the between-event residuals shown in seen Figure 3 (a) and the repeated simulations in Figure 5 (a).
- We can also notice improved residuals for the SPFS station when comparing Figure 3 (b) with the repeated simulations for this strong motion station shown in Figure 5 (b). SPFS is located in the foothills region.
- Figure 4 (a) shows considerable scatter in shear velocity profiles between strong motion station for the Canterbury Plains and Banks Peninsula subregions. The strong motion stations in the Foothills however, have shear velocity profiles that closely cluster around the mean for this subregion.

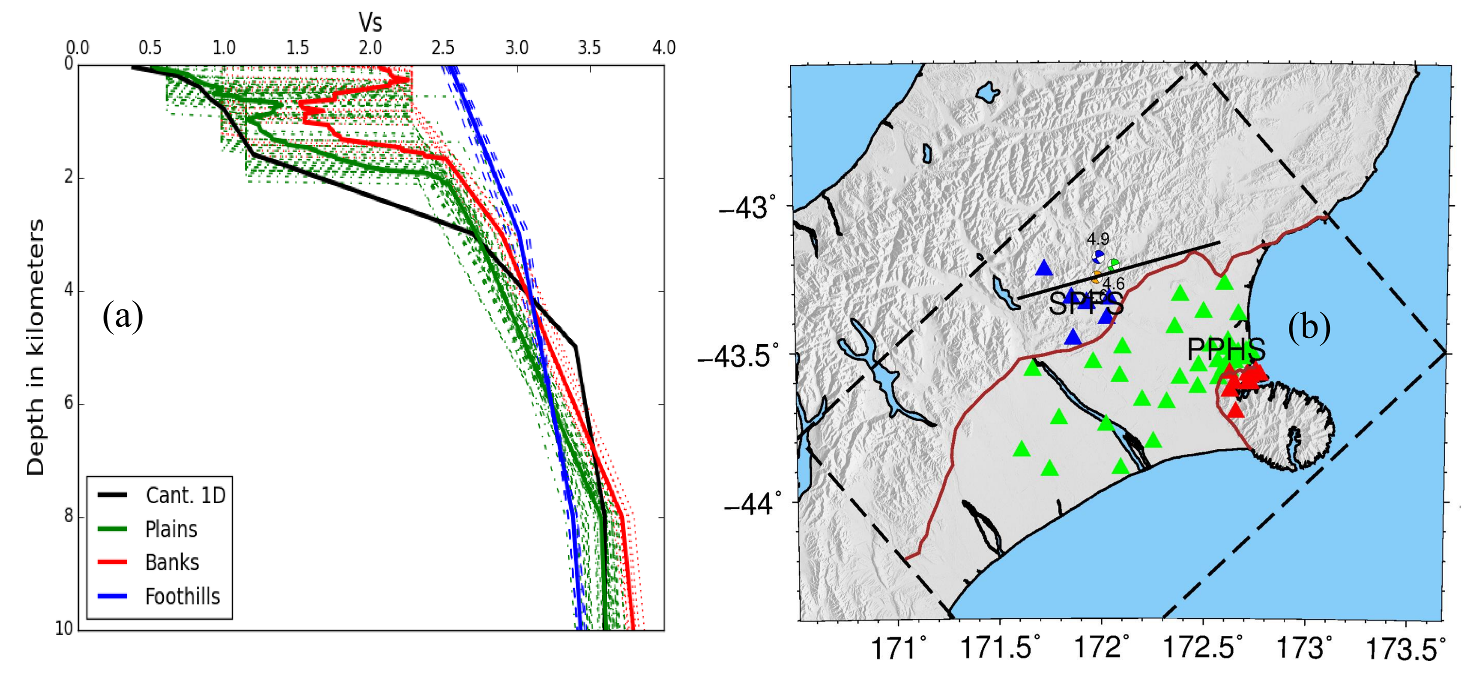

Figure 4: Shear wave velocity profiles at strong motion stations grouped into three regions.

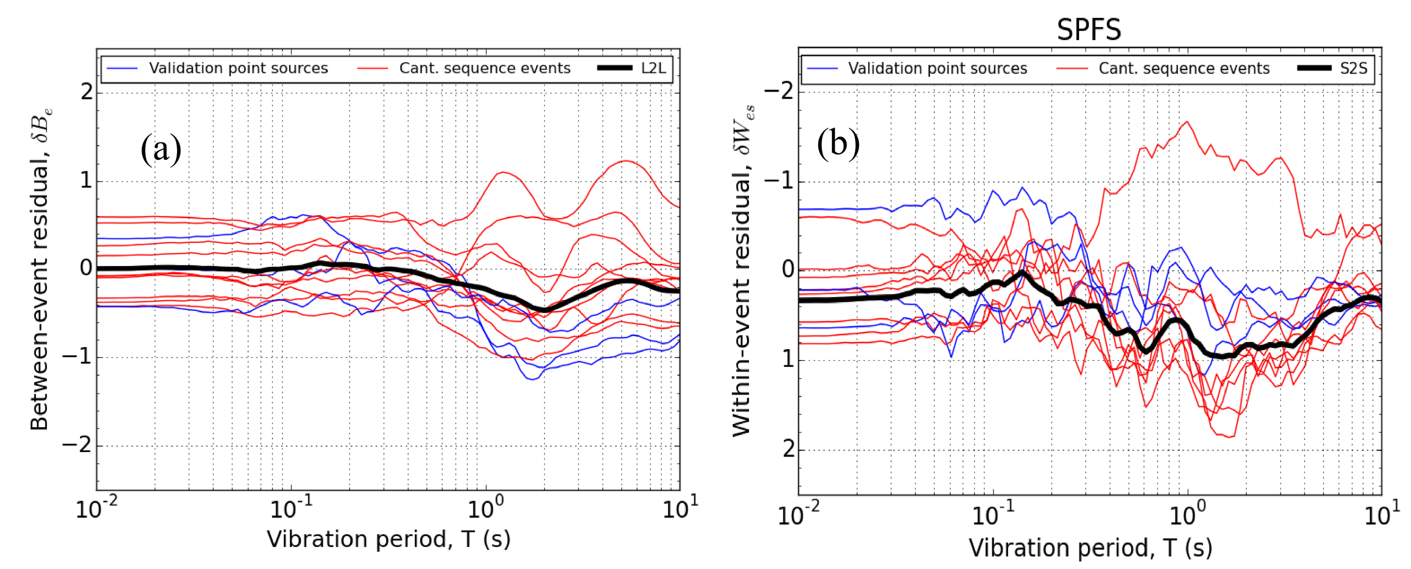

Figure 5: (a) Between-event residuals and (b) within-event residuals to show site-to-site effects from location-specific 1D velocity models for the three subregions.

6. Future work

- Work is currently underway to quantitatively understand the impact of a PP fault rupture in addition to the qualitative results shown in this poster.
- We are also working to extend the region-dependent shear velocity model approach from section 5 so as to carry out the 1D high frequency part of the simulations for each strong motion station with the shear velocity profile appropriate for that station.