Ground motion simulation of Porters Pass fault earthquakes in the Canterbury region

June 21, 2016

Broadband simulation — Background

- Hybrid methods go back to the work of Hartzell et al. (1999)

  Hybrid methods compute low and high frequencies separately and combine them to a broadband waveform. See

  Broadband Ground–Motion Simulation Using a Hybrid Approach. Robert W. Graves and Arben Pitarka. *Bulletin of the Seismological Society of America. Vol. 100, 2010*

- Use of stochastic methods also go back decades. See paper below and references therein.

  Revisions to Some Parameters Used in Stochastic-Method Simulations of Ground Motion. David M. Boore and Eric M. Thompson. *Bulletin of the Seismological Society of America. Vol. 105, 2015*

Background

Physics based LF simulation

- The $3D$ wave equation of a viscoelastic medium is solved numerically.

$$\partial_j \left(C_{ijkl} \partial_l u_k \right) + F_i = \rho \frac{\partial^2}{\partial t^2} u_i \tag{1}$$

- The medium is treated as anisotropic and inhomogeneous thus energy dissipation due to heat loss from viscosity, anelastic attenuation etc. is incorporated.
- Computational demands restricts this approach to about 1 hz.
- The source $\vec{F}$ can be a point source or a finite fault. This is the kinemetic description of source.
- In contrast in dynamic modeling the source rupture has its differential equations coupled to the wave equation and both are solved simultaneously.

Background

HF stochastic simulation

- For simplicity consider a point source and to elucidate the physics assume a single subfault and no reflected waves in which case the acceleration amplitude in the frequency domain is given by the expression

$$A(f) = S(f)G(f)P(f)C\,. \tag{2}$$

- For a rupture speed V_r the corner frequency

$$f_c = \frac{1}{(\pi^2 Const)^{1/3}} V_r \left(\frac{\Delta\bar{\sigma}_p}{M_0} \right)^{1/3} . \tag{3}$$

Increasing the stress drop increases the corner frequency in the source function $S(f)$. Thus the characteristic ω^2 decay starts at a larger frequency. We expect larger simulated amplitudes compared to observed data, if we over estimate stress drop.

Motivation

Porters Pass fault

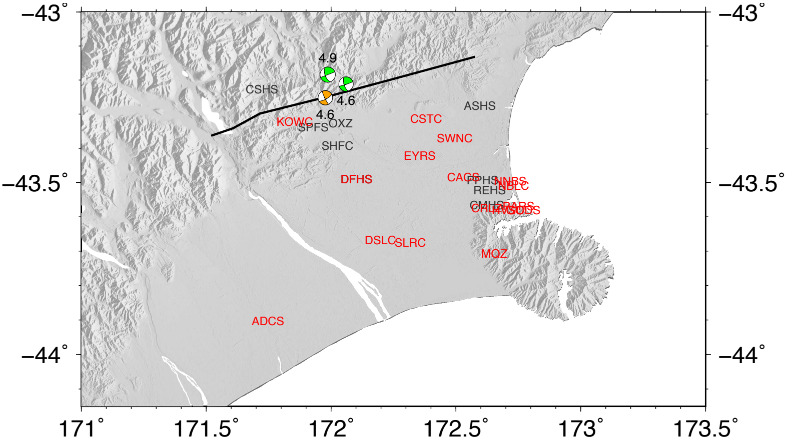


Figure: $M_w 4.6$ Sep 04, 2010 recording stations are shown in black.

Motivation

Porters Pass fault

- Closer in proximity to Christchurch compared to Alpine fault.
- We use the small magnitude events near the Porters Pass to build confidence in our simulation methodology in the event of simulating a future large magnitude earthquake that originates from this region.
- Validating the broadband Graves and Pitarka code on the edges of the Canterbury velocity model.
- A test case before extending the Canterbury velocity model to a larger domain. One of several fault systems that are to be incorporated in the QuakeCoRE platform.

Motivation

Porters Pass fault

- Capable of producing $M_w 7.5$
- Single event displacement of 6.3 m.
- length 90km, slip rate 0.75 mm/yr
- Recurrence interval of 8360 years.
- active shallow, other crustal faulting
- The shorter segment (82km) has a slip rate of $3.$ mm/yr, 1900 years recurrence interval and can produce a $M_w 7.5$ event.

Holocene paleoearthquakes on the strikeslip Porters Pass Fault, Canterbury, New Zealand. Matthew Howard , Andrew Nicol , Jocelyn Campbell , Jarg R. Pettinga. *New Zealand Journal of Geology and Geophysics Vol. 48, Iss. 1, 2005*

Earthquake events

Source modeling

- We do not carry out source inversion. We rely on GeoNet for point source magitude and depth estimates who use SeisComP3 (See Determination of source origin and magnitude estimate).
- All 3 events are simulated as point sources.

Porters Pass-Grey Long Fault adjacent		
Earthquake	Depth in km Centroid/Hypocenter	% double couple
M_w4.6 Sep 04, 2010	8/8	93
M_w4.6 Nov 06, 2010	6/8	70
M_w4.9 Apr 29, 2011	7/11	70

Analysis of results

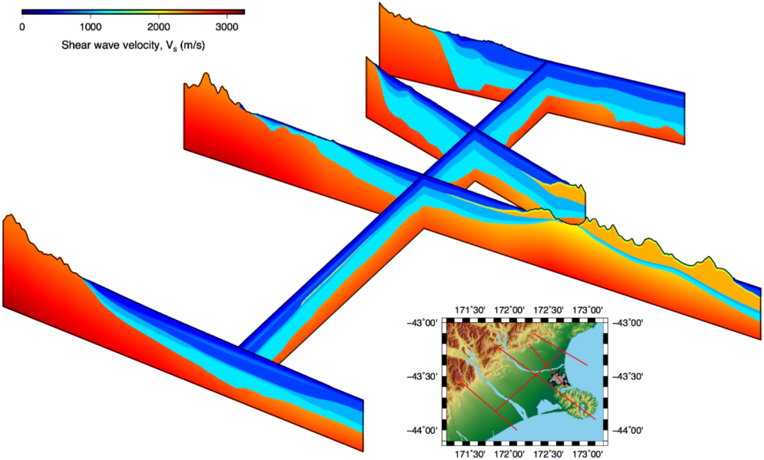
- In what follows we consider various comparisons of simulations to observations.
- We first look at the bias for all three simulations together with parameter values found to work well for the Canterbury region (See reference below).
- We then assess results for each simulation one at a time.

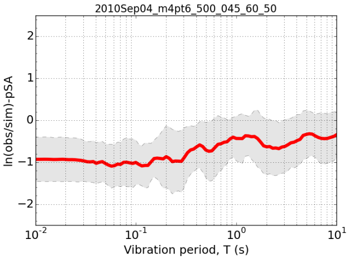
I quantify the goodness of fit of the data and simulation as the natural logarithm of the ratio (Obs/Sim) of Pseudo spectral acceleration undergone by a damped single degree of freedom oscillator. This is a common practice.

Strong ground motions from the 2010-2011 Canterbury earthquakes and the predictive capability of empirical and physics-based simulation models. Bradley, B. A., Jeong, S. and Razarfindrakoto, H. N. R. *Sydney, Australia: 10th Pacific Conference on Earthquake Engineering. 2015*

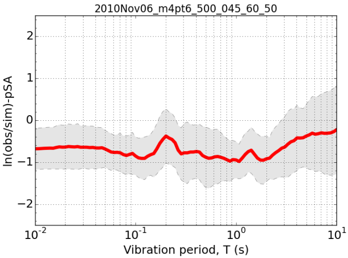
Canterbury velocity model cross sections

2. Path: Complex 3D geology - Canterbury

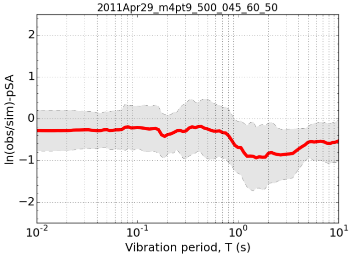




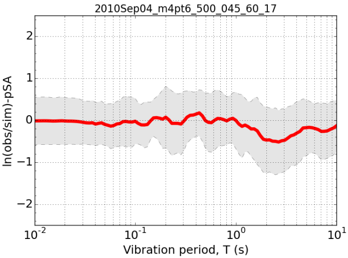
(a) Stress drop $\sigma_p = 50$ bar



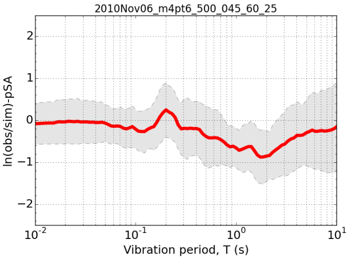
(b) Stress drop $\sigma_p = 50$ bar



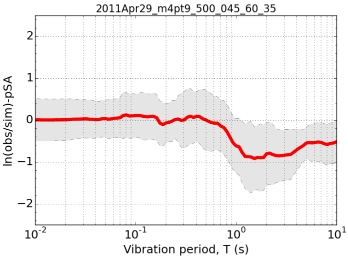
(c) Stress drop $\sigma_p = 50$ bar



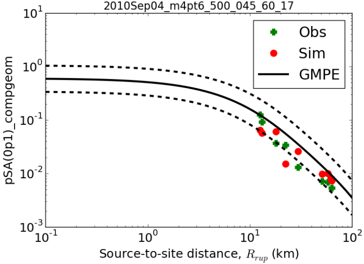
(a) Stress drop $\sigma_p = 17$ bar



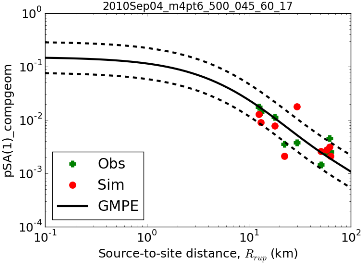
(b) Stress drop $\sigma_p = 25$ bar



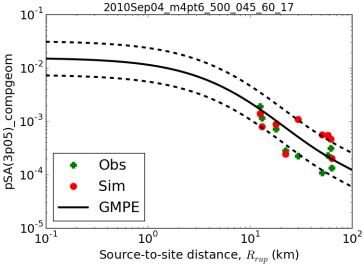
(c) Stress drop $\sigma_p = 35$ bar



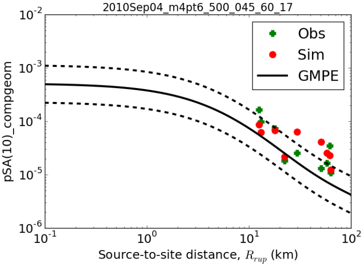
(a) $PSA = 0.1$ sec, $\sigma_p = 17$ bar



(b) $PSA = 1$ sec, $\sigma_p = 17$ bar



(c) $PSA = 3$ sec, $\sigma_p = 17$ bar



(d) $PSA = 10$ sec, $\sigma_p = 17$ bar

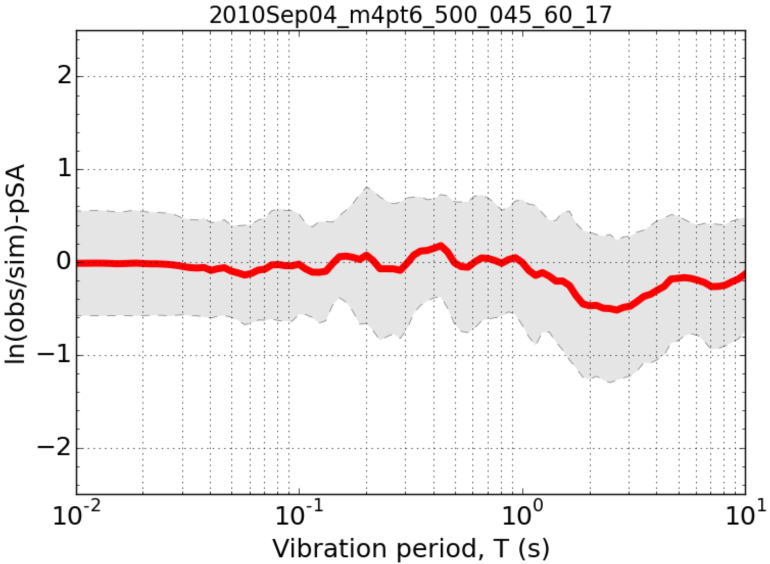
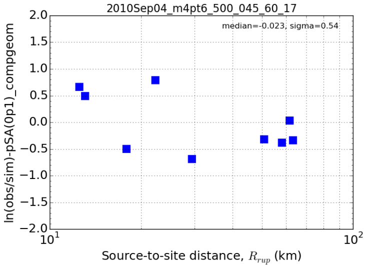
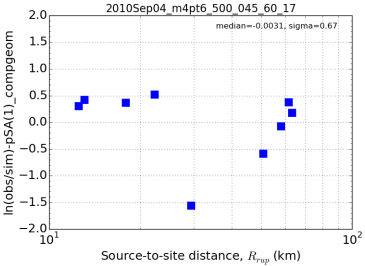


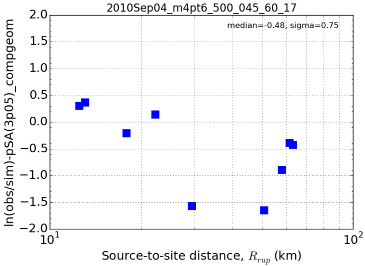
Figure: $M_w 4.6$ Sep 04, 2010 bias with stress drop $\sigma_p = 17$ bar



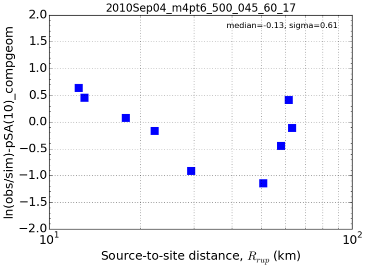
(a) $PSA = 0.1$ sec, $\sigma_p = 17$ bar



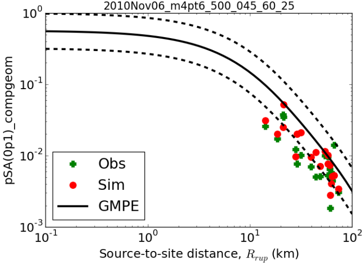
(b) $PSA = 1$ sec, $\sigma_p = 17$ bar



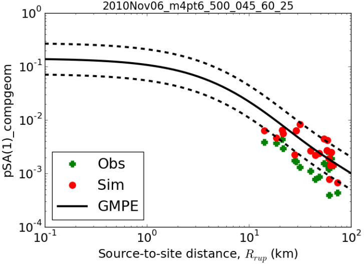
(c) $PSA = 3$ sec, $\sigma_p = 17$ bar



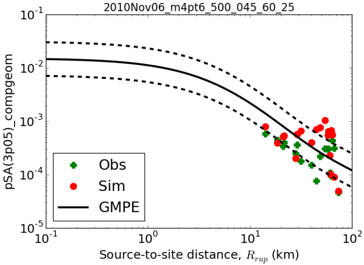
(d) $PSA = 10$ sec, $\sigma_p = 17$ bar



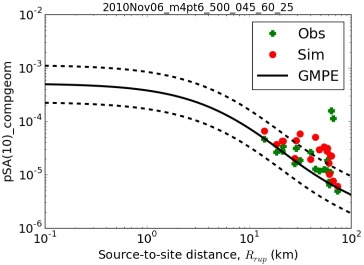
(a) $PSA = 0.1$ sec, $\sigma_p = 25$ bar



(b) $PSA = 1$ sec, $\sigma_p = 25$ bar



(c) $PSA = 3$ sec, $\sigma_p = 25$ bar



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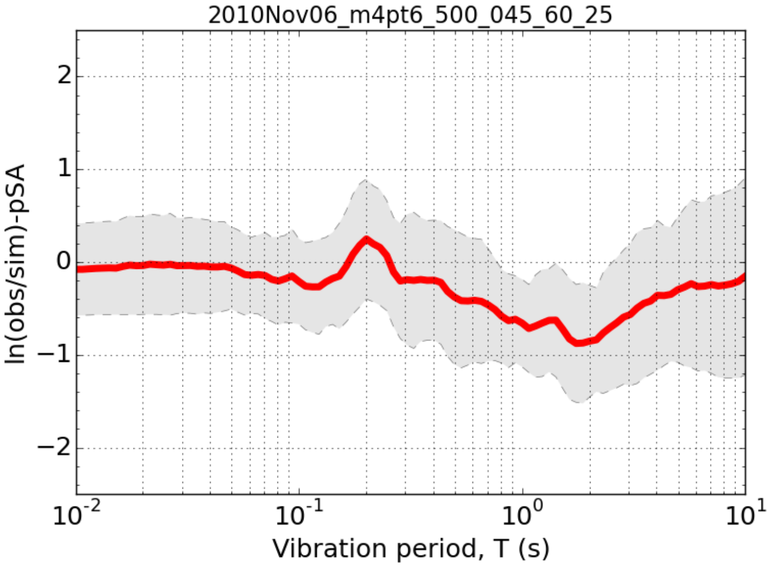
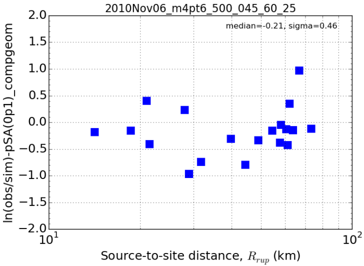
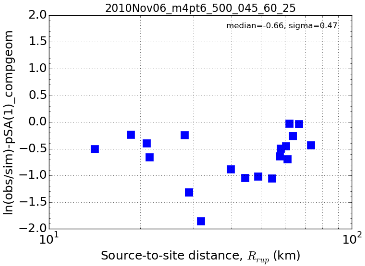


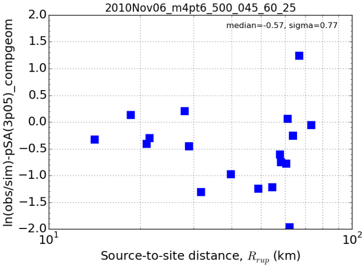
Figure: $M_w 4.6$ Nov 06, 2010 bias with stress drop $\sigma_p = 25$ bar



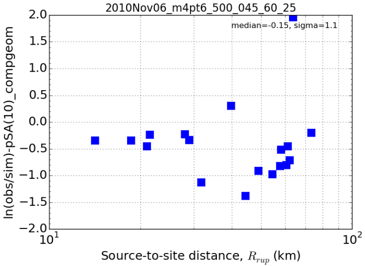
(a) $PSA = 0.1$ sec, $\sigma_p = 25$ bar



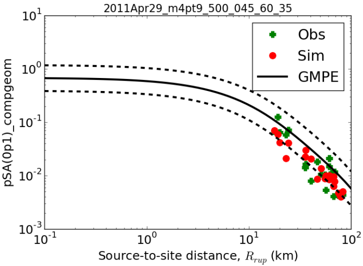
(b) $PSA = 1$ sec, $\sigma_p = 25$ bar



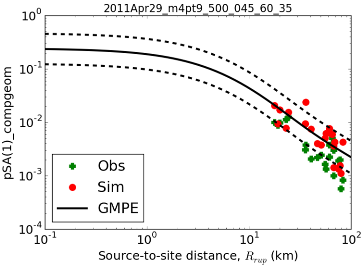
(c) $PSA = 3$ sec, $\sigma_p = 25$ bar



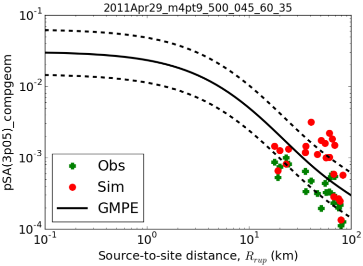
(d) $PSA = 10$ sec, $\sigma_p = 25$ bar



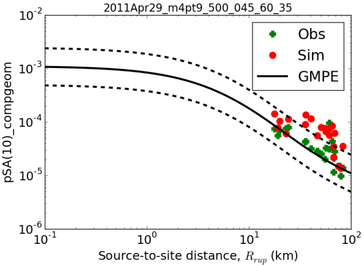
(a) $PSA = 0.1$ sec, $\sigma_p = 35$ bar



(b) $PSA = 1$ sec, $\sigma_p = 35$ bar



(c) $PSA = 3$ sec, $\sigma_p = 35$ bar



(d) $PSA = 10$ sec, $\sigma_p = 35$ bar

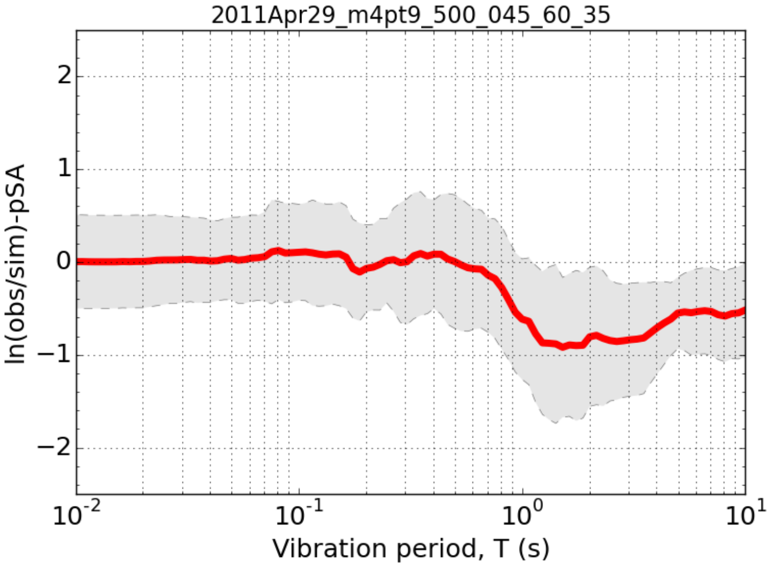
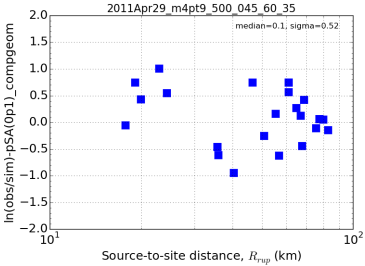
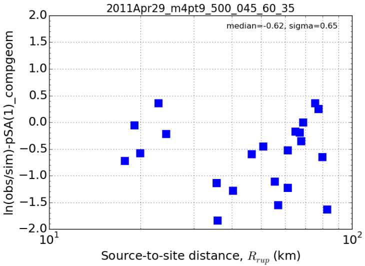


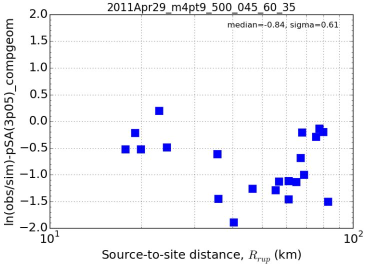
Figure: $M_w 4.9$ Apr 29, 2011 bias with stress drop $\sigma_p = 35$ bar



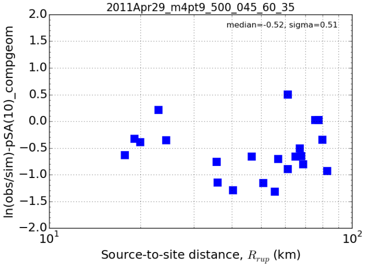
(a) $PSA = 0.1$ sec, $\sigma_p = 35$ bar



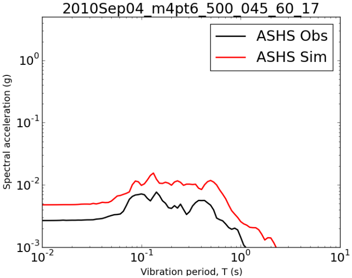
(b) $PSA = 1$ sec, $\sigma_p = 35$ bar



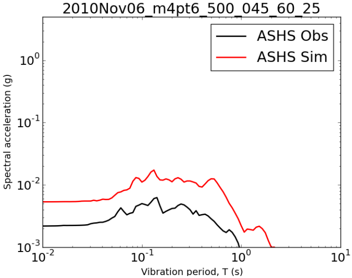
(c) $PSA = 3$ sec, $\sigma_p = 35$ bar



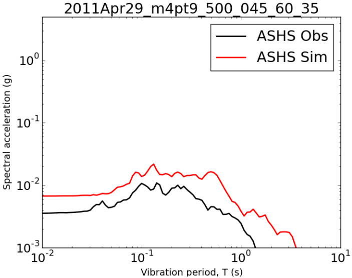
(d) $PSA = 10$ sec, $\sigma_p = 35$ bar



(a) Stress drop $\sigma_p = 17$ bar



(b) Stress drop $\sigma_p = 25$ bar



(c) Stress drop $\sigma_p = 35$ bar

Conclusion | Ongoing work

- The simulations trace the observations even when there are deviations from the GPME. This is so because our goodness of fit metric is the PSA from observations and not GMPE.
- There is systematic amplitude over prediction in simulations. While this can be artificially adjusted for the high frequency part by lowering the stress drop, the over prediction in low frequency part can not be accounted for in this manner.
- We under-predict amplitudes close to source and over estimate amplitudes for stations farther away from source.
- Work is underway to understand and quantify uncertainties and biases as intra-event and between event residuals.

conclusoin | Ongoing work

- As of yet sufficient analysis has not been performed to separate site specific effects and make conclusive statements. See ASHS station where the PSA amplitude are higher than observations for all three events.
- One conclusion we draw is that the 1D velocity model is better suited for the Canterbury plains and fails to adequately capture the impacts from the shallow depth at the Porters Pass location. A different 1D velocity model that is better suited for the Porters Pass region will be tested.

Acknowledgment

- Publicly available strong motion data from GeoNet
- QuakeCoRE

Appendix

- Link to strong motion stations map.
- Link to interactive map showing NZ strong motion Network.
- Link to google map showing topography.