Toward Hybrid Broadband Ground Motion Simulation Validation for New Zealand-wide $M_w \geq 3.5$ Earthquakes

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1. Background and Objectives

This poster presents preliminary ground motion simulation validation results considering earthquakes of $3.5 \leq Mw \leq 5.0$ across New Zealand using the Graves and Pitarka (2010,2015) hybrid approach with NZ-specific inputs. The performance of the simulations, and conventional empirical ground motion models (for benchmarking purposes), are subsequently quantified using a mixed-effects analysis framework. A thorough validation of the Canterbury region was carried out by Lee et al. (2018).

A total of 563 earthquake ruptures, modelled as point sources, are considered with 4419 quality-assured ground motions recorded across 277 stations, as shown in Figure 1. Source characteristics and observed ground motions are obtained from GeoNet. To scale our analyses to a large number of ground motions we have also developed a neural network for ground motion quality classification.

The ground motion simulations were performed on event-specific computational domains, with a grid spacing of 400m, to optimize total compute core hour requirements during workflow optimization.

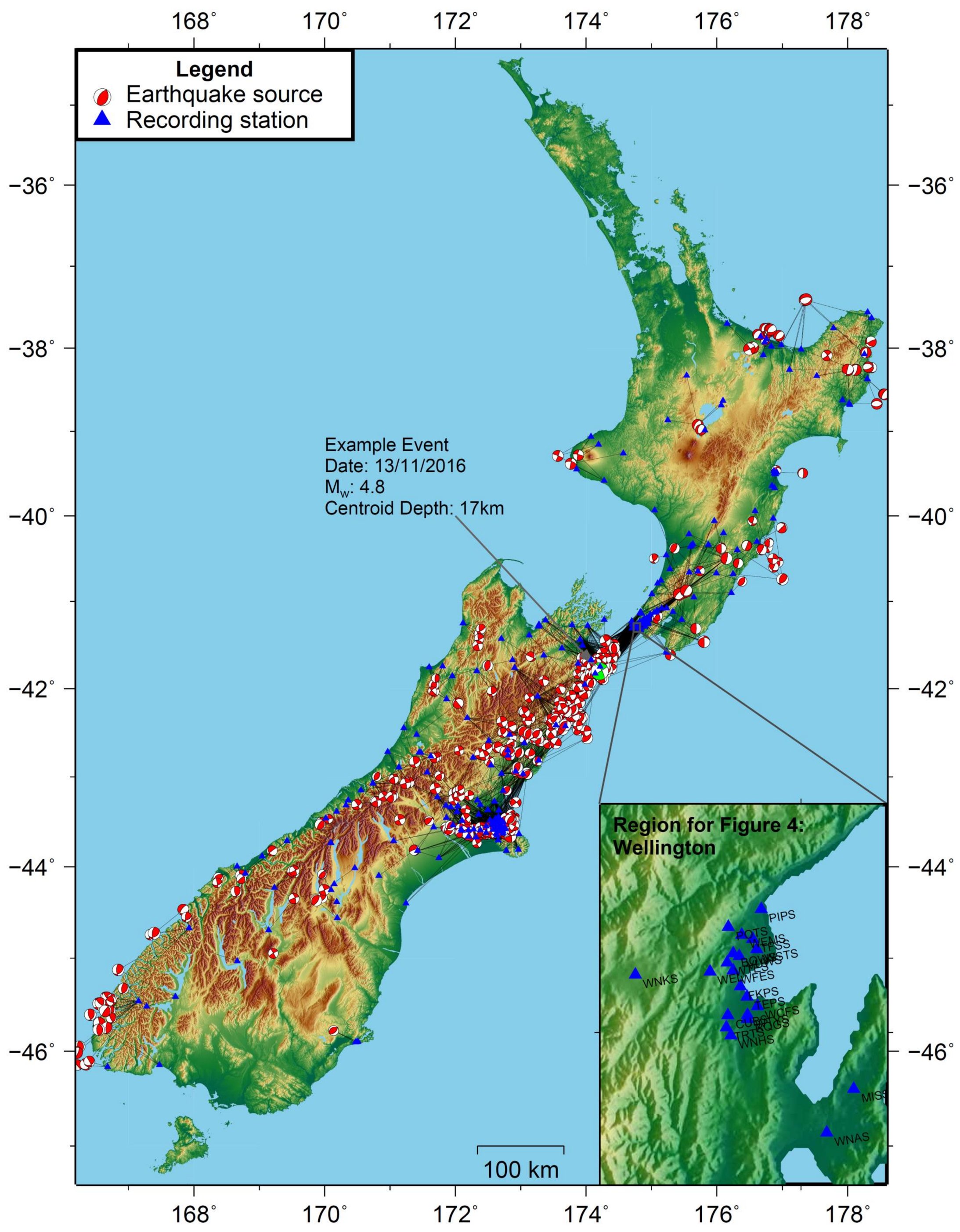

Figure 1: Map of New Zealand highlighting the 563 earthquake events, 277 recording stations and observed ground motion ray paths.

The low-frequency (LF) simulations utilize a unified New Zealand Velocity Model (NZVM) while the high-frequency (HF) simulations utilize a generic regional 1D velocity model (which has no explicit region-specific basin models). In the LF simulations, a minimum shear wave velocity of 500m/s is enforced, yielding a maximum frequency of 0.25Hz in the present results.

2. Example Results for a Single Event

Results from the 13th November 2016 M_w 4.8 earthquake located in the Marlborough region at the top of the South Island (shown as the green source in Figure 1) are presented. Figure 2 provides a comparison of the observed and simulated velocity time series at 6 strong motion stations located in Marlborough and Wellington, and Figure 3 presents ground motion intensity measures as a function of source-to-site distance (R_{rup}), which illustrate that:

- Simulated velocity waveforms are dominated by high frequencies and amplitudes appear to be visually overpredicted for Marlborough sites and Wellington Rock sites, but not for Wellington Basin sites. Arrival times of simulations are generally earlier than observed ground motions, possibly due to the lack of low velocity sedimentary basin models. Simulated waveform durations also appear to be significantly too short.
- Both simulated and empirical prediction of PGA and pSA(1.0s) match the observations well on average. However, simulated 5-95 significant duration (D_{s595}) appears to be significantly underpredicted while the empirical prediction compares well with observations.

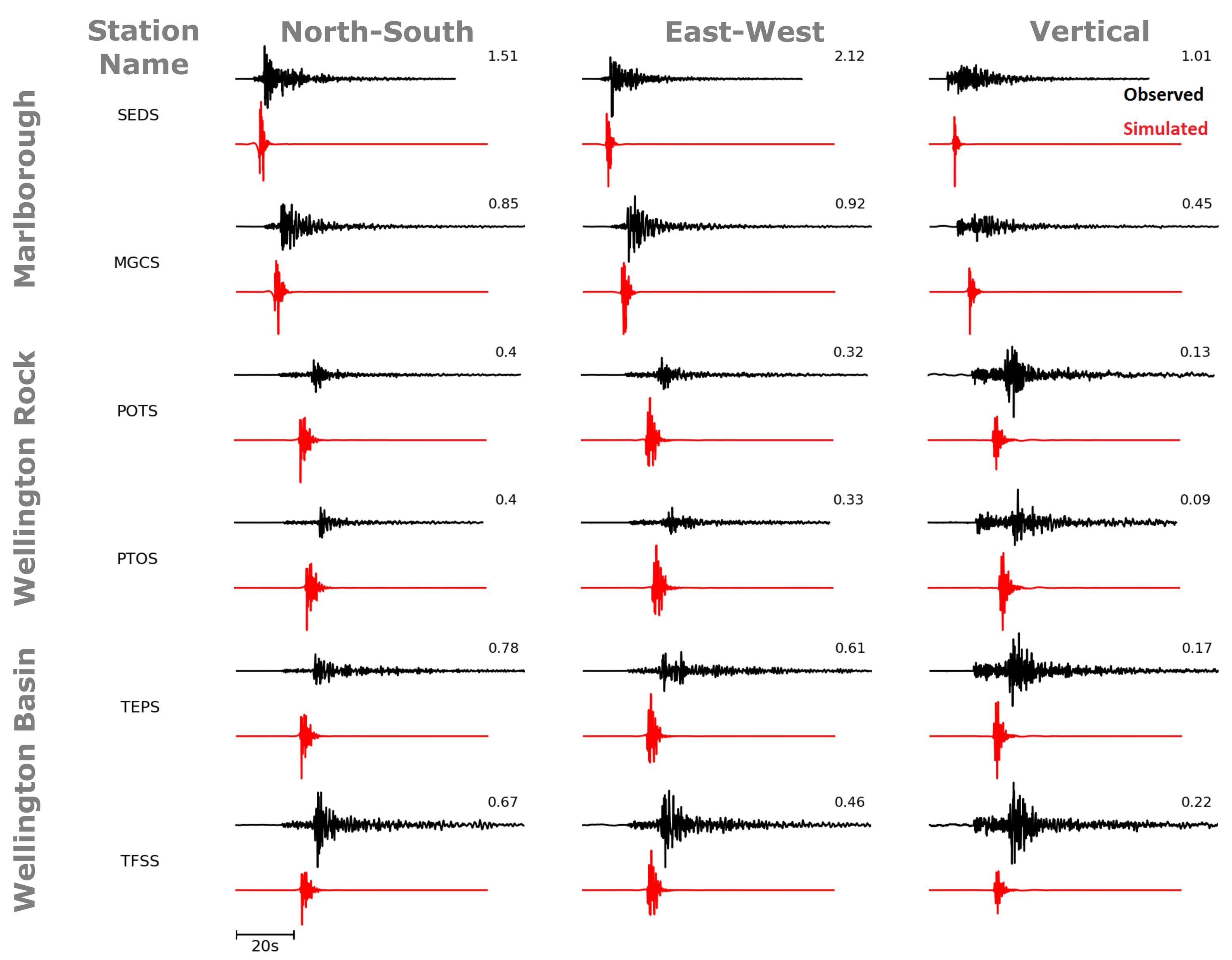

Figure 2: Observed (black) and simulated (red) broadband velocity time series. Maximum PGV are provided to the right of each waveform pair in cm/s.

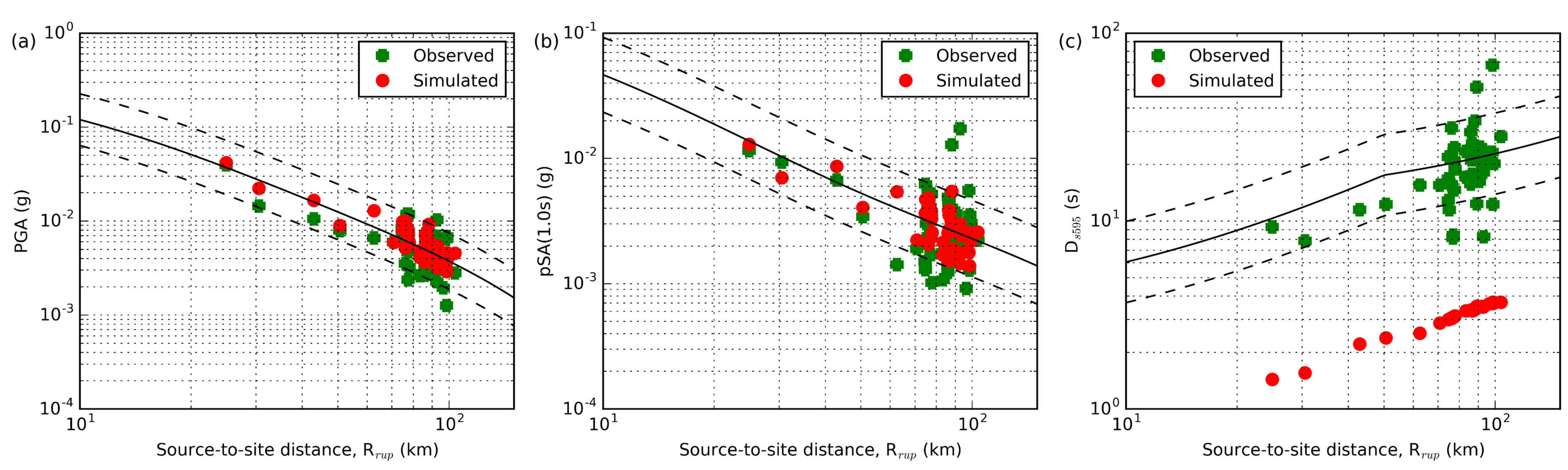

Figure 3: Observed, simulated and empirically predicted geometric mean ground motion intensity measures: (a) PGA, (b) pSA(1.0s), and (c) D_{s595}.

3. Observed Systematic Effects in Ground Motion Modelling

By considering all 563 earthquakes, systematic ground motion effects can be determined. The mixed-effects analysis identified significant variation in systematic site-to-site residuals ($\delta S2S_s$) across New Zealand. To highlight this, as an example, Figure 4 presents the spatial distribution of $\delta S2S_s$ for pSA(1.0s) in the Wellington region (as shown in Figure 1) for simulation. Key trends include:

- Sites located in the Wellington Basin generally have positive $\delta S2S_s$ and are therefore relatively underpredicted. These sites are generally native alluvium, or fill on reclaimed land. The underprediction manifests from the lack of a basin model in the simulations as the Wellington Basin has a natural period between 1.0-2.0s resulting in amplification at these periods.
- Sites located on rock generally have negative $\delta S2S_s$ and are therefore relatively overpredicted. This could be caused by various factors in the HF simulations such as the use of a generic 1D velocity model, a constant κ_0 value for all sites, or a path duration model which is too short.
- The spatial variation of $\delta S2S_s$ for empirical prediction is similar to that of simulations as site effects were considered in the simulations using V_{s30}-based empirical amplification factors.

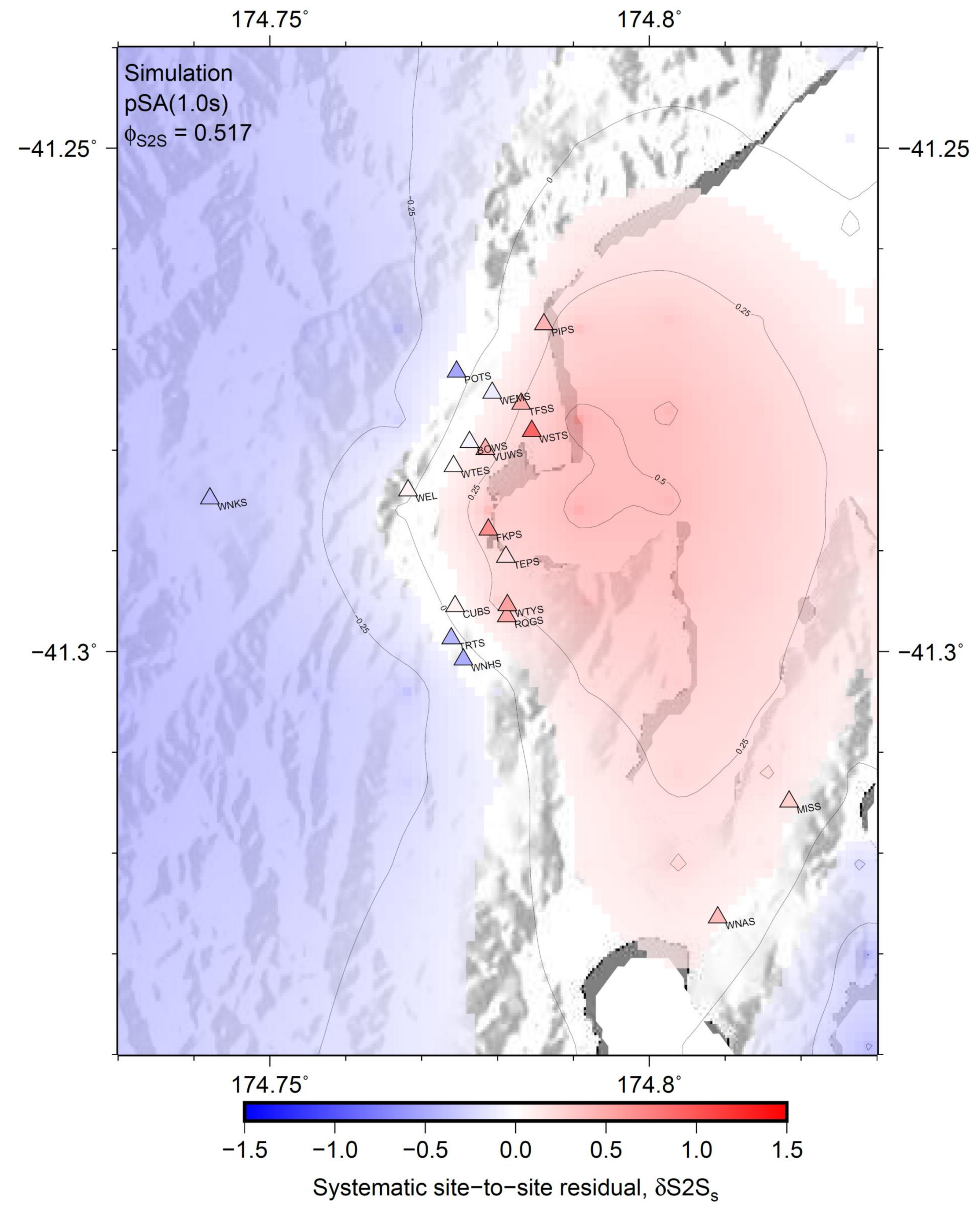

Figure 4: Spatial variation of simulation $\delta S2S_s$ for pSA(1.0s) in the Wellington City area.

Figures 5 presents the computed within-event residuals (δW_{es}) and corresponding $\delta S2S_s$ (solid thick lines) for the simulated and empirical ground motion predictions at the MGCS, POTS and TEPS sites which are located in the Marlborough Basin, on rock in Wellington, and in the Wellington Basin, respectively. The results show that:

- Simulated and empirical results are very similar for all intensity measures considered and will therefore be discussed together.
- The MGCS site has $\delta S2S_s$ with a broad peak centered near T = 1.0s which may be caused by the sloping V-shaped Marlborough basin, which is not modelled in the simulations, amplifying a broad range of periods.
- The POTS site is located north of the Wellington Fault and shows relatively flat $\delta S2S_s$ for pSA with only minor period-dependent fluctuations as most of the rock site response is captured.
- The TEPS site is located on engineered fill in the Wellington sedimentary basin and shows a significant narrow-banded peak around T = 1.0s suggesting that the simulations (and empirical prediction) are underpredicting at this period. As mentioned prior, this is because the Wellington Basin is not included in the crustal velocity models used.

The discrepancies between simulation and observation suggest that better velocity modelling, through the inclusion of sedimentary basin models, and more rigorous treatment of site effects, either through site-specific HF simulations and/or explicit site response analysis, are required.

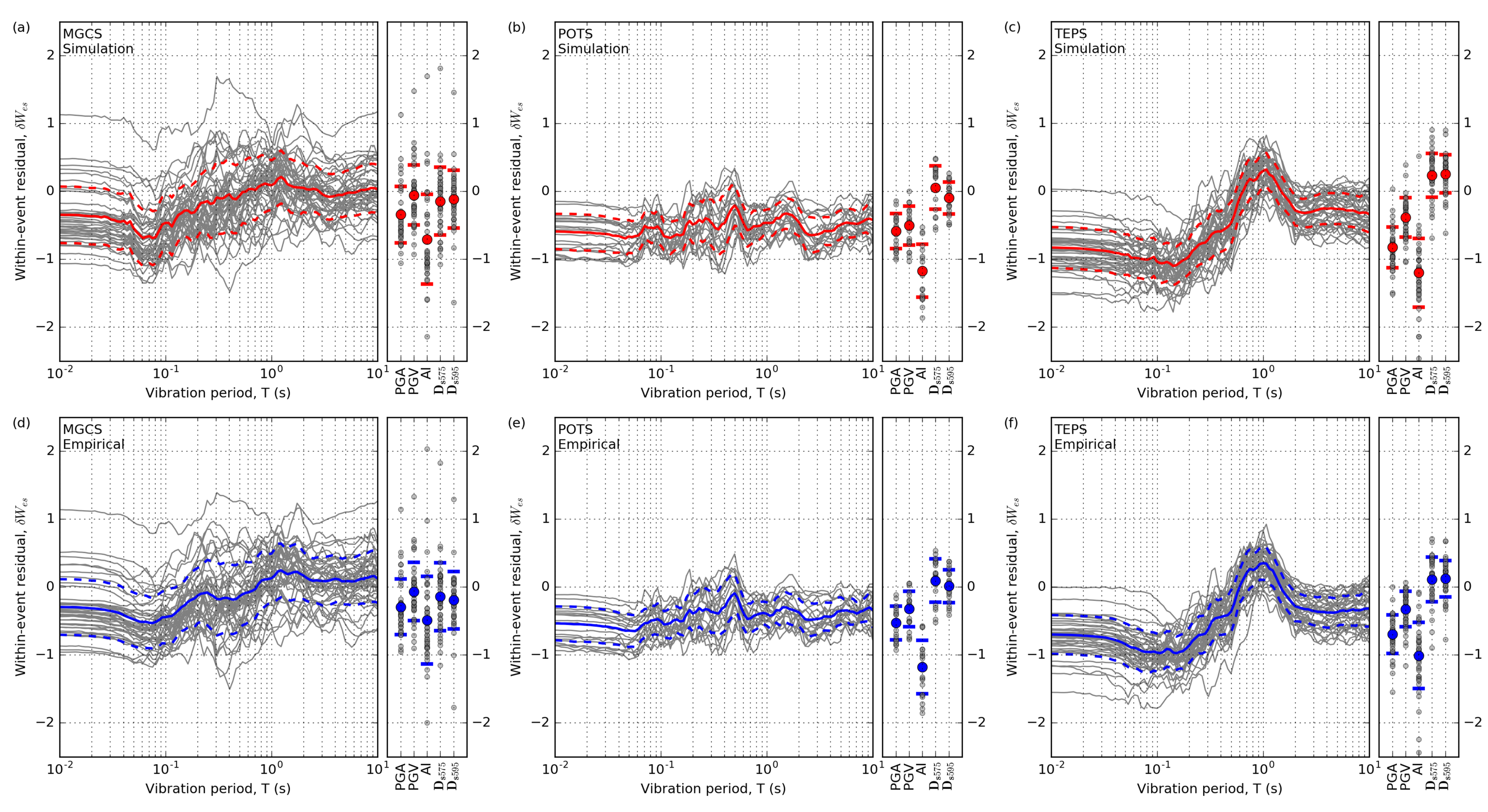

Figure 5: Within-event residuals for the: (a) simulated MGCS, (b) simulated POTS, (c) simulated TEPS, (d) empirical MGCS, (e) empirical POTS, and (f) empirical TEPS predictions.

4. Future Work

There are several items of work which follow on from the work conducted in this study in terms of improving the accuracy and precision of predictions, and furthering the validation effort:

- Run the simulations at a finer grid spacing (e.g. 0.1km) to capture smaller-scale features. The simulations in this study were run at 0.4km grid spacing to test the computational workflow.
- Add additional sedimentary basin models into the crustal velocity models.
- Include moderate magnitude earthquakes (e.g. M_w 5.0+) in the validation.
- Implement improvements to the simulation methodology and validate the improved versions.