QuakeCoRE
NZ Centre for Earthquake Resilience

Investigation of Systematic Ground Motion Effects Through Ground Motion Simulation of Small-to-Moderate Magnitude Earthquakes

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1. Background and Objectives

This poster presents results from ground motion simulations of small-to-moderate magnitude ($3.5 \leq M_w \leq 5.0$) earthquake events in the Canterbury, New Zealand region using the Graves and Pitarka (2010,2015) methodology. Subsequent investigation of systematic ground motion effects highlights the prediction bias in the simulations which are also benchmarked against empirical ground motion models (e.g. Bradley (2013)).

In this study, 144 earthquake ruptures, modelled as point sources, are considered with 1924 quality-assured ground motions recorded across 45 strong motion stations throughout the Canterbury region, as shown in Figure 1. The majority of sources are $M_w \geq 4.0$ and have centroid depth (CD) 10km or shallower. Earthquake source descriptions were obtained from the GeoNet New Zealand earthquake catalogue.

The ground motion simulations were performed within a computational domain of 140km x 120km x 46km with a finite difference grid spacing of 0.1km. The low-frequency (LF) simulations utilize the 3D Canterbury Velocity Model while the high-frequency (HF) simulations utilize a generic regional 1D velocity model. In the LF simulations, a minimum shear wave velocity of 500m/s is enforced, yielding a maximum frequency of 1.0Hz.

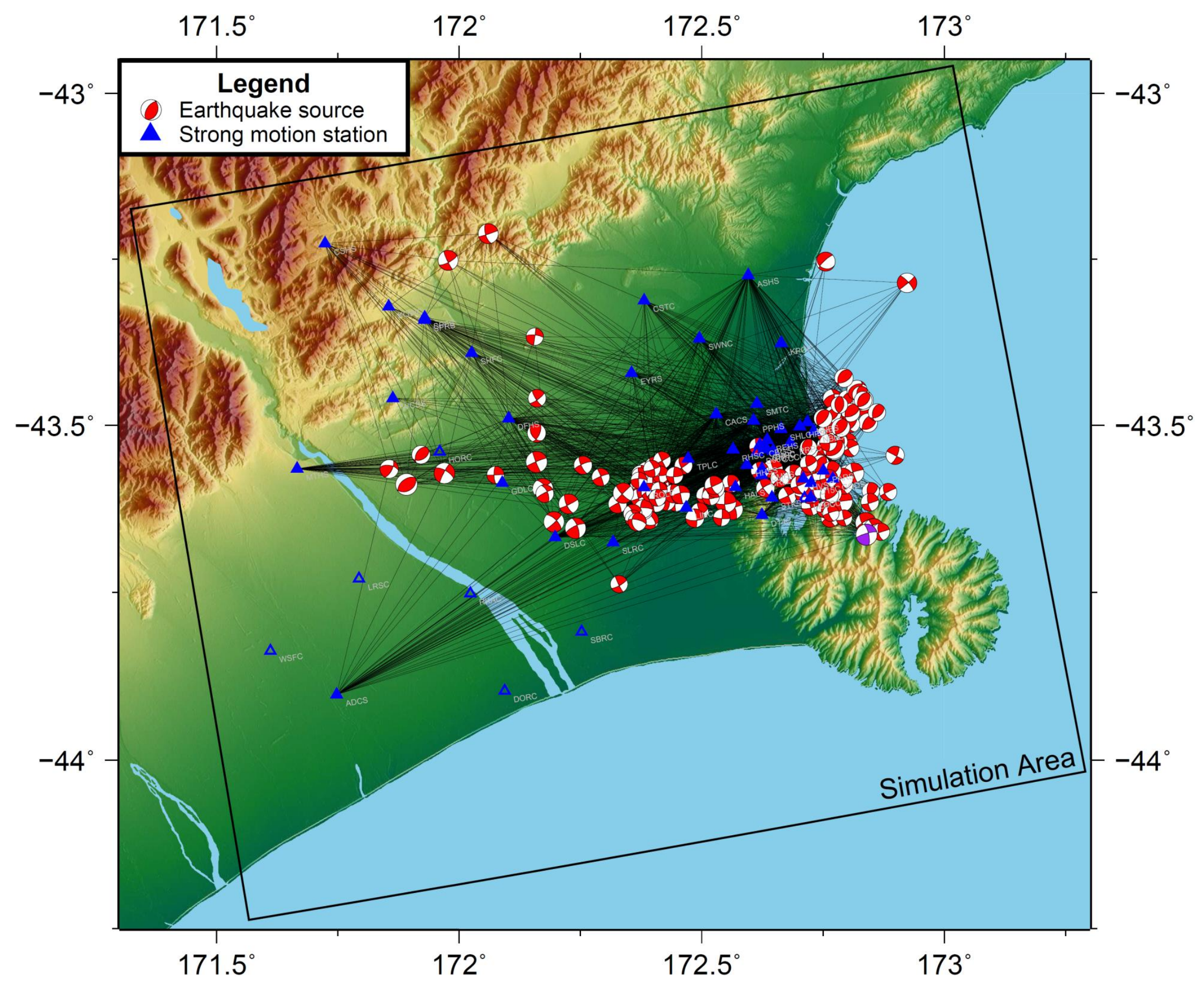

Figure 1: 144 earthquake sources, 53 strong motion stations (8 without any high-quality recordings), and their corresponding ray paths.

2. Representative Results for an Individual Event

Results from the 23rd December 2011 M_w 4.9 earthquake located CD=4km below Banks Peninsula (shown as the purple source in Figure 1) are presented here to highlight characteristics of the simulations and observations. Figure 2 provides a comparison of the observed and simulated velocity time series at 10 strong motion stations (grouped by location) and Figure 3 presents ground motion intensity measures as a function of source-to-site distance (R_{rup}), which illustrate that:

- Waveform amplitudes and arrival times appear visually to be well predicted. Additionally, rock sites are dominated by HF ground motions while Canterbury Plains sites have significant late-arriving basin waves.
- Both simulation and empirical models generally compare well with observed amplitudes for the PGA, pSA and Arias intensity. However, simulated significant durations, D_{s595}, are generally underpredicted due to the path duration model in the HF simulations not appropriately accounting for all factors which increase duration with R_{rup}.
- Between 20—50km, long period pSA (e.g. T=3.0s) is overpredicted and D_{s595} is better predicted due to overly strong basin waves.

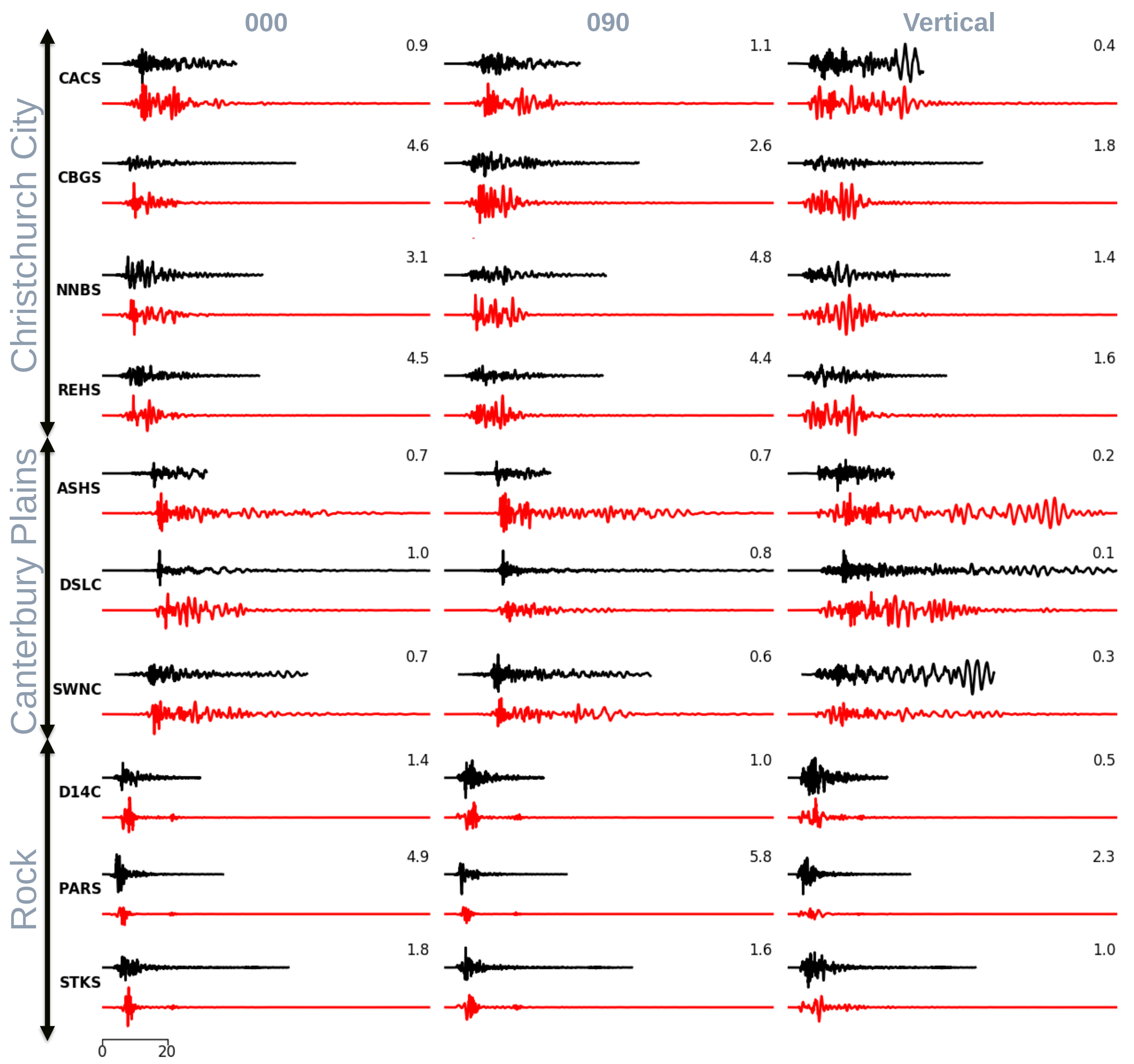

Figure 2: Observed (black) and simulated (red) broadband velocity time series. Maximum PGV are provided to the right of each waveform pair in cm/s.

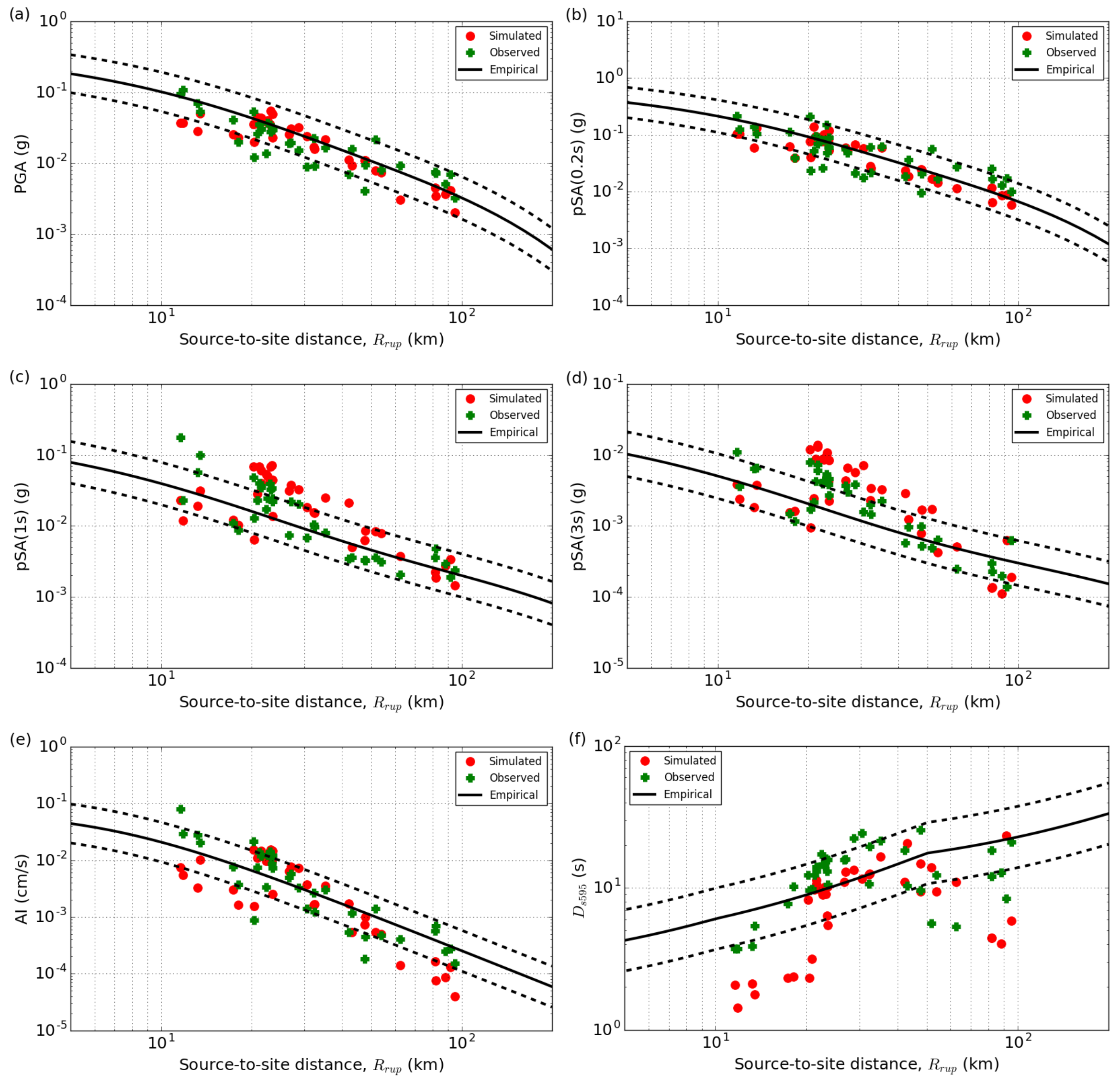

Figure 3: Observed, simulated and empirically predicted geometric mean ground motion intensity measures.

3. Observed Systematic Effects in Ground Motion Modelling

By considering all 144 earthquakes, systematic ground motion effects can be determined. Figures 4a and 4b present the computed pSA between-event residuals (δB_e) and systematic location-to-location residuals ($\delta L2L$) for simulated and empirical predictions, respectively:

- The simulation δL2L has negative bias at all periods considered. At short periods, this is due to the underprediction of path duration. At long periods, this is caused by overamplification via V_{s30}-based factors.
- The empirical δL2L suggests that the empirical GMM overpredicts at short periods, up to roughly T=0.3s, is practically unbiased between T=0.3—3.0s and increasingly underpredicts for T>3.0s.
- Although not shown, simulated Arias intensity was found to be unbiased.

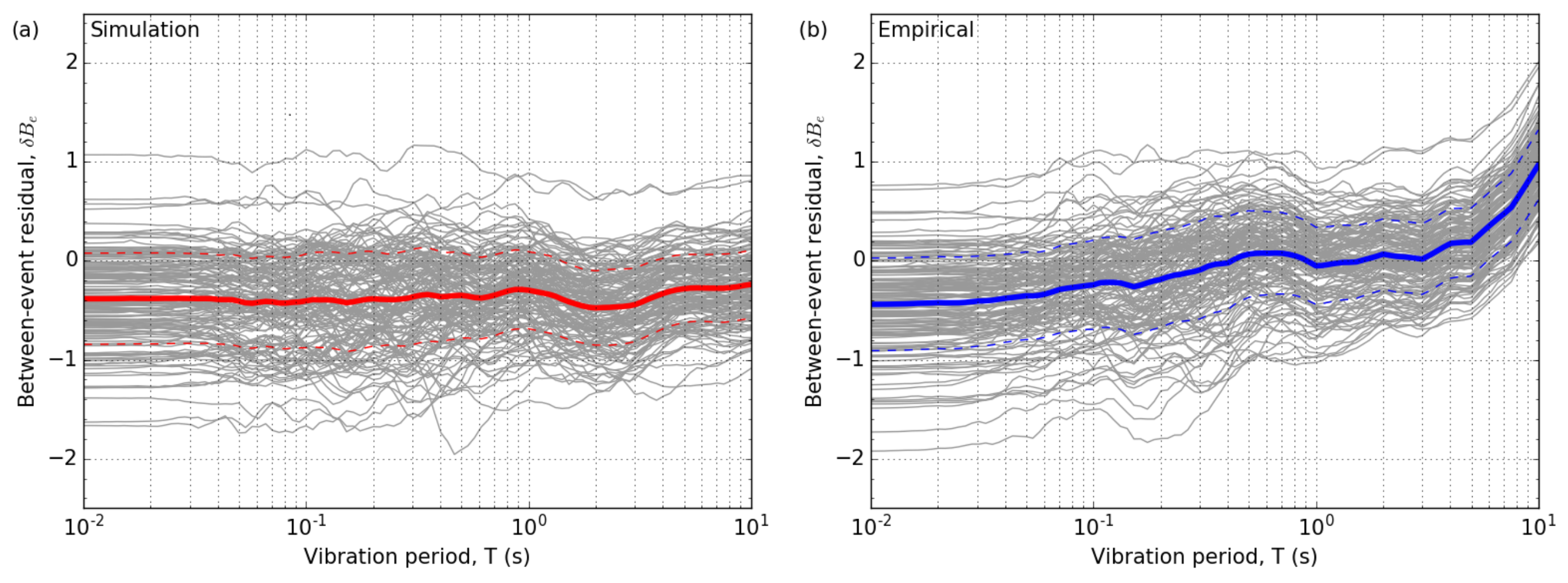

Figure 4: Computed between-event residuals for the 144 earthquakes: (a) simulated vs observed pSA; and (b) empirical vs observed pSA.

4. Location-specific Within-event Residuals

The systematic site-to-site residual ($\delta S2S_s$) values from the 45 strong motion stations can be plotted across the Canterbury region to assess its spatial variation. Figure 5 presents the spatial distribution of simulation $\delta S2S_s$ for PGA which identifies several trends:

- Rock sites are generally underpredicted at the Canterbury foothills and Banks Peninsula volcanics areas. This is caused by HF ground motion amplitudes being underpredicted as a result of the generic 1D velocity model not modelling the rock.
- The Christchurch city region can be separated into two areas, the western side which is overpredicted and the eastern site which is underpredicted. This segregation is primarily a result of the different surficial geology, gravels in the west and marine-fine sediments in the east.

Figures 6 presents the computed pSA within-event residuals (δW_{es}) and $\delta S2S_s$ for the simulated and empirical ground motion predictions at the D14C and CBGS sites which are located on the Banks Peninsula volcanics and in Christchurch city, respectively:

- For the D14C site, both simulated and empirical predictions, on average, are underpredicting at short periods with positive $\delta S2S_s$. For simulations, this is attributed to the generic 1D velocity model which is representative of a sedimentary basin profile.
- For the CBGS site, the period dependent variations at short vibration periods (T<1.0s) are a result of site-specific wave propagation effects caused by interbedded marine and gravel formations, and small-scale near-surface heterogeneities.

The $\delta S2S_s$ are relatively similar between simulation and empirical prediction as both consider site effects through V_{s30}-based amplification factors. The discrepancies between simulation and observation suggest explicit site response analysis is needed.

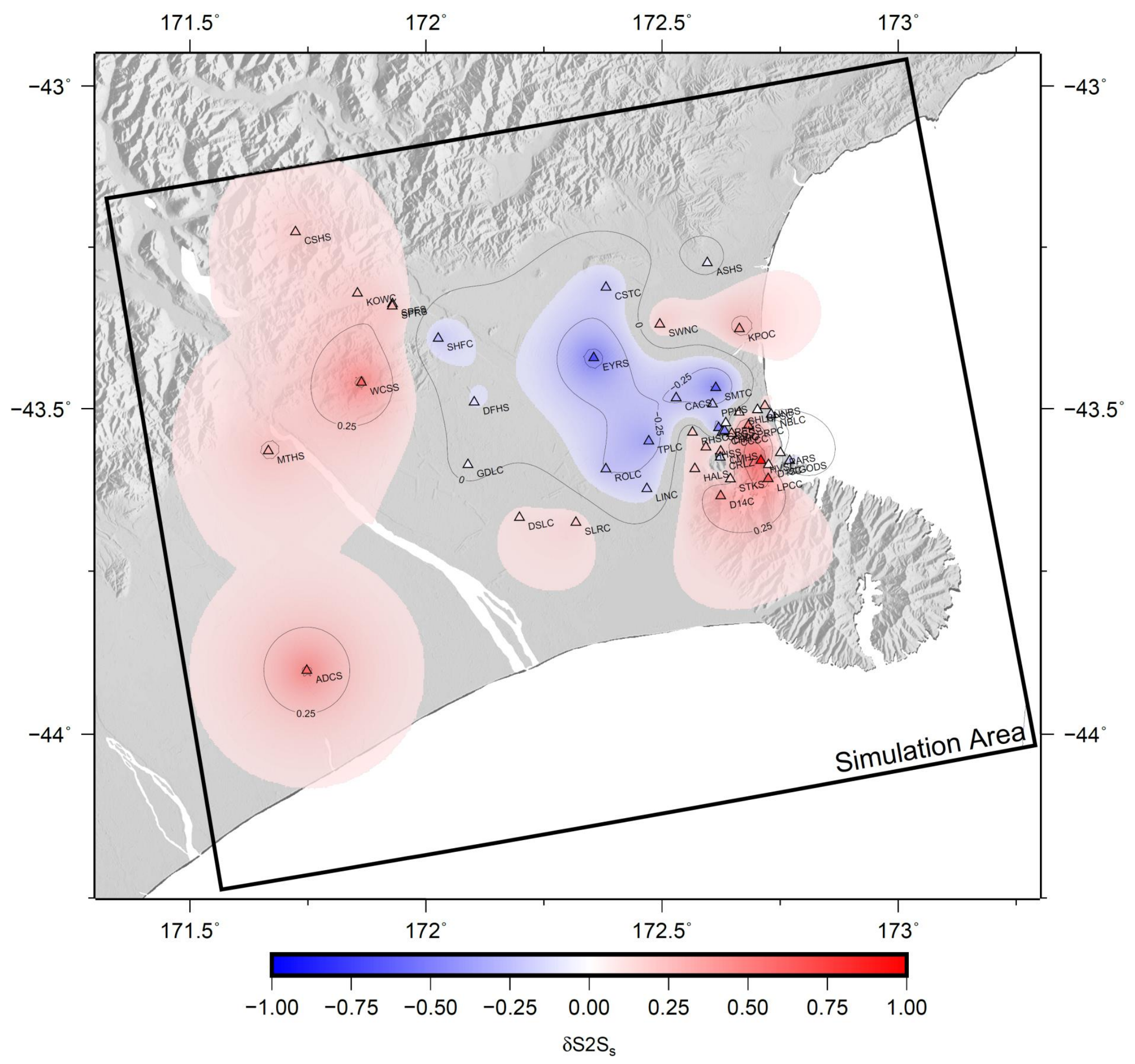

Figure 5: Spatial distribution of systematic site-to-site residuals for simulated PGA across the Canterbury region.

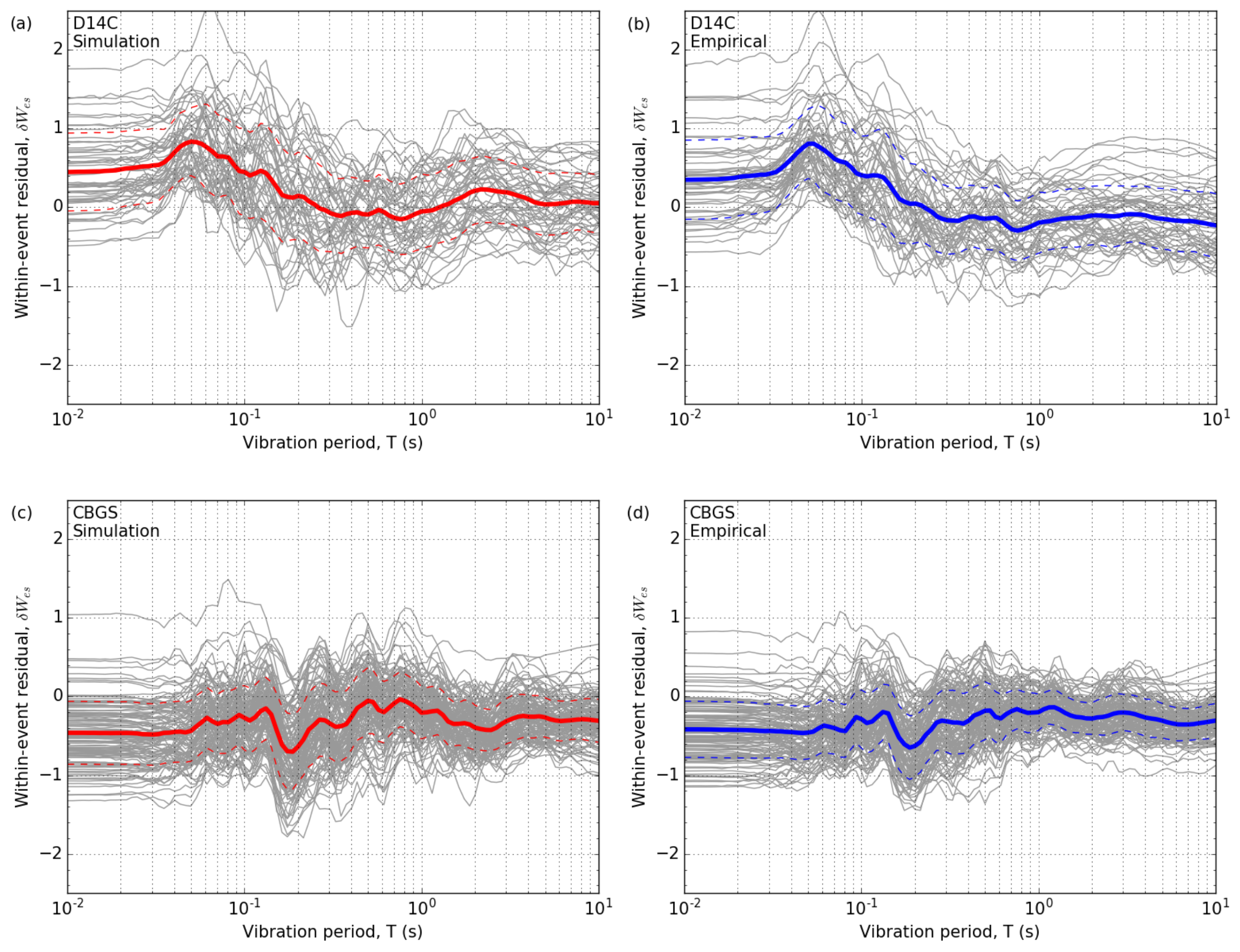

Figure 6: Computed pSA within-event residuals for the: (a) simulated D14C; (b) empirical D14C; (c) simulated CBGS; and (d) empirical CBGS predictions.