# Hybrid Broadband Ground Motion Simulation Validation for $M_w \geq 3.5$ New Zealand Earthquakes

QuakeCoRE NZ Centre for Earthquake Resilience

UC UNIVERSITY OF CANTERBURY Te Whare Wānanga o Waitaha CHRISTCHURCH NEW ZEALAND

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## 1. Background and Objectives

This poster presents a ground motion simulation validation study in New Zealand considering small magnitude earthquakes ($3.5 \leq M_w \leq 5.0$). 498 earthquakes were modelled as point sources with 5350 ground motion recordings across 293 stations, shown in Figure 1. This study utilized a 'Modified' Graves and Pitarka (2010,2015) hybrid broadband ground motion simulation methodology but also compares results with the 'Standard' simulation methodology without modifications. The Modified methodology employs the Boore and Thomson (2014) high frequency (HF) path duration model and does not apply empirical $V_{s30}$-based site amplification to the low frequency (LF) component of the simulation, based on work by Lee et al. (2019).

The LF component of the Standard simulations uses a benchmark version of the unified New Zealand Velocity Model (NZVM) while the Modified simulations use an updated NZVM with seven new basins in addition to the existing Canterbury basin model, as shown in Figure 1. The HF component of the simulations use a generic 1D velocity model (which has no explicit region-specific basin models). The LF simulations are run with a finite difference grid spacing of 100m with a minimum shear wave velocity of 500m/s, yielding a maximum frequency of 1.0Hz. Measured $V_{s30}$ values are used where available for HF empirical site amplification, otherwise values are taken from the Foster et al. (2019) national $V_{s30}$ model.

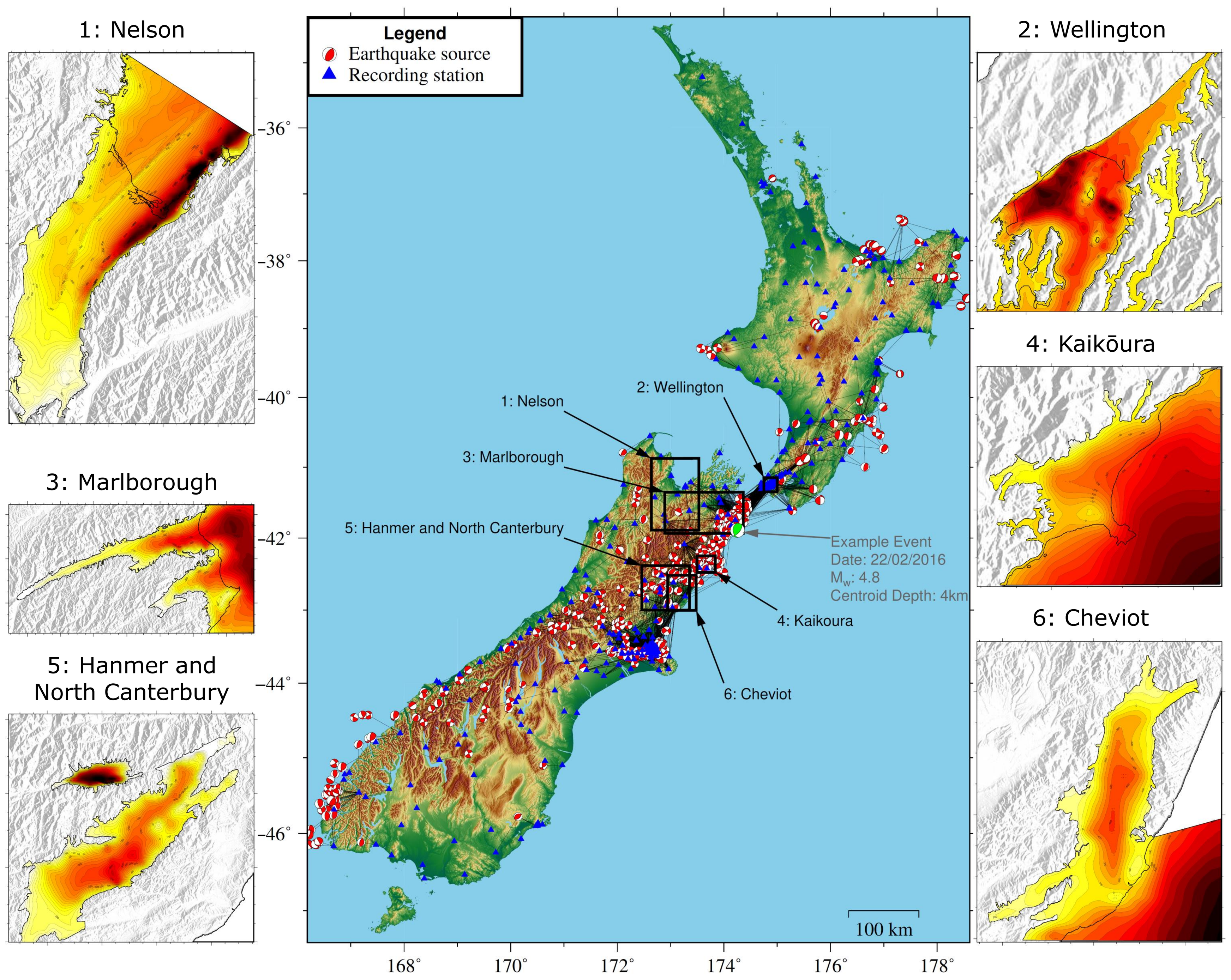


**Figure 1: Map of New Zealand highlighting the 496 earthquake events, 293 recording stations and observed ground motion ray paths. Top of Basement rock elevation contour maps of the new sedimentary basins are also shown.**

## 2. Simulated Ground Motions

To highlight the effect of methodological modifications and improvements to crustal velocity modelling, waveforms from an example event (location shown in Figure 1) are shown here. Waveforms from the Standard and Modified simulation methodologies are presented in red and blue, respectively, alongside corresponding observed waveforms in black. Stations LHUS, WEMS and TEPS are located in the Wellington Basin while SEDS is located in the Marlborough Basin.

- Modified simulations have longer duration of HF motion than Standard simulations and more strongly resemble the observed waveforms. PGV (and peak acceleration intensity measures) are also lower and more comparable to observed values.
- Standard simulations show excessively large LF amplitudes throughout the records when compared to observed ground motions. Modified simulations reduce these amplitudes and are more conforming with observations.
- Modified simulations have long period basin-generated waves as a result of the recently-developed sedimentary basins which were not present in the Standard simulations which used a benchmark NZVM version. Basin waves are particularly prevalent at the SEDS site.

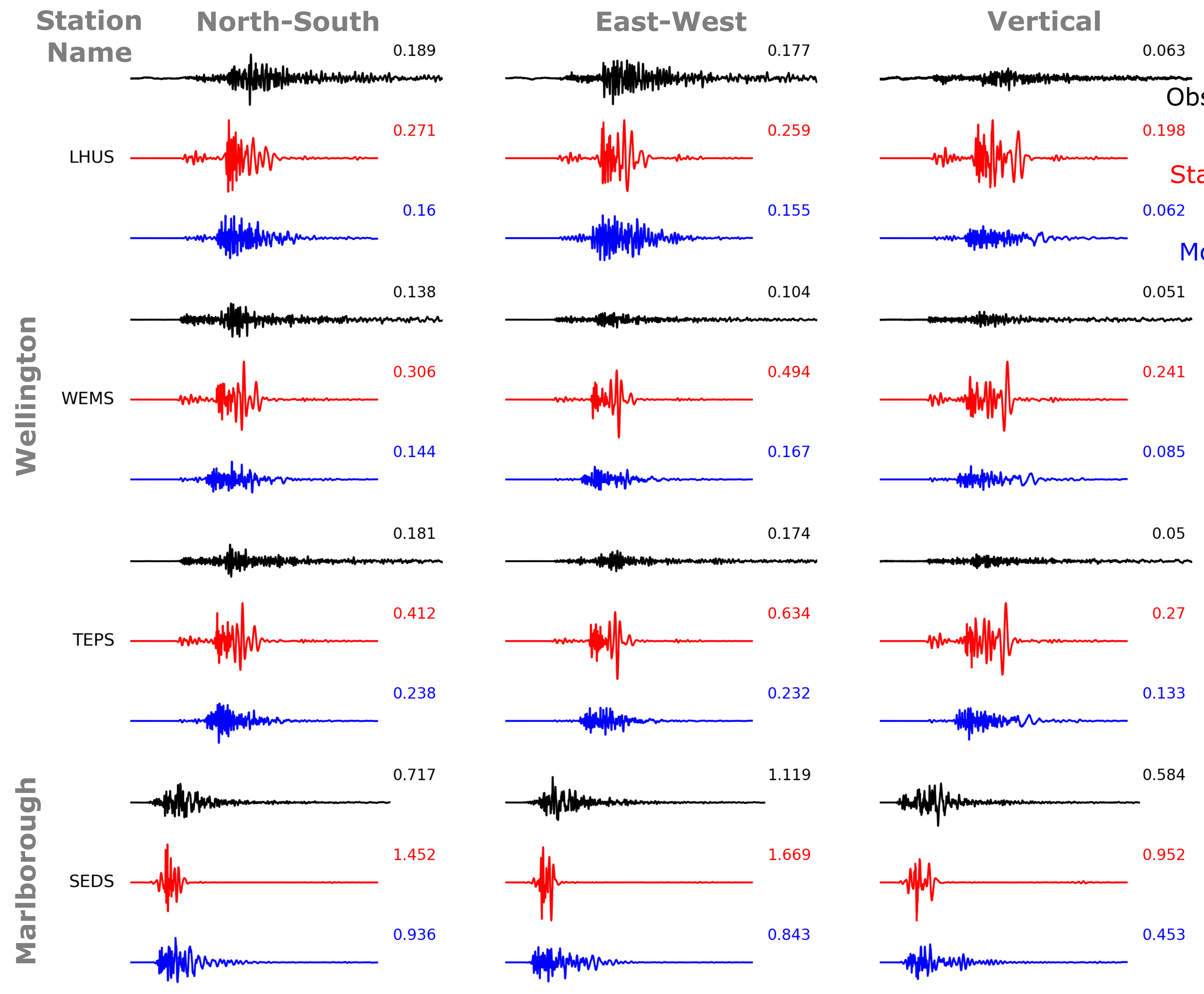


**Figure 2: Observed (black), Standard simulation (red) and Modified simulation (blue) broadband velocity waveforms. PGV are provided to the right of each waveform in cm/s.**

## 3. Systematic Effects in Ground Motion Modelling

A quantitative analysis of systematic effects was carried out using a mixed-effects framework on ground motion intensity measure residuals considering all records across all earthquakes. Figure 3 presents the model prediction bias and total standard deviation. The modified simulation methodology can be seen to reduce bias for spectral accelerations across all vibration periods, PGA, PGV and significant durations. All subsequent analysis considers only the Modified simulation methodology.

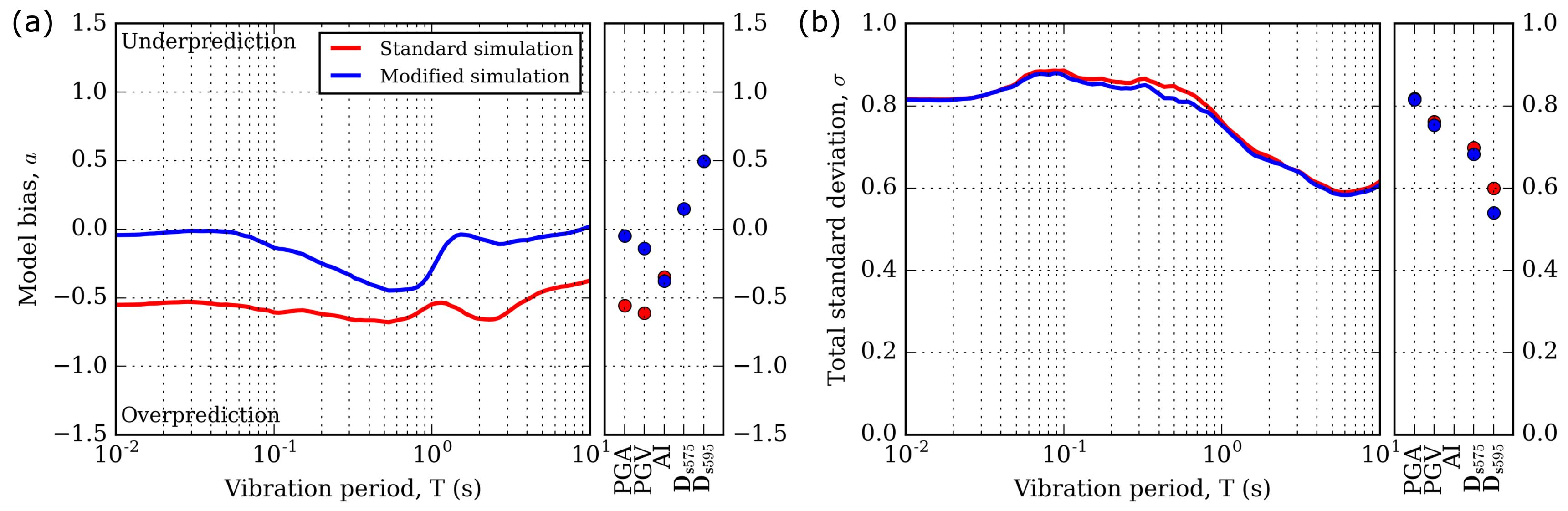


**Figure 3: Simulation (a) model prediction bias, and (b) total standard deviation.**

The between-event residuals ($\delta B_e$) of each earthquake were investigated to determine systematic effects associated with source modelling.

- Figure 4 presents the PGA $\delta B_e$ for all simulated earthquakes using the Modified methodology. Spatial variations in $\delta B_e$ exist throughout New Zealand with some local trends.
- A constant Brune stress parameter of 50 bars was used for all ruptures, which is inferred to be the primary cause of the variability of $\delta B_e$ as the ruptures are modelled as point sources.
- Several studies (e.g. Kaiser and Oth, 2014, and Ren et al. 2018) calculated inferred stress drop using spectral inversion. The inferred values were found to be correlated with $\delta B_e$ from this study.
- Therefore we can form a distribution of stress drop conditional on $\delta B_e$ which can subsequently be used to develop a spatially varying coefficient model which can be used to improve the accuracy and precision of the simulations.

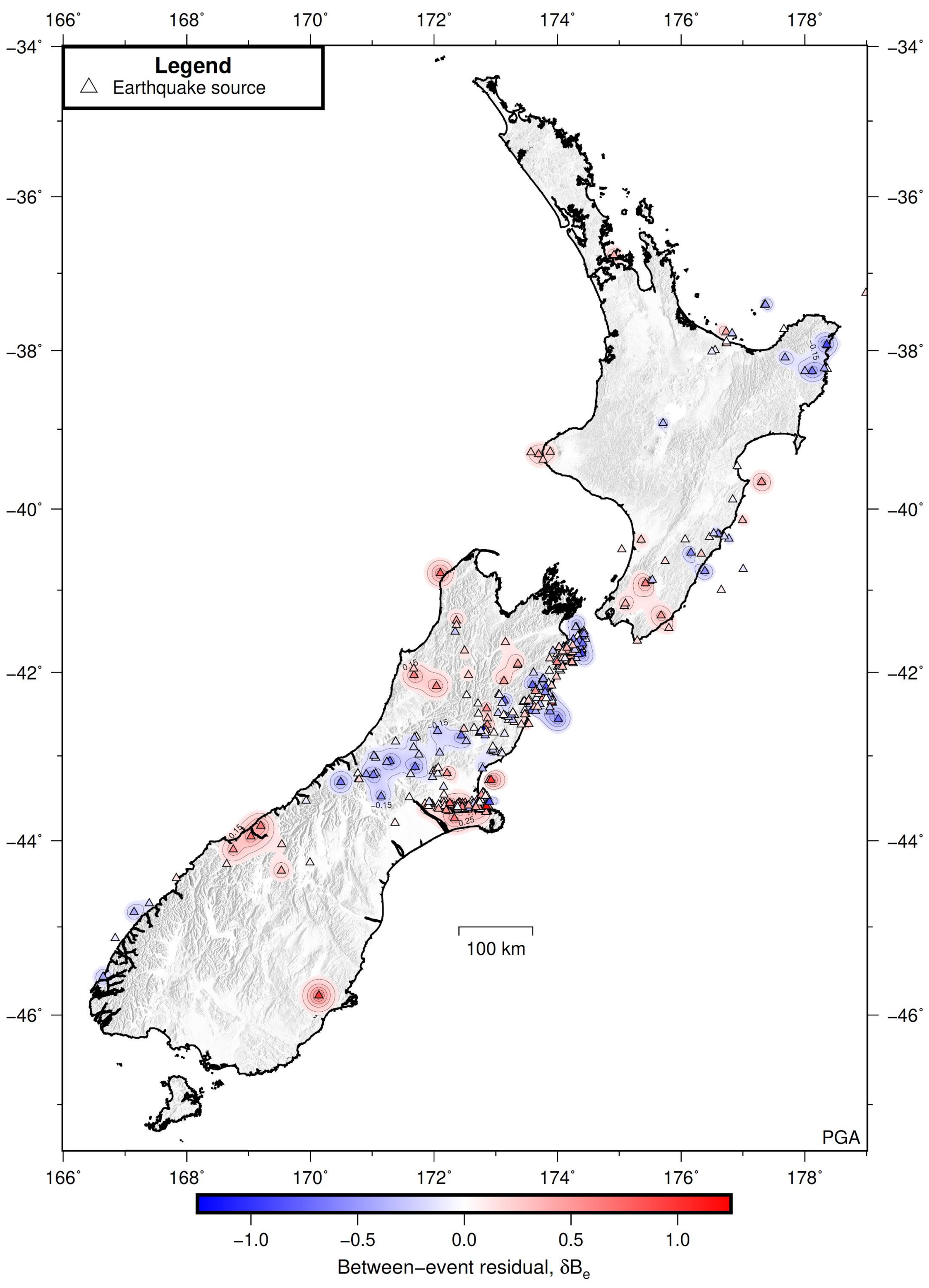


**Figure 4: Spatial variation of $\delta B_e$ for PGA across New Zealand using the Modified methodology.**

An investigation of systematic site-to-site residuals ($\delta S2S_s$) for each station has identified subsets of sites which appear to systematically exhibit bias. Figure 5 presents biases associated with four subsets highlighted by comparing the global model prediction bias (as shown in Figure 3) in blue, the global bias plus the specific station's $\delta S2S_s$ in grey, and the subset bias in black (taken as the average of the grey lines).

- Figure 5a: Several sites located on stiff gravel deposits appear to have been assigned $V_{s30}$ values which are relatively low and therefore have been overamplified by the empirical $V_{s30}$-based amplification factor. The inverted triangular shape of the overprediction between 0.1-1.5s is indicative of overamplification from the empirical $V_{s30}$-based site amplification applied to the HF simulation component.
- Figure 5b: Several sites located on stiff rock appear to have been assigned Vs30 values which are more characteristic of a soil site and therefore have also been overamplified by the empirical Vs30-based amplification factor.
- Figure 5c: Numerous sites with shallow soil overlying stiff rock also exhibit systematic bias as the resolution of the simulations cannot adequately capture the shallow impedance contrast which causes large HF amplitudes, and therefore underprediction at short periods.
- Figure 5d: Many sites located in sedimentary basins which are not modelled in the crustal velocity models were also found to be underpredicted at longer periods (i.e. 1-4s) corresponding to the profiles of the sedimentary basins.

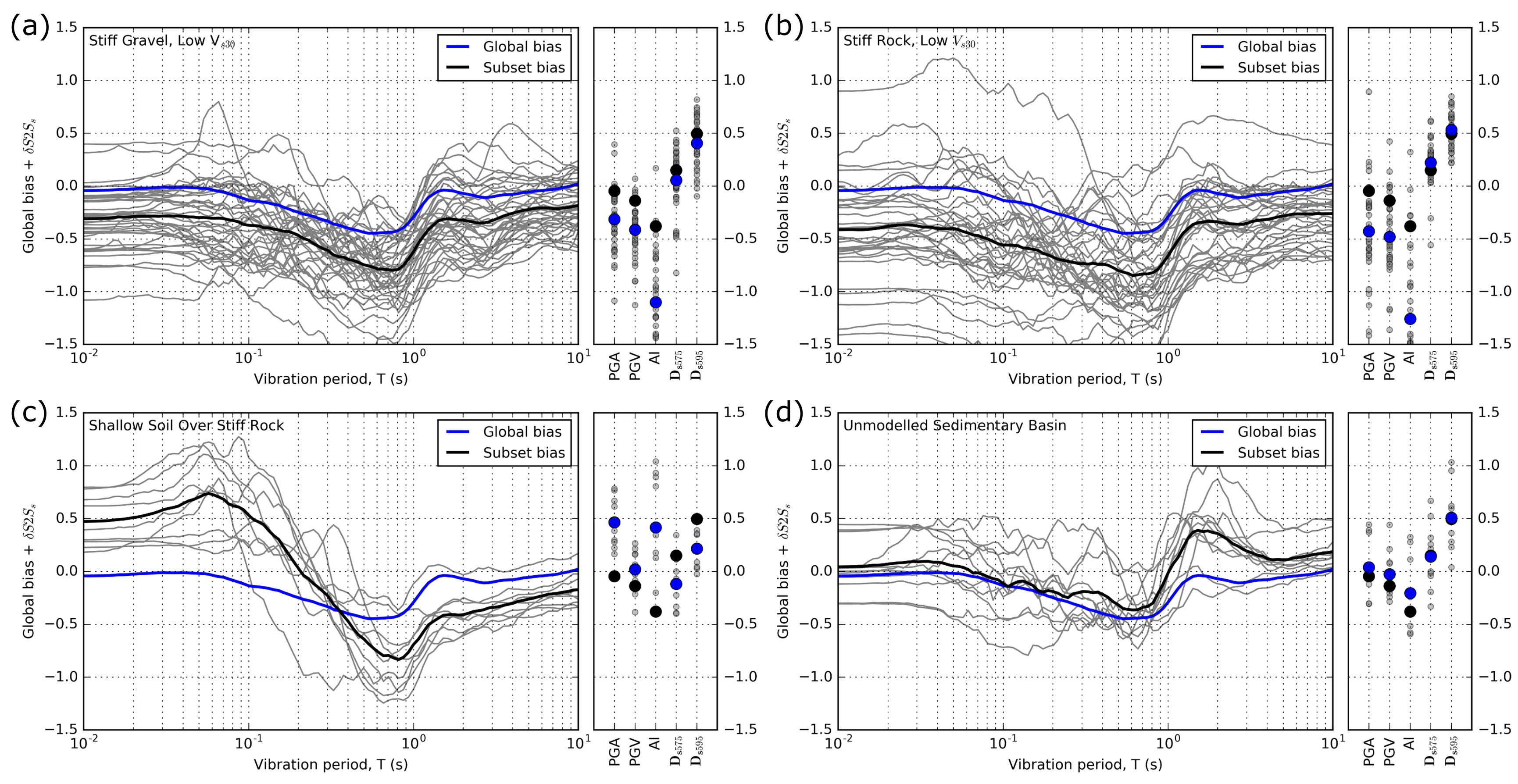


**Figure 5: Global bias and subset bias for (a) stiff soil, low $V_{s30}$ sites, (b) stiff rock, low $V_{s30}$ sites, (c) shallow soil overlying stiff rock sites, and (d) unmodelled sedimentary basin sites.**