Investigation of systematic ground motion effects through hybrid broadband simulation of 144 small-to-moderate magnitude earthquakes

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Overall aim

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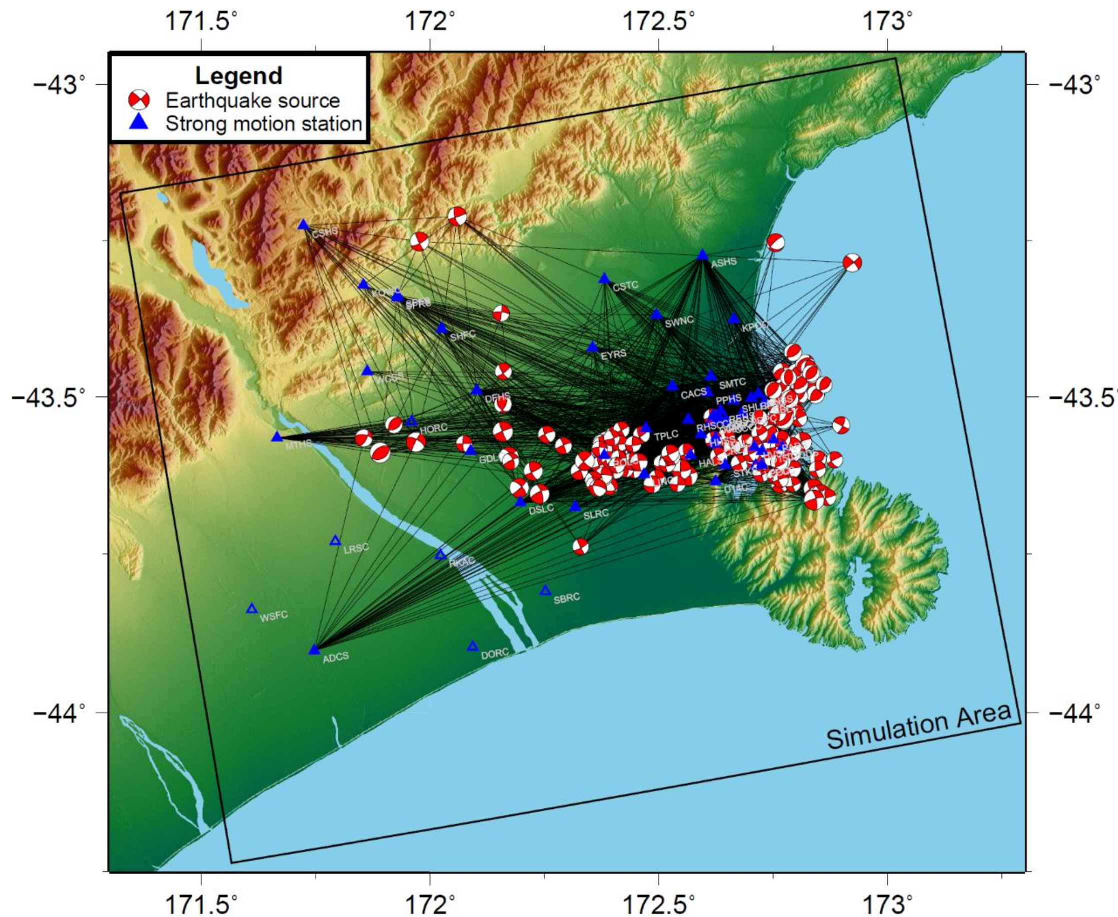
- Identify systematic biases in Graves and Pitarka (2010,2015) hybrid broadband ground motion simulation methodology.
- Also benchmark simulation against empirical ground motion models, GMMs (e.g. Bradley 2013, Afshari and Stewart 2016, Campbell and Bozorgnia 2012).

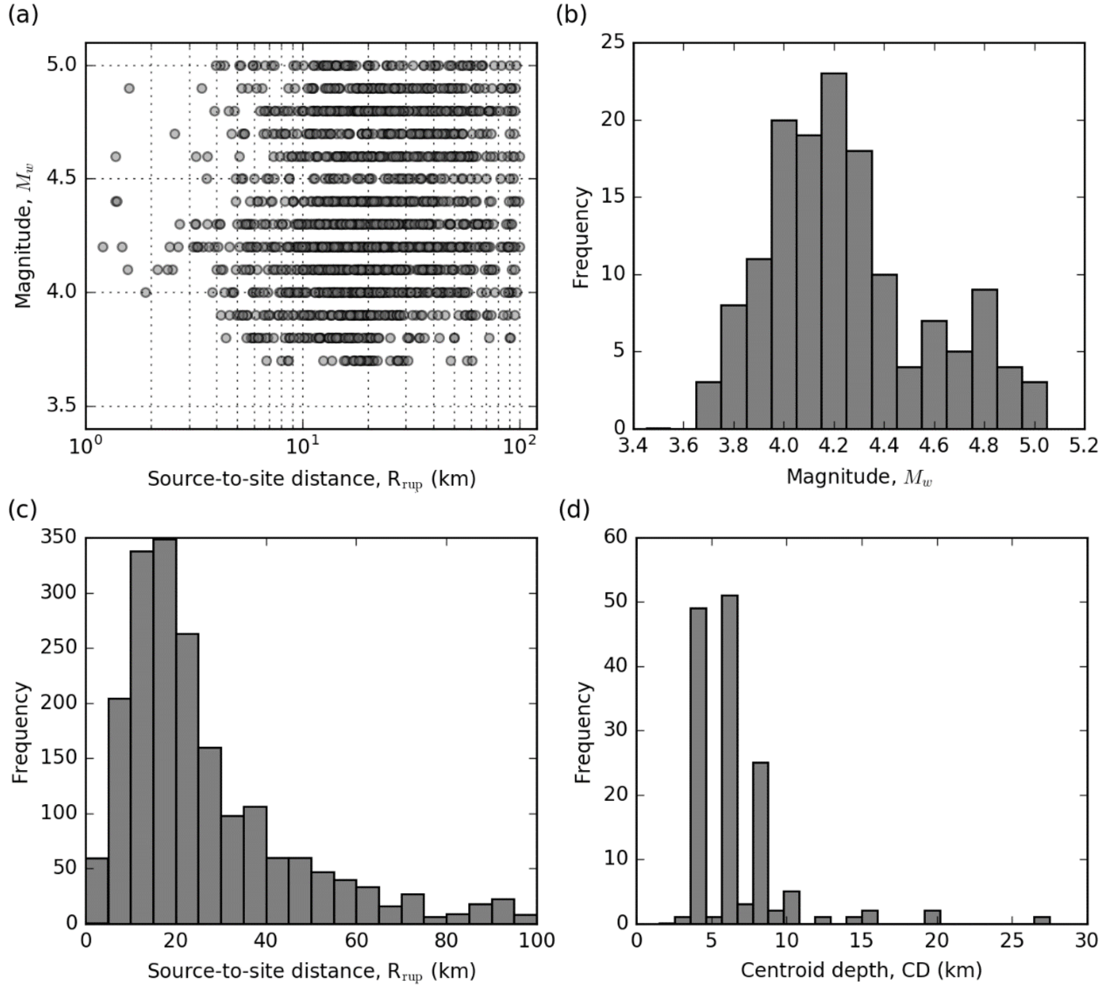
Earthquakes and SMS considered

- 144 earthquakes with 3.5 < Mw ≤ 5.0 from GeoNet EQ catalogue.
- 1924 “high-quality” ground motions recorded across 45 strong motion stations.



Source and station distributions

- Good coverage across magnitudes and distances.



Broadband ground motion simulation methodology

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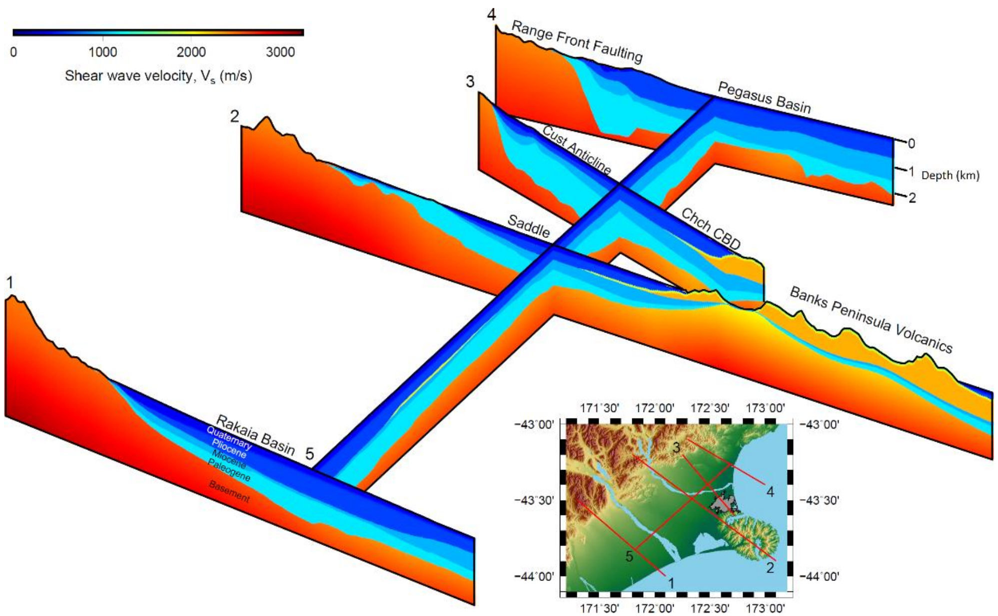
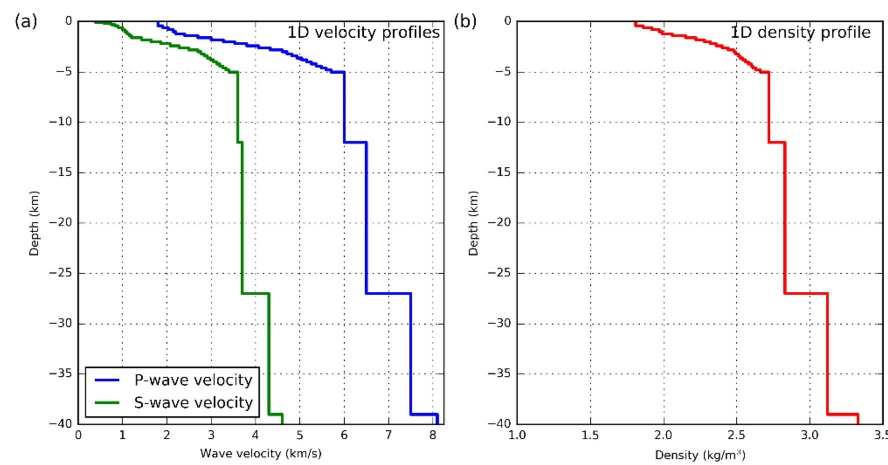
- Graves and Pitarka (2010,2015) hybrid approach.
- Low-frequency component from comprehensive physics-based wave propagation.
- High-frequency component from simplified physics-based wave propagation.
- Period-dependent empirical V_{s30}-based site amplification.

Seismic velocity models

- 3D Canterbury velocity model for LF.

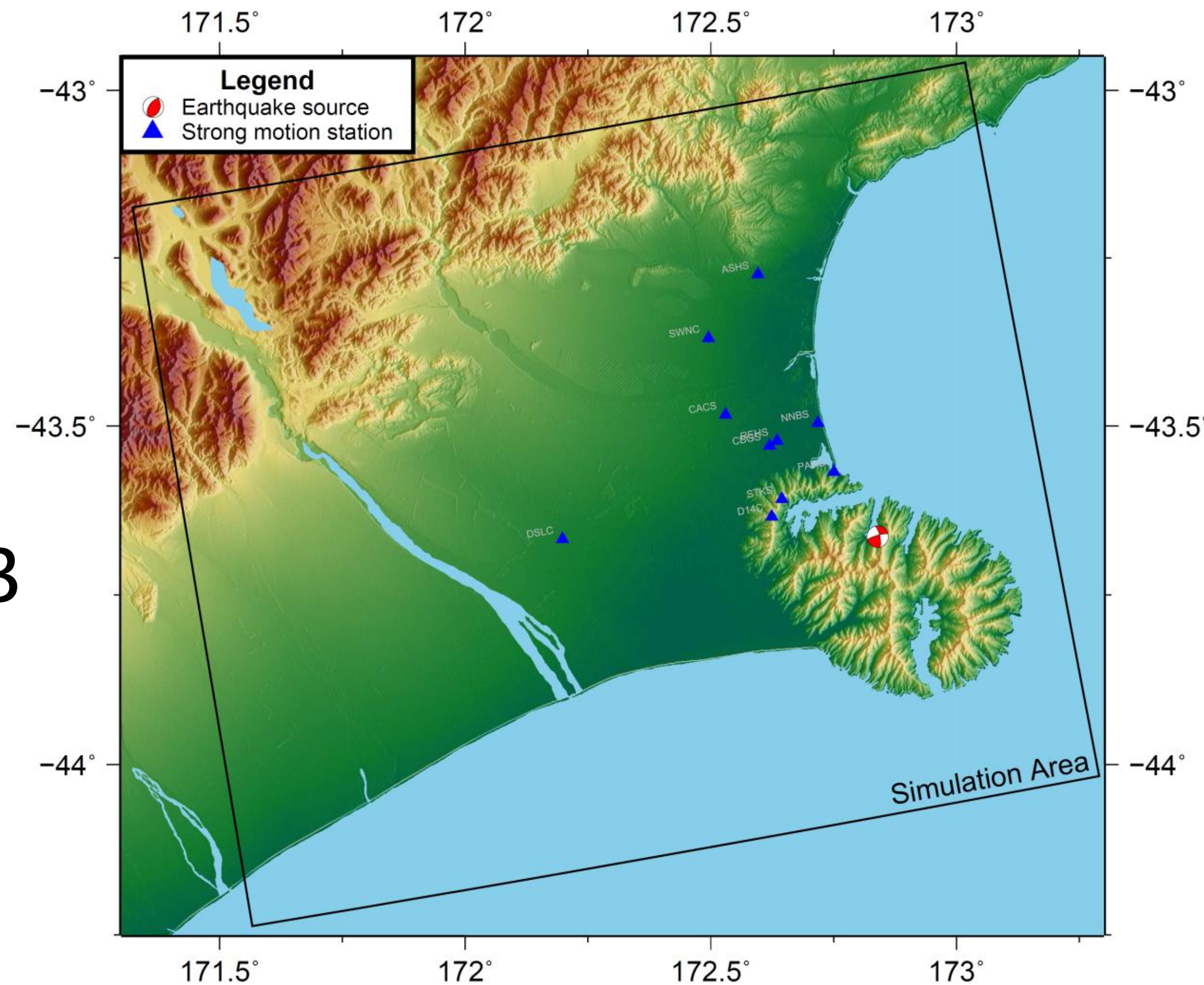


- 1D velocity model for HF.

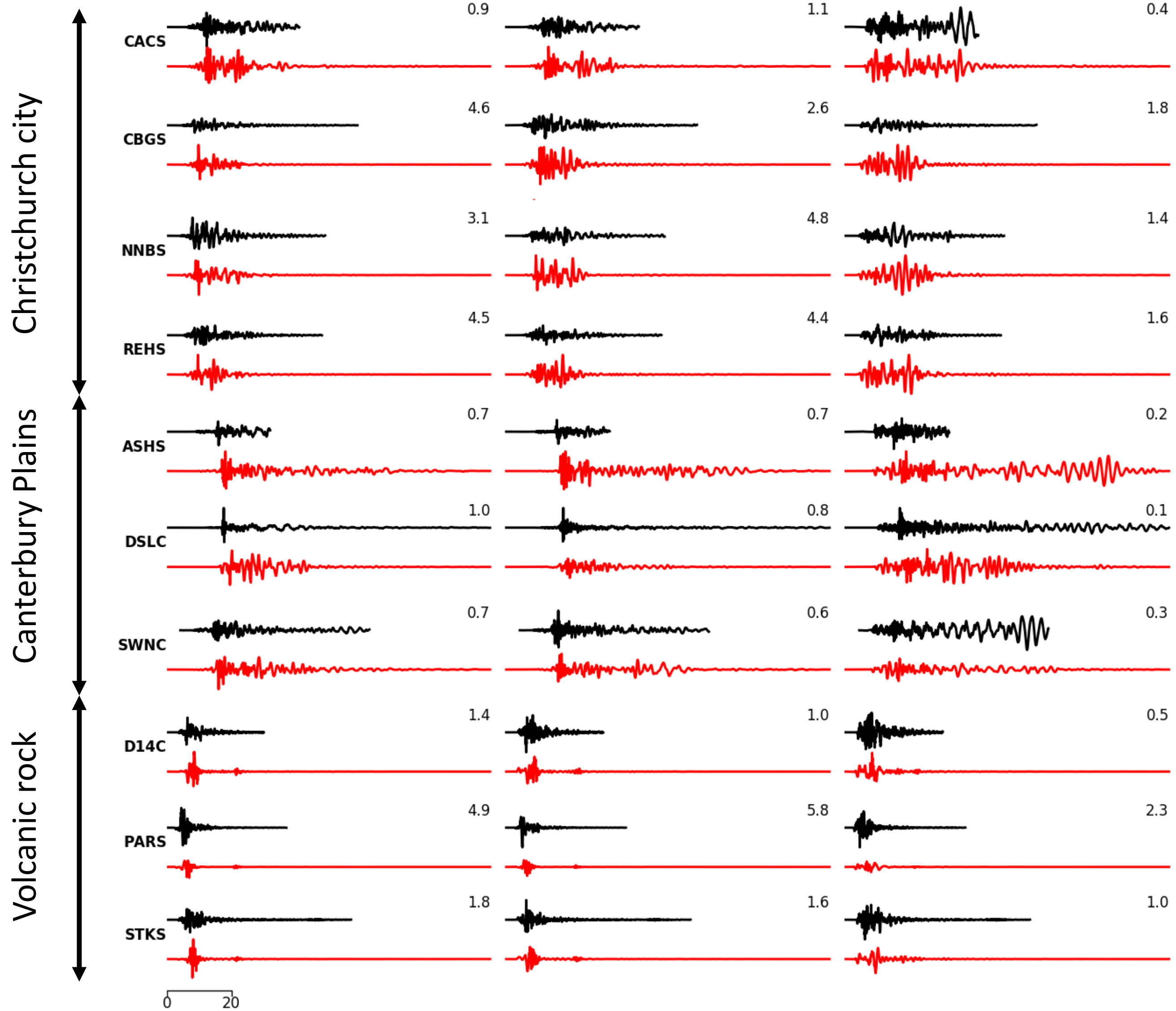


Individual earthquake results

- Mw 4.9 earthquake located 4km under Banks Peninsula.
- Recorded at 43 strong motion stations, 10 shown here.



Individual earthquake results - waveforms



Intensity measure scaling with source-to-site distance

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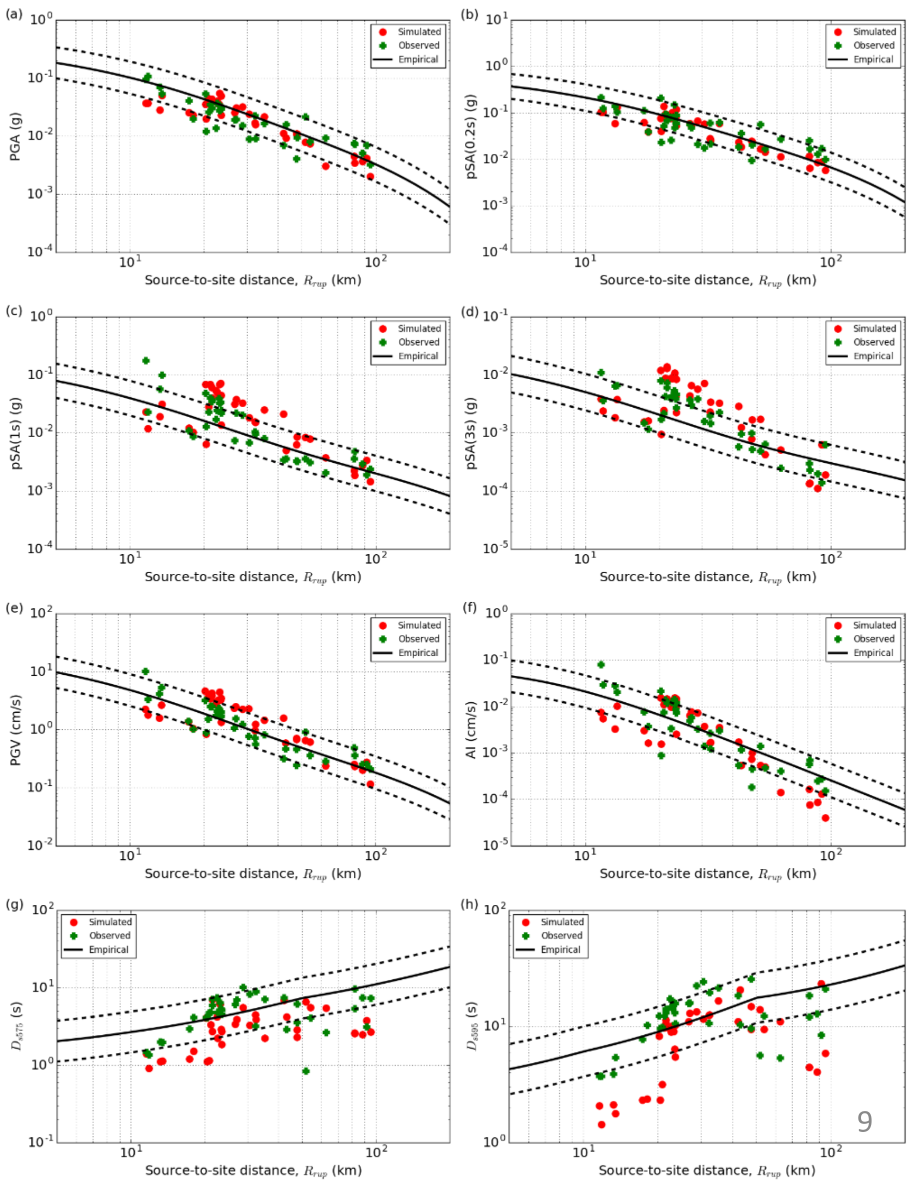
- Acceleration IMs generally well predicted.
- Exception is pSA(3.0s) when there are overly strong basin waves.
- Durations largely underpredicted.
- Exception is when duration is governed by basin waves.



Non-ergodic framework

- General form of a ground motion model for event *e* and station *s:*

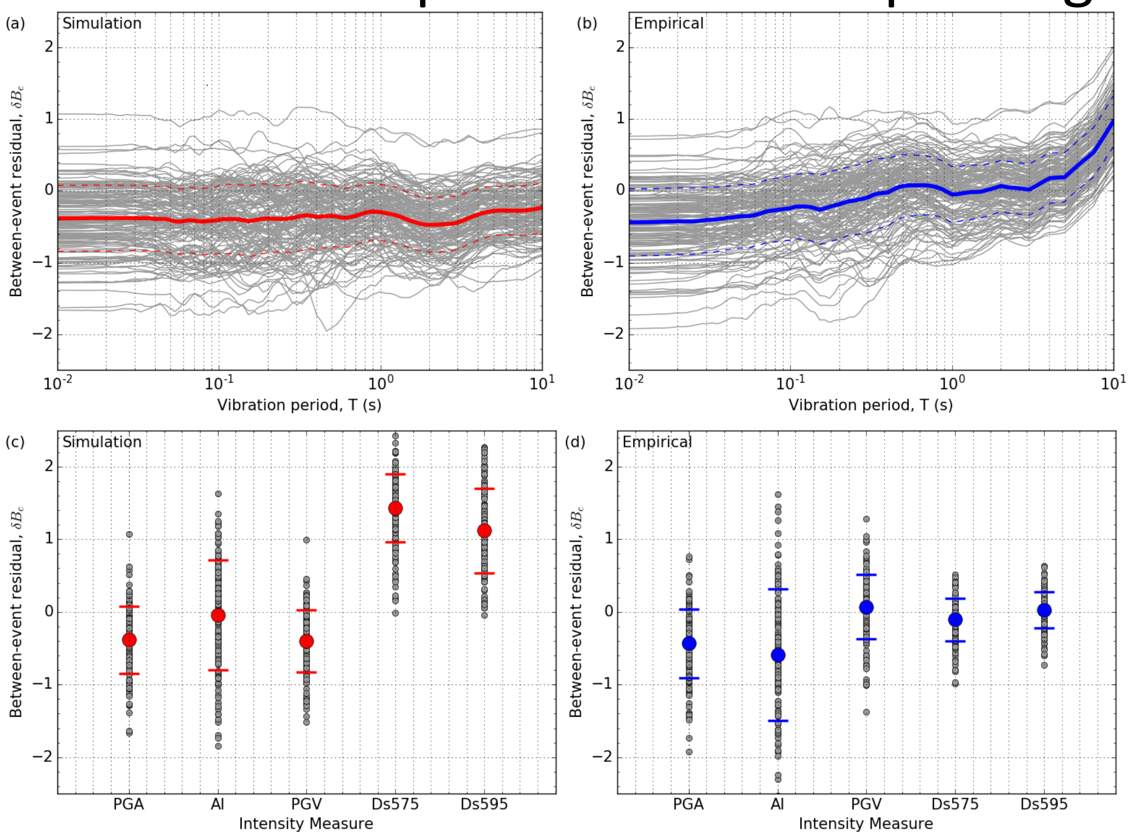
$$\ln IM_{es} = f_{es} + \delta B_e + \delta W_{es}$$

- where δB_e is the between-event residual and δW_{es} is the within-event residual.
- And the systematic site-to-site residual is defined as:

$$\delta S2S_s = \frac{1}{NE_s} \sum_{e=1}^{NE_s} \delta W_{es}$$

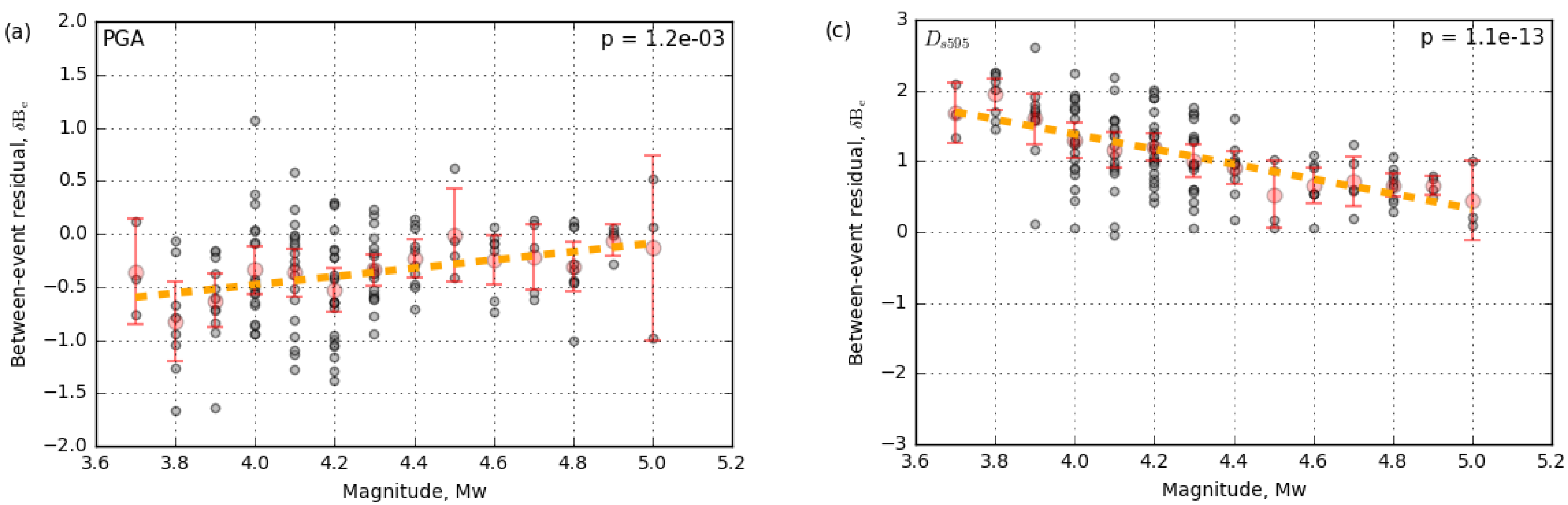
Between-event Residuals

- Simulation tends to overpredict at all periods.
- Bradley (2013) empirical GMM overpredicts at short periods and underpredicts at long periods.
- Simulated durations underpredicted but empirical good.



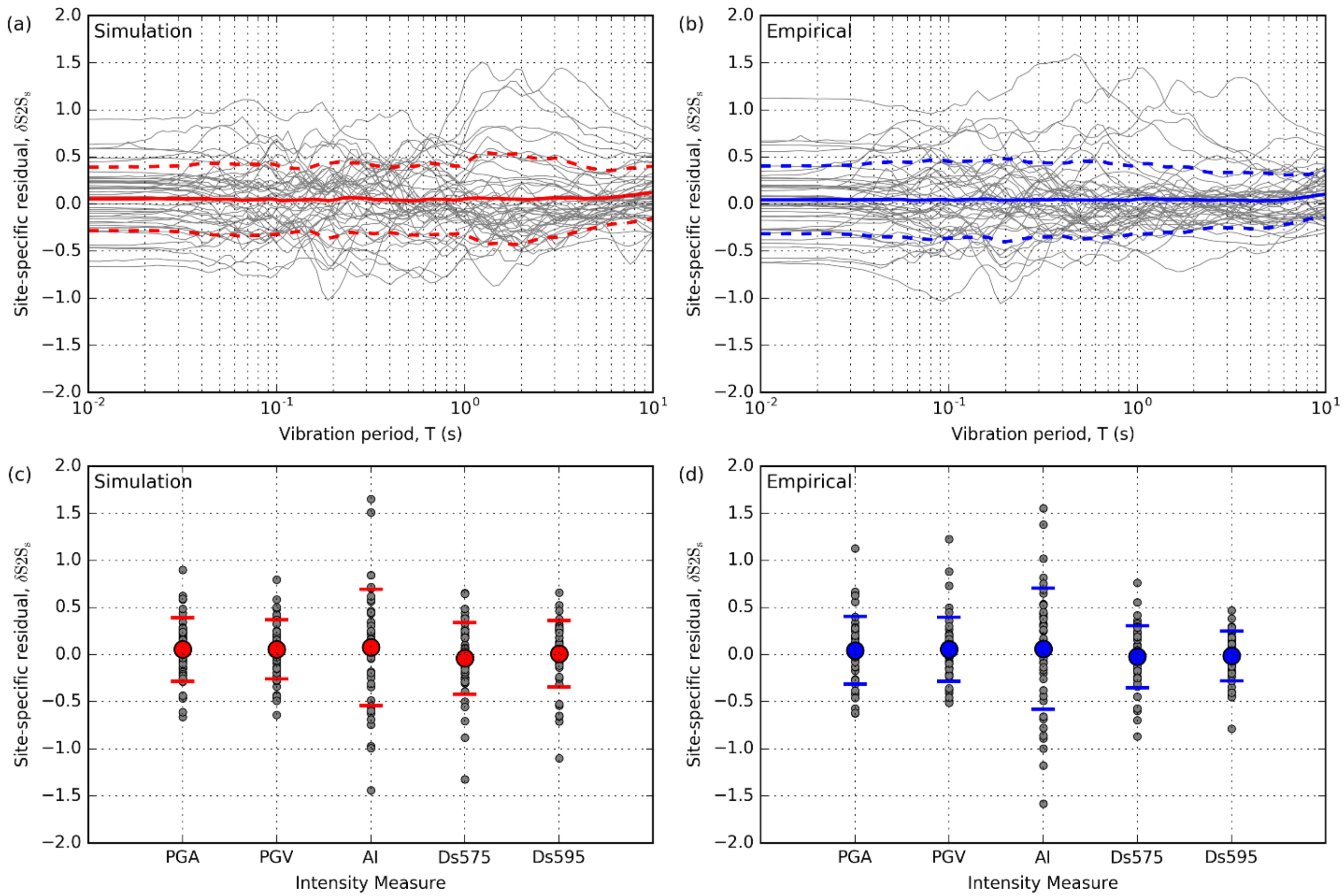
Comparison with Predictor Variables

- δB_e and magnitude have a positive trend for PGA but a negative trend for D_{s595}
- A result of path duration, which has less influence as the source duration increases with increasing magnitude.



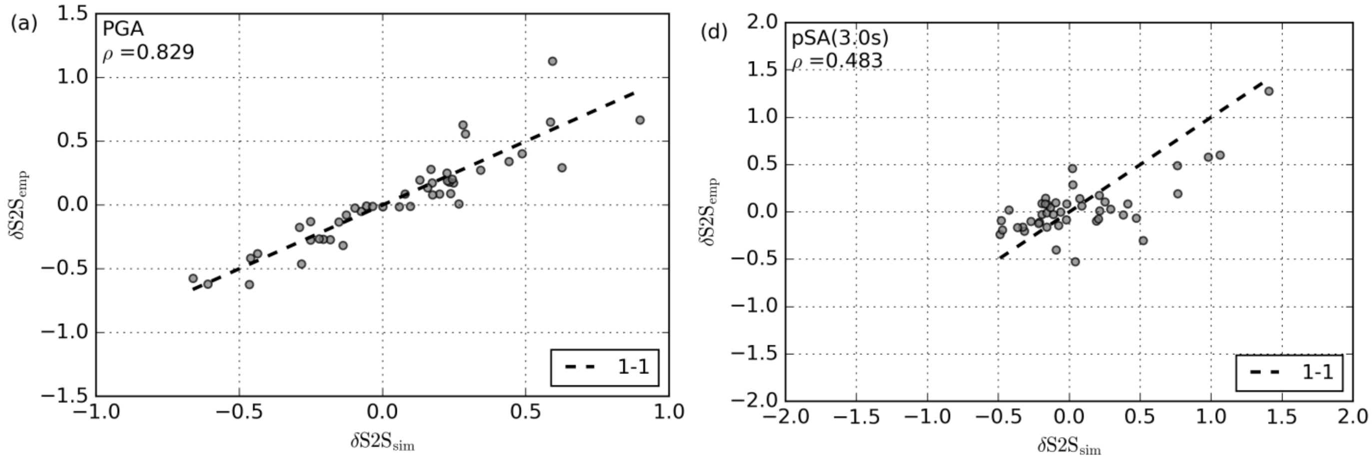
Within-event Residual

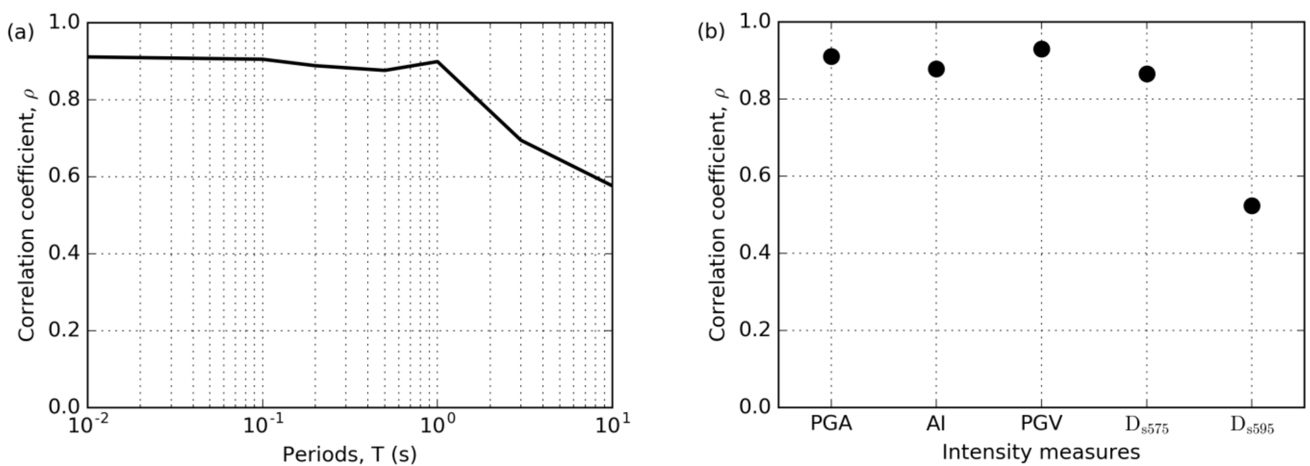
- Systematic site-to-site residual essentially zero.
- Significant variability from systematic site effects.



Within-event Residual

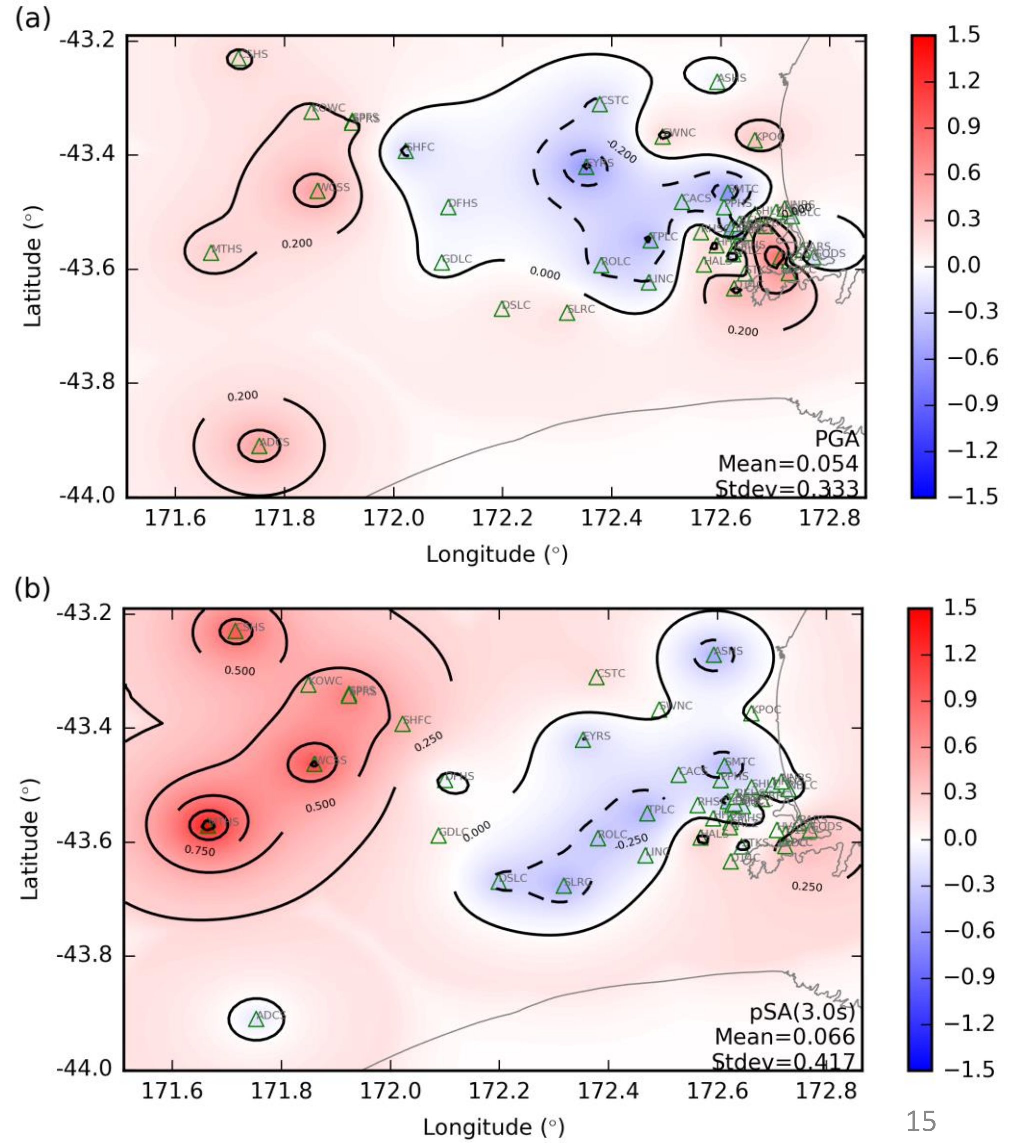
- Similar between simulation and empirical because both consider site amplification through V_{s30}.





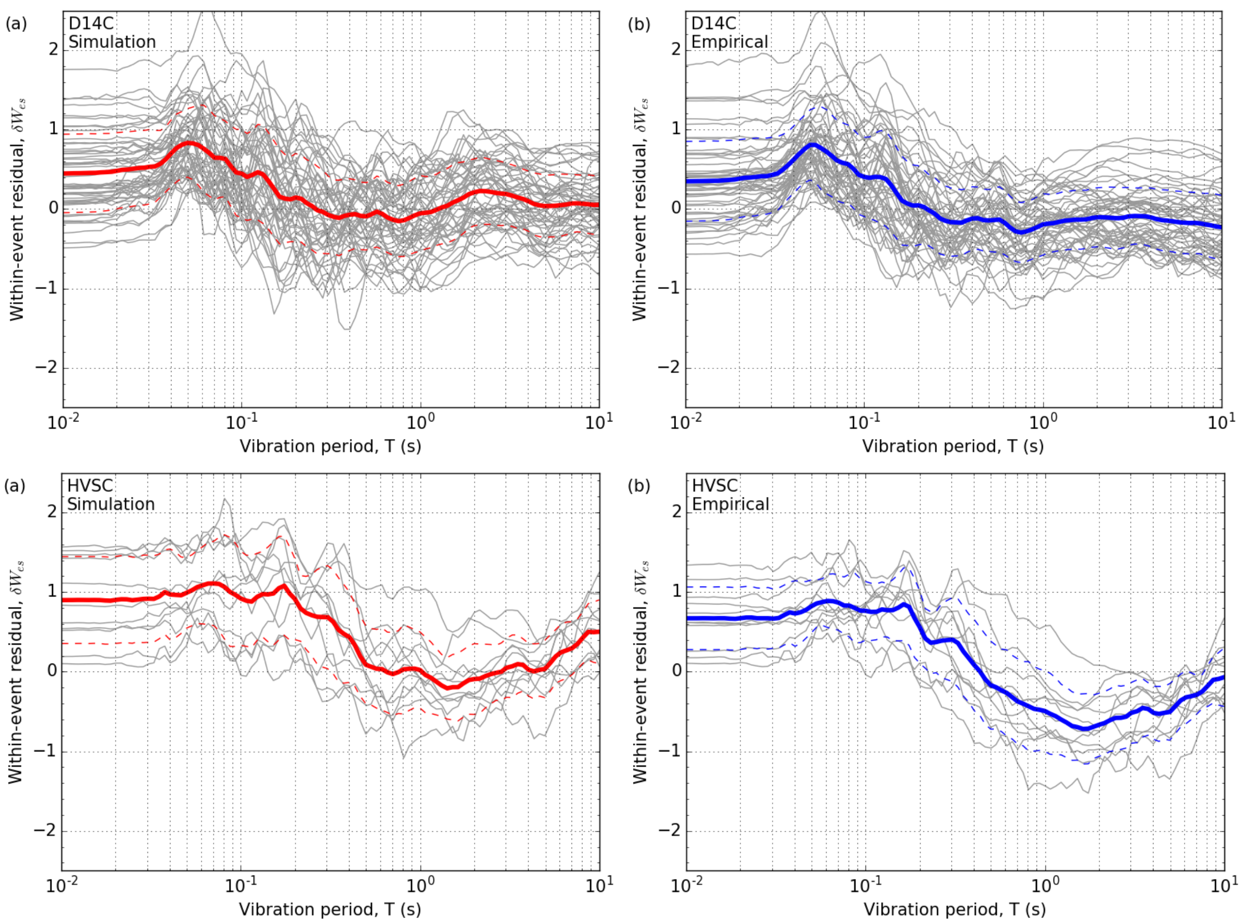
Spatial distribution of site-to-site residuals

- Rock sites are generally overpredicted.
- Separation across Christchurch city at short periods.
- Discrepancies suggest explicit site response is needed.



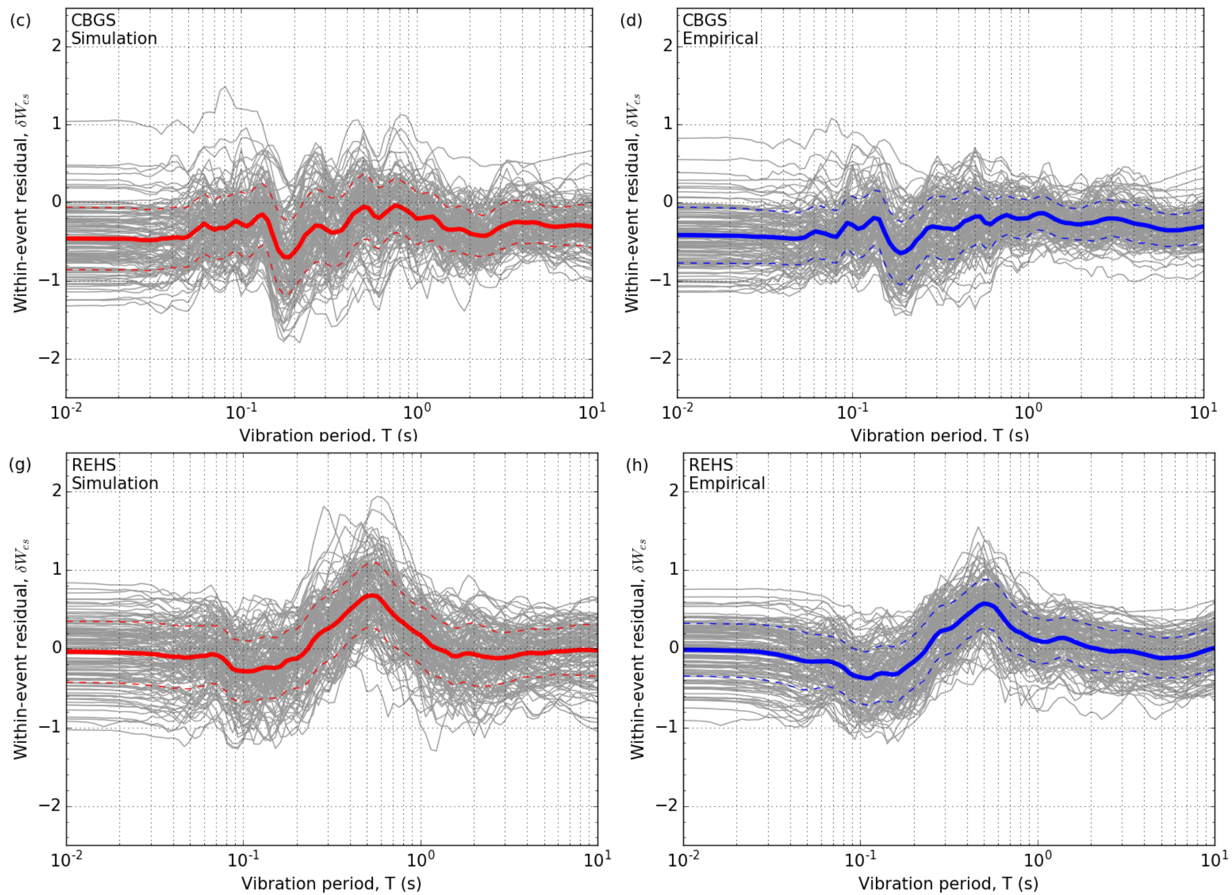
Rock sites

- Generally underpredicts short periods.
- Long periods usually predicted well.
- Some long period overprediction at Heathcote Valley.



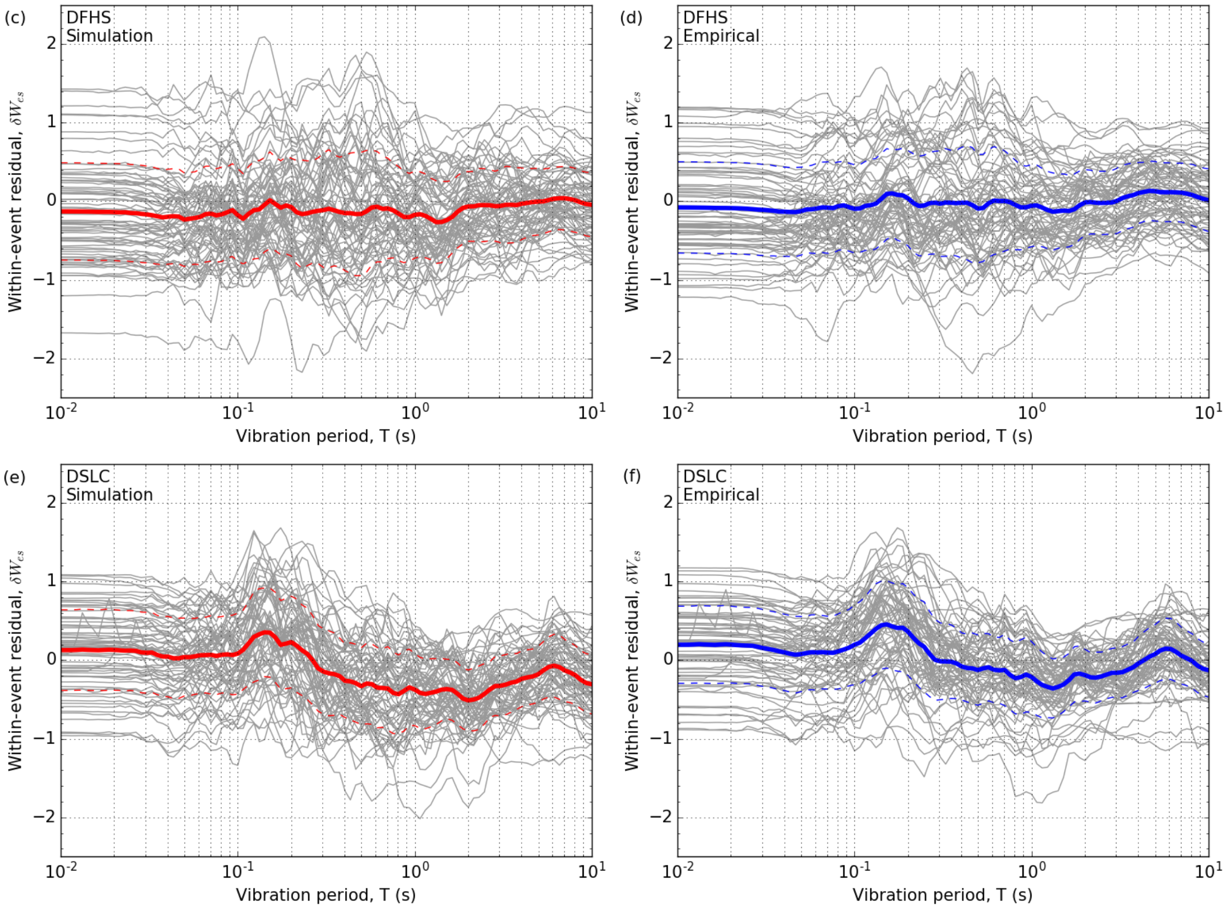
Christchurch city sites

- Variations from 0.05-1.0s caused by small-scale heterogeneities.
- REHS in particular is underpredicted at 0.6s, corresponding to the mode of vibration down to Riccarton Gravel.



Canterbury Plains sites

- Some sites appear to be well predicted.
- DSLC site is overpredicted above 0.3s, likely to be partially attributed to overamplification and overly strong basin waves.



Discussion and Conclusions

- Results highlight some limitations.
- Underprediction of significant durations and overprediction of HF ground motion IMs.
  Implement new path duration.
- Underprediction of HF ground motions on rock sites.
  Implement site specific 1D profiles.
- Overprediction of LF ground motion IMs.
  Modify the V_{s30}-based site amplification.

Future Work

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- Implementing the recommended changes in the ground motion simulation workflow.
- Extending this work to larger magnitude earthquakes as well.
- Extending this work to South Island and New Zealand wide applications.