

Validation of ground motion simulations in the Canterbury region

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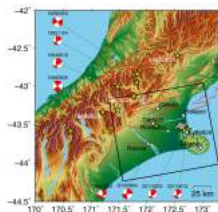
¹University of Canterbury

²U.S. Geological Survey



Motivation

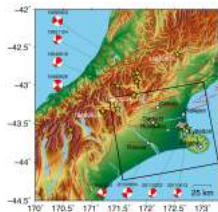
- To ensure robustness and reliability of ground motion for engineering use
- Lack of ground motion records for distances less than 10km
- Structural analyses: need of acceleration time series



Why Canterbury?

- Canterbury earthquake sequence has provided a **wealth of ground motion data**
- Systematic biased: shortcomings of the empirical ground motion prediction

Motivation



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Objective

- To analyze Canterbury events using **physics-based methods**
- To investigate the importance of **rupture model** in ground motion simulations

Broadband Simulation Methodology

Hybrid broadband approach (Graves and Pitarka 2010, 2015)

Low Frequency Simulation ($f < 1\text{Hz}$)

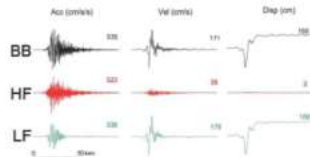
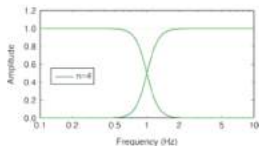
- Finite difference method
- Source: kinematic model
- 1D/3D velocity structure

High Frequency Simulation ($f > 1\text{Hz}$)

- Semi-empirical approach
- Downsample kinematic model
- Simplified 1D velocity structure

Broadband ground motion (0-10 Hz)

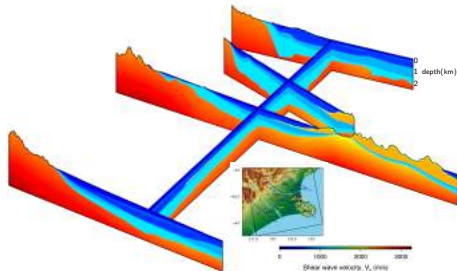
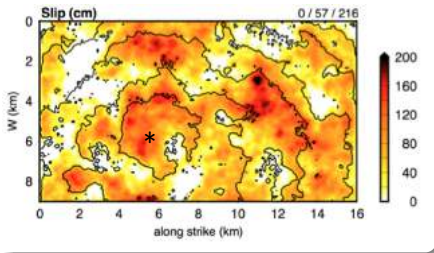
- Site amplification: Vs30-based
- Match filtering



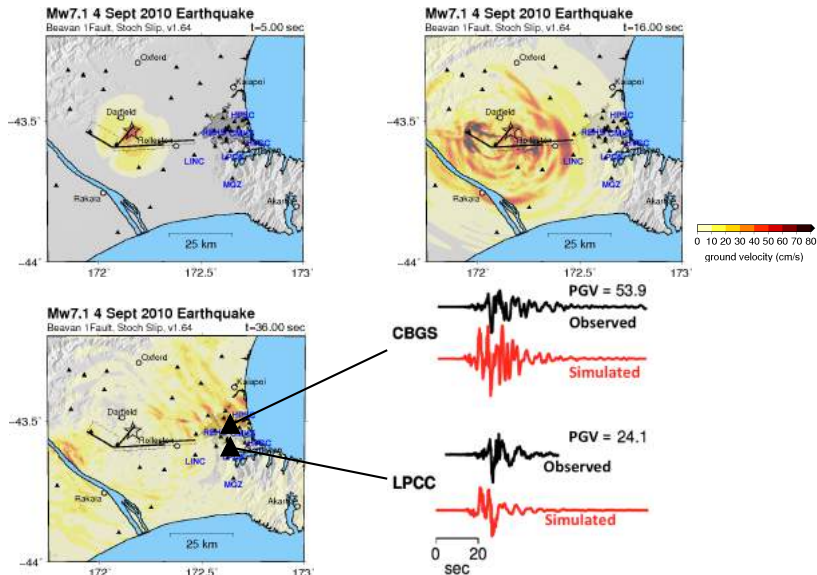
Courtesy of J. Bayless

Key ingredients

- **Source model:** generated using stochastic slip generator
- **Crustal structure:** 3D velocity model (Lee et al., 2016)



Ground shaking for the $M_w 7.1$ Darfield event

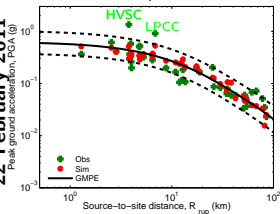


PGA and SA distance-decays (v1.64)

PGA

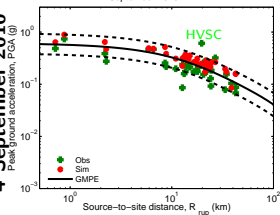
22 February 2011 Mw 6.2

22 February 2011

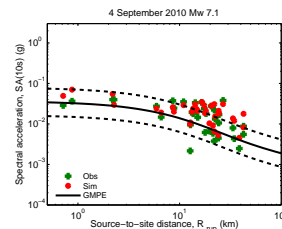
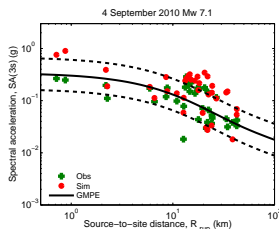
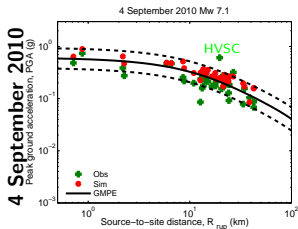
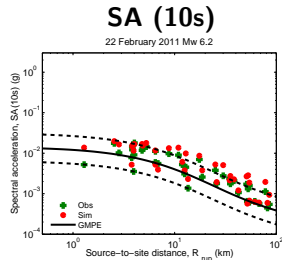
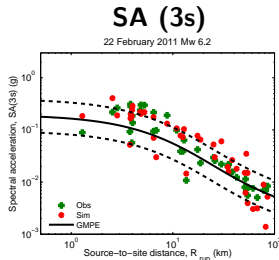
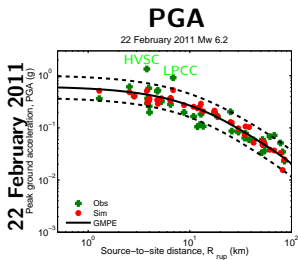


4 September 2010 Mw 7.1

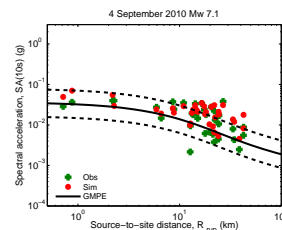
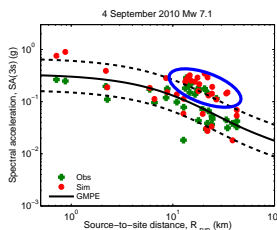
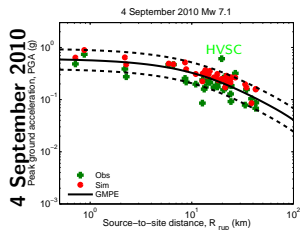
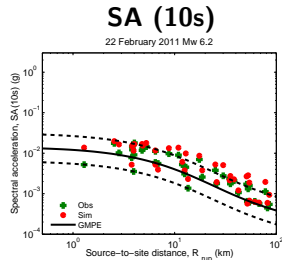
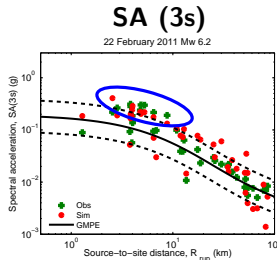
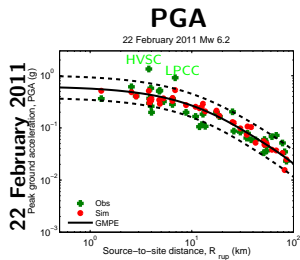
4 September 2010



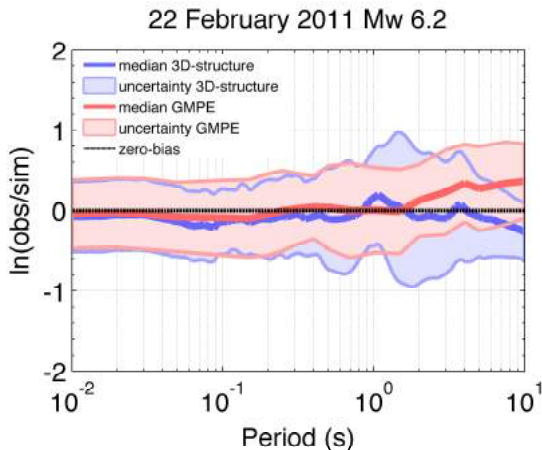
PGA and SA distance-decays (v1.64)



PGA and SA distance-decays (v1.64)



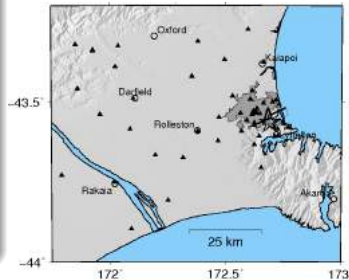
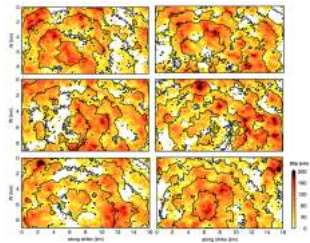
Spectral acceleration residuals



- Median values oscillate around zero model-bias
- Simulations reduce the long-period bias compared with the GMPE prediction

Source sensitivity: 2011 M_w 6.2 Christchurch

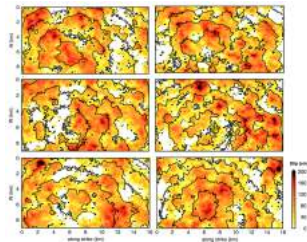
Slip models



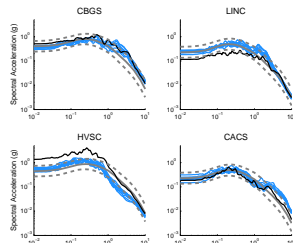
- Incorporate source variability: 10 rupture model realizations for M_w 6.2 Christchurch event
- Fixed fault geometry and hypocenter

Source sensitivity: 2011 M_w 6.2 Christchurch

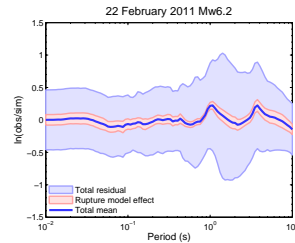
Slip models



Spectral acceleration



Total-source bias

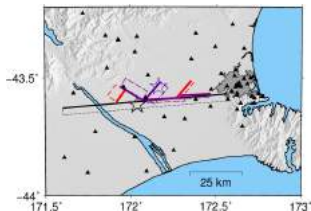


- Source effect: relatively small (about 10% total residual)
- Overall between-event residual: unbiased prediction
- Note: variability originates solely from spatial distribution of rupture model

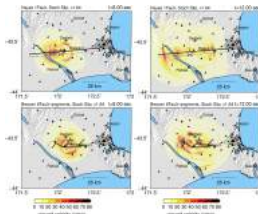
Source sensitivity: M_w 7.1 Darfield

Poster006

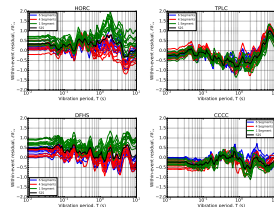
Fault geometry



Ground motion pattern



SA-bias

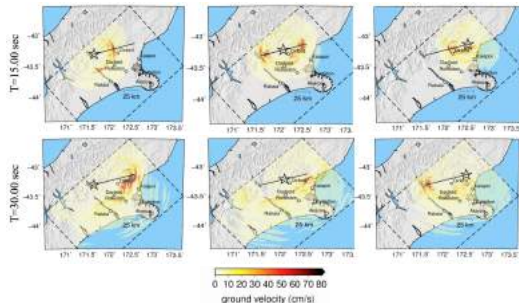


- Presence of strong wavefront distortion for the multi-fault segment faults
- Variability of spectral acceleration residual is relatively large for stations close to the fault
- Fault segmentations are required particularly west of the fault to better match the observed ground motion records

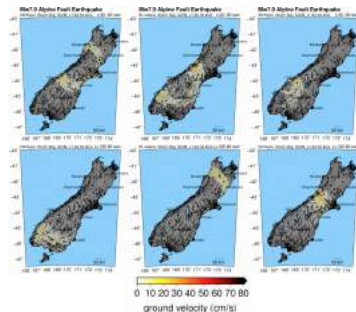
Beyond Canterbury

- Impacts of hypocenter location and the finite-fault model.
- Potential level of ground shaking in different areas.
- **Validation** is done based on **moderate magnitude events** that occurred in the vicinity of the faults.

Porter Pass fault (Poster011)



Alpine fault



Summary

- This study suggests that the effect of rupture model on ground motion depends on the source size and the dimension of the source complexity.
- Ground motion simulations capture the structural complexity of sedimentary basin.
- Simulation provide equal or better predictions of the observed ground motion amplitudes compared to that of the empirical GMPE.

Implications

- Better understanding of the ground motion variability.
- Benefits in improving the seismic hazard analyses and the building code.



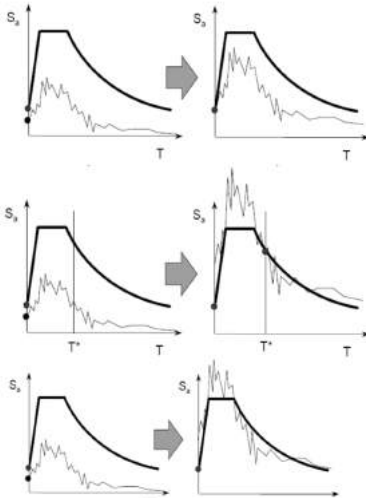
QuakeCoRE
NZ Centre for Earthquake Resilience



Thank You



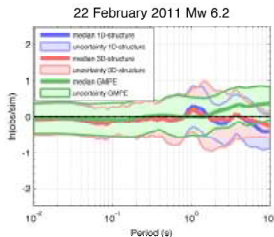
Spectral matching



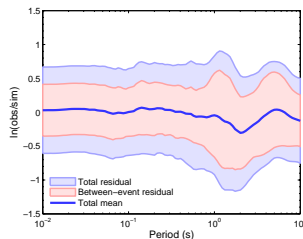
- Choose target spectrum
- Ground motion: based on the dominant M_w and distance that contribute to the hazard
- NZ Seismic design code (NZS1170.5:2004):
[$0.4T1$, $1.3T1$]

Total Residual - Sensitivity tests

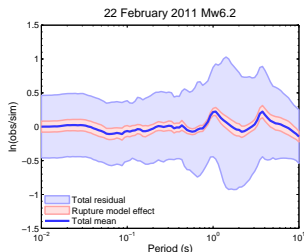
Structure effect



Overall residuals for the 10 events

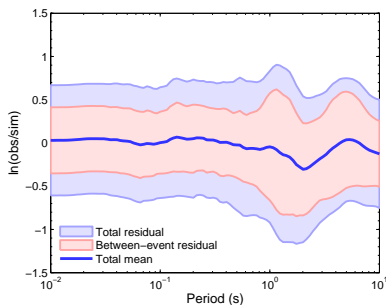


Source effect



- Median values oscillate around zero model-bias
- Simulations reduces the LP bias compared with the GMPE prediction
- Effect of source: relatively small (about 10% total residual)
- Overall between-event: unbiased

Total and between-event residuals

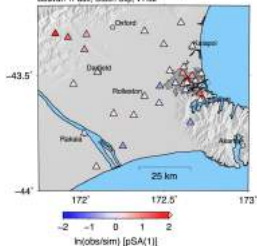


- Between-event residuals contribute about 50% of the total residual.
- No apparent trend with the event magnitude

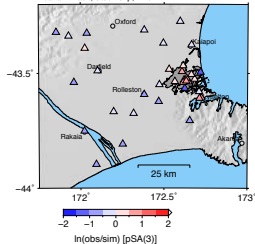
Spatial variability of residuals for 1D and 3D-structures (Feb 22)

Mw6.2 22 Feb 2011 Earthquake

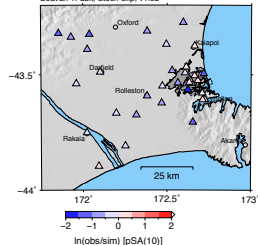
Beavan 1Fault, Stoch Slip, v1.02

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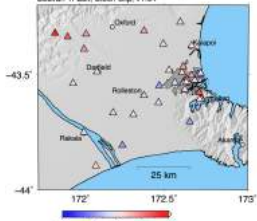
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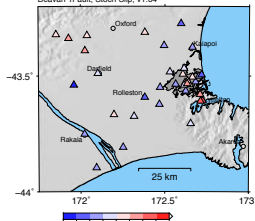
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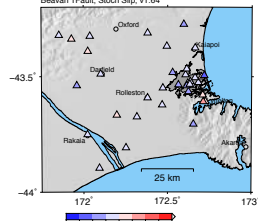
Beavan 1Fault, Stoch Slip, v1.64

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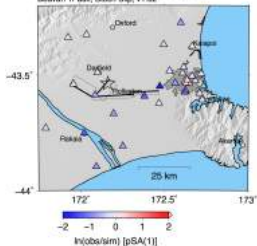
Beavan 1Fault, Stoch Slip, v1.64



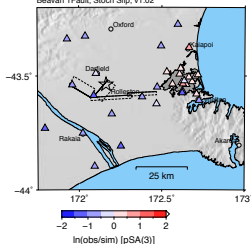
Spatial variability of residuals for 1D and 3D-structures (Sept 4)

Mw7.1 4 Sept 2010 Earthquake

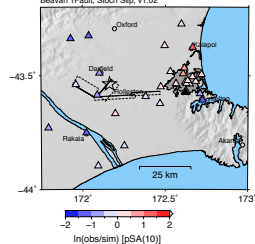
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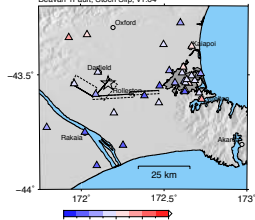
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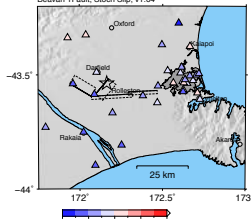
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