Incorporating Soil Nonlinearity into Physics-Based Ground Motion Simulations

Chris de la Torre

23 February 2017

Advisor: Brendon Bradley
Co-Advisor: Misko Cubrinovski
Co-Advisor: Liam Wotherspoon

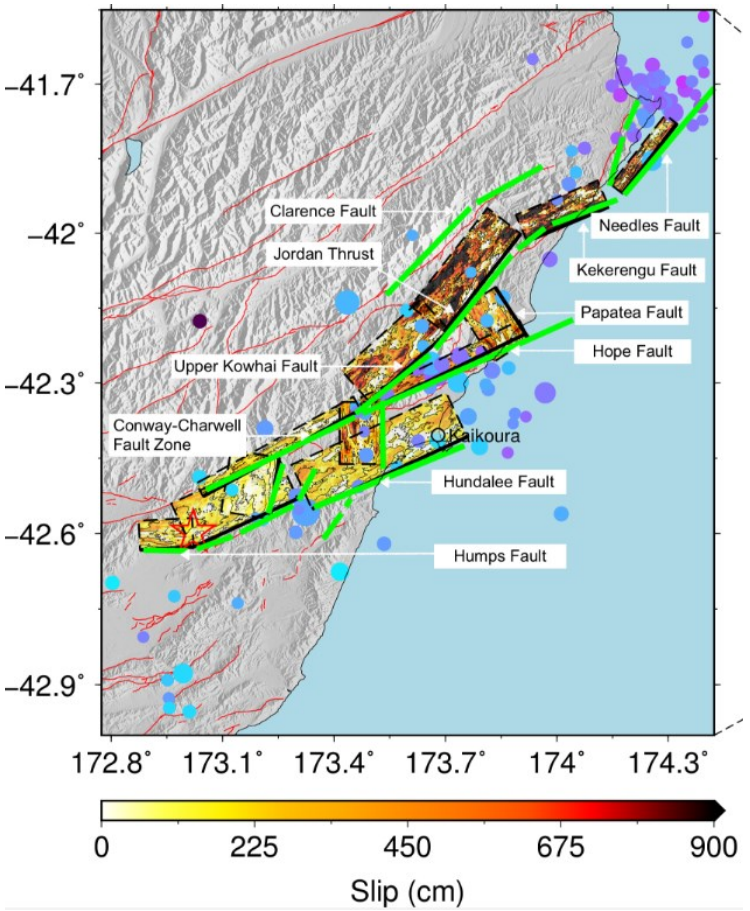
UC UNIVERSITY OF CANTERBURY

QuakeCoRE NZ Centre for Earthquake Resilience

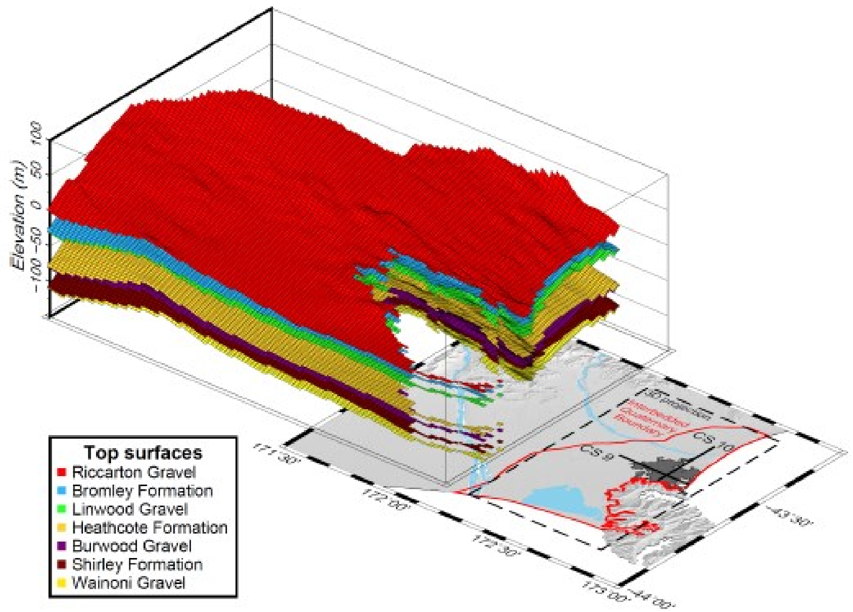
Seismic Source

Source-to-Site Path

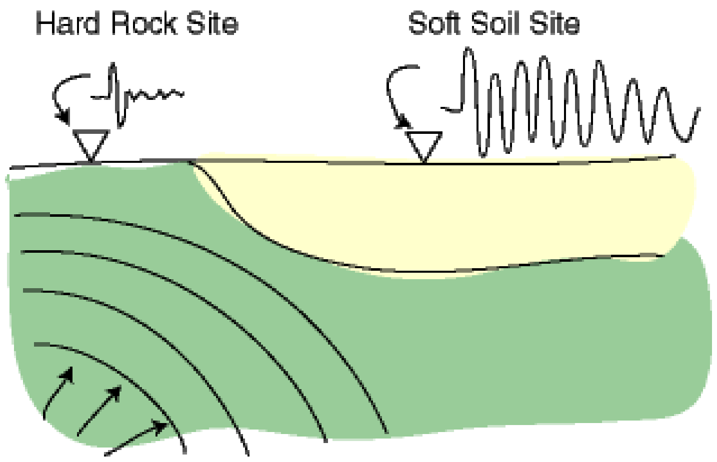
Site Effects



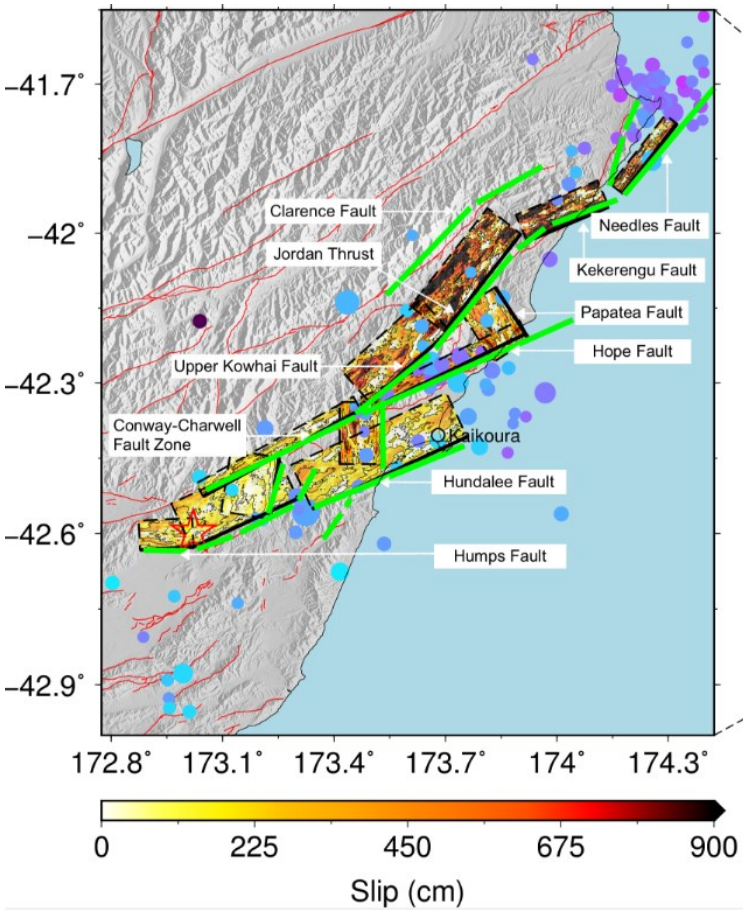
Bradley et al. (2017)



Lee et al. (2015)

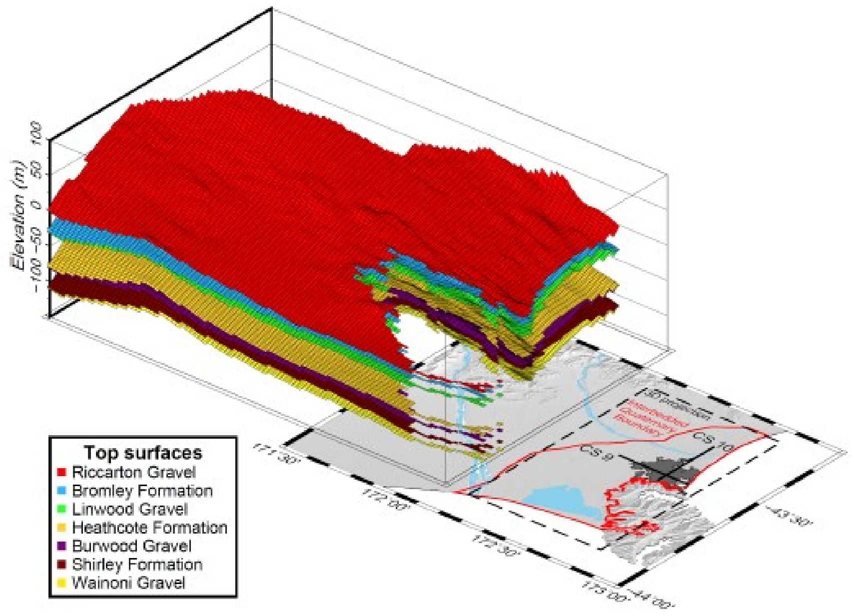


Seismic Source



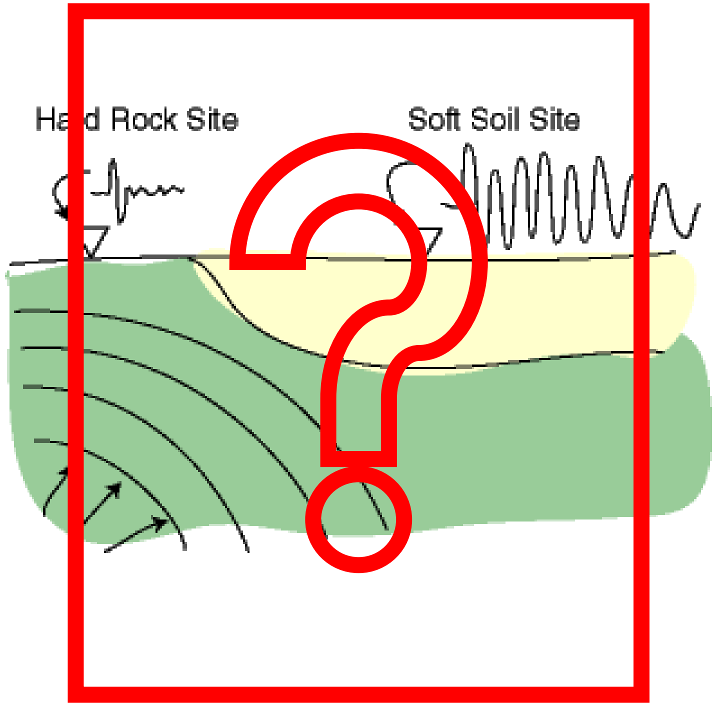
Bradley et al. (2017)

Source-to-Site Path



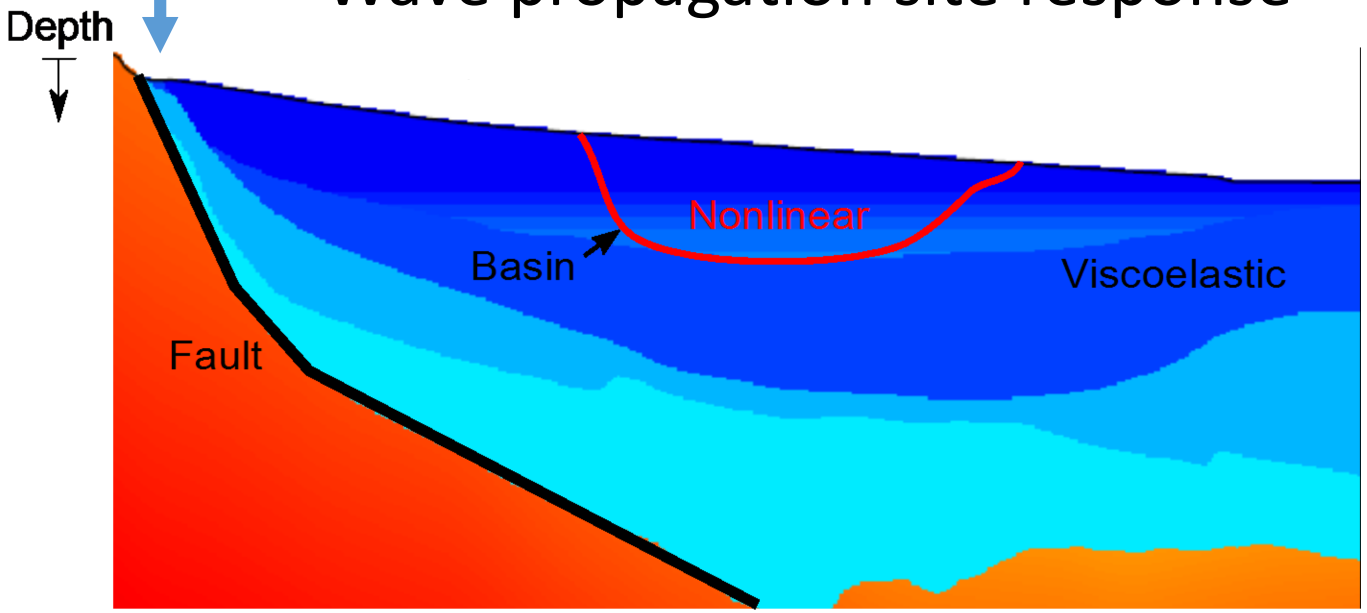
Lee et al. (2015)

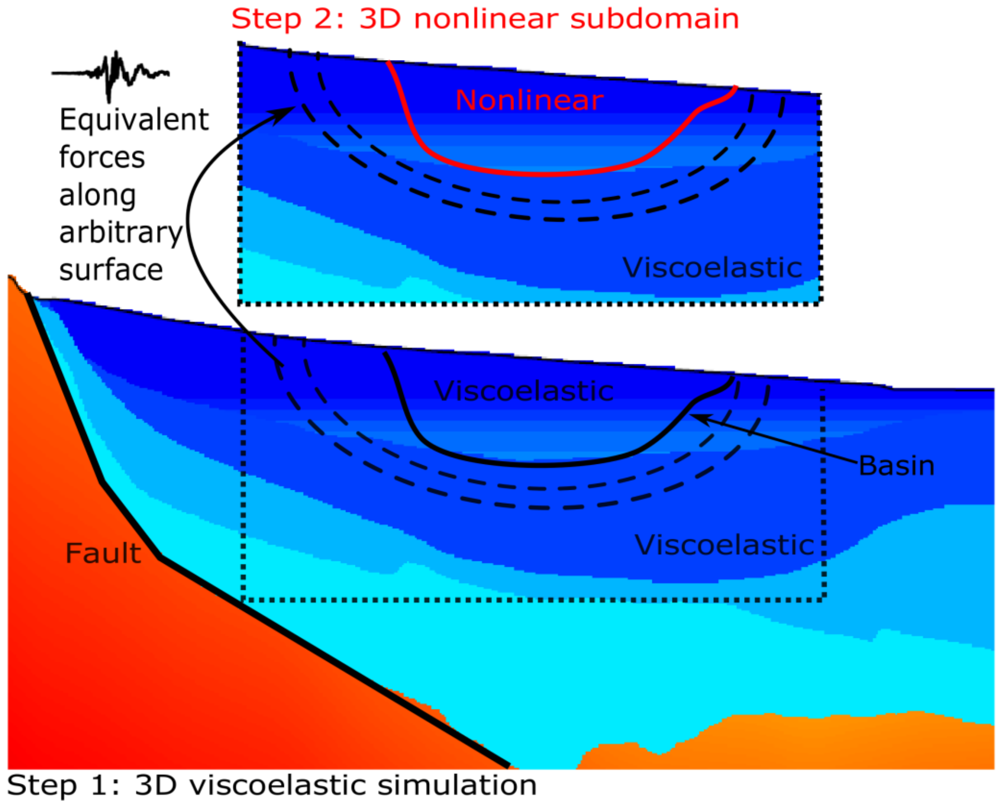
Site Effects



Nonlinear Site Effects in Simulations

- 4 Methods for Incorporating Site Effects:
  - Fully coupled 3D
  - Domain Reduction Method
  - Empirical Vs30-based
  - Wave propagation site response

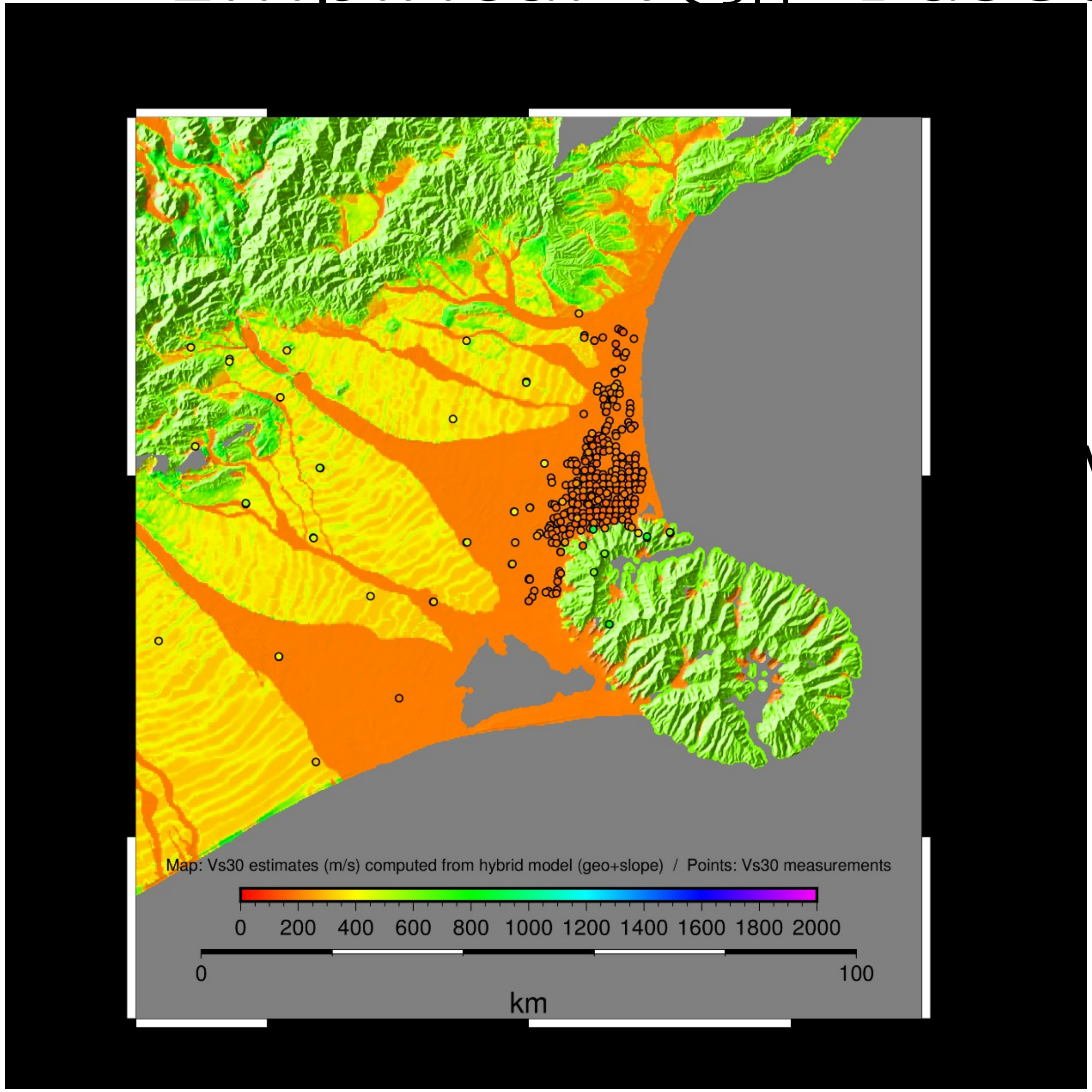




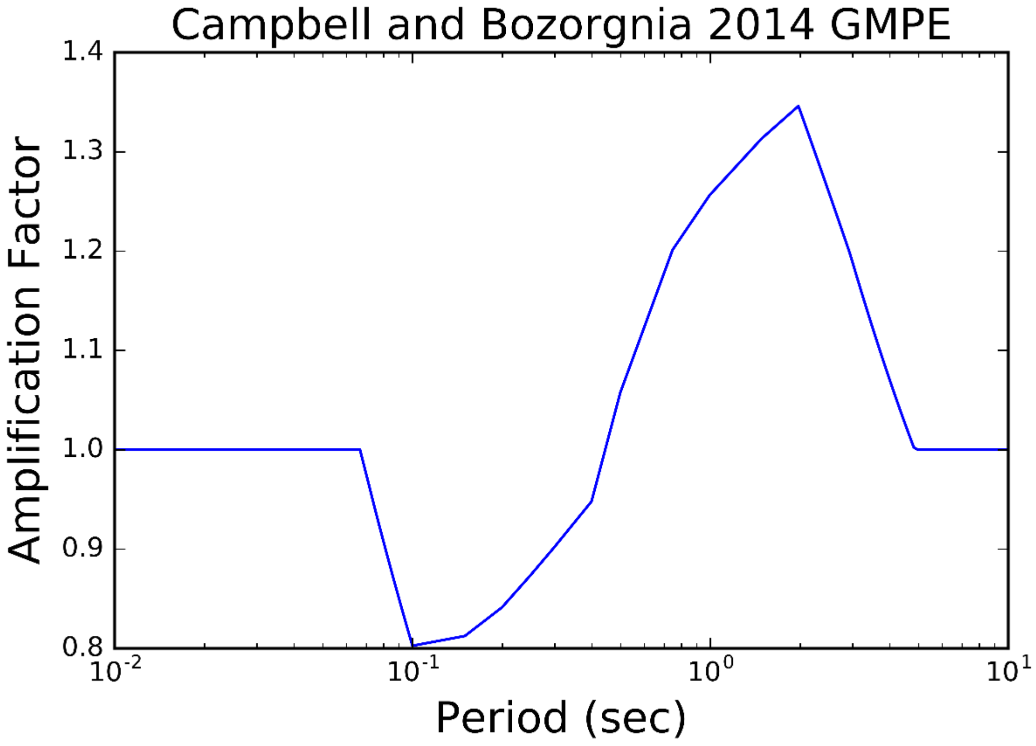
References: Xu et al. (2003), Taborda and Bielak (2009), and Restrepo et al. (2012)

References: Bielak et al. (2003), and Yoshimura et al. (2003)

Empirical V_{S30}–Based Factors

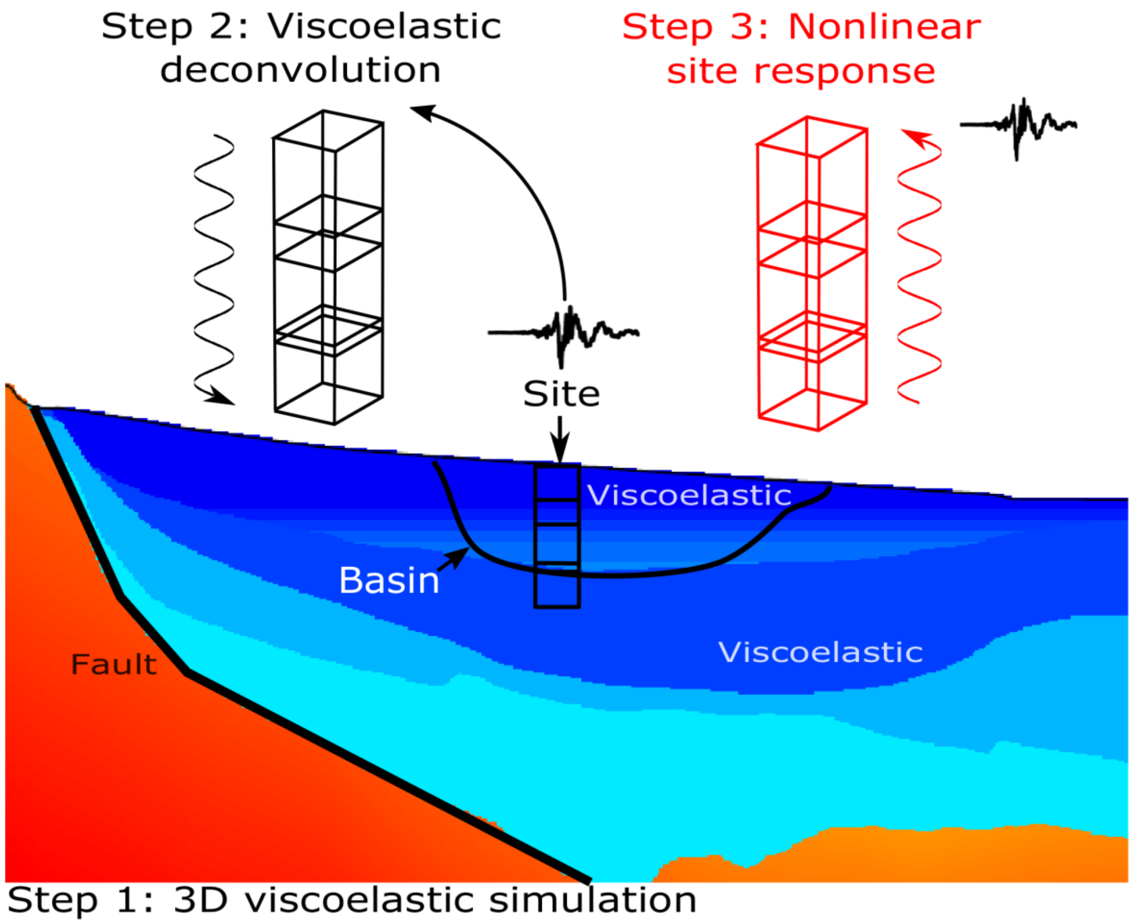


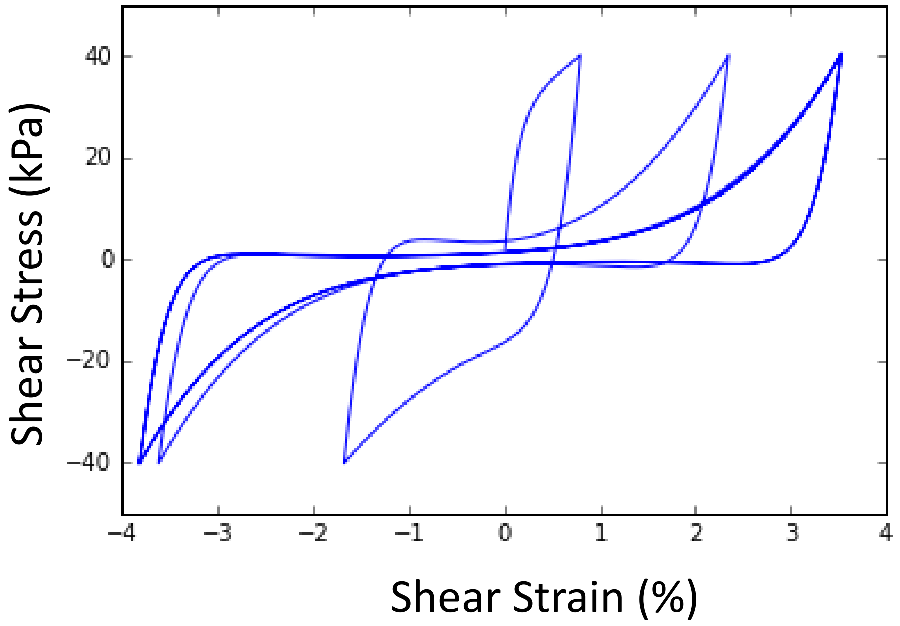
V_{S30}, PGA



References: Graves and Pitarka (2010, 2015)

1D Wave Propagation Site Response





<u>References:</u> Hartzell et al. (2002), and Roten et al. (2012)

Summary of Previous Studies

- Hartzell et al. 2002
  - Mw6.5 Seattle Fault, USA
  - Linear, Eq. Linear, Total and Effective Stress Nonlinear

	East–West Acc.	North–South Acc.	East–West Vel.	North–South Vel.	PSA 0.1 Sec North–South	PSA 0.33 Sec North–South	PSA 1.0 Sec North–South	PSA 3.3 Sec North–South
Input Motion*	705	760	75	125	1150	1370	740	455
SHAKE91	1.3	1.1	1.3	1.4	0.8	1.0	1.0	1.6
DESRA2	1.3	1.3	1.3	1.3	0.7	1.1	1.2	1.2
NONLI3 OCR = 3	1.0	1.0	1.2	1.2	1.2	1.1	1.2	1.3
NONLI3 OCR = 1	0.6	0.6	1.2	1.2	0.9	1.0	1.2	1.3
NOAH	0.7	0.6	1.8	1.7	1.1	1.3	1.8	1.8

*All values are in cgs units (cm/sec, cm/sec^2)

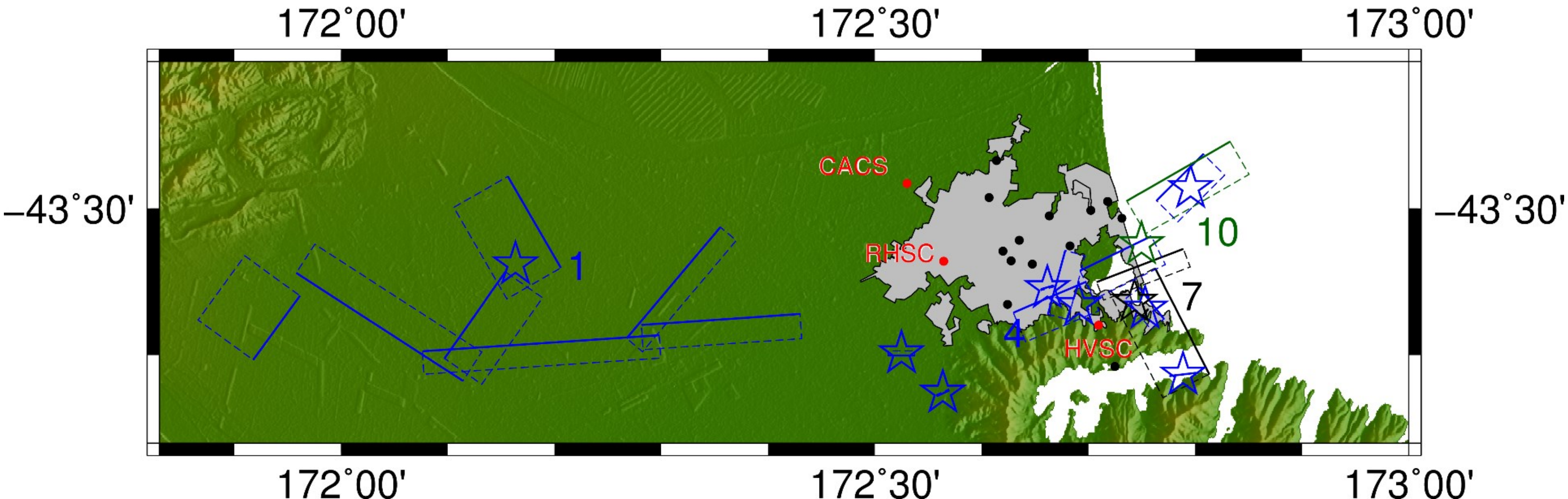
- Roten et al. 2012
  - Mw7.0 Wasatch Fault, Utah, USA
  - Total Stress Nonlinear

Outline of Objectives

- Objective 1: Nonlinearity in Simulations of the 2010-2011 Canterbury Eqs
- Objective 2: Effective Stress Site Response for Liquefiable Sites
- Objective 3: Model Uncertainty in 1D Site Response Analysis
- Objective 4: Apply Lessons Learned to Kaikoura Earthquake at Wellington

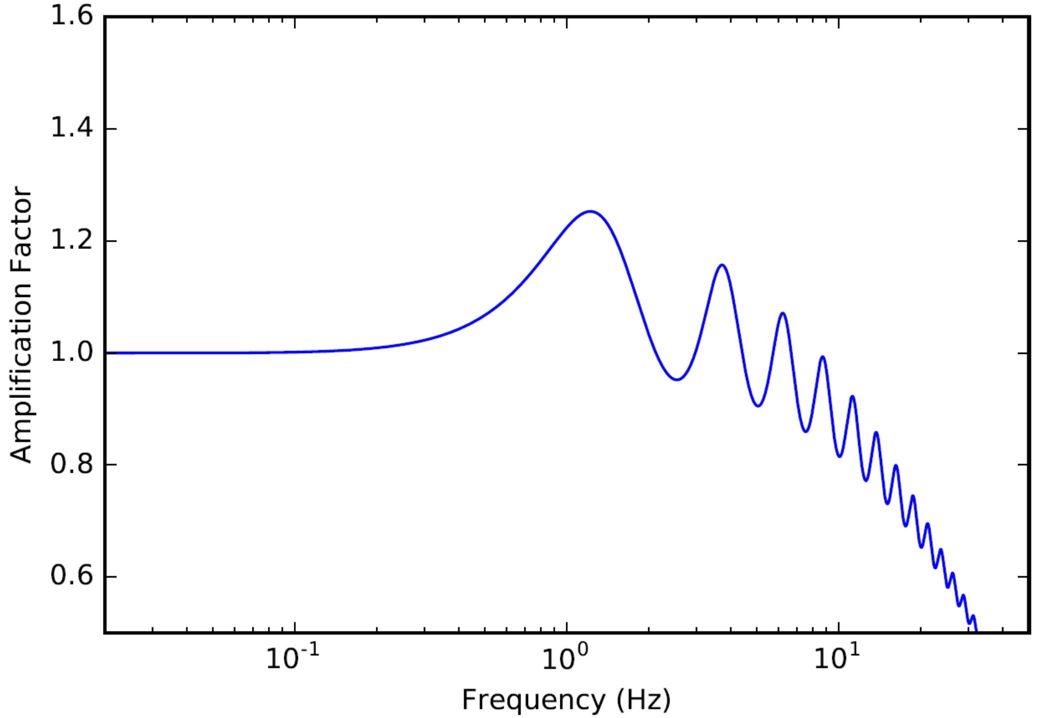
Objective 1: 2010-2011 Canterbury EQs

- Simulations from Razafindrakoto et al 2016.
- 10 events Magnitude 4.7 – 7.1
- 17 strong motion stations in Christchurch
- Total stress site response



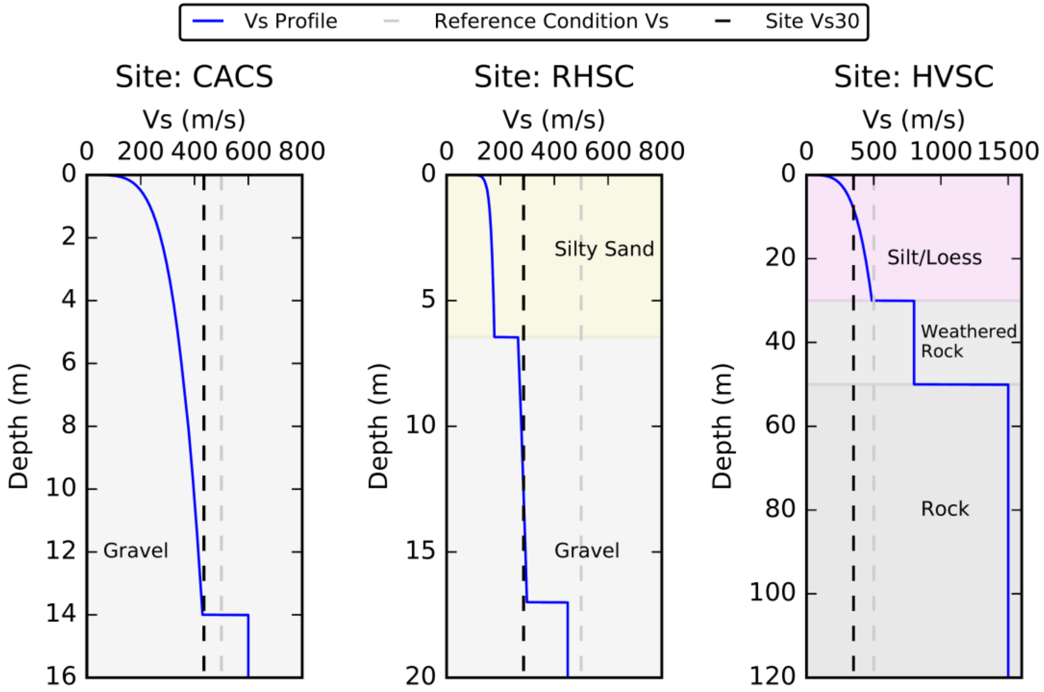
1D Wave Propagation Site Response Analysis

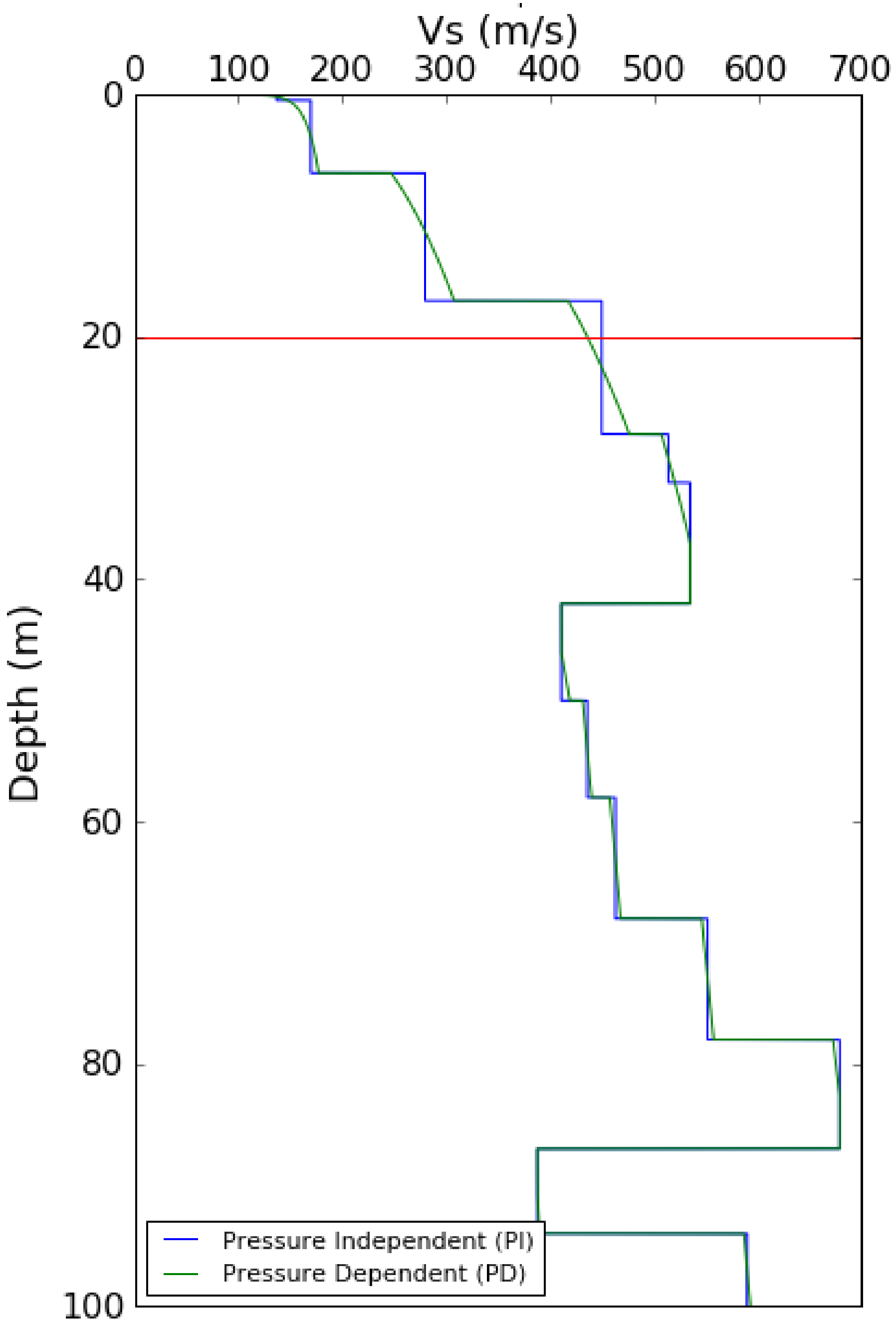
- Deconvolve with frequency domain solution
  - From $V_{S,ref}$ to stiff soil/rock
  - Riccarton gravel: V_S = 400 – 600 m/s
- OpenSees FE Code
- PDMY Constitutive Model



Site Characterisation

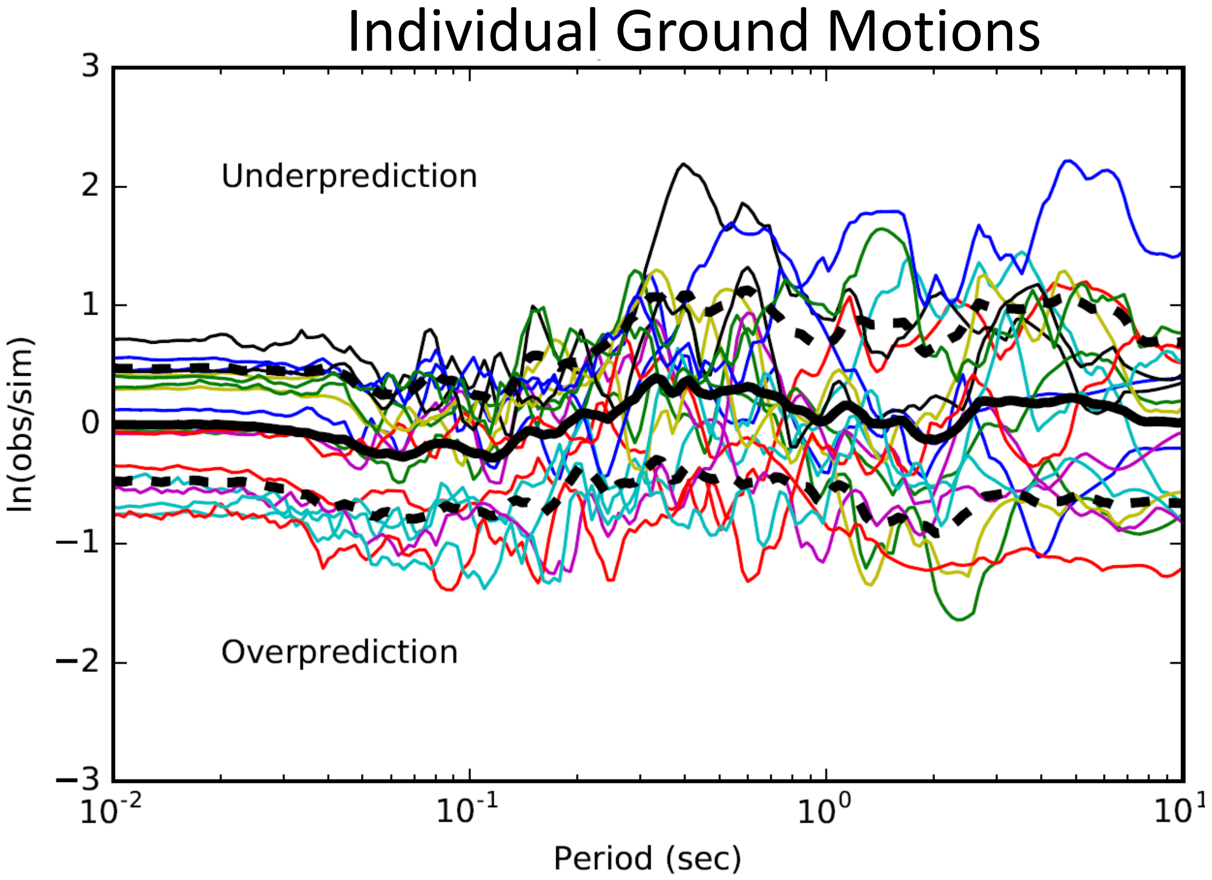
- Wood et al. (2011) and Wotherspoon et al (2014)
- SPT, CPT, V_S
- Deep V_S profiles: Teague et al. 2017

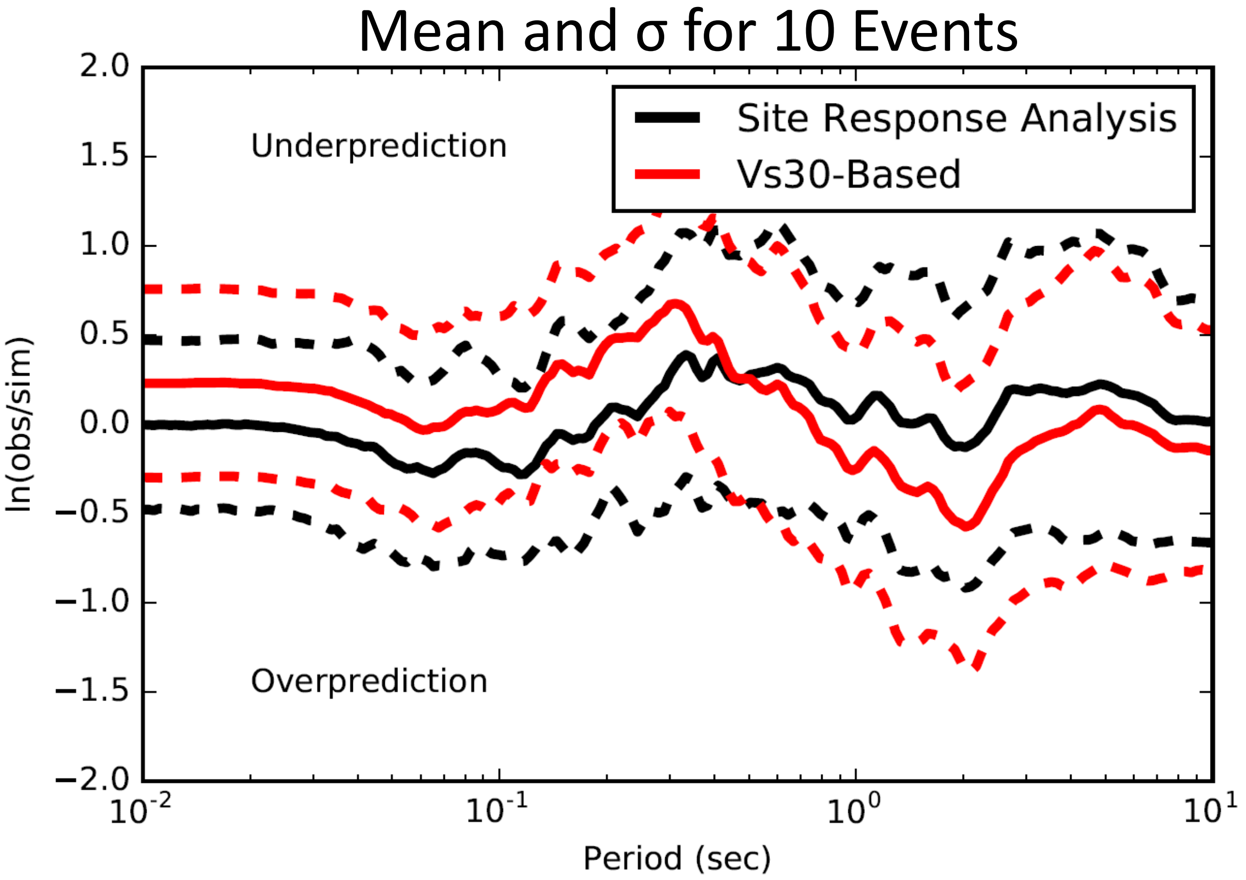




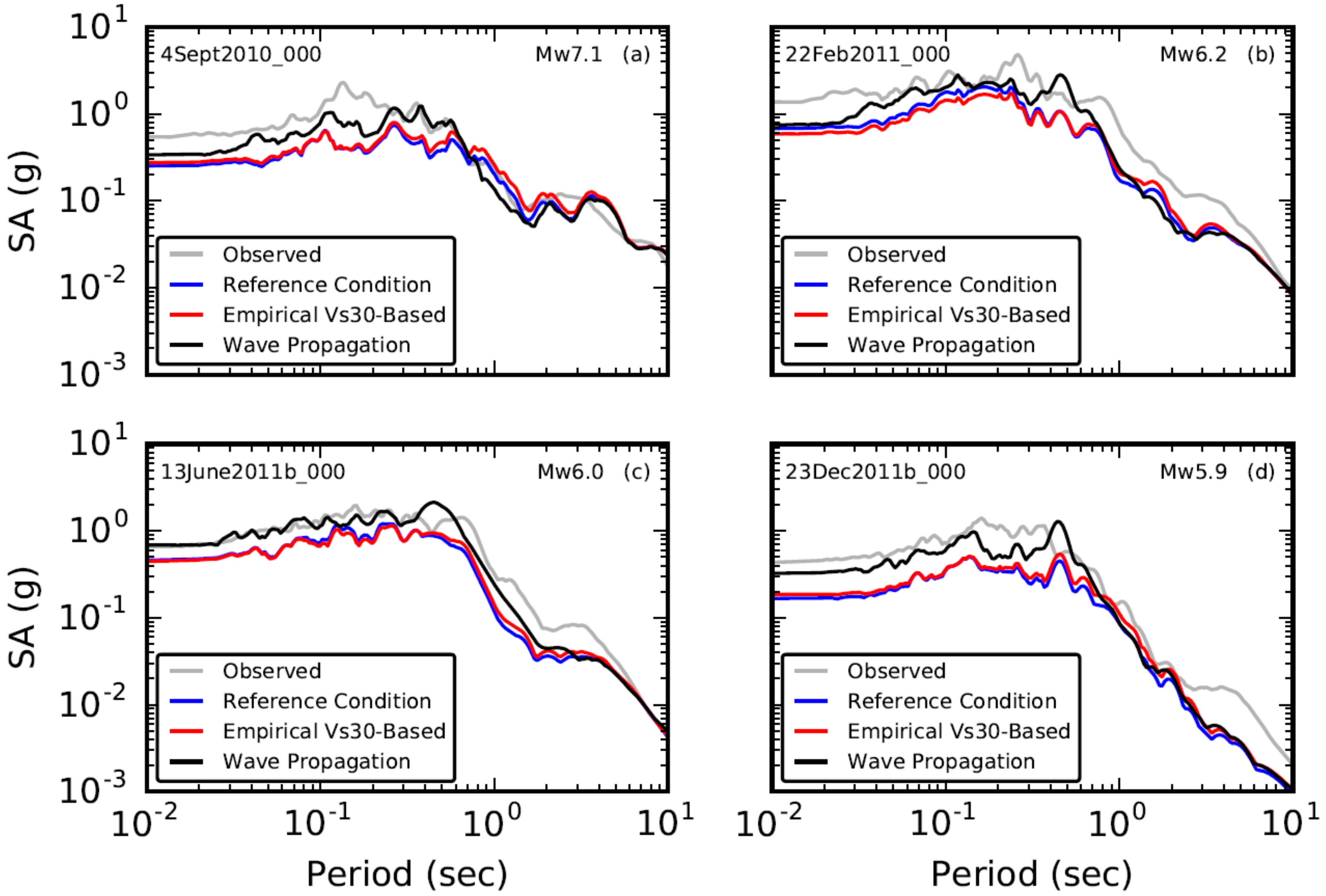
Metric for Quality of Simulations

- Residual = $\ln(PSA_{Observed}) - \ln(PSA_{Simulated})$

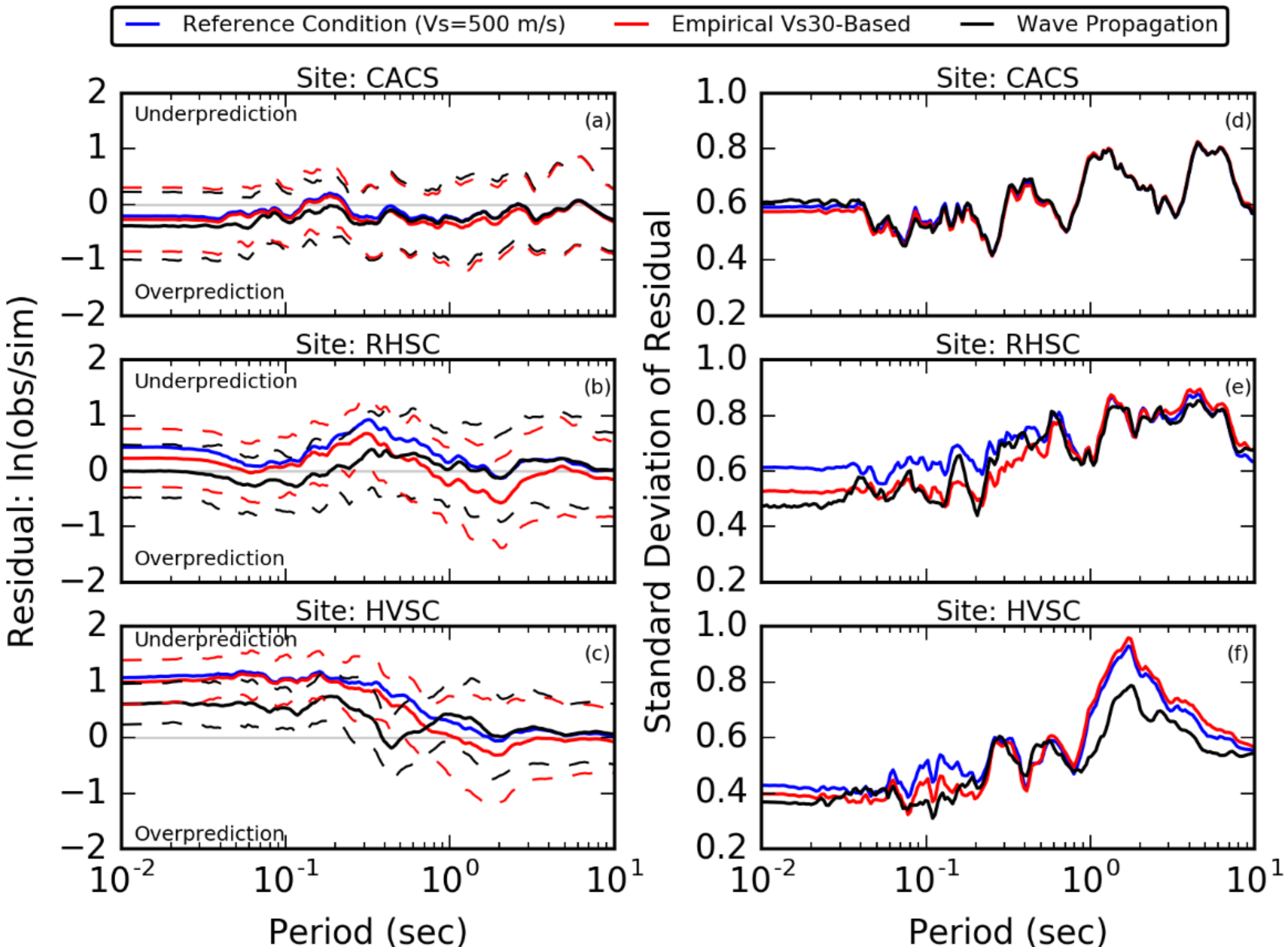




Comparison of Response Spectra



Example Results: 3 Sites



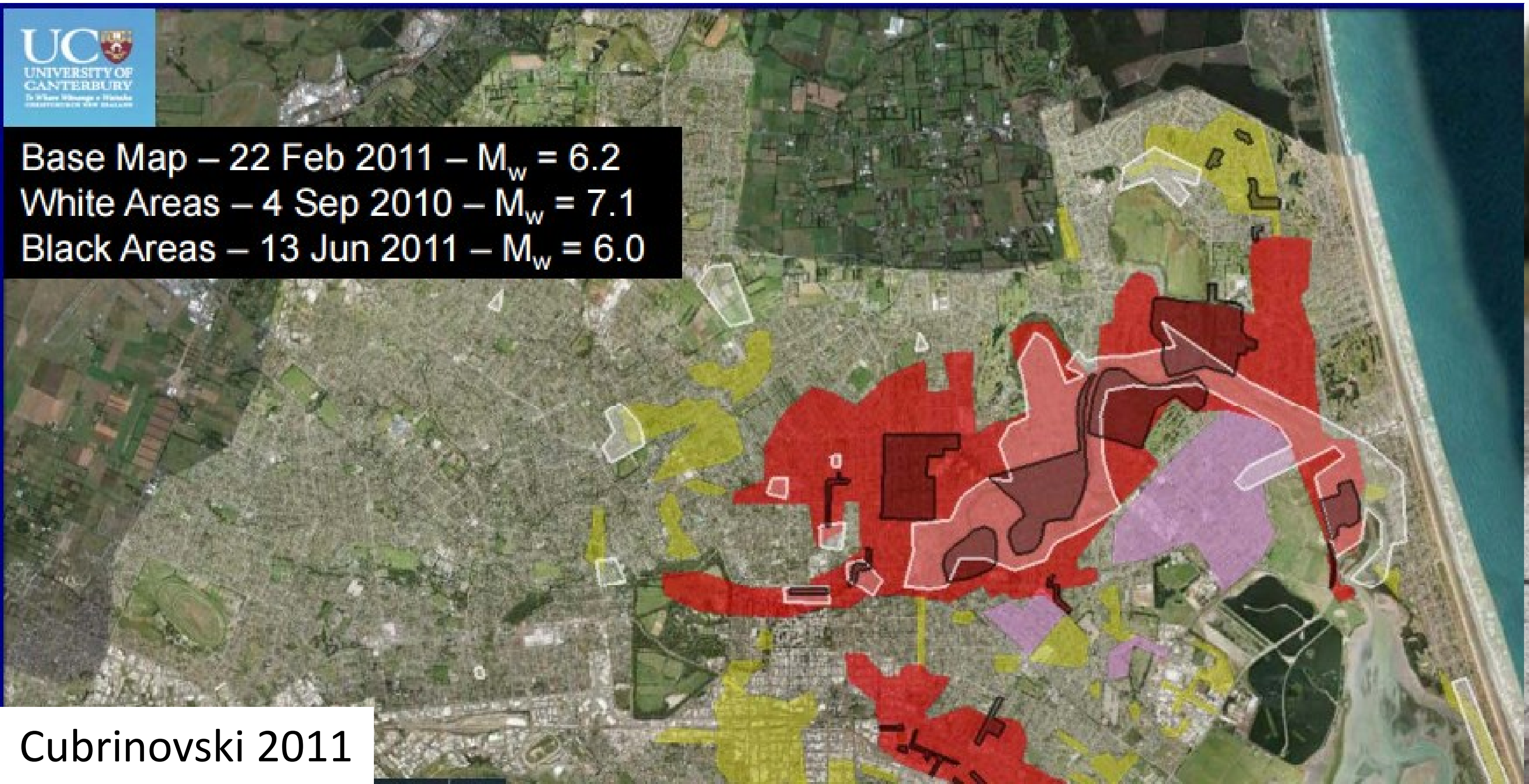
Stiff Site → No Improvement

Intermediate Site → Moderate Improvement

Large Impedance Contrast → Significant Improvement

Objective 2: Effective Stress Site Response

- Liquefaction in Mw7.1 Darfield and Mw6.2 Christchurch EQs
- Stress-density constitutive model
- When is Effective Stress > Total Stress ??



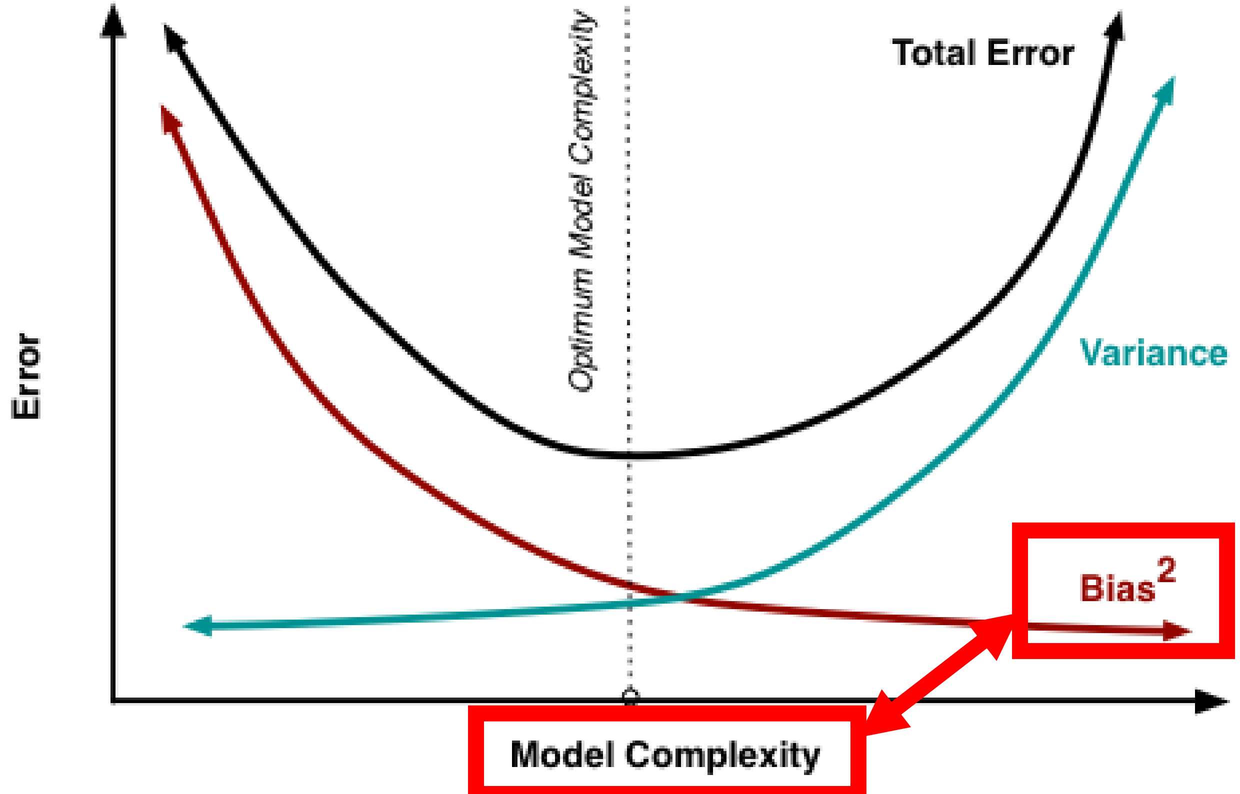
Cubrinovski 2011

Objective 3: Model Uncertainty in Site Response

- Can we reduce bias by increasing model complexity??
- Maintain same site characterization data

- Increasing model complexity
  - Pressure Dependent Vs
  - 3D-1D Site Response

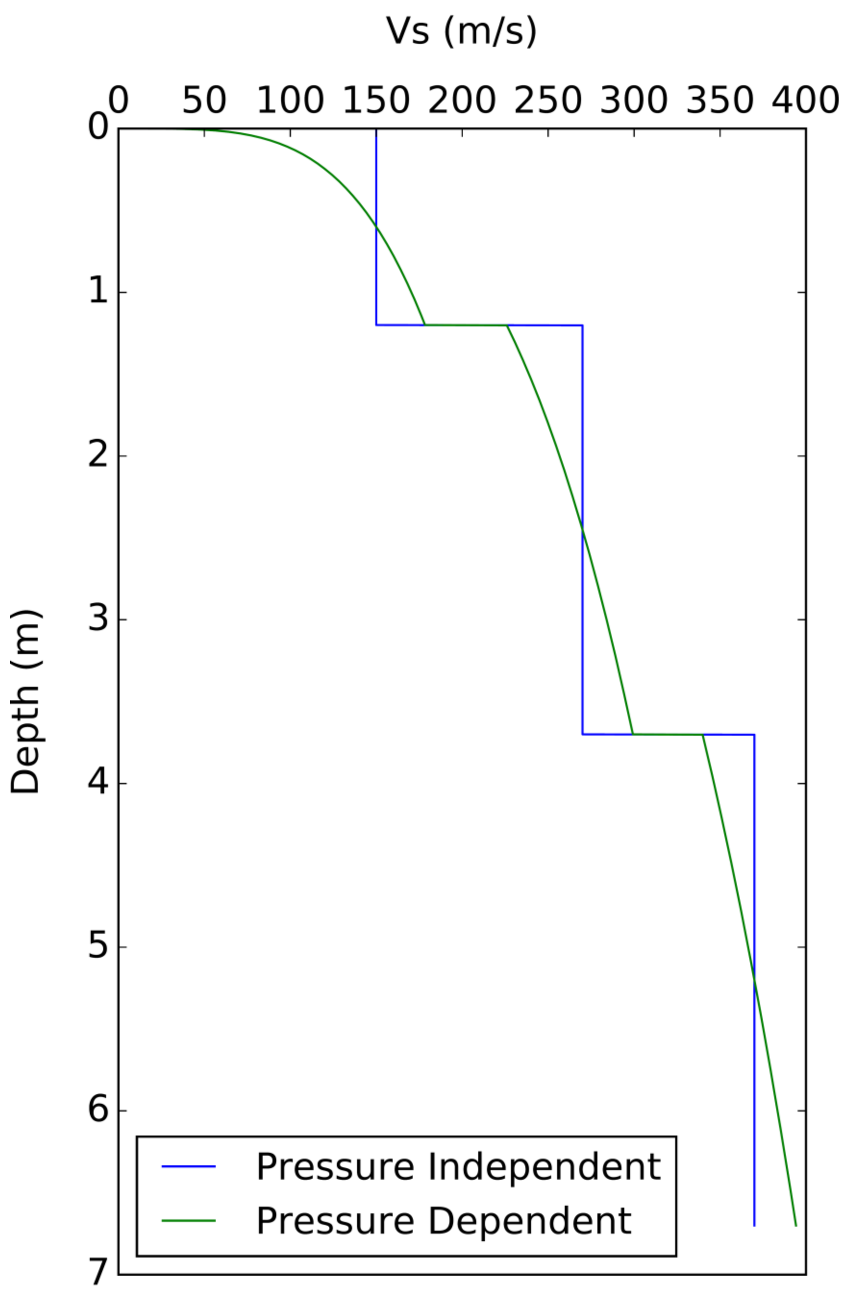
Fortmann-Roe



Pressure-Dependent V_S

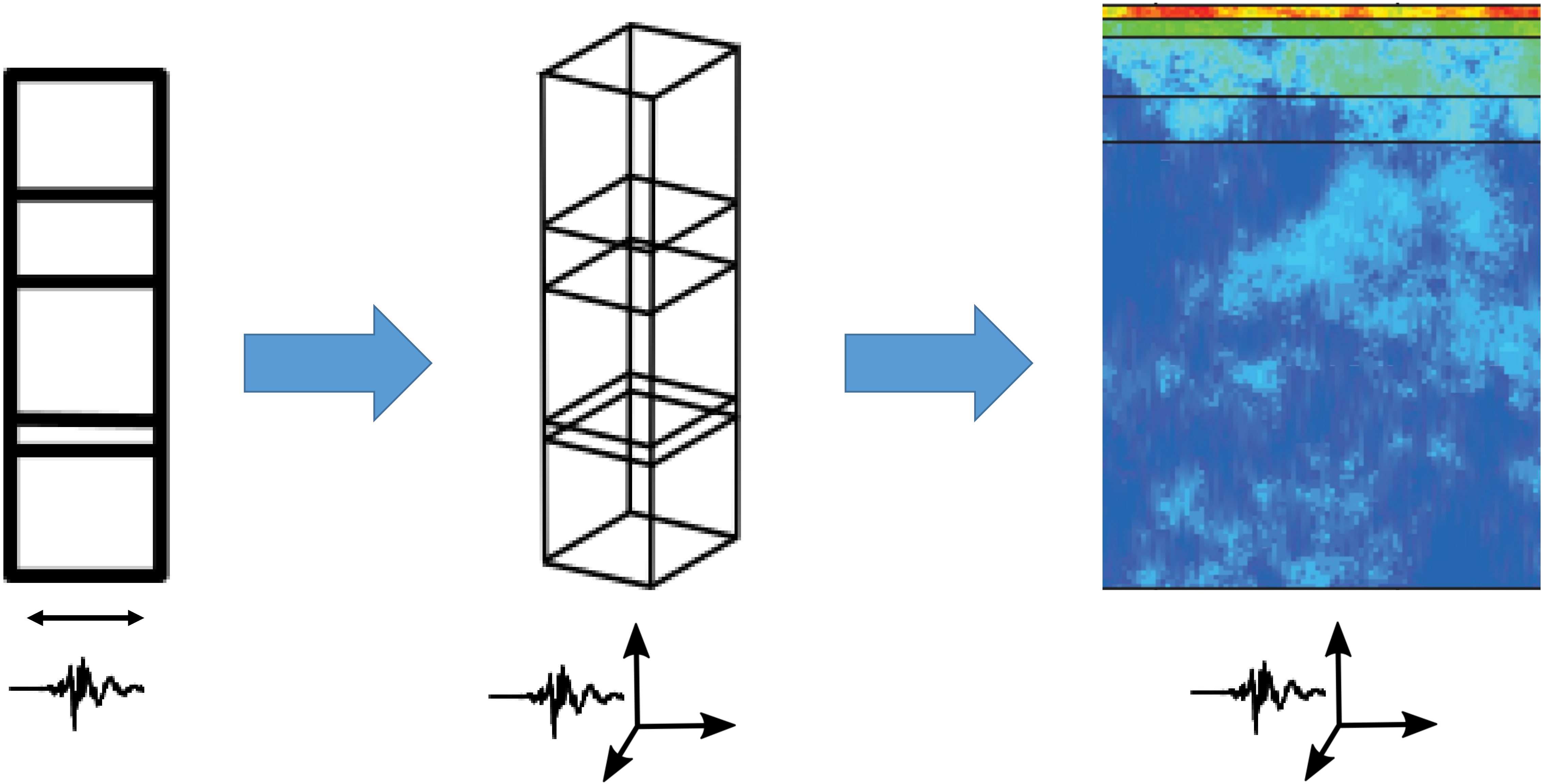
- Published profiles: Constant Vs
- Pressure dependence = depth dependence
- Maintain equal travel time btwn profiles

$$G = G_{ref} * \left(\frac{p'}{p'_{ref}}\right)^d$$



3D-1D Site Response

Thompson et al. 2009



Objective 4: 2016 Mw7.8 Kaikoura EQ

- Severe liquefaction of reclaimed land:
  - Hydraulically-placed dredged fill
  - End-dumped quarry rock

Thank you!

- Acknowledgements:
  - Funding:
    - QuakeCoRE
    - University of Canterbury
  - Advisors:
    - Brendon Bradley
    - Misko Cubrinovski
    - Liam Wotherspoon
  - Support:
    - Chris McGann
    - Seohko Jeong
    - Hoby Razafindrakoto
    - Viktor Polak