

# Coupling Nonlinear Ground Response Analysis with Physics- Based Ground Motion Simulation

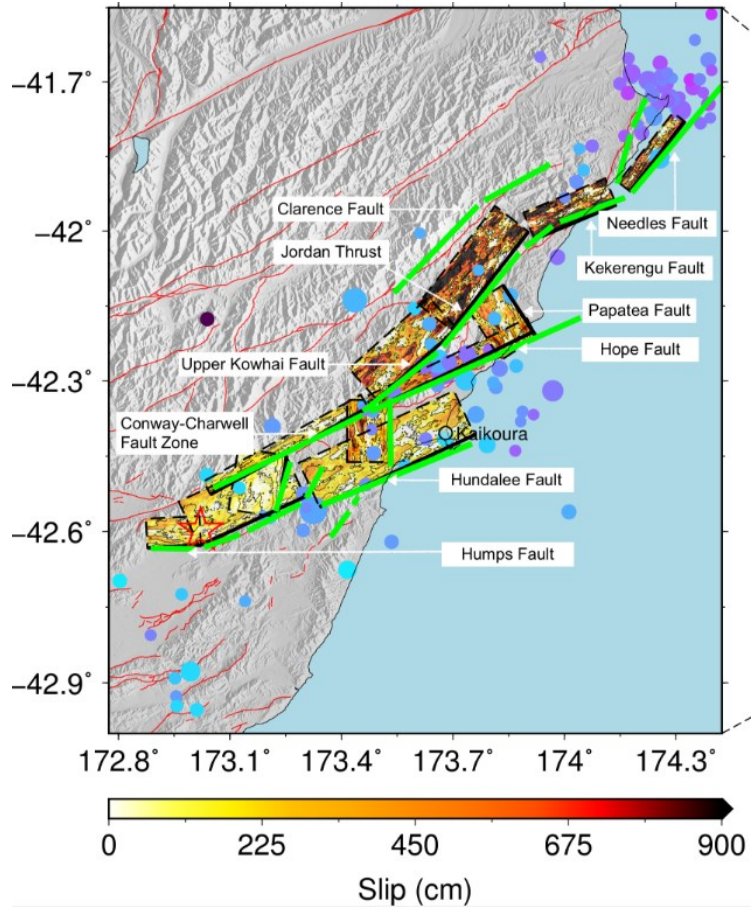
Chris de la Torre

22 June 2017



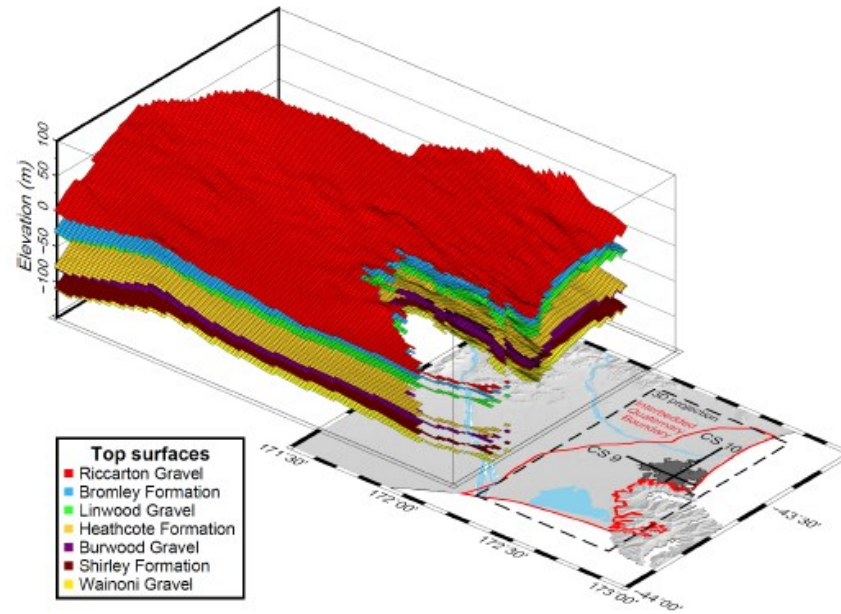
QuakeCoRE  
NZ Centre for Earthquake Resilience

# Seismic Source



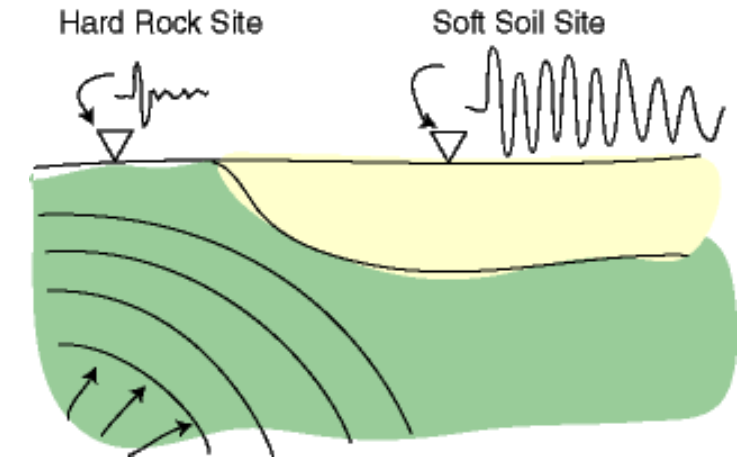
Bradley et al. (2017)

# Source-to-Site Path

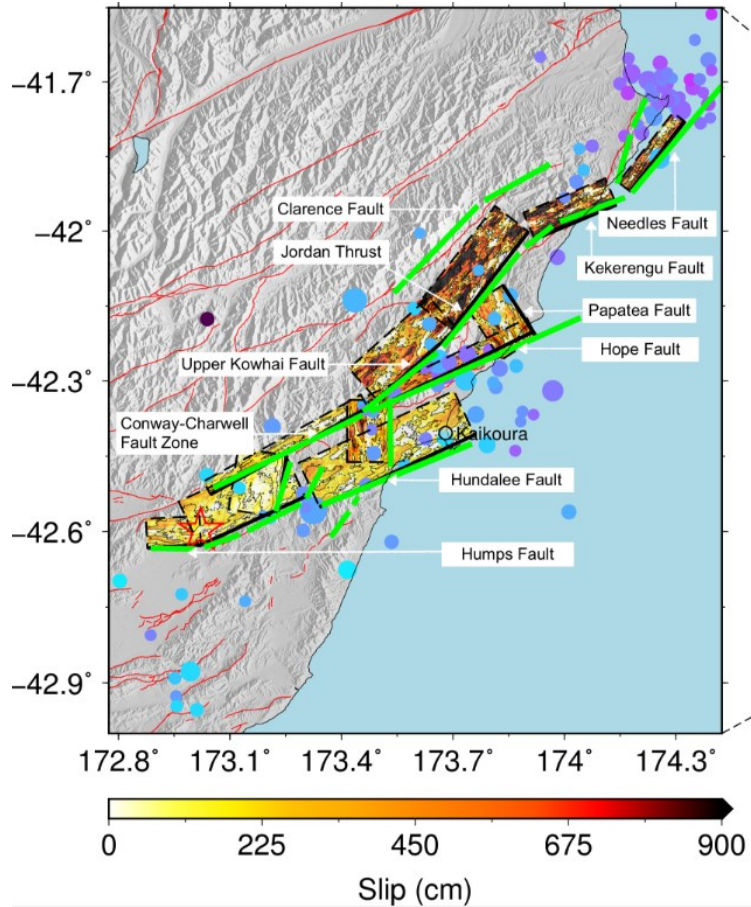


Lee et al. (2015)

# Site Effects

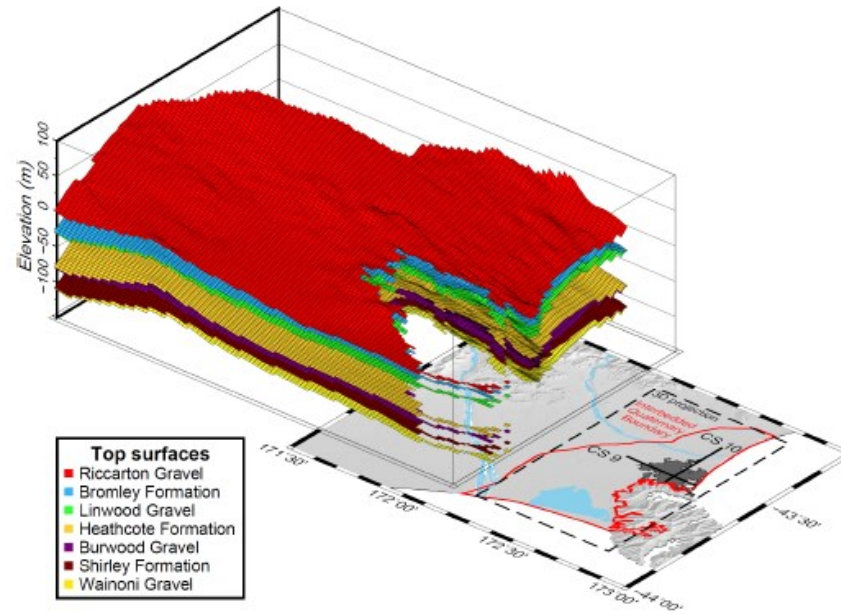


# Seismic Source



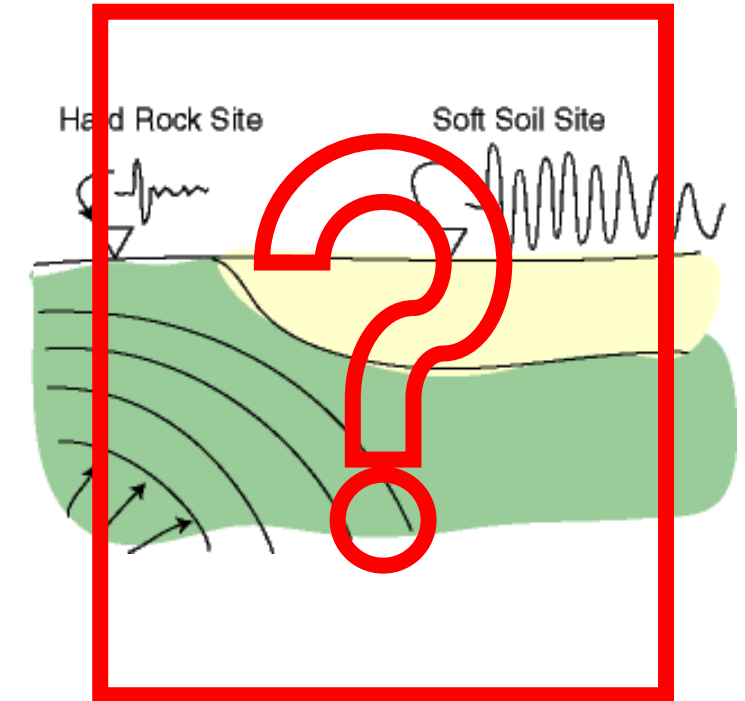
Bradley et al. (2017)

# Source-to-Site Path

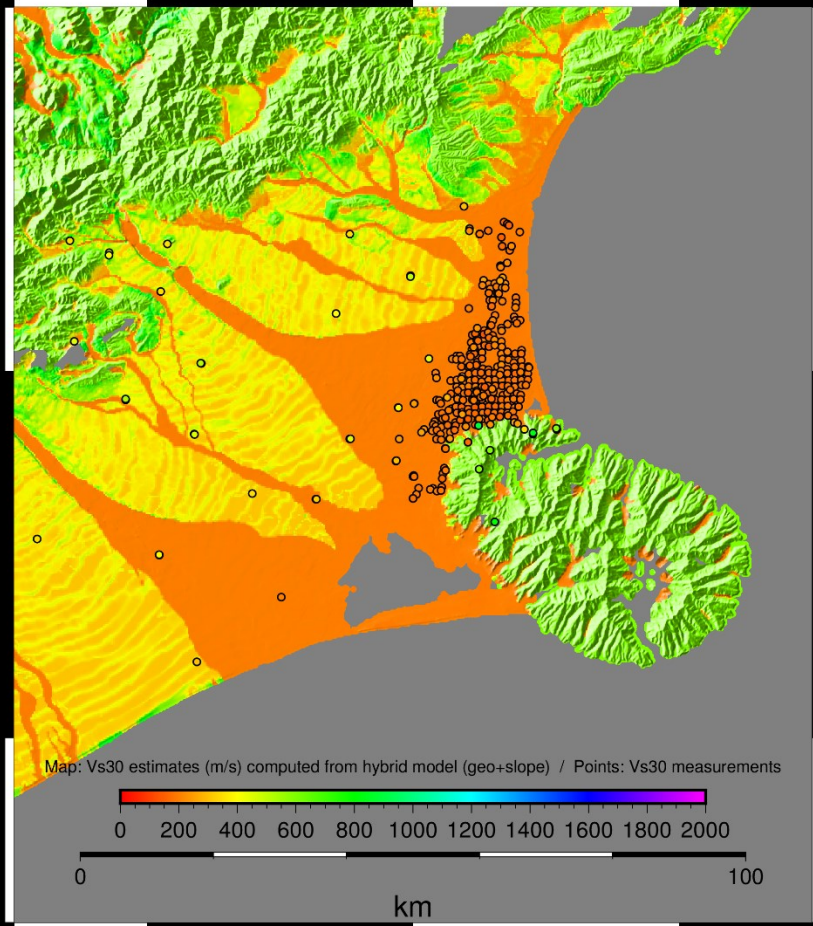


Lee et al. (2015)

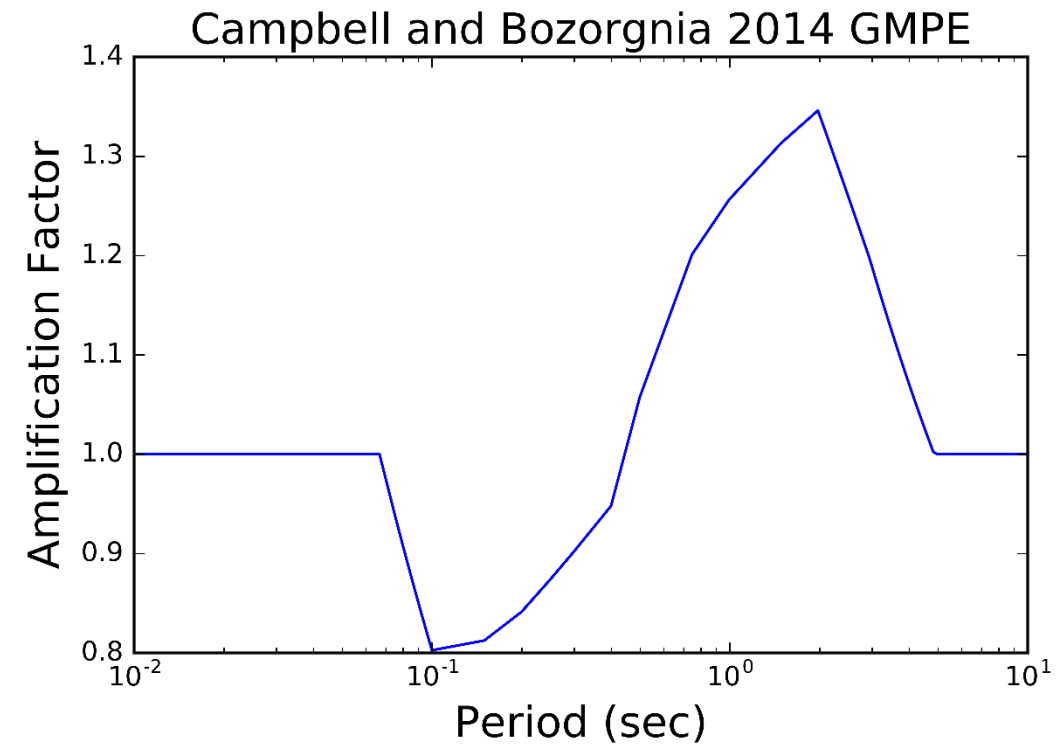
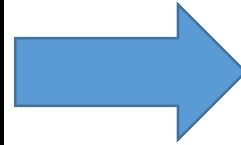
# Site Effects



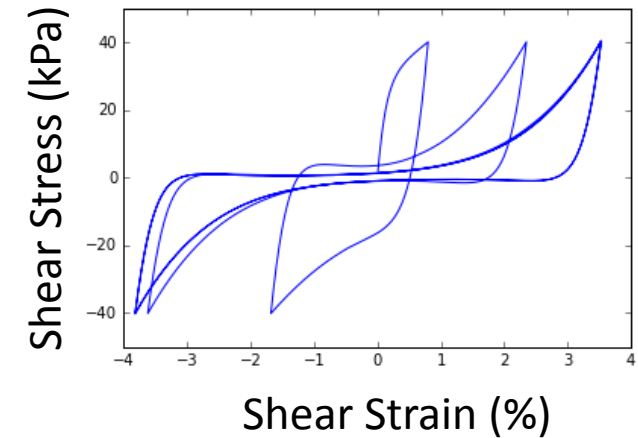
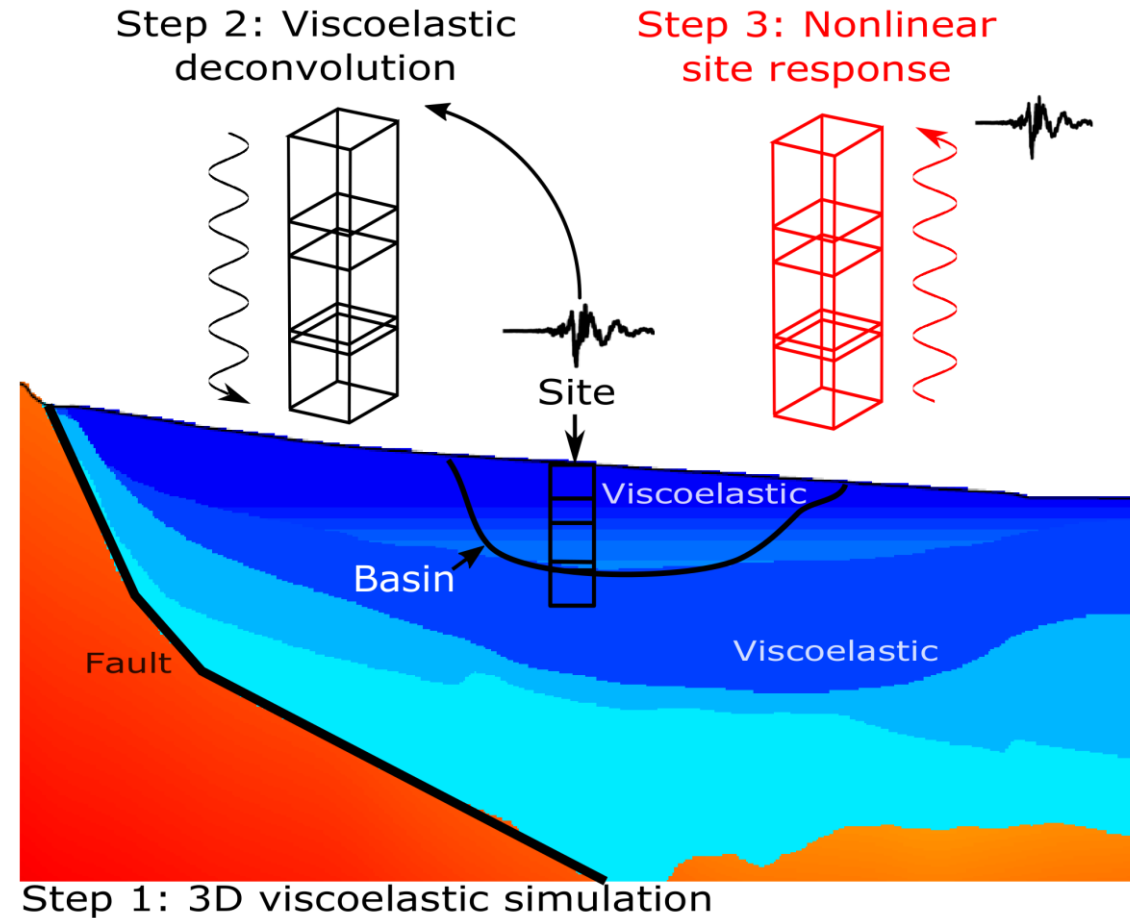
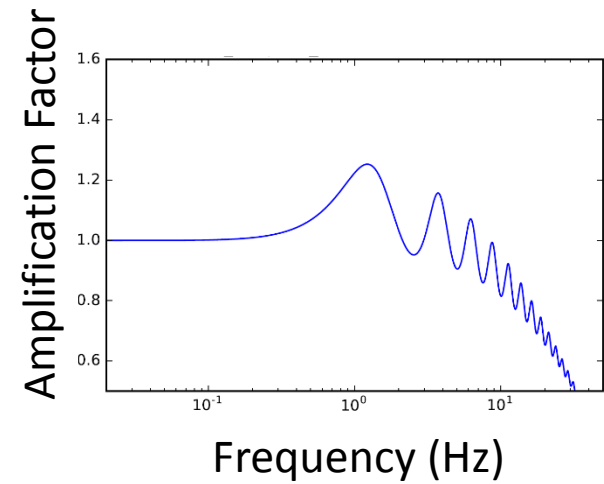
# Empirical $V_{S30}$ -Based Factors



$V_{S30}$ , PGA



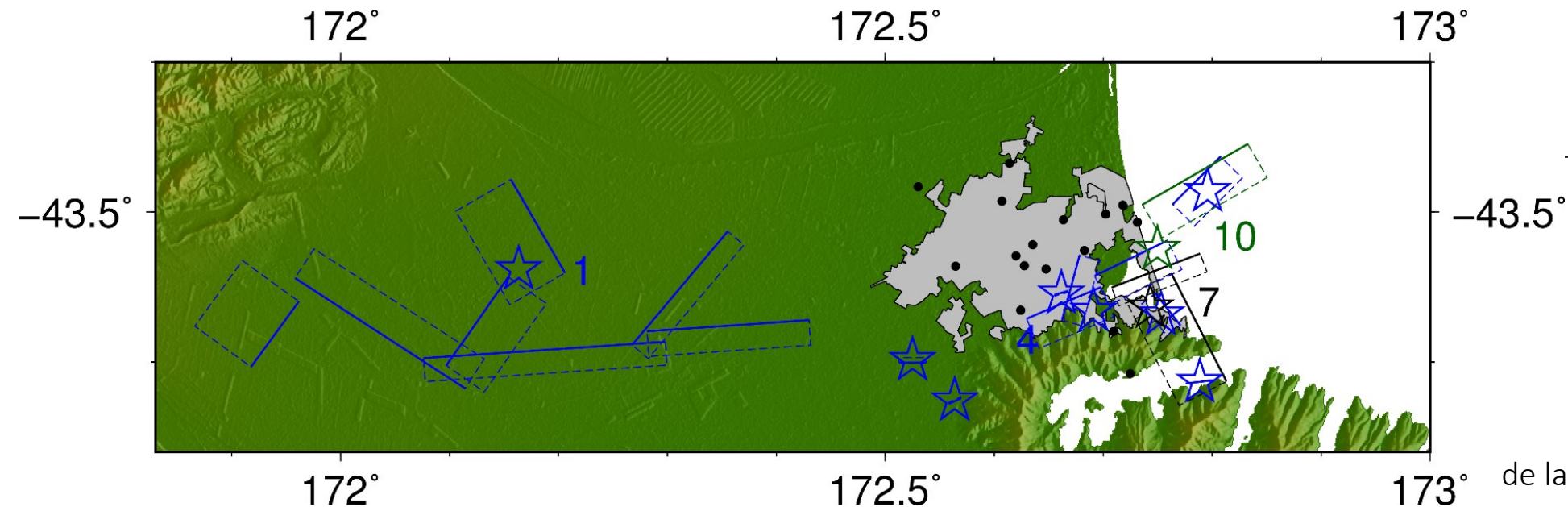
# 1D Wave Propagation Site Response



# Simulations of 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

Event Date	$M_W$	Event ID
04/09/2010	7.1	1
19/10/2010	4.8	2
26/12/2010	4.7	3
22/02/2011	6.2	4
16/04/2011	5.0	5
13/06/2011a	5.3	6
13/06/2011b	6.0	7
21/06/2011	5.2	8
23/12/2011a	5.8	9
23/12/2011b	5.9	10

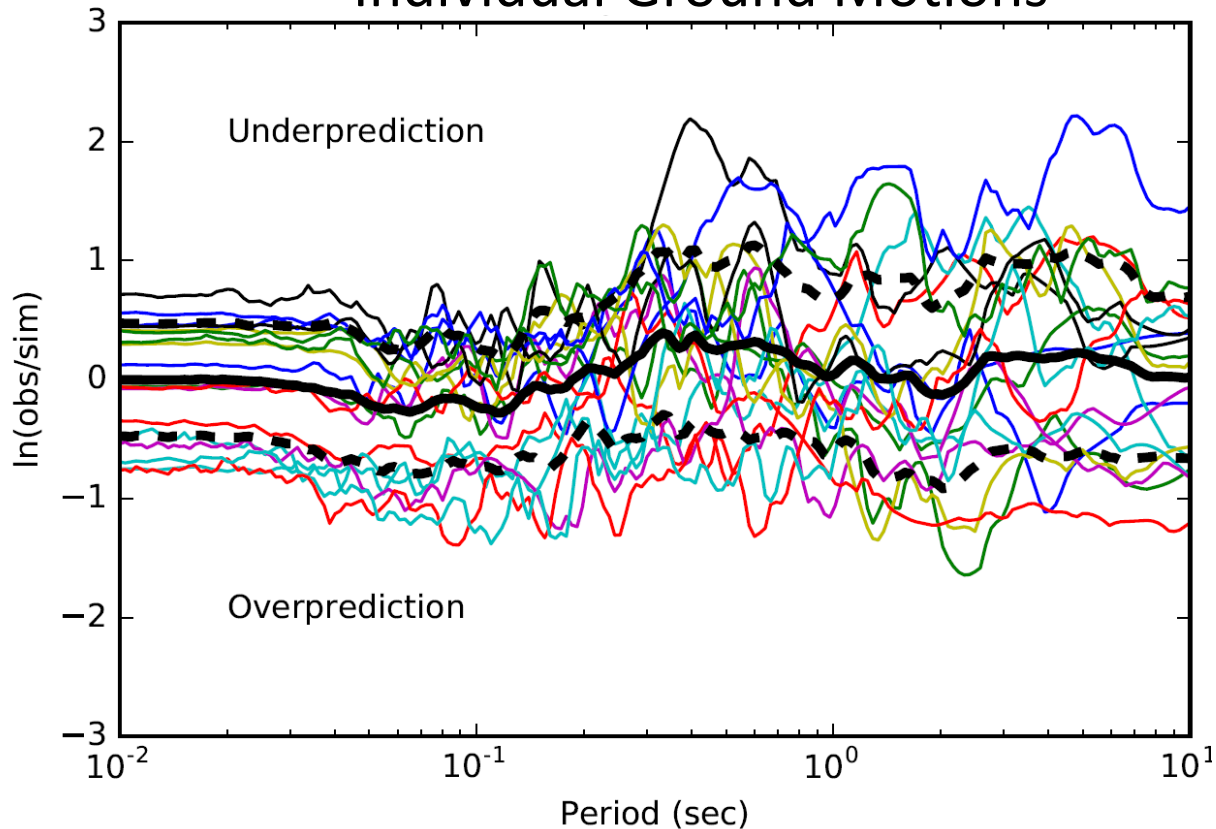


de la Torre et al. (2017)

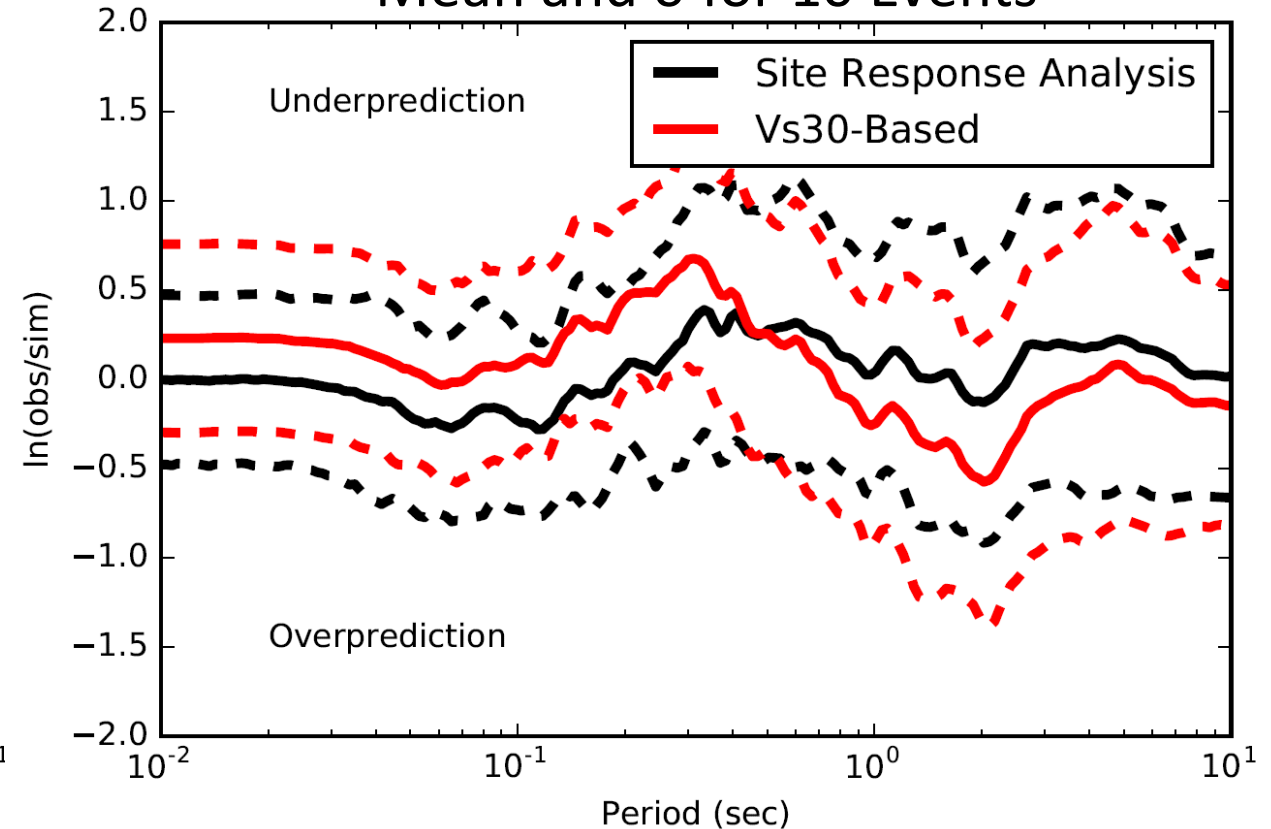
# Metric for Quality of Simulations

- Residual =  $\ln(\text{PSA}_{\text{Observed}}) - \ln(\text{PSA}_{\text{Simulated}})$

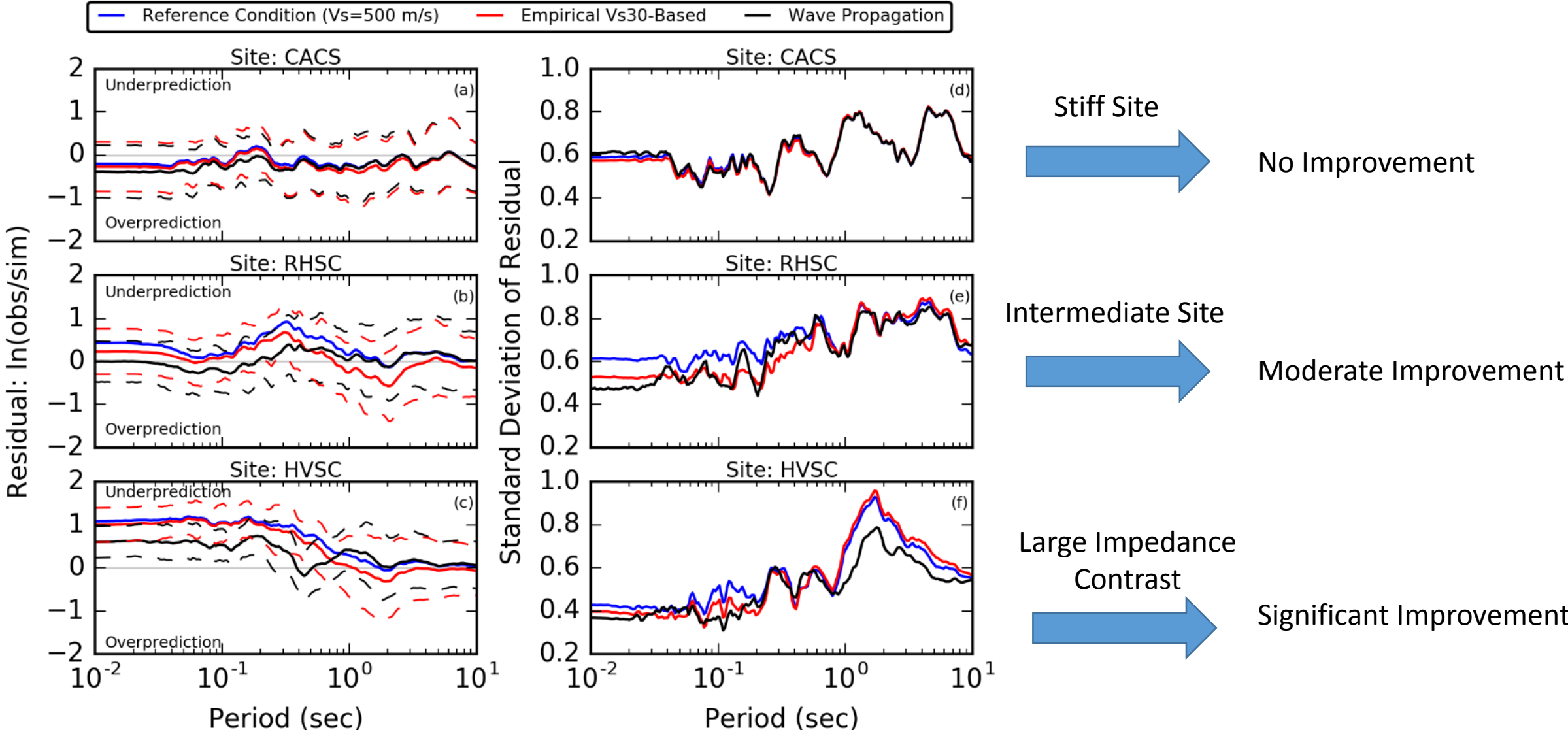
## Individual Ground Motions



## Mean and $\sigma$ for 10 Events

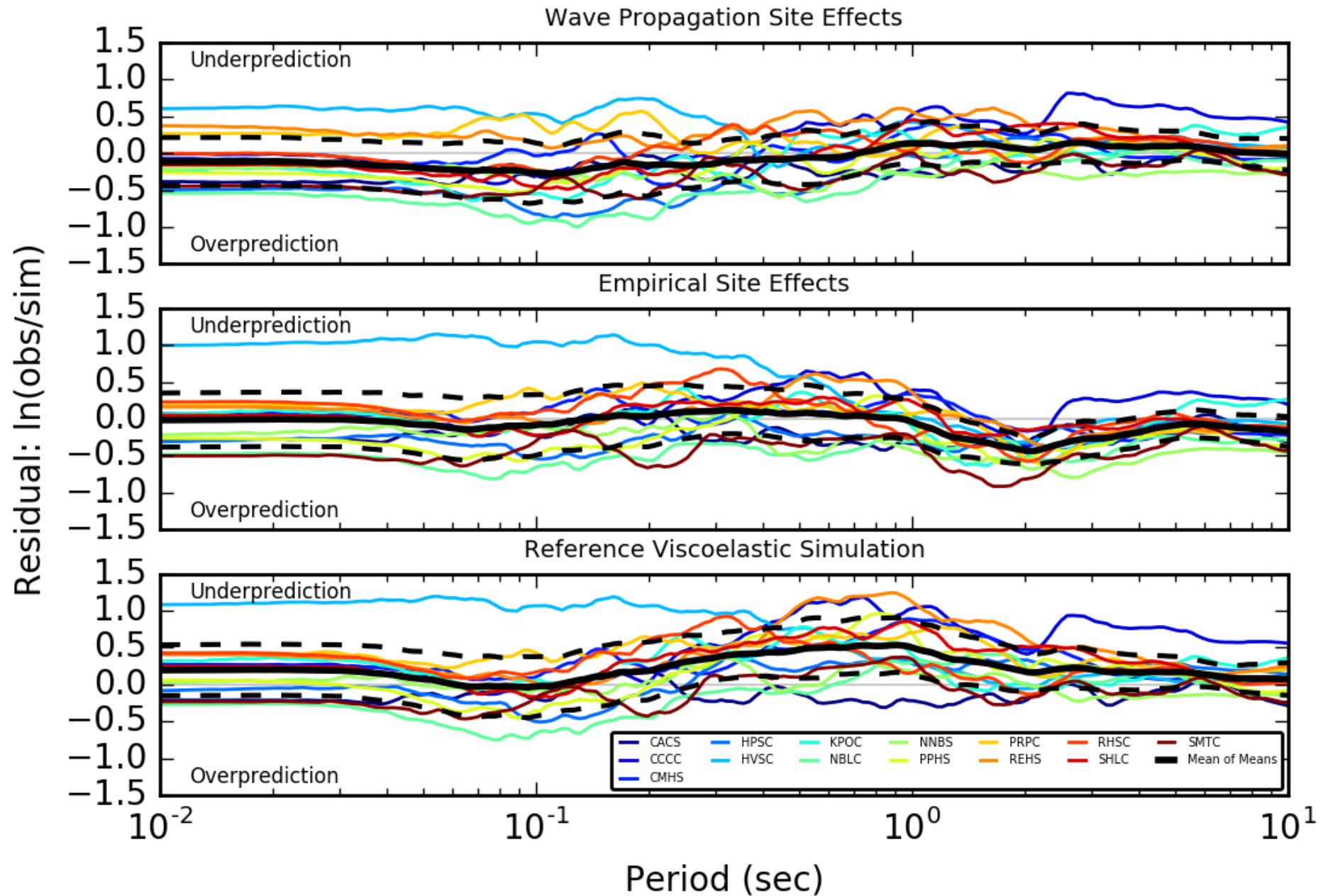


# Example Results: 3 Sites

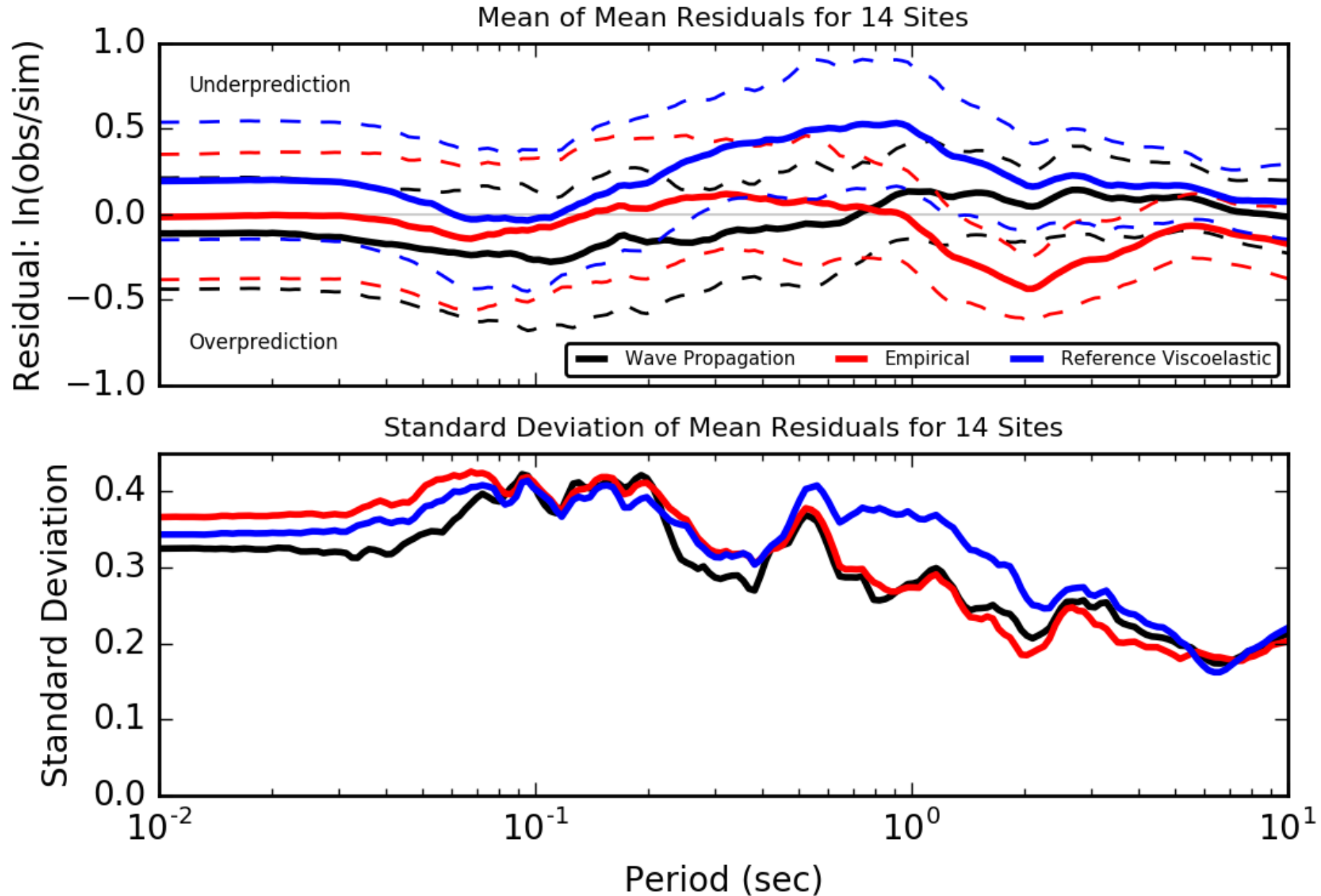




# Results for 14 Sites

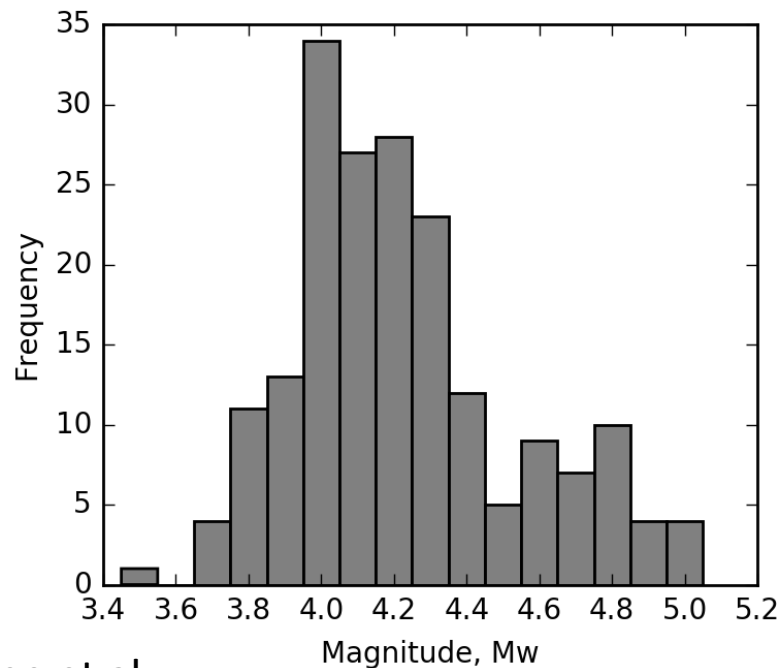


# Mean Results for 14 Sites

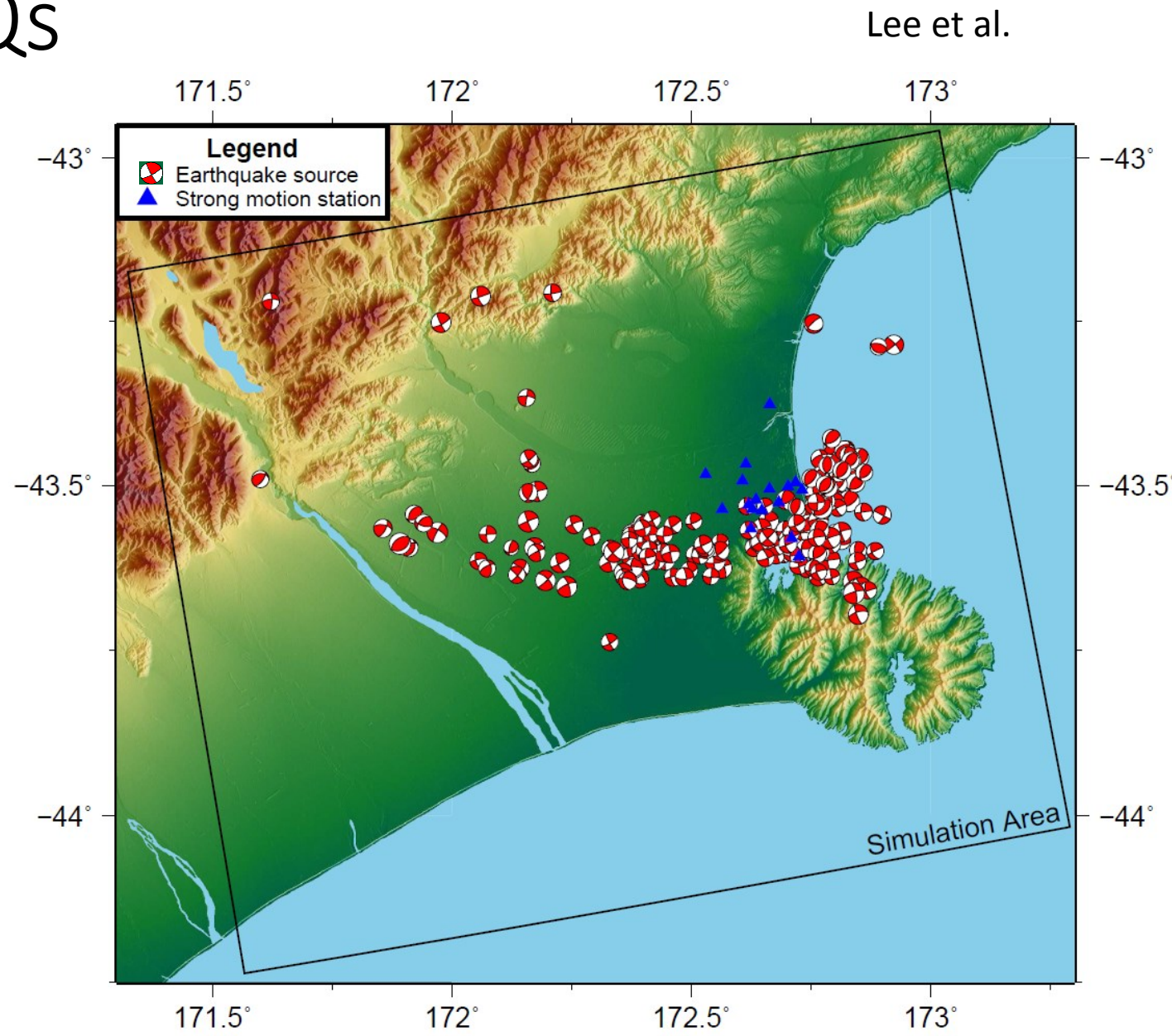


# Extension to More EQs

- 192 EQs
  - Mw 3.5-5.0
- Site Response at same 17 SMS

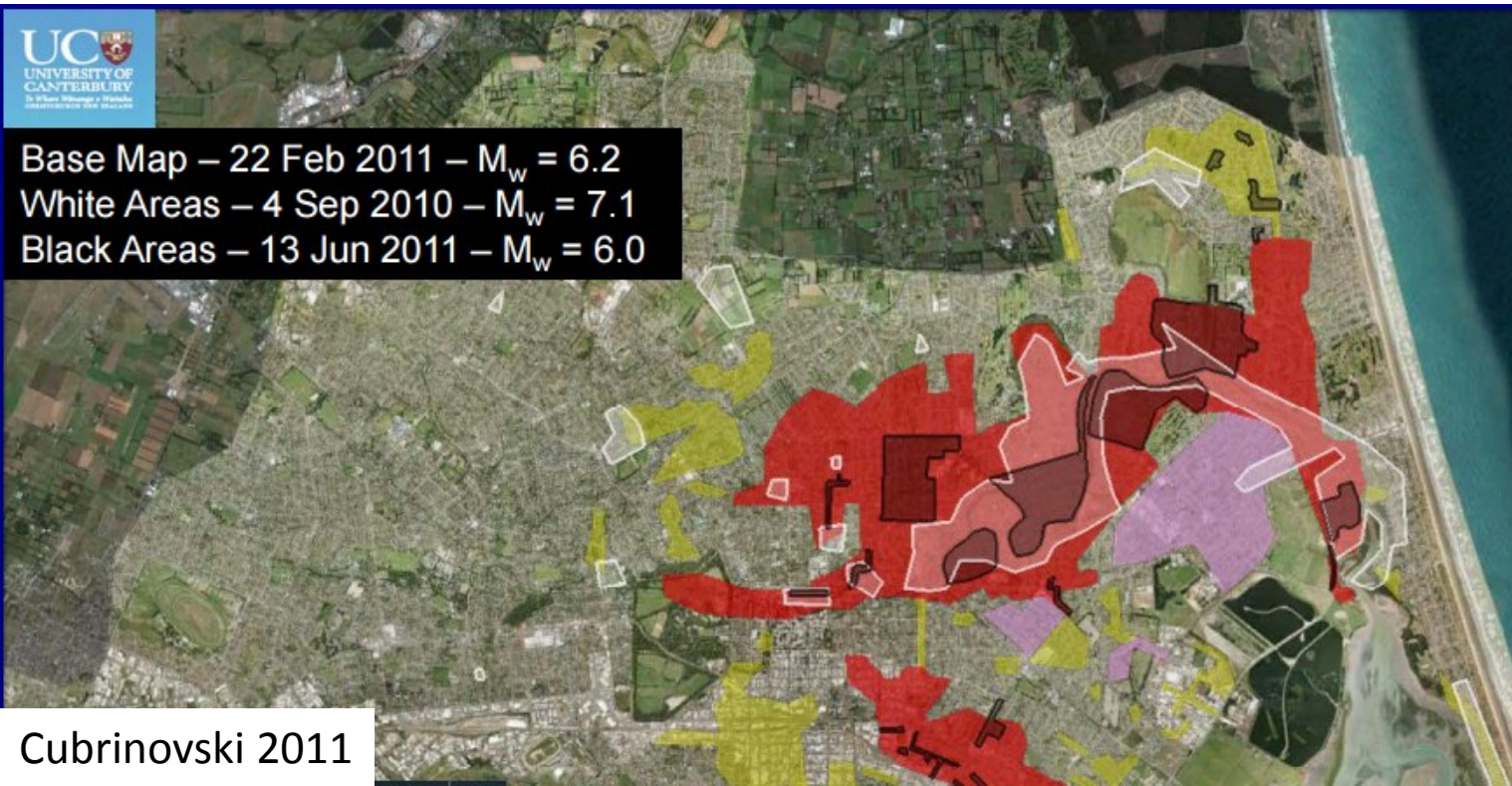


Lee et al.



# Effective Stress Site Response

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



# Extension to Other Regions: Wellington

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



# Site Investigations at CentrePort

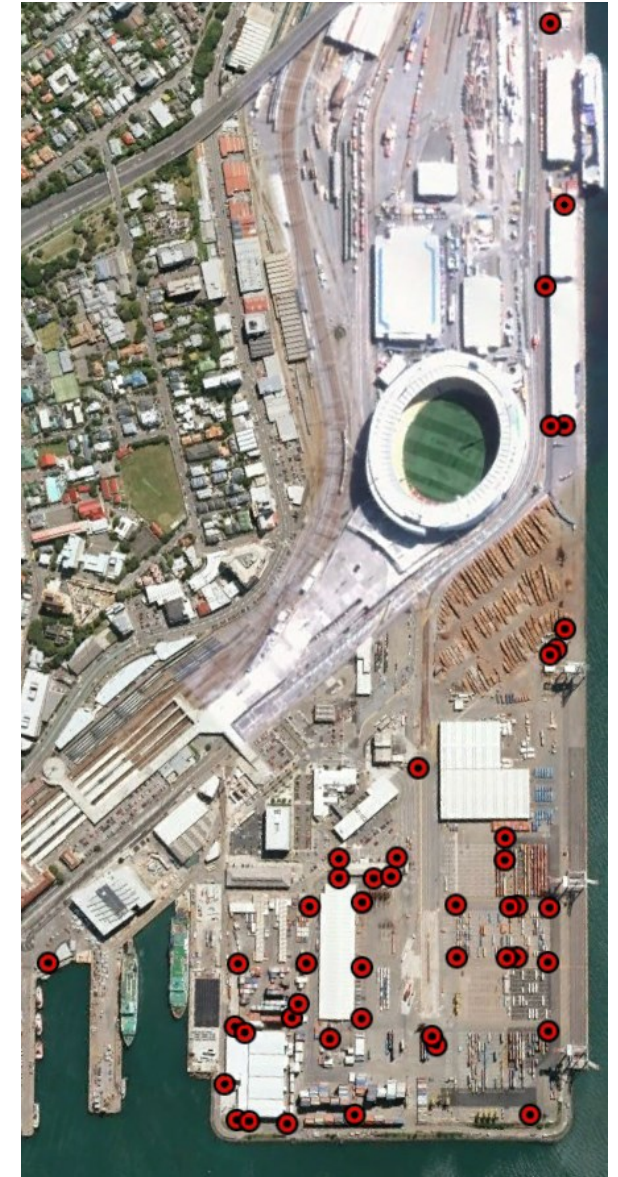
## Surface Wave Testing

- Active and passive arrays
- Wotherspoon and Cox



## CPT

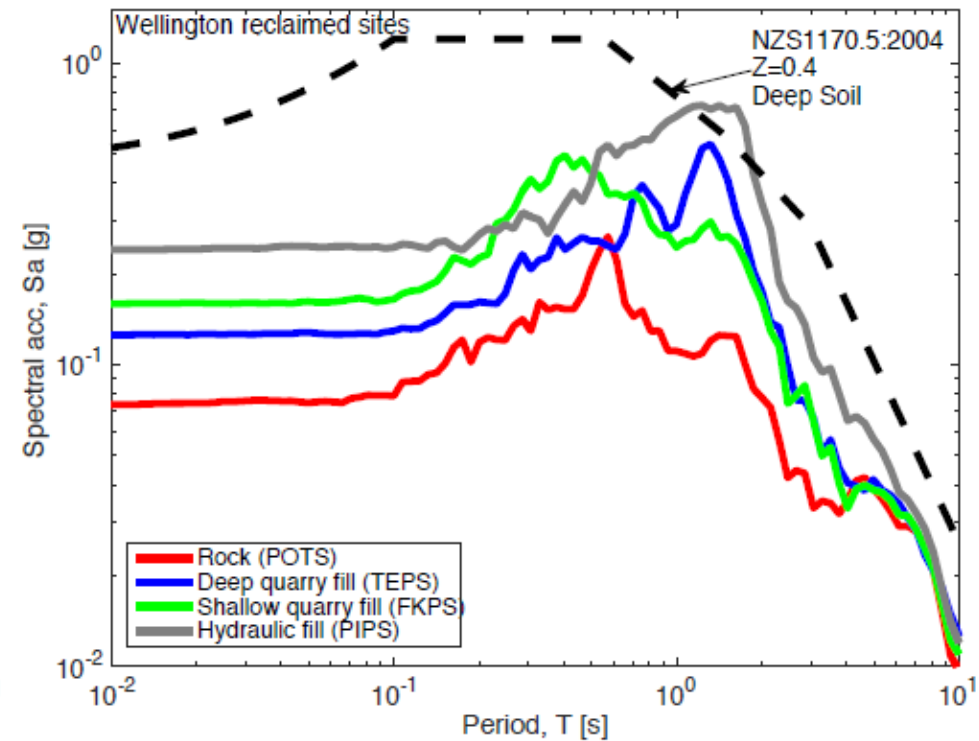
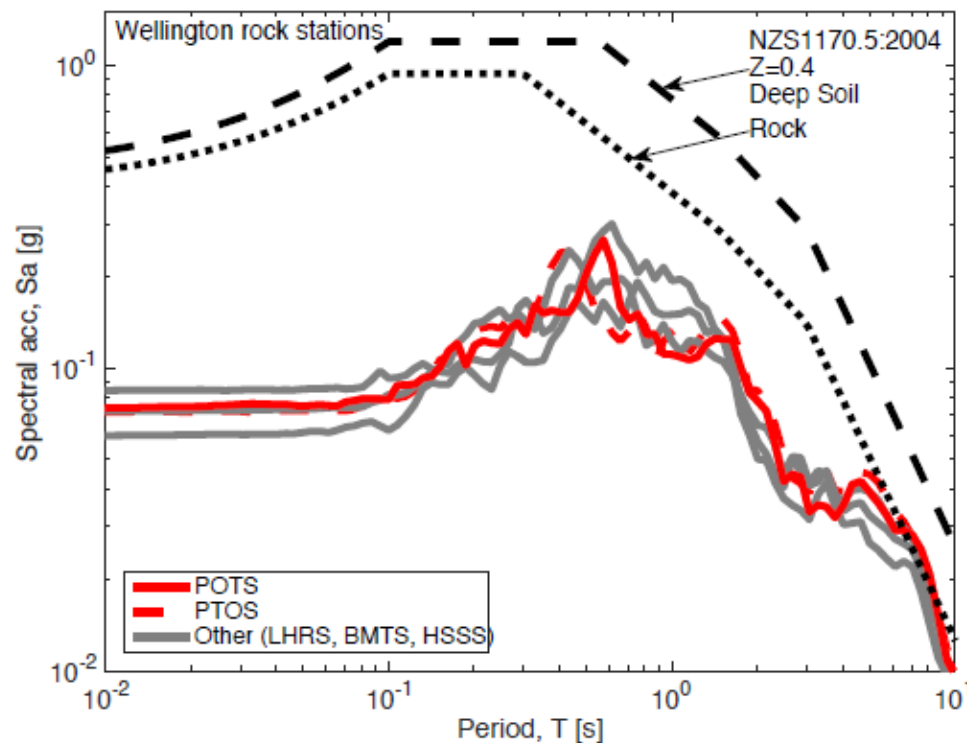
- 48 Locations
- Cubrinovski and Bray



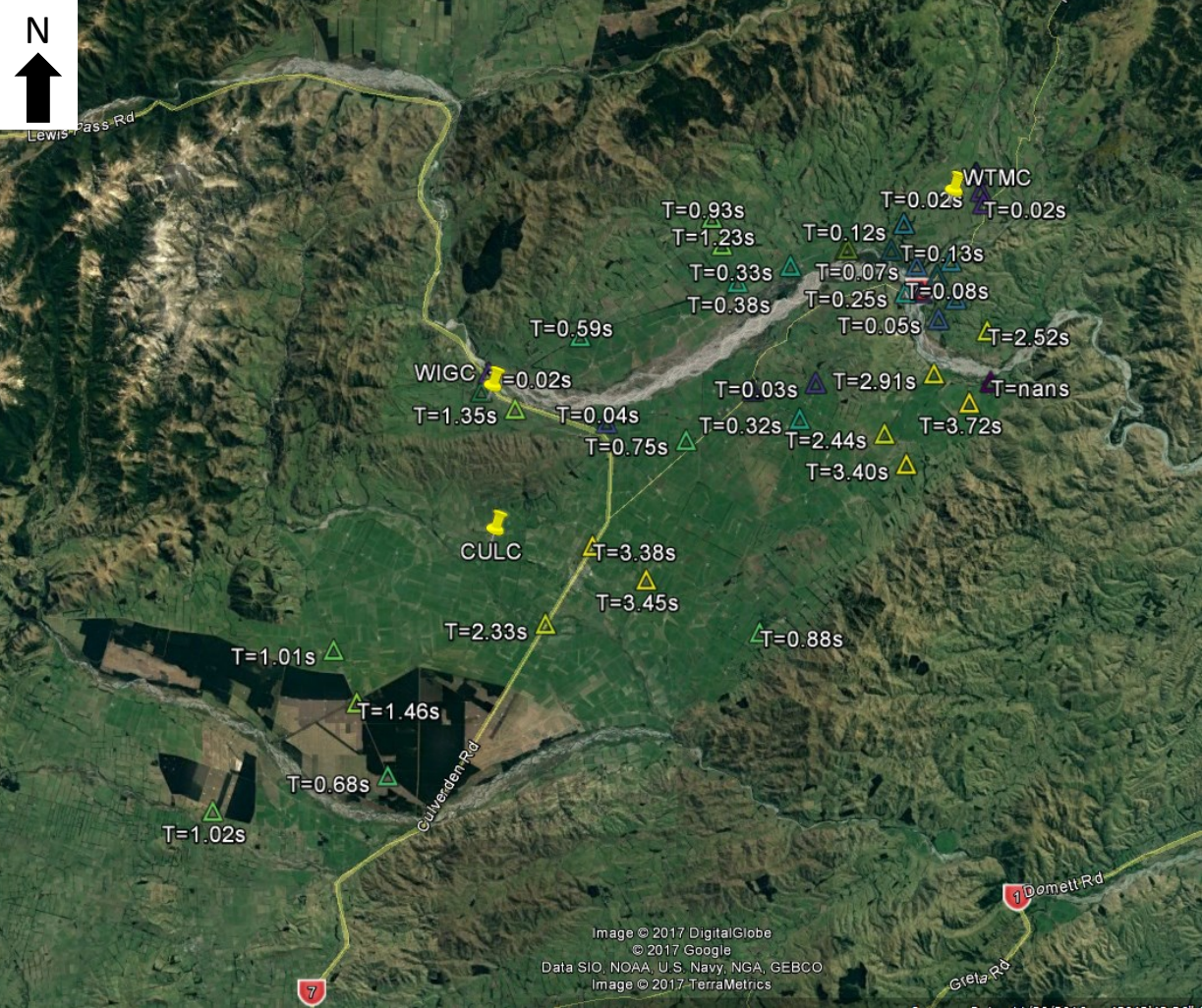
# Greater Wellington Area

- Several reference rock records
- Deep/shallow soil
- Native/reclaimed soil

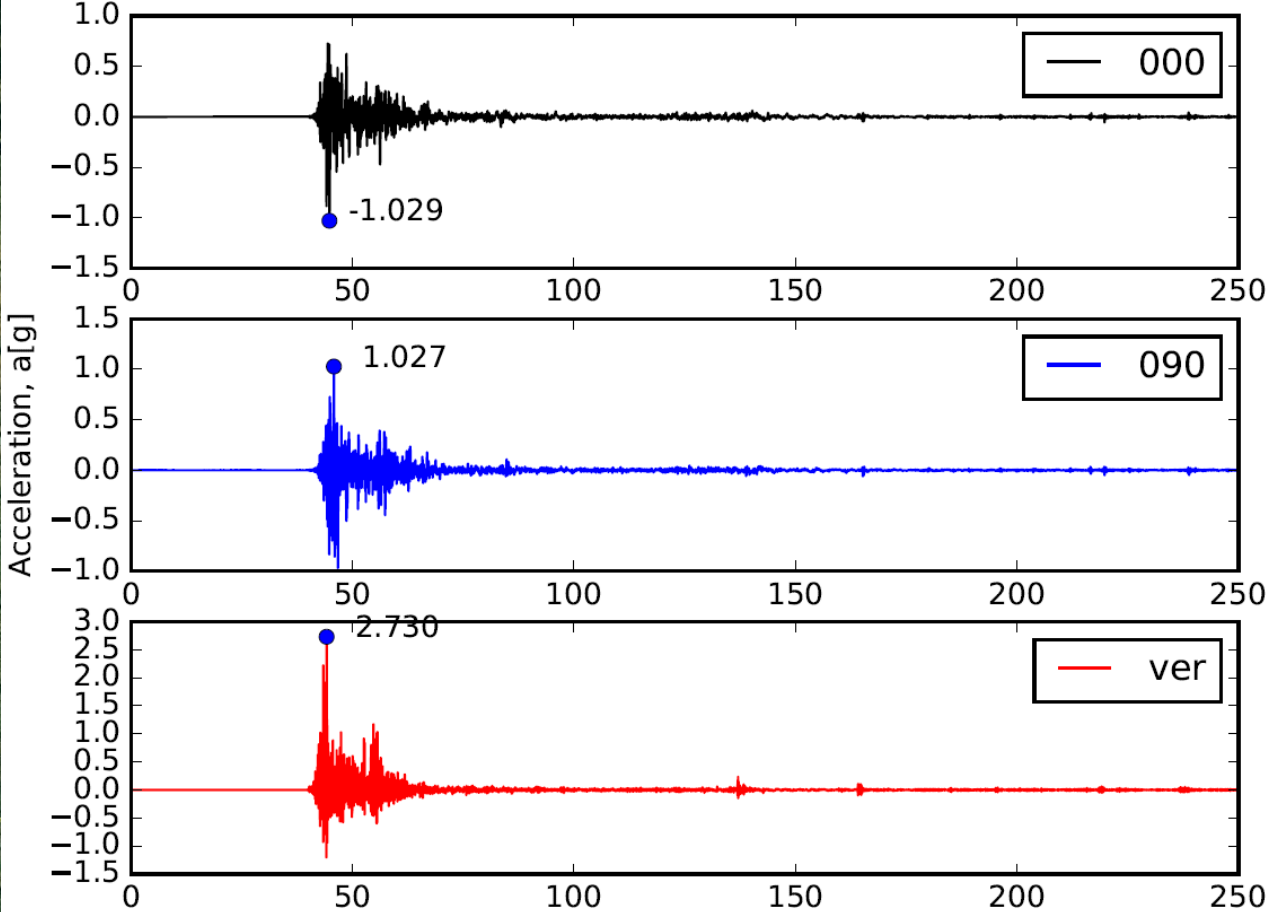
Bradley et al. (2017)



# Extension to Other Regions: Waiau



WTMC, PGA geometric mean=1.028





# Thank you!

- Acknowledgements:

- Funding:

- QuakeCoRE
    - University of Canterbury

- Advisors:

- Brendon Bradley
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