Creating a physics-based understanding of the spatial correlation of earthquake-induced ground motions in regions of complex geology

Robin Lee

University of Canterbury

QuakeCoRE Annual Meeting

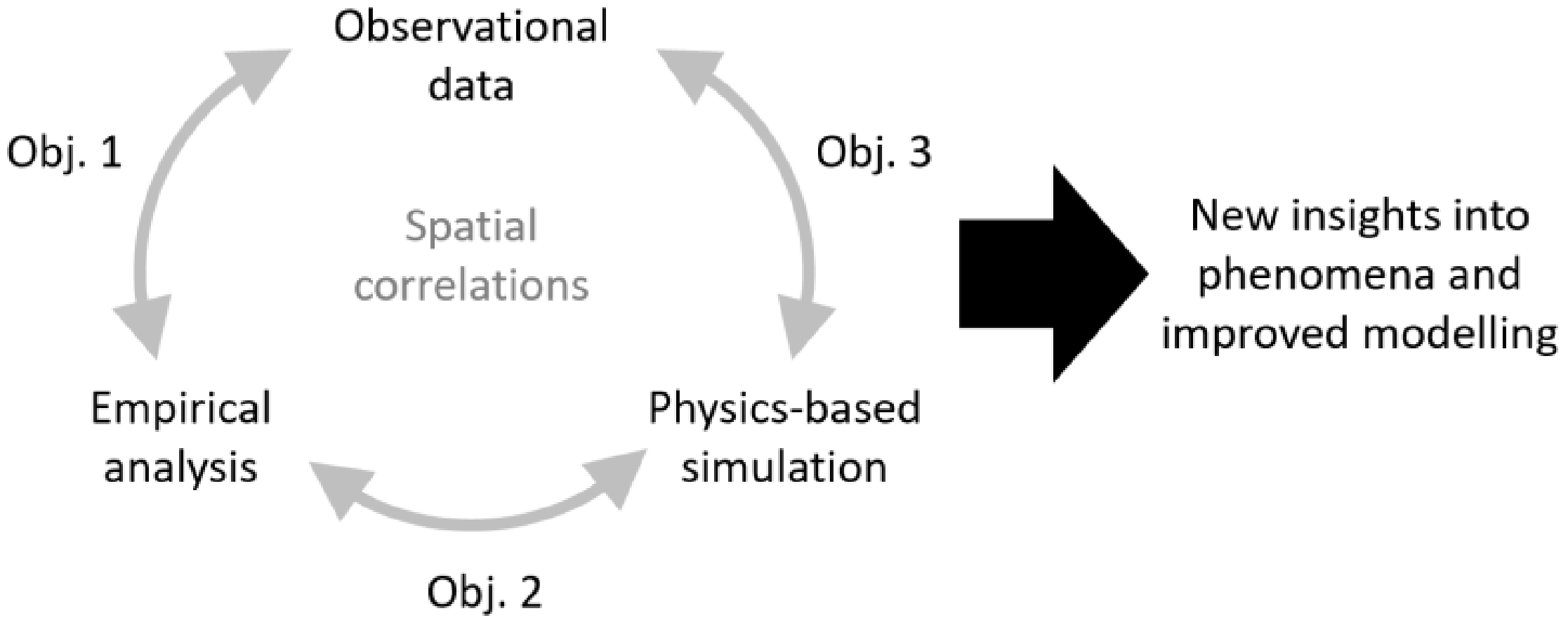
28/08/2023

Introduction

- Spatial correlations in ground motions are important for distributed assets:
  - Portfolios of buildings
  - Horizontal infrastructure
- For many years, traditional models of spatial correlation have been limited by observed data density.
- Recently, this has been (partially) alleviated by:
  - Increase in station density and instrument quality = more observations
  - High fidelity physics-based ground motion simulations
- Existing and currently improving NZ datasets provides opportunity to:
  - Advance spatial correlation modelling
  - Validate spatial correlations in physics-based ground motion simulations

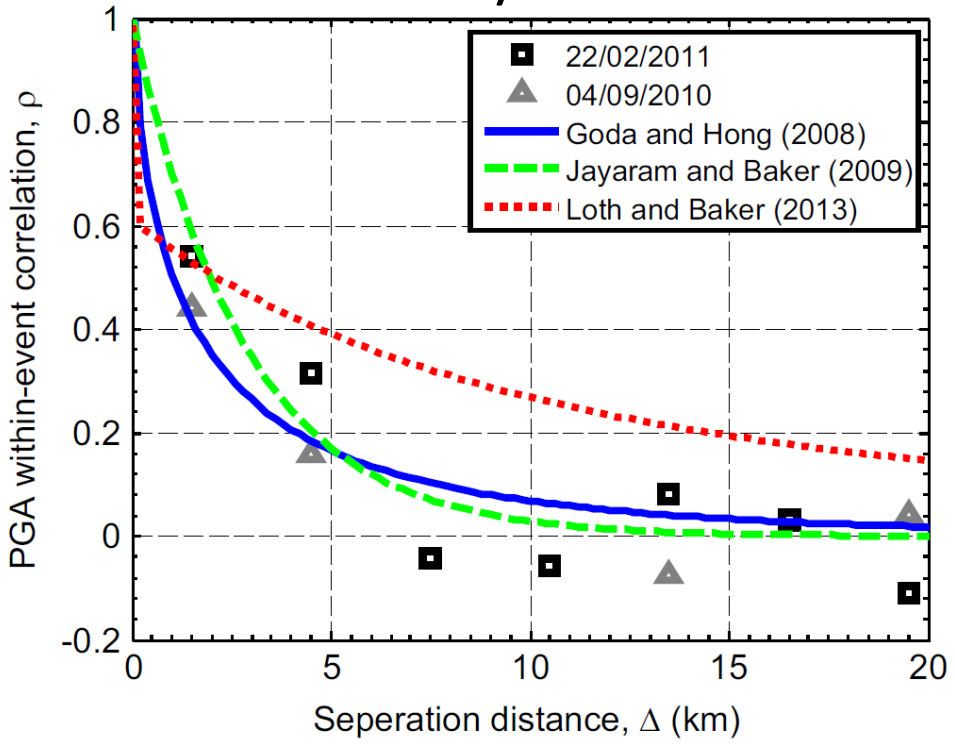
Introduction

- “Domain Map” of the project.

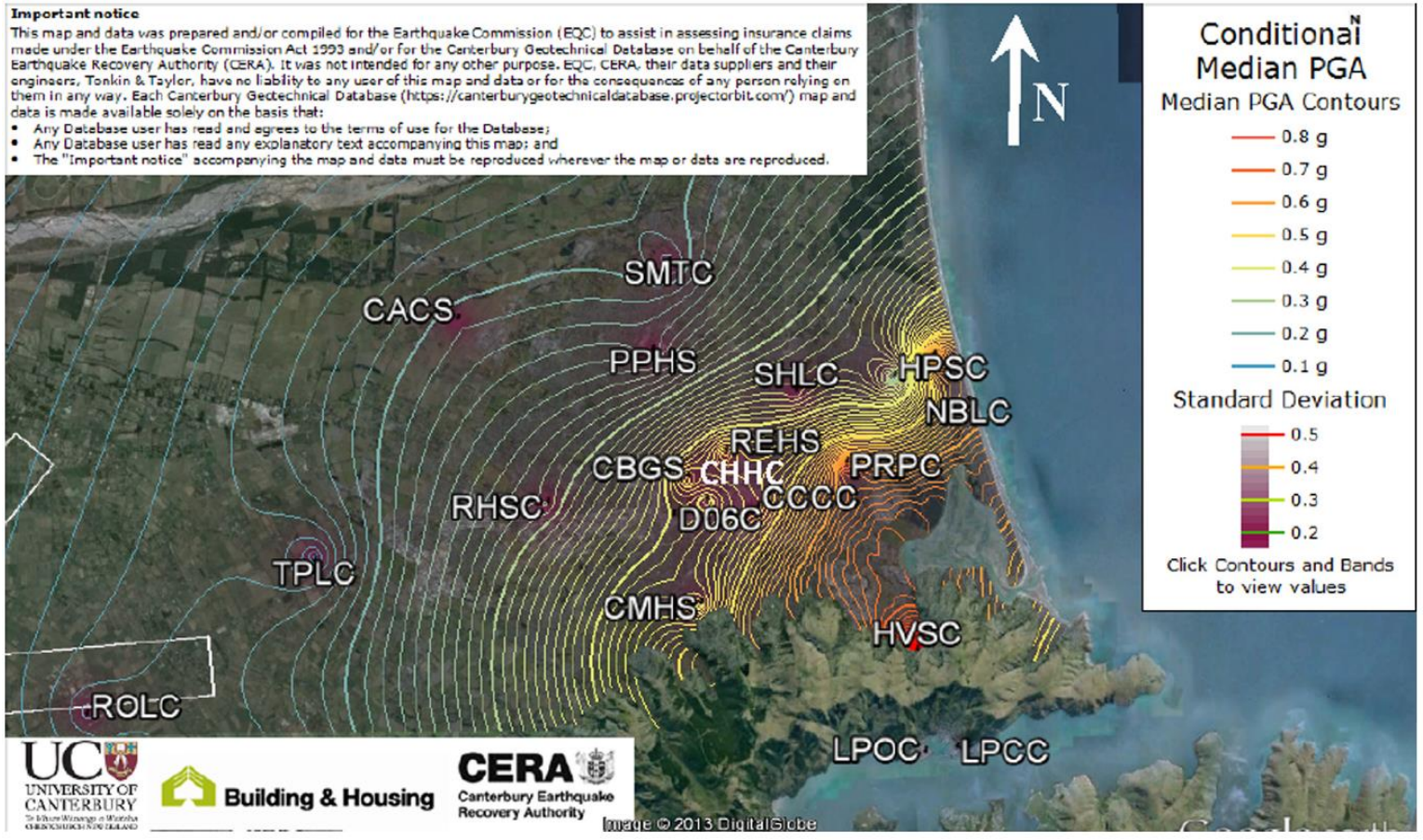


Objective 1: Analysis of Observational Data

- NZ-based studies on spatial correlation of observational data:
  - Bradley (2014) - Site-specific and spatially-distributed ground-motion intensity estimation in the 2010–2011 Canterbury earthquakes.



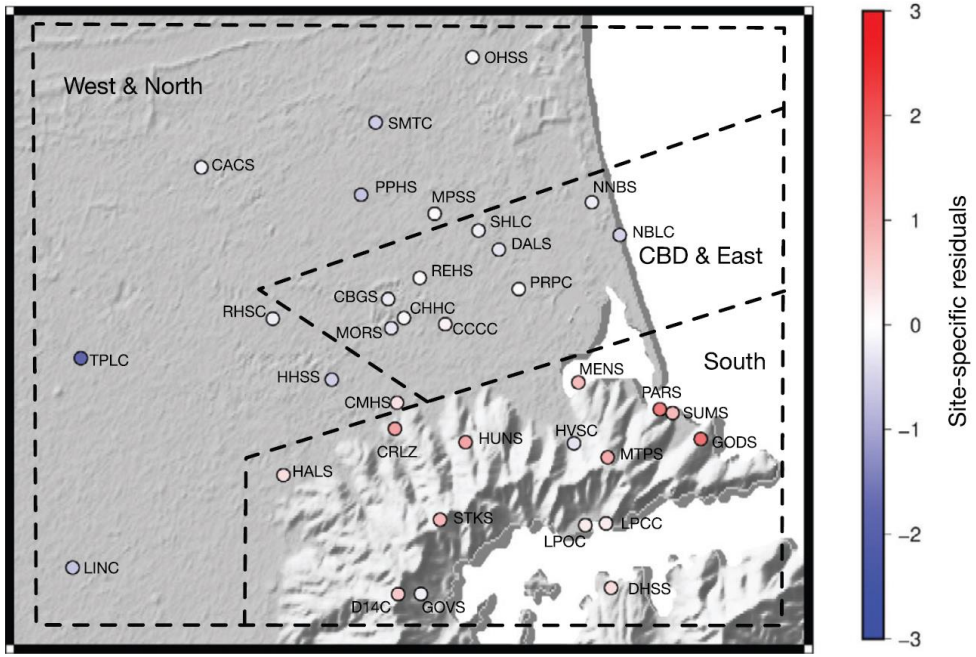
(Bradley 2014 SDEE)



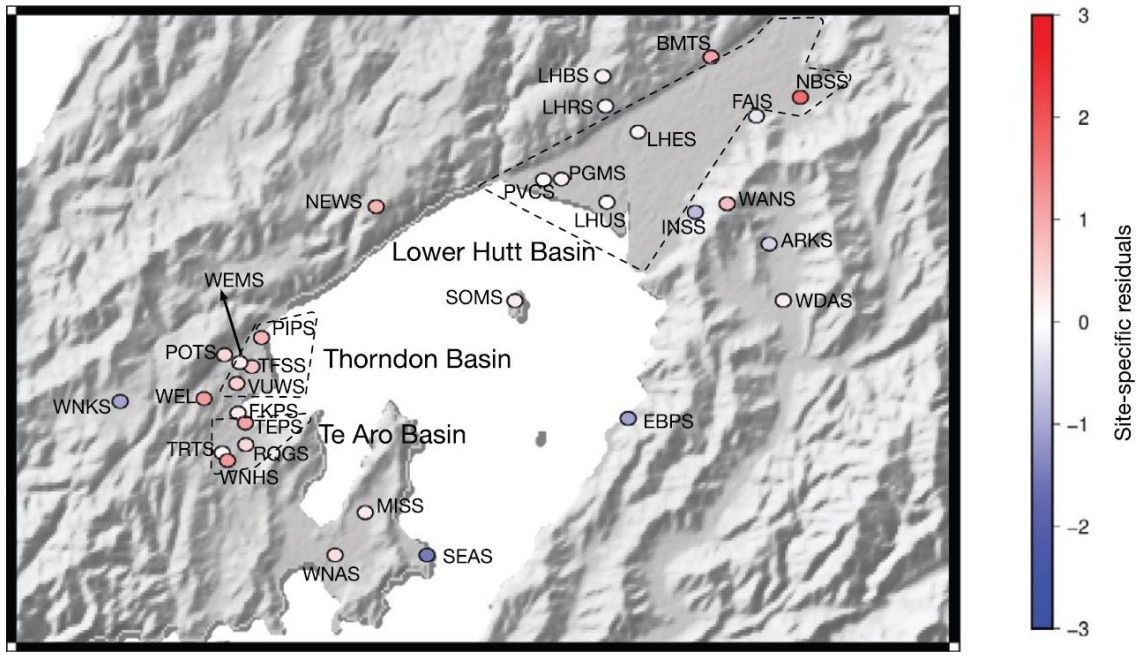
Objective 1: Analysis of Observational Data

- NZ-based studies on spatial correlation of observational data:
  - Chen et al. (2021) - Non-Stationary Spatial Correlation in New Zealand Strong Ground-Motion Data

Christchurch



Wellington



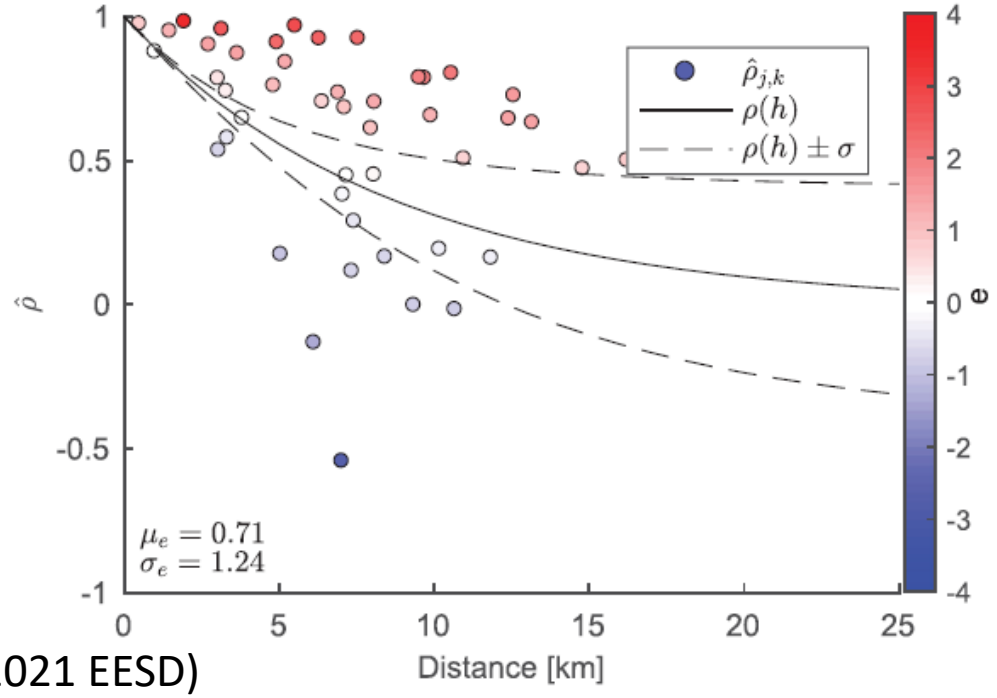
(Chen et al. 2021 EESD)

Objective 1: Analysis of Observational Data

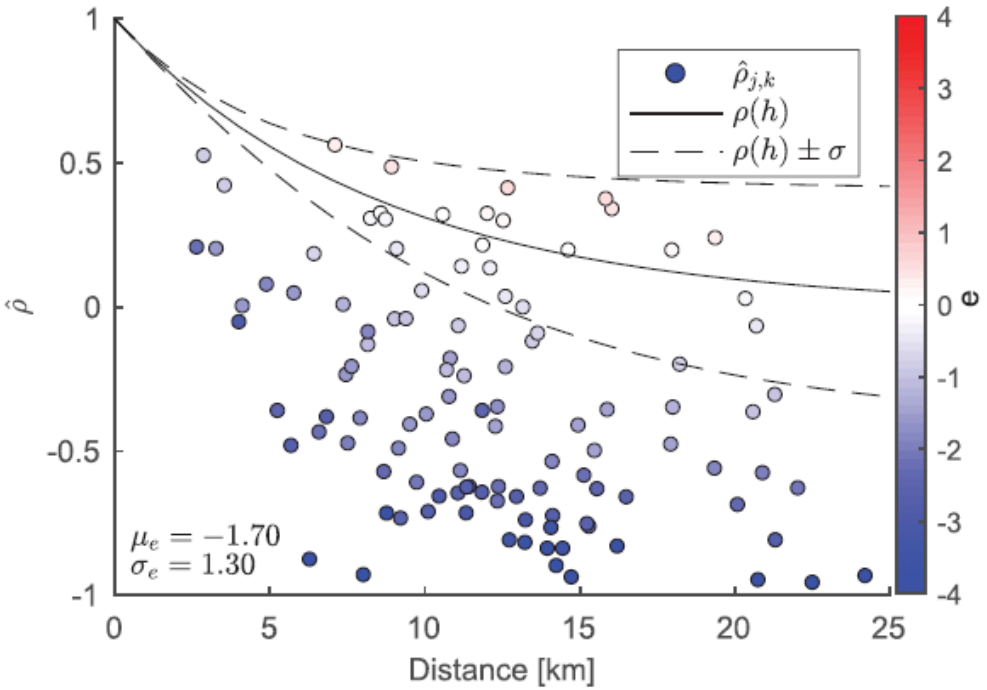
- NZ-based studies on spatial correlation of observational data:
  - Chen et al. (2021) - Non-Stationary Spatial Correlation in New Zealand Strong Ground-Motion Data

Christchurch

Stations Within South Only



South Stations To Other Subregion

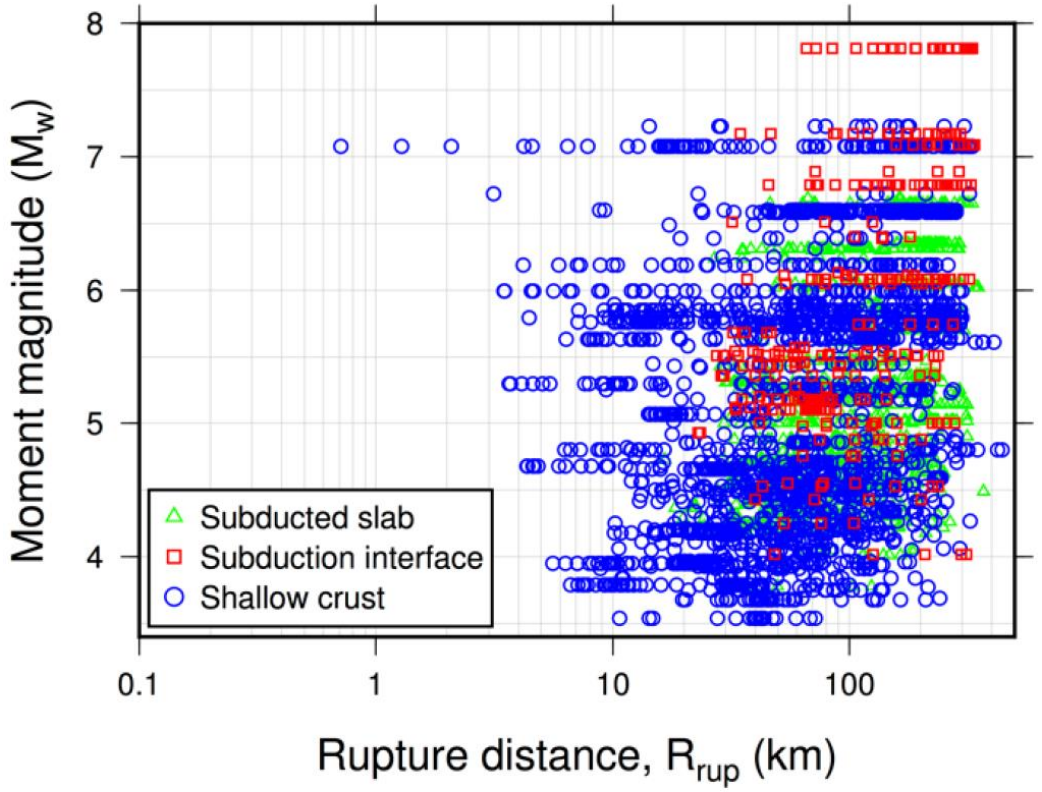


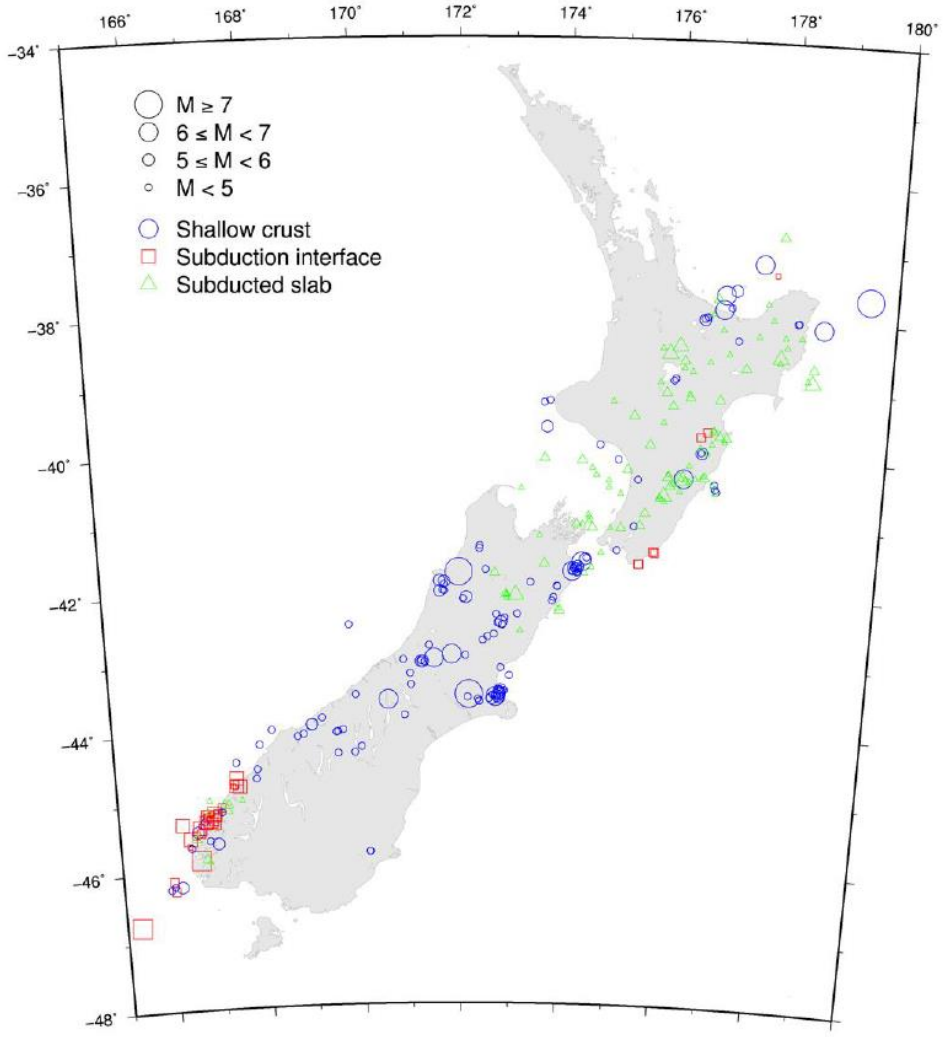
(Chen et al. 2021 EESD)

Objective 1: Analysis of Observational Data

- Chen et al. (2021) used the NZ SMDB Van Houtte et al. (2017).

	Earthquakes	Stations	Records
Van Houtte et al. (2017)	277	415	4,309

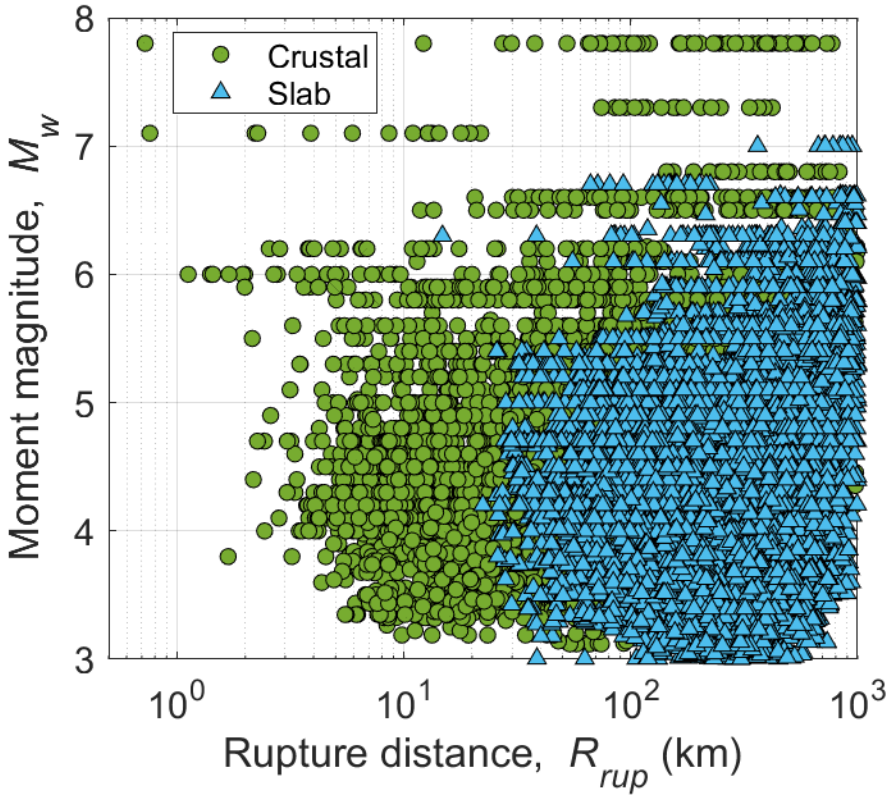


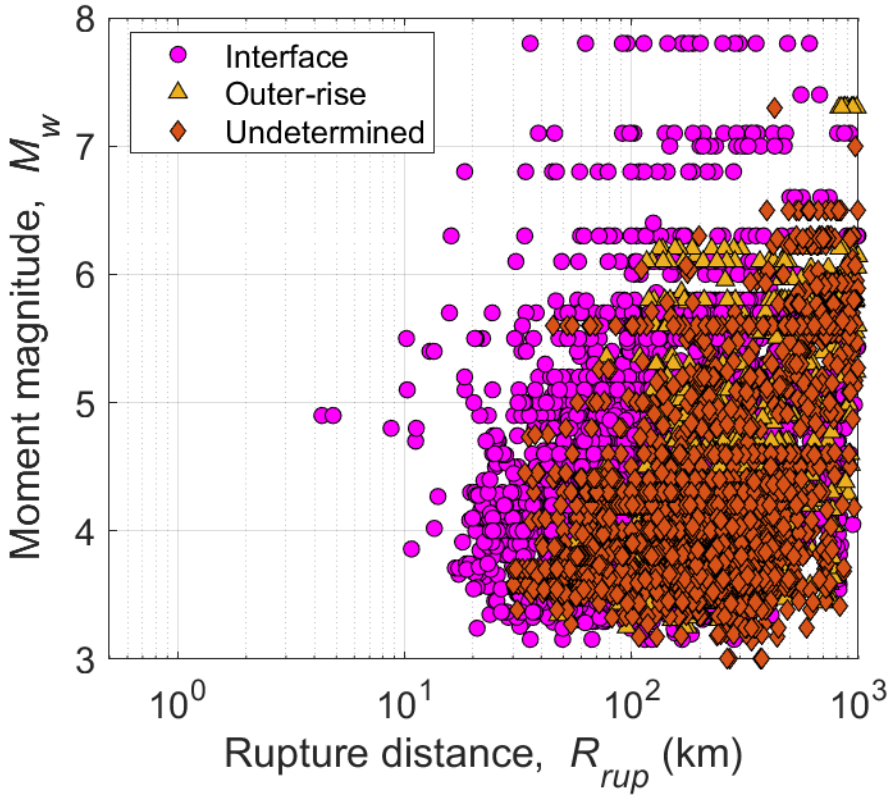


Objective 1: Analysis of Observational Data

- Recently-developed NZ GMDB v3.3 Hutchinson et al. (2023).

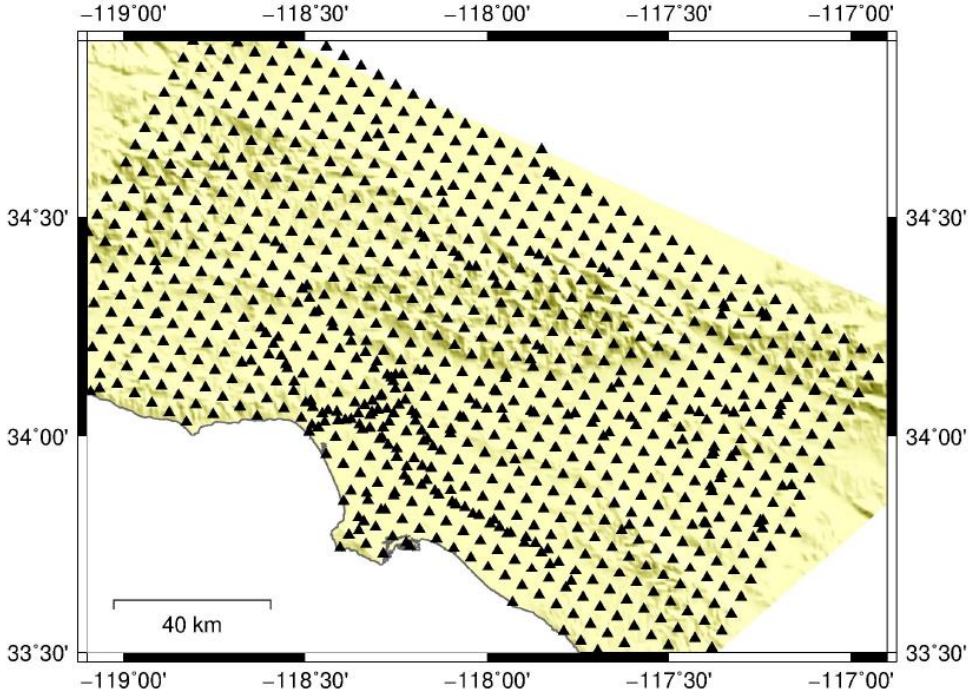
	Earthquakes	Stations	Records
Van Houtte et al. (2017)	277	415	4,309
Hutchinson et al. (2023)	5067	359	32,348

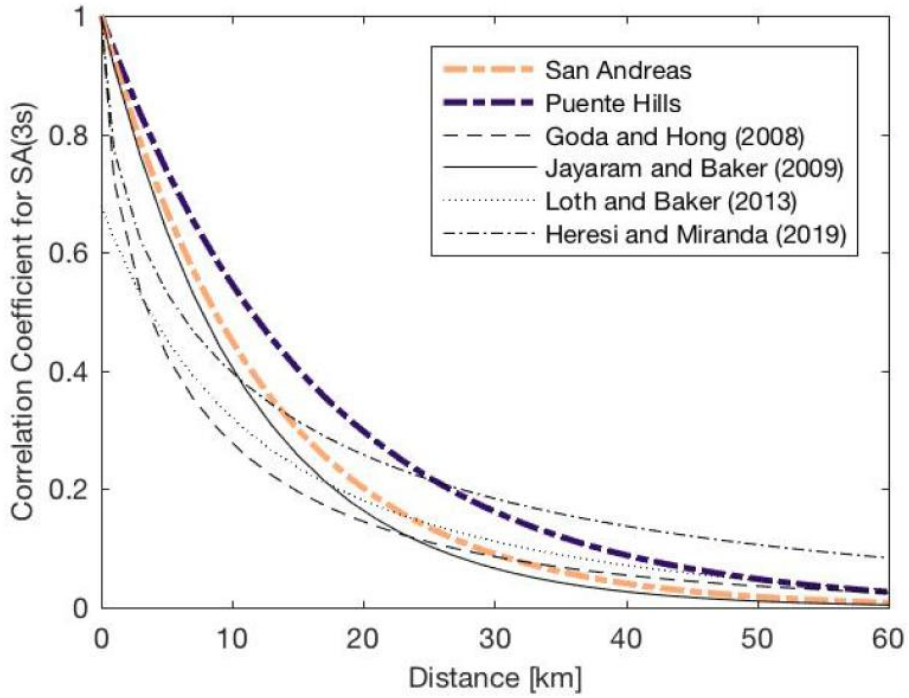




Objective 2: Analysis of Simulations

- Studies on spatial correlation of physics-based ground motion simulations:
  - Chen and Baker (2019) - Spatial correlations in CyberShake physics-based ground motion simulations.



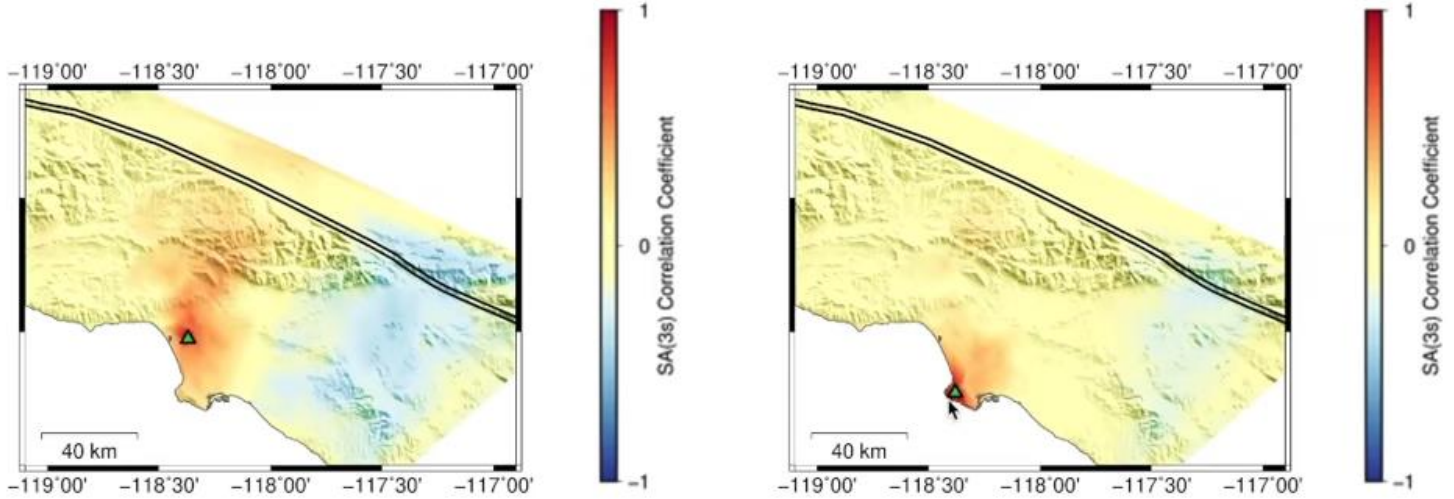


(Chen and Baker 2019 BSSA)

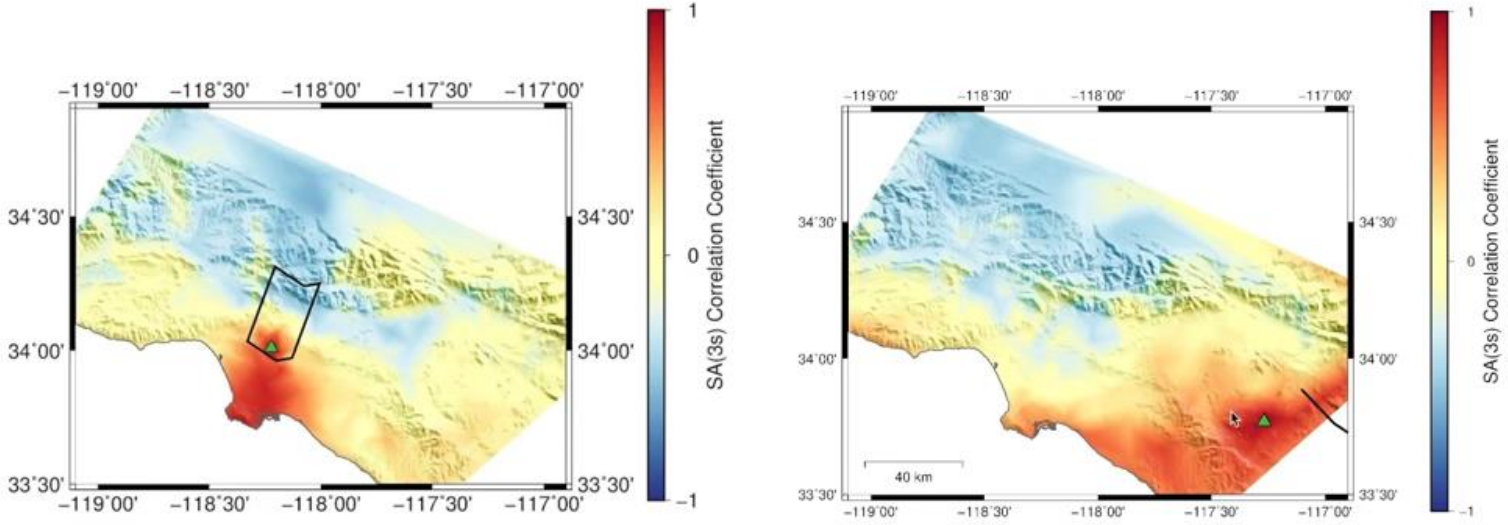
Objective 2: Analysis of Simulations

- Chen and Baker (2019) identified correlation structures in the simulations.

Influence of Geology:



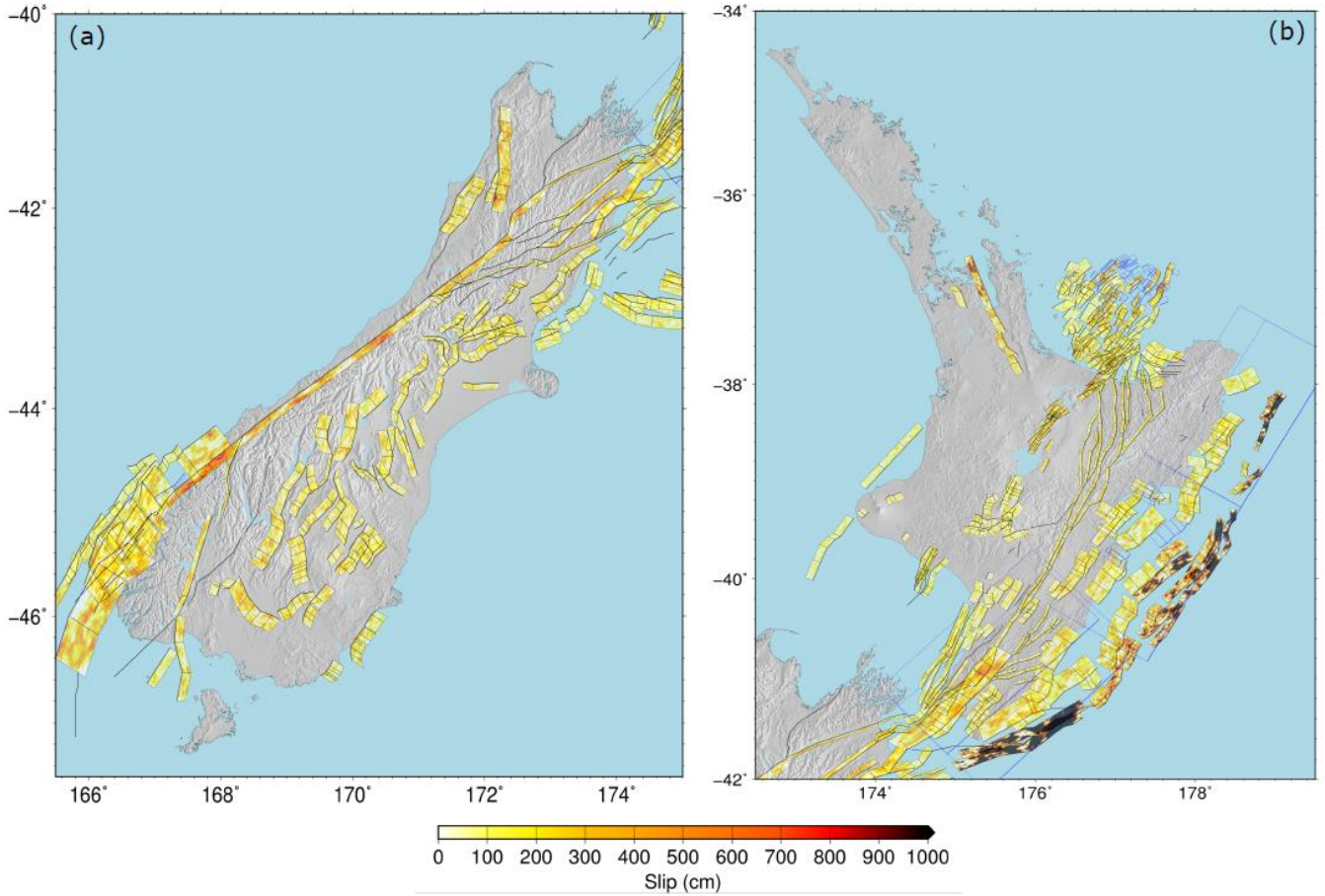
Influence of Source-to-Site Azimuth:



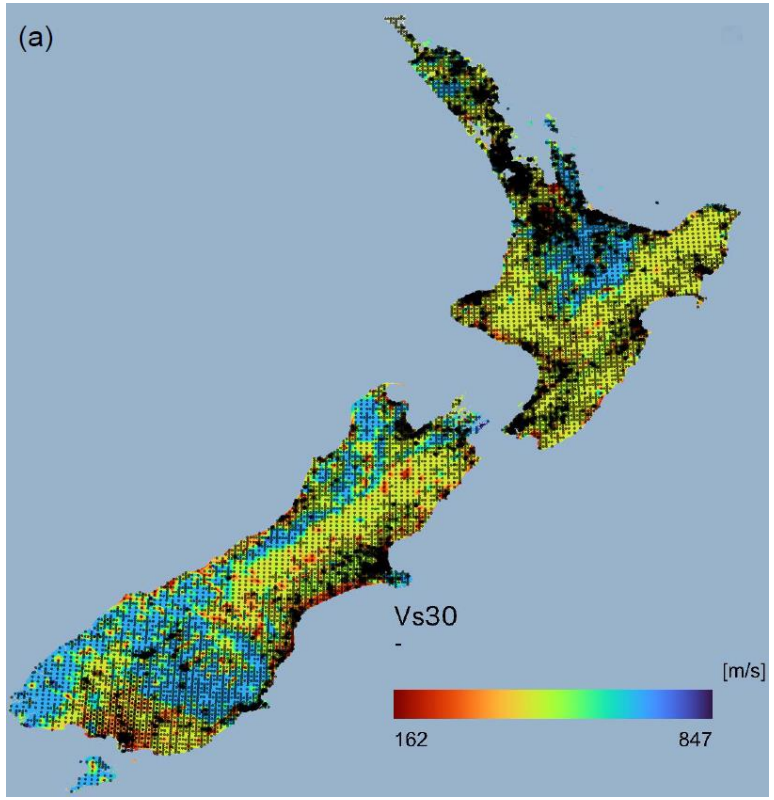
Objective 2: Analysis of Simulations

- CybershakeNZ

Seismic Source Model (~400-500)



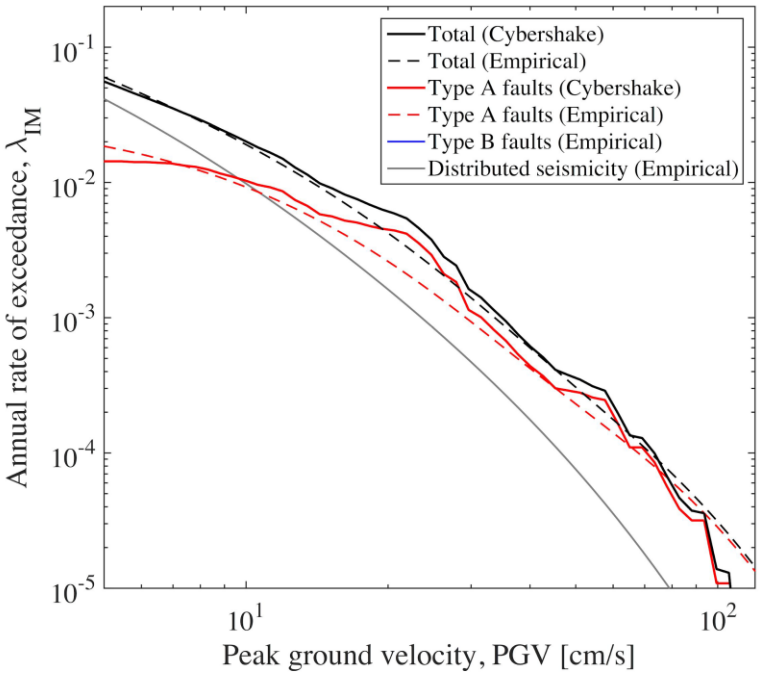
Simulation Output Locations (25948)

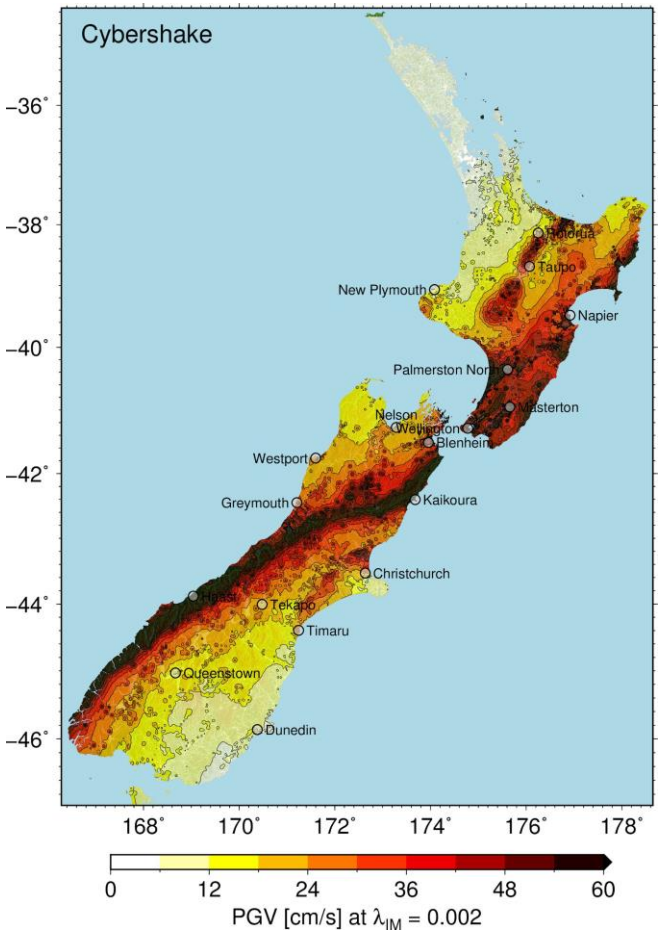


Objective 2: Analysis of Simulations

- CybershakeNZ

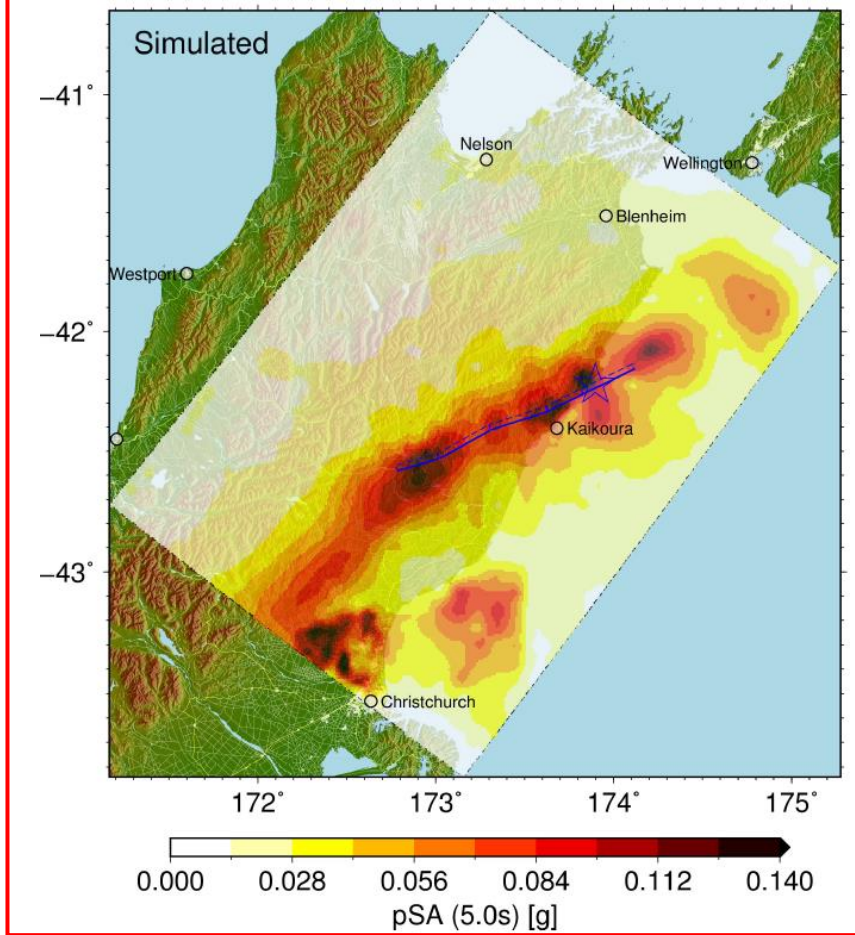
Typical Hazard Results from CyberShakeNZ





(Tarbali et al. 2018, 2019)
(Motha et al. 2020)
(Bae et al. 2023)

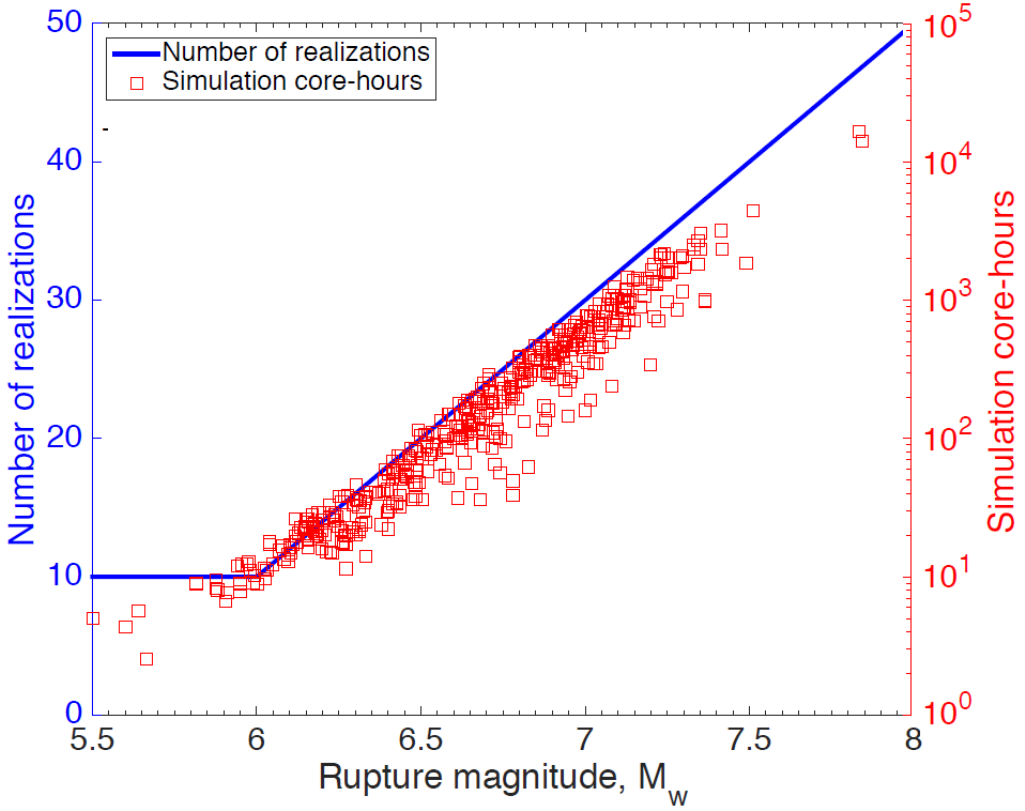
Each Simulation Results in Prediction of Ground Motion Intensity Measures



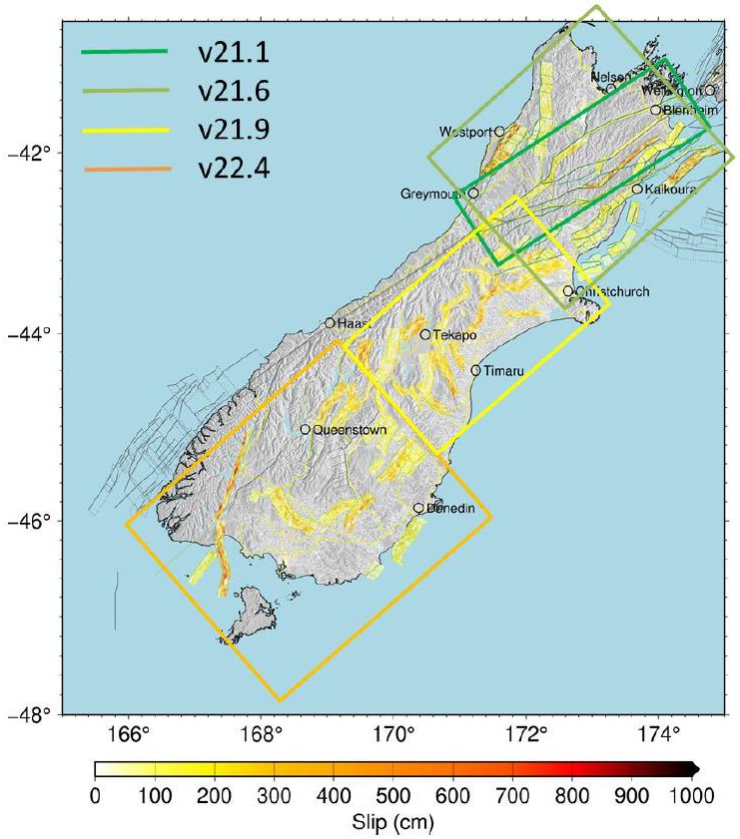
Objective 2: Analysis of Simulations

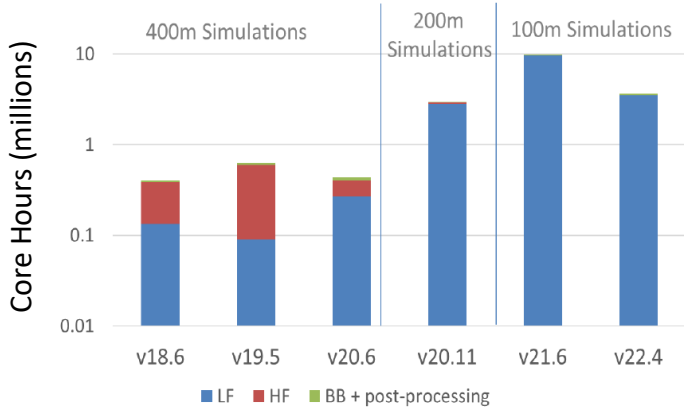
- CybershakeNZ

Several Realizations per Rupture



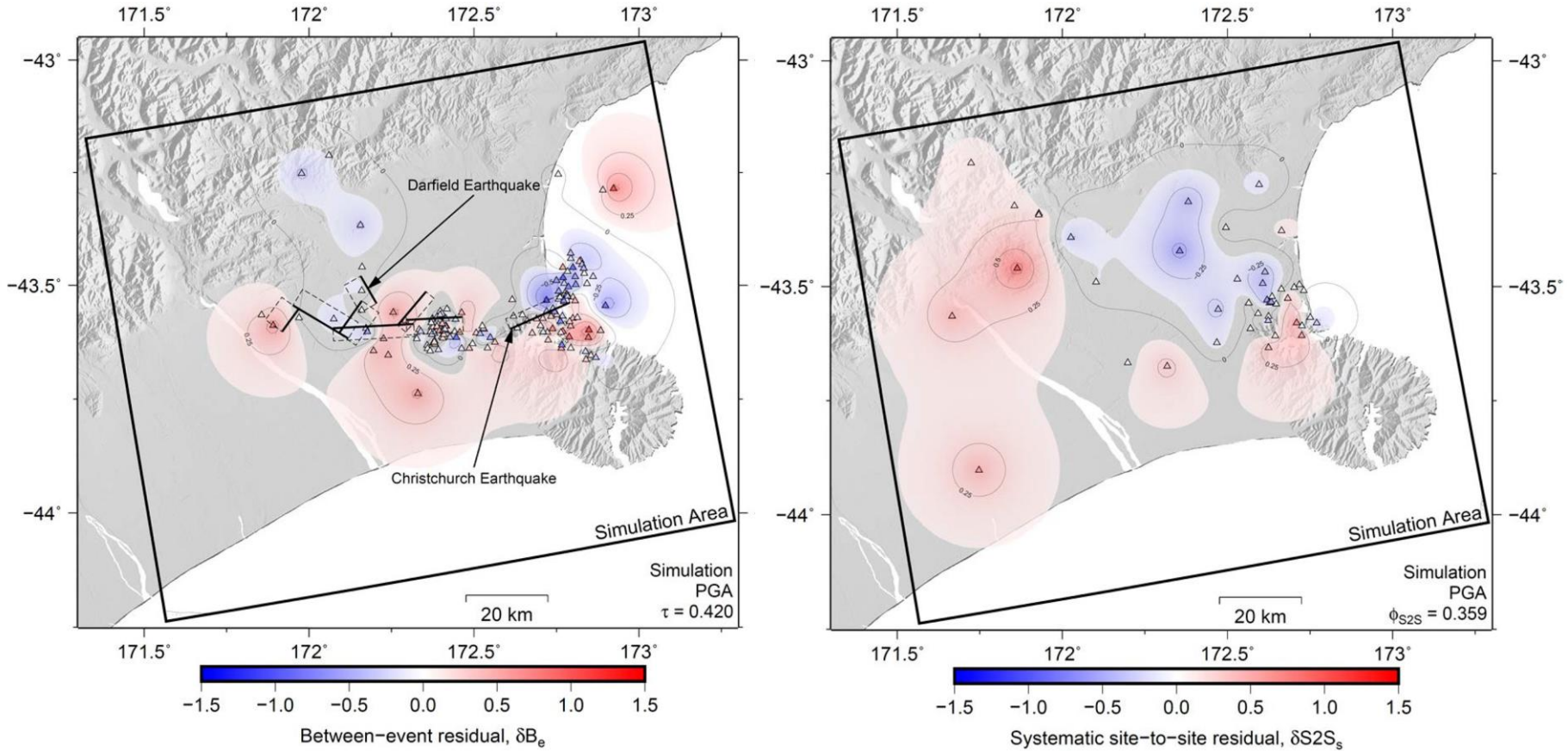
Progress Towards High Resolution Simulations





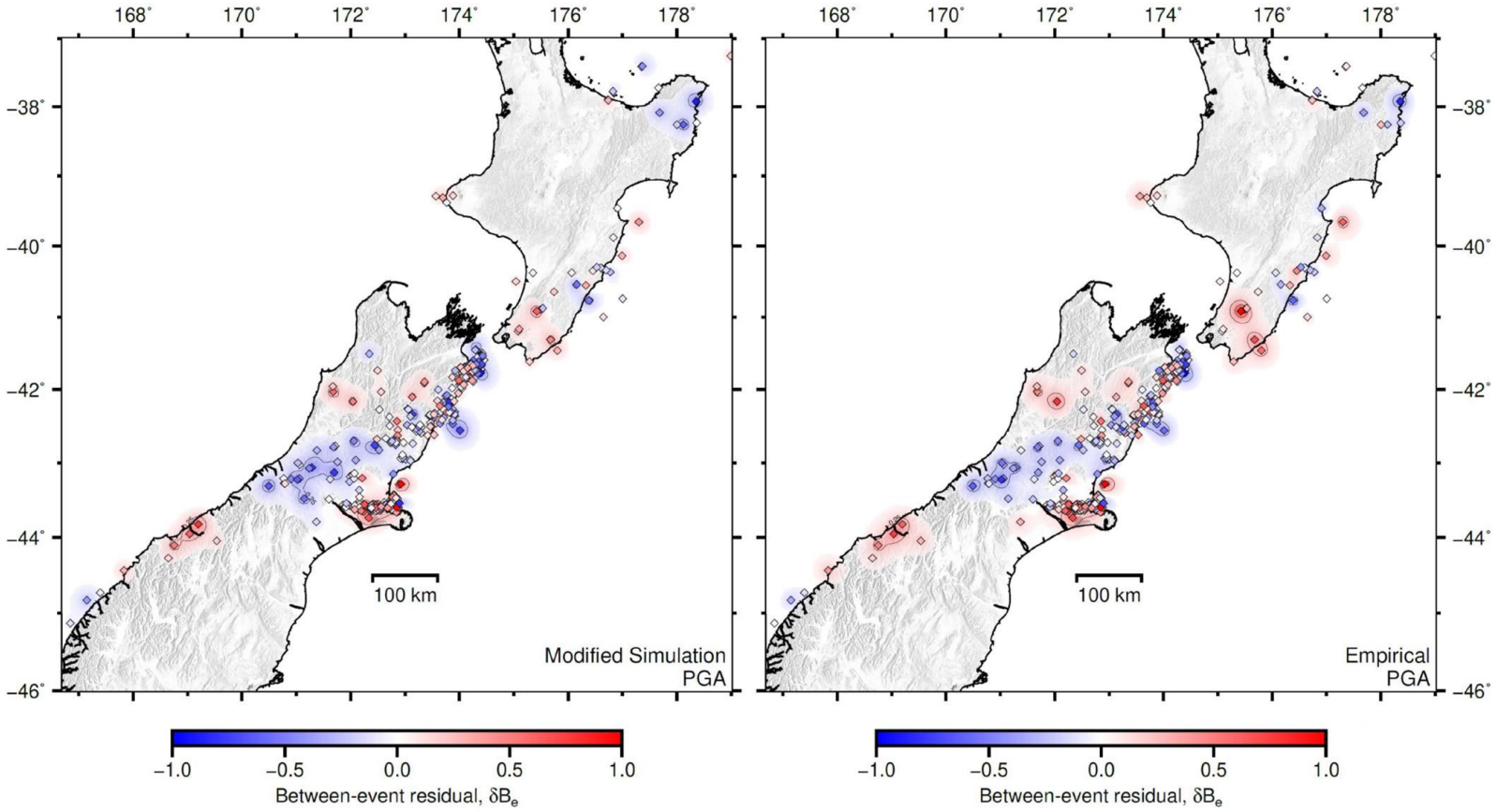
Objective 3: Validation of Simulations

- Studies on location-by-location validation of simulations in NZ:
  - Lee et al. (2020) - Hybrid broadband ground motion simulation validation of small magnitude earthquakes in Canterbury, New Zealand.



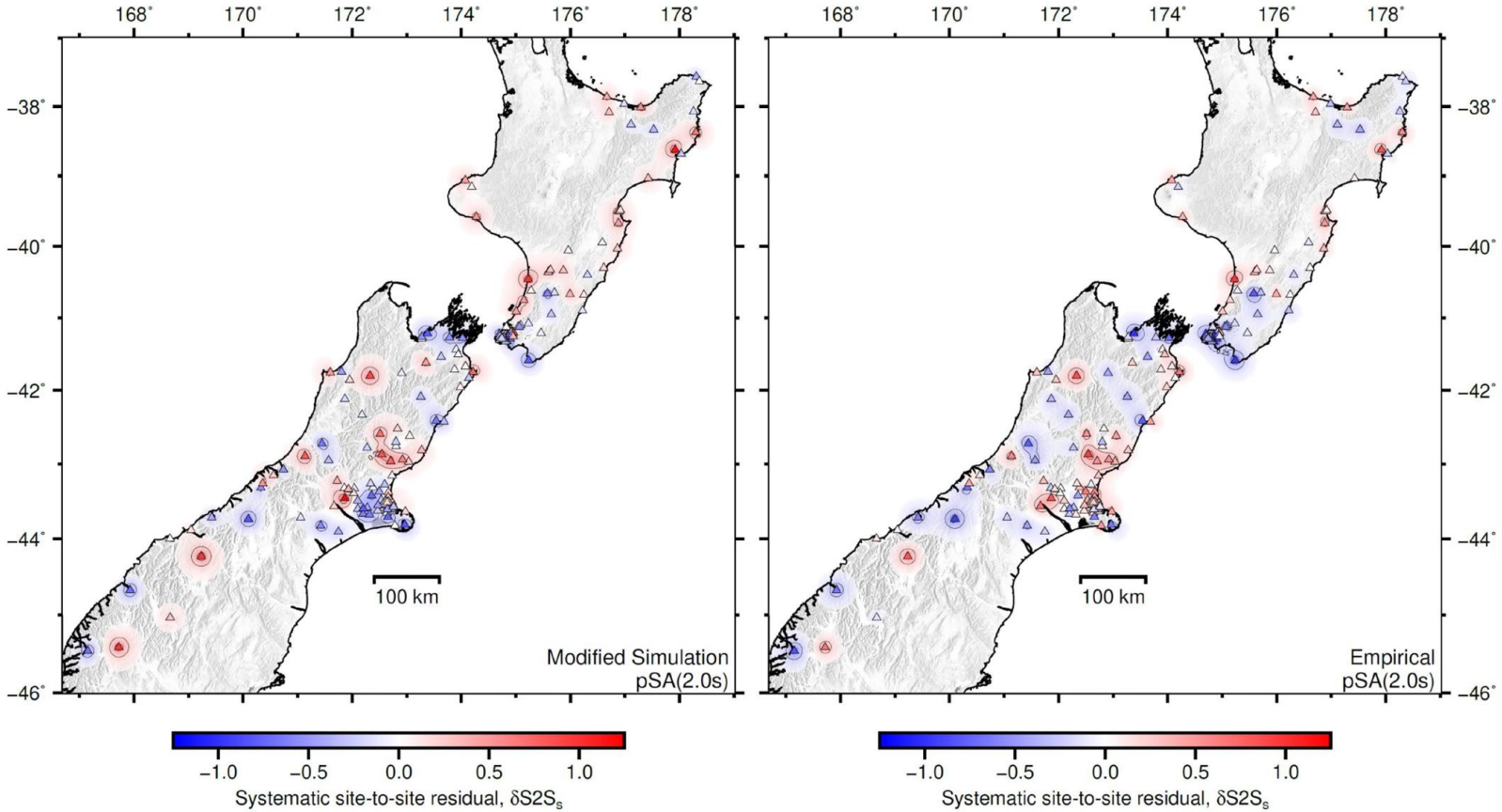
Objective 3: Validation of Simulations

- Studies on location-by-location validation of simulations in NZ:
  - Lee et al. (2022) - Hybrid broadband ground motion simulation validation of small magnitude active shallow crustal earthquakes in New Zealand.



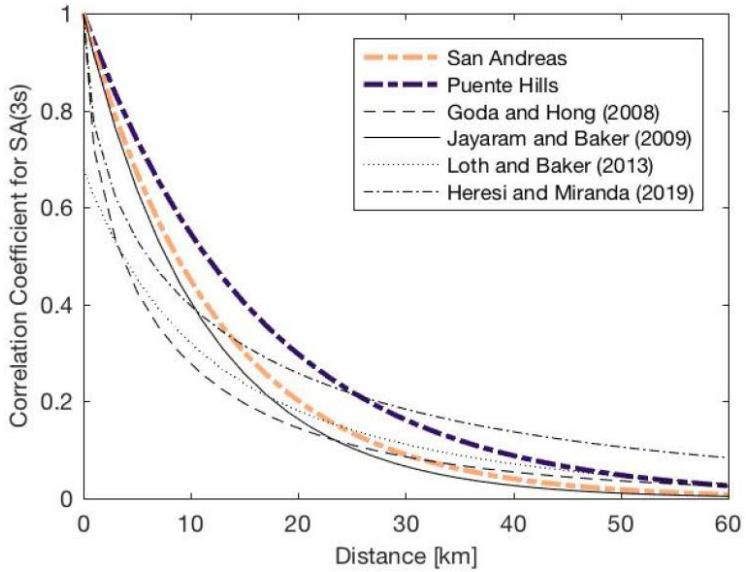
Objective 3: Validation of Simulations

- Studies on location-by-location validation of simulations in NZ:
  - Lee et al. (2022) - Hybrid broadband ground motion simulation validation of small magnitude active shallow crustal earthquakes in New Zealand.



Objective 3: Validation of Simulations

- Previous validation primarily through comparison of “observation only” and “simulation only” models.



- However, spatial trends and clusters in obs-sim residuals exist and imply spatial correlation exists in them too.
- An analysis of obs-sim residuals could illuminate key features that are not currently (or incorrectly) modelled in the simulations.

(Main) Challenges

- Observational Data:
  - Quality control of ground motions and metadata.
- Simulations:
  - Computational challenges with running high resolution simulations.
  - Scientific advances to facilitate simulation of high frequencies that are seismologically accurate (e.g., rupture and velocity models).
- Logistic:
  - Finding a PhD student to do the work.

https://lee-robin.github.io/