UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

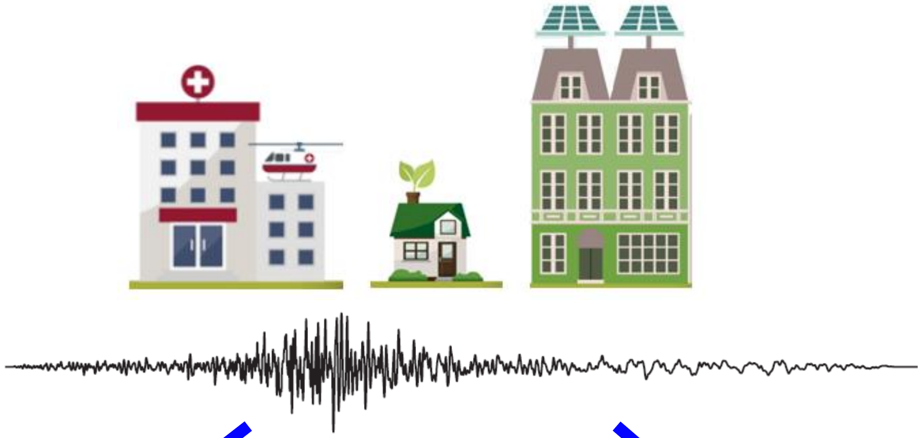
Pathways to incorporate Physics-Based Ground-Motion Modelling into the New Zealand National Seismic Hazard Model

Felipe Kuncar

Brendon Bradley

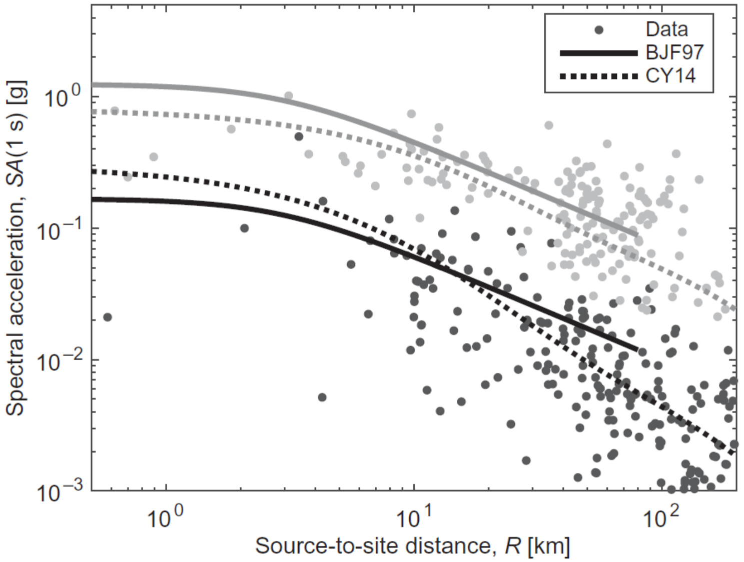
NSHM Workshop|20 May 2024, Christchurch, New Zealand

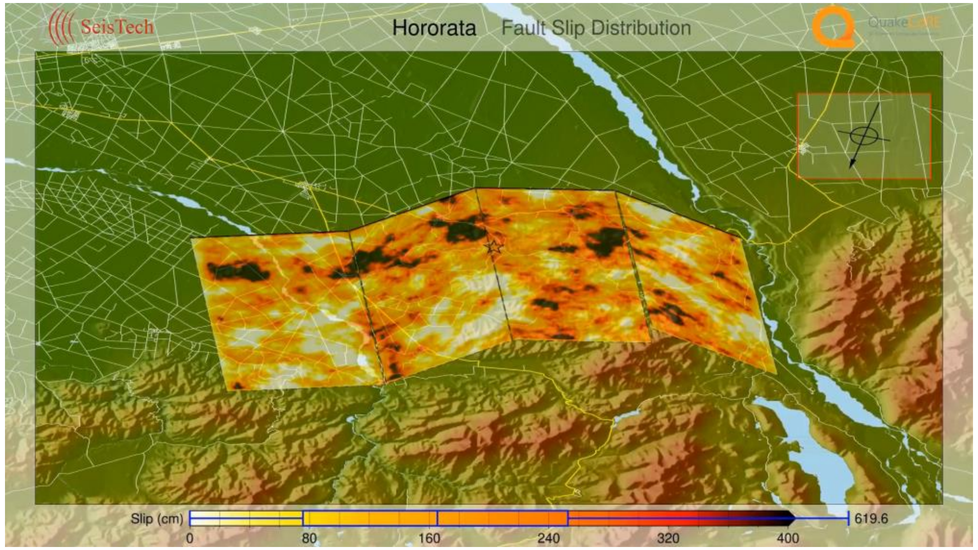
Ground Motion Prediction



“Empirical” Ground-Motion Models (GMMs)

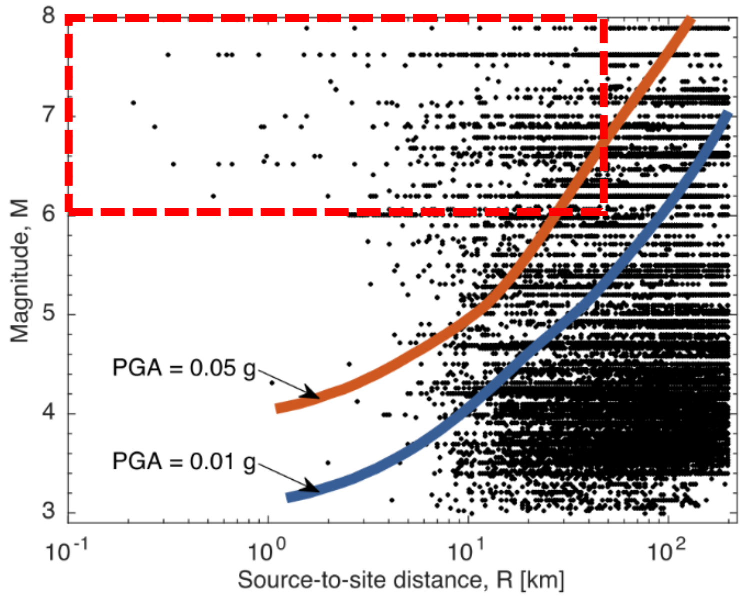
“Physics-Based” Ground-Motion Simulations





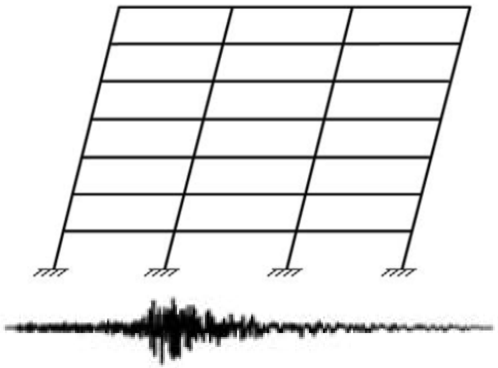
Why Explore the Use of Simulations?

1. Lack of observations at relevant ranges



2. Increasing utilization of ground-motion time series

Time-history analysis



3. Explicit consideration of salient physics

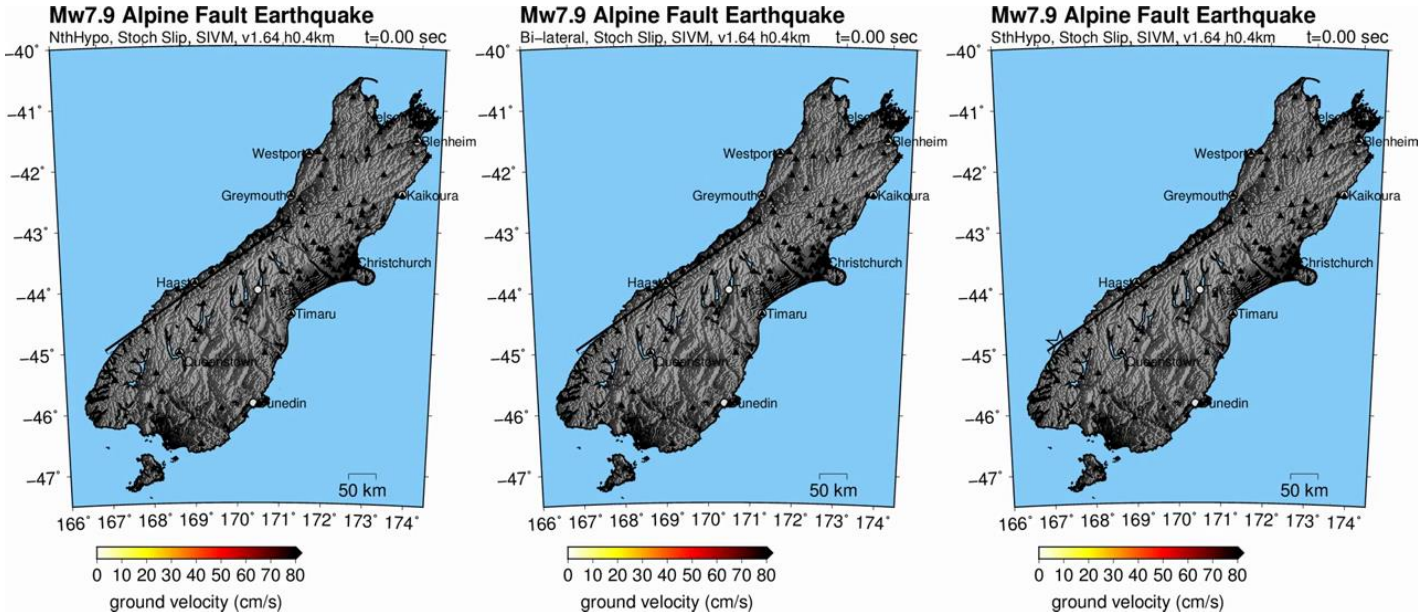
<u>Potential</u> to generate more accurate and precise predictions

Baker, Bradley, Stafford (2021)

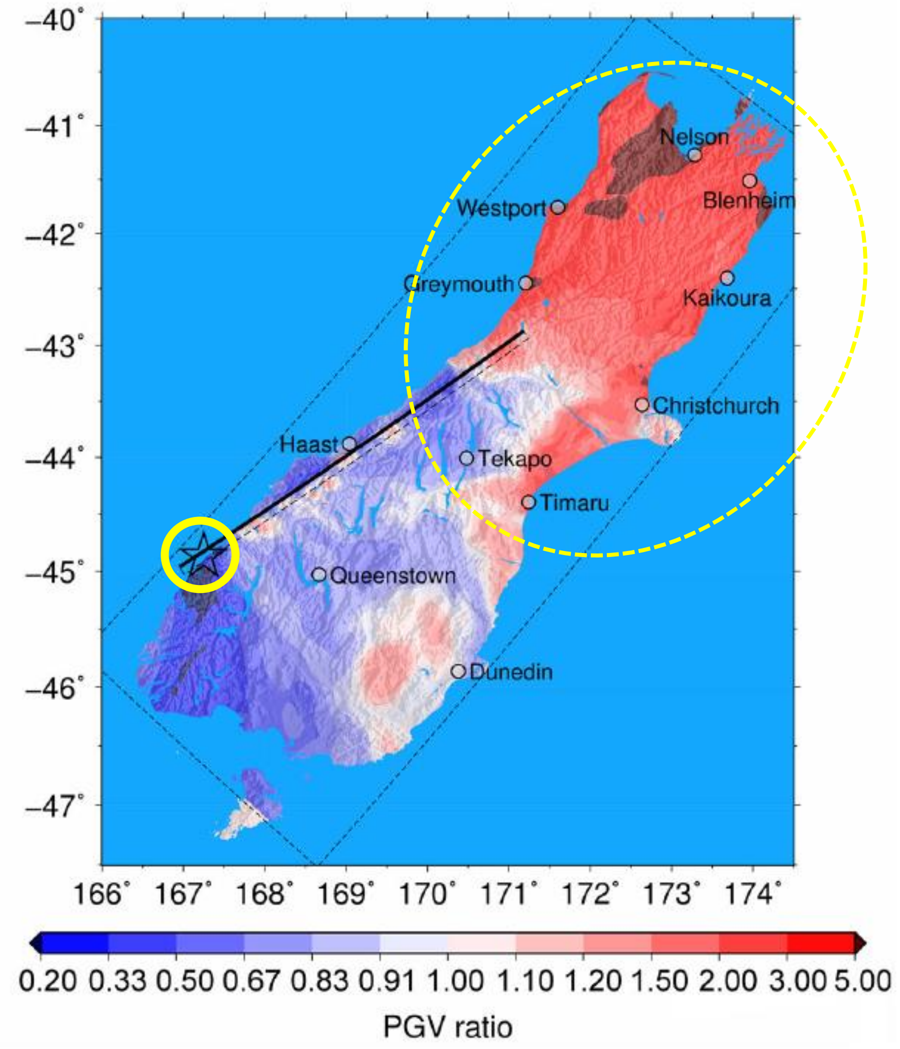
Example 1: Rupture Directivity

Alpine Fault Scenarios

(Bradley et al., 2017a)

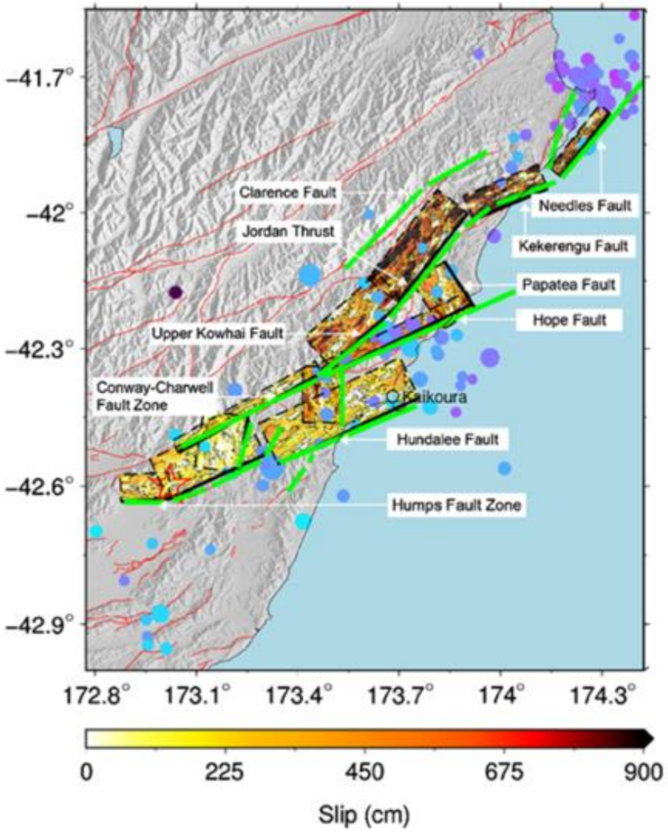


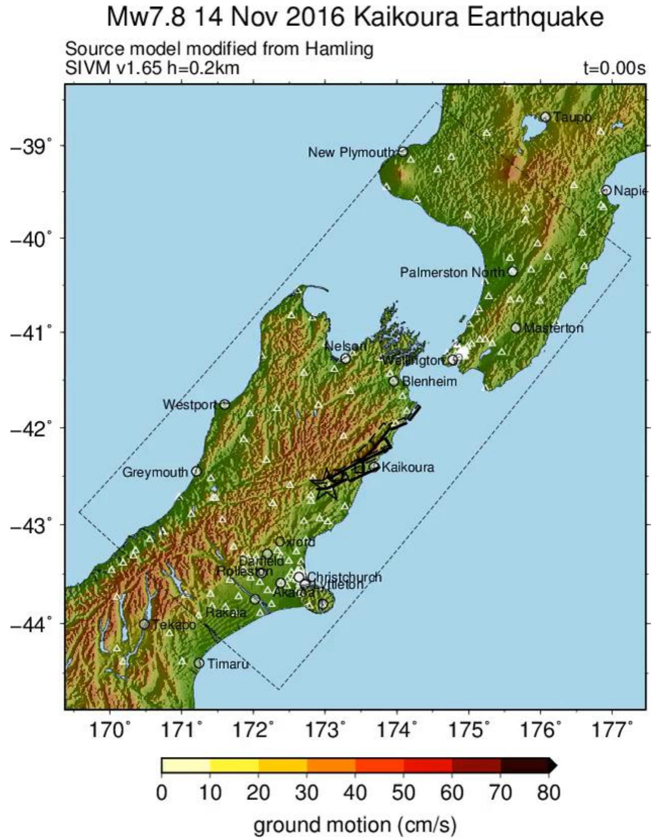
Simulation / Empirical



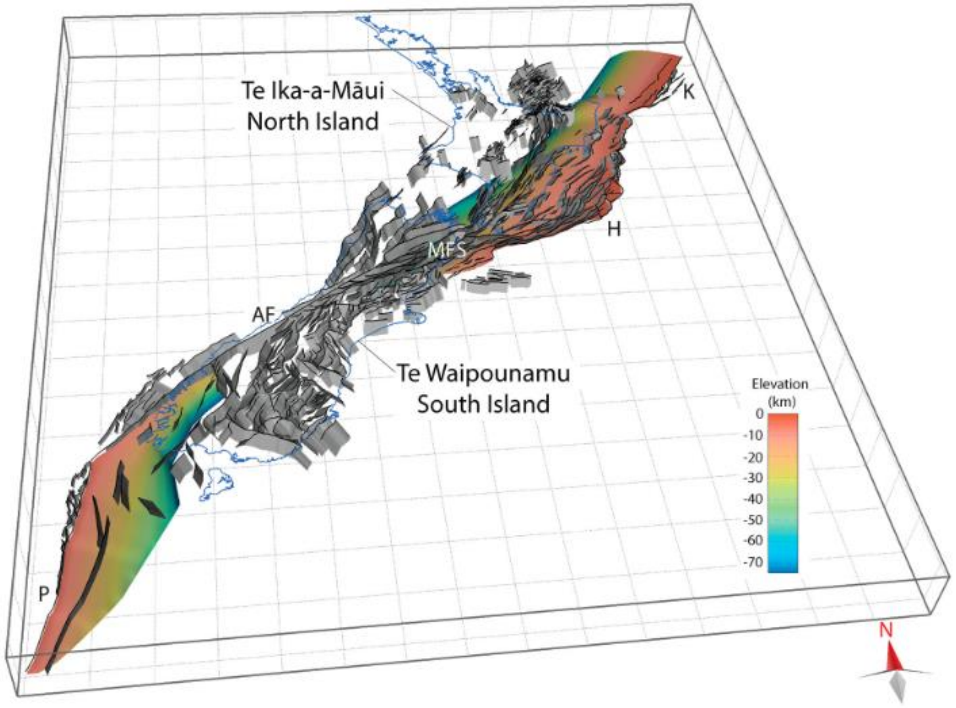
Example 2: Multi-Fault Ruptures

Kaikōura Earthquake
(Bradley et al., 2017b)





NZ CFM v1.0
(Seebeck et al., 2024)



Example 3: Nonlinear Site Effects

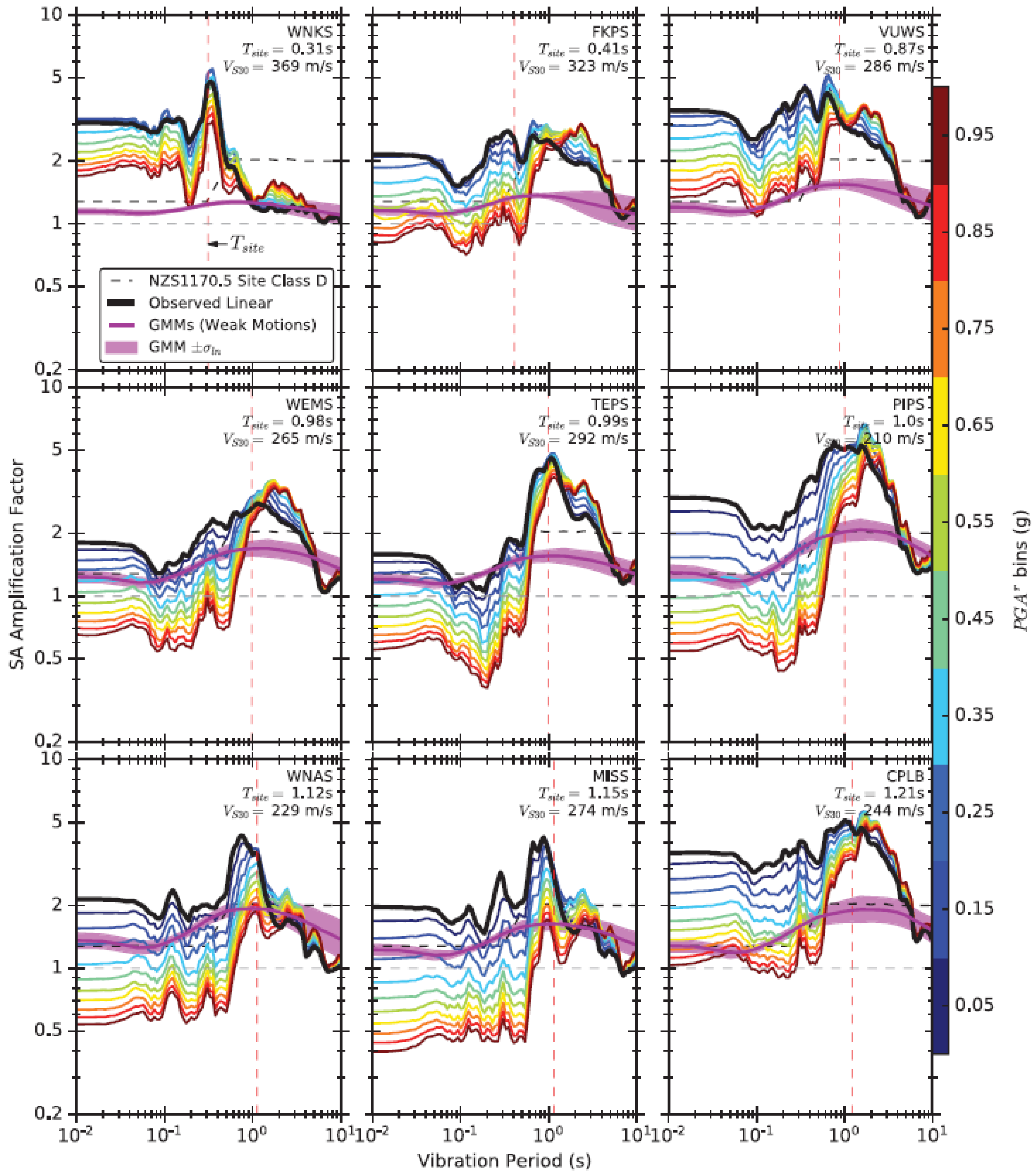
Wellington Case Study

(de la Torre et al., 2024)

Observations
(limited intensity range)

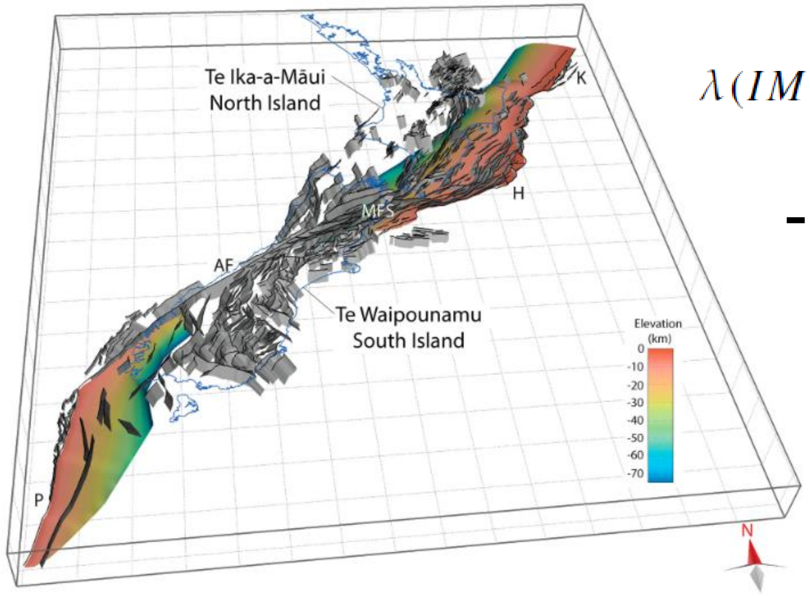
+

1D Time-Domain Nonlinear
Site-Response Analysis



Use of Simulations in the Context of a NSHM

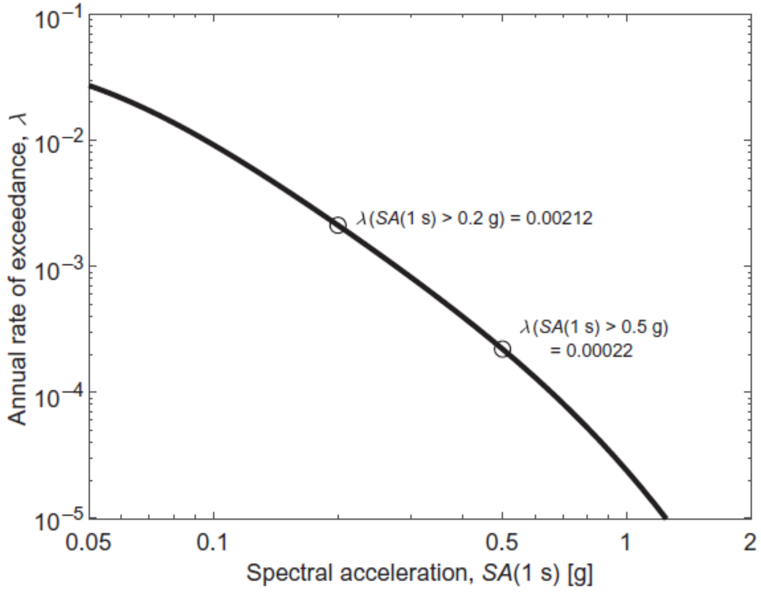
Seismic Source Model



?

$$\lambda(IM > im) = \sum_{i=1}^{n_{rup}} \boxed{P\left(IM > im \mid rup_i, site\right)} \lambda\left(rup_i\right)$$

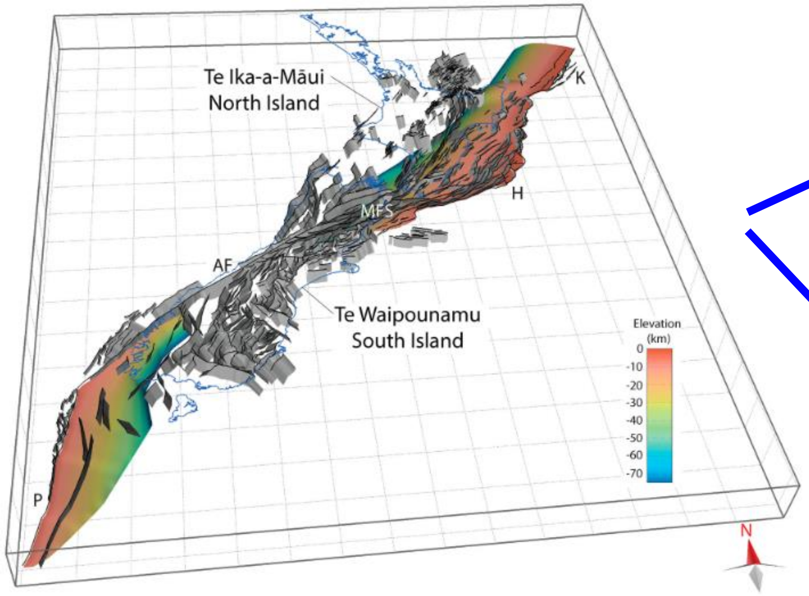
Hazard Curve



What is the role that physics-based ground-motion simulations can play?

Use of Simulations in the Context of a NSHM

Seismic Source Model



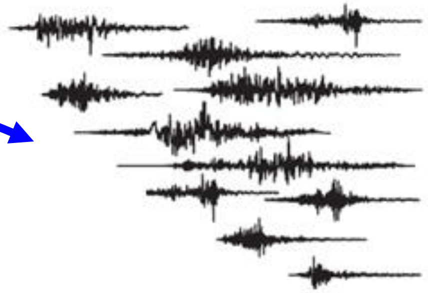
Approach 2

Components developed using simulation insights

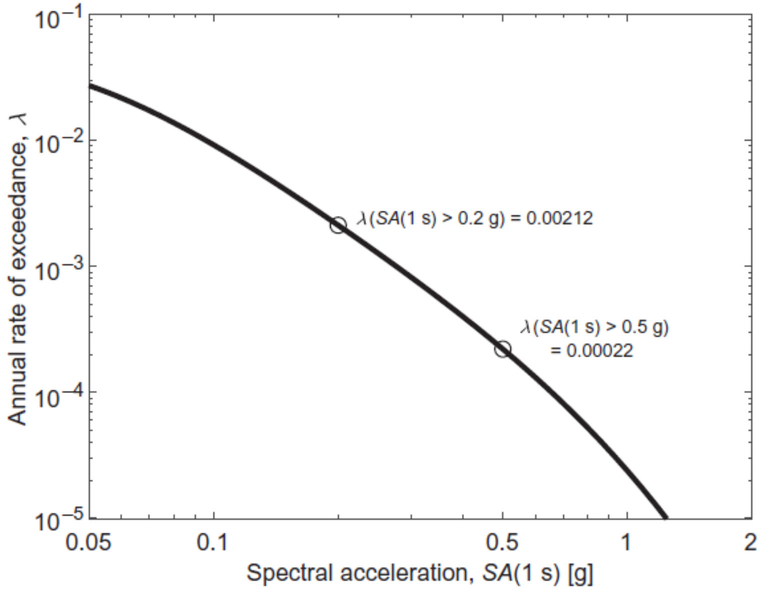
Empirical GMMs

Direct use of Simulations

Approach 1

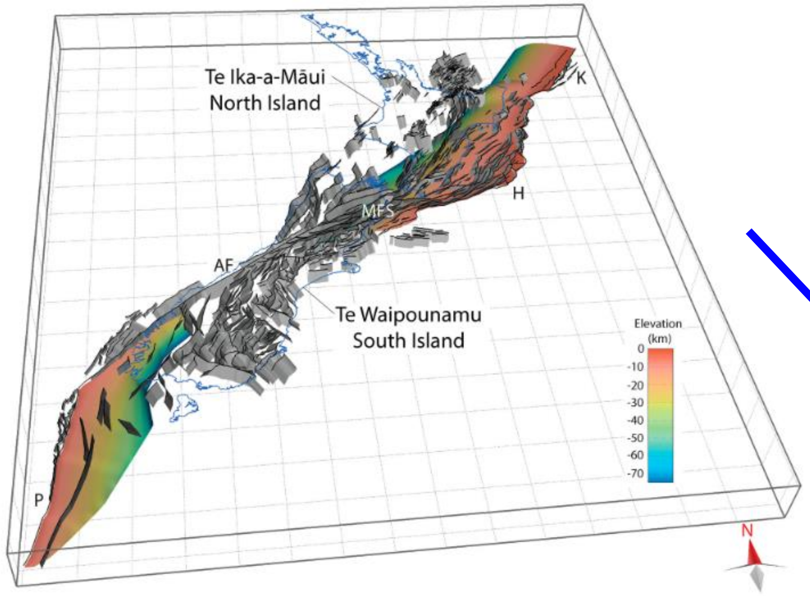


Hazard Curve

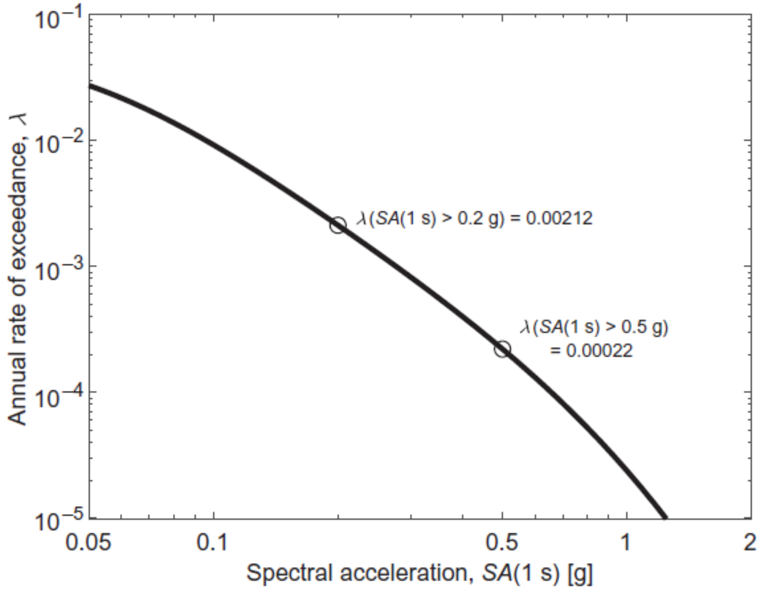


Use of Simulations in the Context of a NSHM: Approach 1

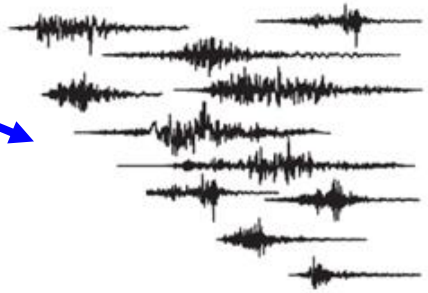
Seismic Source Model



Hazard Curve



Direct use of Simulations



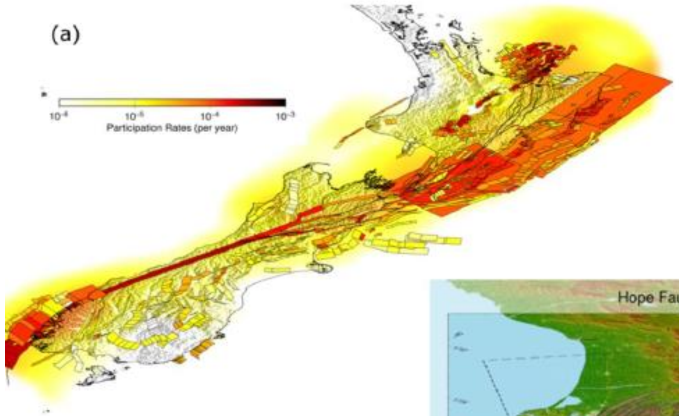
Approach 1

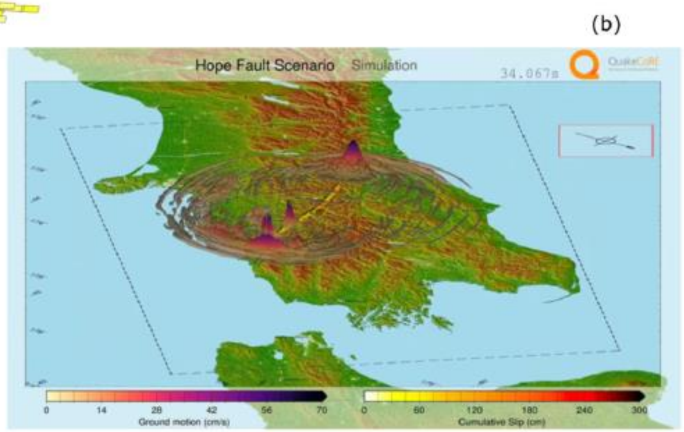
Use of Simulations in the Context of a NSHM: Approach 1

Cybershake NZ

Uncertainty treatment is key (Neill et al.)

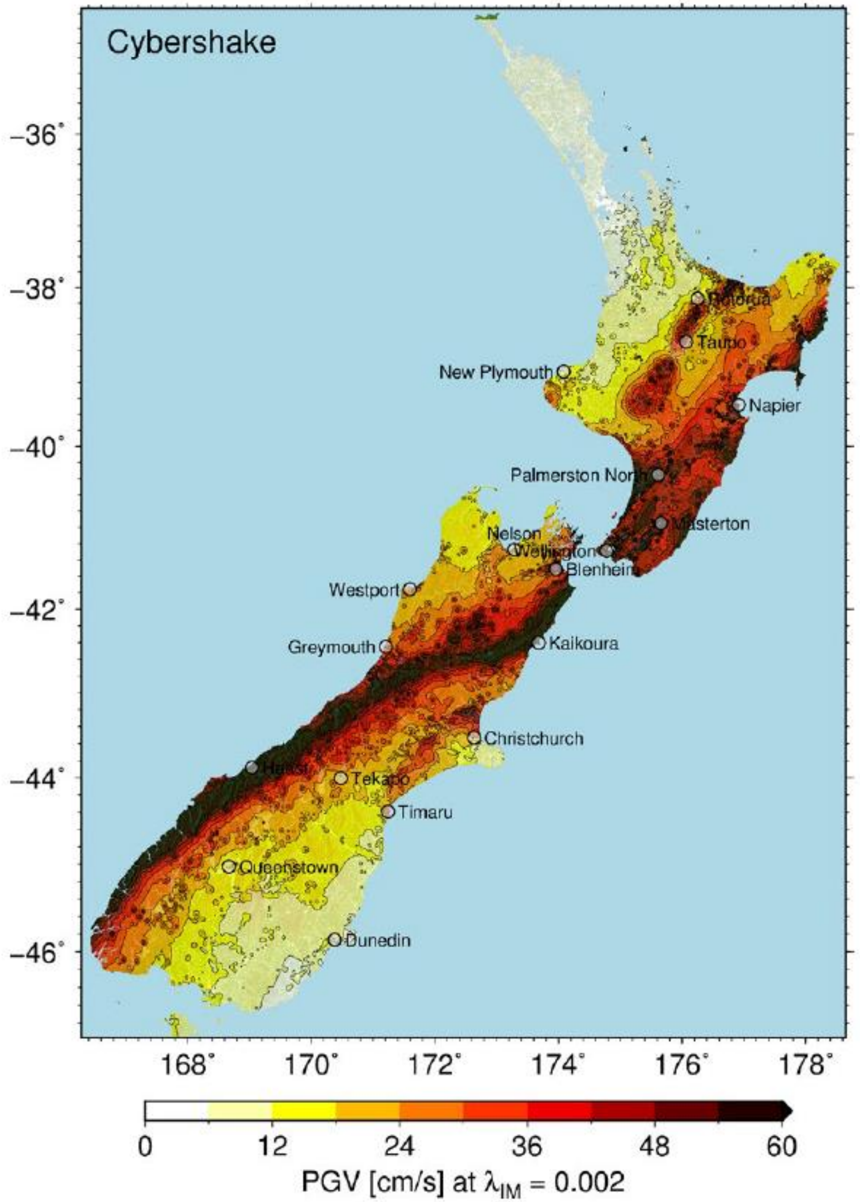
Multiple rupture realizations (hypocentre and slip) for each fault





Hybrid Broadband Ground Motion Simulation Method

Simulations require validation

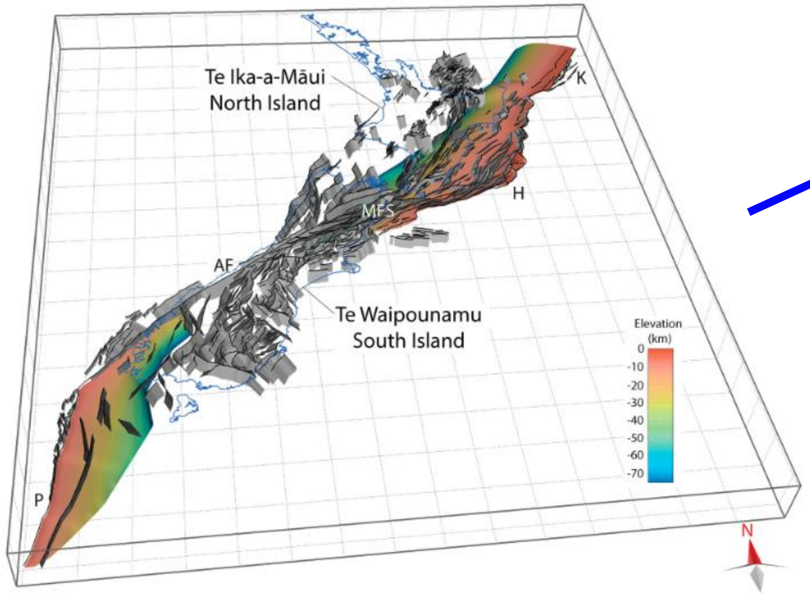


Bradley et al. (2020)

Use of Simulations in the Context of a NSHM: Approach 2

Approach 2

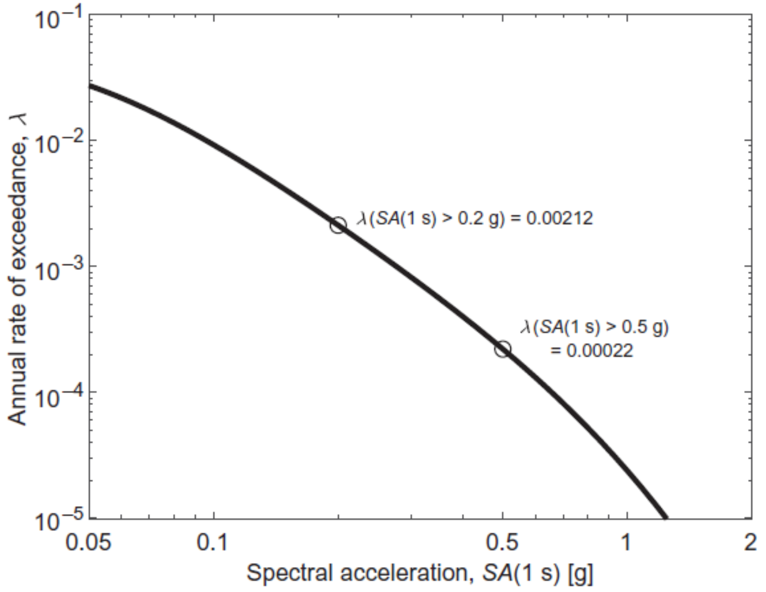
Seismic Source Model



Components developed using simulation insights

Empirical GMMs

Hazard Curve



Use of Simulations in the Context of a NSHM: Approach 2

- Use of physics-based simulations to inform specific GMM components through parametric adjustments

- This is done when predictions are poorly constrained by data or extrapolation is needed beyond the data

- Examples of physics-based adjustments incorporated into the GMM CB14 (Campell & Bozorgnia, 2014):

  - Donahue and Abrahamson (2014) for the hanging-wall effect

  - Walling et al. (2008) for nonlinear site response

Use of Simulations in the Context of a NSHM: Approach 2

CB14 median ground motion model:

$$\ln Y = f_{mag} + f_{dis} + f_{flt} + f_{hng} + \boxed{f_{site}} + f_{sed} + f_{hyp} + f_{dip} + f_{atn}$$

- Data was not sufficient to determine how soil nonlinear effects varied with V_{S30}, ground motion amplitude, and oscillator period
- Functional form based on Walling et al. (2008):

$$\ln(Amp) = \begin{cases} \boxed{a}\ln\left(\dfrac{V_{S30}}{\boxed{V_{LIN}}}\right) - \boxed{b}\ln(PGA_{rock} + \boxed{c_1}) \\ \quad + \boxed{b}\ln\left(PGA_{rock} + c\left(\dfrac{V_{S30}}{\boxed{V_{LIN}}}\right)^{\boxed{n}}\right) + d & for\ V_{S30} < V_{LIN} \\ (\boxed{a} + \boxed{bn})\ln\left(\dfrac{V_{S30}}{\boxed{V_{LIN}}}\right) + d & for\ V_{S30} \geqslant V_{LIN} \end{cases}$$

- Parameter a (linear site response) constrained by data

- Other parameters constrained by multiple (physics-based) 1D equivalent-linear site-response analyses

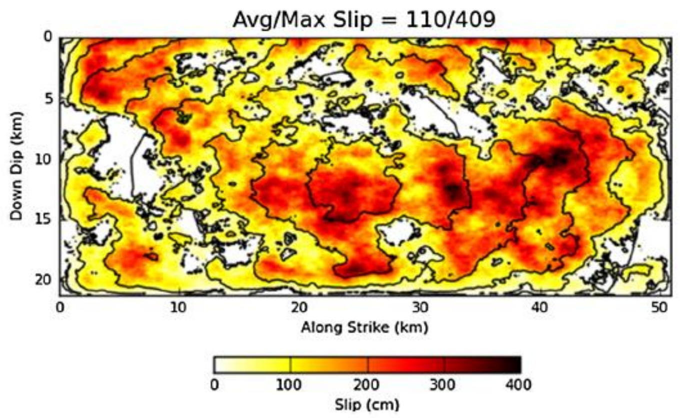
Use of Simulations in the Context of a NSHM: Approach 2

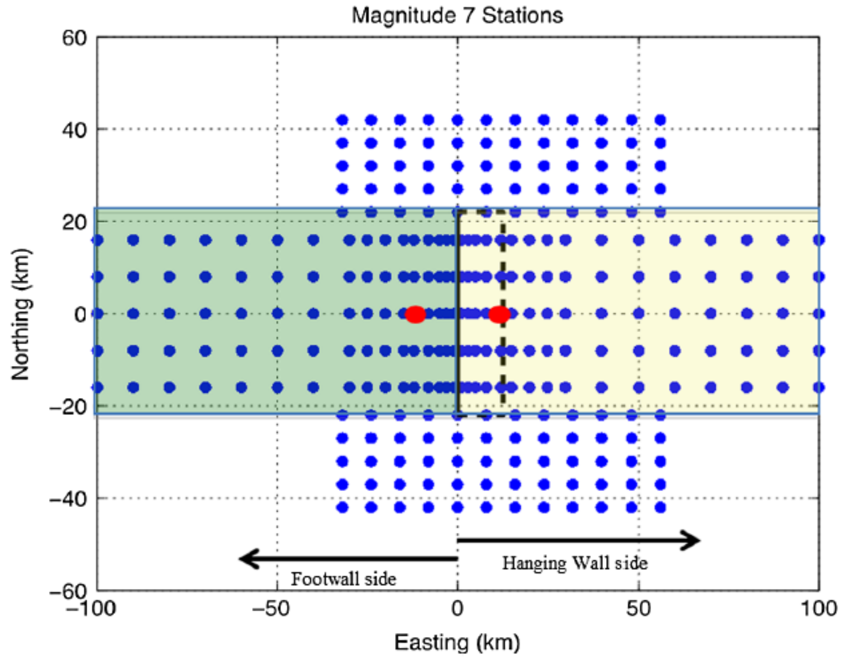
CB14 median ground motion model:

$$\ln Y = f_{mag} + f_{dis} + f_{flt} + \boxed{f_{hng}} + f_{site} + f_{sed} + f_{hyp} + f_{dip} + f_{atn}$$

- Functional form based on Donahue and Abrahamson (2014)

Based on multiple hybrid broadband ground-motion simulations





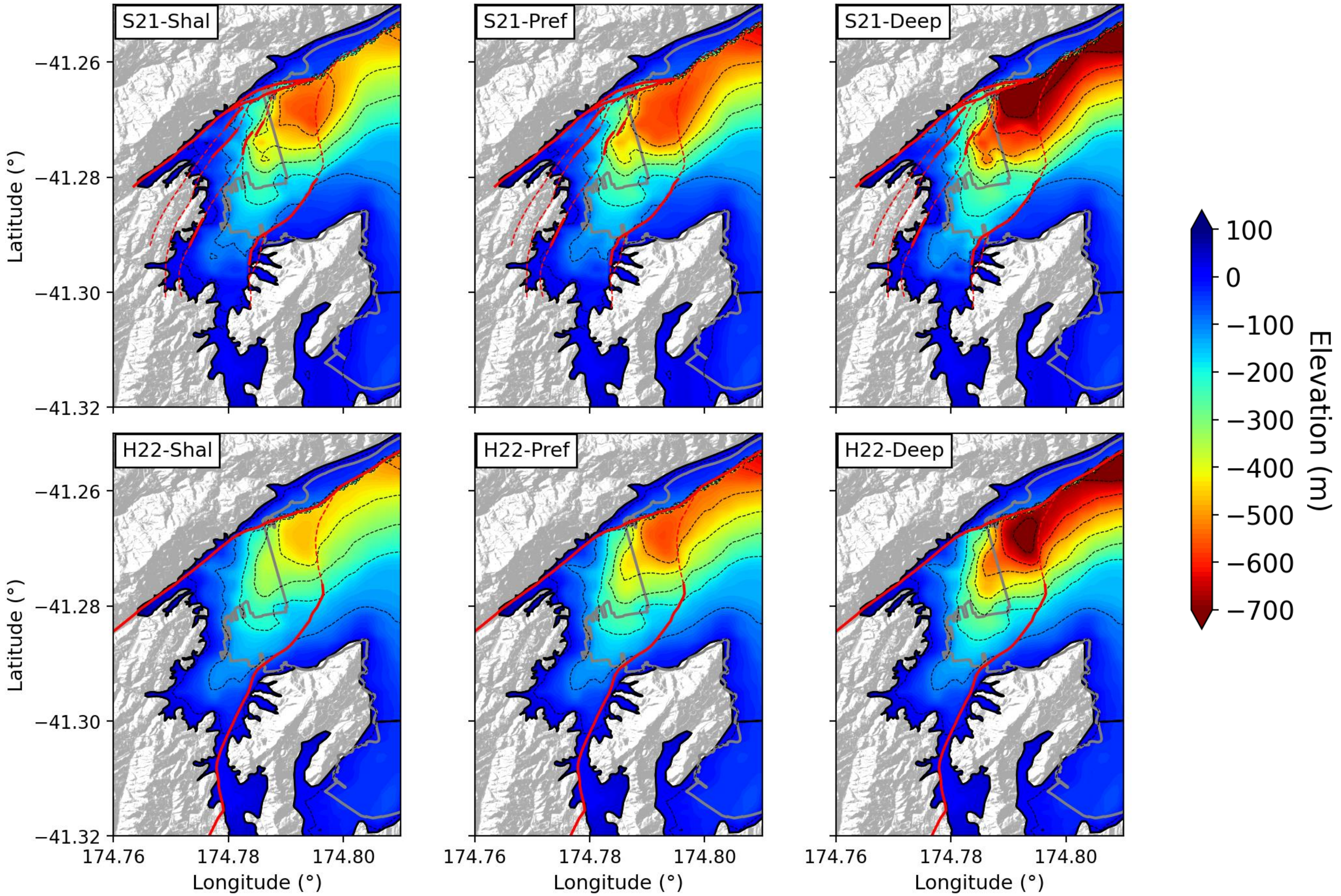
Exploratory Use of Simulations in the NZ NSHM Project

3D Physics-Based Ground-Motion Simulations in Wellington CBD

(Lee et al., 2023, 2024)

Stronach and Stern (2021):

Hill et al. (2022):



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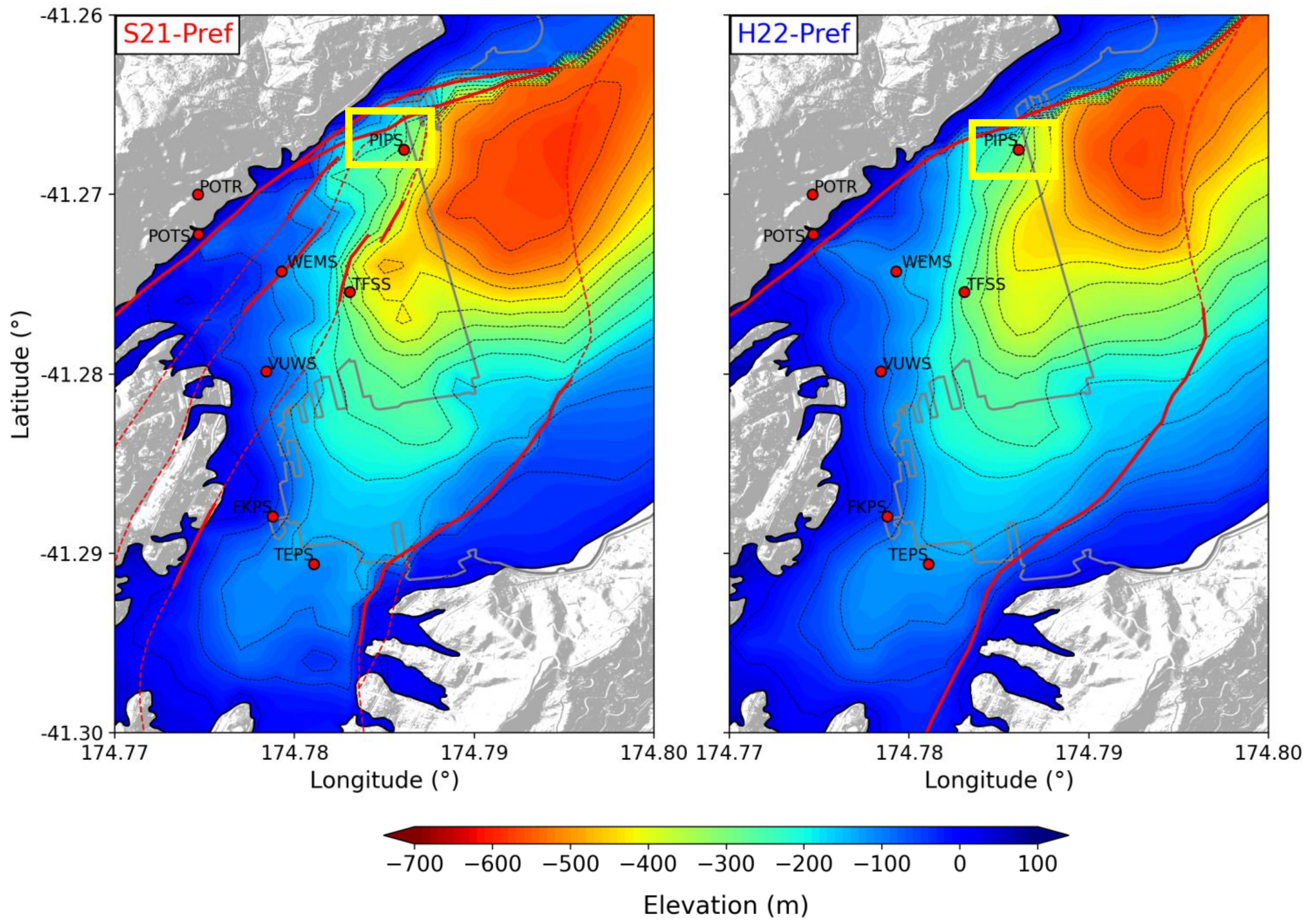
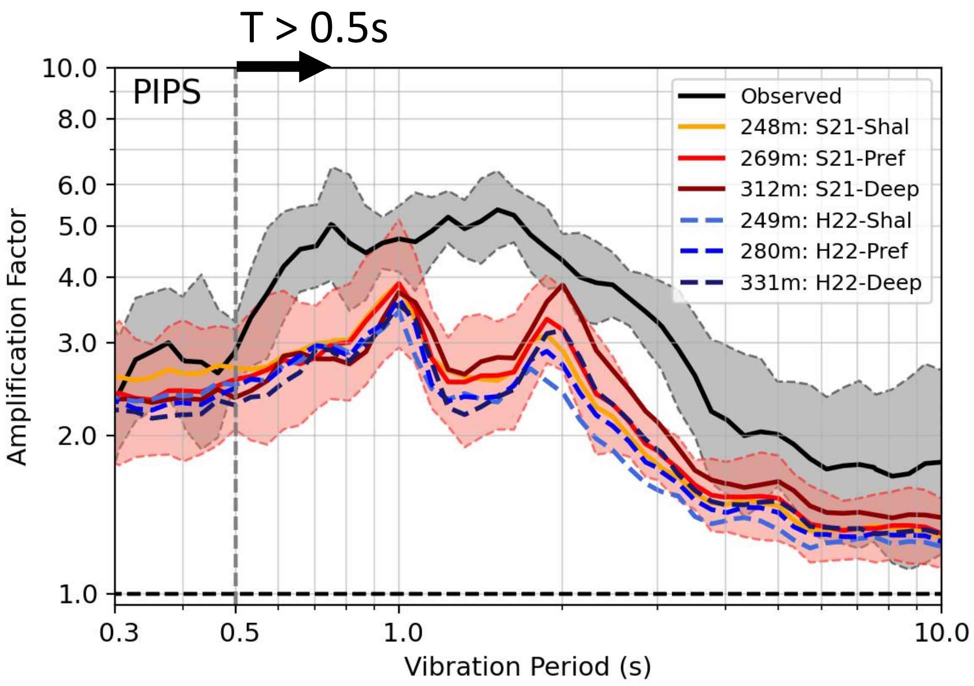


Validation:



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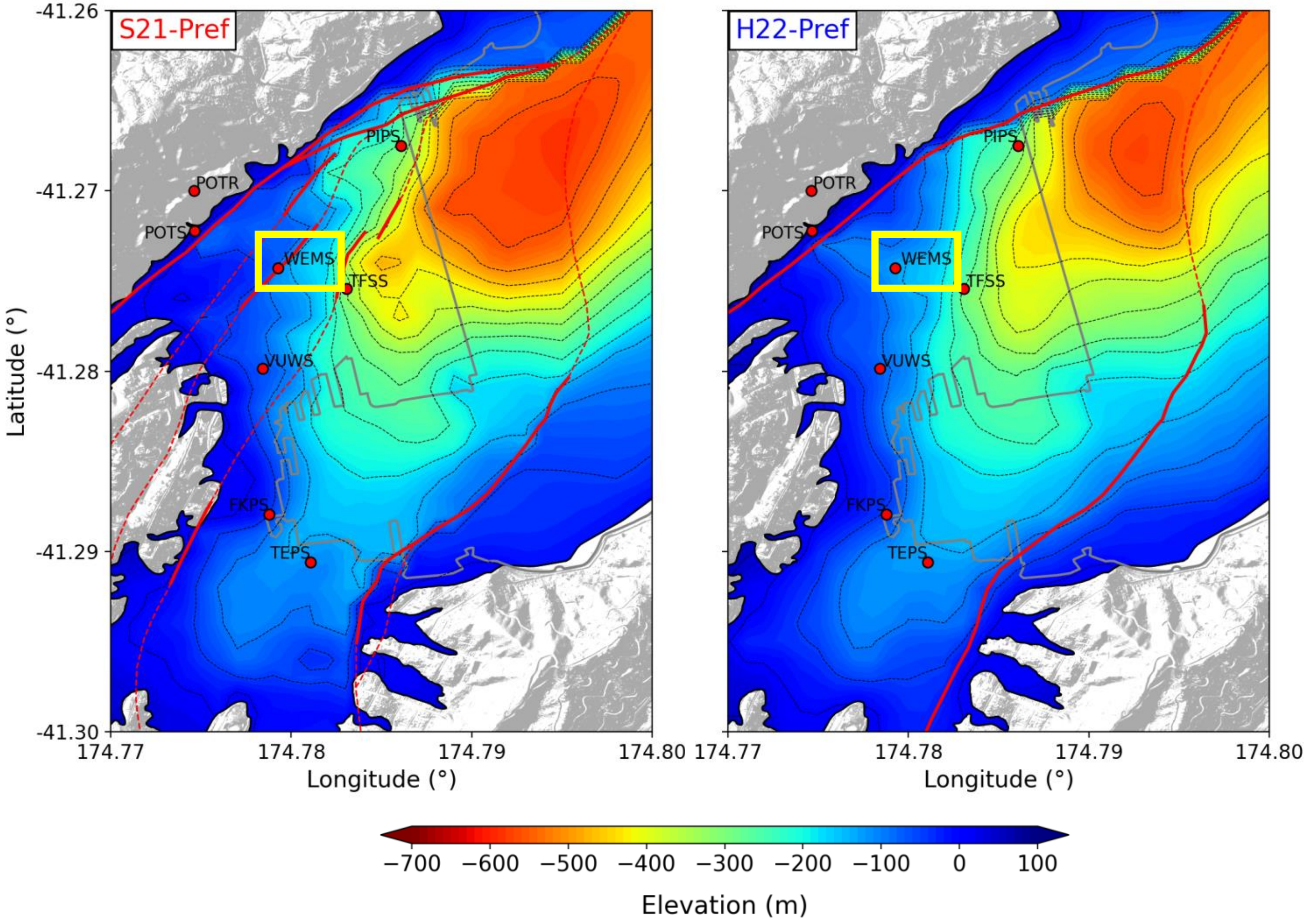

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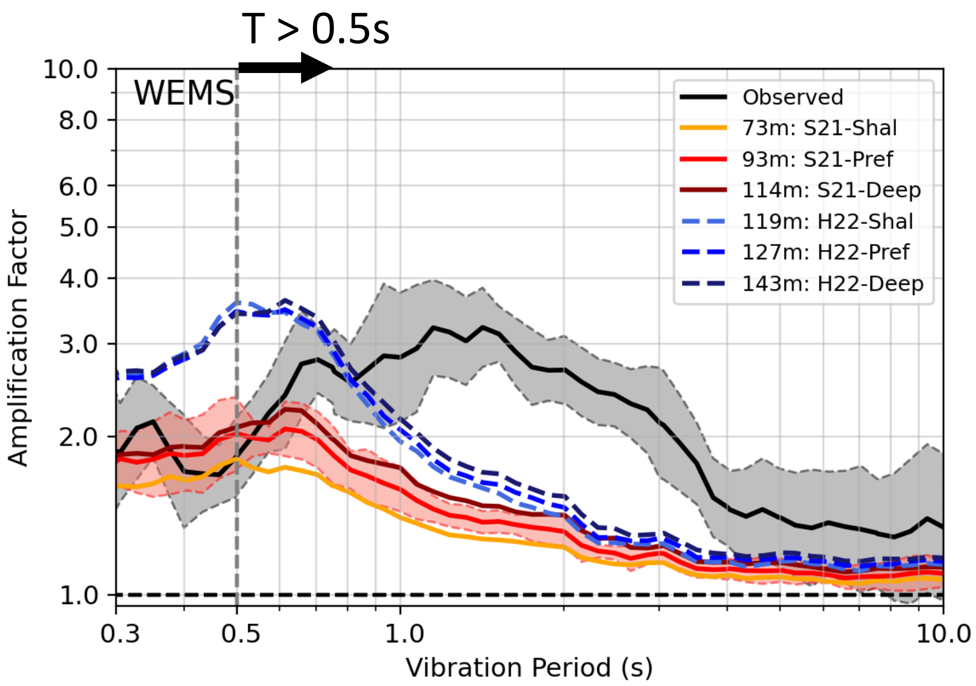


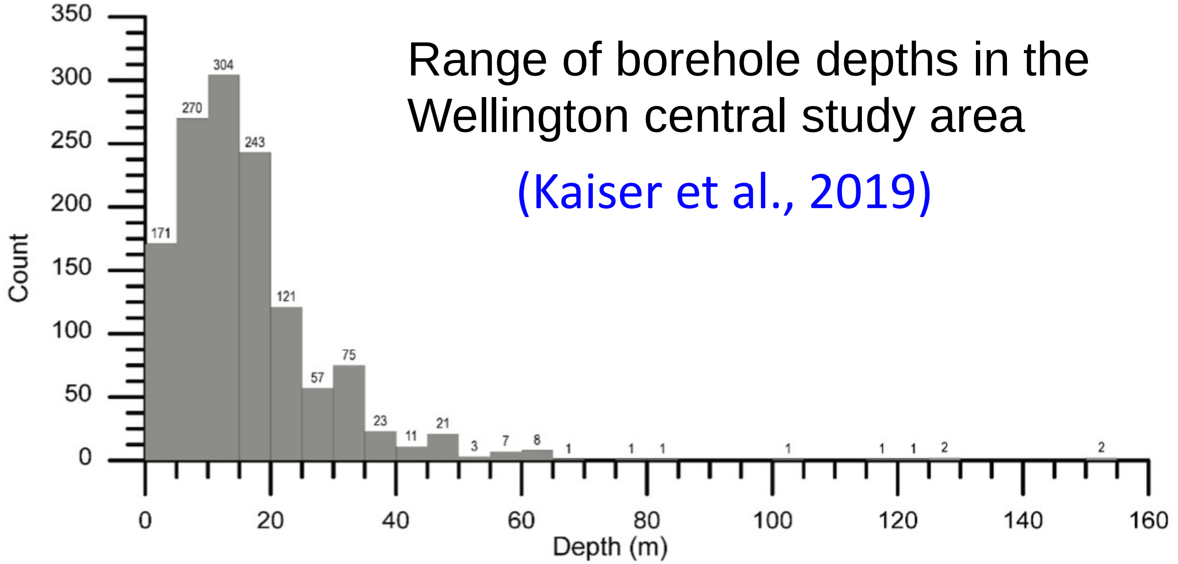
Exploratory Use of Simulations in the NZ NSHM Project

3D Physics-Based Ground-Motion Simulations in Wellington CBD

(Lee et al., 2023, 2024)

Limitations:

- Uncertainty in the basin model
- Lack of (direct) site-characterization at depth



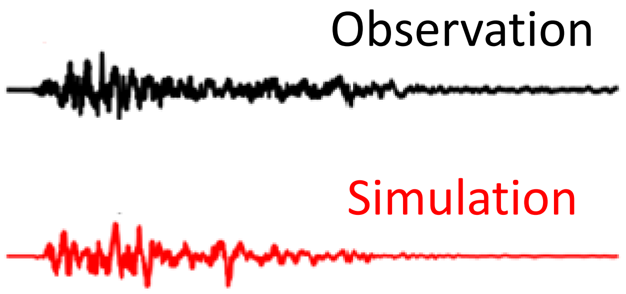
- Spatial resolution (grid spacing 50 m)

Validation against observations is crucial to develop confidence in simulations and improve them

This process requires two key ingredients:

1. Ground-motion observations (Brendon's talk)
2. Site-characterization data (Liam's talk)

Validation



$$\boxed{\Delta_{es} = \ln IM_{Obs,es} - \ln IM_{Sim,es}}$$

What are the causes that explain the differences between the observation and the simulation?

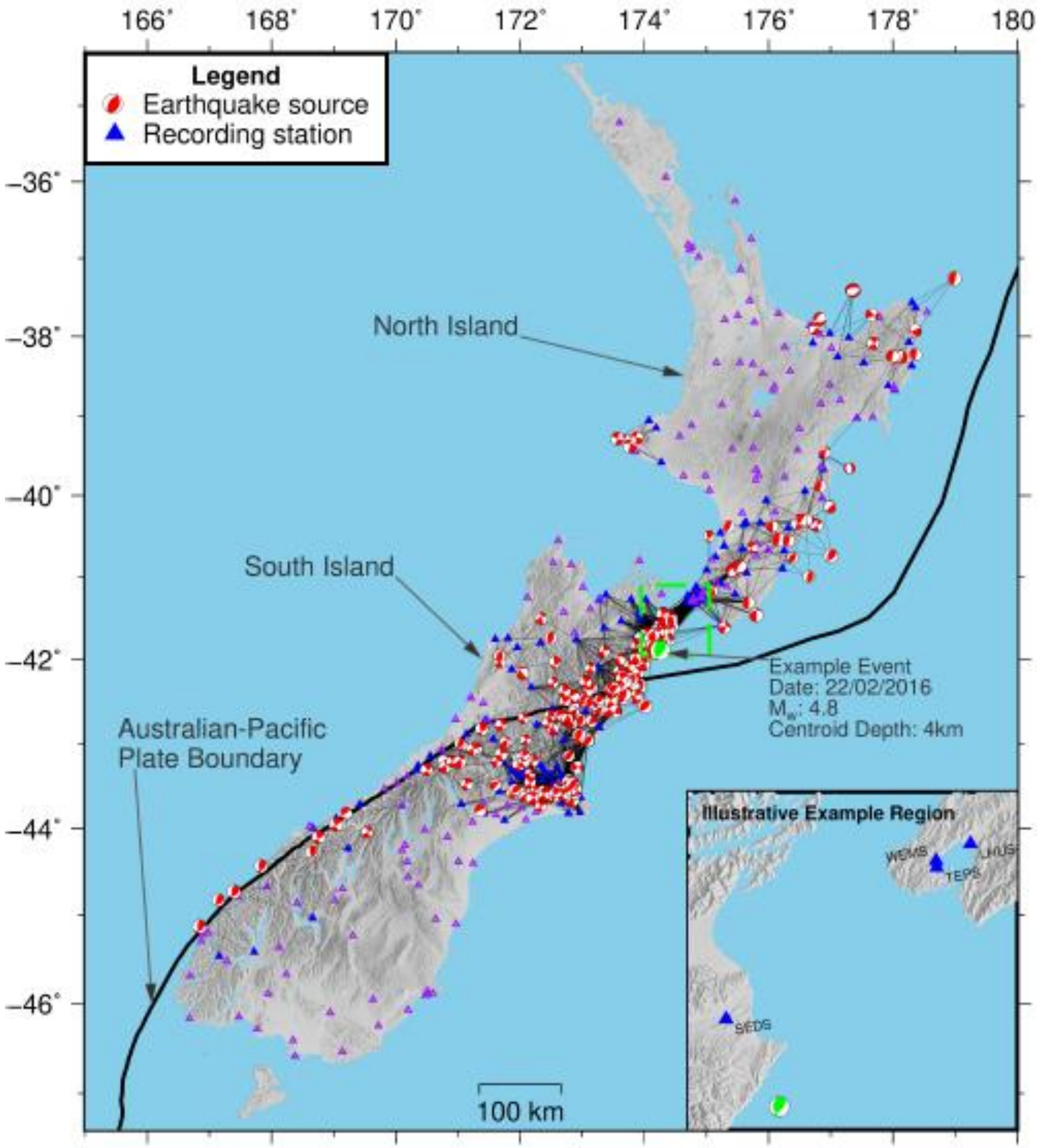
Simulation method? Source model? Velocity model? Site Parameters?

Multiple events and sites:

$$\boxed{\Delta_{es} = a + \delta B_e + \delta S2S_s + \delta W^0_{es}}$$

Lee et al. (2022)

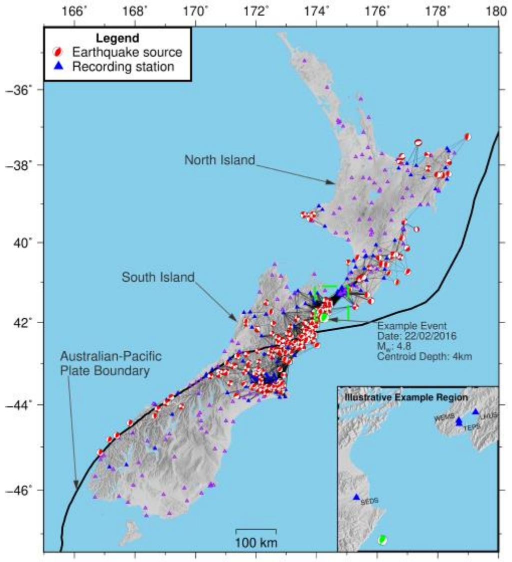
479 Small-Magnitude Events | **212** Sites



Magnitude

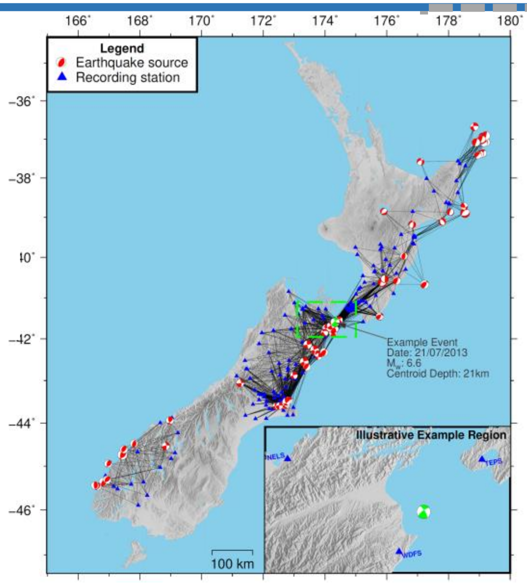
3.5 Point Sources **5.0** Inferred Finite Faults **7.0** Finite Faults **7.8**

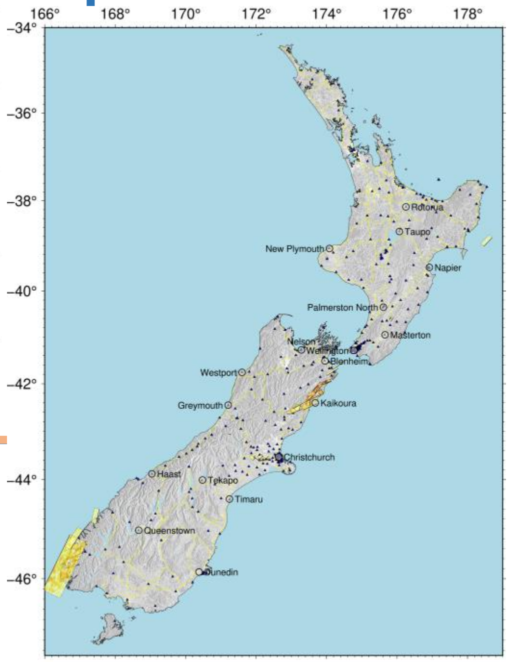
Crustal



479 events (Lee et al. 2022)

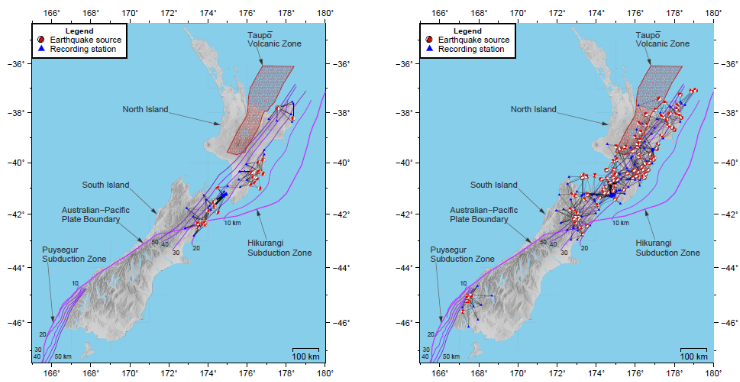
75 events (Lee et al.)





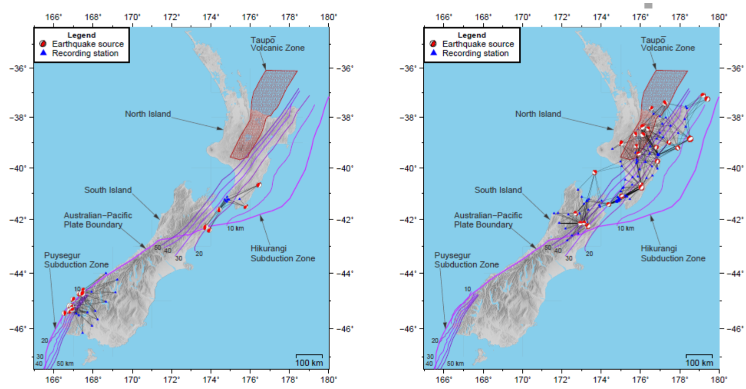
10+ events (Pájaro et al.)

Subduction



(a) Interface data (b) Slab data

≈ 163 events (Dupuis et al.)

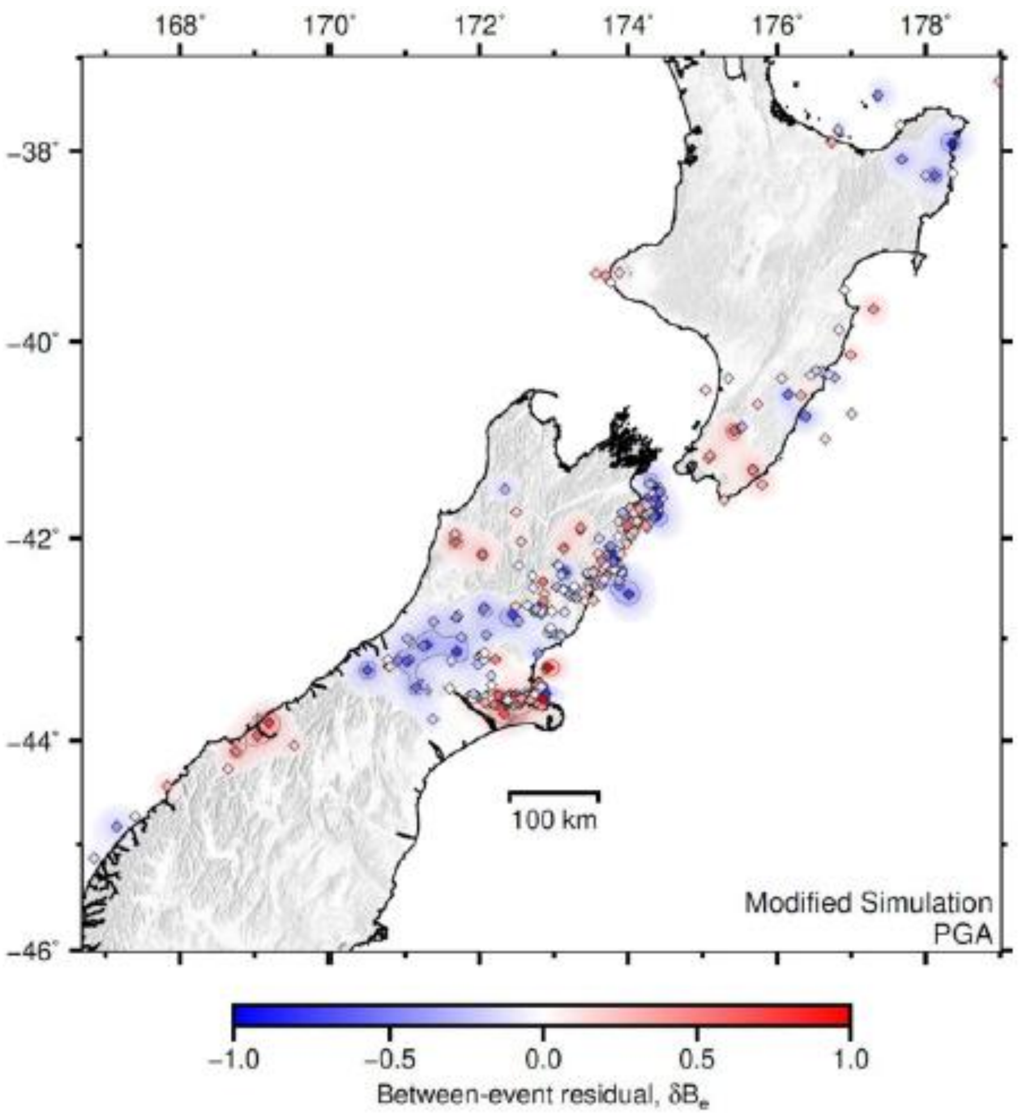


(a) Interface data (b) Slab data

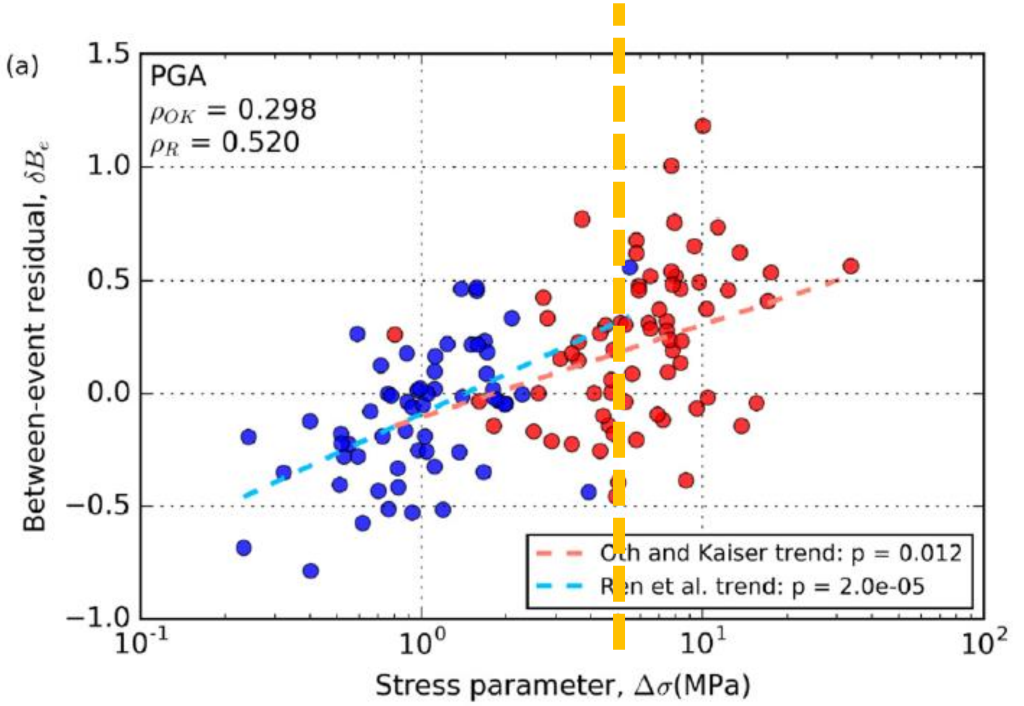
≈ 42 events (Dupuis et al.)

Learning from Validation

$$\Delta_{es} = a + \boxed{\delta B_e} + \delta S2S_s + \delta W_{es}^0$$



Constant value of Δσ used in simulations

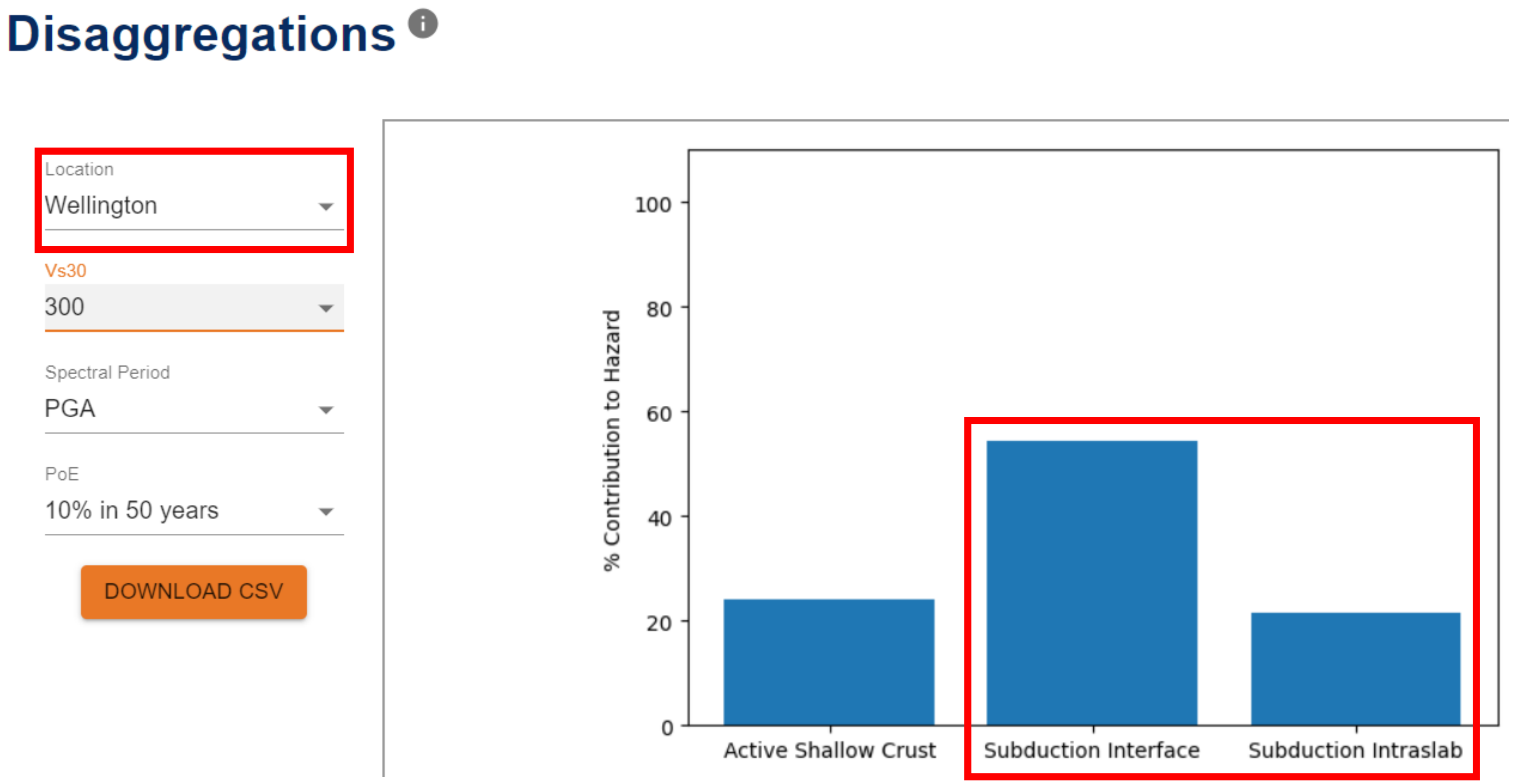


Regionalization of Δσ in simulations?

(Lee et al., 2022)

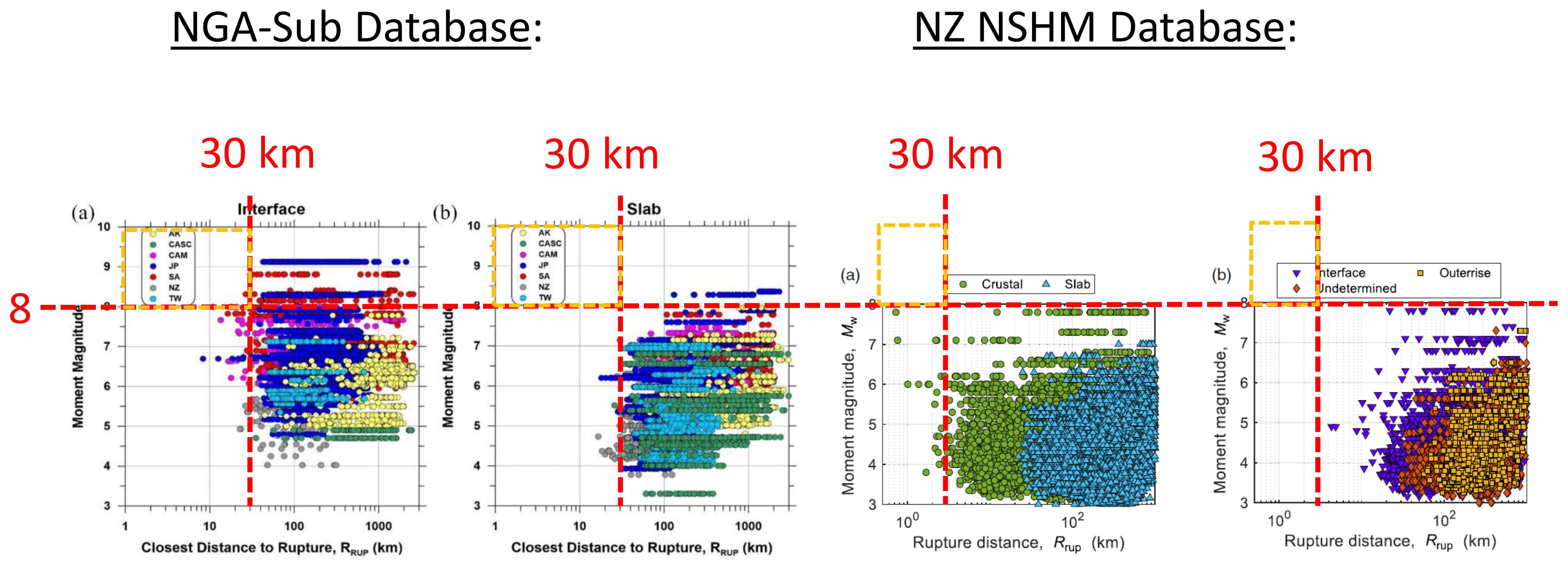
Other Short-Term Uses of Simulations in the NSHM

- In the “short” term, “Approach 2”: Informing GMMs through simulations
- Advances in Subduction GMMS



Other Short-Term Uses of Simulations in the NSHM

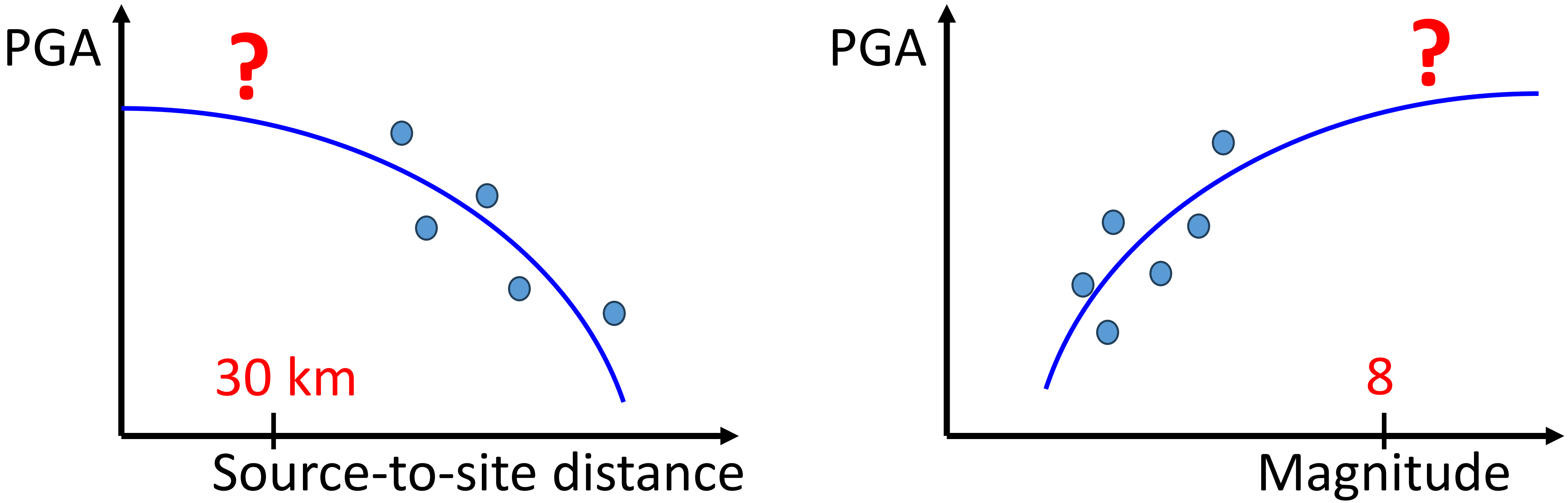
- Advances in Subduction GMMS



(Bozorgnia et al., 2022) (Hutchinson et al., 2023)

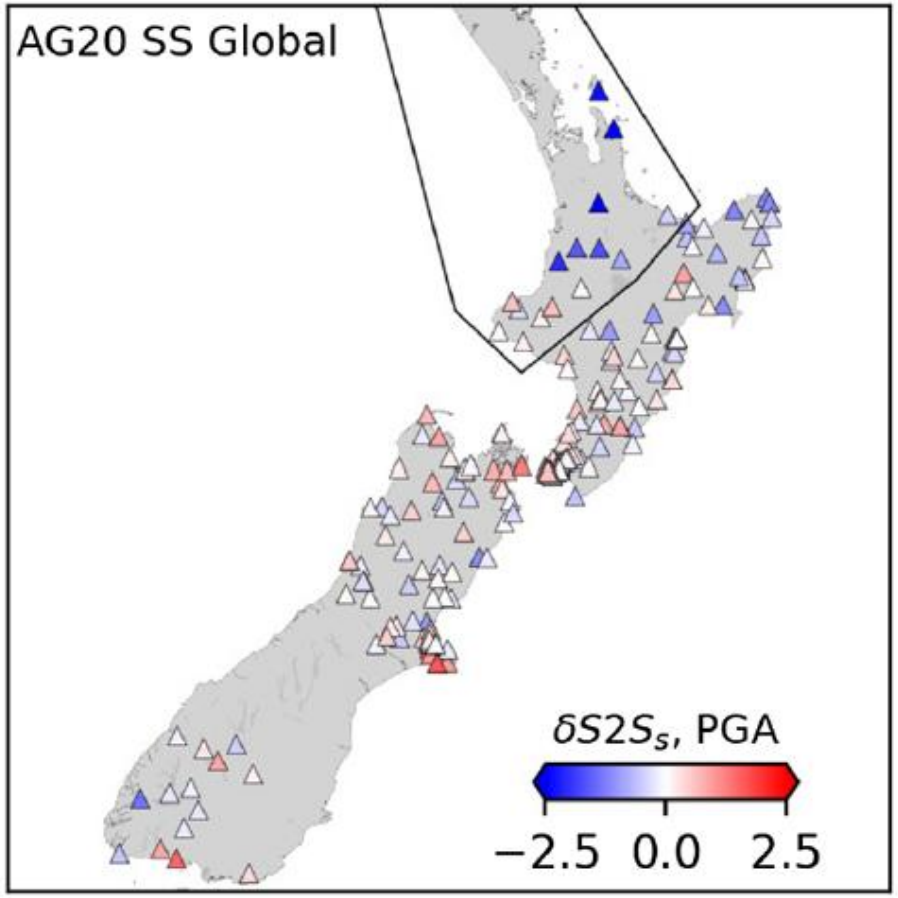
Other Short-Term Uses of Simulations in the NSHM

- Advances in Subduction GMMS



Use of physics-based ground-motion simulations for NZ-specific extrapolation beyond the data (e.g., distant and magnitude scaling of the ground motion)

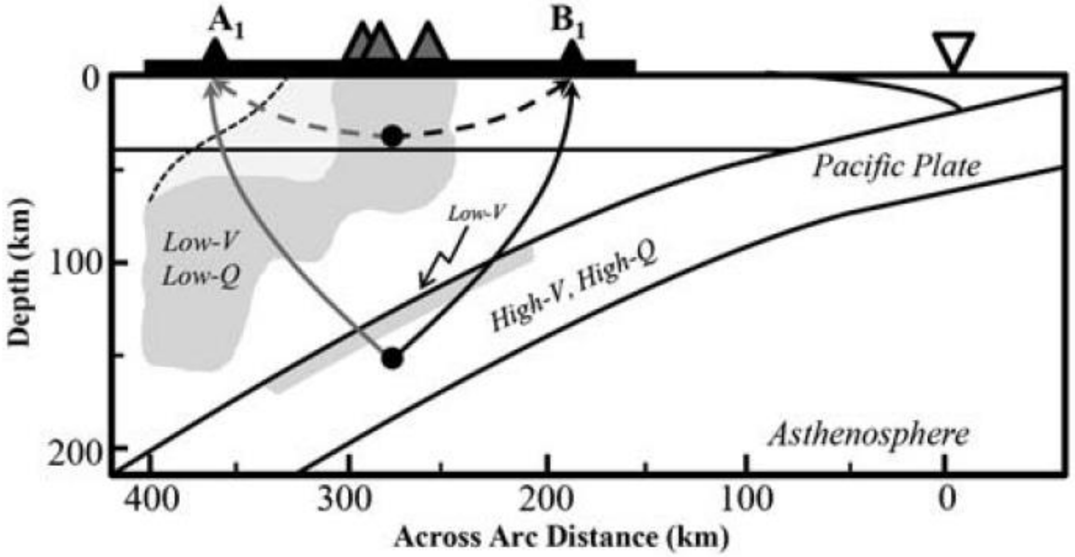
Other Short-Term Uses of Simulations in the NSHM



Significant overprediction throughout and to the west of the Taupō Volcanic Zone

(Lee et al., 2024)

Back-arc anelastic attenuation

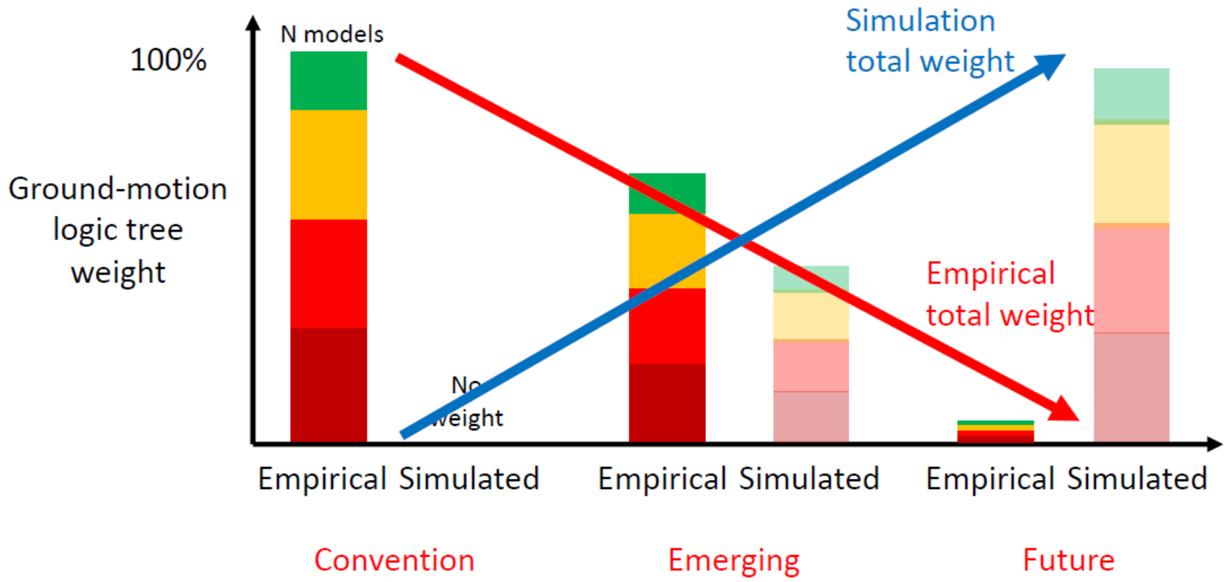


(Ghofrani and Atkinson, 2011)

- Back-arc anelastic attenuation effect was incorporated using a generic adjustment
- **Use of simulations for a NZ-specific adjustment**

Closing Remarks

- Simulations can be used for direct computation of PSHA (Approach 1) or to inform empirical GMM components (Approach 2)
- Due to ongoing challenges in Approach 1 regarding validation and uncertainty treatment, Approach 2 will most likely be the initial focus, with progressively greater use of Approach 1



- Validation (with a large number of observations and high-quality site-characterization data) is key to adopt simulations
- Possible uses of simulations: regionalization, extrapolation, back-arc attenuation effects

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