UNIVERSITY OF CANTERBURY
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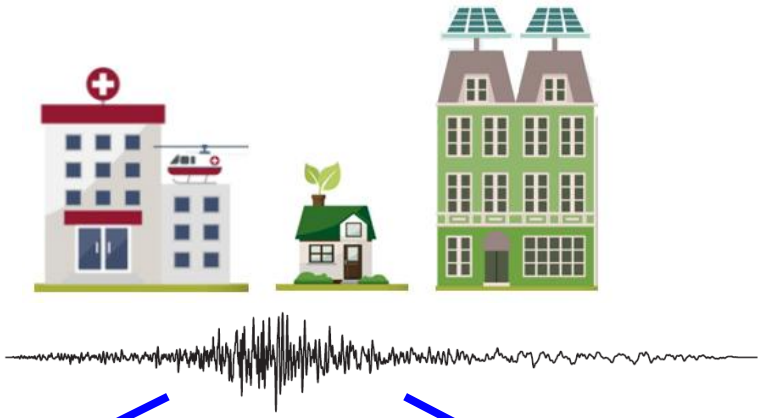
QuakeCoRE
NZ Centre for Earthquake Resilience
Te Hiranga Rū

Modelling site effects in hybrid broadband ground-motion simulation: insights from validation studies in New Zealand

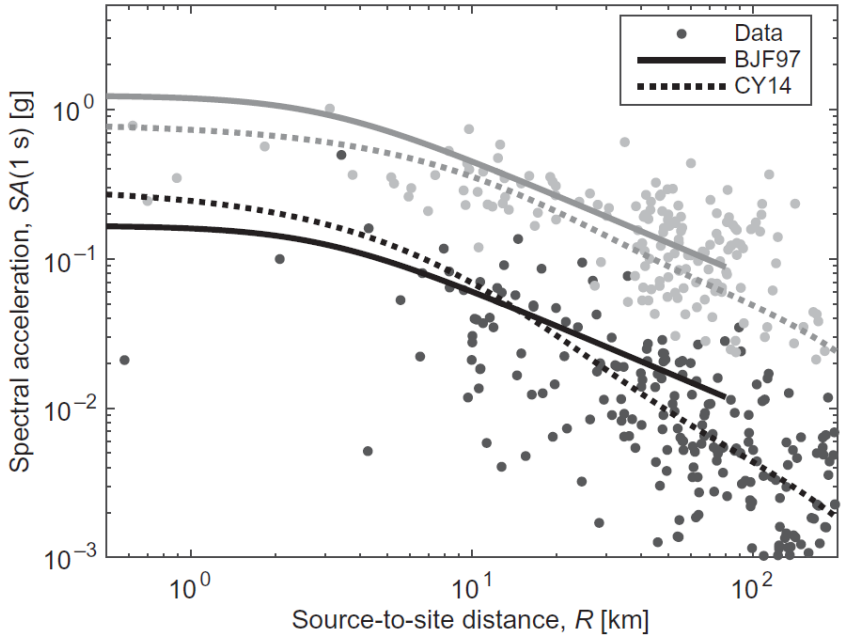
Felipe Kuncar, Brendon Bradley, Christopher de la Torre, Adrian Rodriguez−Marek, Chuanbin Zhu, Robin Lee

PBD-V | 4 November 2026, Puerto Varas, Chile

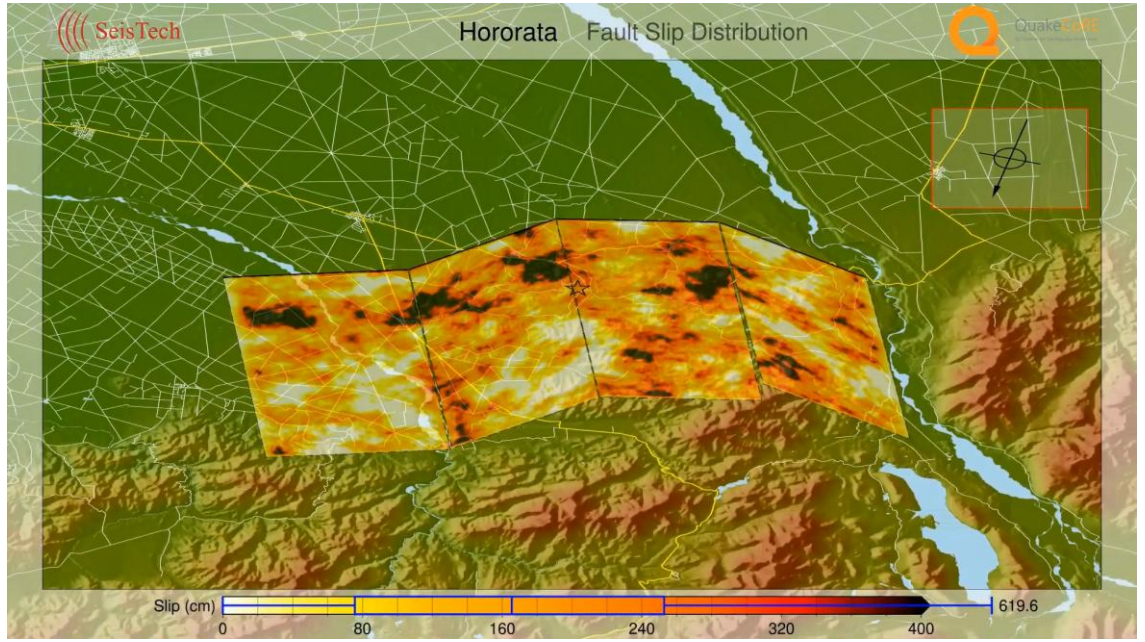
A new paradigm in ground-motion prediction



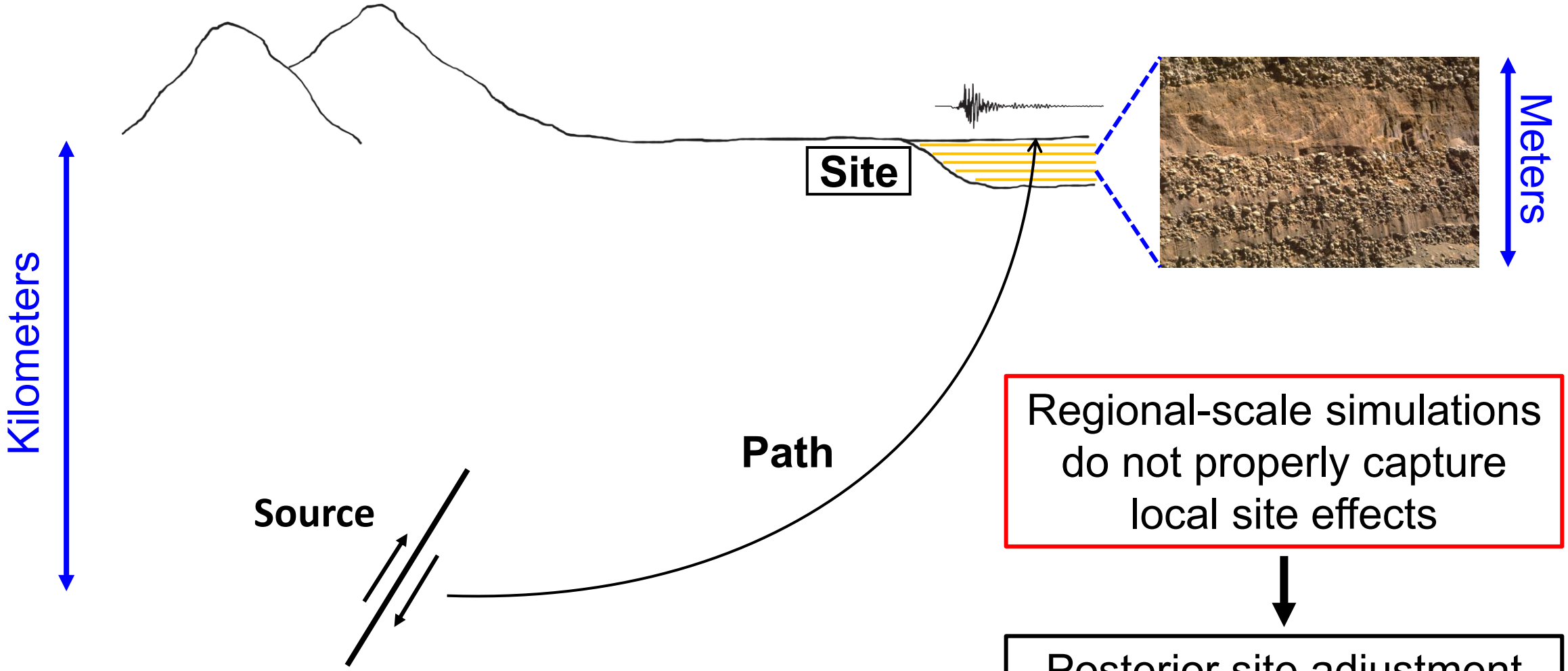
Empirical models (GMMs)



Physics-based ground-motion simulations



Capturing local site effects is challenging: adjustment is needed



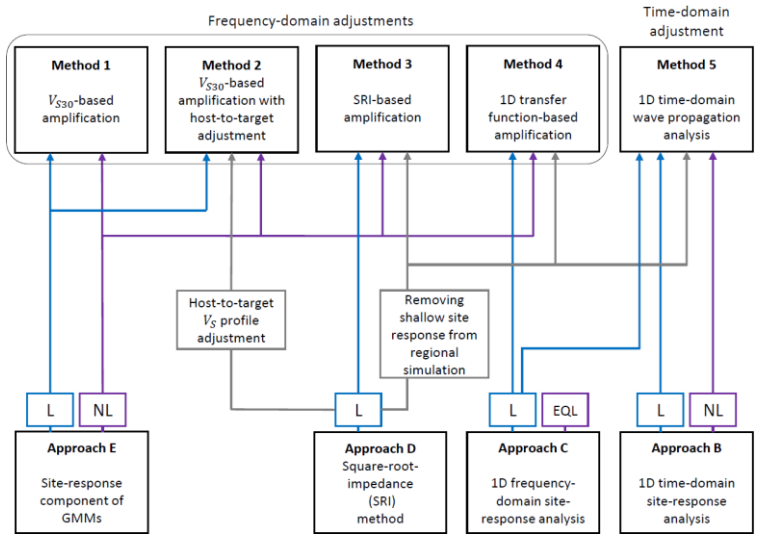
Regional-scale simulations do not properly capture local site effects

↓

Posterior site adjustment

How to properly perform the site adjustment?

Methods



Less data → **More data**

V_{S30}

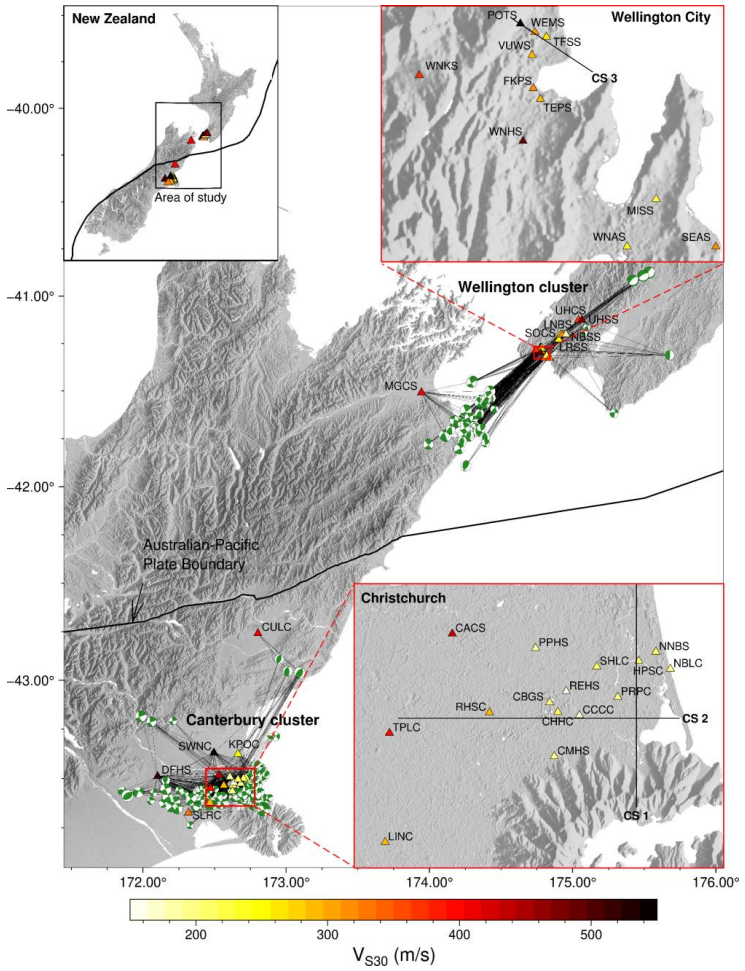
V_S profile

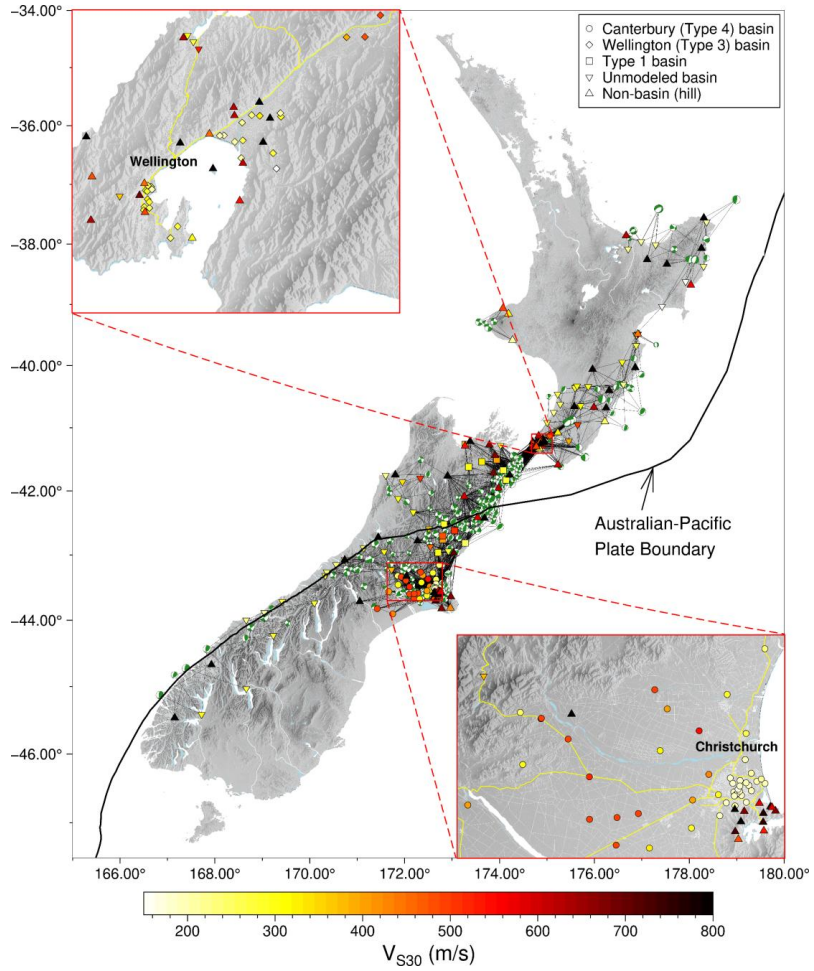
V_S profile + CPT, SPT, lab data

Validation Study 1

Validation Study 2

Small-magnitude crustal earthquakes and strong-motion stations in **New Zealand**





Validation methodology: residual analysis

Observation  $\rightarrow IM_{Obs,es}$

Simulation  $\rightarrow IM_{Sim,es}$

Prediction residual:

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

Computed for **multiple** ground motions

- Residual components:

$$\Delta_{es} = a + \underbrace{\delta S2S_s}_{\text{Site}} + \underbrace{\delta B_e}_{\text{Event}} + \underbrace{\delta \mathrm{W}_{\mathrm{es}}^{0}}_{\text{Remaining}}$$

- Residual variability components:

$$\sigma^2 = \underbrace{\phi_{S2S}^2}_{\text{Site}} + \underbrace{\tau^2}_{\text{Event}} + \underbrace{\phi_{ss}^2}_{\text{Remaining}}$$

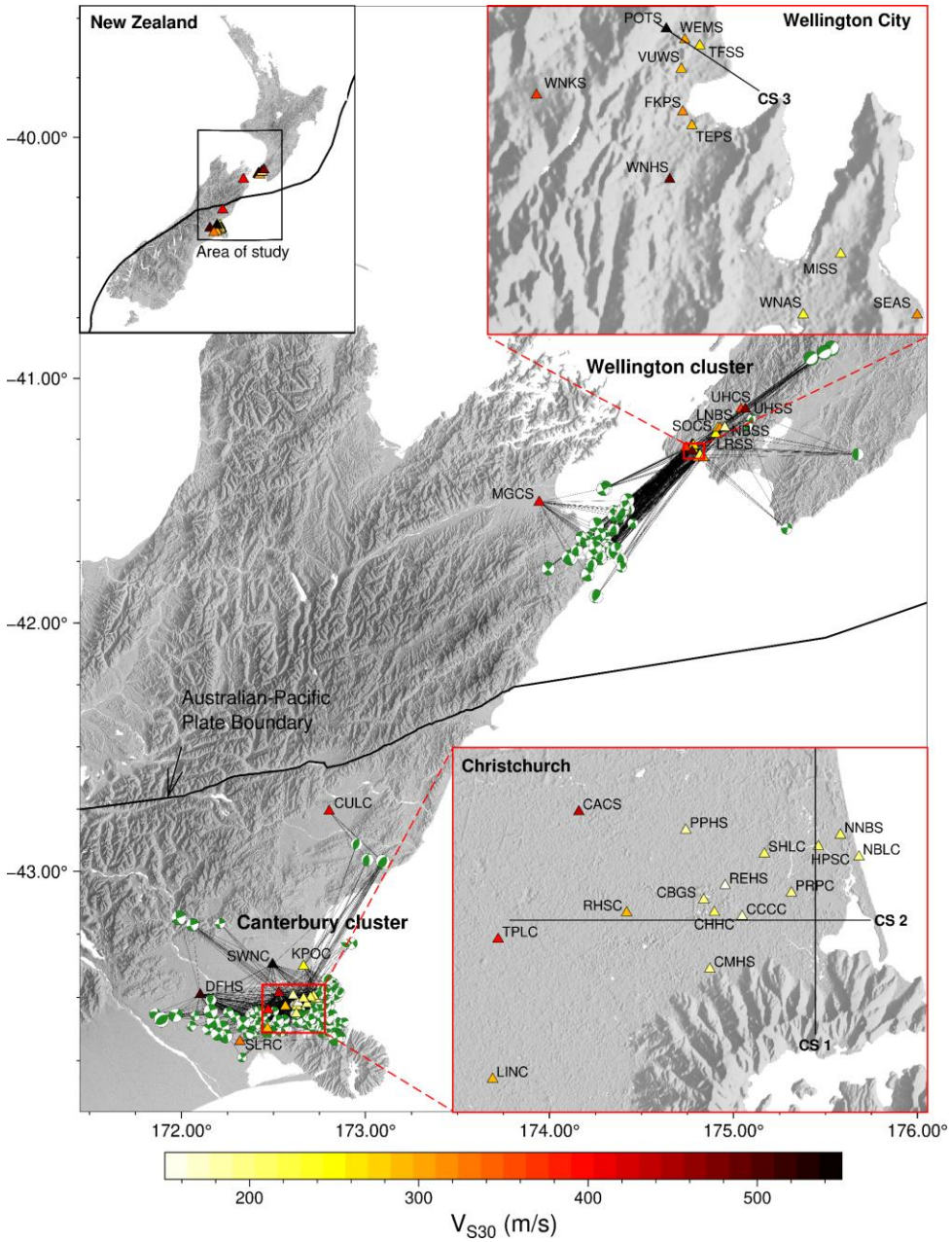
→ Statistical evaluation of **accuracy** and **precision** of the simulations

Validation Study 1:
Evaluation of methods based on a V_S profile

Validation study 1

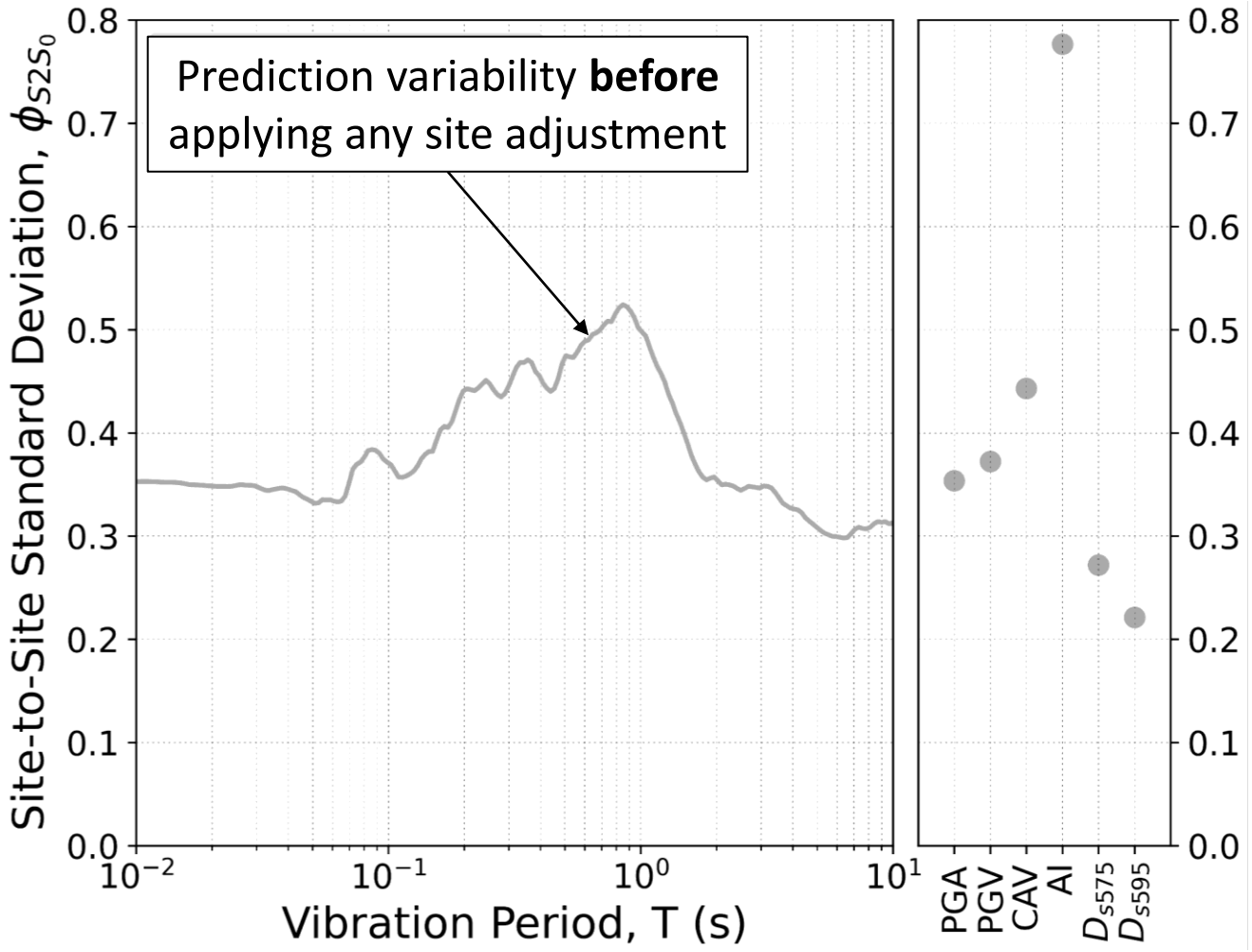
- **38 sites** with a measured V_S profile
- 213 events, 1,446 ground motions
- **Focus:**

Methods based on a V_S profile
vs.
Methods based on V_{S30}



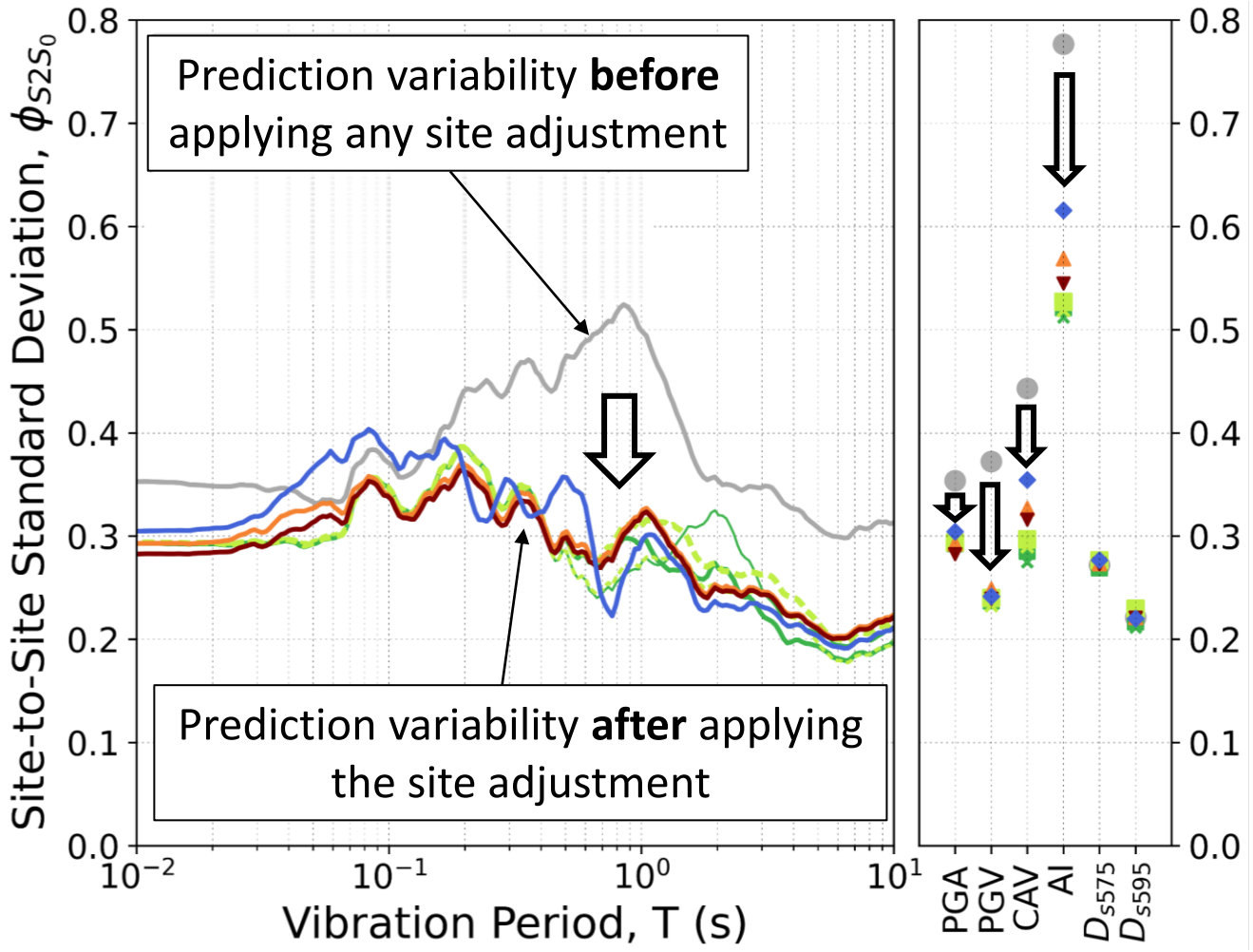
Site adjustments allow for a reduction in residual variability

Residual variability (based on the **1,446 ground motions**):



Site adjustments allow for a reduction in residual variability

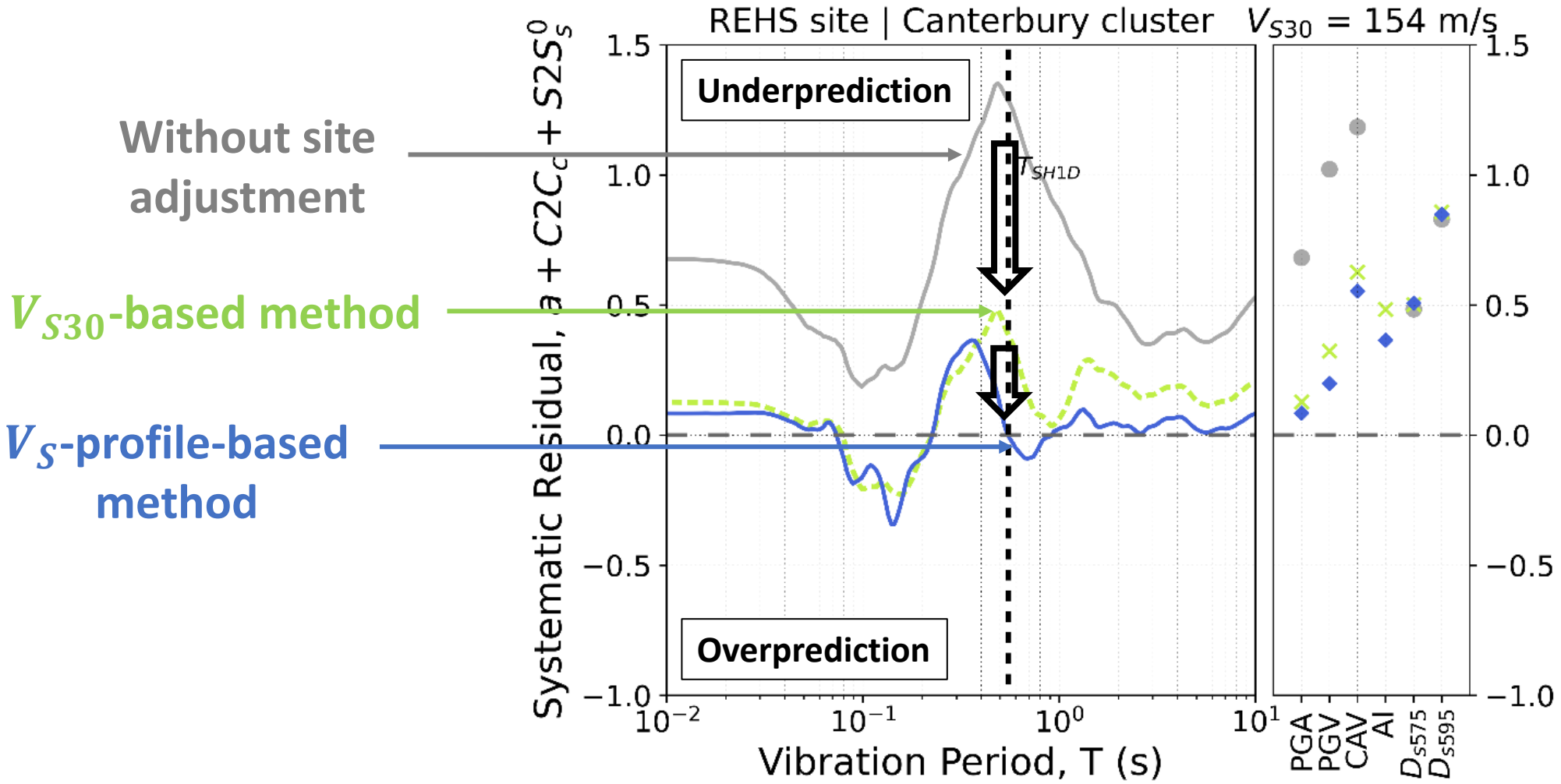
Residual variability (based on the **1,446 ground motions**):



- Significant improvement in simulation **precision** after incorporating site effects
- **Comparable performance** between methods based on V_{S30} and based on a V_S profile

Further improvements obtained using a V_S profile

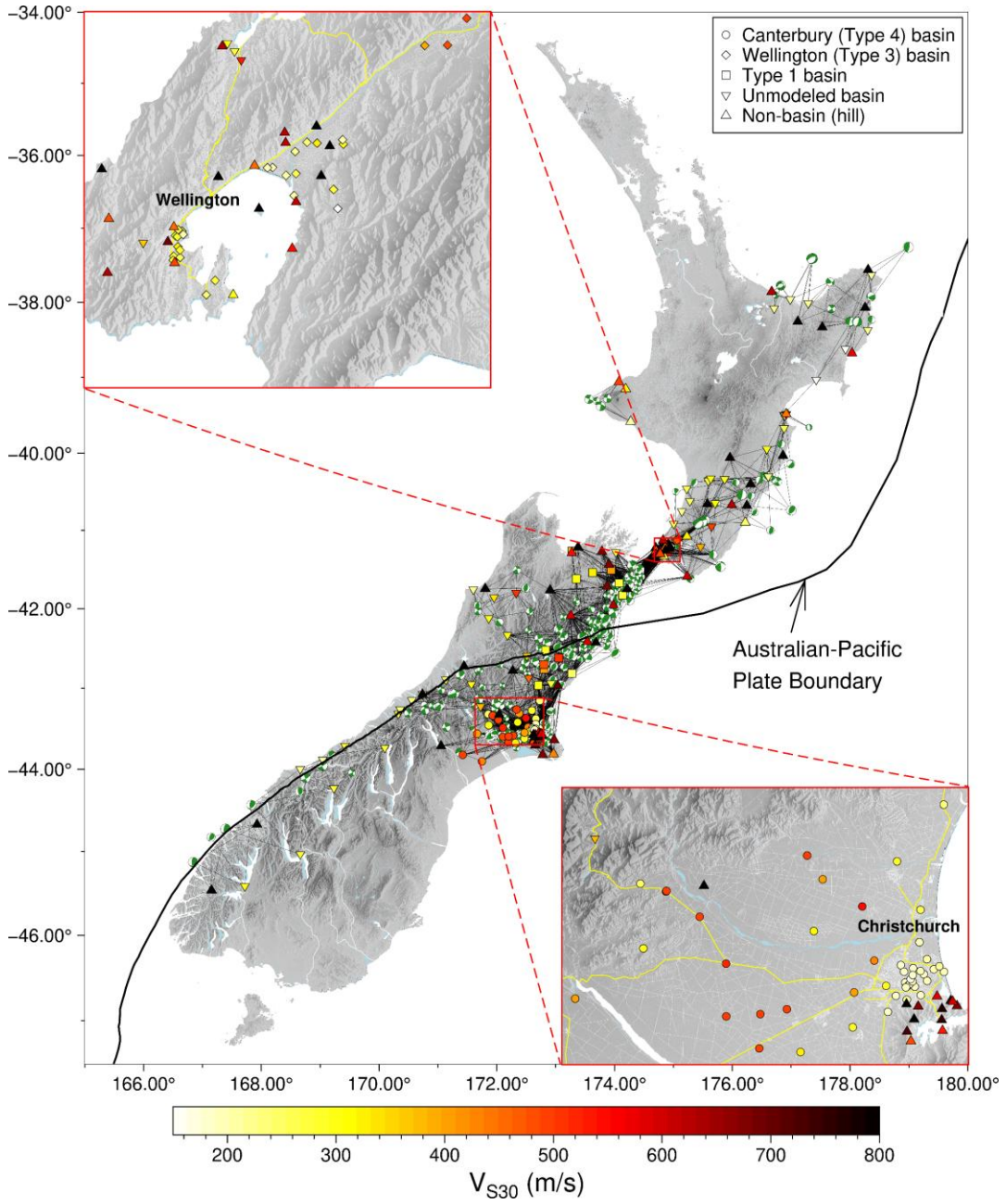
V_S-profile-based methods **show further improve simulation accuracy** for certain site conditions. E.g., relatively soft sites with strong resonances



Validation Study 2:
Evaluation of V_{S30}-based methods

Validation Study 2

- **212 sites** with a V_{S30} estimate
- 479 events, 5,218 ground motions
- **Focus:** Best practices for the implementation of V_{S30}-based methods
- **In this presentation:** How to apply the site adjustment to the low-frequency (LF) simulation component?
- **Not covered in this presentation:**
  - Alternative V_{S30}-based models
  - Host-to-target adjustment

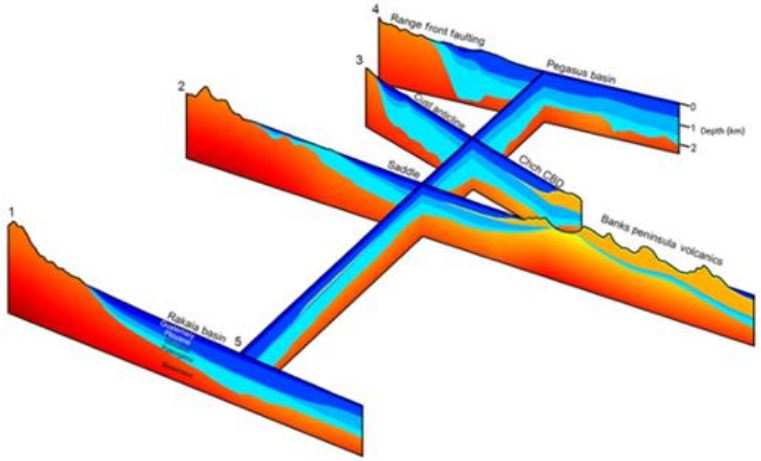


How to apply the site adjustment to the LF sim component?

- Hybrid ground-motion simulation method:

Low-Frequency (LF)

3D Wave Propagation



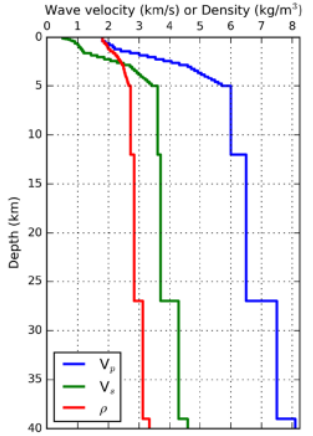
Transition Freq.

1 Hz

(this study)

High-Frequency (HF)

Simplified Physics ~ 1D



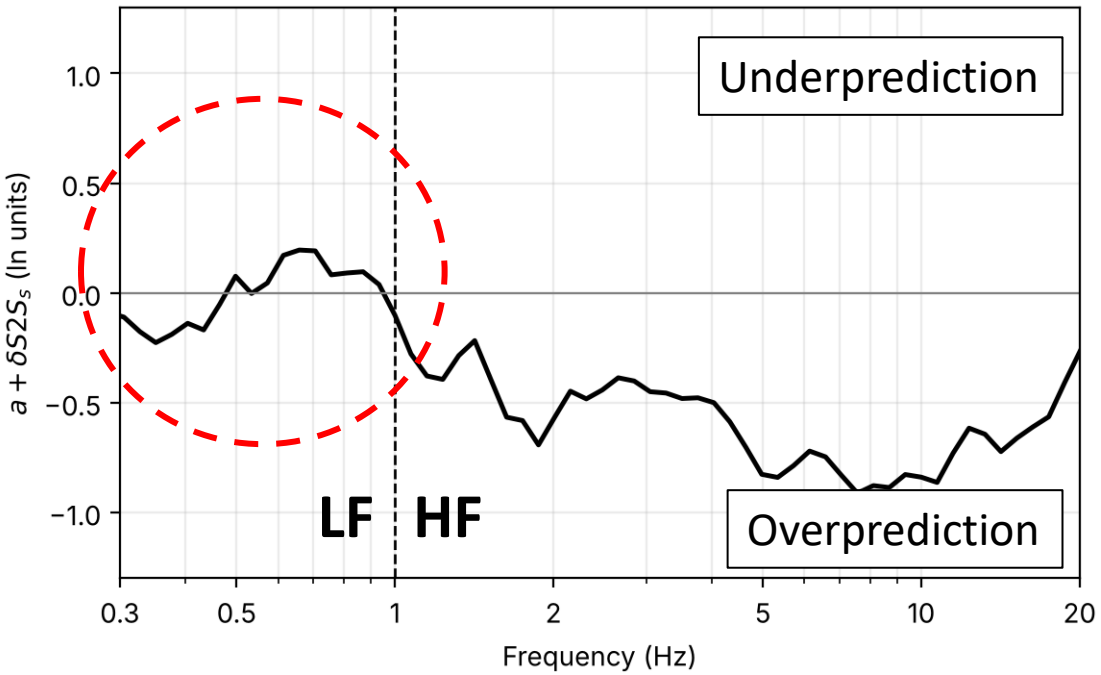
Problem:

- Applying the site factor to the LF simulation component produces **overprediction**
- **Hypothesis:** 3D velocity model already captures site effects (e.g., Lee et al., 2020)
- Not applying the site factor to the LF simulation component produces **underprediction**

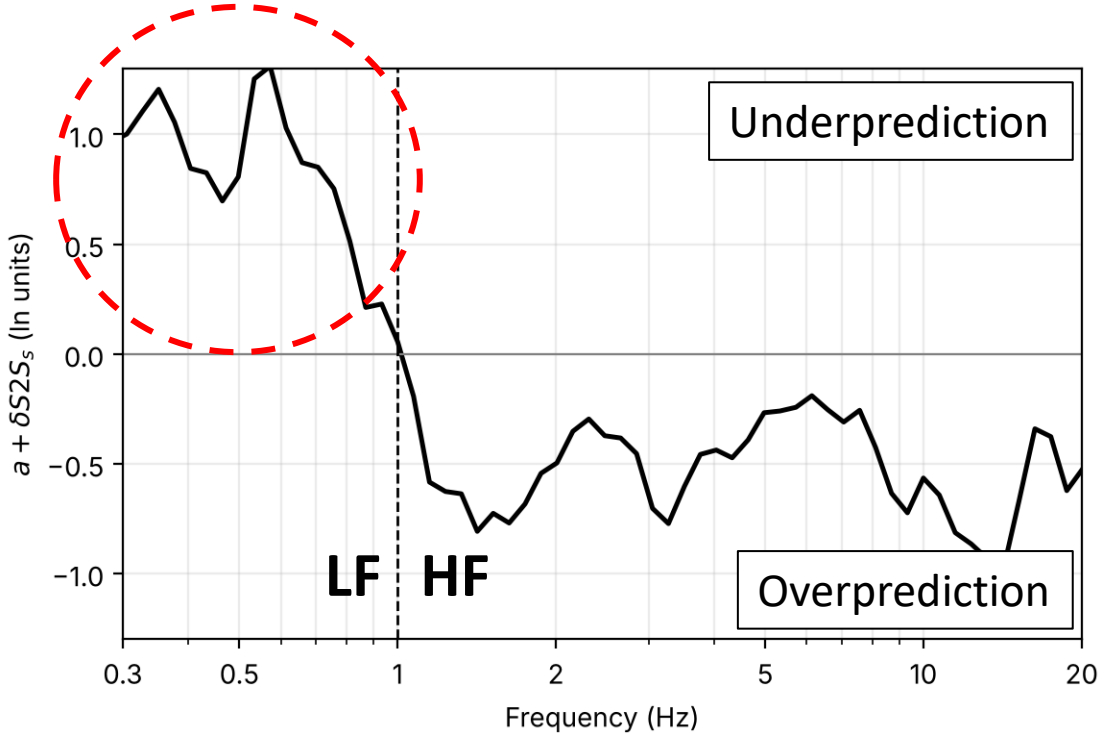
The answer is not the same for every site

Systematic residual when the site factor is not applied to the LF simulation component:

Station located at a hill

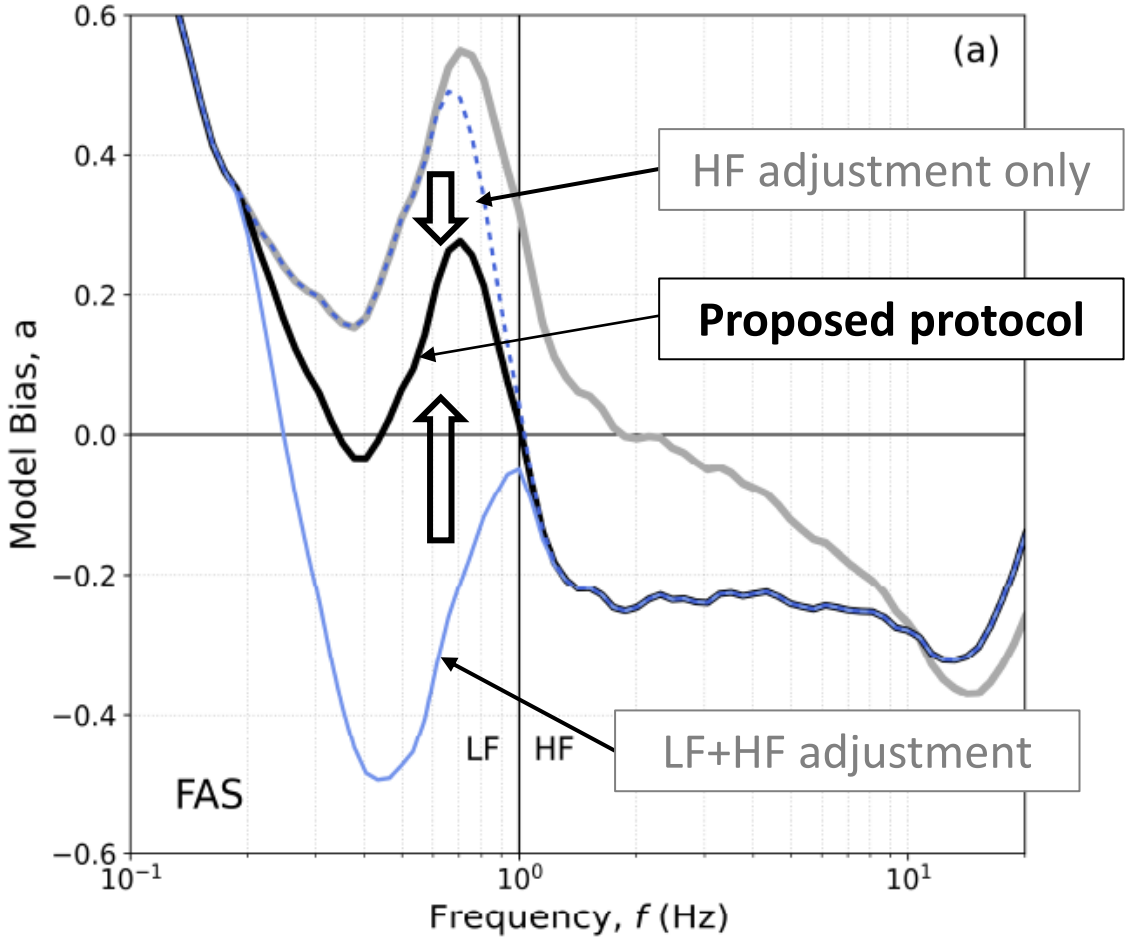


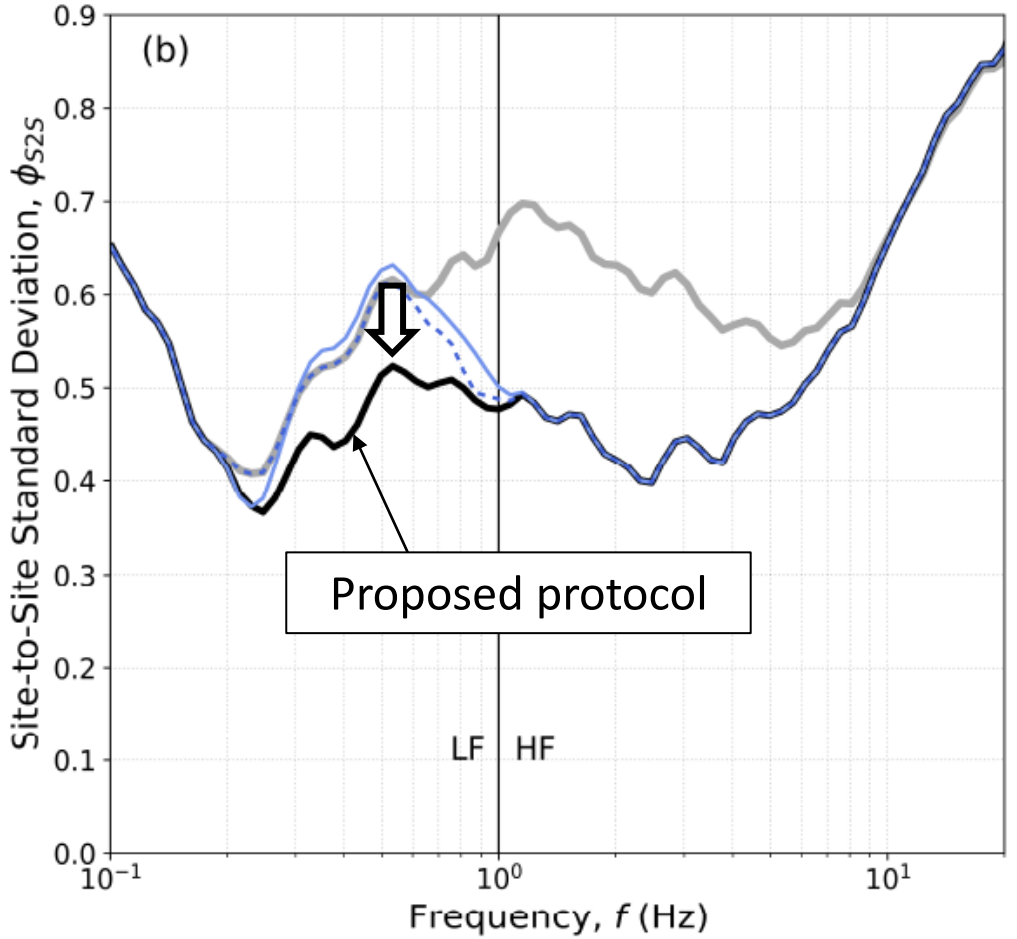
Station located within a basin that is not explicitly modelled



Proposed protocol improves simulation performance

- Application protocol based on **geomorphic** and **basin model quality** classifications
- Protocol **improves** both the **accuracy and precision** of the simulation



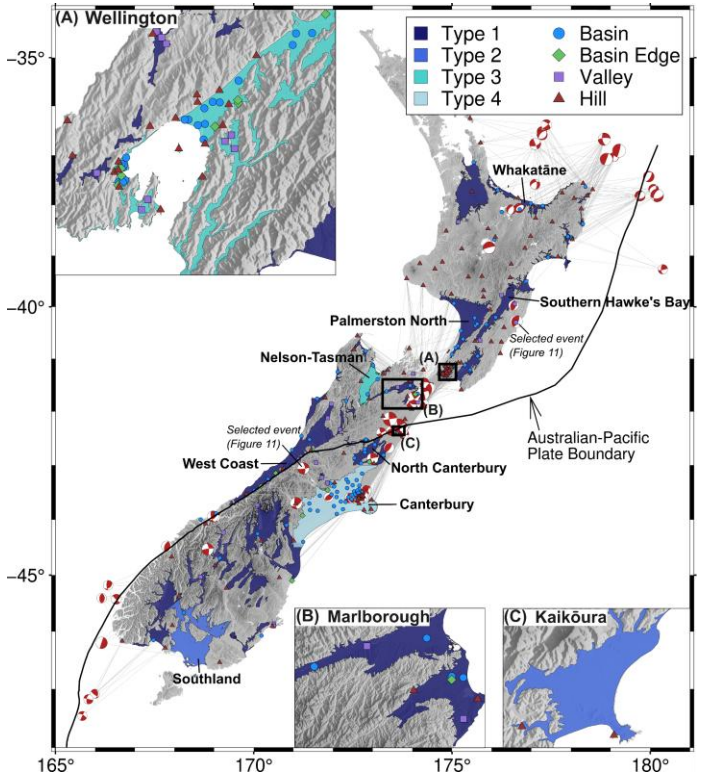


Conclusions

- Incorporating shallow site effects with any of the methods considered **significantly improved simulation precision**
- This improvement in precision was **comparable across methods**
- **Methods based on a V_S profile** can offer further improvements in prediction for **specific site conditions**
- The application of site factors based on V_{S30} to the LF simulation component can be informed by **geomorphic** and **basin model quality** classifications

Ongoing Research and Near-Term Activities

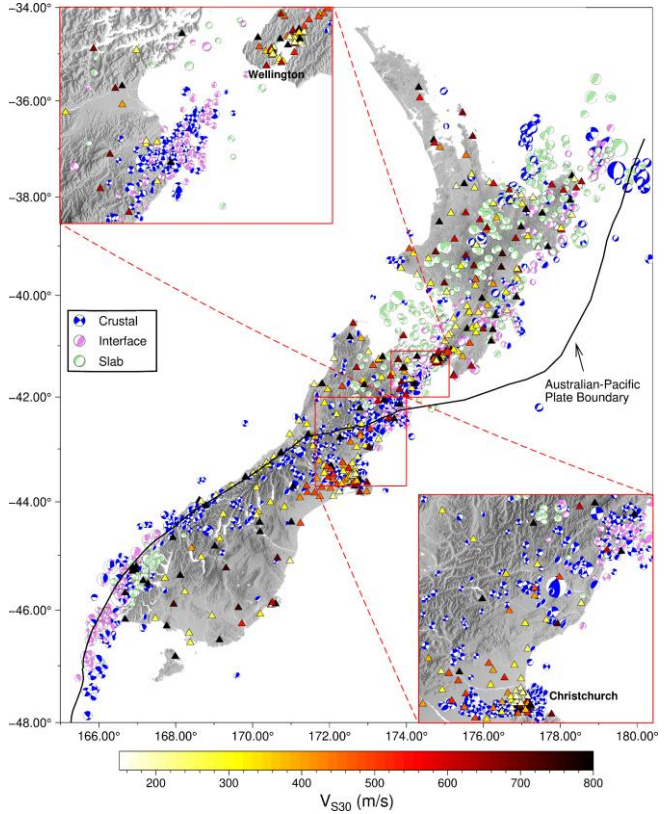
Significant velocity model improvement



Tiwari et al. (2026)

45 basin models

Larger validation database (M 3.5-7.8)



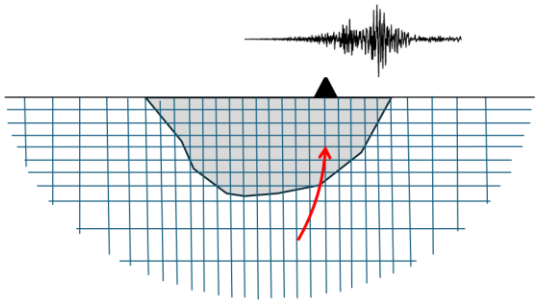
Kuncar et al. (in prep.)

1,600+ earthquakes

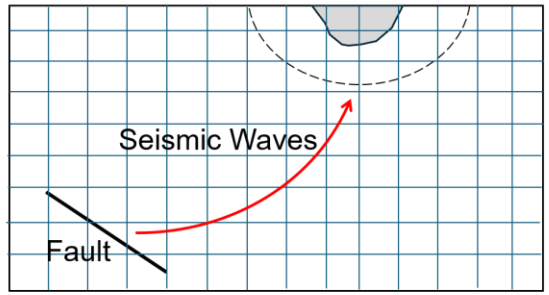
Site adjustments based on 2D/3D site response

Simulated ground motion, accounting for 3D site effects

Local Model: High-resolution basin model used for 3D site-response analysis

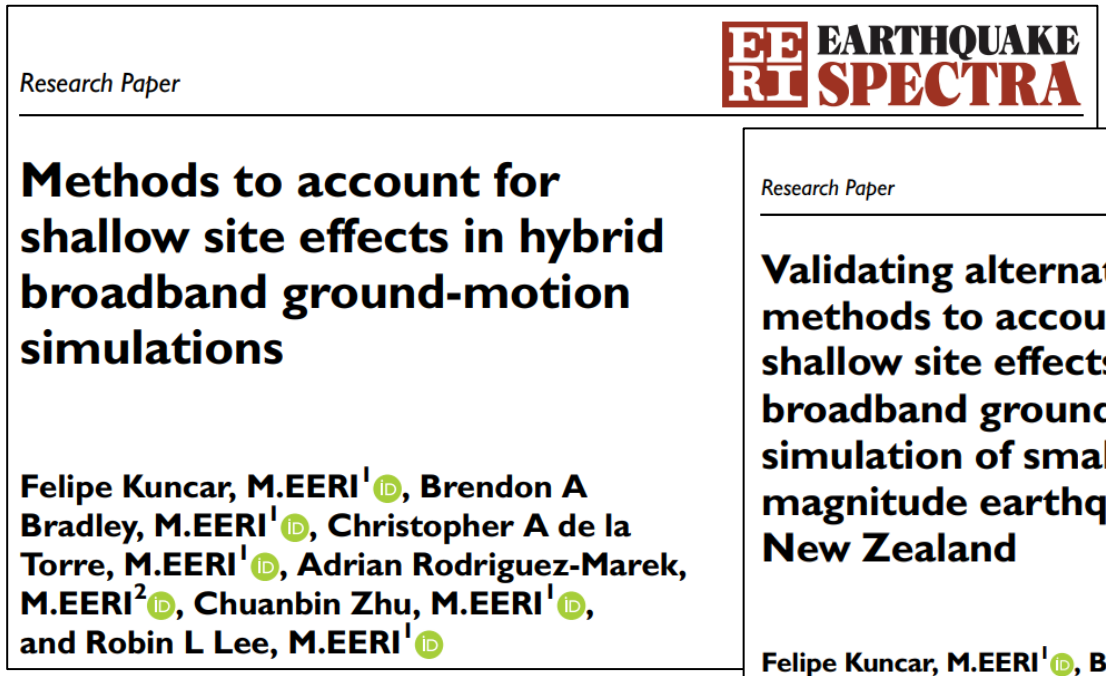


Model integration using the Domain Reduction Method



Regional Model: Used for regional ground-motion simulation. It has low near-surface spatial resolution

If you want to learn more about the work summarized in this presentation:

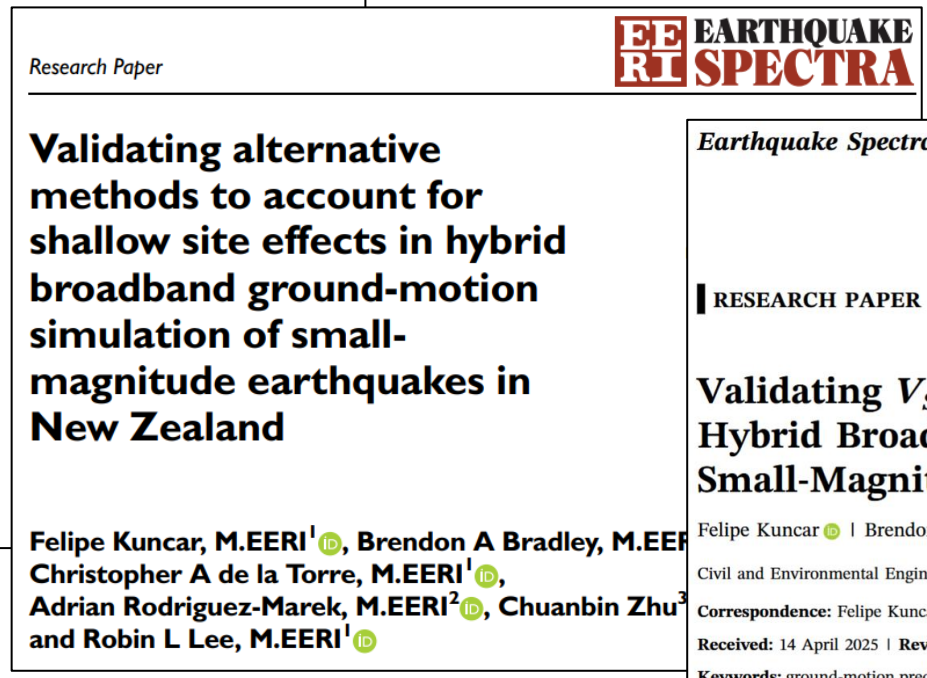


Research Paper

EARTHQUAKE SPECTRA

Methods to account for shallow site effects in hybrid broadband ground-motion simulations

Felipe Kuncar, M.EERI[1], Brendon A Bradley, M.EERI[1], Christopher A de la Torre, M.EERI[1], Adrian Rodriguez-Marek, M.EERI[2], Chuanbin Zhu, M.EERI[1], and Robin L Lee, M.EERI[1]

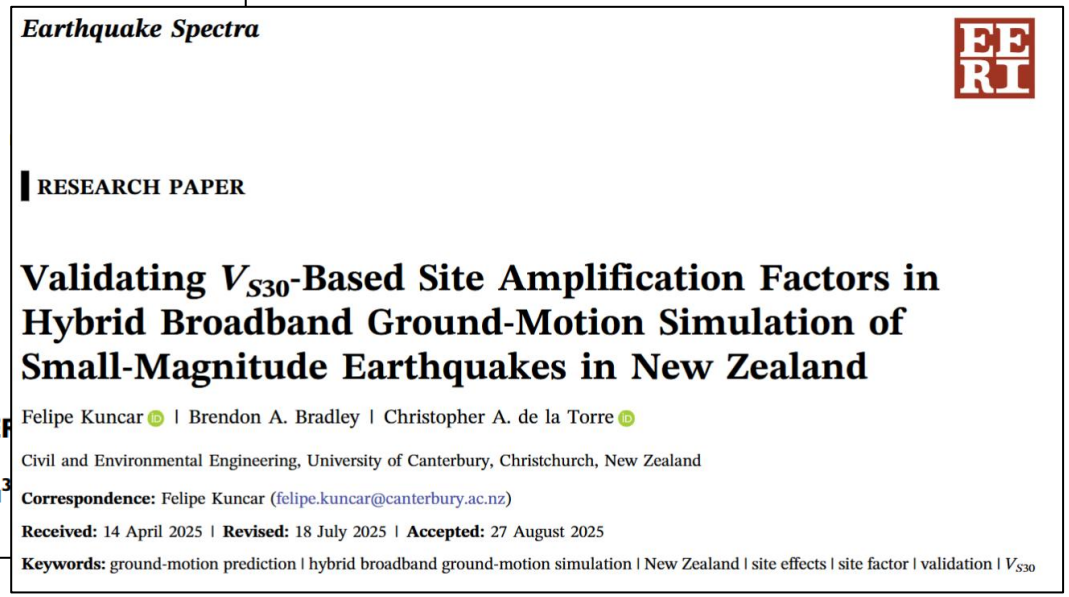


Research Paper

EARTHQUAKE SPECTRA

Validating alternative methods to account for shallow site effects in hybrid broadband ground-motion simulation of small-magnitude earthquakes in New Zealand

Felipe Kuncar, M.EERI[1], Brendon A Bradley, M.EERI
Christopher A de la Torre, M.EERI[1],
Adrian Rodriguez-Marek, M.EERI[2], Chuanbin Zhu[3]
and Robin L Lee, M.EERI[1]



Earthquake Spectra

RESEARCH PAPER

Validating V_{S30}-Based Site Amplification Factors in Hybrid Broadband Ground-Motion Simulation of Small-Magnitude Earthquakes in New Zealand

Felipe Kuncar | Brendon A. Bradley | Christopher A. de la Torre

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Keywords: ground-motion prediction | hybrid broadband ground-motion simulation | New Zealand | site effects | site factor | validation | V_{S30}