Evaluating the Performance of 1D Site-Response Analysis in Ground-Motion Simulations: Insights from Small-Magnitude Events recorded in the Canterbury Region

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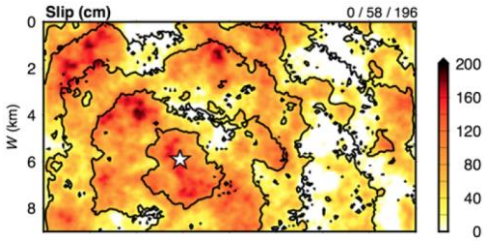
DT1 Call | 24/11/2022

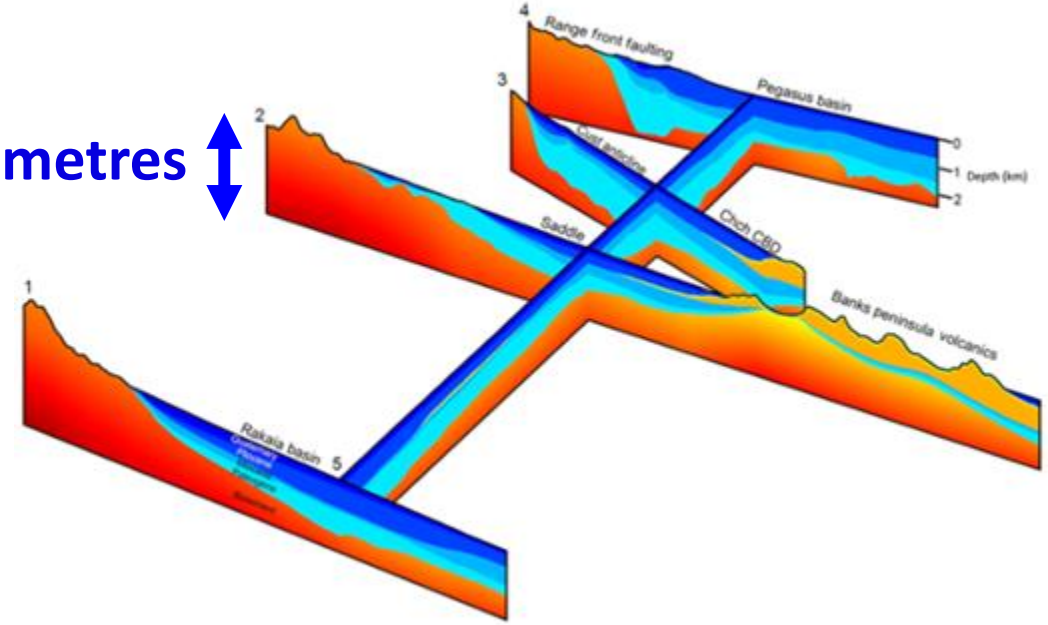
Motivation and Research Question

Motivation



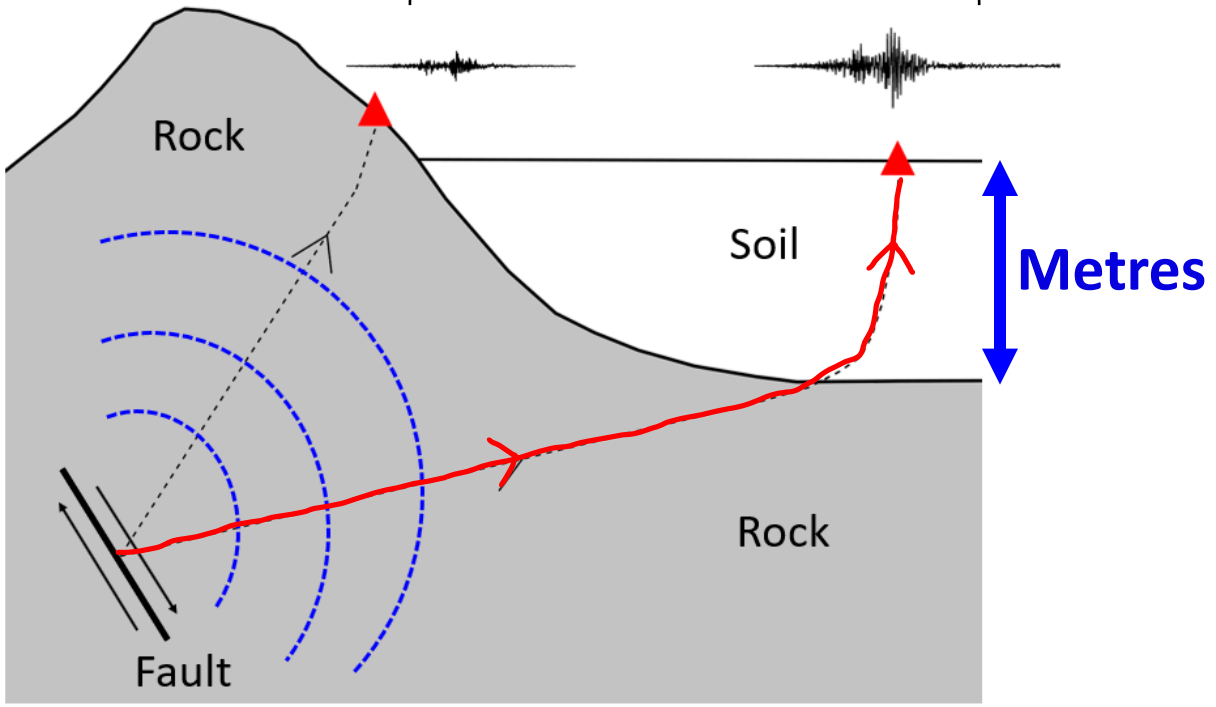
1. Source

Kilometres



2. Path

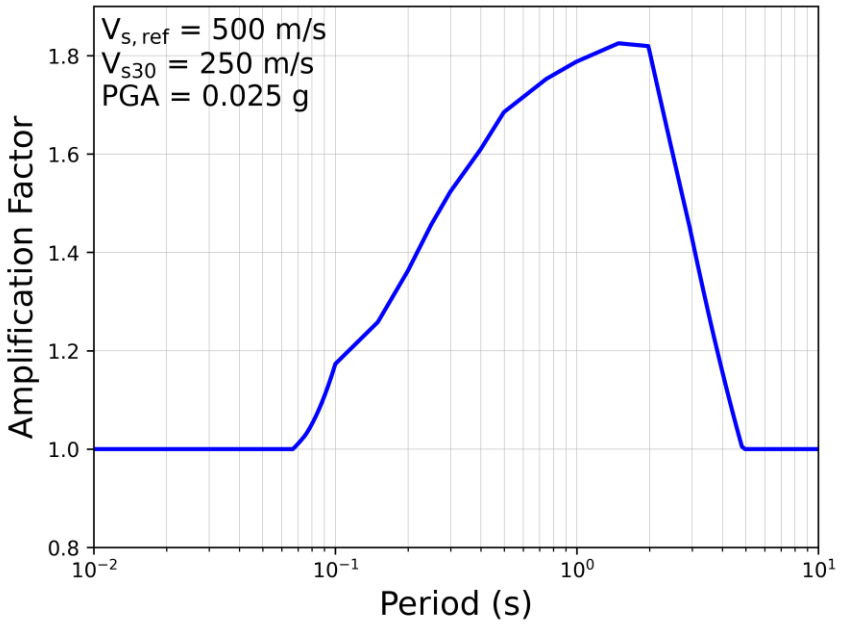
3. Local Site Effects



Research Question

Approach 1 (conventional):

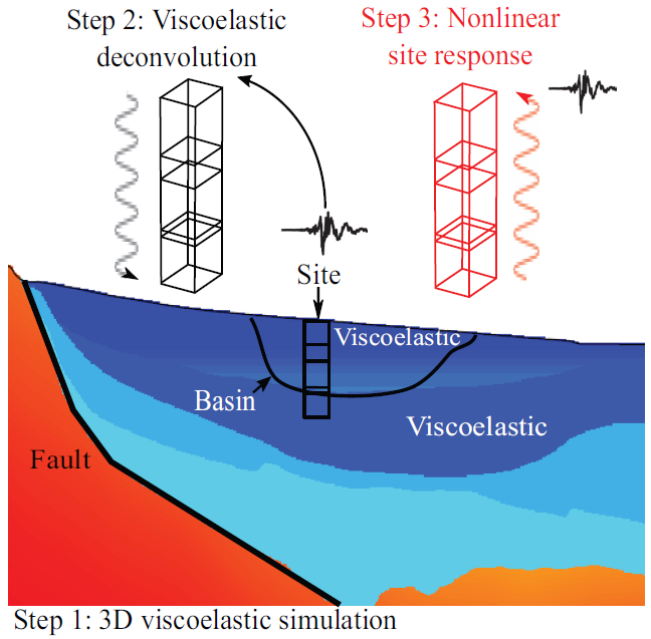
Empirical Amplification Factor



vs

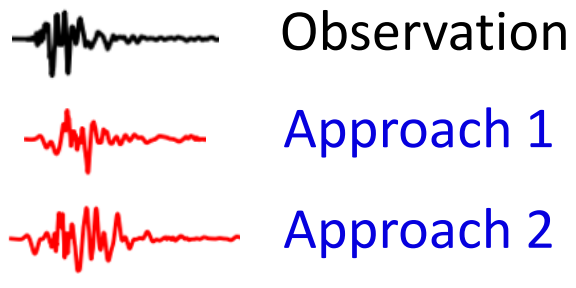
Approach 2:

Physics-Based Site-Response Analysis



Under what conditions can we improve predictions by **explicitly modelling local site effects** using site-response analysis?

Validation

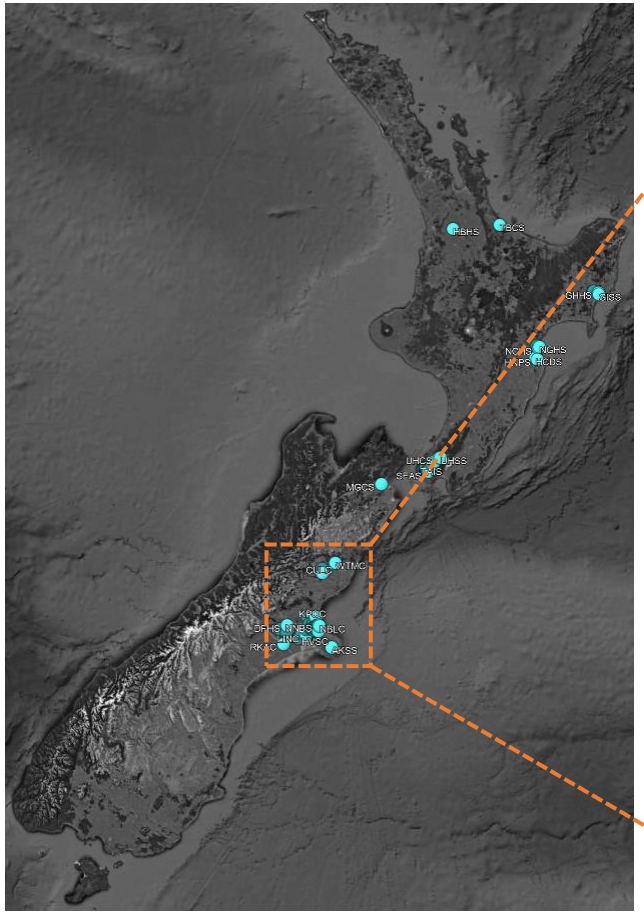


Sites and Observational Data Considered

Sites

Full study area

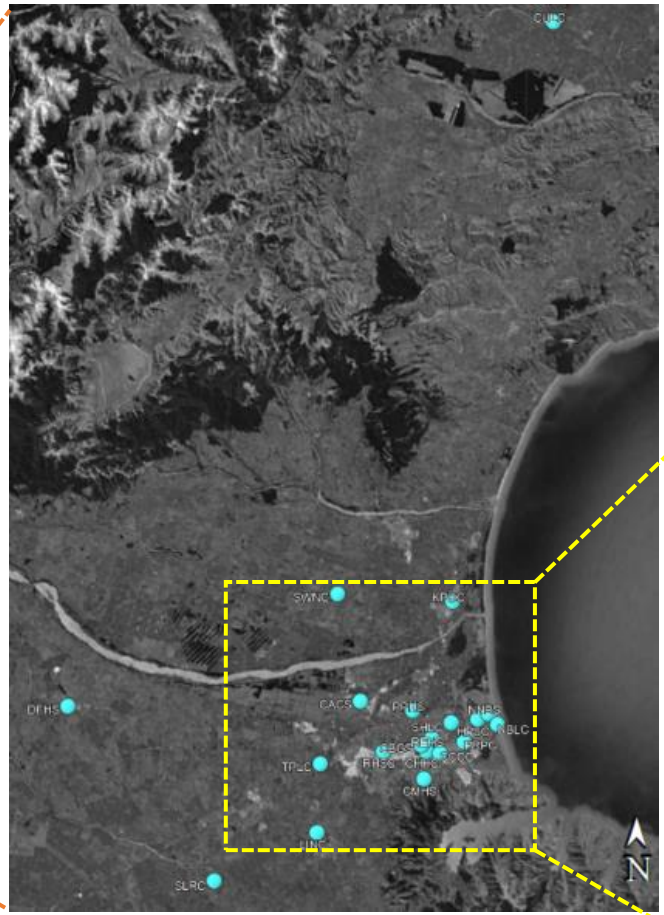
New Zealand | > 50 sites



- Strong-motion station
- High-quality Vs profile

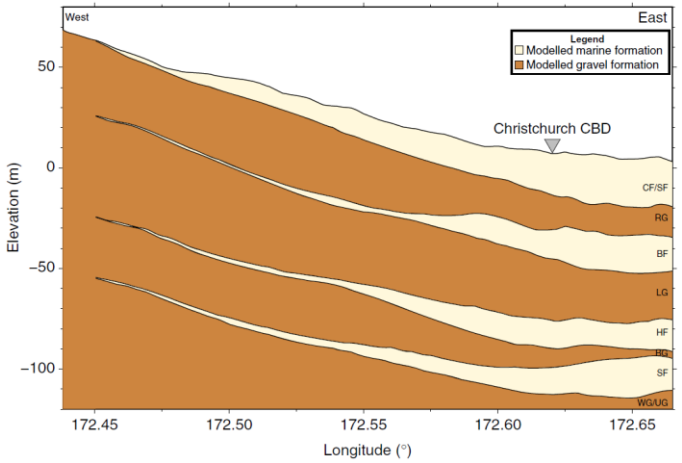
Current phase of the study

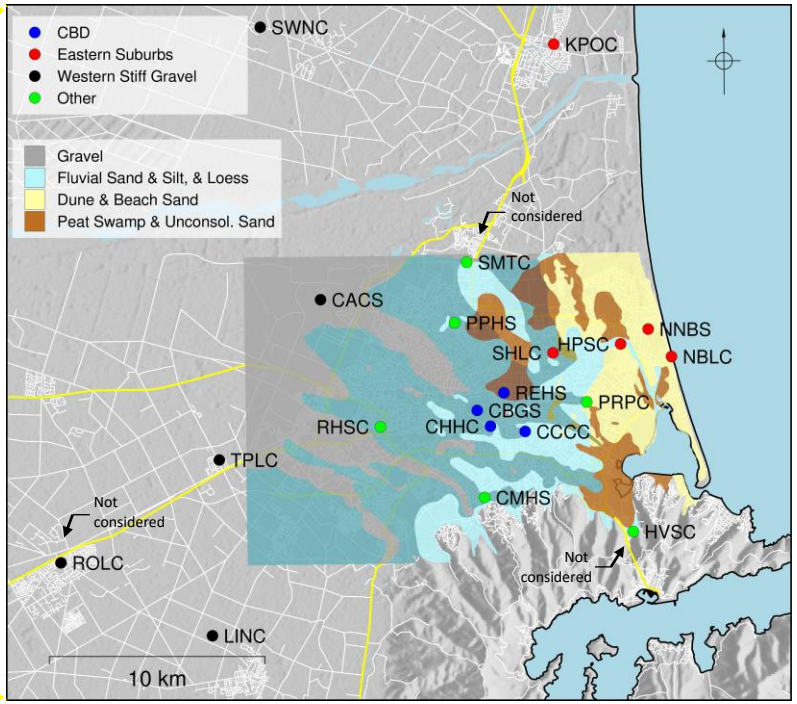
Canterbury Region | 20 sites (out of 28)



- ≥ 3 recordings

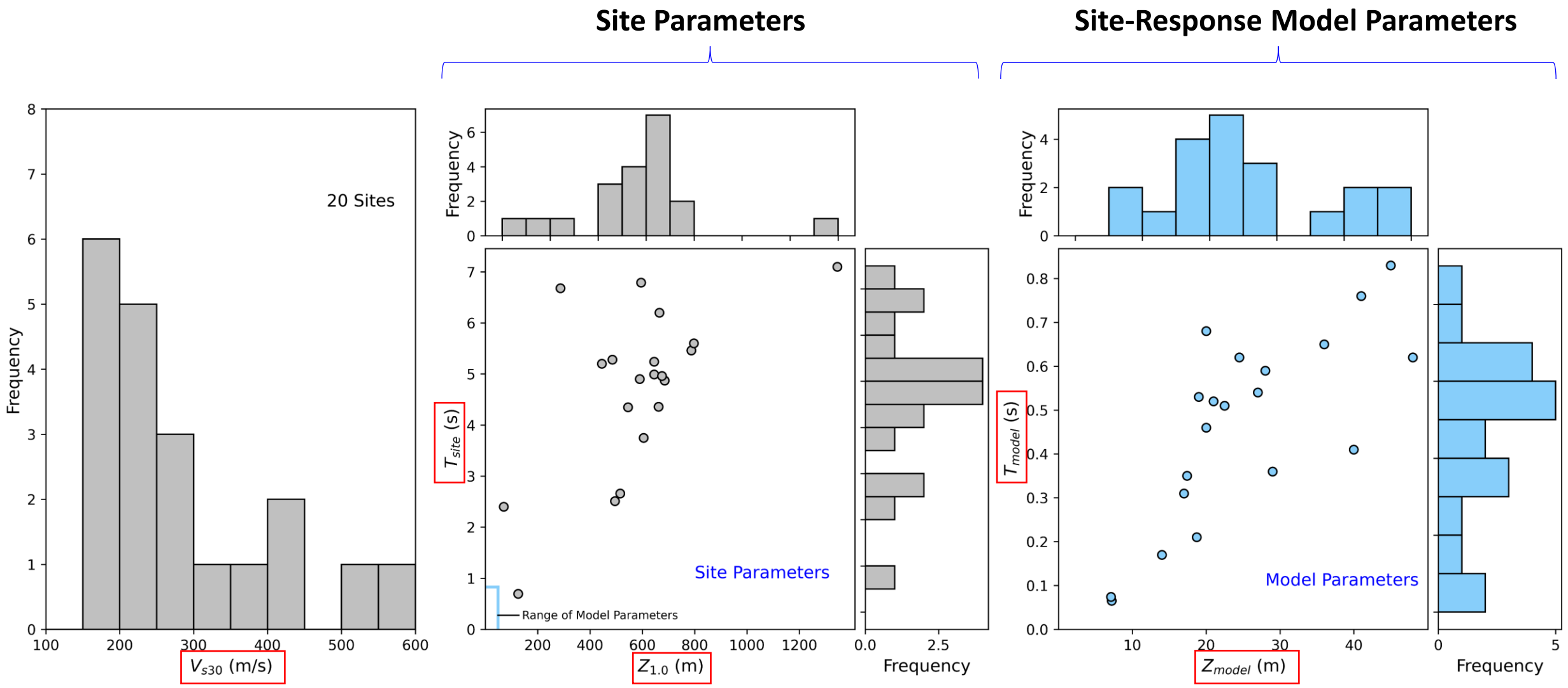
Christchurch Geology





Spatial variability of soil properties

Sites


Site Parameters
Site-Response Model Parameters
20 Sites
Frequency
V_{s30} (m/s)
T_{site} (s)
$Z_{1.0}$ (m)
Site Parameters
Range of Model Parameters
Frequency
T_{model} (s)
Z_{model} (m)
Model Parameters
Frequency

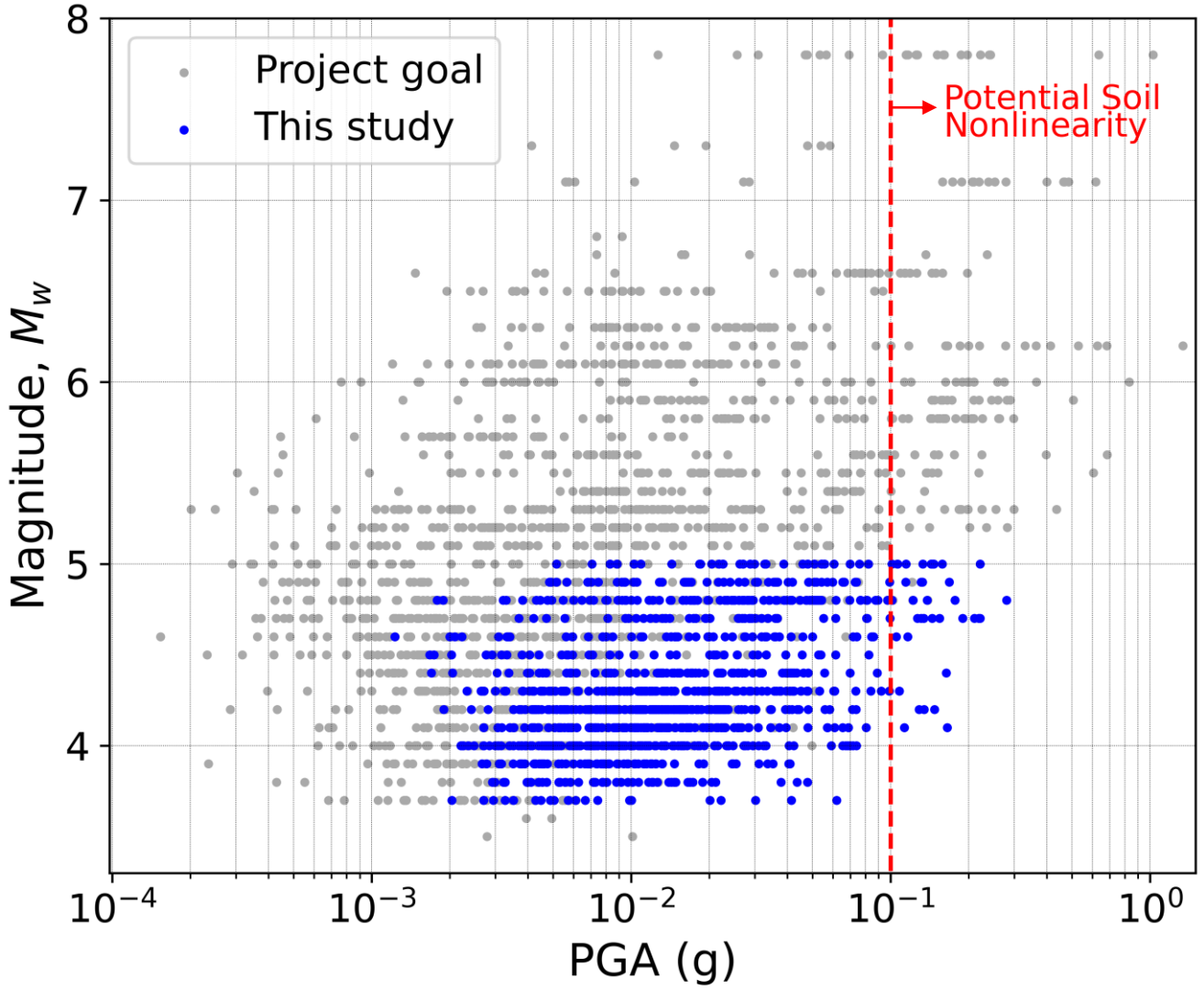
Earthquakes and Ground Motions

- $3.5 \leq M_w \leq 5.0$
- Crustal Events
- $\geq$ 3 Recordings per Site
- $\geq$ 3 Recordings per Event

20 Sites

158 Events

1032 Ground Motions



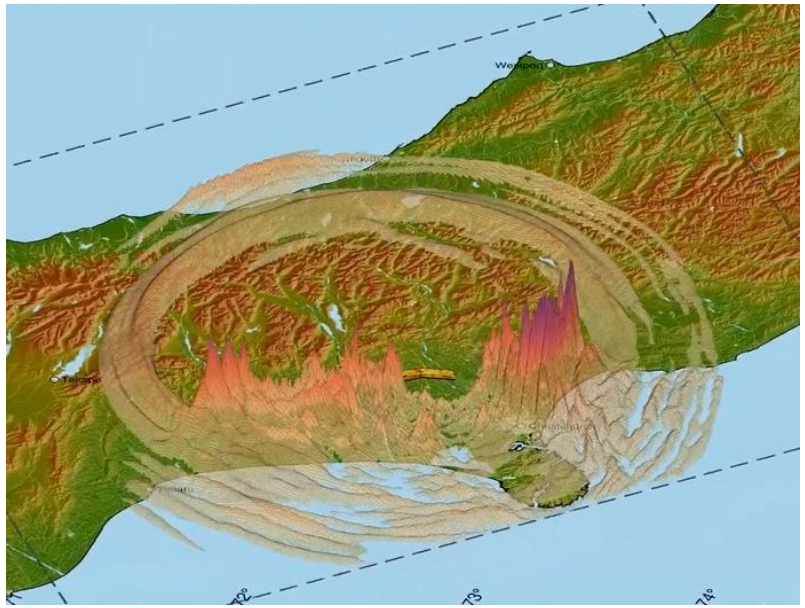
Methodology

Simulation and Site-Response Modelling

Regional-Scale Ground Motion Simulations

Simulations produced by Lee et al. (2022)

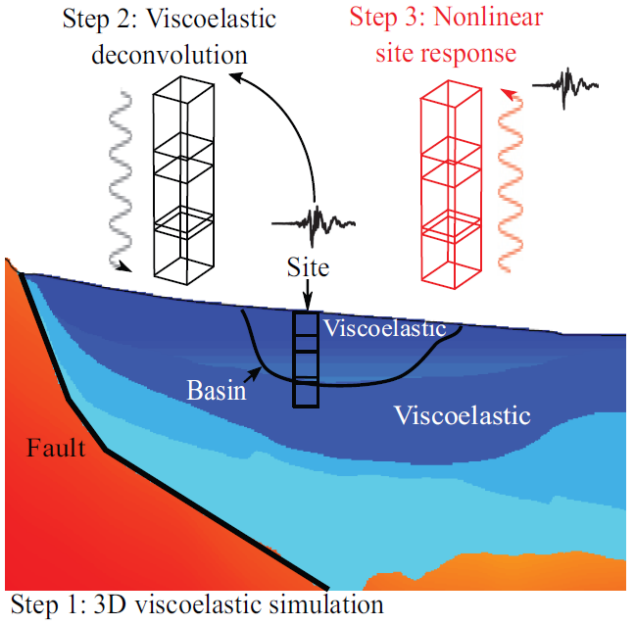
- Hybrid broadband method (Graves & Pitarka, 2010, 2015)
- LF-HF transition frequency of 1 Hz
- Minimum Vs of 500 m/s
- Grid spacing of 100 m



Approach 1: Empirical Amplification Factor

- Campbell & Bozorgnia (2014)

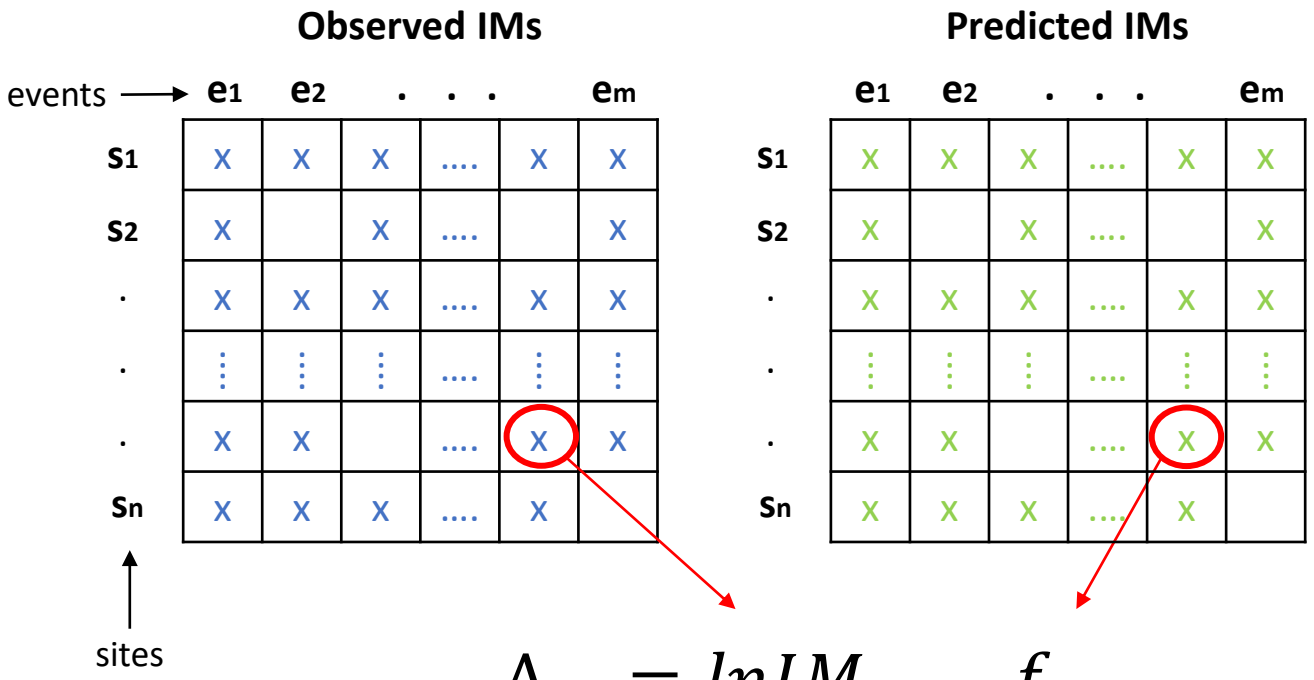
Approach 2: Site-Response Analysis



Step 1: 3D viscoelastic simulation

- 1D Wave Propagation
- OpenSees
- PDMY02, PIMY

Validation: Residual Analysis



$$\Delta_{es} = lnIM_{es} - f_{es}$$

Prediction residual

Partitioning of the residual

(mixed-effects regression)

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

Model bias

Between-event residual

Site-to-site residual

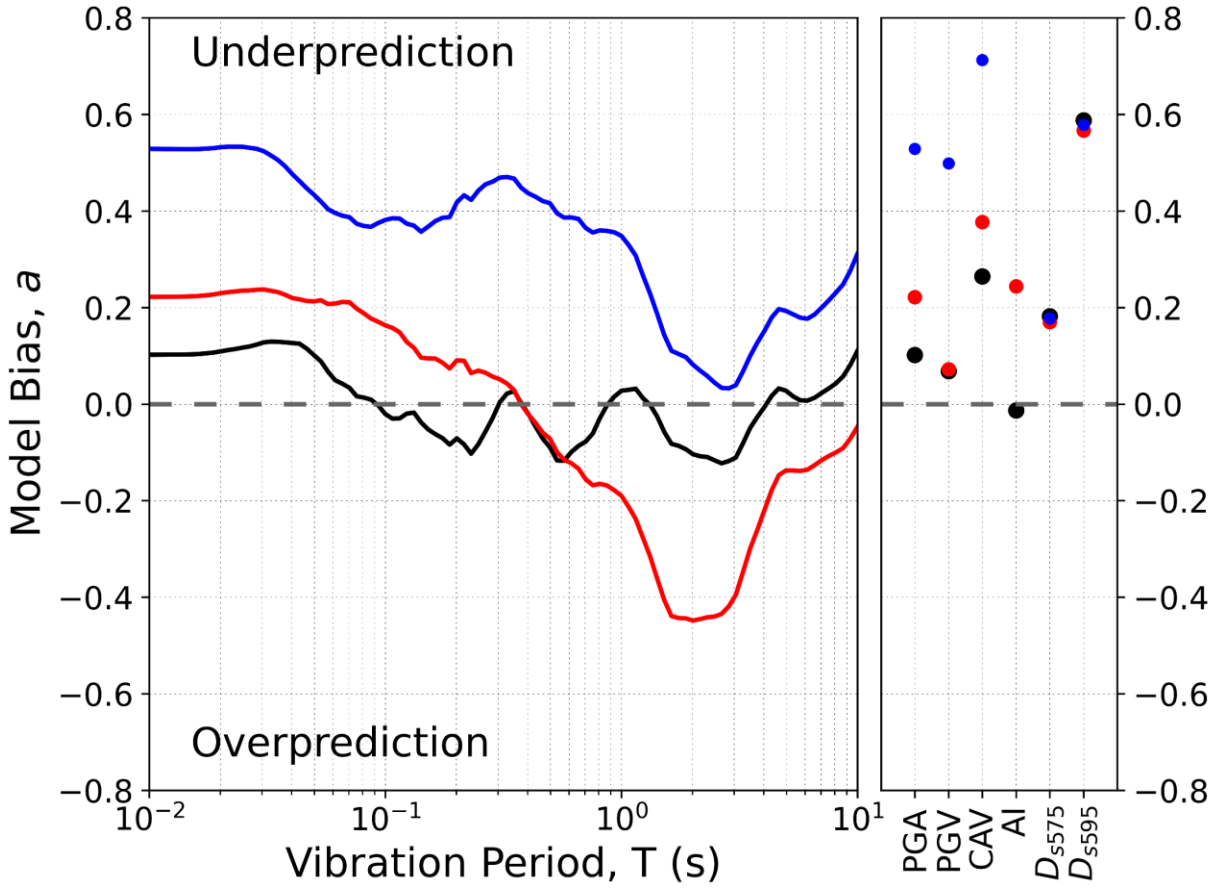
Remaining residual

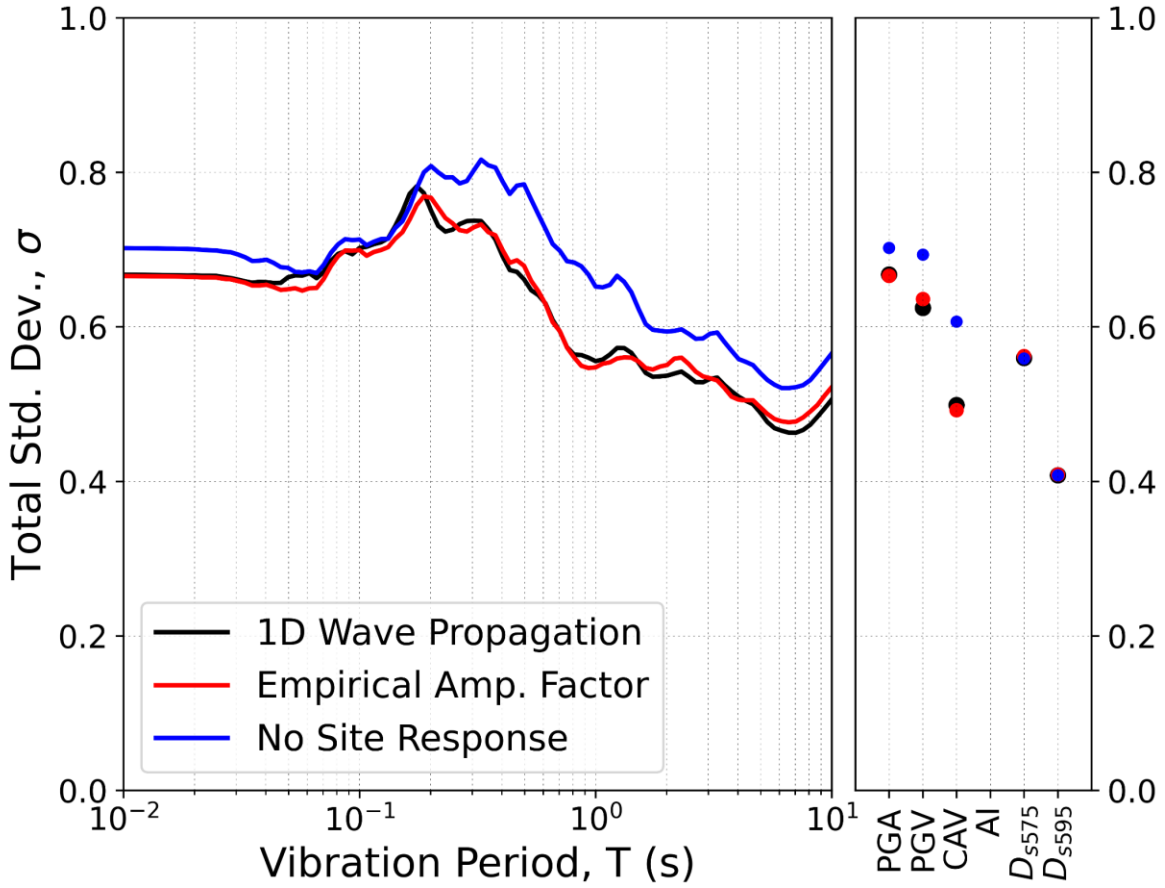
'Systematic Residual':

$$a + \delta S2S_s$$

Results

Model Prediction Bias and Total Variability





(1) Underprediction with No Site Response

(2) Underprediction/Overprediction with Emp AF

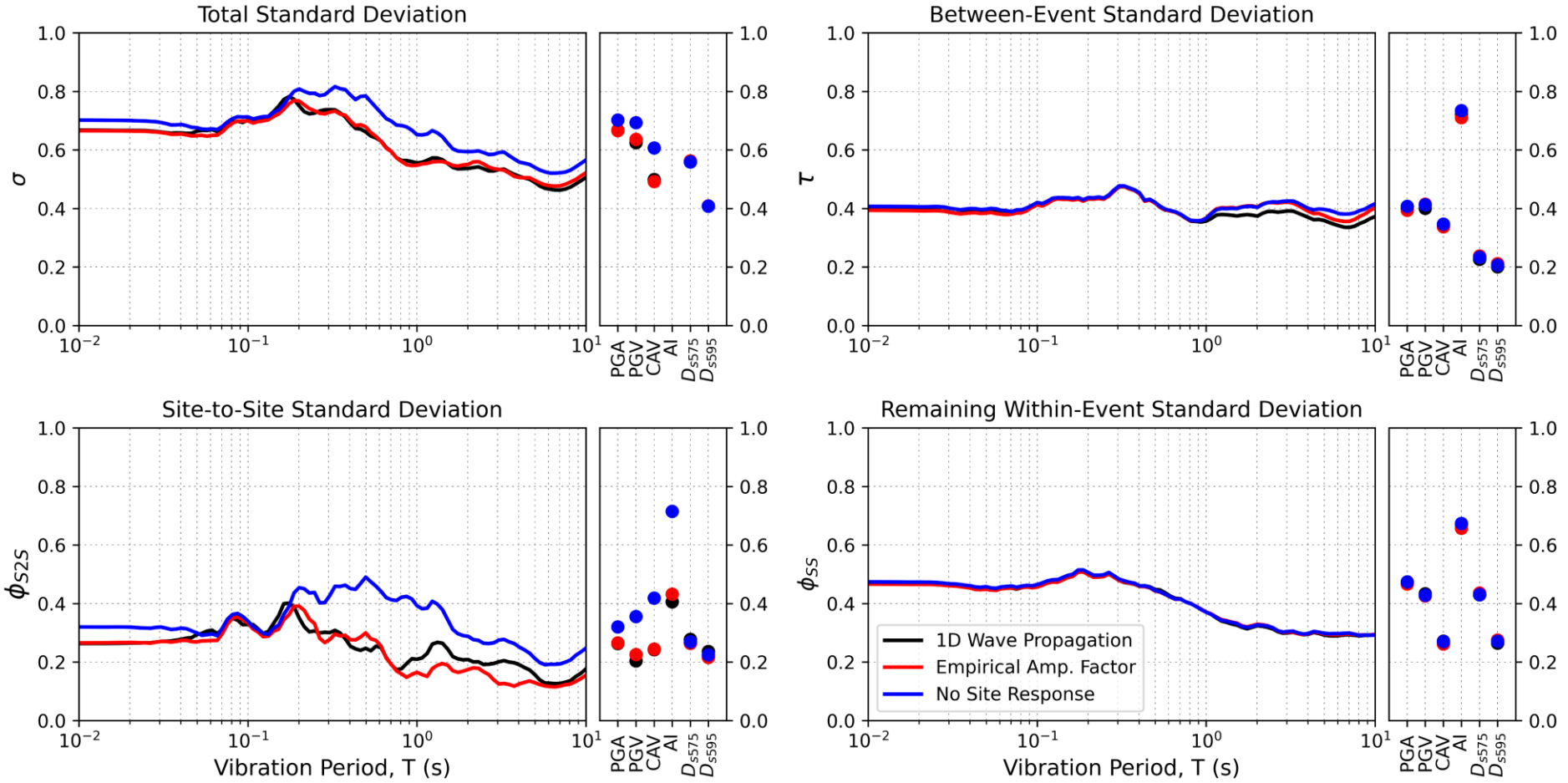
(3) 1D SRA shows the lowest model bias

(1) Reduction in σ from No Site Response

(2) Both approaches for capturing site effects show comparable variability in their predictions

Variance Decomposition

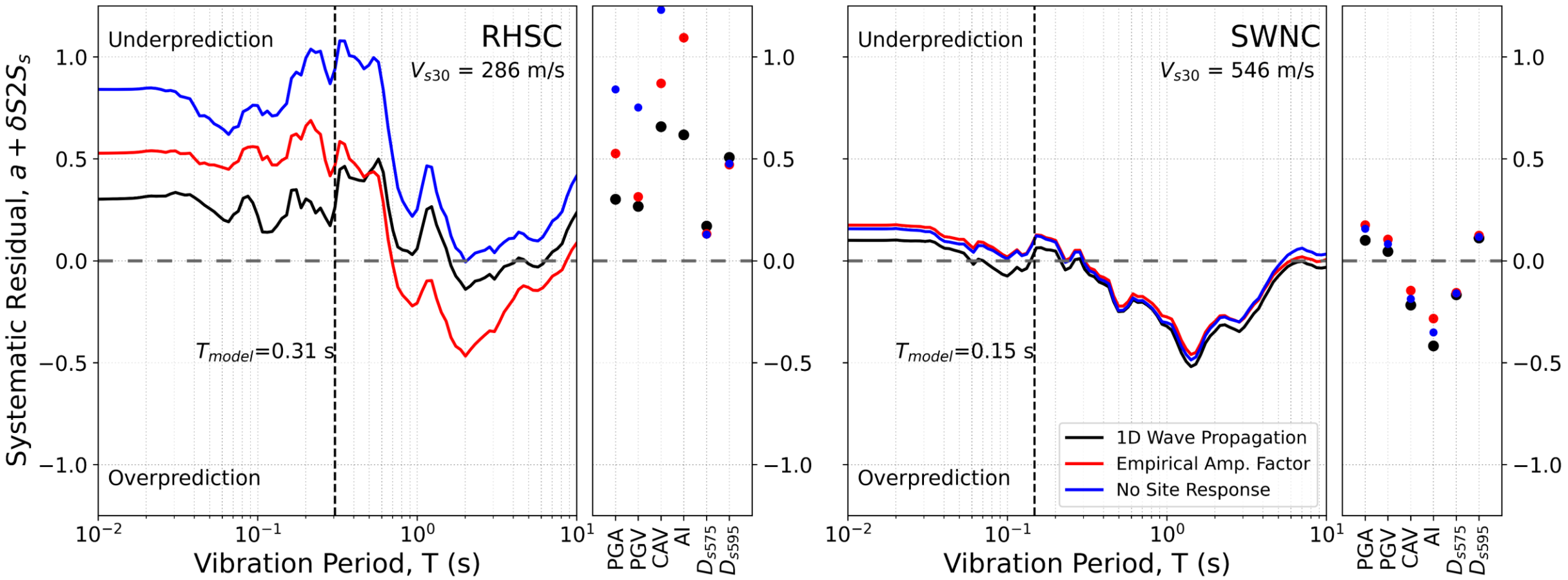
$$\sigma^2 = \tau^2 + \phi_{S2S}^2 + \phi_{SS}^2$$



(1) τ and ϕ_{SS} have similar magnitud

(2) The reduction in σ is given by a reduction in ϕ_{S2S}

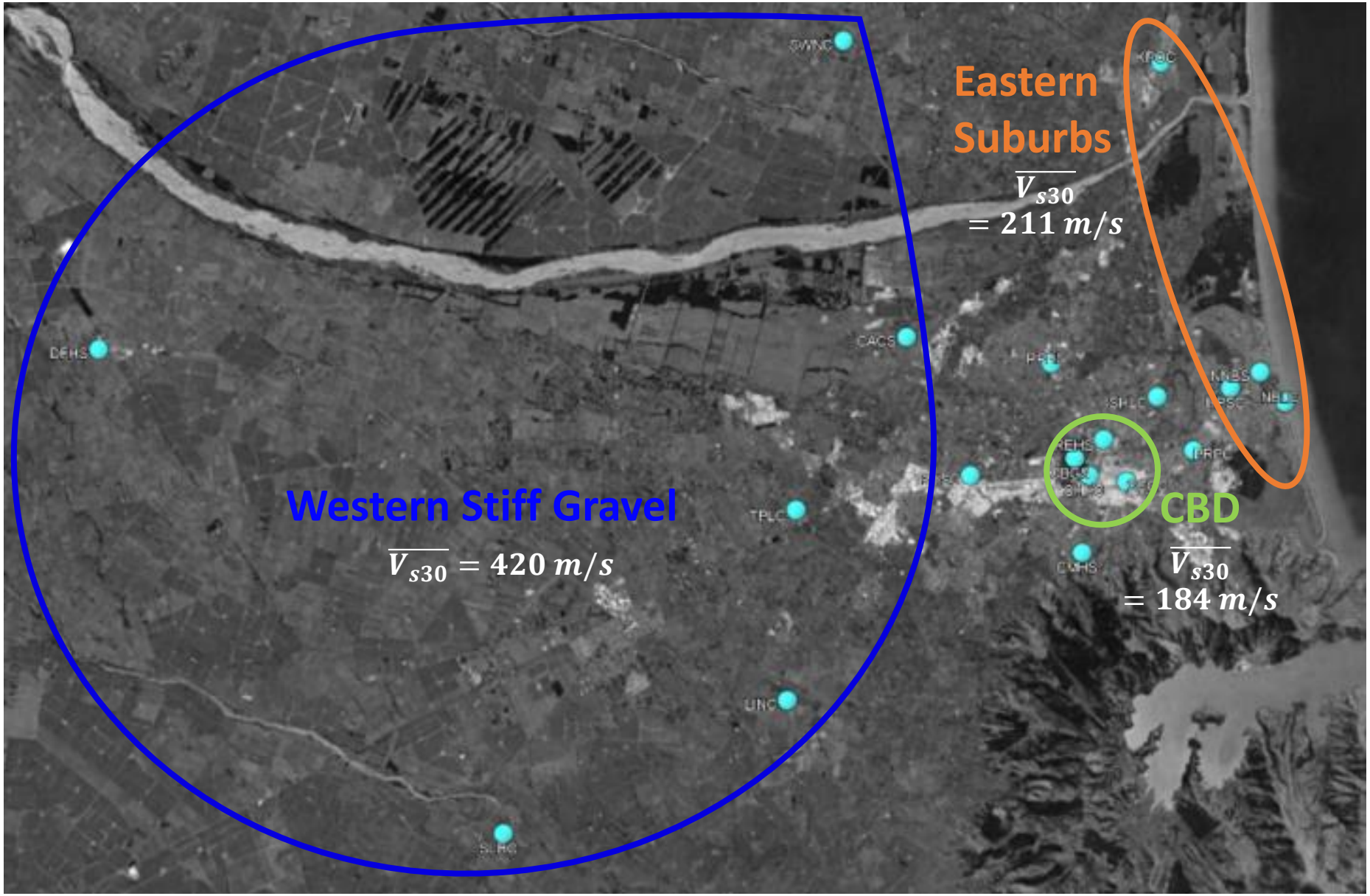
Disaggregating the Results



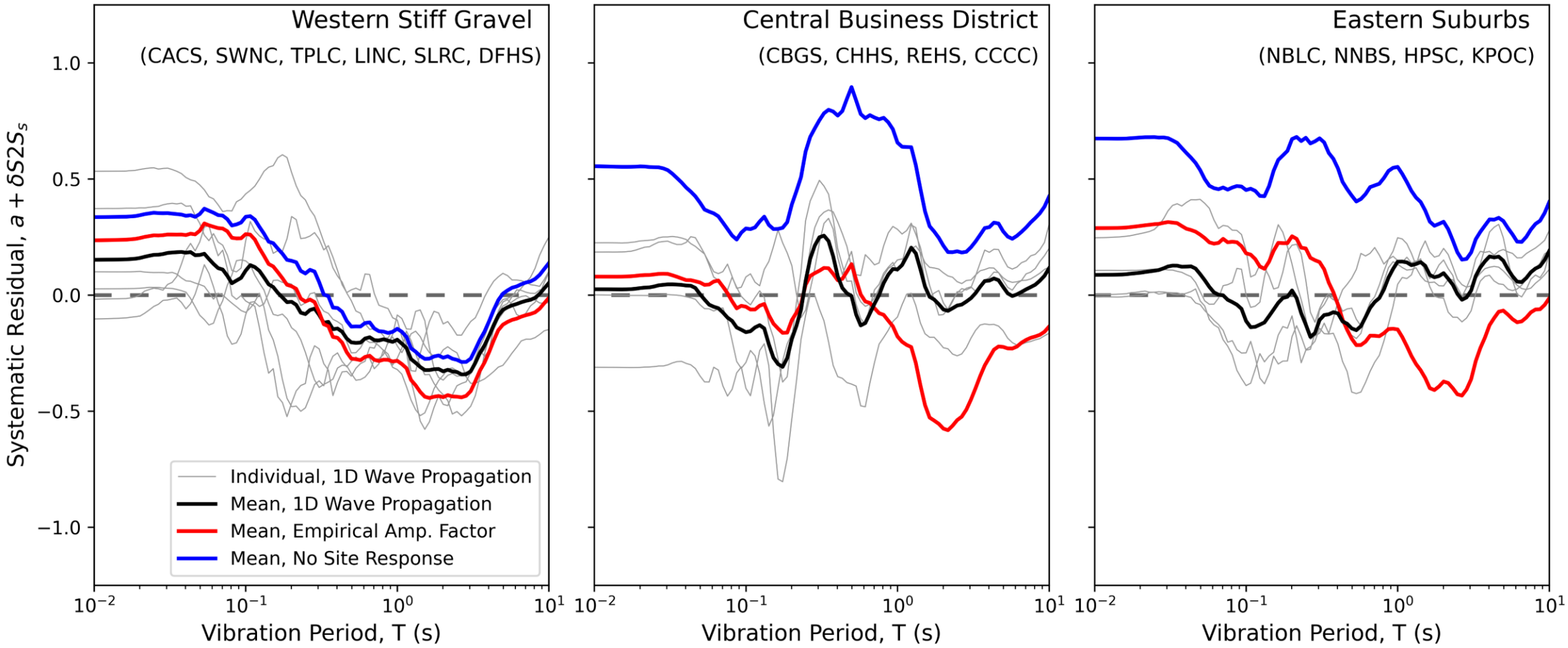
When the results are disaggregated by site, significant differences are found in the relative performance of both approaches

Scrutinizing the Entire Dataset

Sub-Regions of Christchurch



Sub-Regions of Christchurch

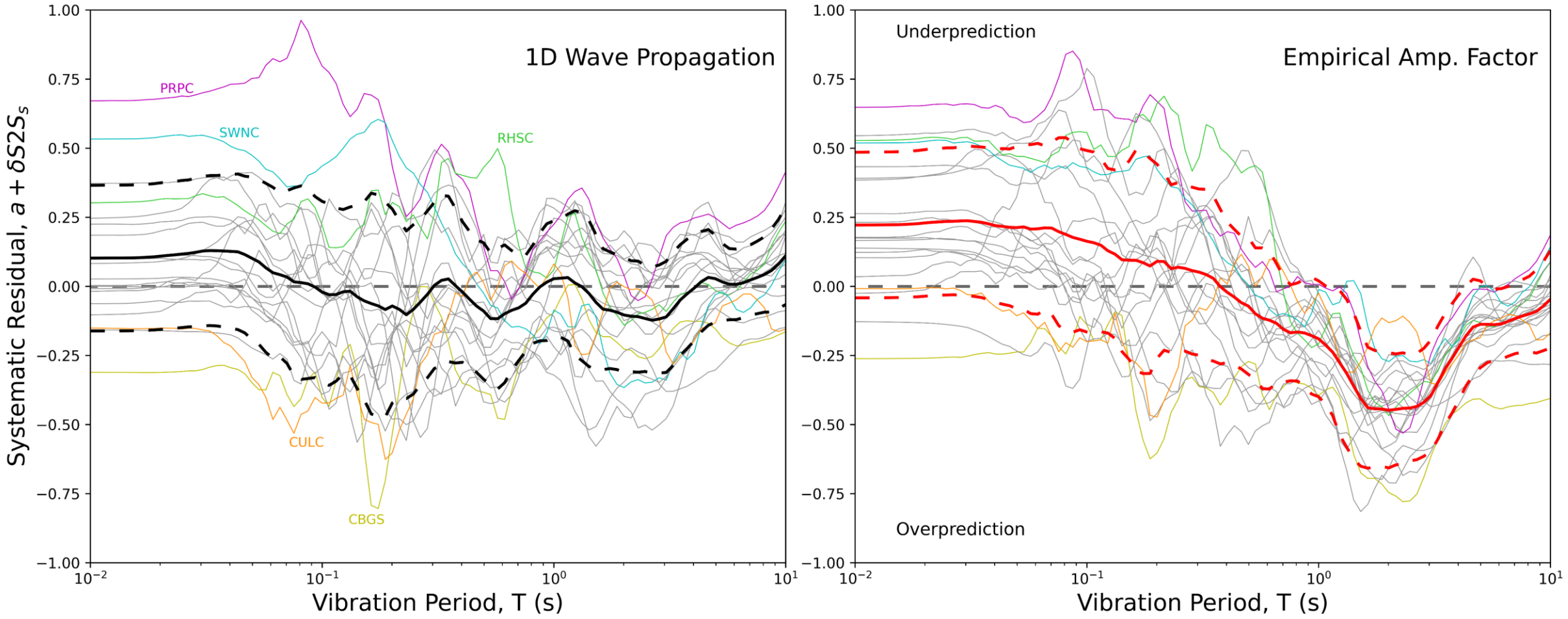


- Sites little affected by site effects
- It reveals imprecisions in the simulation

- Variability between sites
- Similar performance of both approaches at short periods

- Better performance using 1D site-response analysis

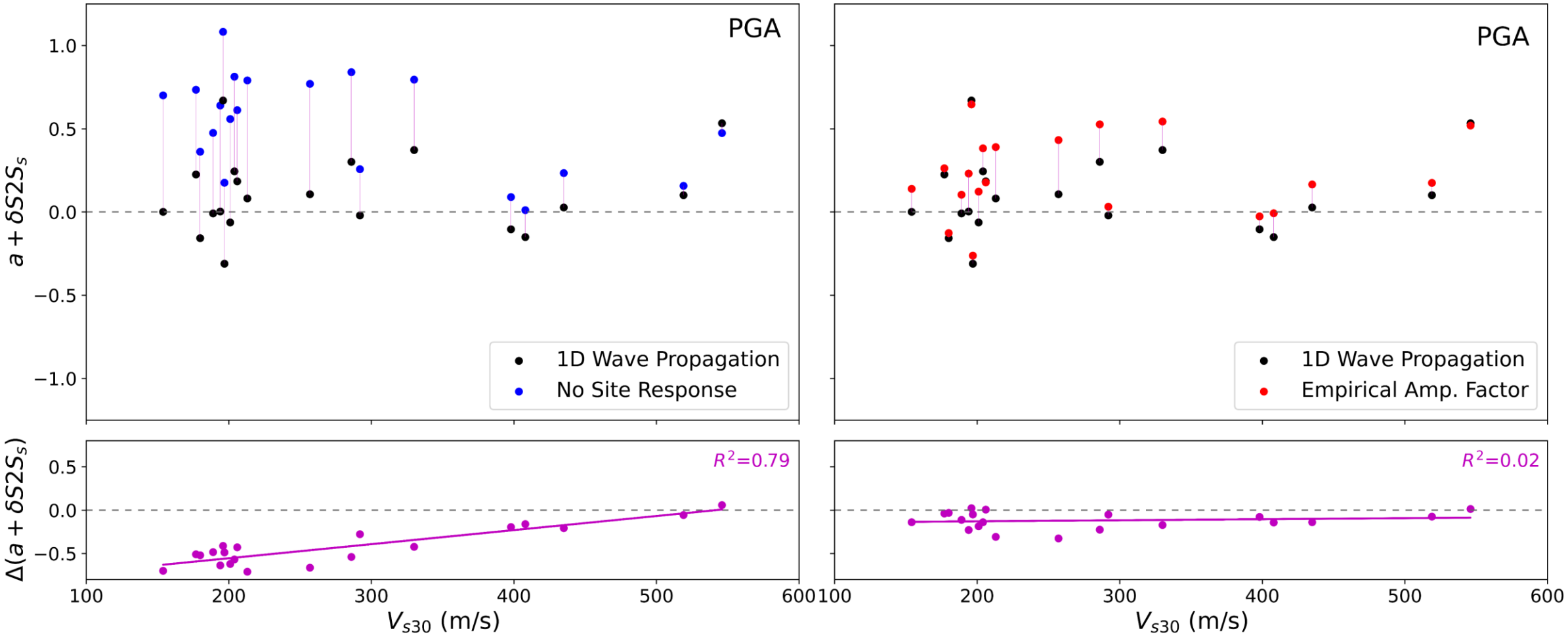
Sites with Significant Residuals



Sites outside the limits of +/- σ are worth examining in more detail

Parameter Dependency

Research Question: Under what conditions can we improve predictions…?



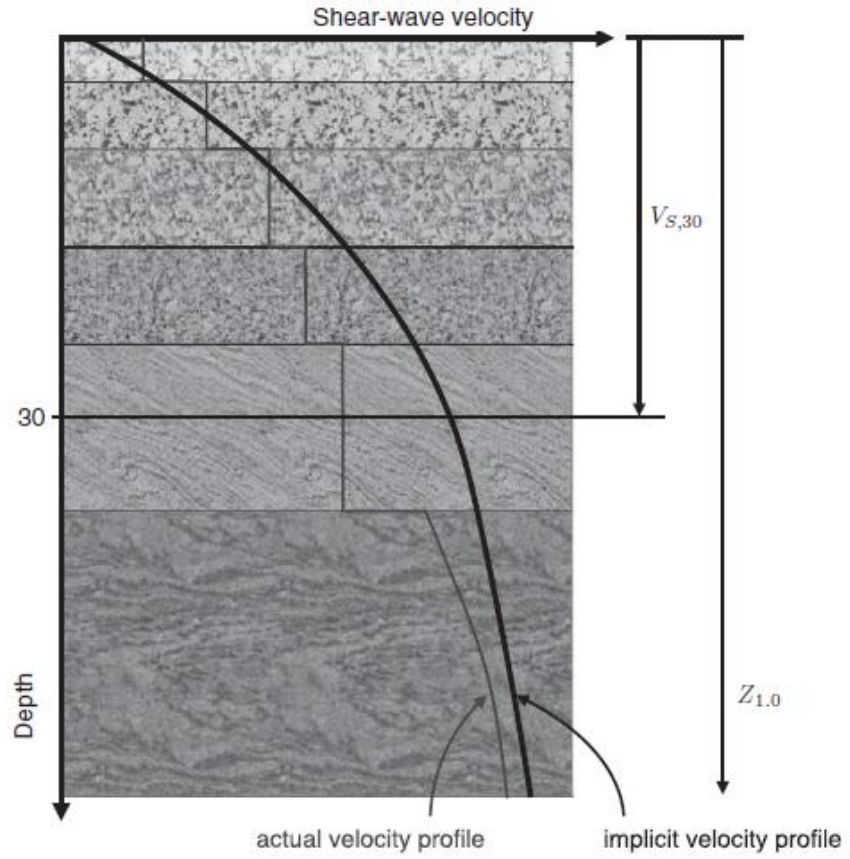
V_{S30} is a good predictor

V_{S30} is a bad predictor

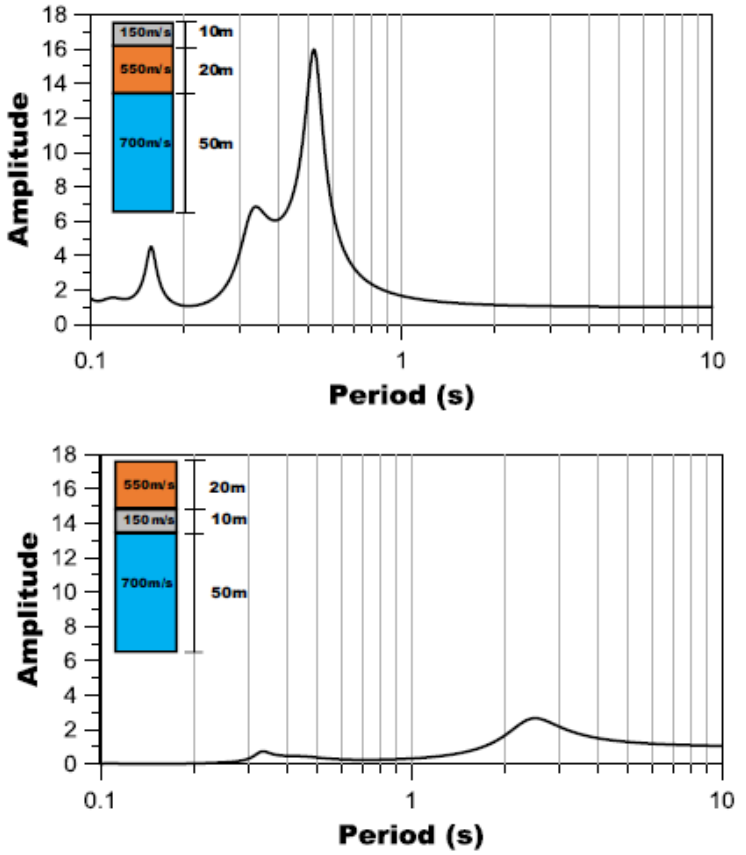
Learning from the Modelling Limitations

Limitation of the Empirical Amplification Factor

Baker et al. (2021)

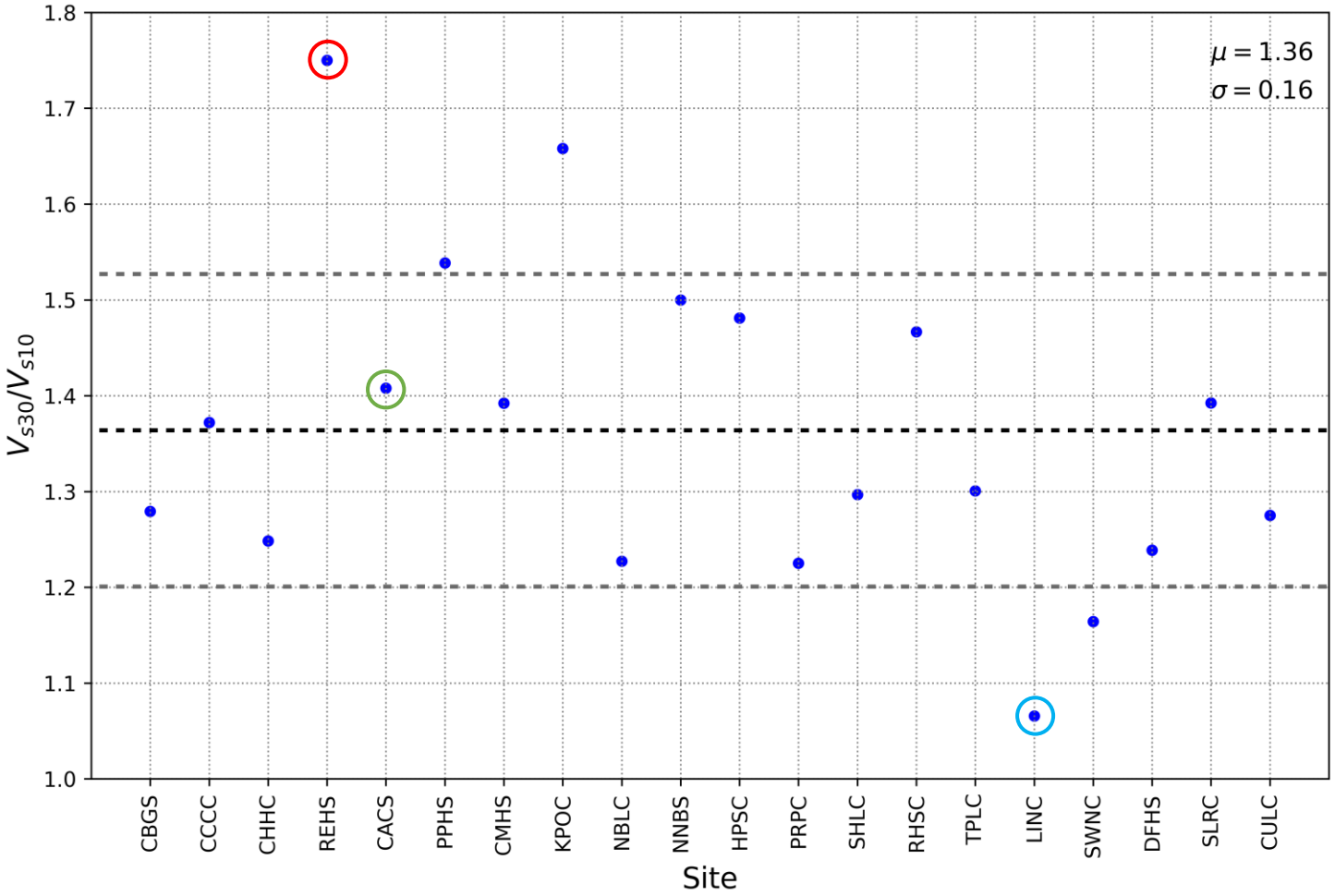


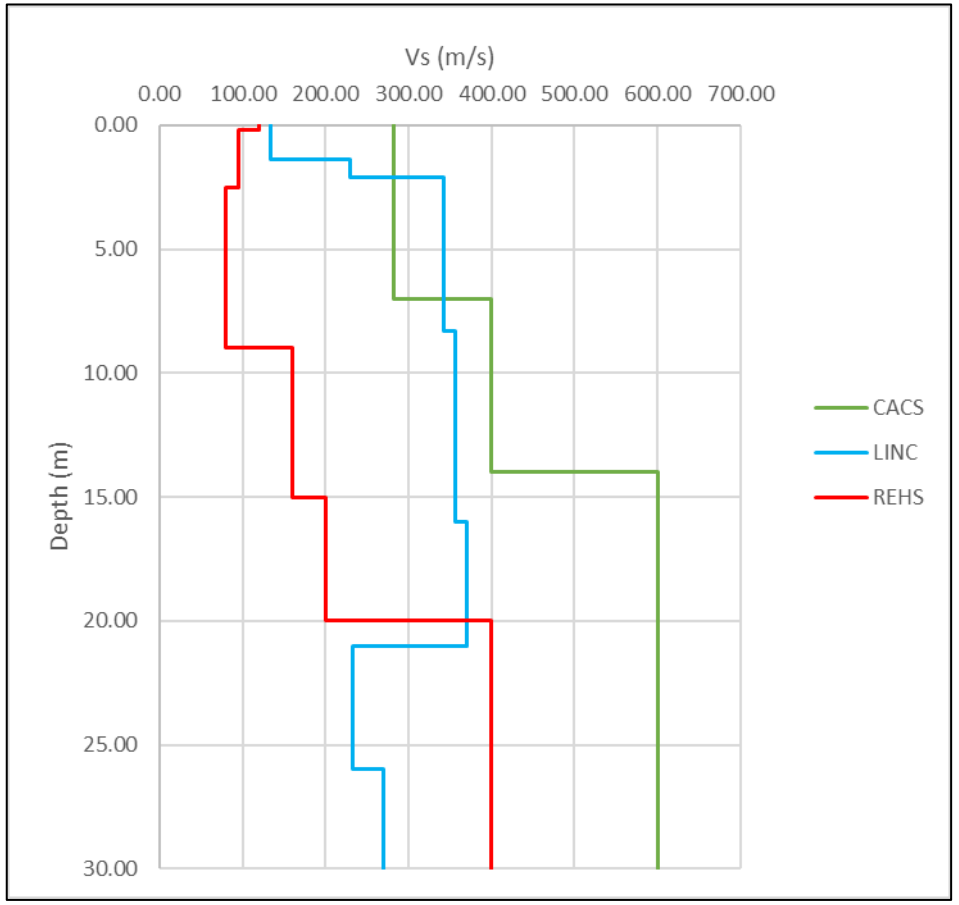
Verdugo et al. (2018)



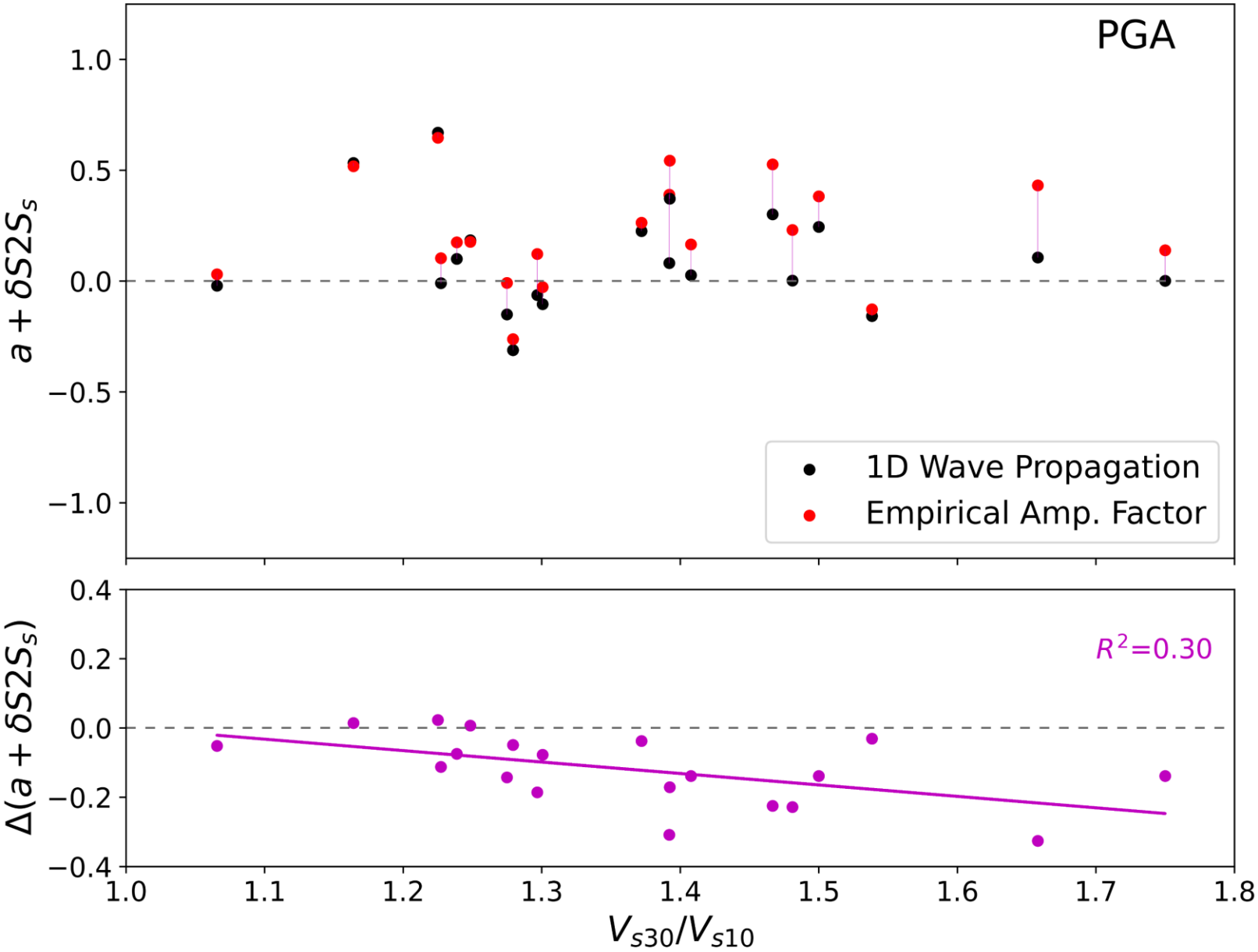
Is there something in **the shape of the Vs profile** that influences the relative performance of this approach?

Examining the parameter V_{s30}/V_{s10}



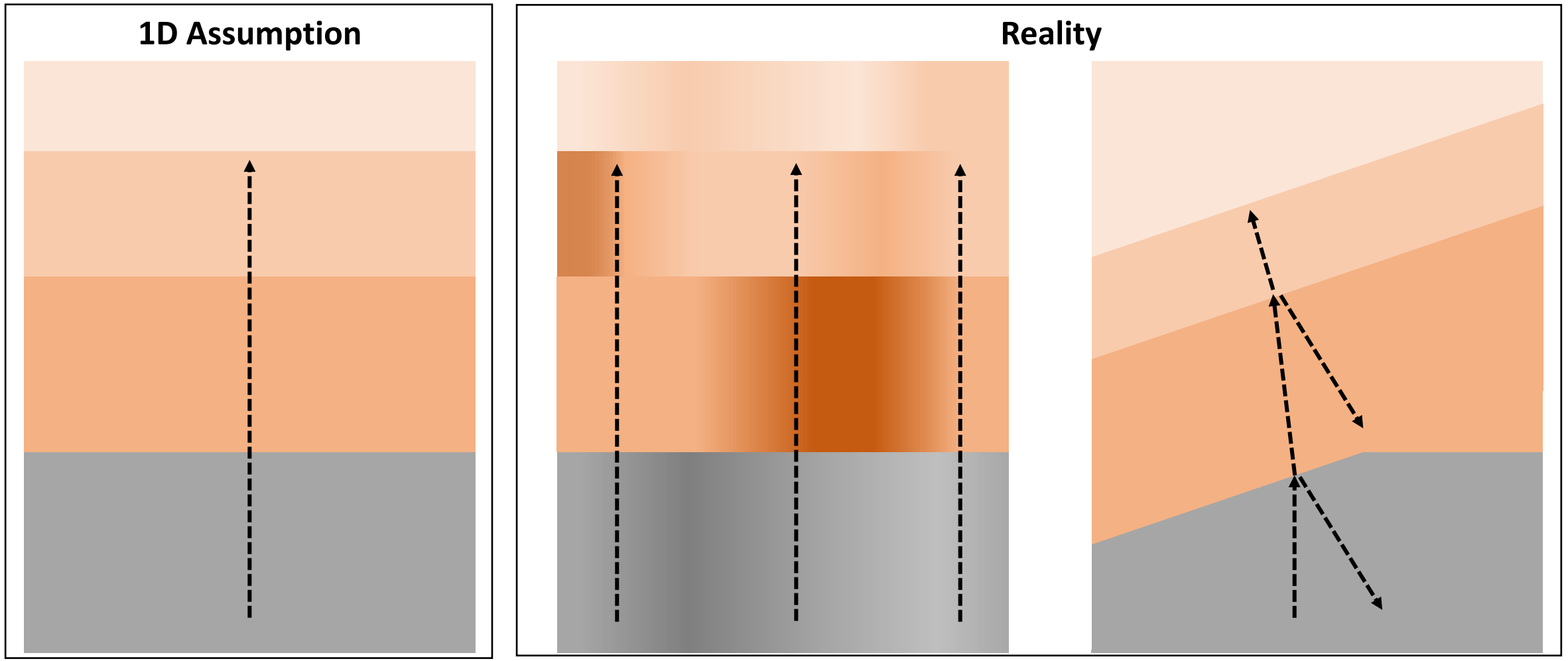


Examining the parameter V_{s30}/V_{s10}



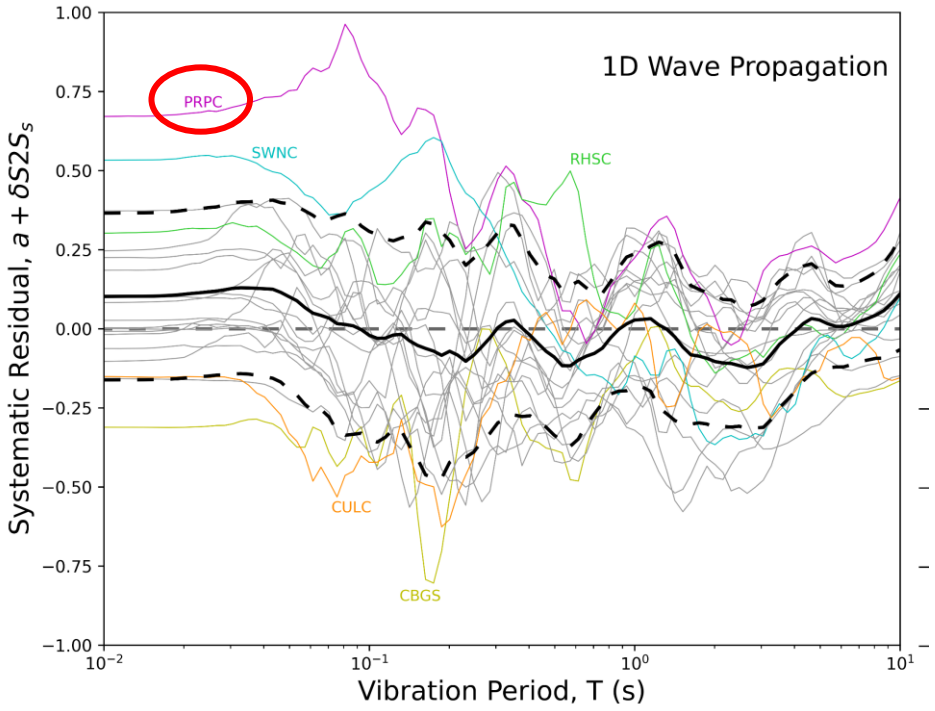
- Vs30/ Vs10 is a better predictor
- The idea of examining “the shape” of the Vs profile looks promising

Limitation of the 1D Site-Response Analysis

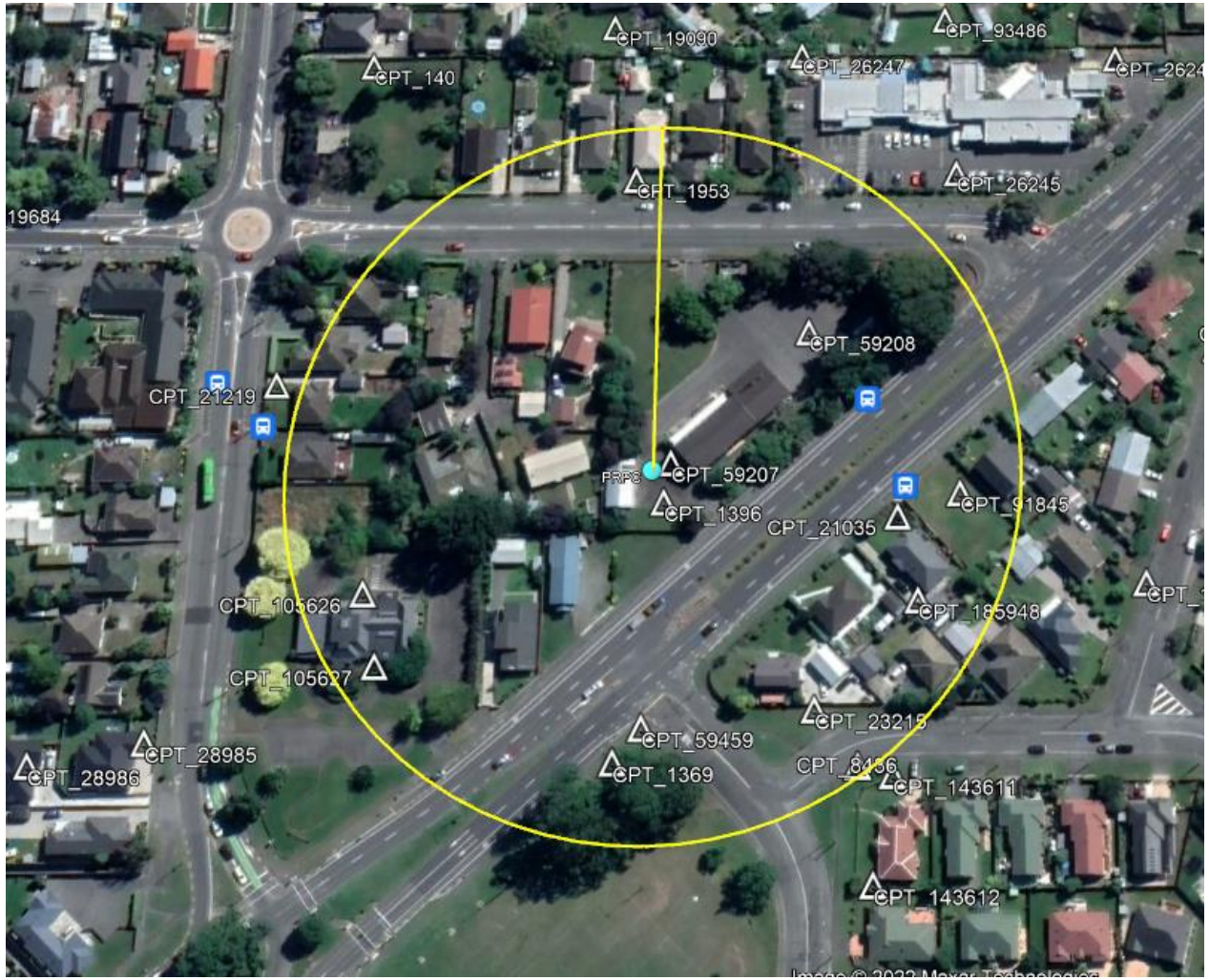


How do the **actual (3D) site conditions** influence the relative performance of this approach?

Next Step: Evaluating the Site Complexity using the NZGD

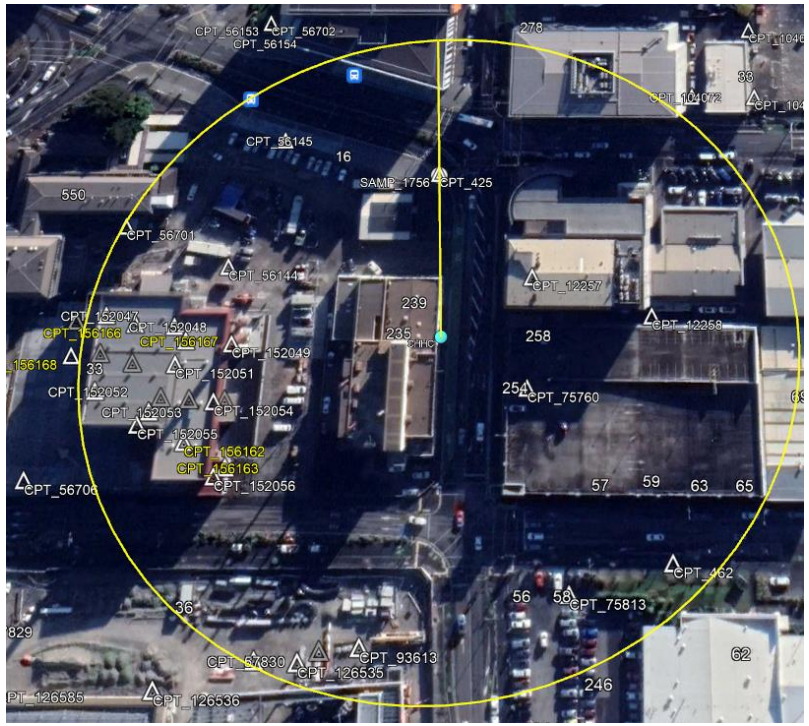


The abundance of CPT data in the NZGD can help to characterise the spatial variability of Vs and other properties



Next Step: Evaluating the Site Complexity using the NZGD

CHHC



REHS

CMHS

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