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

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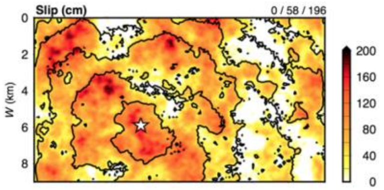
Motivation

1. Source Effects

Kilometres

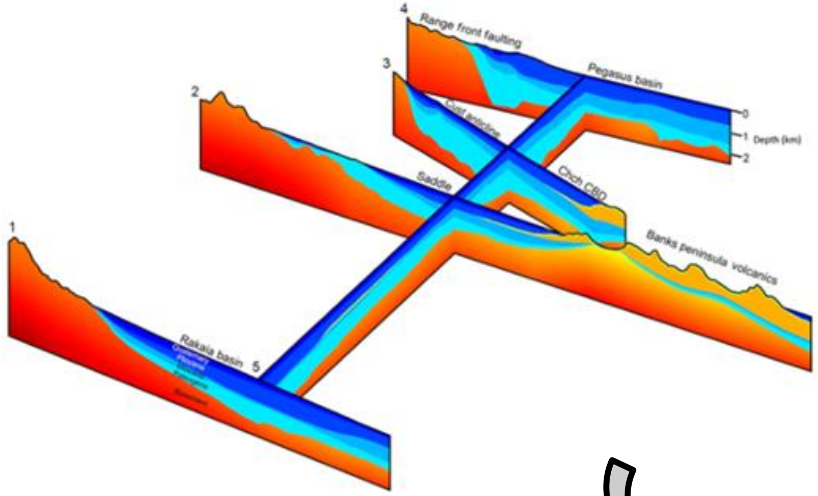


Regional simulations: several kilometres

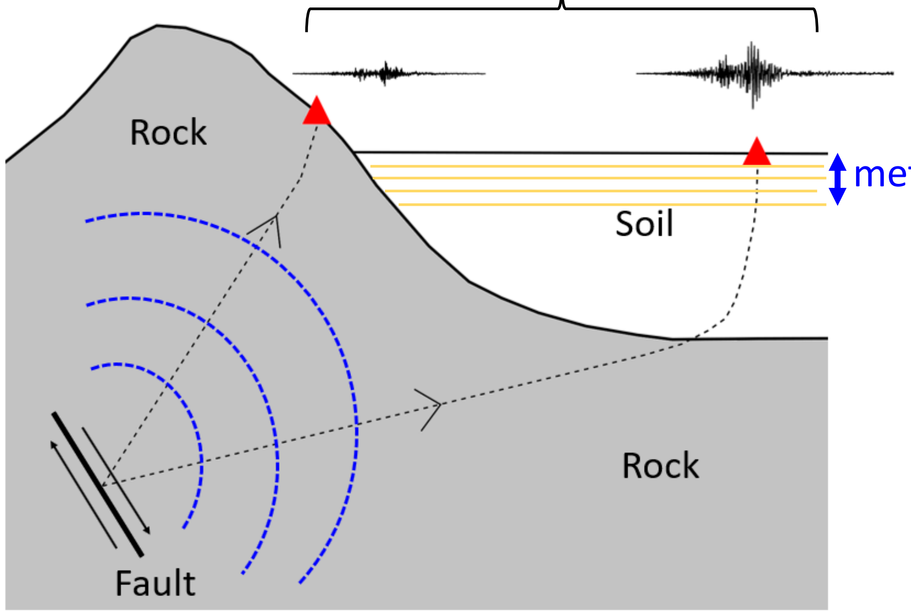
Shallow site effects occur on a scale of meters

2. Path Effects

Kilometres



3. Shallow site effects



meters

hundreds of meters

Hybrid broadband ground-motion simulation

Transition frequency: **1 (Hz)**

Low-frequency (LF) Simulation

3D wave propagation

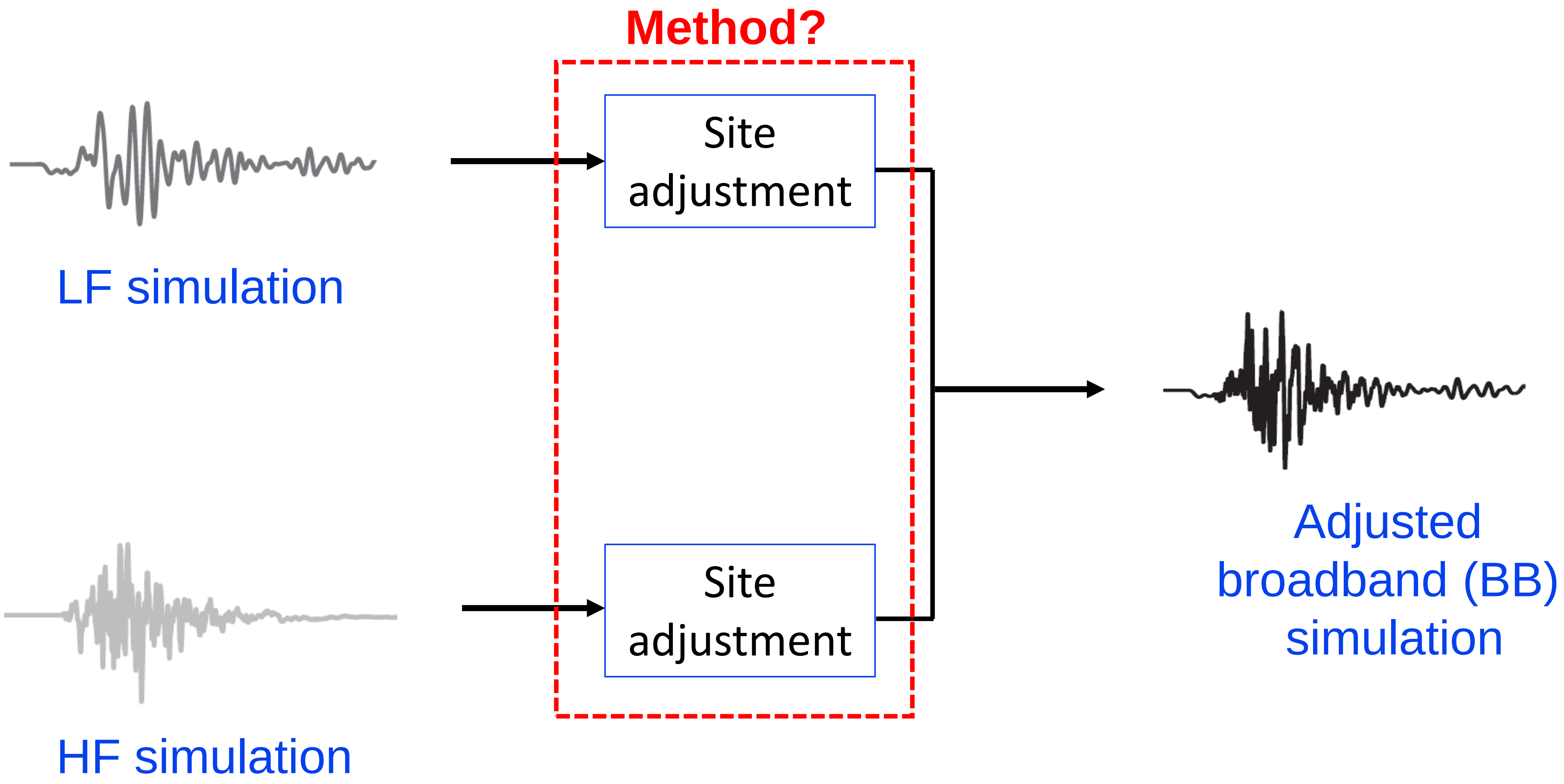
Limitations:

- Coarse spatial resolution
- Minimum V_S is high (500 m/s)
- Soil nonlinearity not included

High-frequency (HF) Simulation

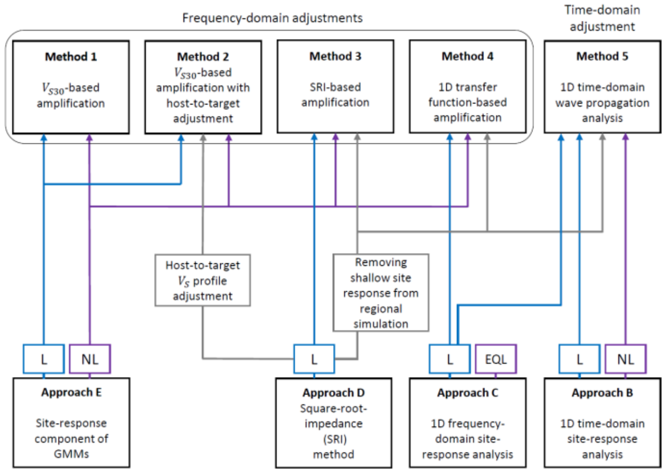
Simplified physics ~ 1D

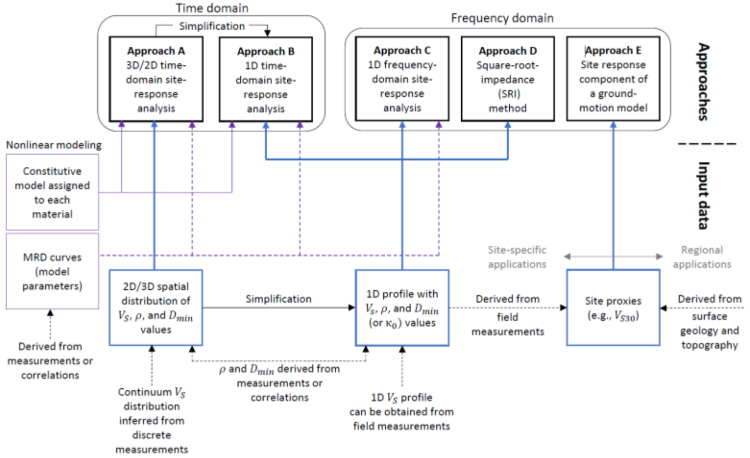
Hybrid broadband ground-motion simulation



PhD Thesis Structure

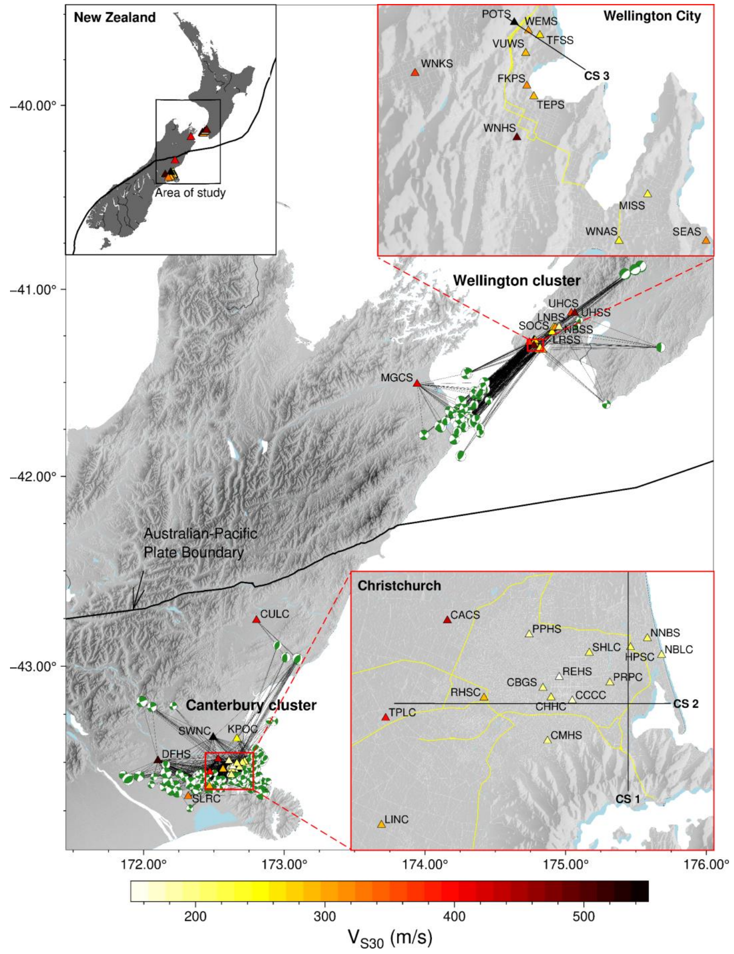
Journal Article 1:
Methods



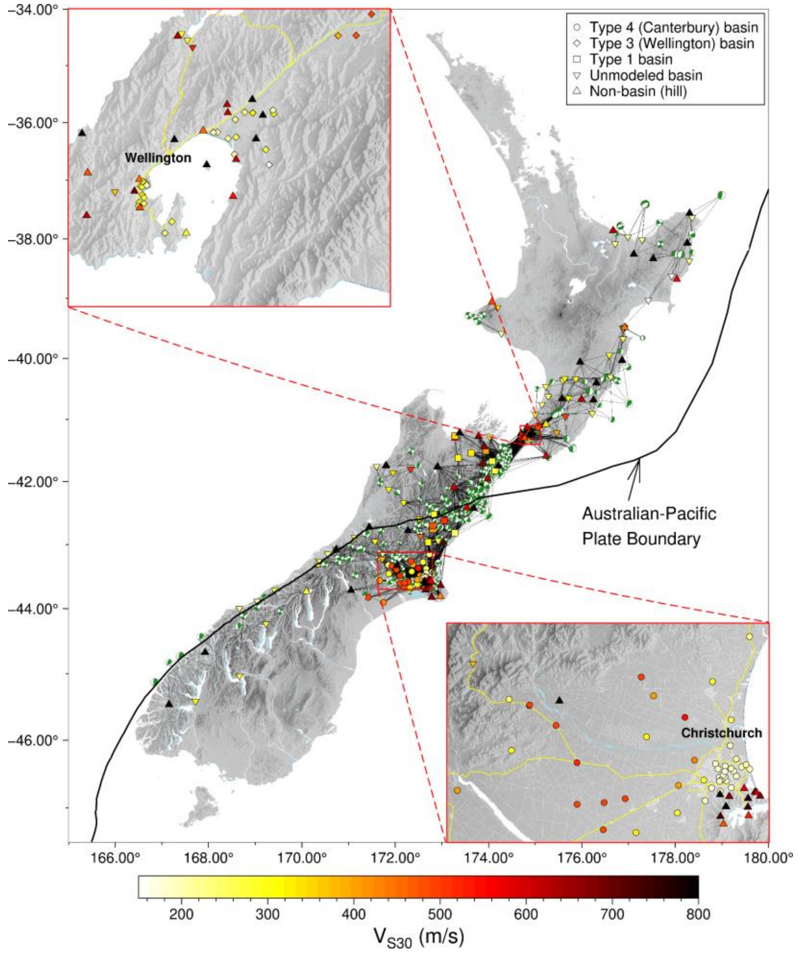


Today's discussion

Journal Article 2:
Validation using **38 sites** with a V_S profile



Journal Article 3:
Validation using **212 sites** with V_{S30}



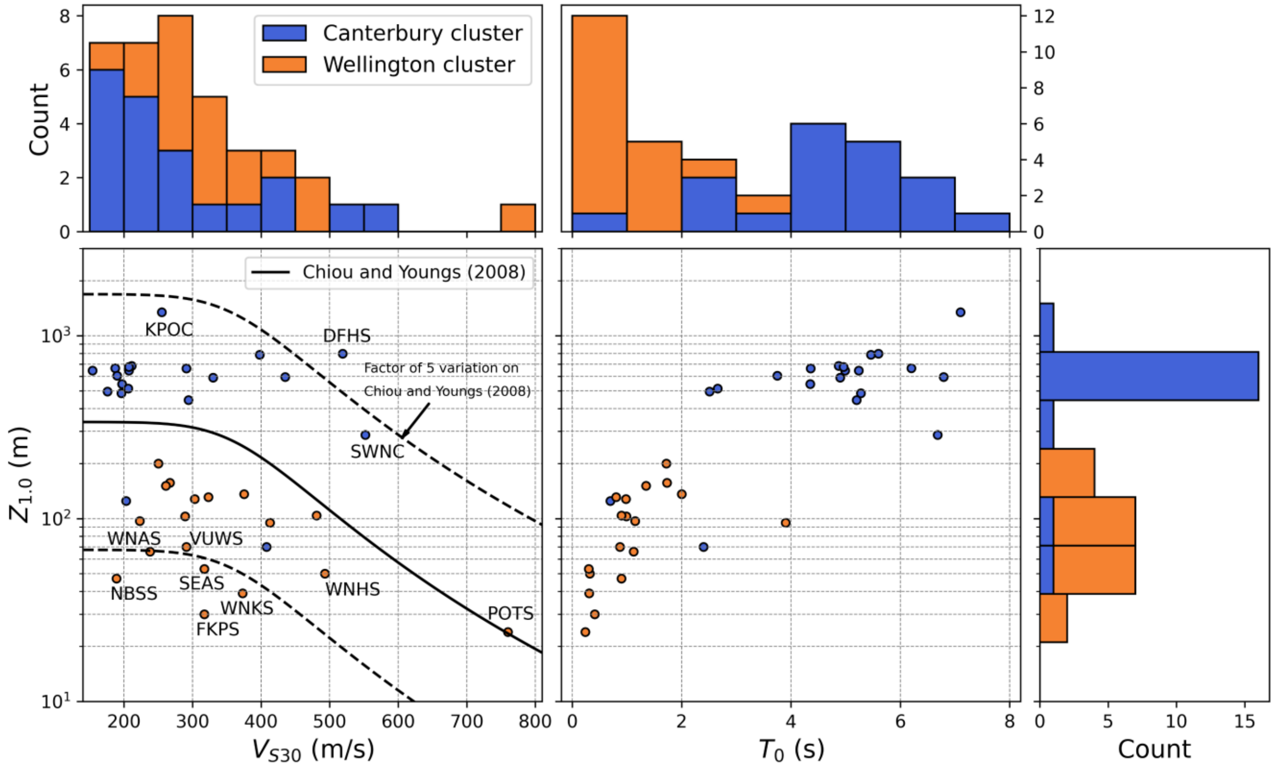
Methods to account for shallow site effects

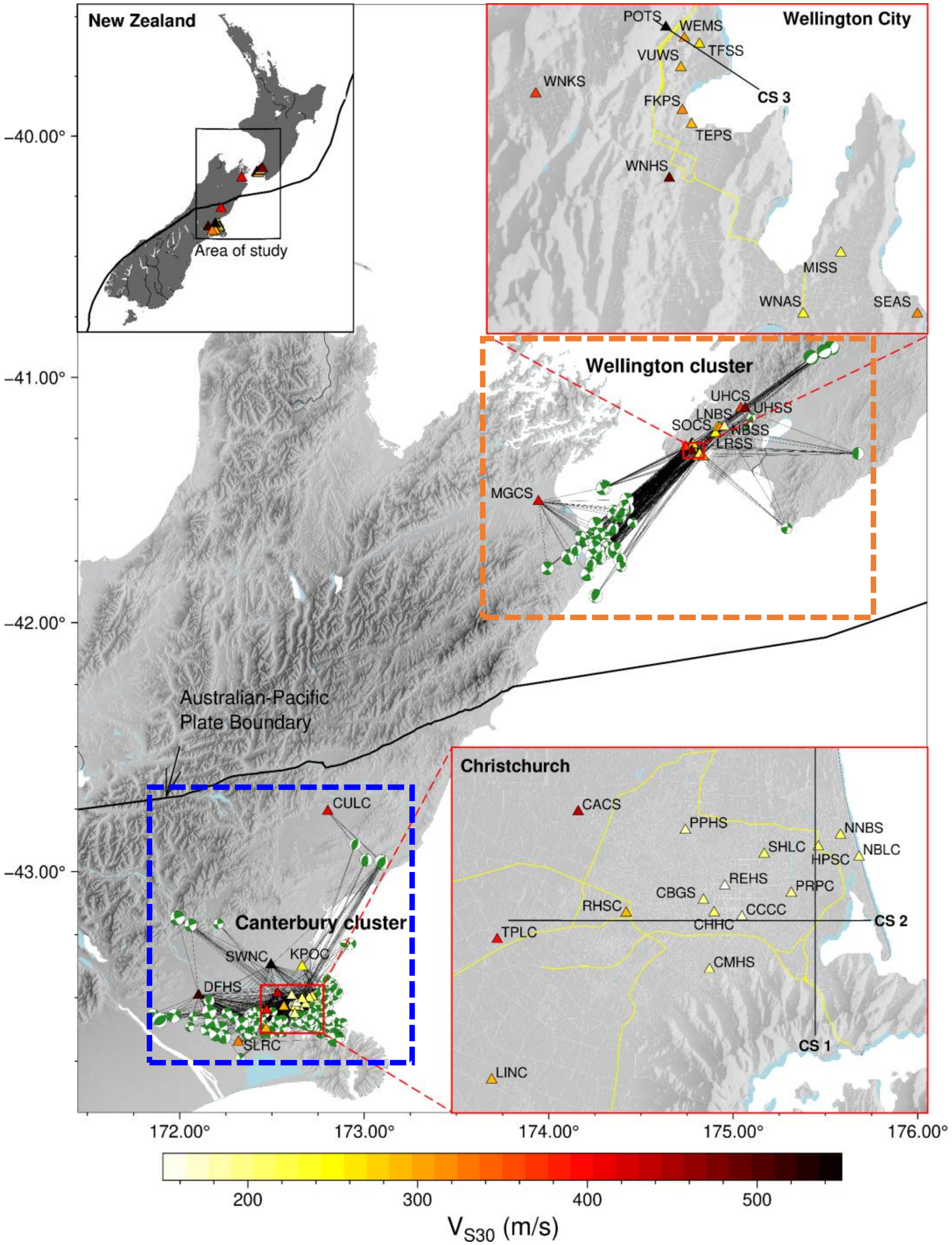
	Method	Site Factor (SF) formulation	Site data
GMM	V_{S30}-based SF	$\frac{\exp[f_S(V_{S30,actual})]}{\exp[f_S(V_{S30,sim})]} = SF_{1,L} \cdot SF_{1,NL}$	V_{S30}
SRI method	SRI-based SF - Full κ_0	$\left[\frac{A_{SRI,actual}}{A_{SRI,sim}} \cdot \frac{\exp(-\pi f \kappa_{0,actual})}{\exp(-\pi f \kappa_{0,sim})}\right] \cdot SF_{1,NL}$	V_S Profile
SRI method	SRI-based SF - $\Delta\kappa_0$	$\left[\frac{A_{SRI,actual}}{A_{SRI,sim}} \cdot \frac{\exp(-\pi f \Delta\kappa_{0,actual})}{\exp(-\pi f \Delta\kappa_{0,sim})}\right] \cdot SF_{1,NL}$	V_S Profile
1D transfer function	SH1D-based SF	$\left[\frac{TF_{SH1D,actual}}{A_{SRI,sim} \cdot \exp(-\pi f \Delta\kappa_{0,sim})}\right] \cdot SF_{1,NL}$	V_S Profile

<u>Research question</u>: Do the $\boldsymbol{V_S}$ **profile-based methods** provide a significant improvement in predictions relative to the $\boldsymbol{V_{S30}}$**-based approach**?

Ground motion and site data

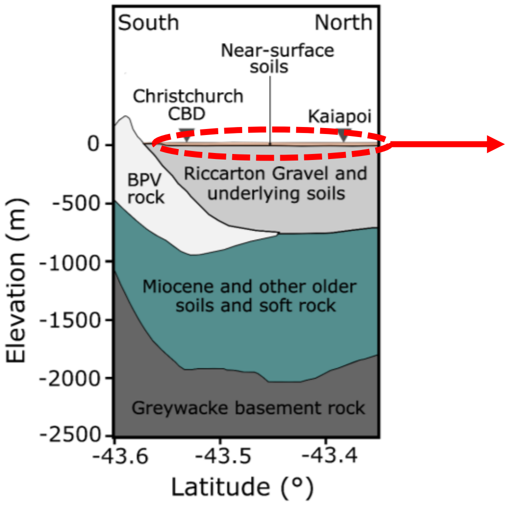
- **38** strong-motion station sites
- **213** small-magnitude $(\mathbf{3.5 \leq M_W \leq 5.0})$ events
- **1446** ground motions

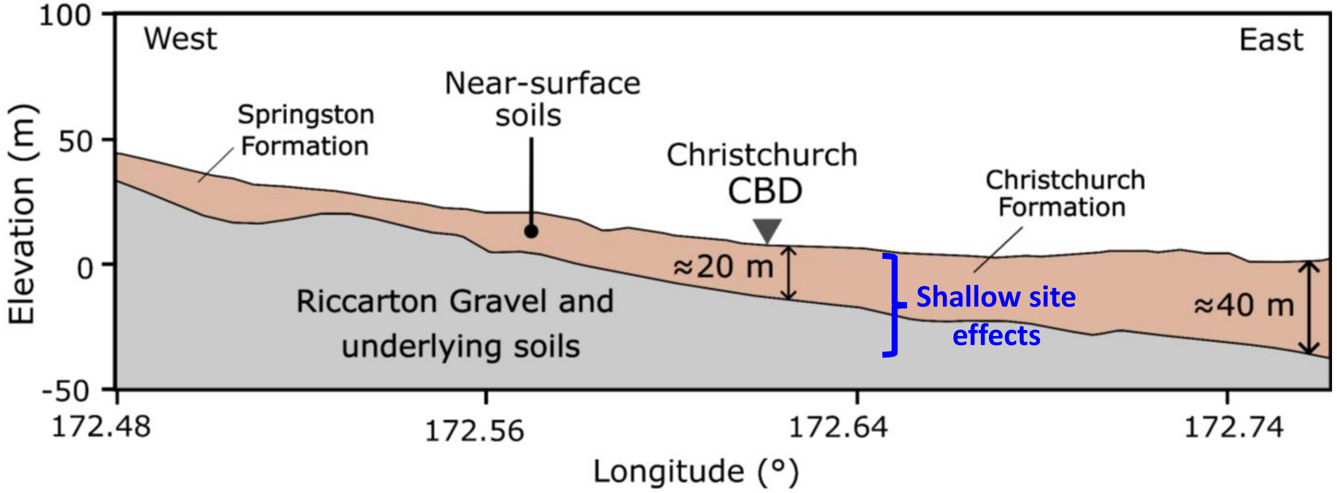




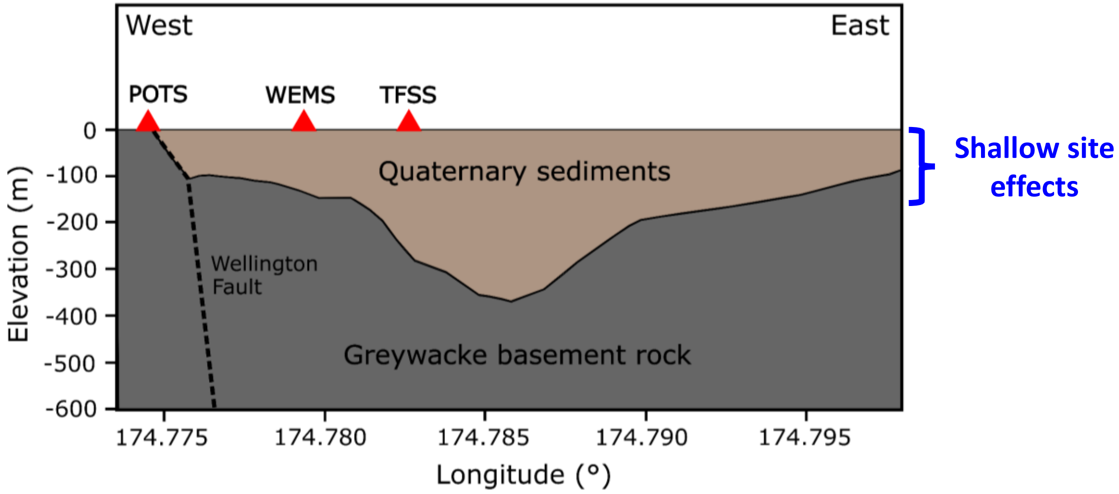
Regional features

- **Canterbury Cluster:**





- **Wellington Cluster:**

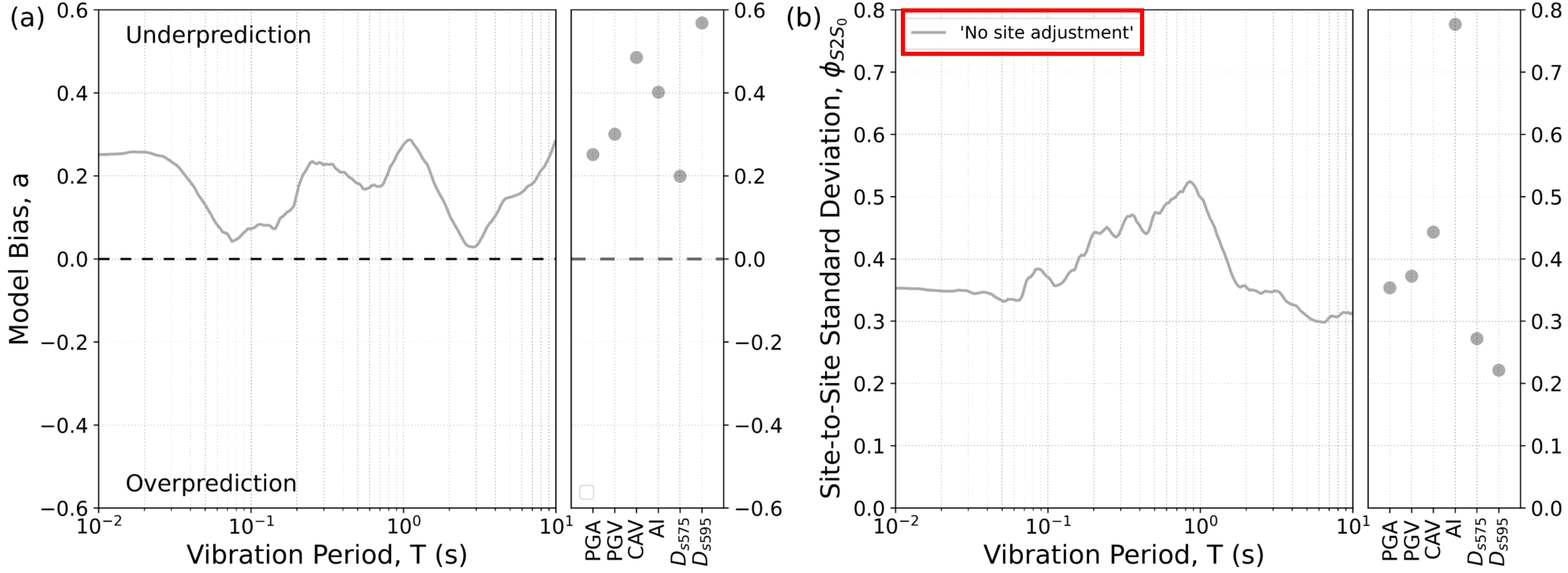


Model bias and site-to-site variability

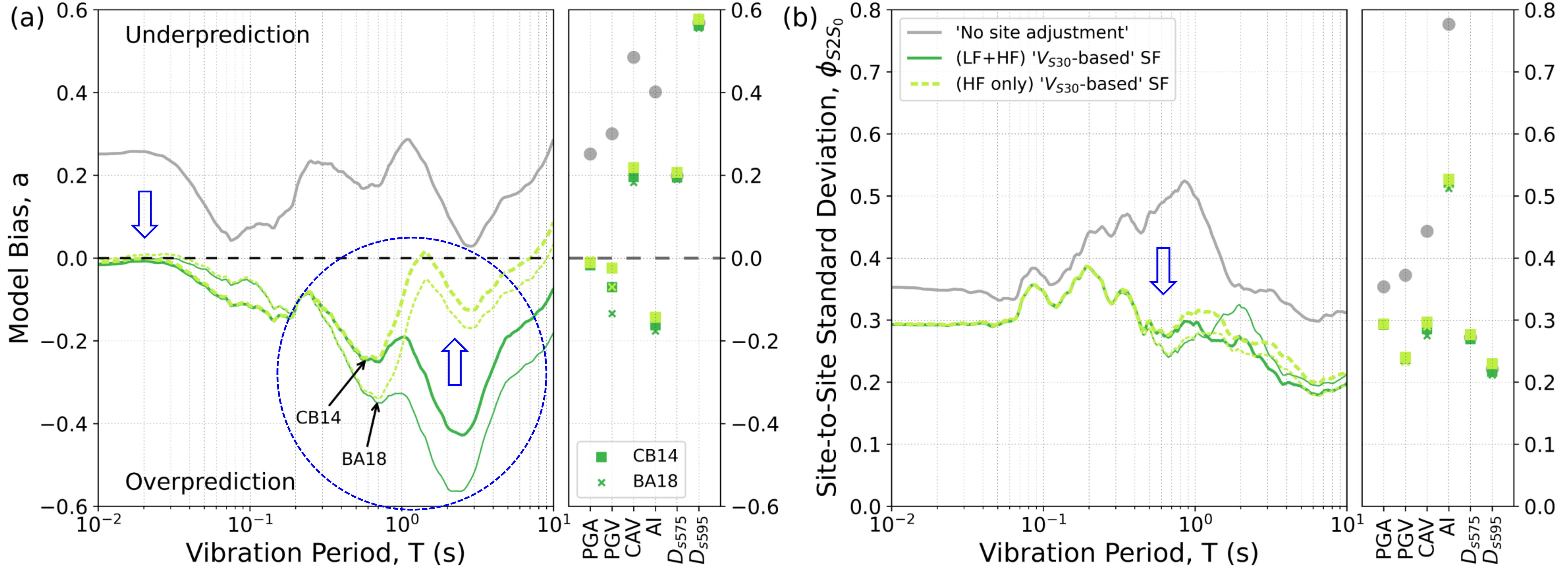
1446 ground motions $\longrightarrow$

$$\Delta_{es} = \ln IM_{Obs,es} - \ln IM_{Sim,es} = \boxed{a} + \delta C2C_c + \underbrace{\delta S2S_s^0}_{\phi_{S2S}^0} + \delta B_e^0 + \delta W_{es}^0$$

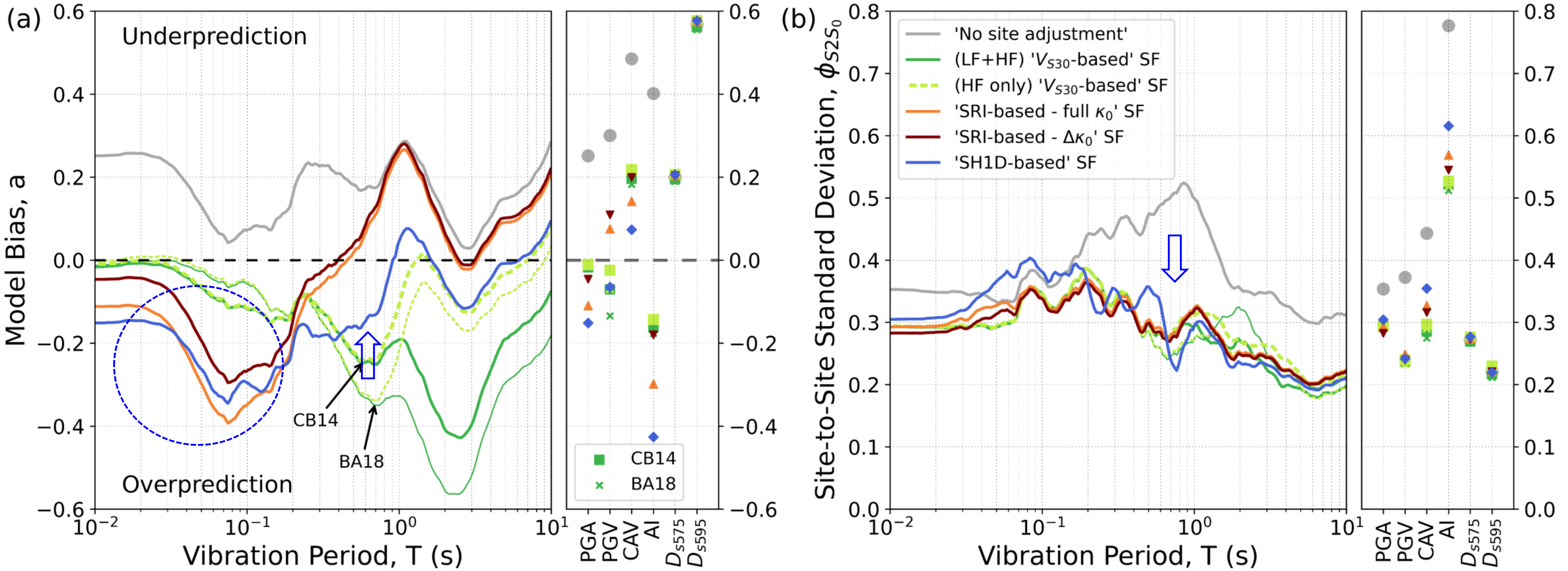
Model bias



Model bias and site-to-site variability



Model bias and site-to-site variability

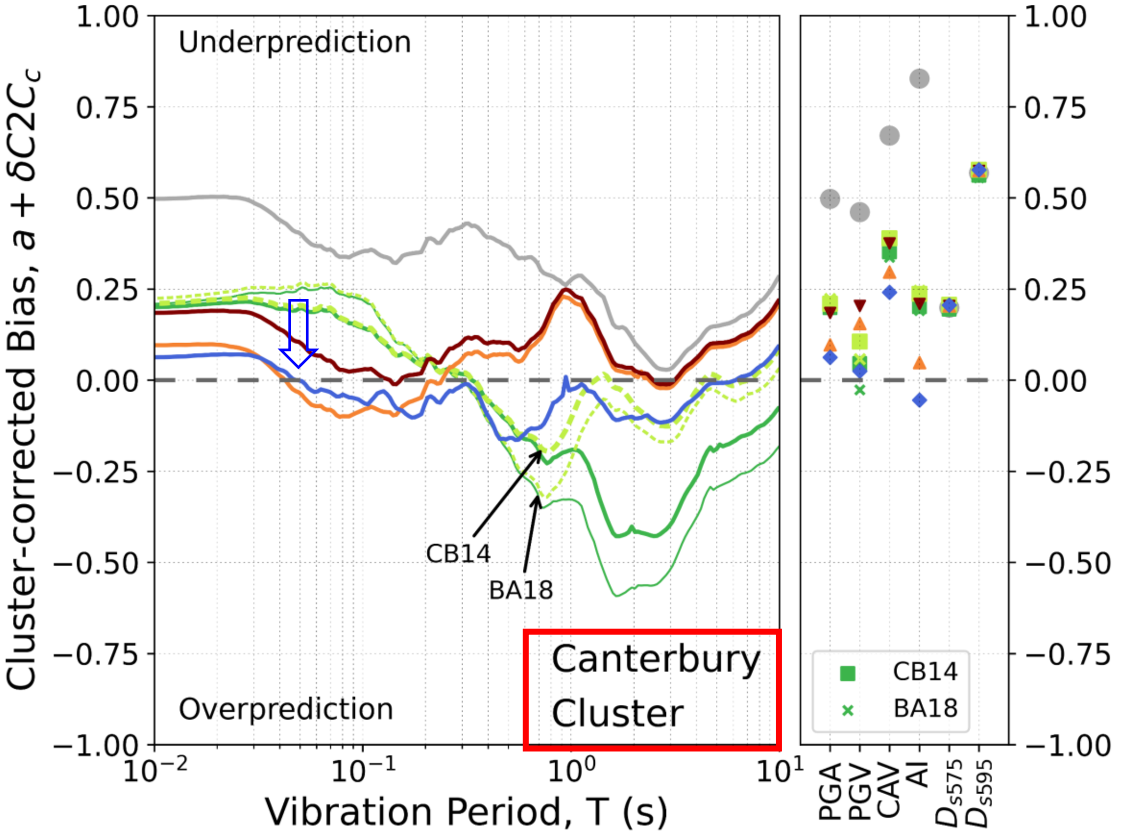


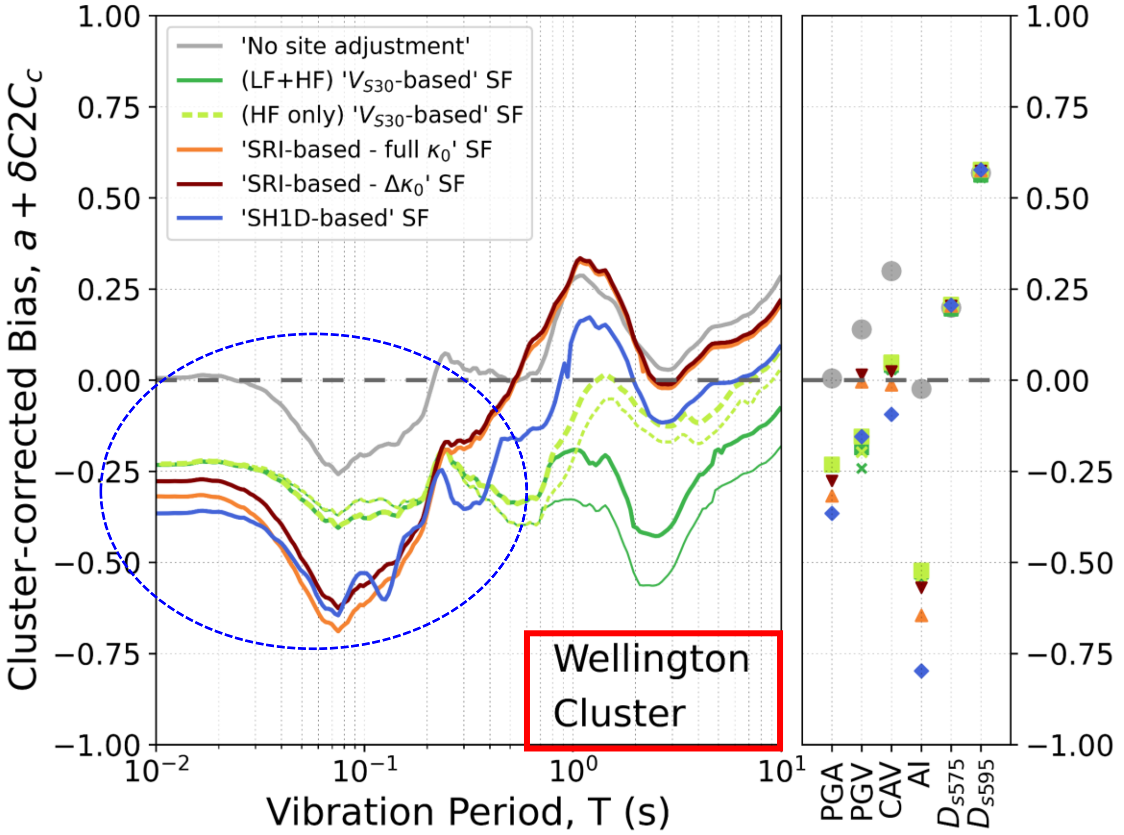
→ Similar reduction in site-to-site variability between methods

Model bias and site-to-site variability

$$\Delta_{es} = \ln IM_{Obs,es} - \ln IM_{Sim,es} \quad = \boxed{a + \delta C2C_c} + \delta S2S_s^0 + \delta B_e^0 + \delta W_{es}^0$$

Cluster-corrected bias



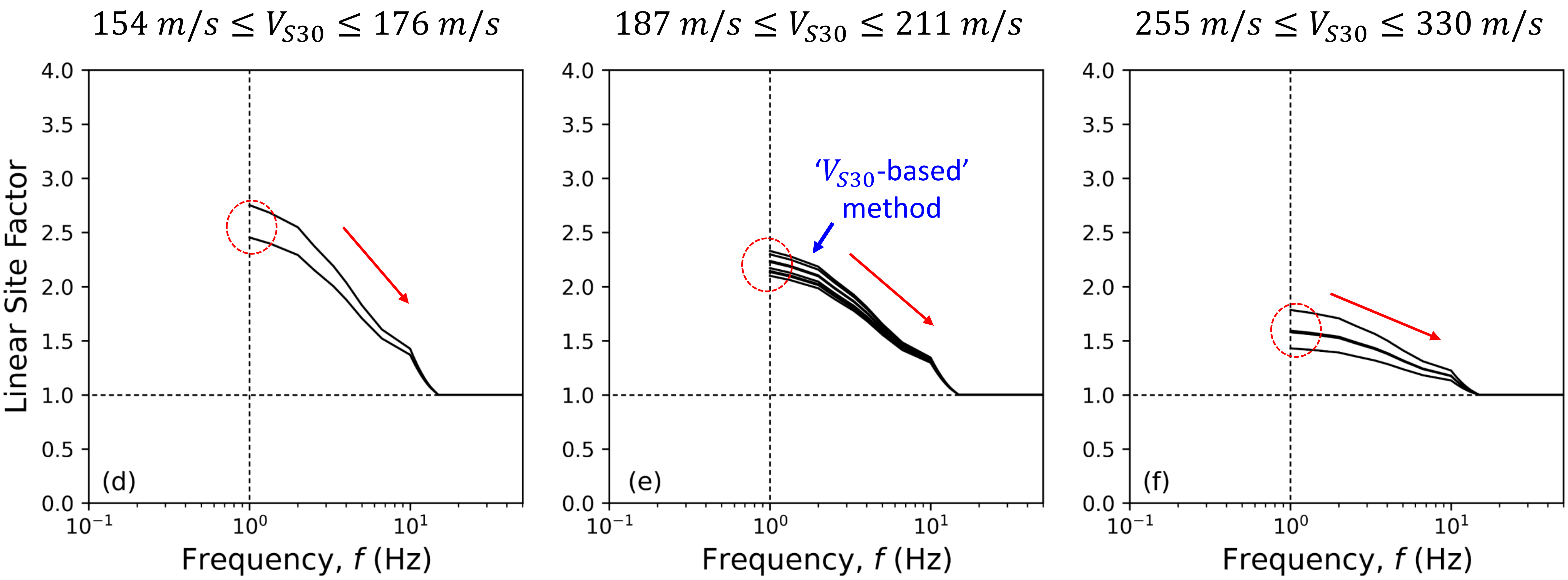


V_S profile-based methods display better performance than V_{S30}-based approach

Systematic overprediction at short periods (source and path effects)

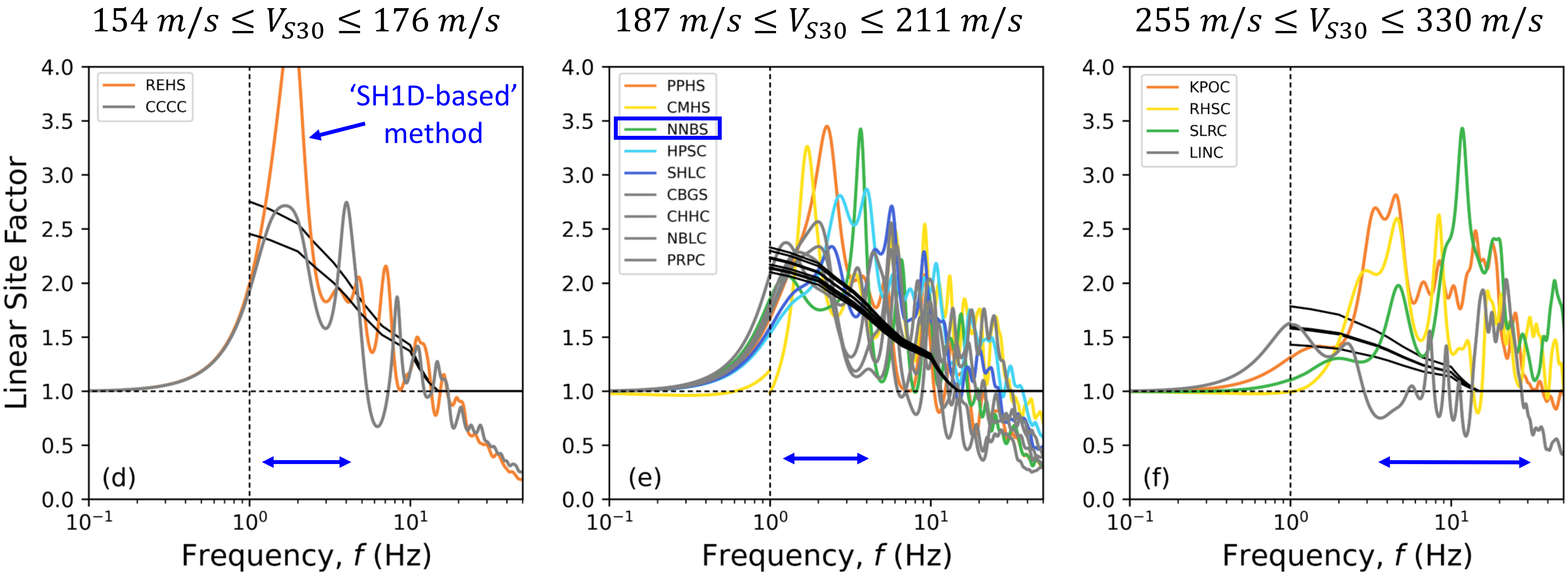
Comparison of site adjustments for soil sites

15 soil sites in the Canterbury cluster:



Comparison of site adjustments for soil sites

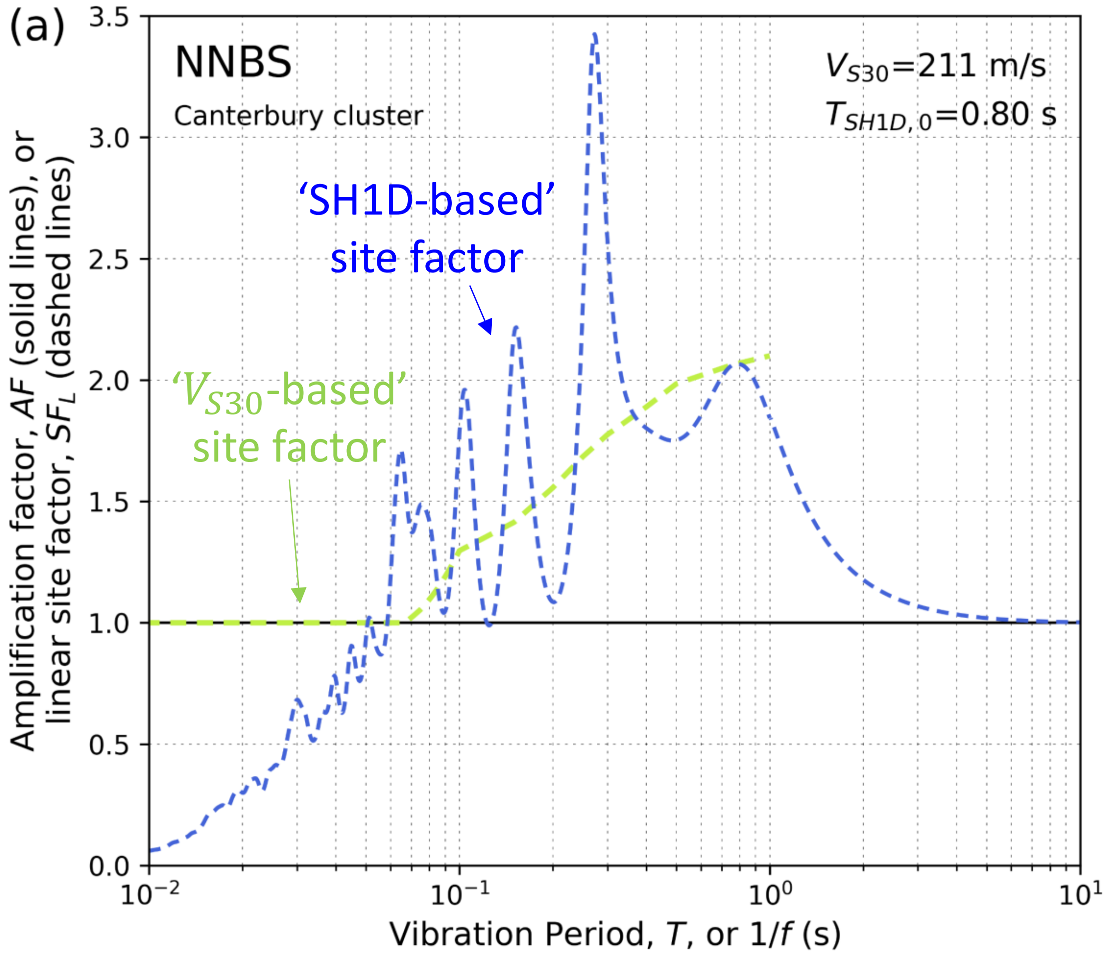
15 soil sites in the Canterbury cluster:



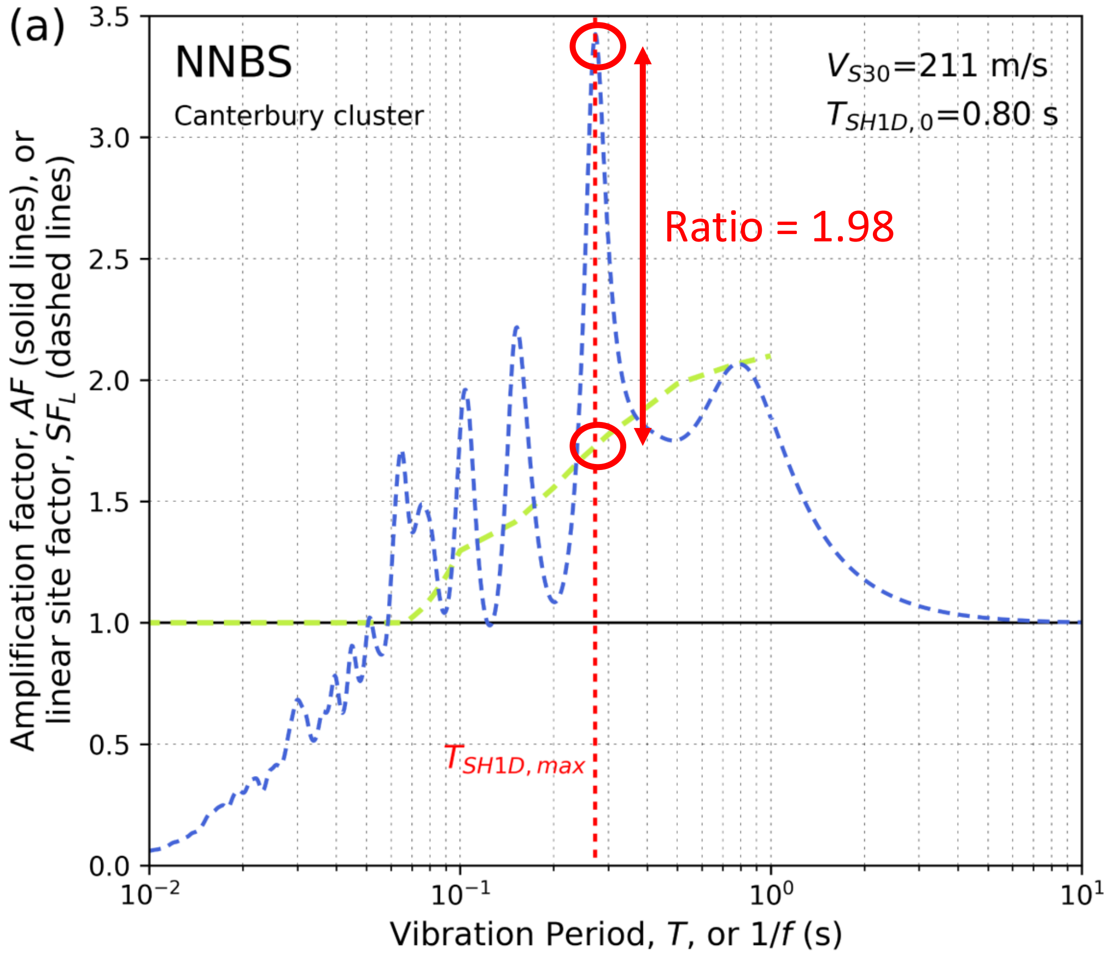
(1) Relatively soft sites with large amplification over narrow frequency bands in the intermediate frequency range

(2) Relatively stiff sites with significant amplification at frequencies considerably higher than 1 Hz

Comparison of site adjustments for soil sites



Comparison of site adjustments for soil sites



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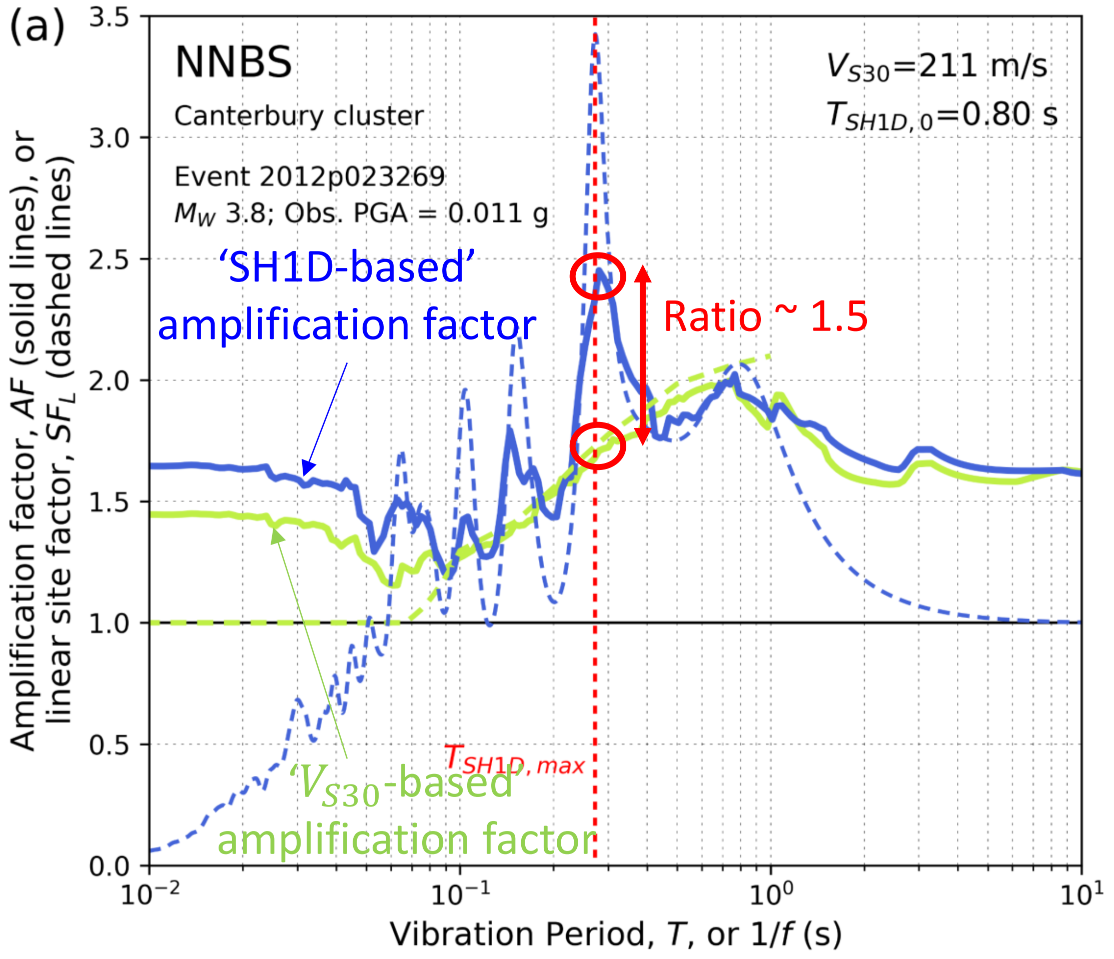


Site factor (SF)

Applied in the Fourier spectral domain

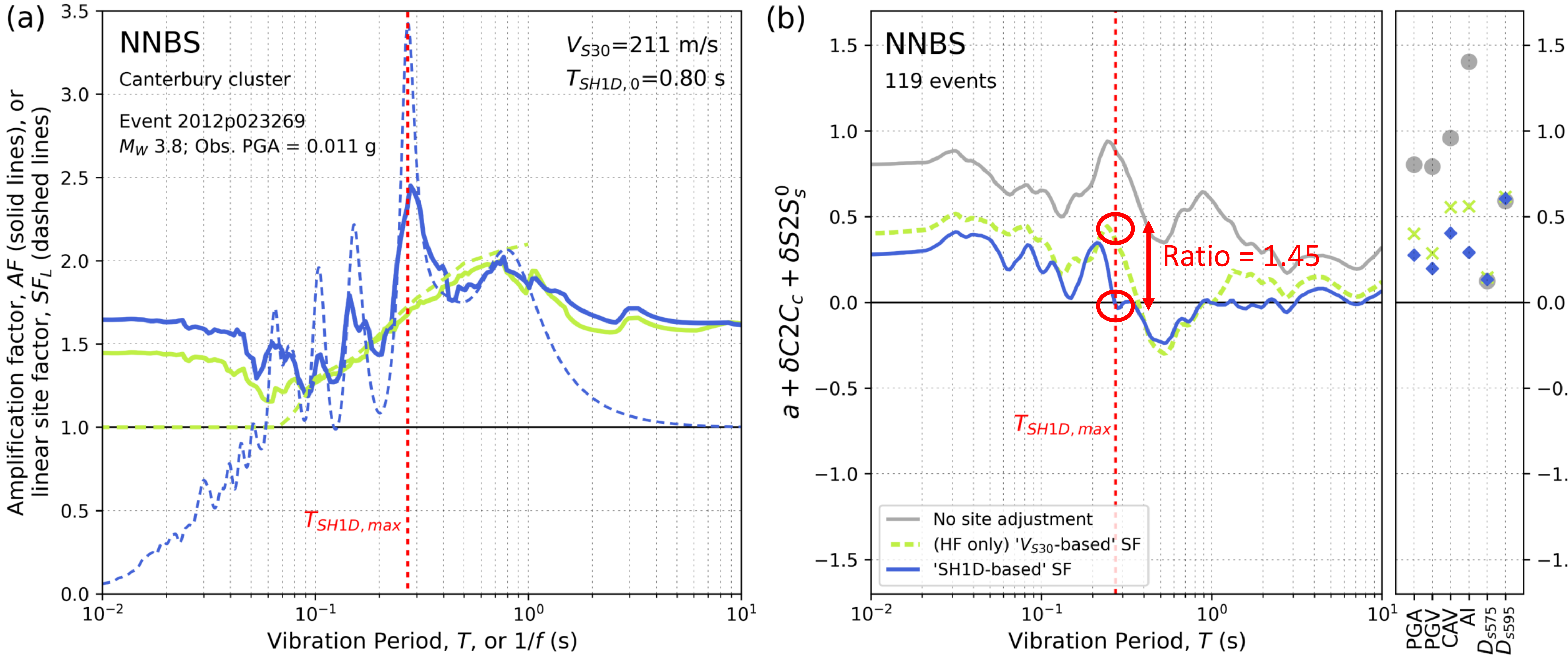
Smoothing of the resonant peaks and troughs

Amplification factor (AF)

Computed in the response spectral domain

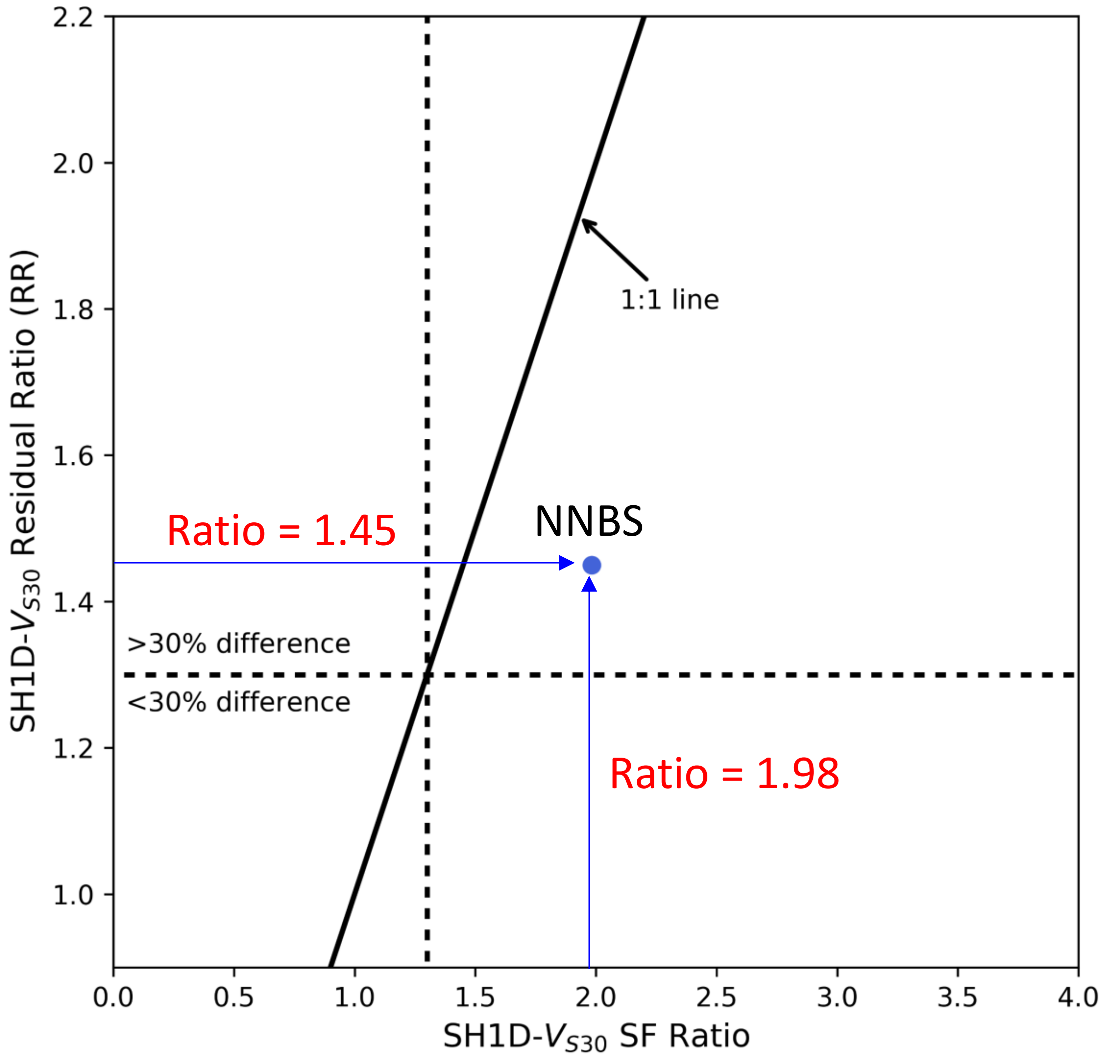
Large differences in the site factors are reduced

Comparison of site adjustments for soil sites



- In this case, the SH1D-based method improves prediction at $T_{SH1D,max}$
- Similar prediction at other periods

Comparison of site adjustments for soil sites



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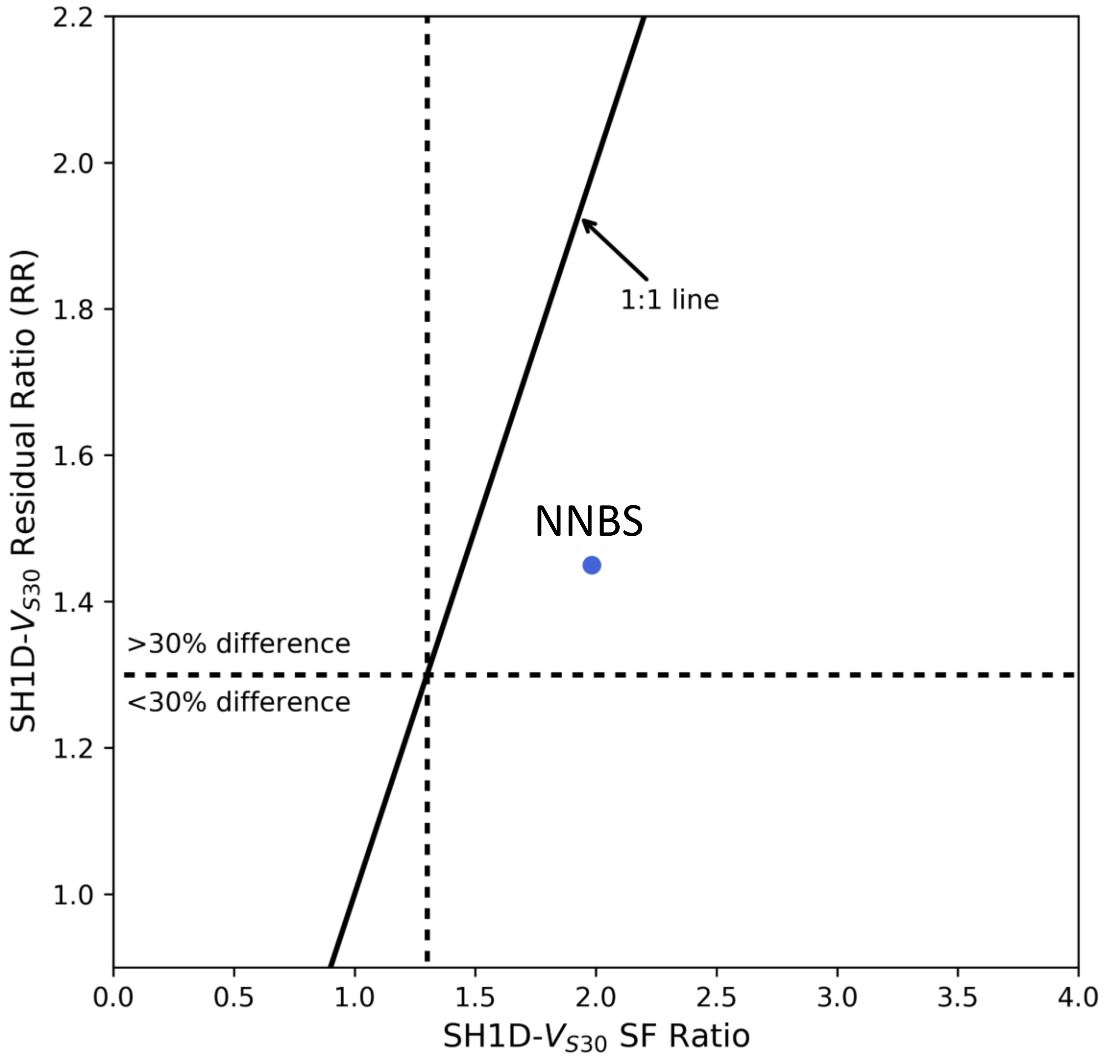

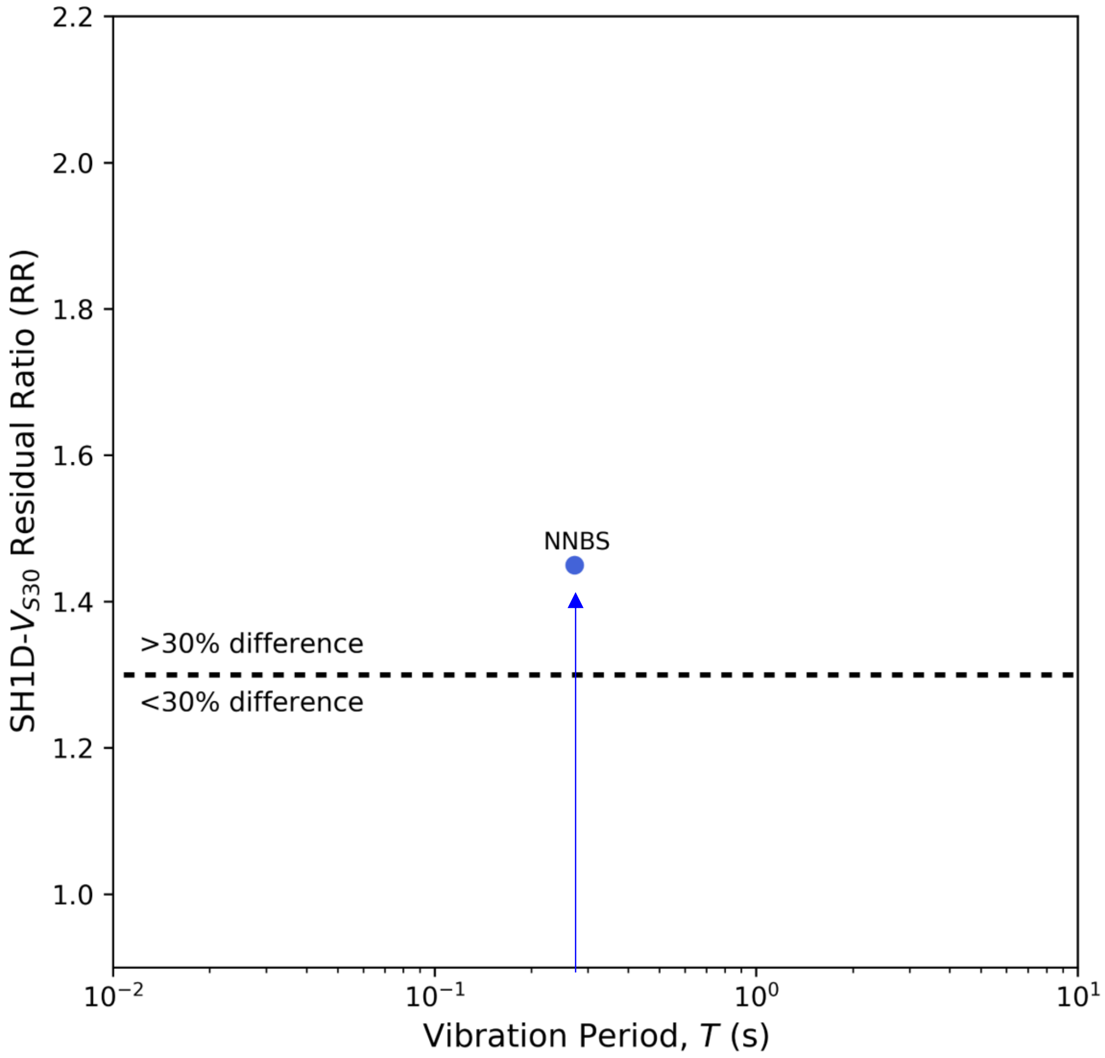

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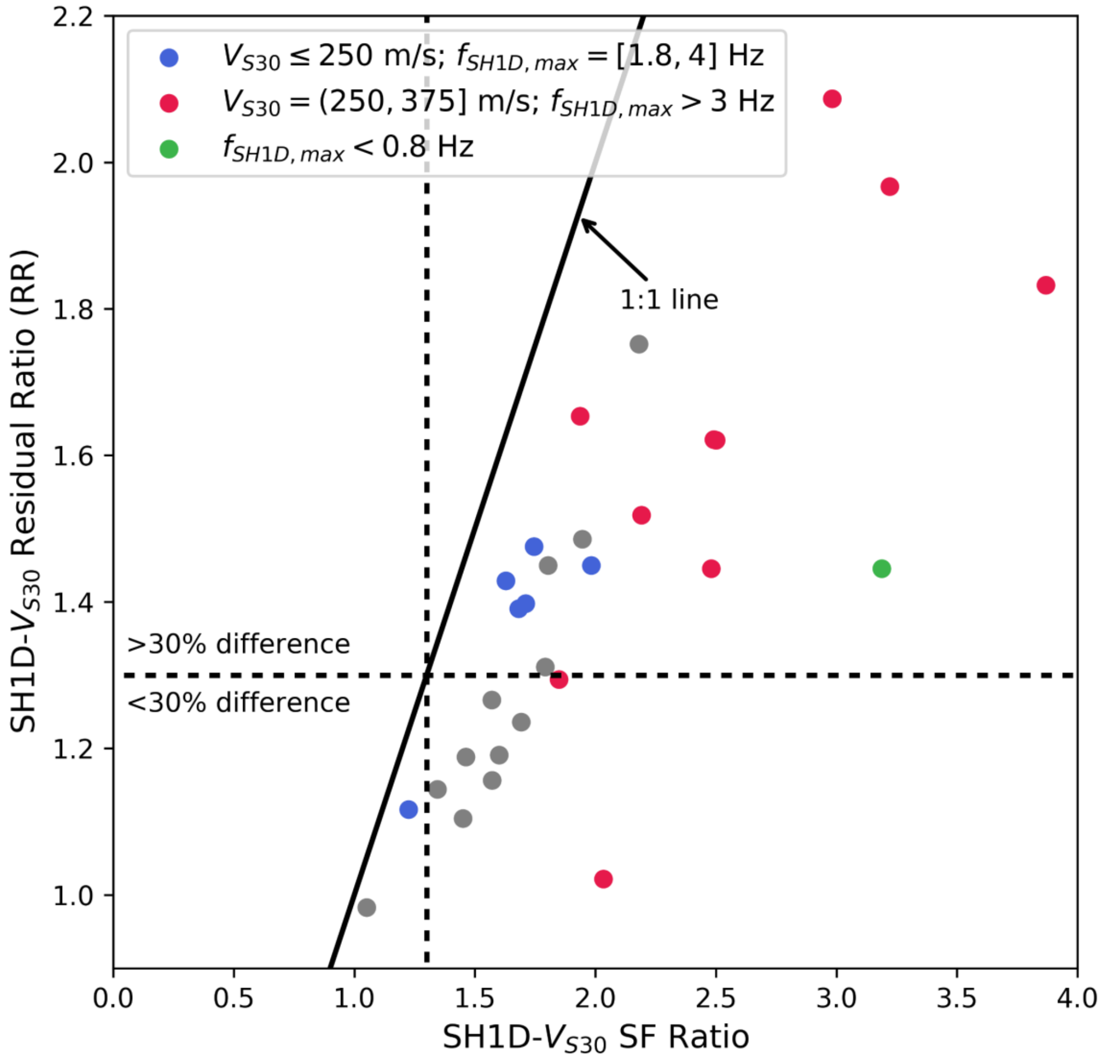
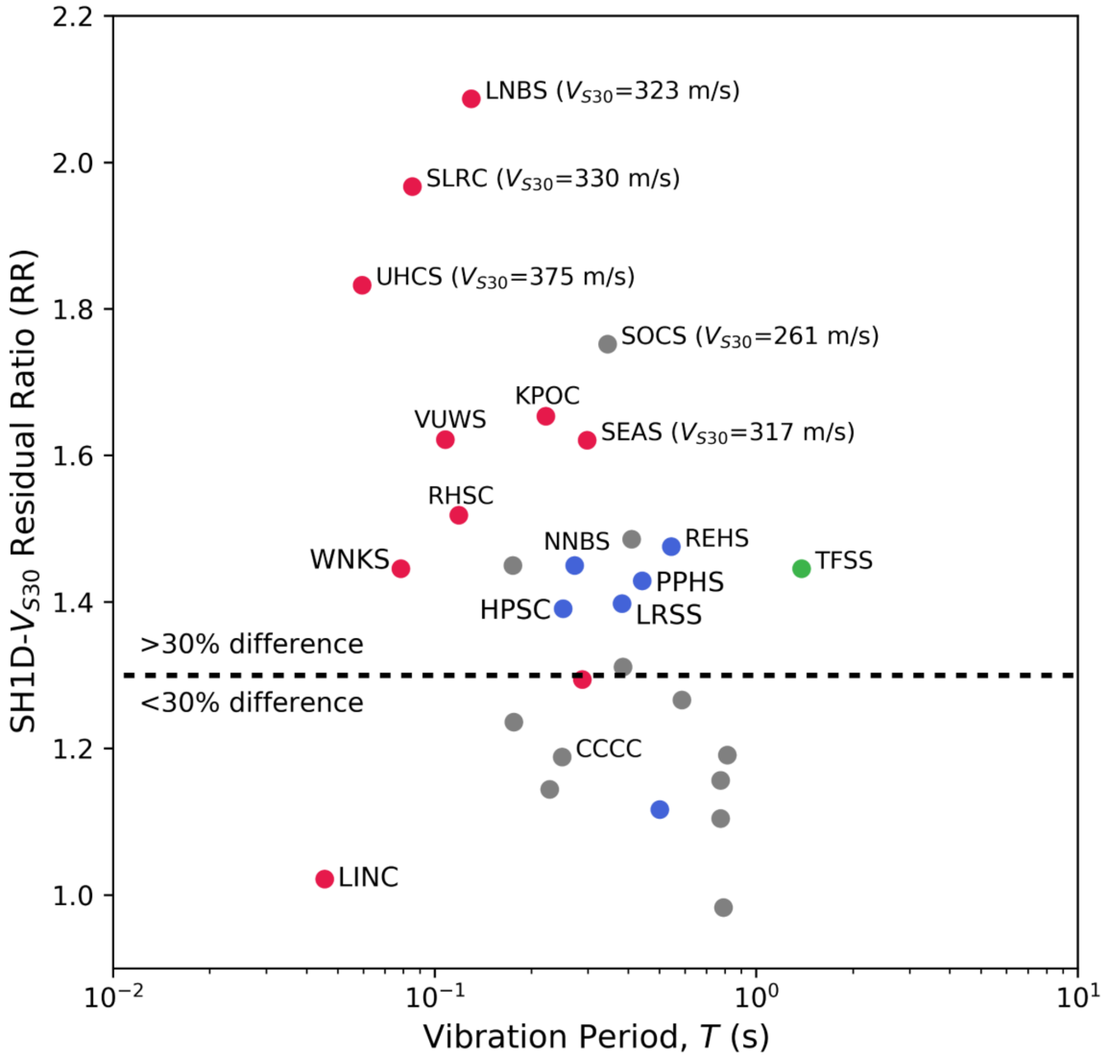


Residual ratios are systematically lower than site factor ratios

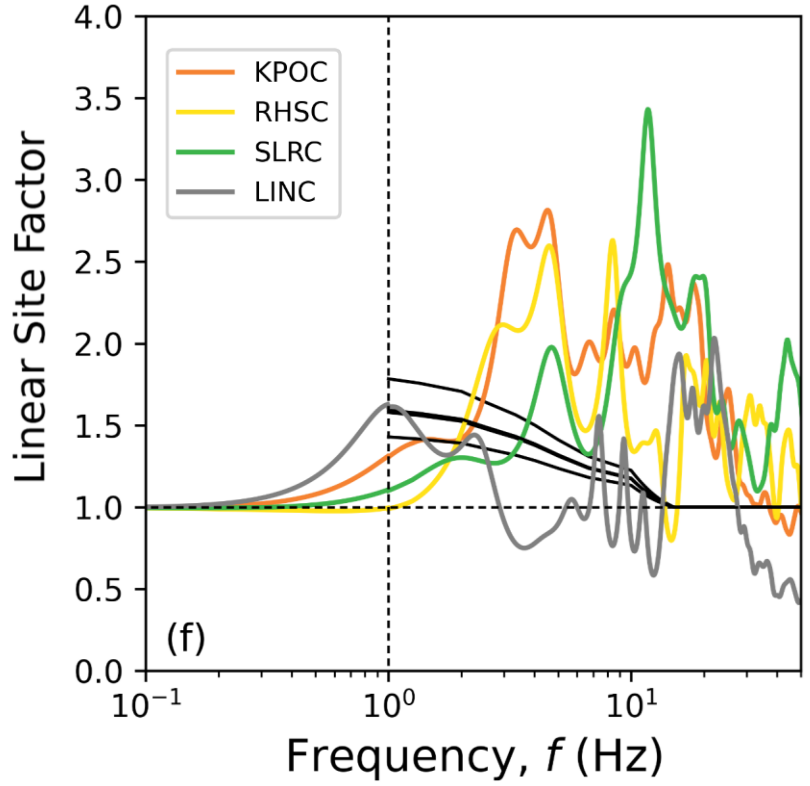


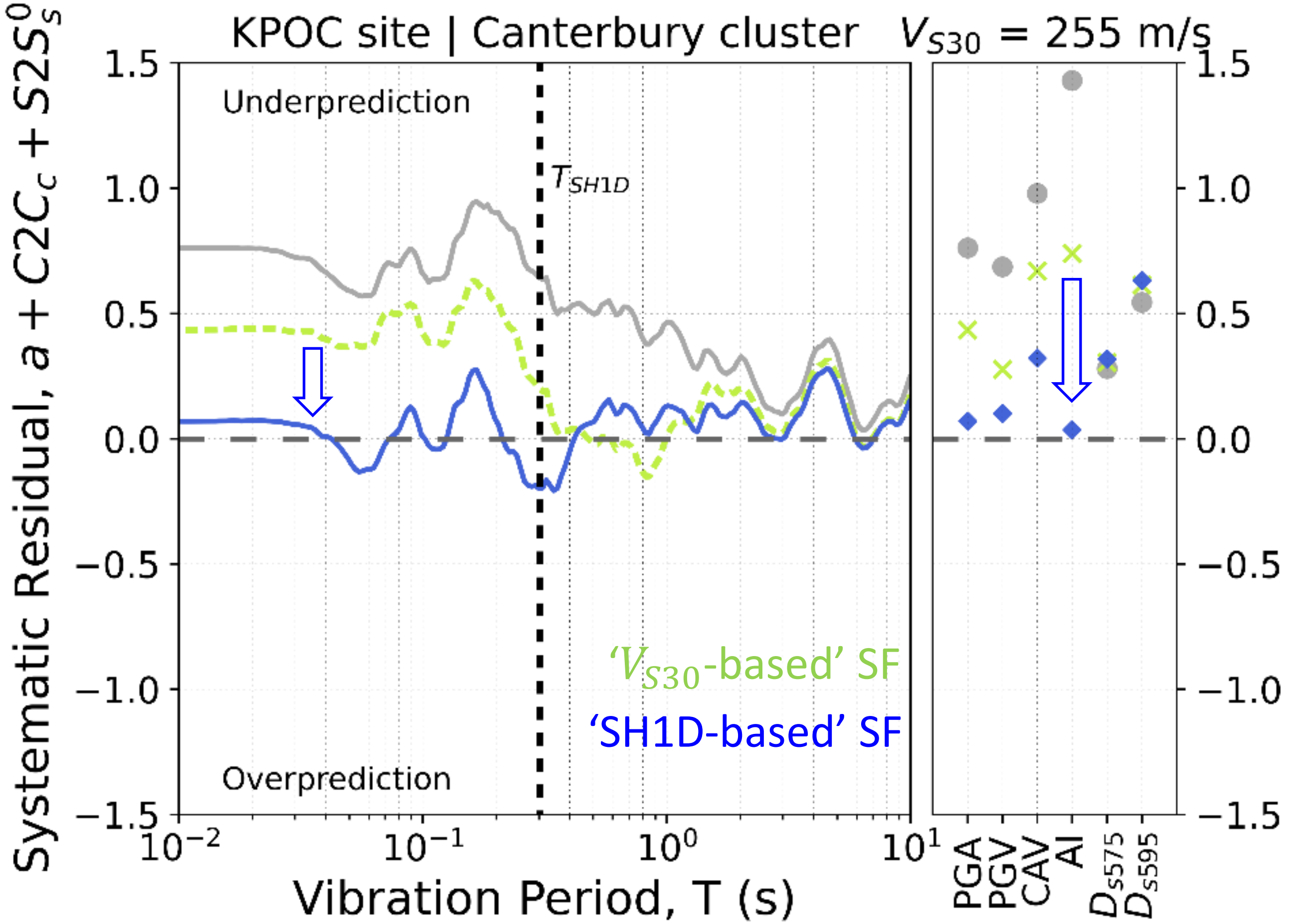
More significant residual ratios: relatively stiff sites displaying high-frequency amplification

Comparison of site adjustments for soil sites

Relatively stiff sites displaying high-frequency amplification

$255\,m/s \leq V_{S30} \leq 330\,m/s$





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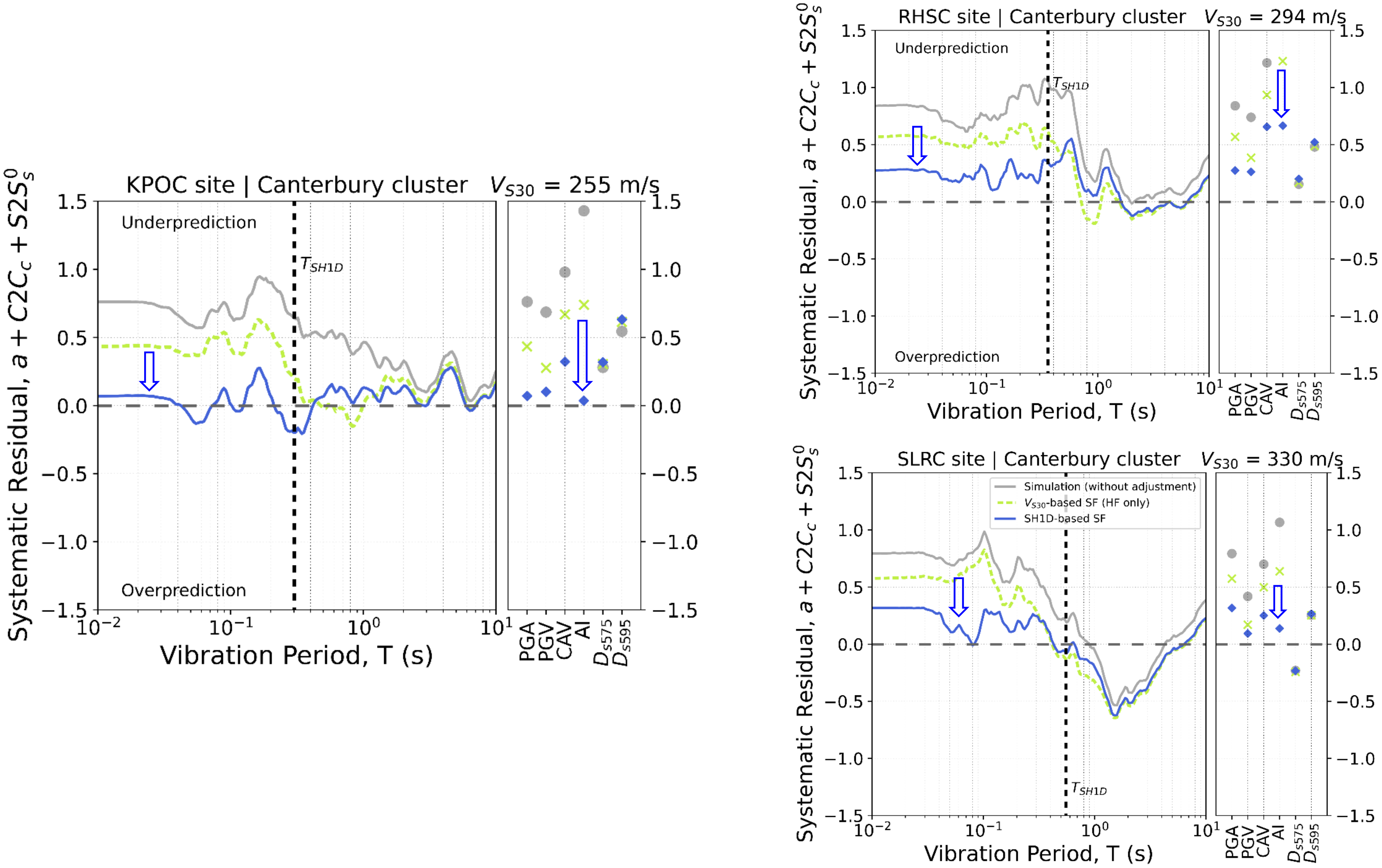

Closing Remarks

- The incorporation of shallow site effects significantly reduced the prediction site-to-site variability

- Comparable reduction between methods: the use of more detailed site-characterization data does not necessarily translate into significantly superior predictions

- Parametric and modelling uncertainties, in addition to smoothing of the site adjustment in the response spectral domain

- SH1D-based method showed particular benefit in some cases (four cases were identified in the paper), including relatively stiff sites with high-frequency resonances