QuakeCoRE
NZ Centre for Earthquake Resilience

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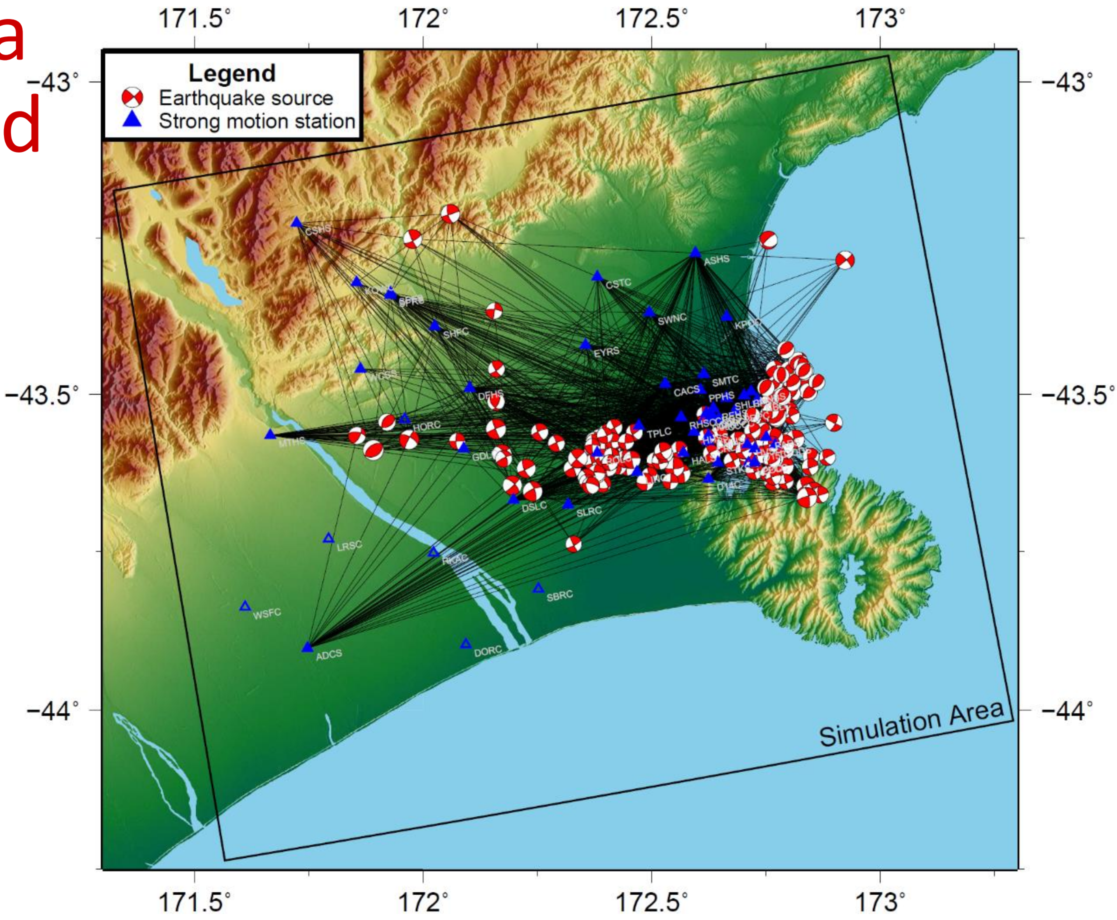
Improvements to ground motion simulations of small-to-moderate magnitude earthquakes in the Canterbury, NZ region

25-01-2015 QuakeCoRE Flagsip 1 Meeting

Background

- Graves and Pitarka (2010,2015) hybrid methodology.
- 144 earthquakes 3.5<Mw≤5.
- 1924 observed ground motions.
- 45 strong motion stations.



Graves and Pitarka

- LF from comprehensive physics-based wave propagation.
- HF from simplified ray theory-based wave propagation.
- Period-dependent empirical Vs30-based site amplification.

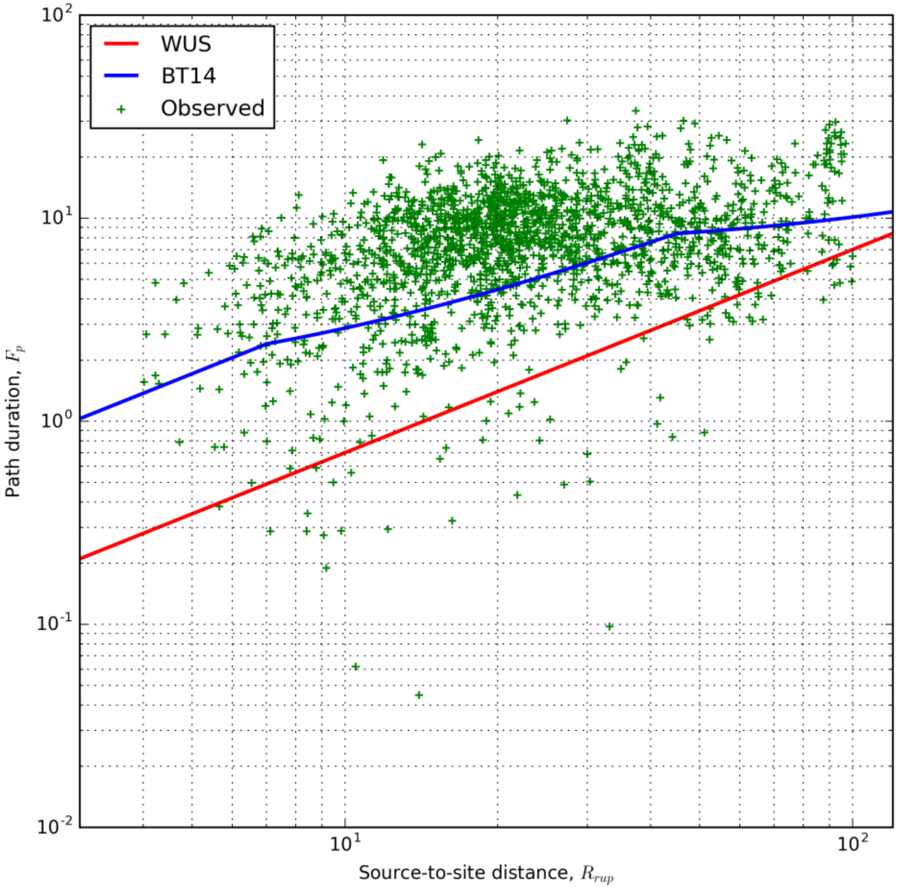
Key Findings

- Short period pSA is overpredicted (HF)
- Long period pSA is overpredicted (particularly between 1-4s) (LF).
- Significant durations were severely underpredicted.

- (These will be shown in later slides)

Improvements

- Identified numerous improvements
  - – Increased path duration Boore and Thomson 2014. ✓
  - – Reduced tapering of long period ✓ empirical V_{s30}-based site amplification.
  - – Site-specific high frequency simulations.



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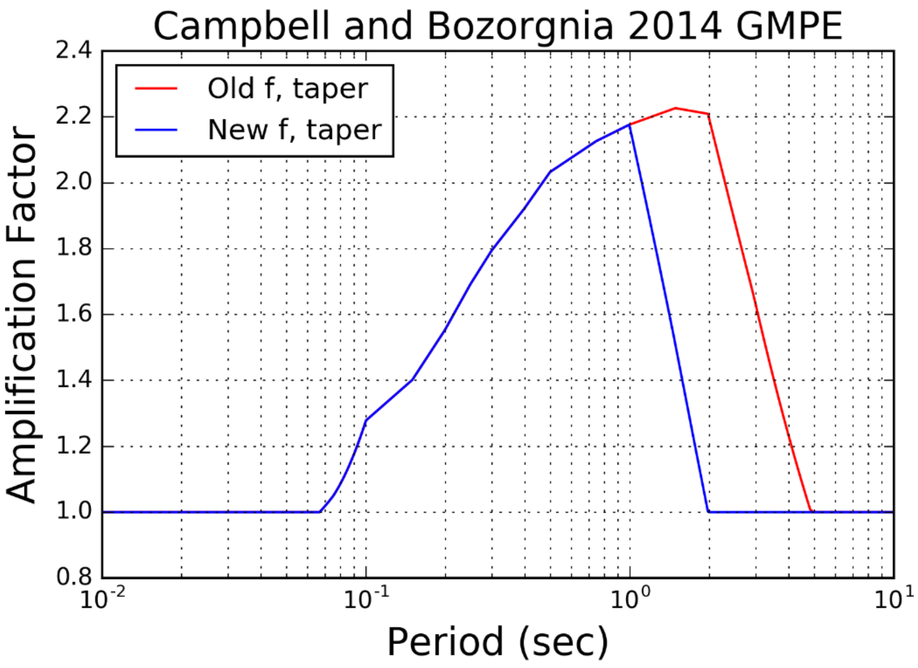

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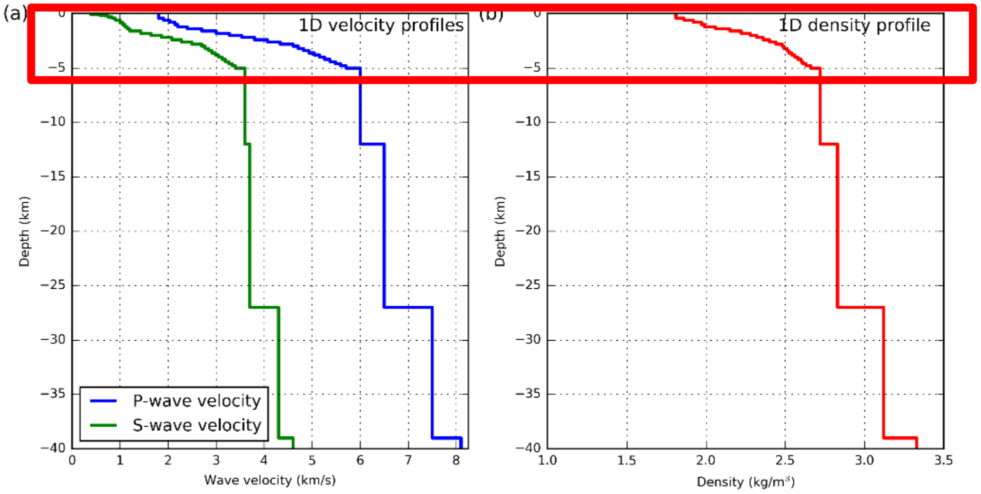


New Simulations

- Simulated and investigated the 144 earthquakes again with each change independently and also collectively.
- Subsequent plots will show the old results to serve as a reference point and subsequent new results.
- Standard deviations of empirical ground motion models also shown.

Non-ergodic Analysis Methodology

- General form of a ground motion model with residuals partitioned assuming a biased dataset.

$$\ln(IM_{es}) = \underbrace{f_{es}}_{\text{Median GMM prediction}} + \underbrace{\Delta_{es}}_{\text{Total residual}}$$

$$= \underbrace{f_{es}}_{\text{Median GMM prediction}} + \underbrace{a}_{\text{Bias}} + \underbrace{\delta B_e}_{\text{Between-event residual}} + \underbrace{\delta W_{es}}_{\text{Within-event residual}}$$

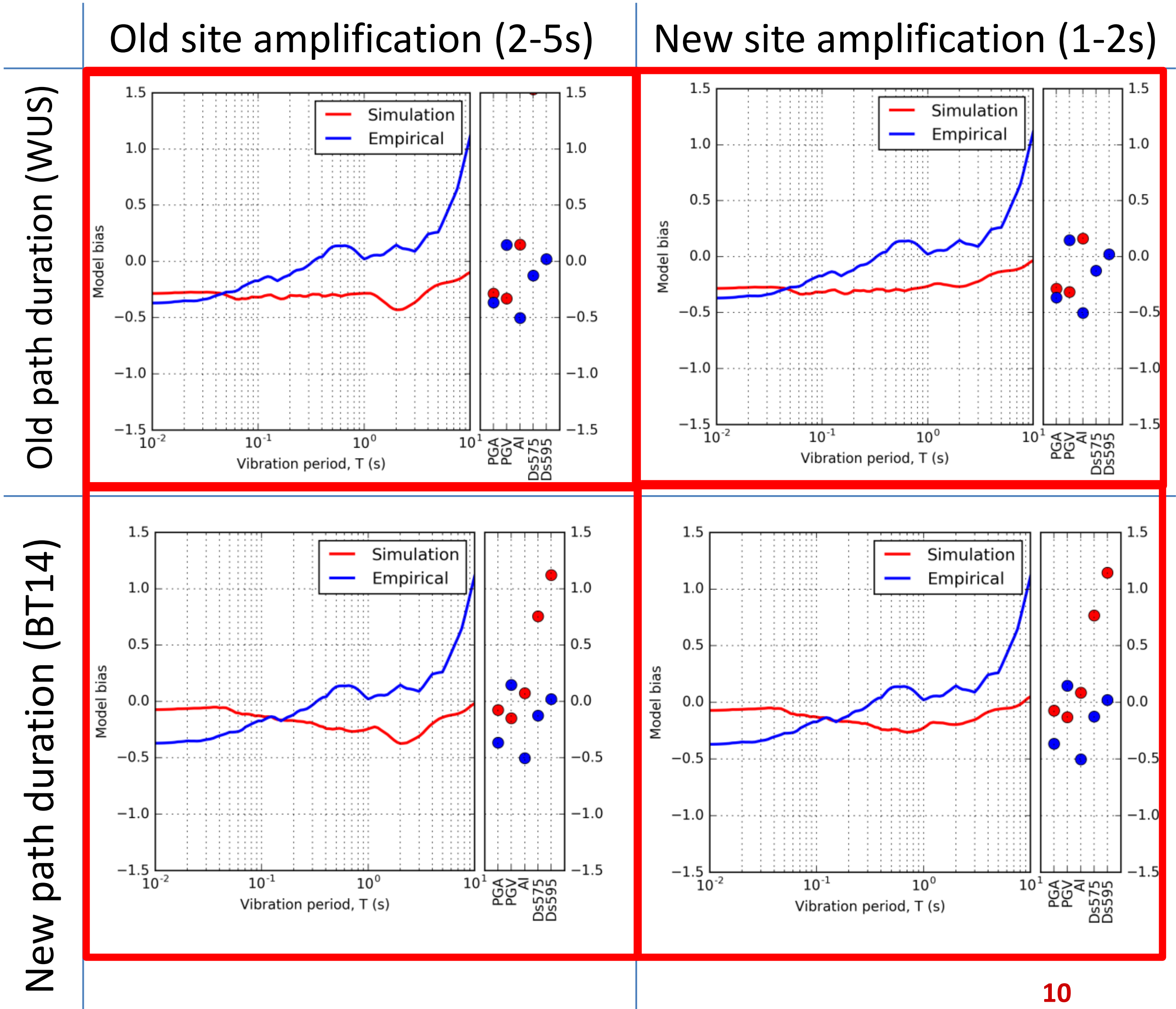
$$= \underbrace{f_{es}}_{\text{Median GMM prediction}} + \underbrace{a}_{\text{Bias}} + \underbrace{\delta B_e}_{\text{Between-event residual}} + \underbrace{\delta S2S_s}_{\text{Systematic site-to-site residual}} + \underbrace{\delta W_{es}^0}_{\text{Site-corrected within-event residual}}$$

$$\delta B_e \rightarrow N(0, \tau) \qquad \delta S2S_s \rightarrow N(0, \phi_{S2S}) \qquad \delta W_{es}^0 \rightarrow N(0, \phi_{SS})$$

Aleatory | Epistemic | Aleatory

Bias, a

- Previously overpredicted pSA at all periods. Duration severely underpredicted (above 1.5 ln units).
- New site amp decreases 1-4s bias.
- New path duration decreases <1s bias. Significantly decreases bias for duration.



Old site amplification (2-5s)

New site amplification (1-2s)

Old path duration (WUS)

New path duration (BT14)

Between-event residuals, δB_e

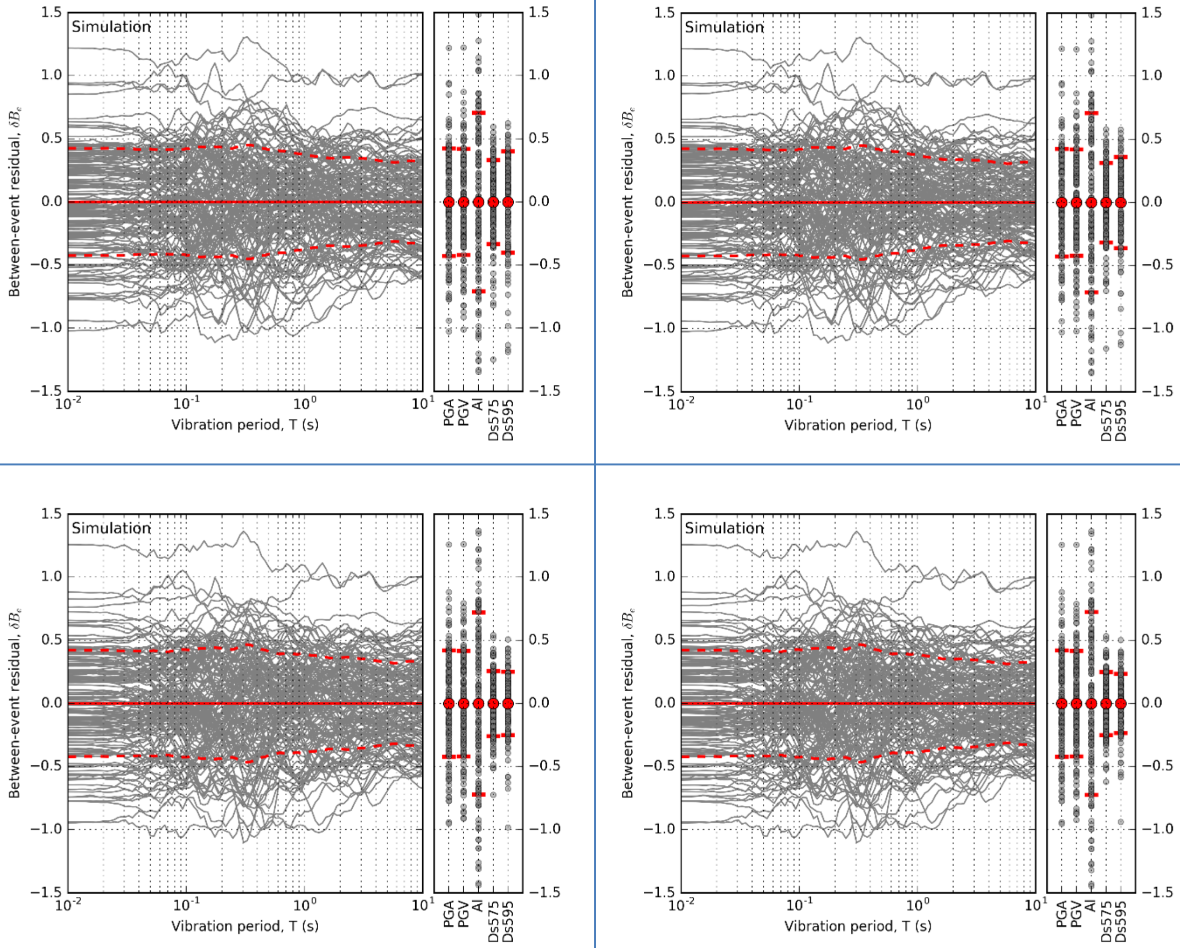
- Changes were broadly applied so not significant changes in δB_e.

Old site amplification (2-5s)

New site amplification (1-2s)

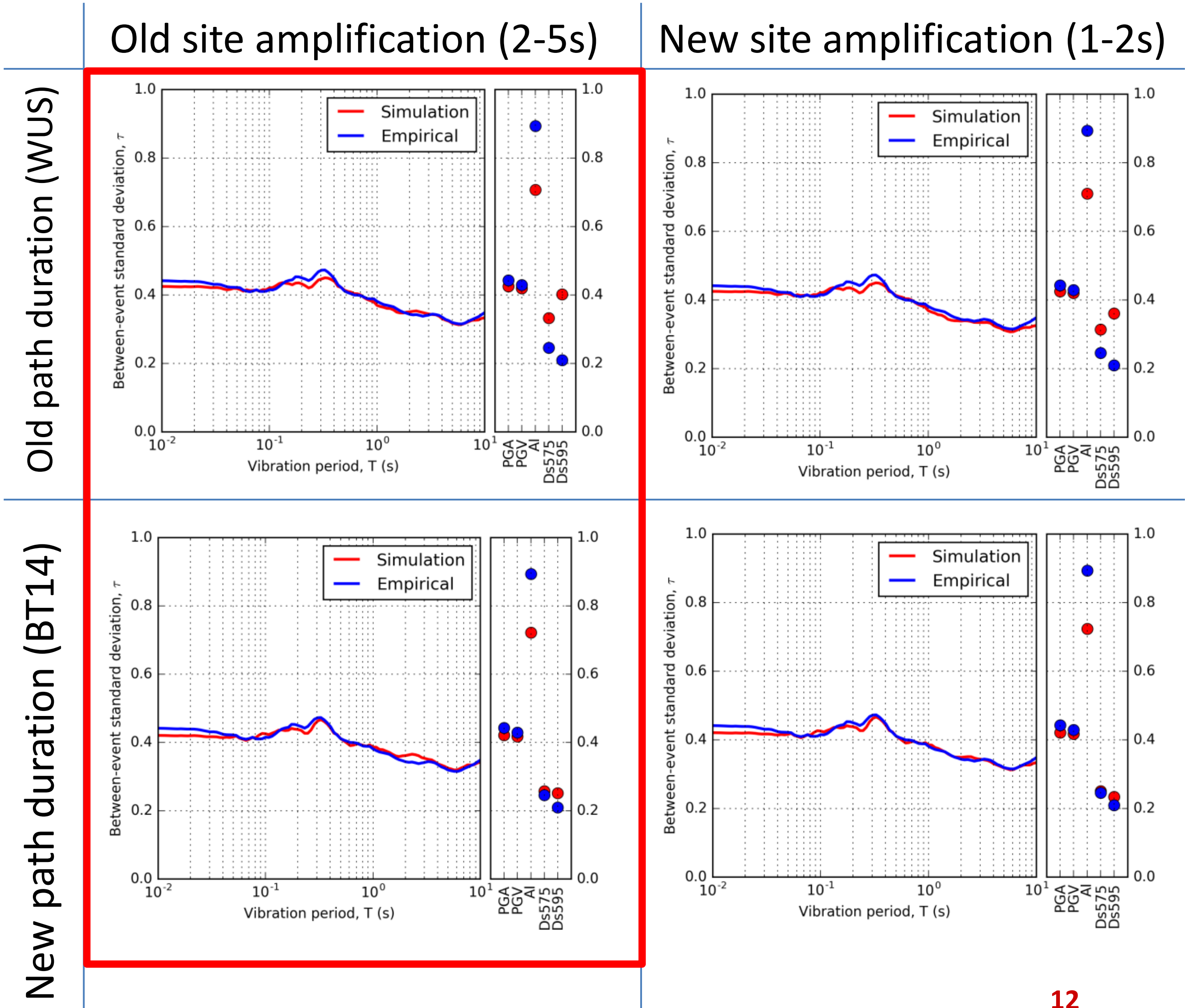
Old path duration (WUS)

New path duration (BT14)



Between-event standard deviation, τ

- Similarly no significant changes in τ except in duration.
- Simulation and empirical are similar.



Old site amplification (2-5s)

New site amplification (1-2s)

Old path duration (WUS)

New path duration (BT14)

Systematic site-to-site residual, δ_{S2S}

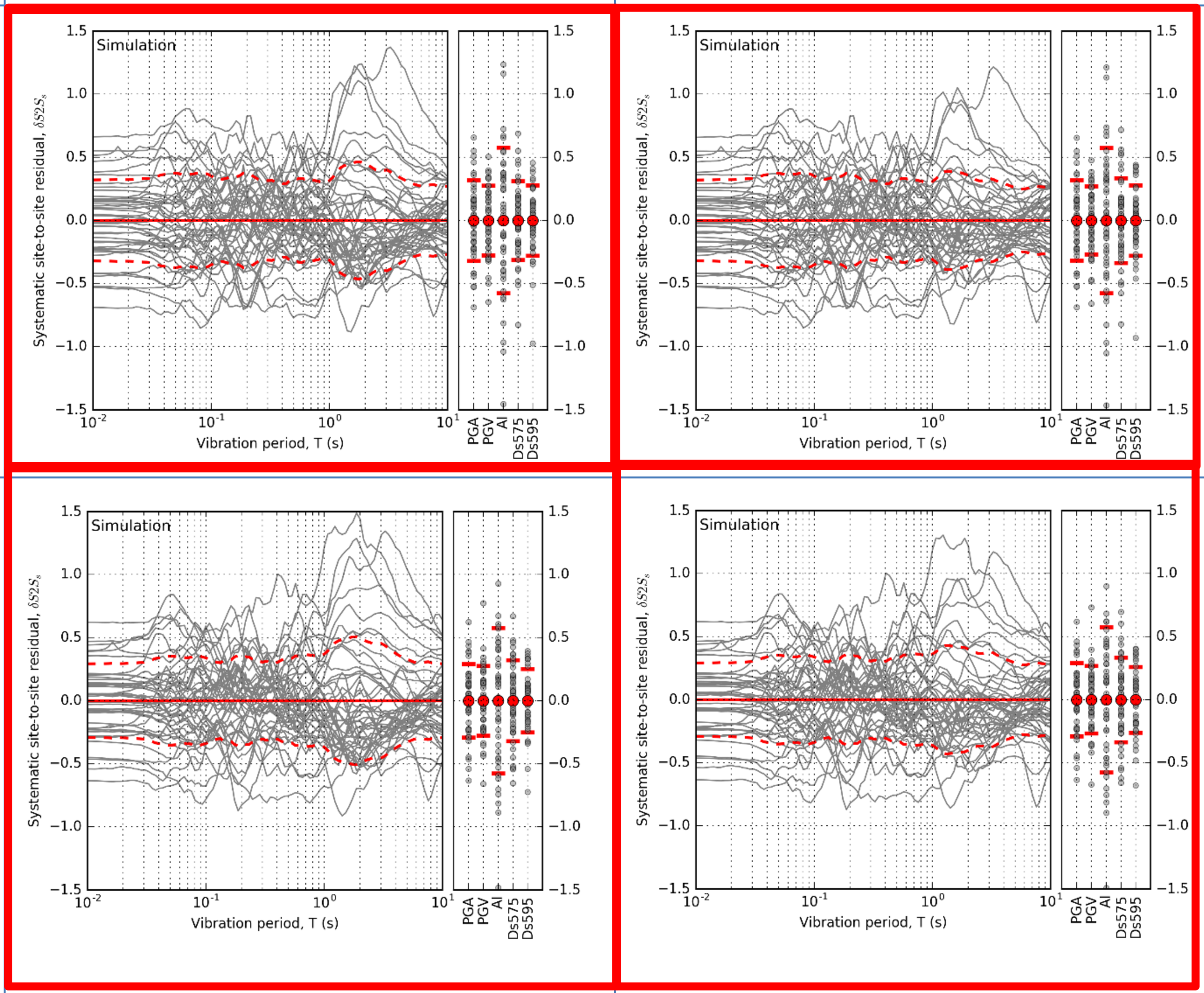
- Previously, larger spread of values between 1-4s.
- The corresponding sites are the Southern Alps range front sites (CSHS, MTHS, WCSS).
- New site amp decreases the underprediction.
- New path duration increases the underprediction.

Old site amplification (2-5s)

New site amplification (1-2s)

Old path duration (WUS)

New path duration (BT14)



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Systematic site-to-site standard deviation, ϕ_{S2S}

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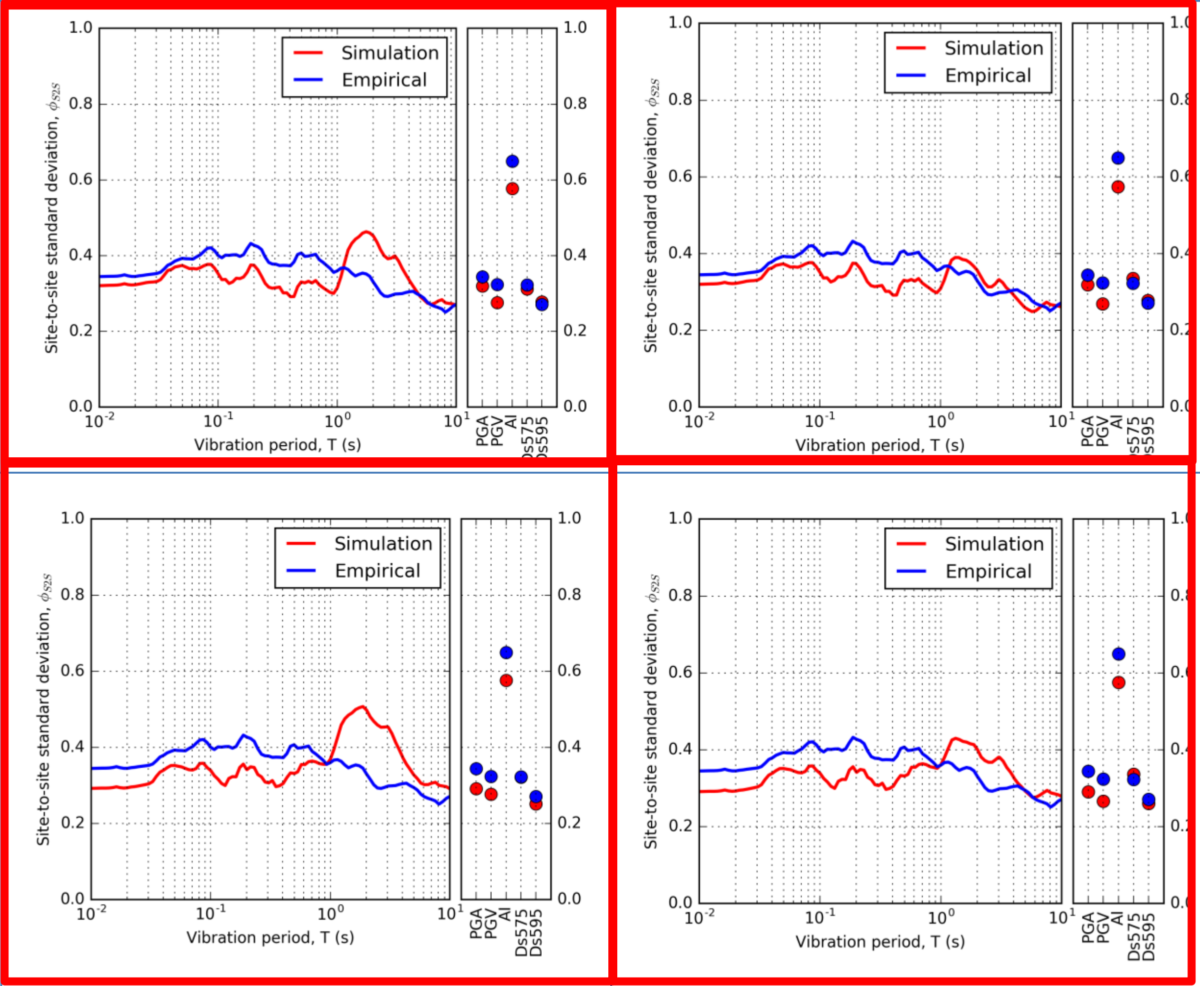
- More evidently shown in the standard deviations.

Old site amplification (2-5s)

New site amplification (1-2s)

Old path duration (WUS)

New path duration (BT14)



Event-corrected single station standard deviation, ϕ_{SS}

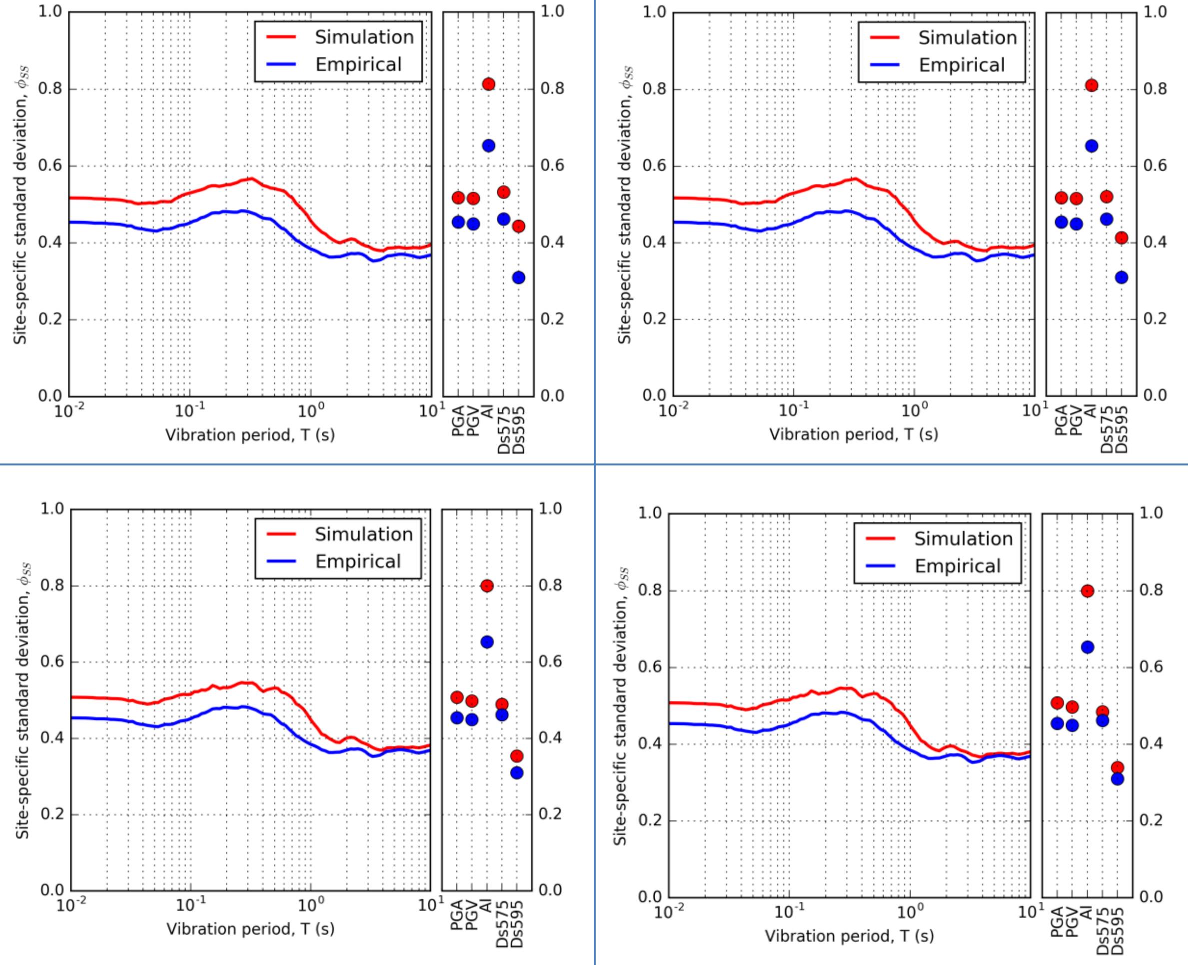
- Relatively similar across all scenarios.

Old site amplification (2-5s)

New site amplification (1-2s)

Old path duration (WUS)

New path duration (BT14)



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Total standard deviation, σ

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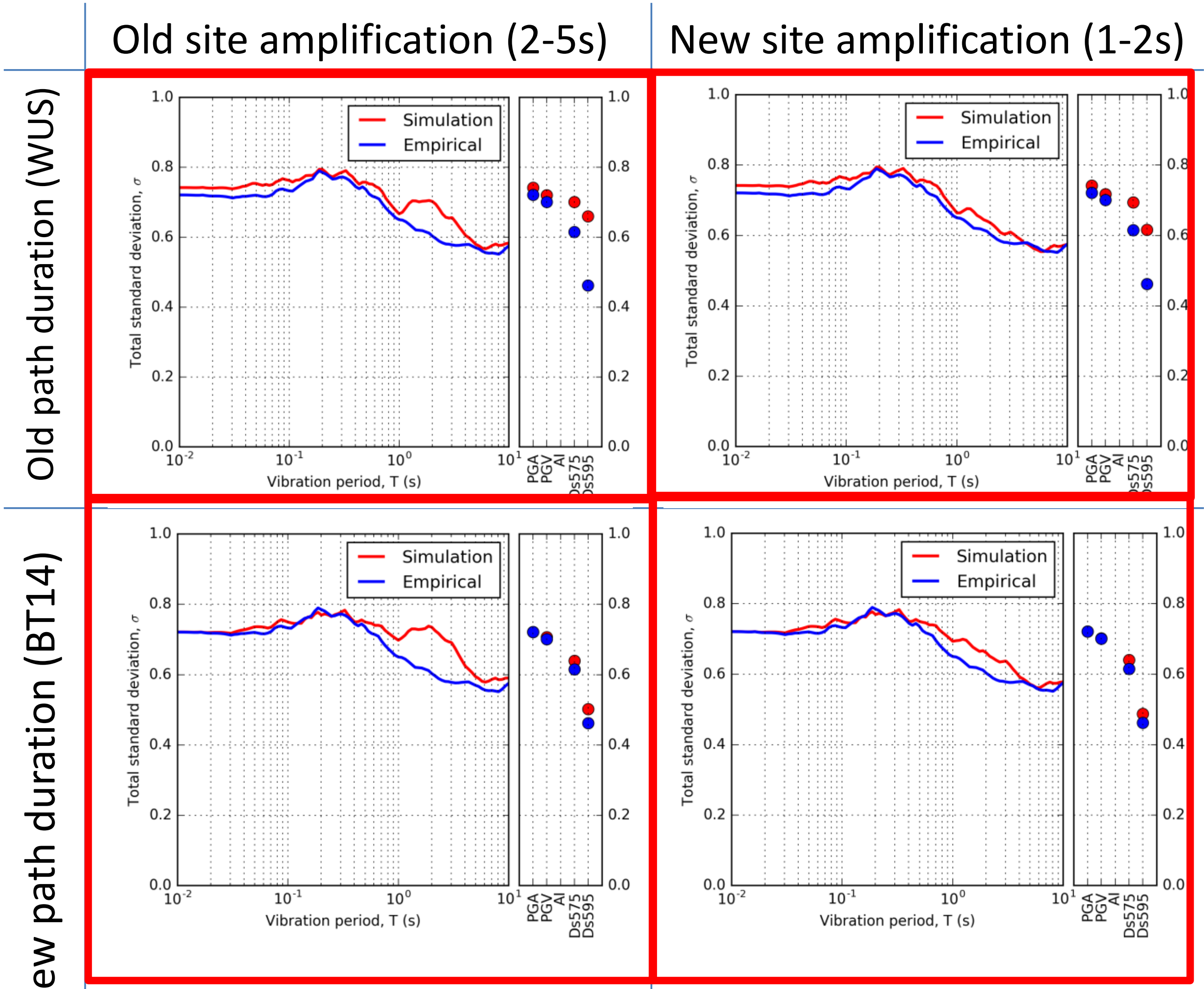
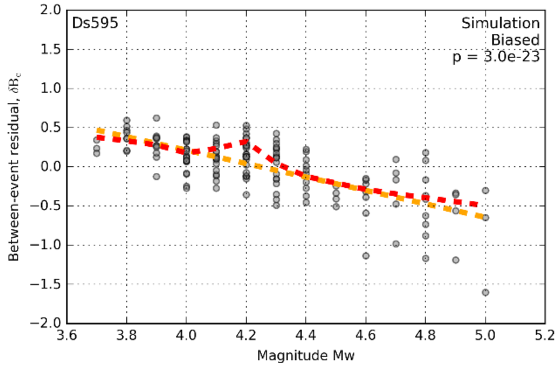
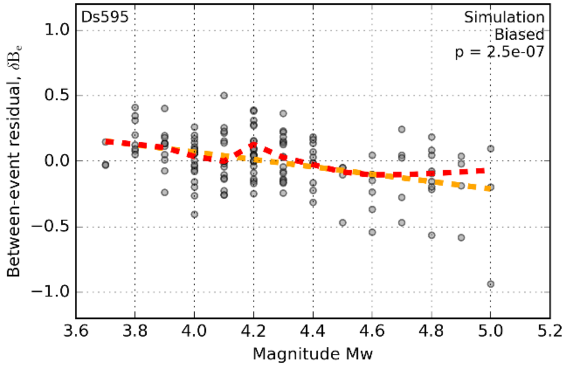
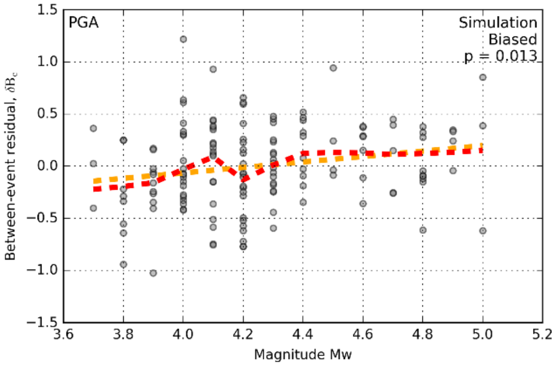
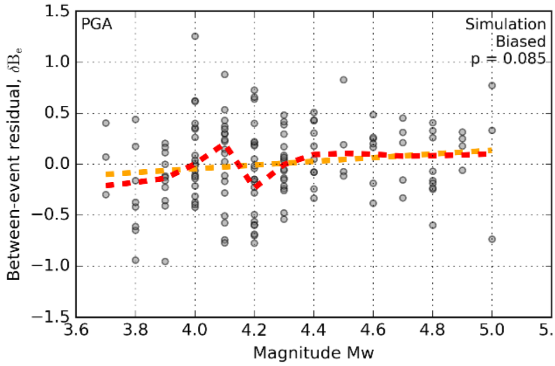
- New site amp decreases standard deviation between 1-4s.
- New path duration decreases significant duration standard deviations but increases 1-4s pSA.
- Collectively similar between simulated and empirical.



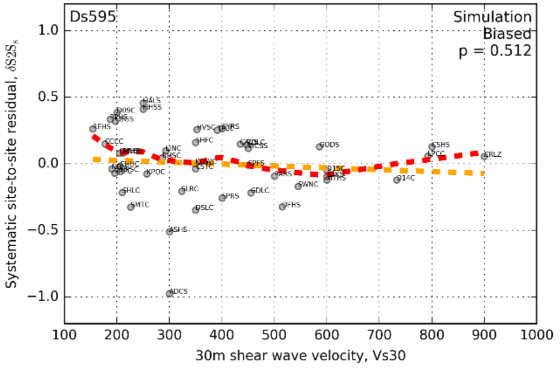
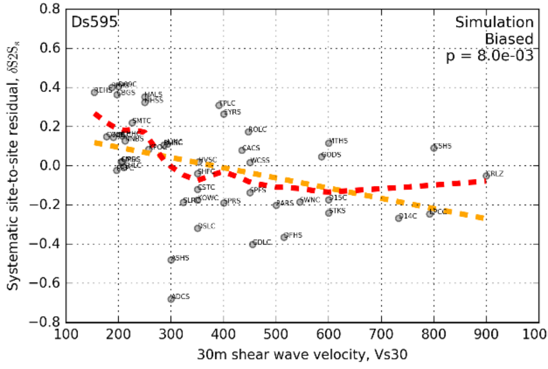
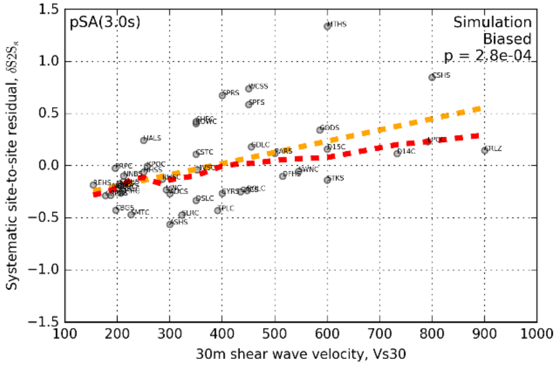
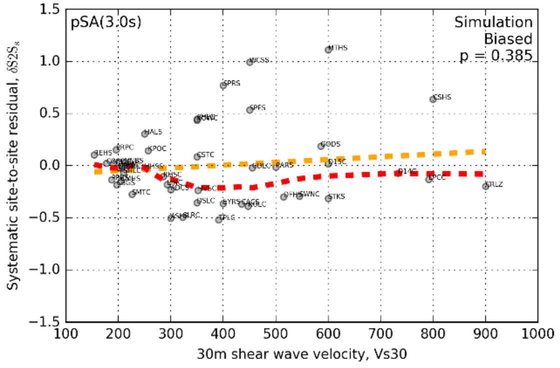
δB_e M_w-dependence

- Mw dependence is significantly decreased for significant durations and PGA.

	Reference Result Old Path Duration, Old Site Amp	New Result New Path Duration, New Site Amp
D_{s595}		
PGA		

δS2S V_{s30}-dependence

- Underprediction of D_{s595} at low V_{s30} develops due to new path duration.
- V_{s30} dependence for pSA(3.0s) is removed due to the new site amplification.

	Reference Result Old Path Duration, Old Site Amp	New Result New Path Duration, New Site Amp
Ds_{595}		
pSA(3.0s)		

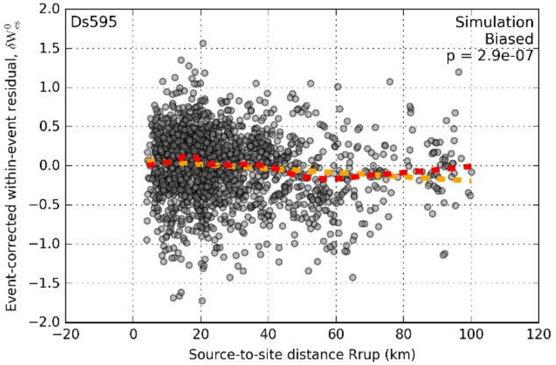
δW_{es}^{0} R_{rup}-dependence

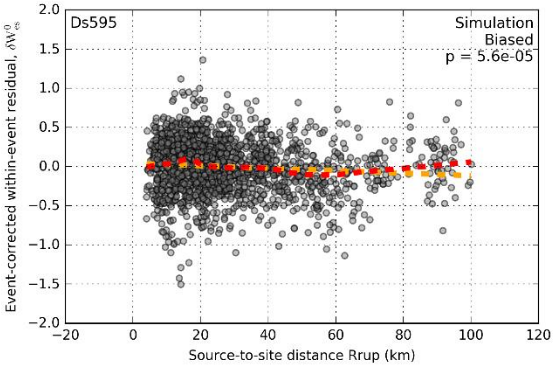
- No R_{rup} dependence for D_{s595} in both cases.
- For PGA and pSA, there is increasing underprediction for R_{rup} above 50km.

Reference Result
Old Path Duration, Old Site Amp

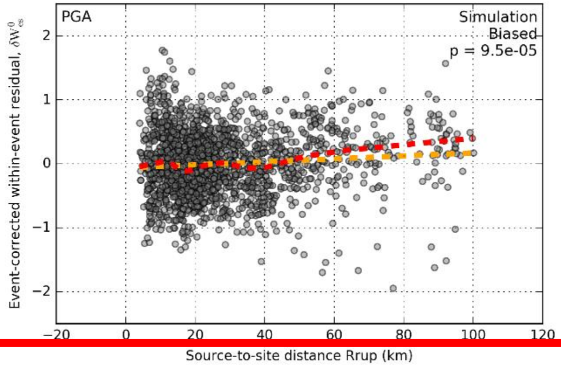
New Result
New Path Duration, New Site Amp

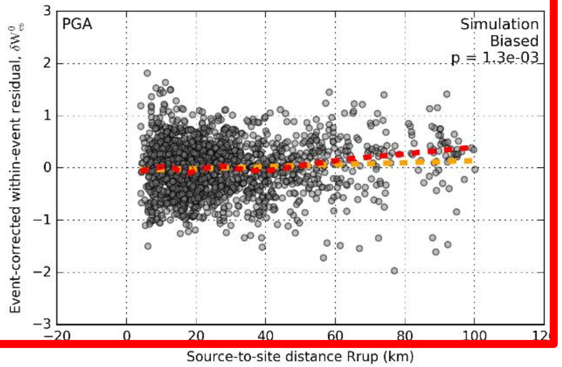
Ds_{595}





PGA





Conclusions and Discussion

- New site amplification has:
  - Decreased overprediction bias
  - Decreased phiS2S at 1-4s periods.
  - Removed dependence of pSA(~3.0s) on Vs30 for δS2S.
- New path duration has:
  - Decreased bias of short period pSA and significant durations.
  - Reduced Mw-dependence for δB_e.

Further Improvements

- Implement site-specific HF simulations:
  - Site specific 1D profile.
  - Site-specific HF attenuation (κ_0).
- Event-specific stress drop.
- 3D velocity model with depth-dependence within layers and heterogeneity.

Future Work

- Extend the validation to larger magnitudes (5<Mw≤6).
- Extend the validation to South Island and New Zealand-wide.