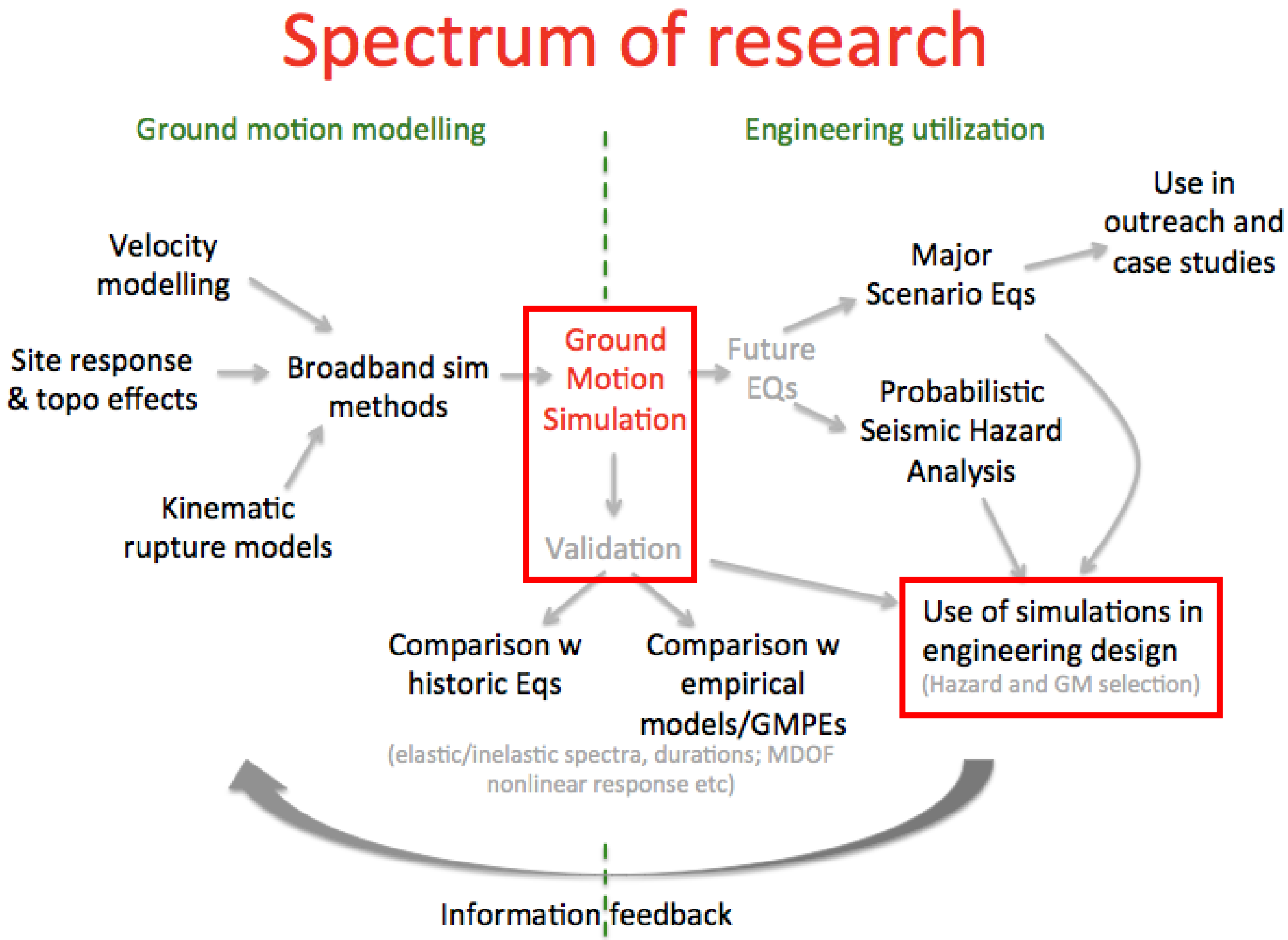
Validation of ground motion simulations with explicit incorporation of uncertainty, for small magnitude earthquakes in Canterbury, New Zealand

QuakeCoRE Flagship 1 meeting

Sarah Neill

23-07-2020

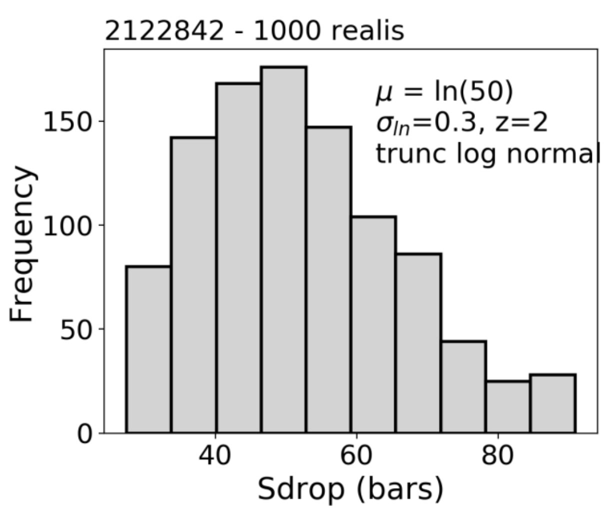
Context and Motivation



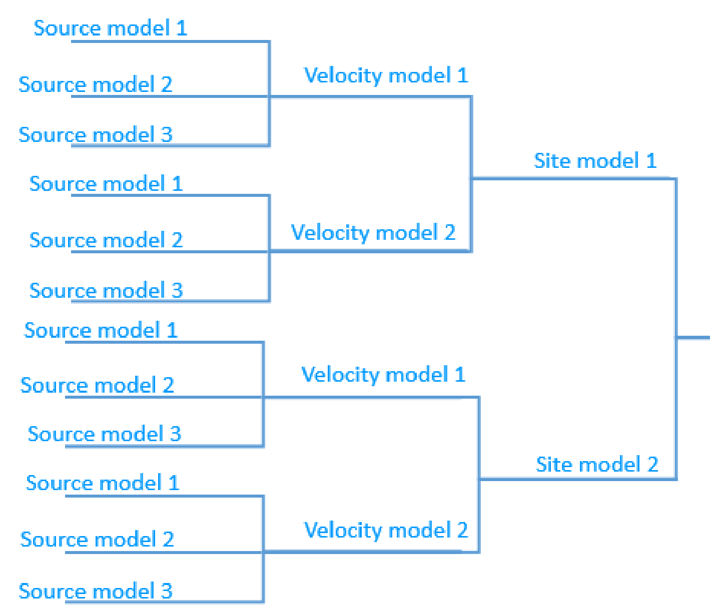
Consideration of uncertainty

For Validation:

- Consider uncertainties of data, parameters & models
- Describe uncertainty distribution for parameters
- Assess parameter correlations
- Consider alternative models



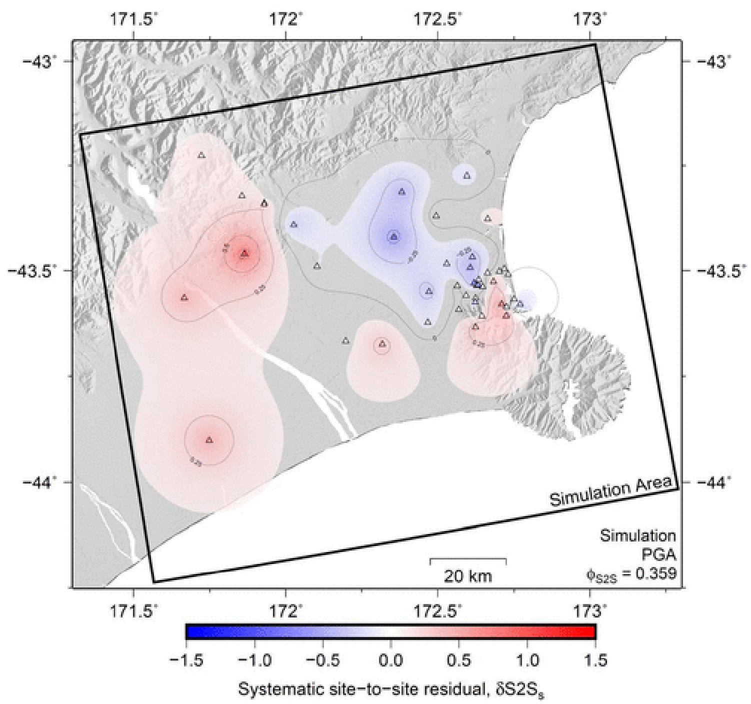
$$M_o \propto \Delta\sigma$$

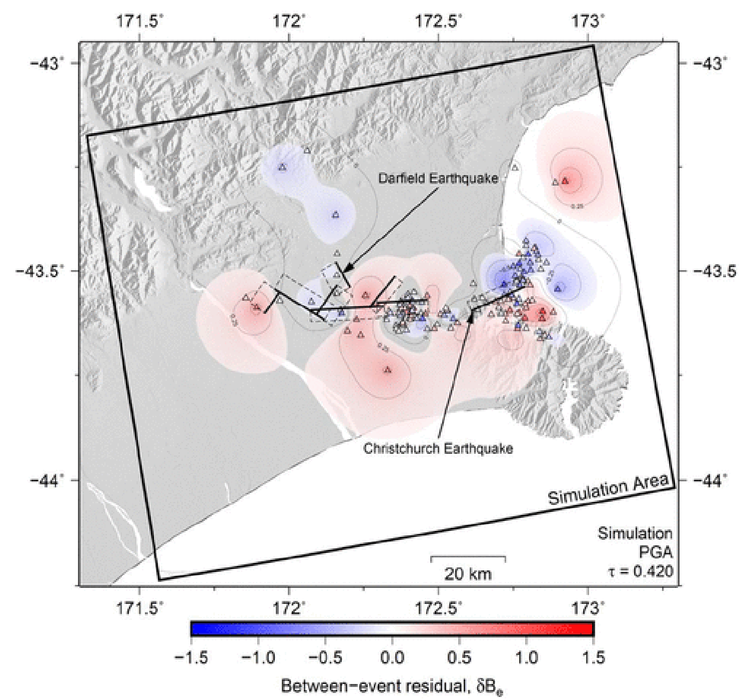


Consideration of uncertainty

For Validation:

- Understand systematic effects of uncertainty
- Assess against observations



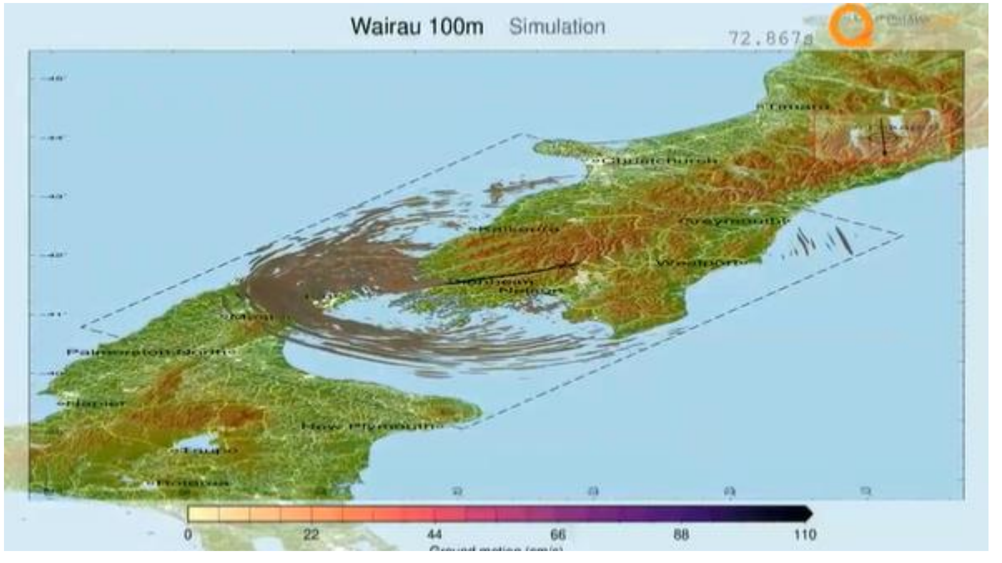


Lee et al 2020

Consideration of uncertainty

Purpose:

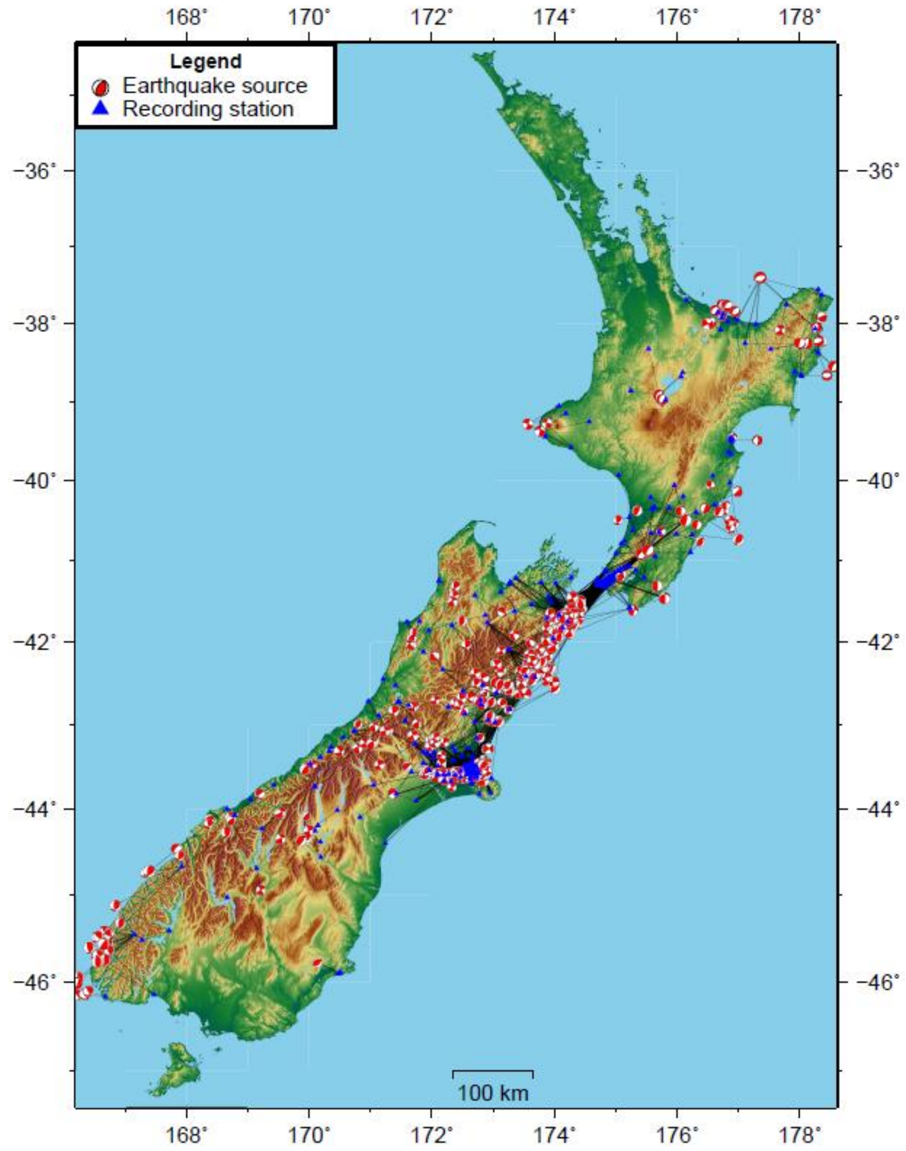
- Apply findings in validation to prediction of future earthquakes



Bradley (2019)

Data set

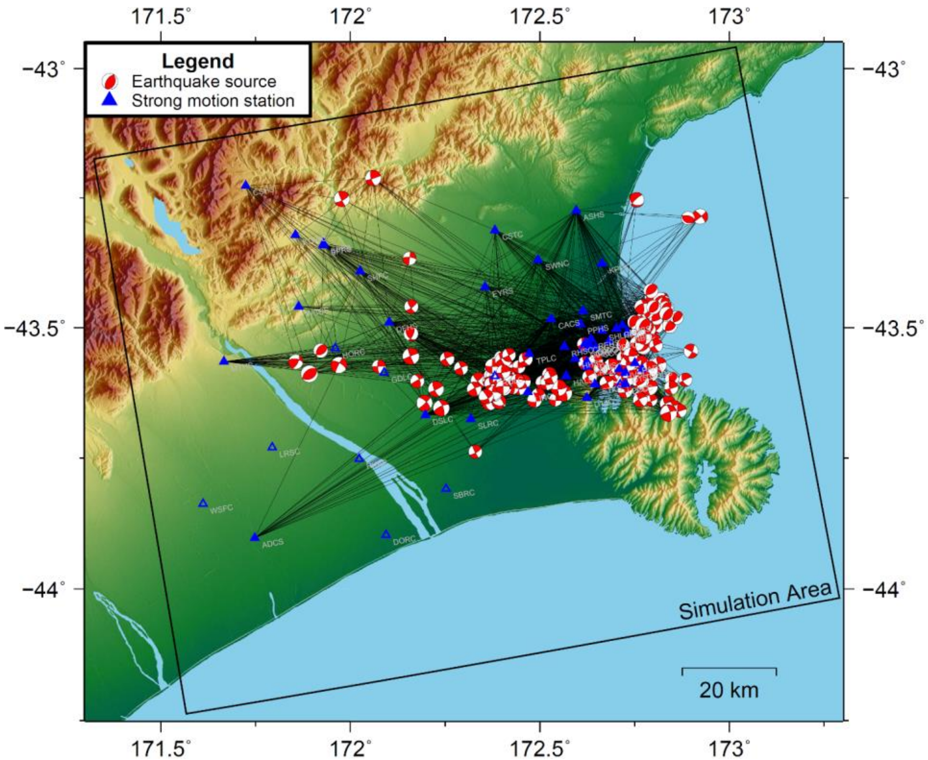
- Small magnitude (Mw 3.5 – 5)
  - Large amount data
  - Point source assumption
  - Linear
  - Less uncertainties



Data set

- Small magnitude
  (Mw 3.5 – 5)
  - Large amount data
  - Point source assumption
  - Linear
  - Less uncertainties

- Canterbury Data
  - Stepping stone to NZ wide
  - Manageable data set
  - Previous research (NZVM)

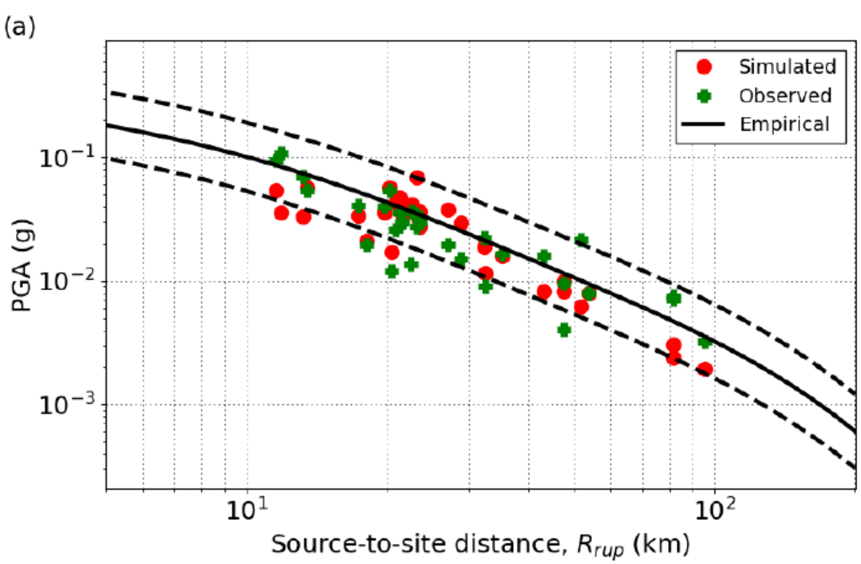


Previous work

Lee et al. (2018)

Validation of GM Sim w/o Modelling Uncertainty

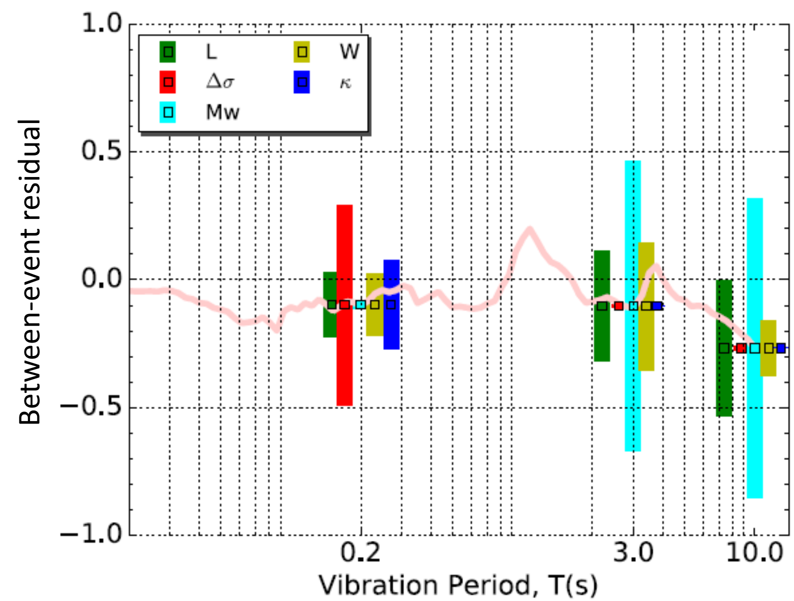
- Median input parameters for validation
- Small and large magnitude events
- Comparisons w/ GMPEs
- Residual analysis



Razafindrakoto et al. (2017)

Pilot Study on Source Modelling Sensitivity

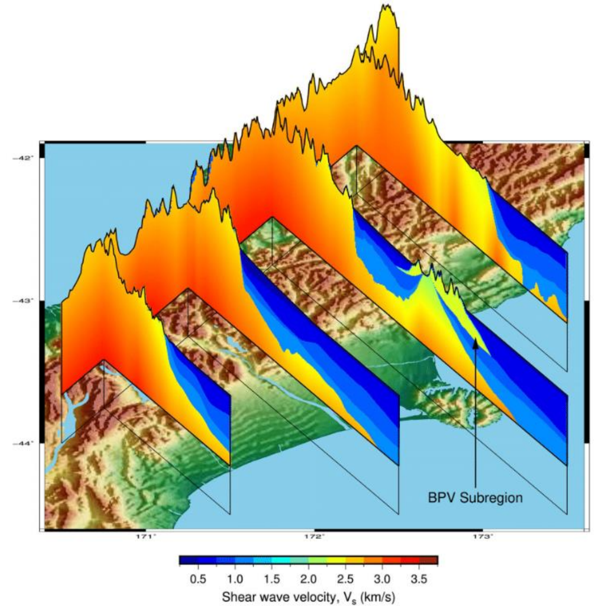
- February 22 & September 4 events
- Perturbations to Mw, A, Ti, Δσ, κ
- Mw and Δσ dominant for between event residuals



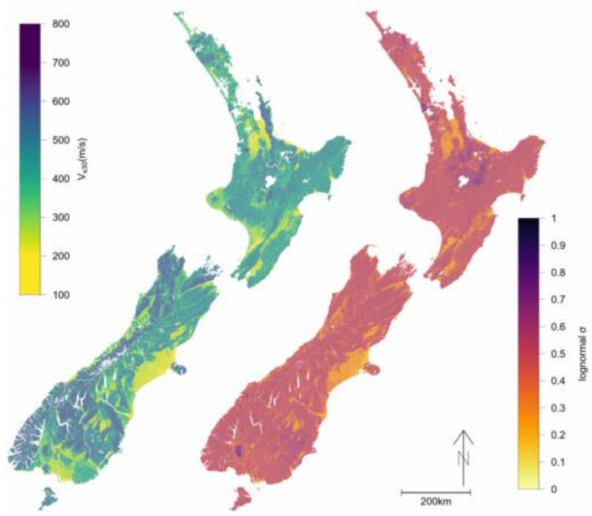
Simulation method

- Previously used for developing median simulations

- Graves and Pitarka hybrid method
- LF comprehensive physics,
- HF simplified physics
- NZVM
- HF empirical Vs30 based site amp.



Thomson (2019)



Foster (2019)

Simulation method

- Previously used for developing median simulations

- Graves and Pitarka hybrid method
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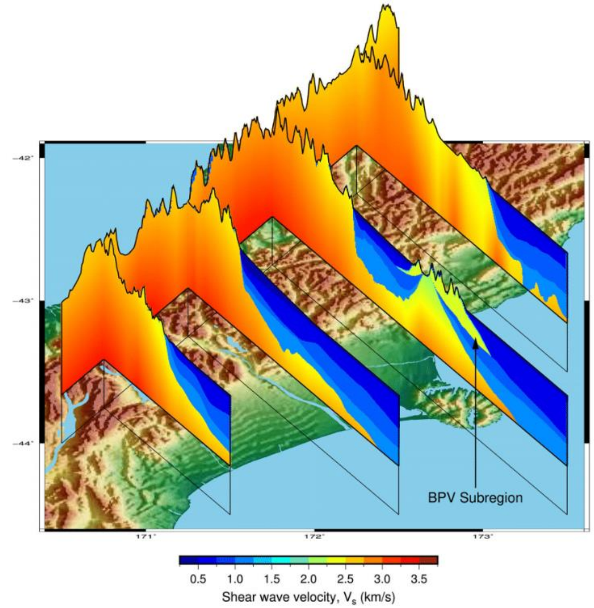
- The focus is σ
- Uncertainty description
- Results Interpretation



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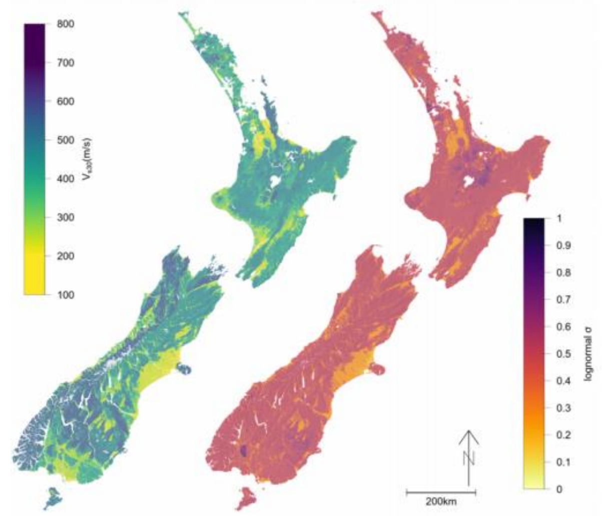
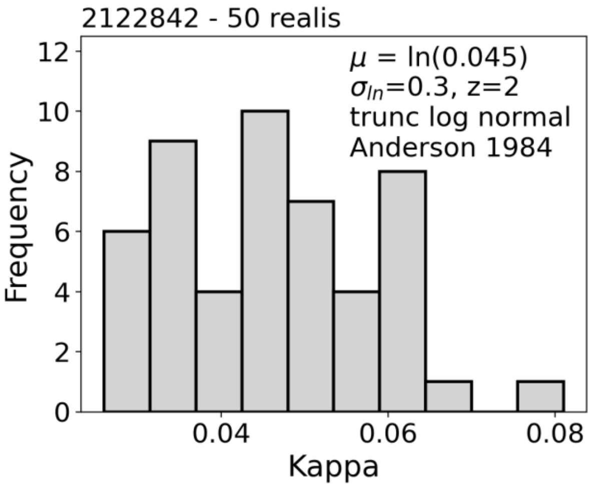


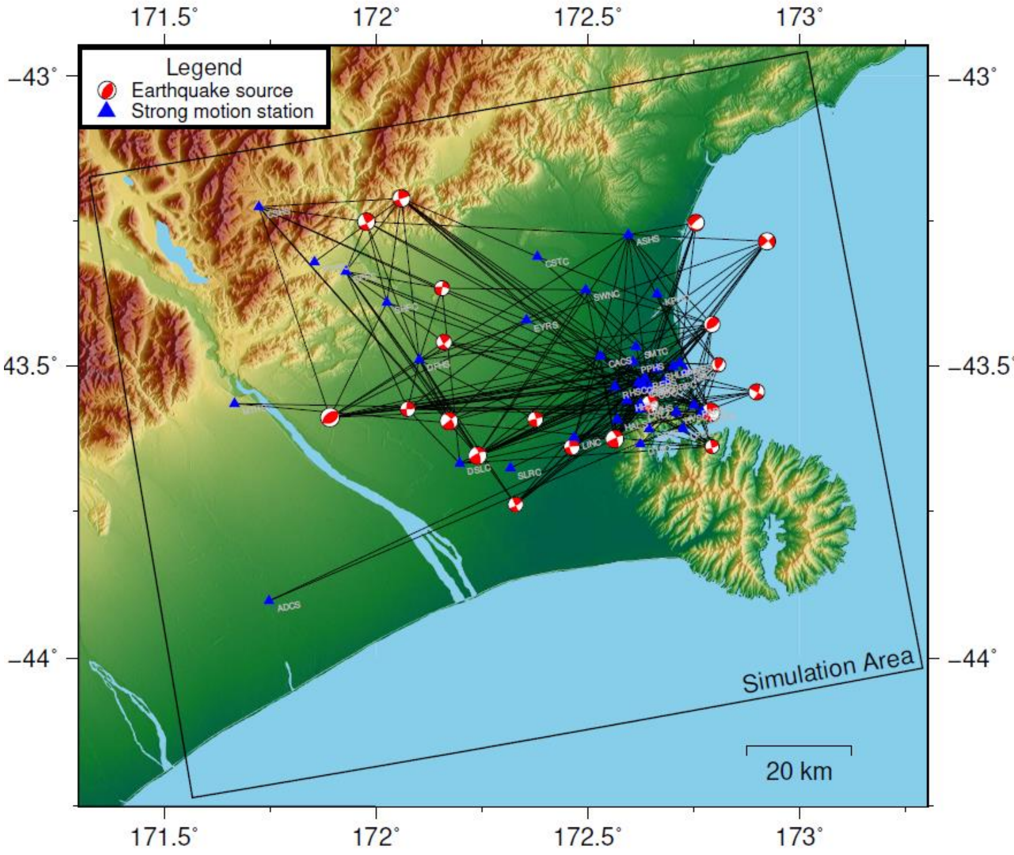
Foster (2019)

Uncertainty Description

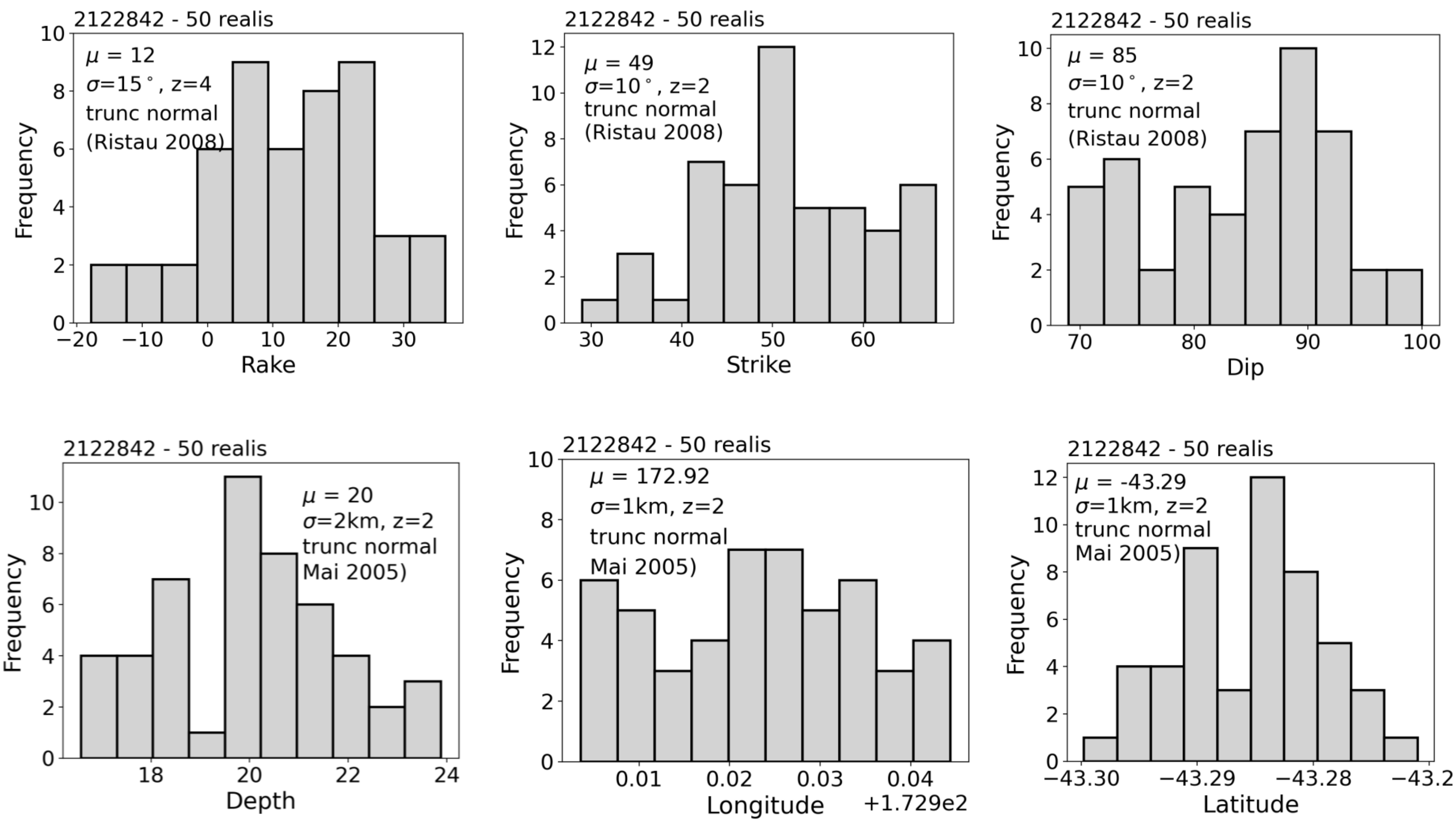
Uncertainty Description:

- 20 events (from 148)
- 39 sites
- 50 realisations
- 14 uncertainties





Uncertainty Description



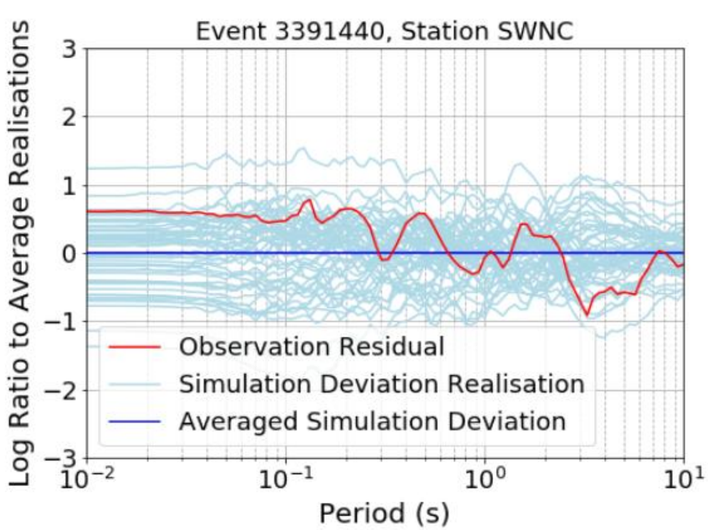
Uncertainty Description

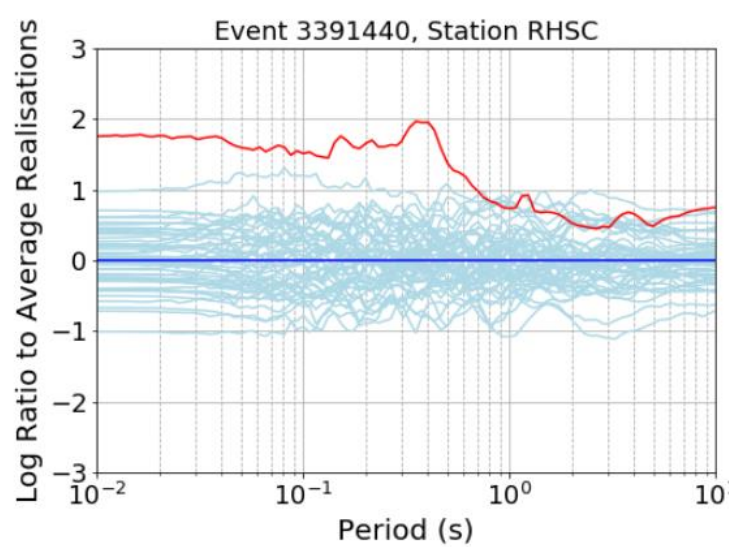
Parameter	Prior Distribution		Reference
Source - Low Frequency: Shear wave velocity (Vs)	Truncated log-normal	σ = 0.05, z = 4	(Graves et al. 2010)
Path - Low Frequency: Anelastic attenuation (Qs)	Truncated log-normal	σ = 0.3, z = 2.5	(Taborda2014)
Path - High Frequency: Anelastic attenuation (qs)	Truncated log-normal	σ = 0.3, z = 2.5	(Ou 1990)
Site - High Frequency: Vs30	Truncated log-normal	σ = varies, z = 2	(Foster el al.)

Results Interpretation Method

- No 1:1 comparison between obs and sim
- Call for a new method!

- New method being tested
- Assess systematic effects
- Computes and compares variance components
- To derive simulation σ





Results Interpretation Method

Variance of observations relative to mean simulation

$$\Delta_{obs} = ln\, IM_{obs} - \mu_{lnIM_{sim}}$$

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τ^2 $\phi_{S2S}{}^2$ $\sigma_{SS}{}^2$

Results Interpretation Method

Partitioning of simulation variance

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$$Var[\Delta_{sim}] = \frac{\sum_k \left(\Delta_{sim_k} - \mu\Delta_{sim_k}\right)^2}{n-1}$$

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Results Interpretation Method

Partitioning of simulation variance

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$$Var[\Delta_{sim}] = V_e + V_s + V_\varepsilon$$

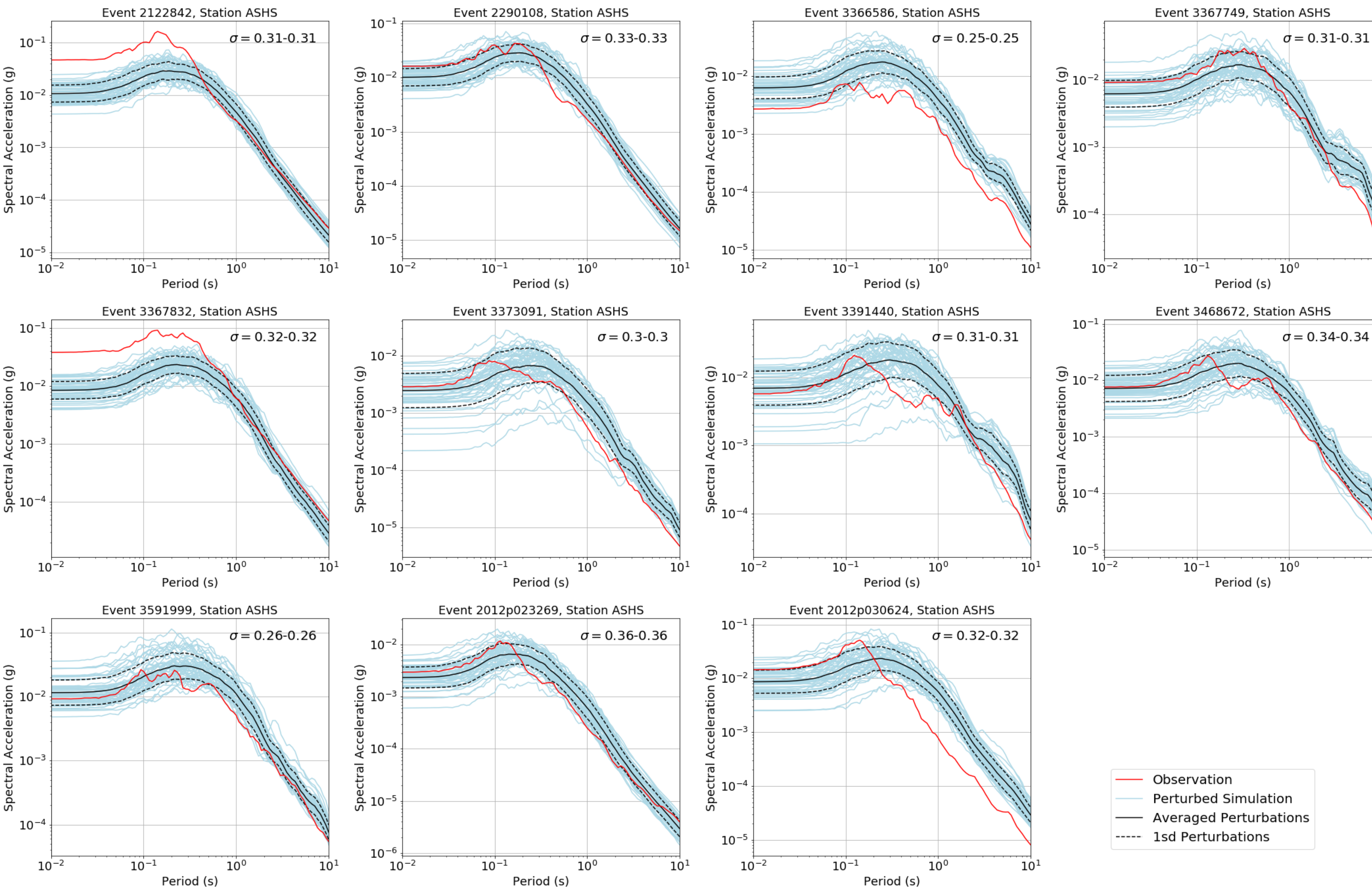
$$Var[\Delta_{sim}] = V_e + V_s + V_\varepsilon = (a_e + \delta_e) + (a_s + \delta_s) + (a_\varepsilon + \delta_\varepsilon)$$

Results Interpretation Method

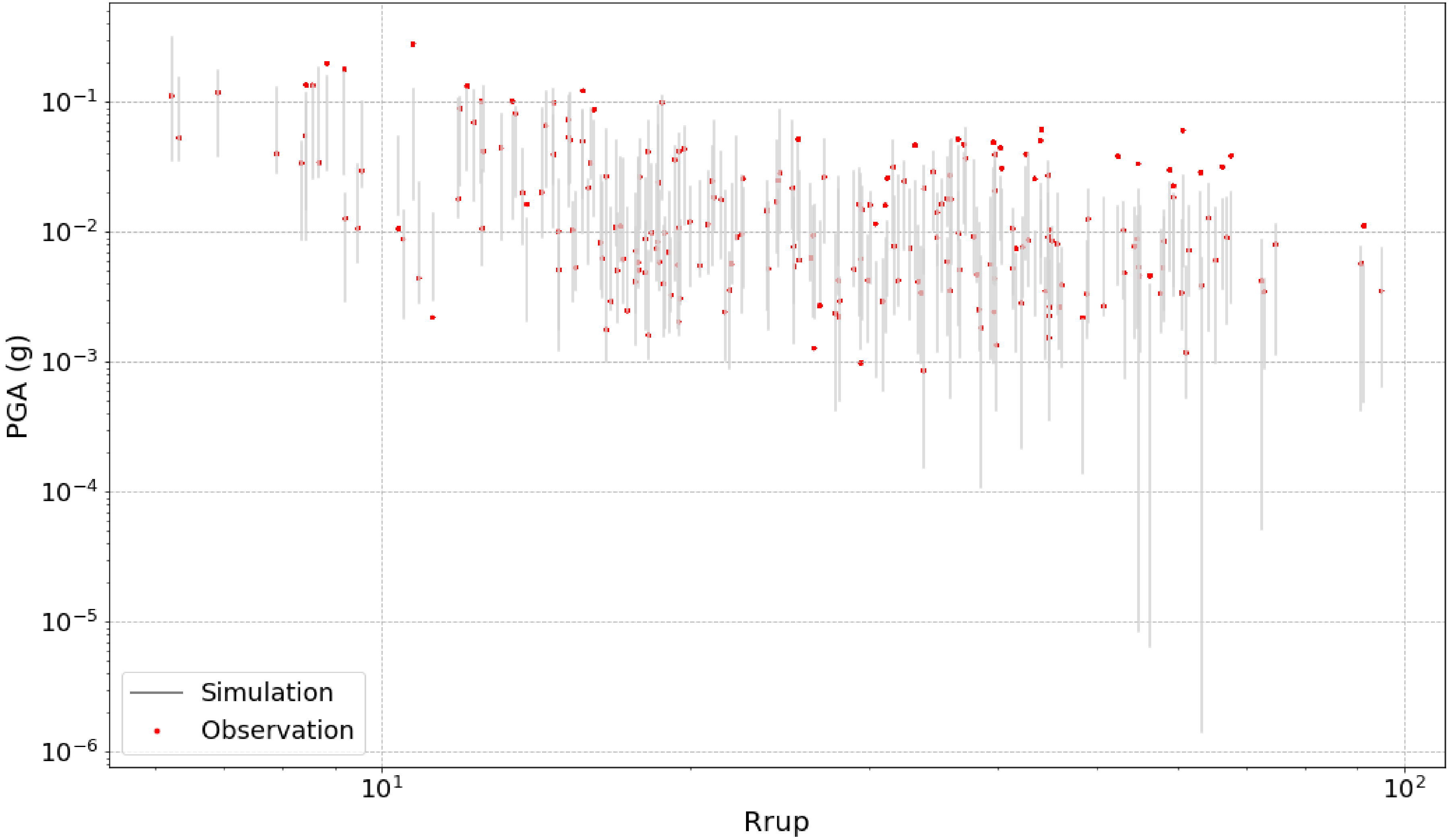
Comparison of obs & sim variance partitioning

Obs		*Sim*
τ^2	with	V_e
ϕ_{S2S}^2	with	V_s
σ_{SS}^2	with	V_ϵ

Results and discussion

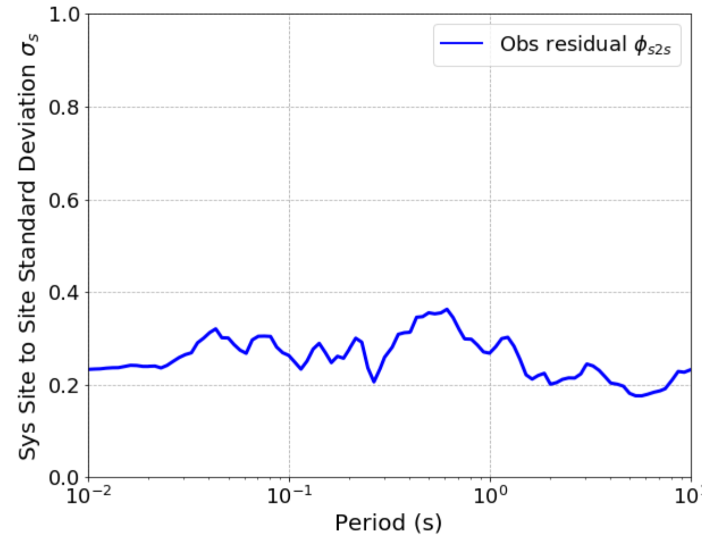


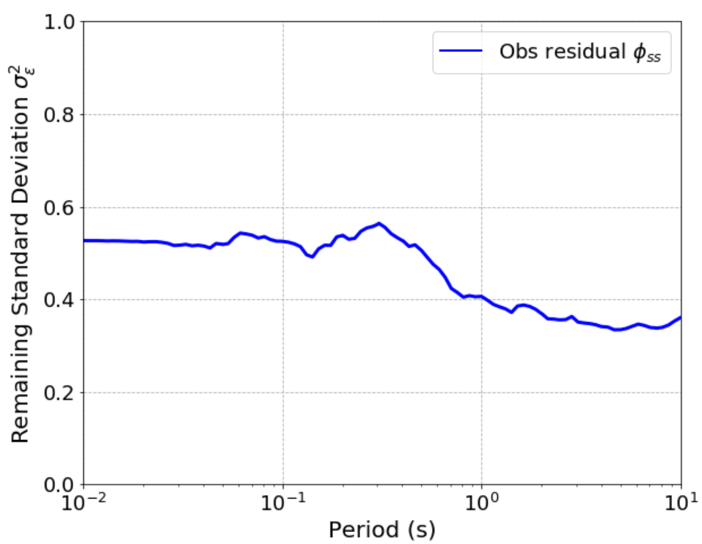
Results and discussion

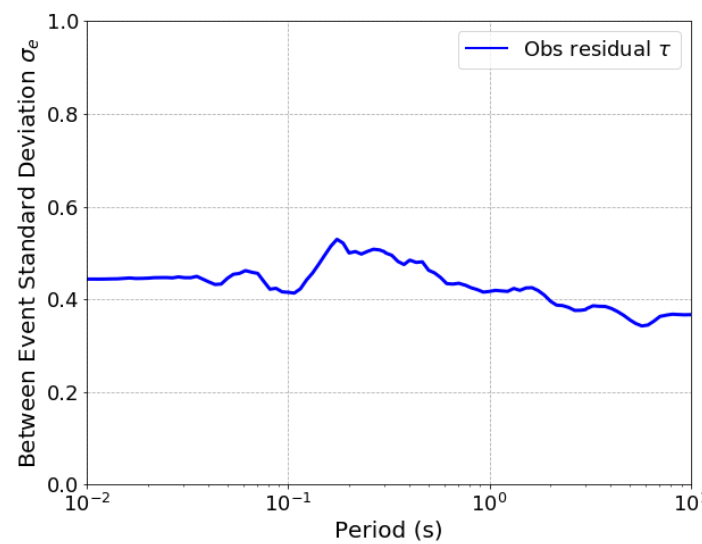


Results and discussion

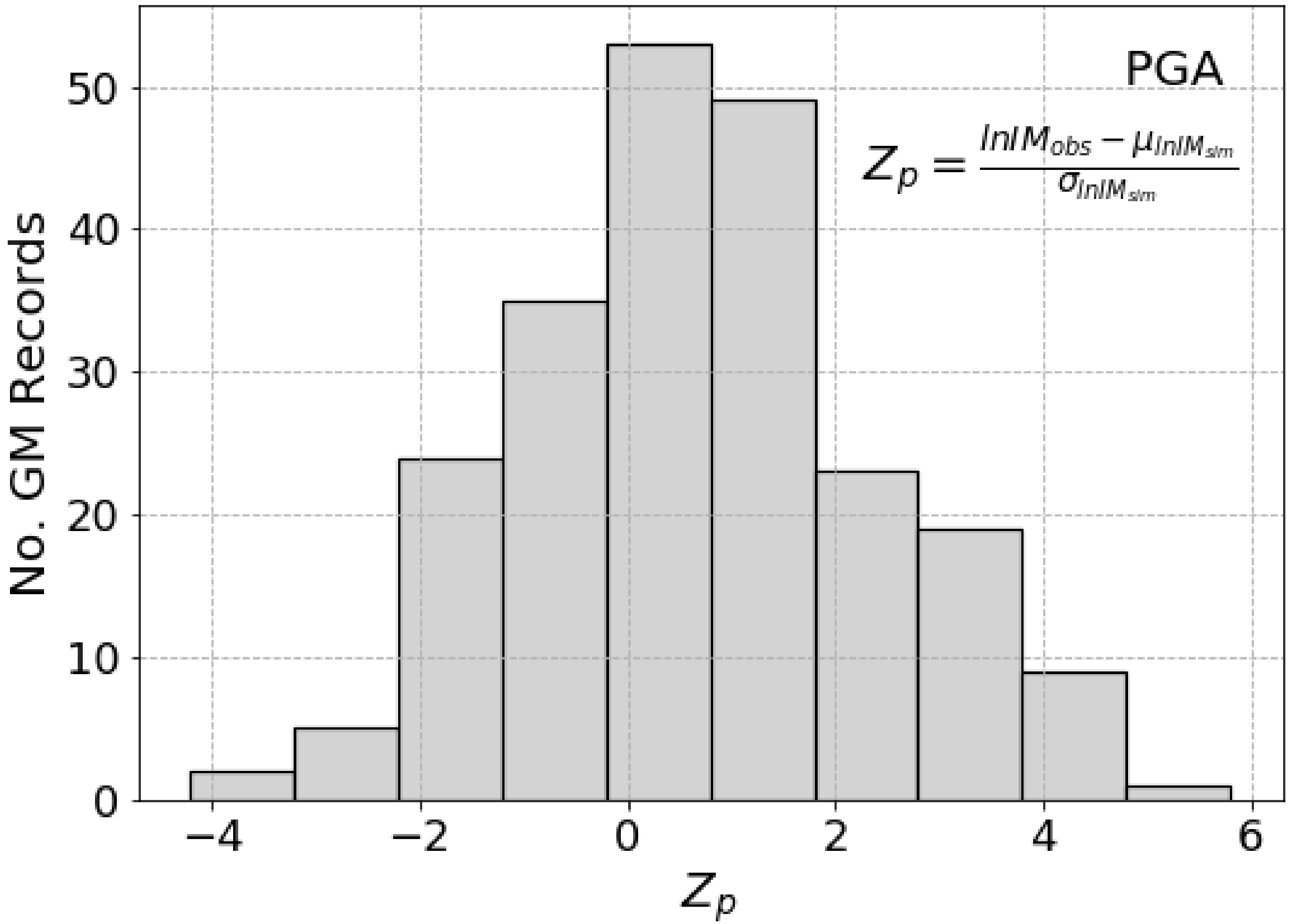
- σ of decomposition of observation residuals
- Compare with sim equivalent (V_x)
- Acceptability criteria







Results and discussion



Future work

More uncertainties needed

- Path duration
- kappa site dependency

Comparison with GMPEs

NZ wide small Mw validation

NZ wide moderate Mw (5-7) validation

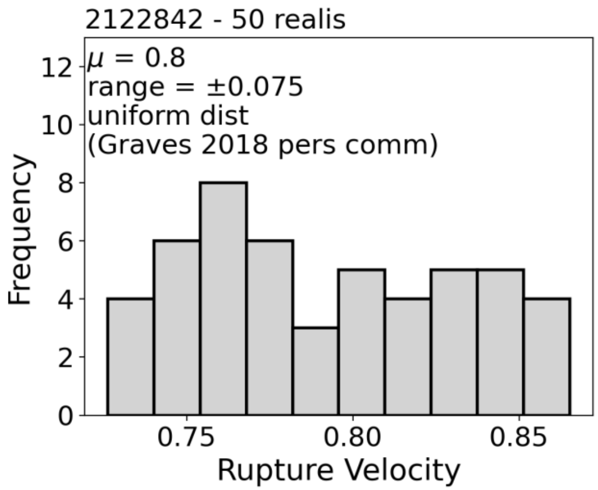
- With additional uncertainties for finite fault

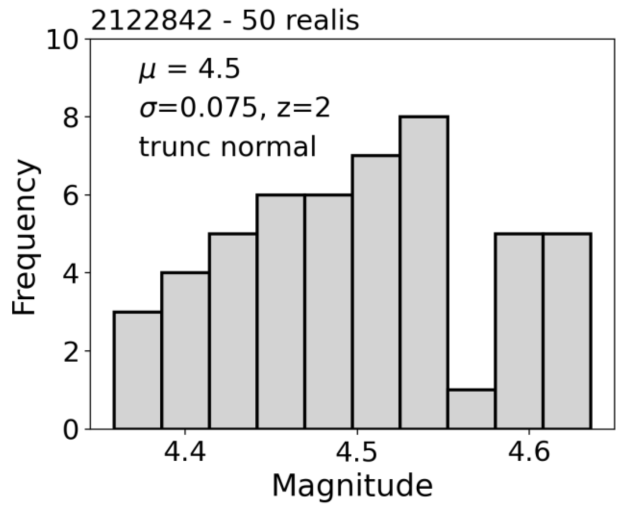
Te Hiranga Rū | QuakeCoRE
Aotearoa New Zealand Centre for Earthquake Resilience

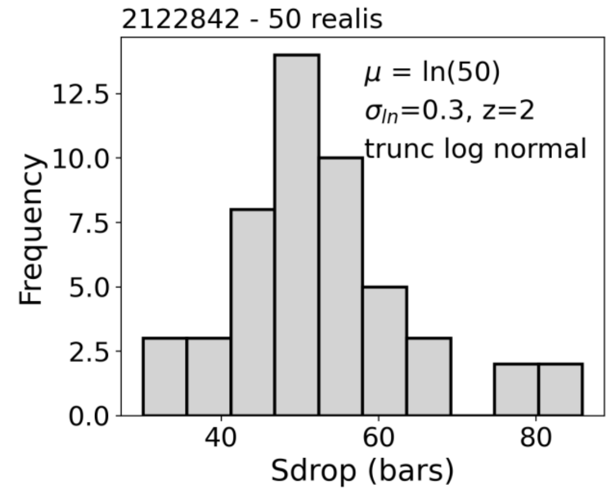
UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

Thank you

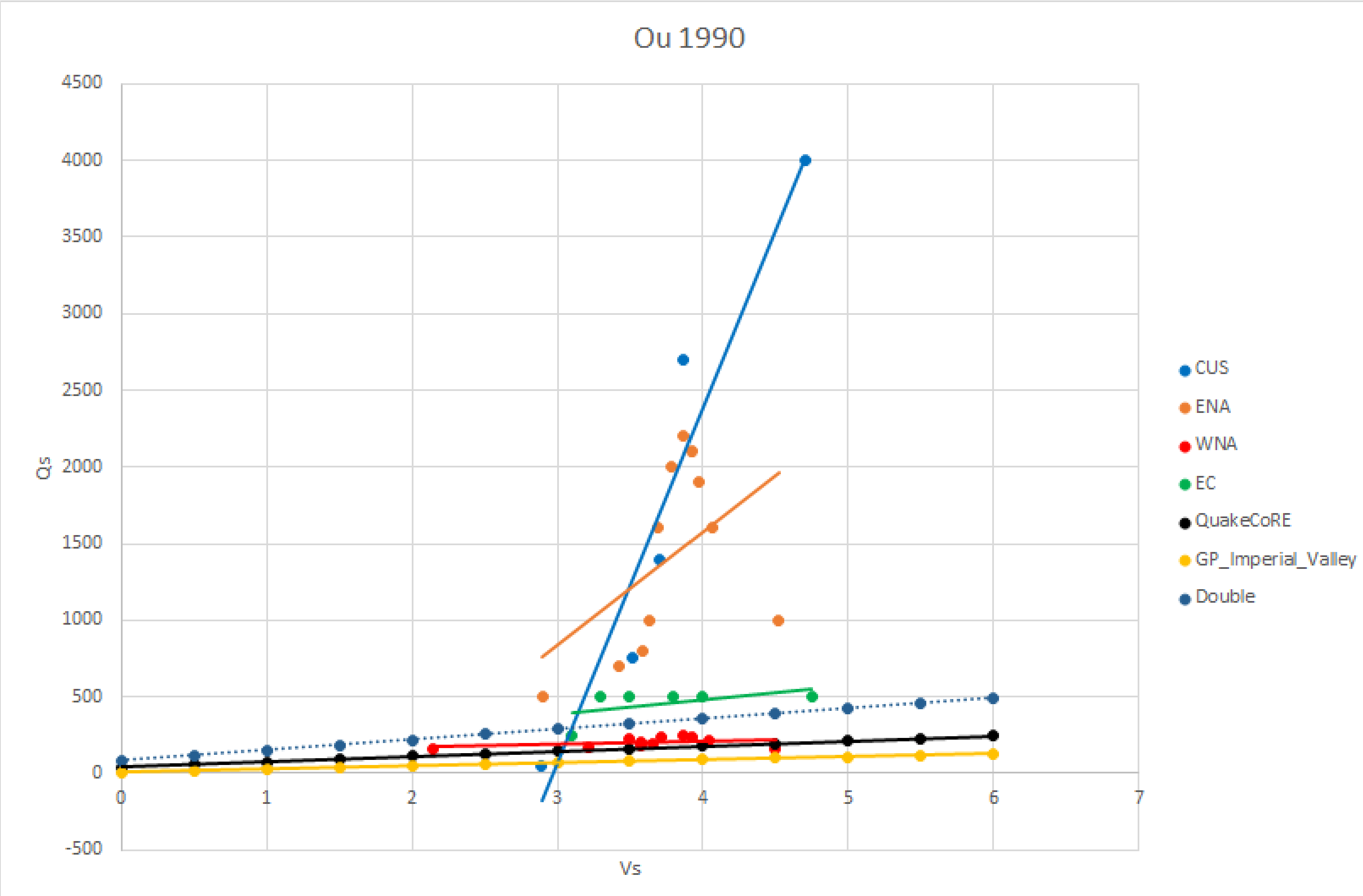
Uncertainty Description





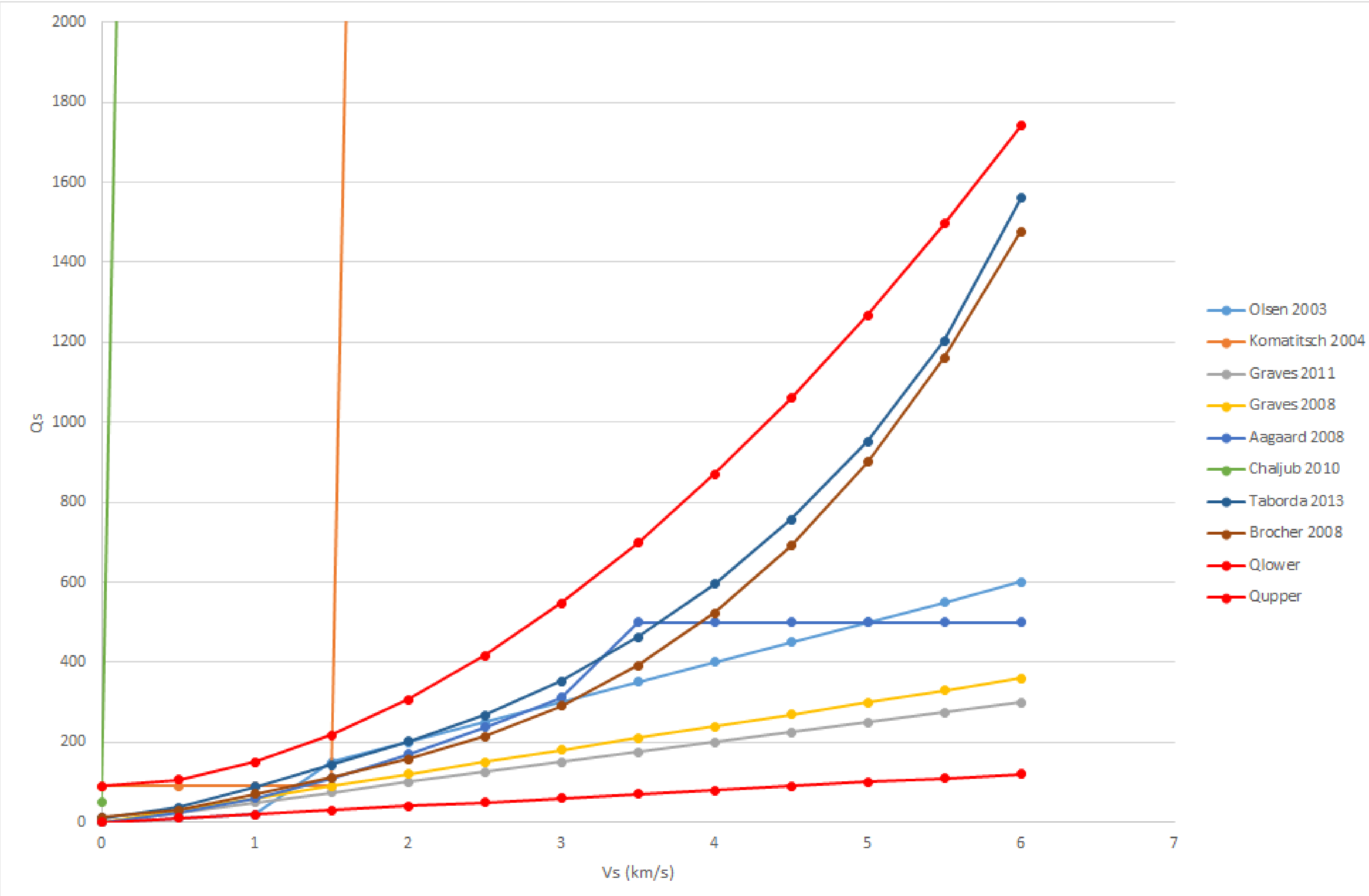


Results - Qs



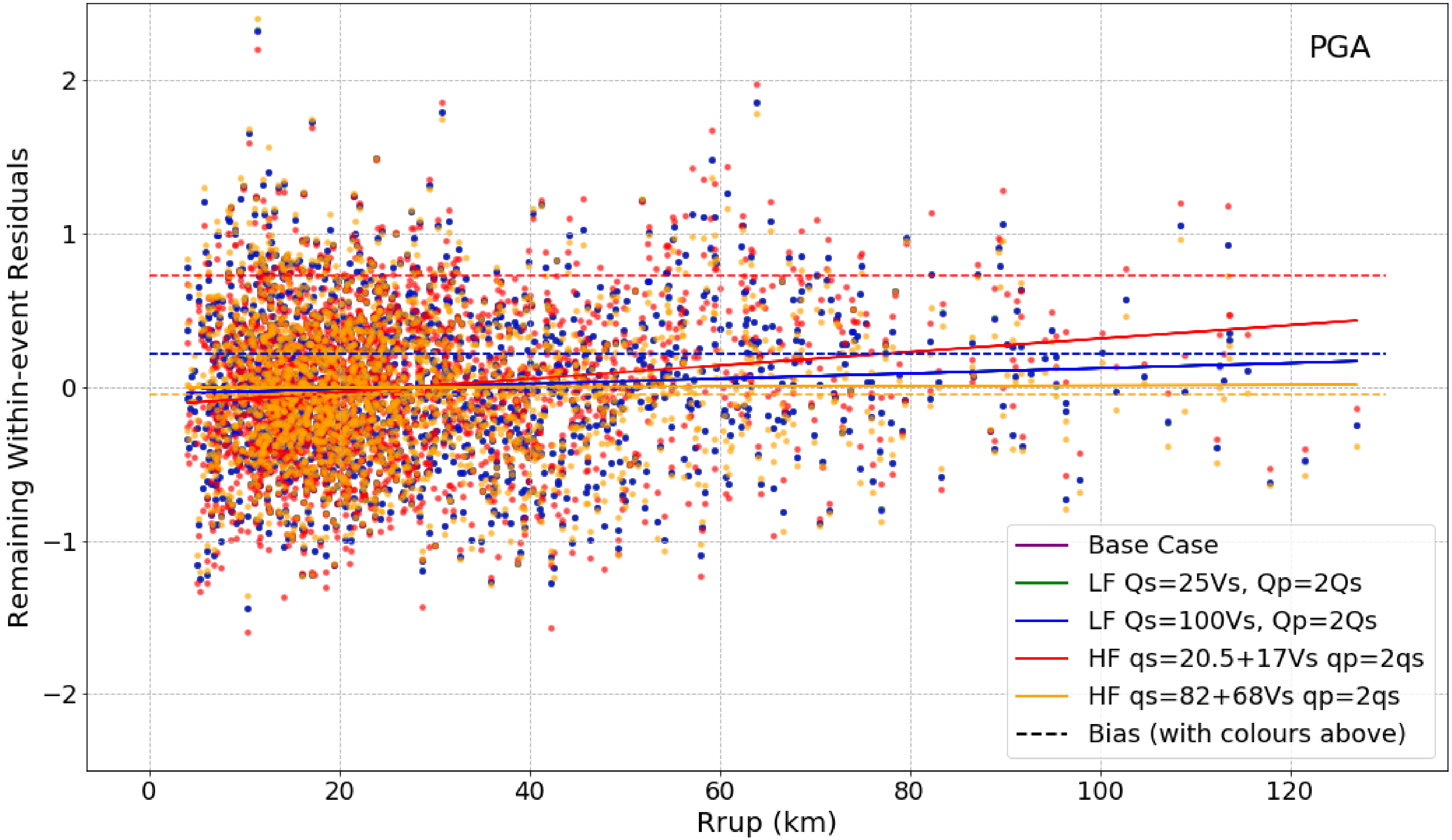
Ou 1990
4500
4000
3500
3000
2500
2000
1500
1000
500
0
-500
Qs
0
1
2
3
4
5
6
7
Vs
CUS
ENA
WNA
EC
QuakeCoRE
GP_Imperial_Valley
Double

Results - Qs

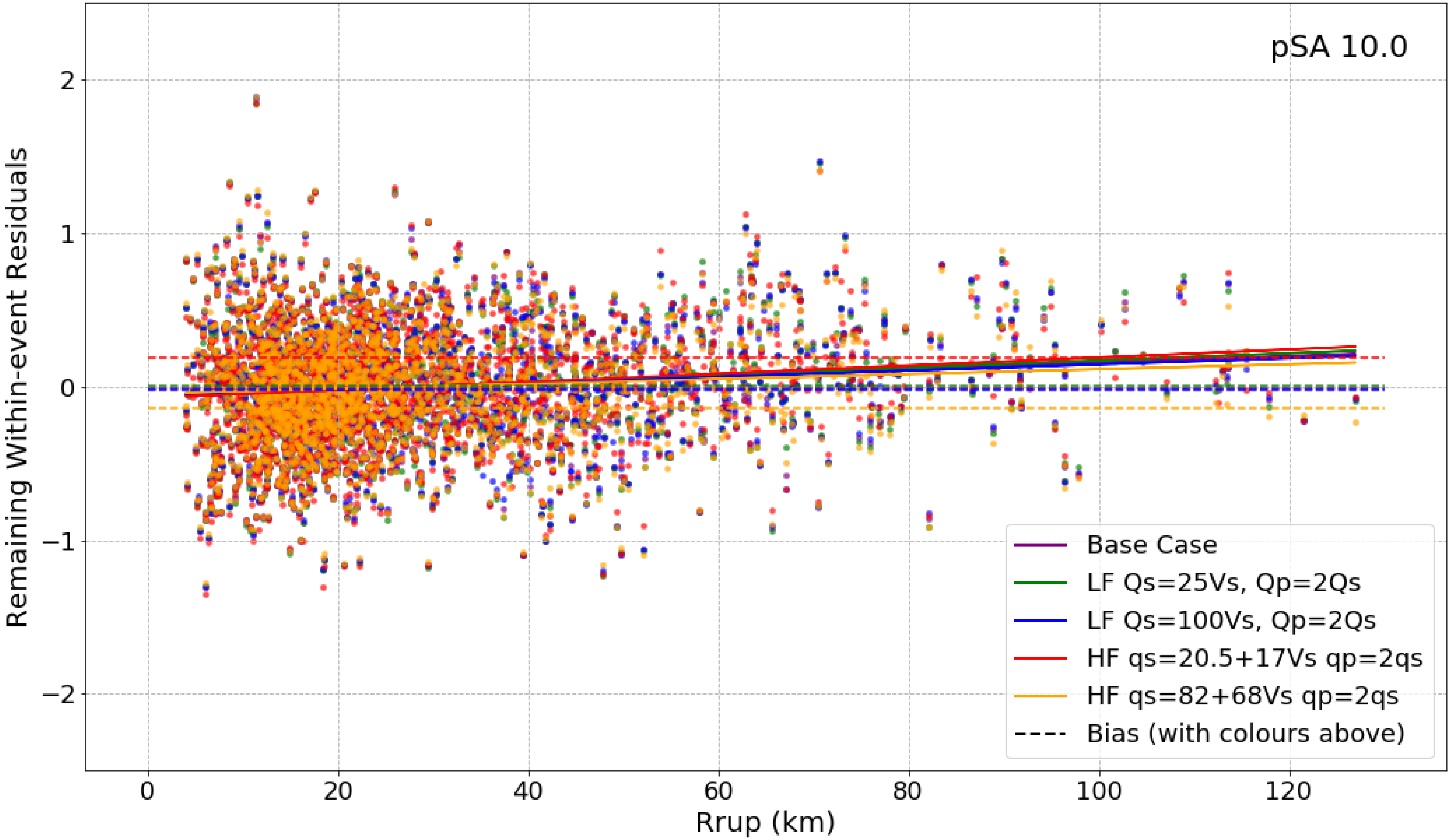


2000
1800
1600
1400
1200
1000
800
600
400
200
0
Qs
0
1
2
3
4
5
6
7
Vs (km/s)
Olsen 2003
Komatitsch 2004
Graves 2011
Graves 2008
Aagaard 2008
Chaljub 2010
Taborda 2013
Brocher 2008
Qlower
Qupper

Results


PGA
Remaining Within-event Residuals
2
1
0
−1
−2
0
20
40
60
80
100
120
Rrup (km)
Base Case
LF Qs=25Vs, Qp=2Qs
LF Qs=100Vs, Qp=2Qs
HF qs=20.5+17Vs qp=2qs
HF qs=82+68Vs qp=2qs
Bias (with colours above)

Results


pSA 10.0
Remaining Within-event Residuals
Rrup (km)
2
1
0
−1
−2
0
20
40
60
80
100
120
Base Case
LF Qs=25Vs, Qp=2Qs
LF Qs=100Vs, Qp=2Qs
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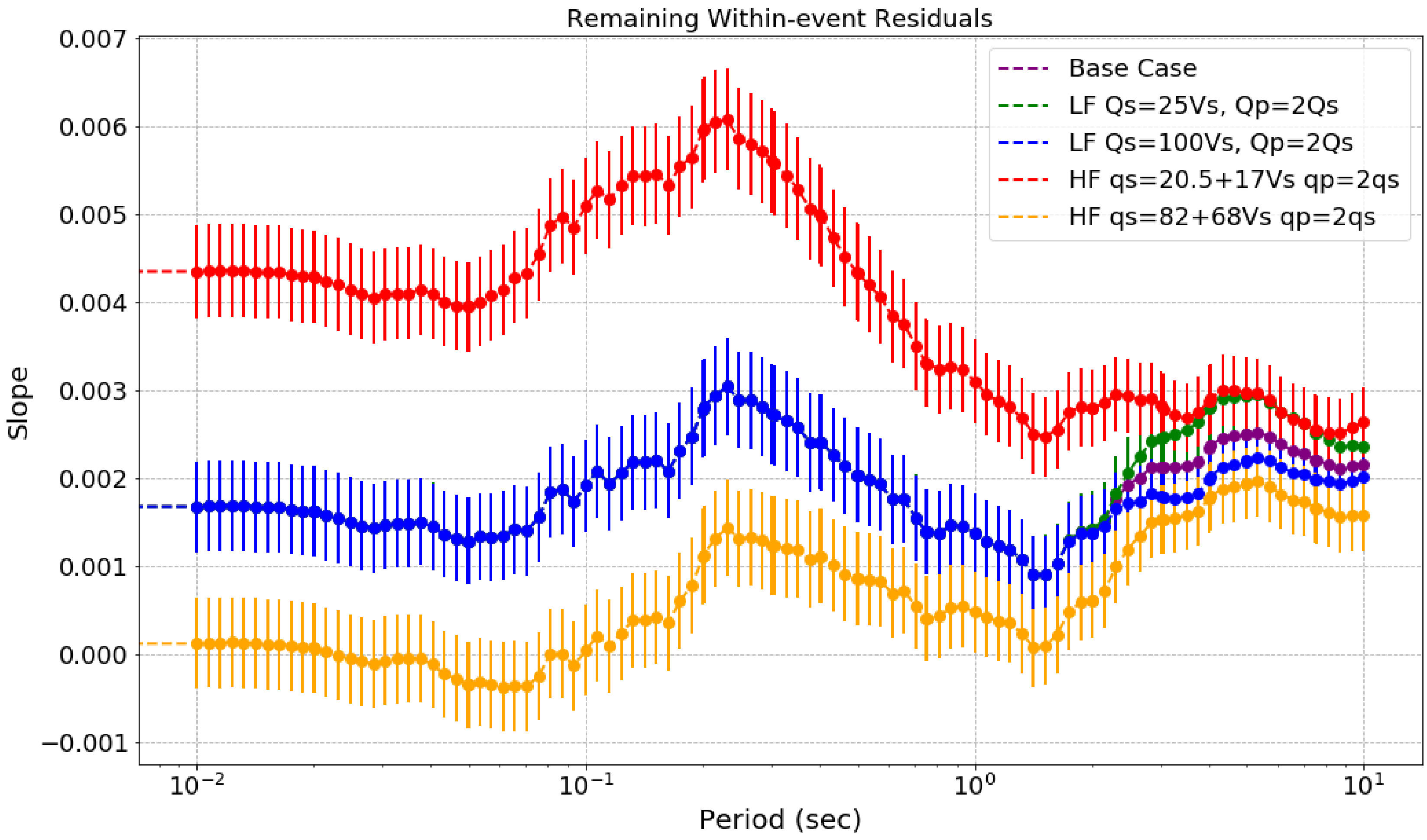
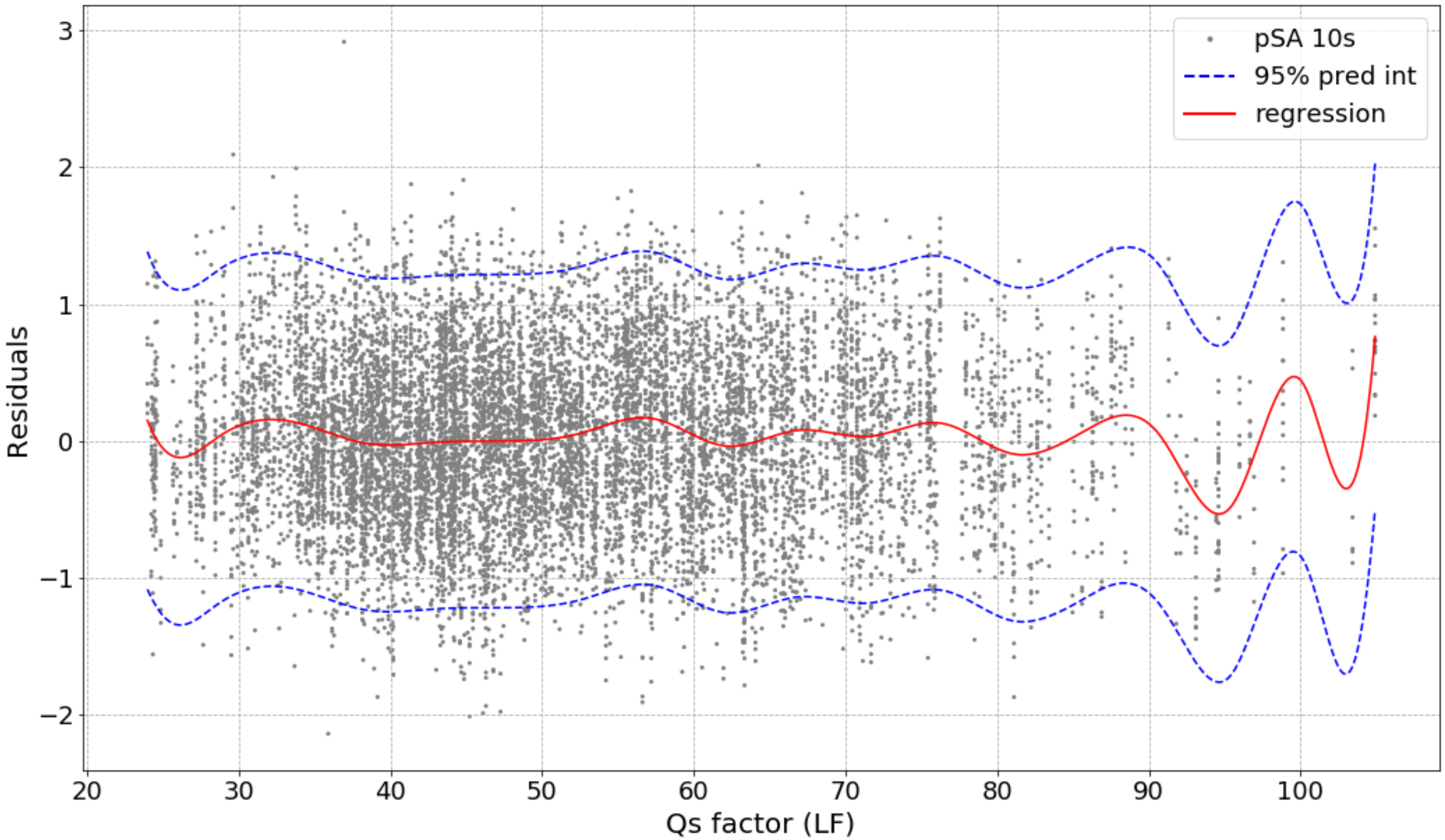
Results

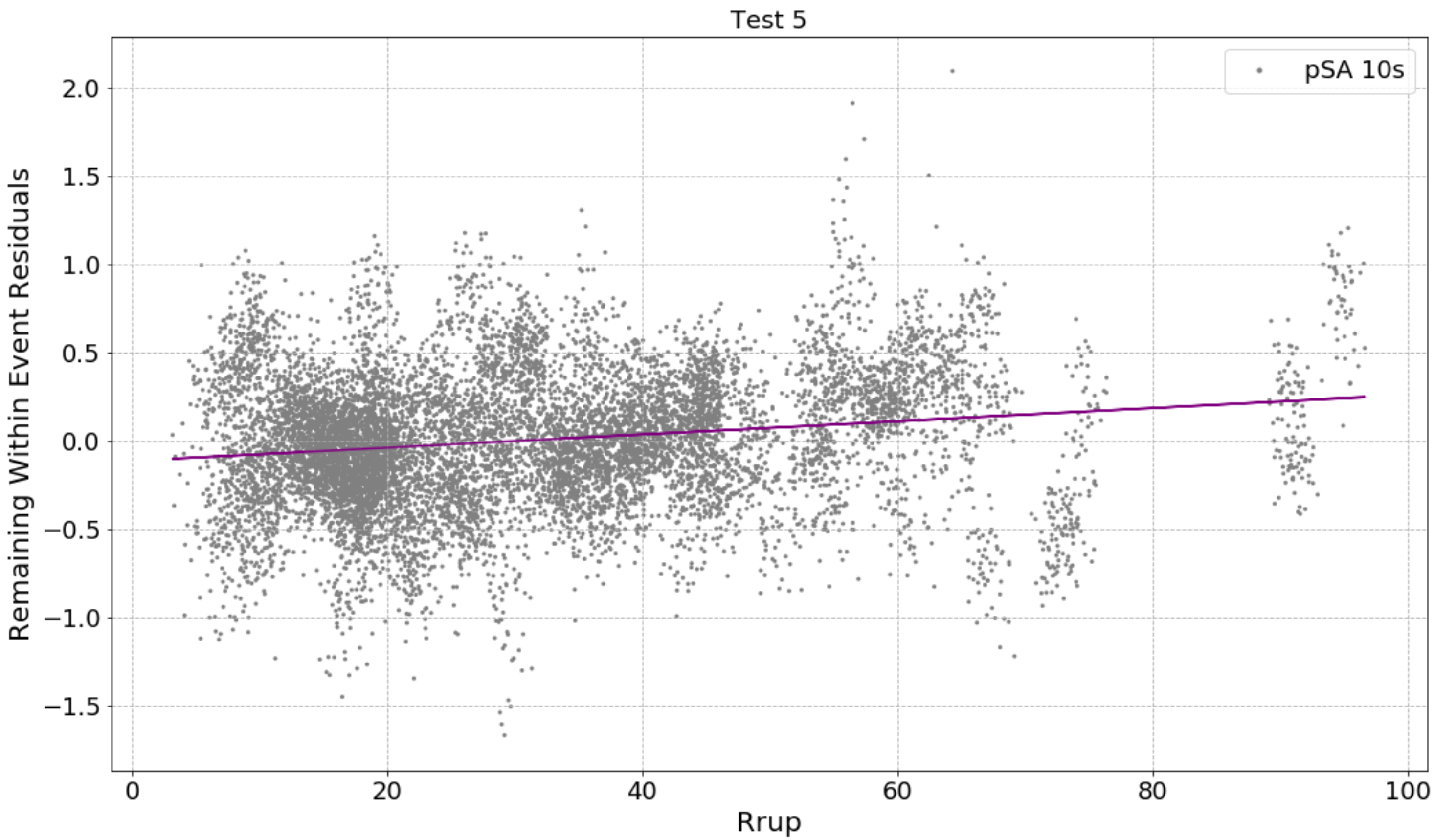


Remaining Within-event Residuals
Base Case
LF Qs=25Vs, Qp=2Qs
LF Qs=100Vs, Qp=2Qs
HF qs=20.5+17Vs qp=2qs
HF qs=82+68Vs qp=2qs
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0.000
−0.001
Slope
10^{-2}
10^{-1}
10^{0}
10^{1}
Period (sec)

Results


pSA 10s
95% pred int
regression
Residuals
Qs factor (LF)
3
2
1
0
−1
−2
20
30
40
50
60
70
80
90
100

Results



Test 5
pSA 10s
Remaining Within Event Residuals
Rrup
2.0
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
0
20
40
60
80
100

Results

- Show some progressive improvements from including Vs30 and Qs (if there is time). Ie different regression results
- Provide some more detail on how mixed effects regression is undertaken (similar style as my 13.07.20 memo to Stafford).

Method

Parameter	Prior Distribution		Reference
Source - Low Frequency:			
Magnitude	Truncated normal	σ = 0.075, z = 2	(Graves 2018)
Hypocentre latitude	Truncated normal	σ = 1km, z = 2	(Mai et al. 2005)
Hypocentre longitude	Truncated normal	σ = 1km, z = 2	(Mai et al. 2005)
Hypocentre depth	Truncated normal	σ = 2km, z = 2	(Mai et al. 2005)
Strike	Truncated normal	σ = 10°, z = 2	(Ristau 2008)
Dip	Truncated normal	σ = 10°, z = 2	(Ristau 2008)
Rake	Truncated normal	σ = 15°, z = 4	(Graves et al. 2010)
Shear wave velocity (Vs)	Truncated log-normal	σ = 0.05, z = 4	
Source - High Frequency:			
Rupture Velocity	Uniform	μ = 0.8, range = ± 0.075	(Graves 2018)
Brunes stress parameter	Truncated log-normal	μ = 50, σ = 0.3, z = 2	
Kappa*	Truncated log-normal	μ = 0.045, σ = 0.3, z = 2	(Anderson et al. 1984)
Path - Low Frequency:			
Anelastic attenuation (Qs)	Truncated log-normal	σ = 0.3, z = 2.5	(Taborda2014)
Path - High Frequency:			
Anelastic attenuation (qs)	Truncated log-normal	σ = 0.3, z = 2.5	(Ou 1990)
Site - High Frequency:			
Vs30	Truncated log-normal	σ = varies, z = 2	(Foster el al.)