UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

QuakeCoRE
NZ Centre for Earthquake Resilience
Te Hiranga Rū

Source Considerations for Moderate Magnitude Earthquake Ground Motion Simulation Validation

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Motivation

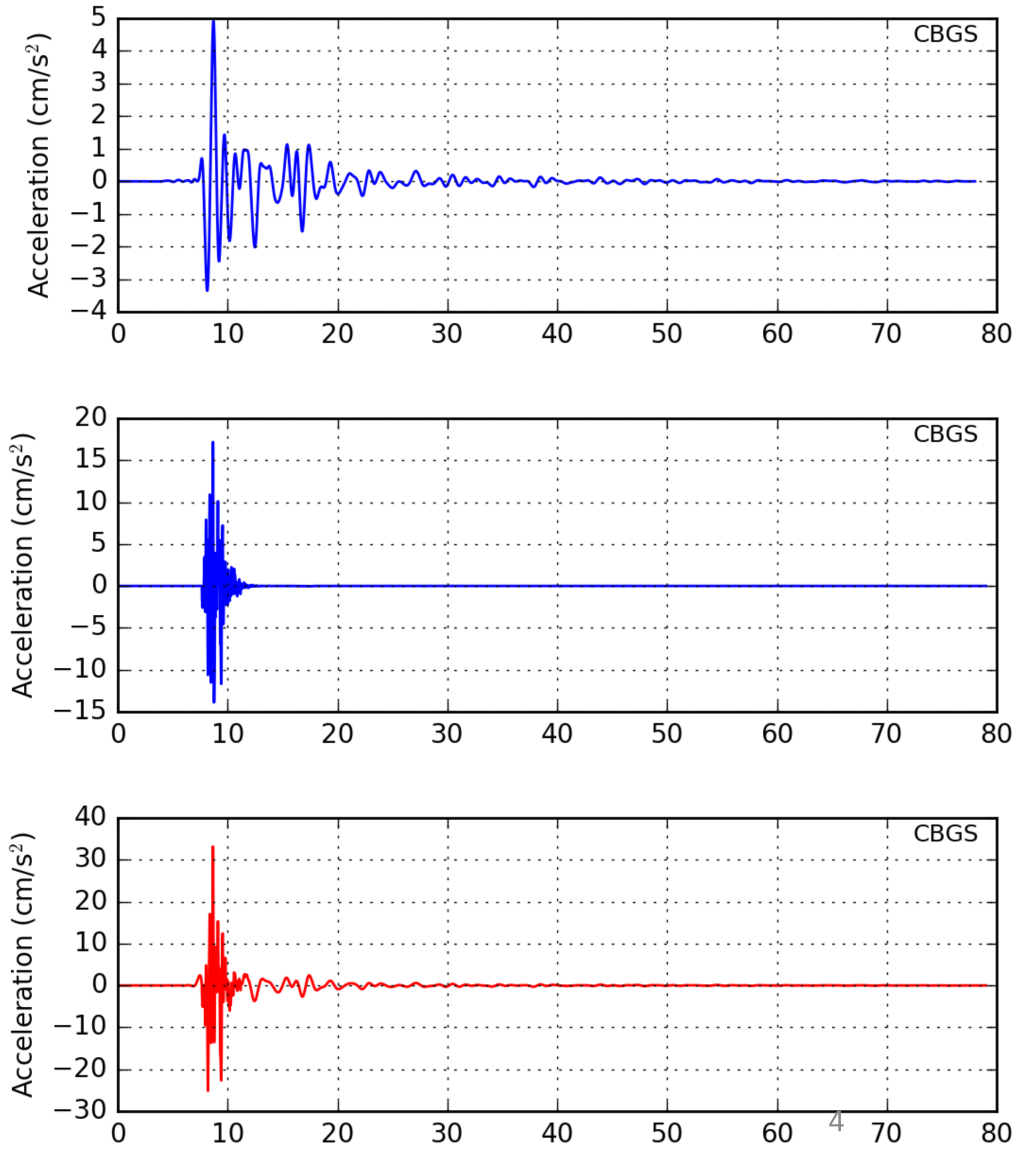
- Ground motion simulation validation allows us to use observations to quantify the predictive capability and infer where improvements can be made.
- Previously focussed on large M_w and small M_w.
- Large M_w studies on Darfield, Christchurch and Kaikōura earthquakes (Razafindrakoto et al. (2018) and Bradley et al. (2017)).
- Small M_w (3.5-5.0) studies for Canterbury and NZ-wide (Lee et al. (2020) and not yet published).
- Moderate (5.0-7.0) M_w currently missing.
- Moving from small to moderate, there are several additional considerations required.

NZ Validation Progression

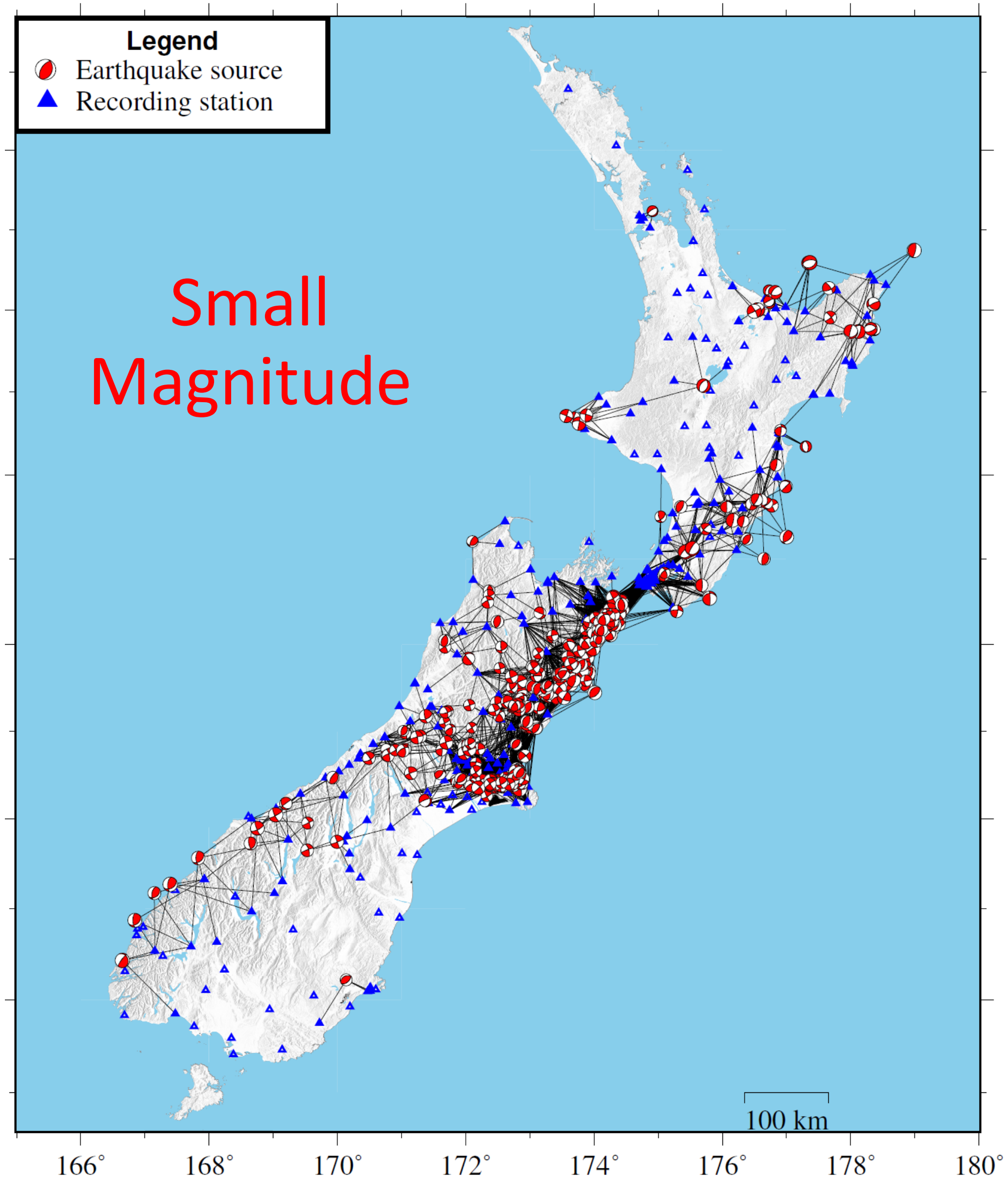
	2015 – 2016	2017 – 2018	2018 – 2019	2020 – ?
Events	M_w 7.1 Darfield M_w 6.2 Christchurch M_w 7.8 Kaikōura	148 Small M_w	498 Small M_w	62 Moderate M_w
Region	Source-specific	Canterbury	New Zealand	“New Zealand”
Velocity Model	NZVM v1.66 (Canterbury Basin only)	NZVM v1.66 (Canterbury Basin only)	NZVM v2.02 (8 sedimentary basins)	NZVM v2.03 (9 sedimentary basins)
Sim Method	Standard Graves and Pitarka (2010,2015)	Standard Graves and Pitarka (2010,2015)	Modified Graves and Pitarka (2010,2015)	Modified Graves and Pitarka (2010,2015,2016)

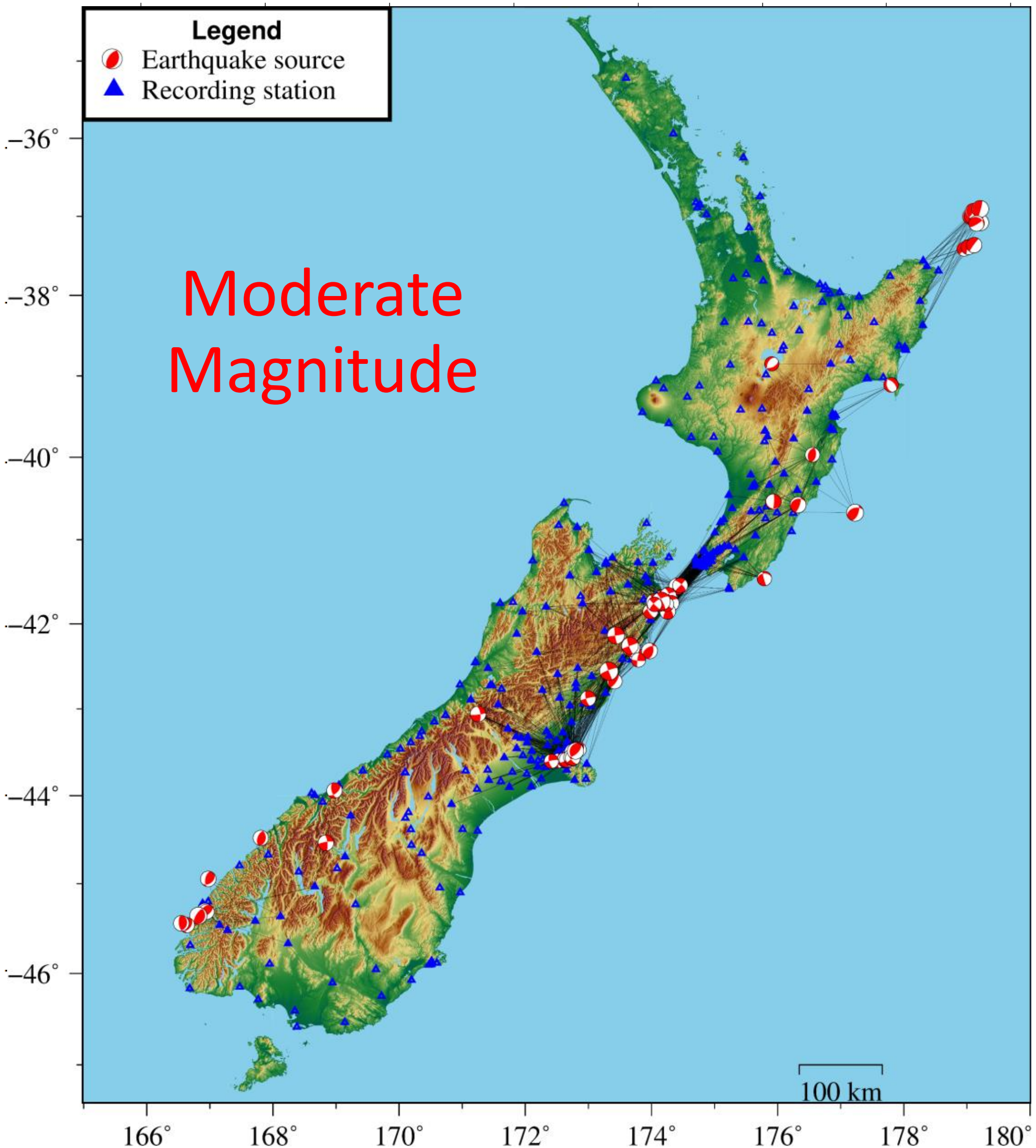
Simulation Methodology

- Widely-used Graves and Pitarka (GP) hybrid approach with modifications.
- Low frequency (LF) component ($f<0.5$Hz) from comprehensive physics-based wave propagation (for 200m finite difference grid spacing).
- High frequency (HF) component ($f>0.5$Hz) from simplified physics-based wave propagation.
- Period-dependent empirical V_{s30}-based site amplification (HF only).
- LF and HF merged to produce broadband (BB) ground motion.



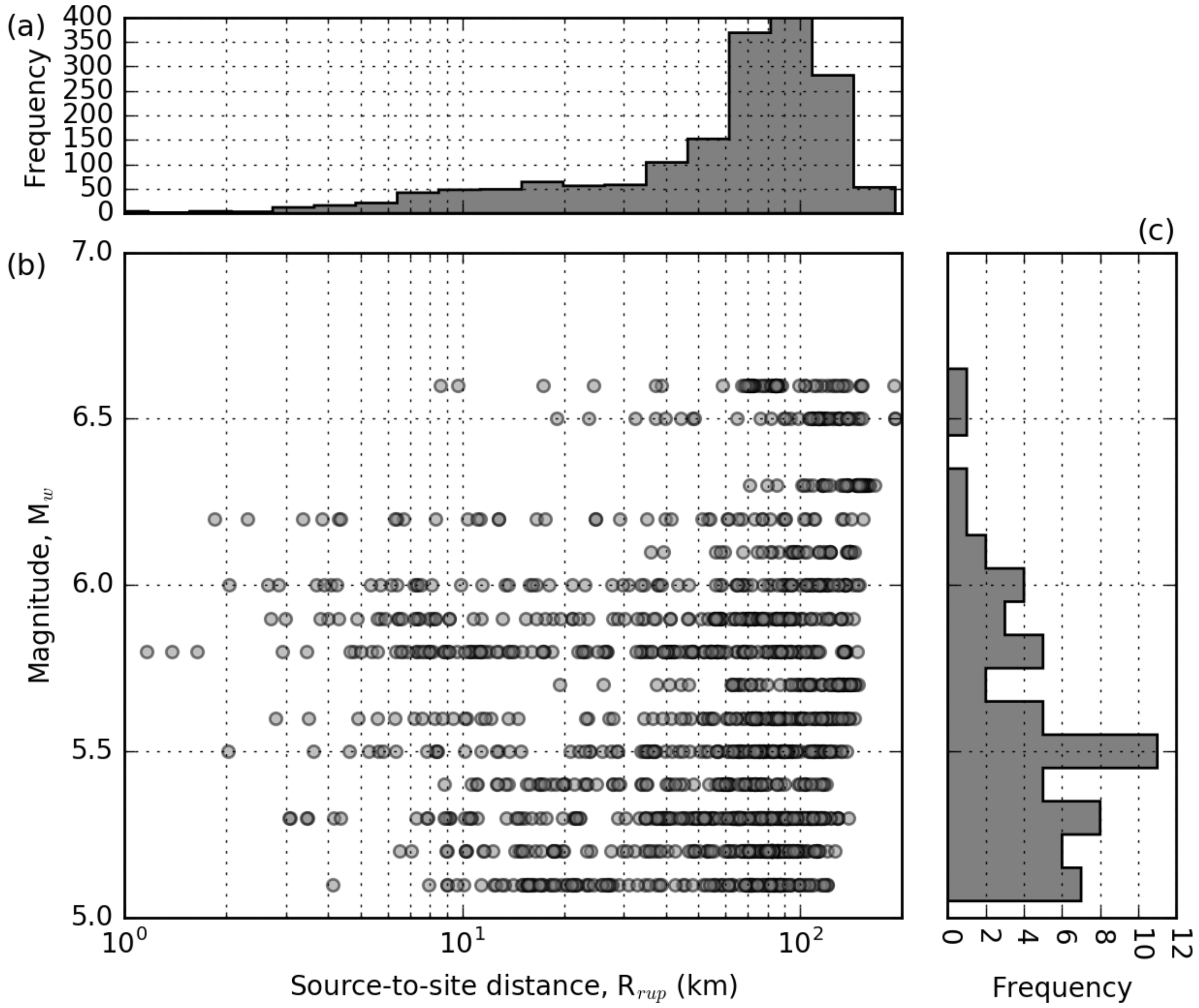
Earthquake Events





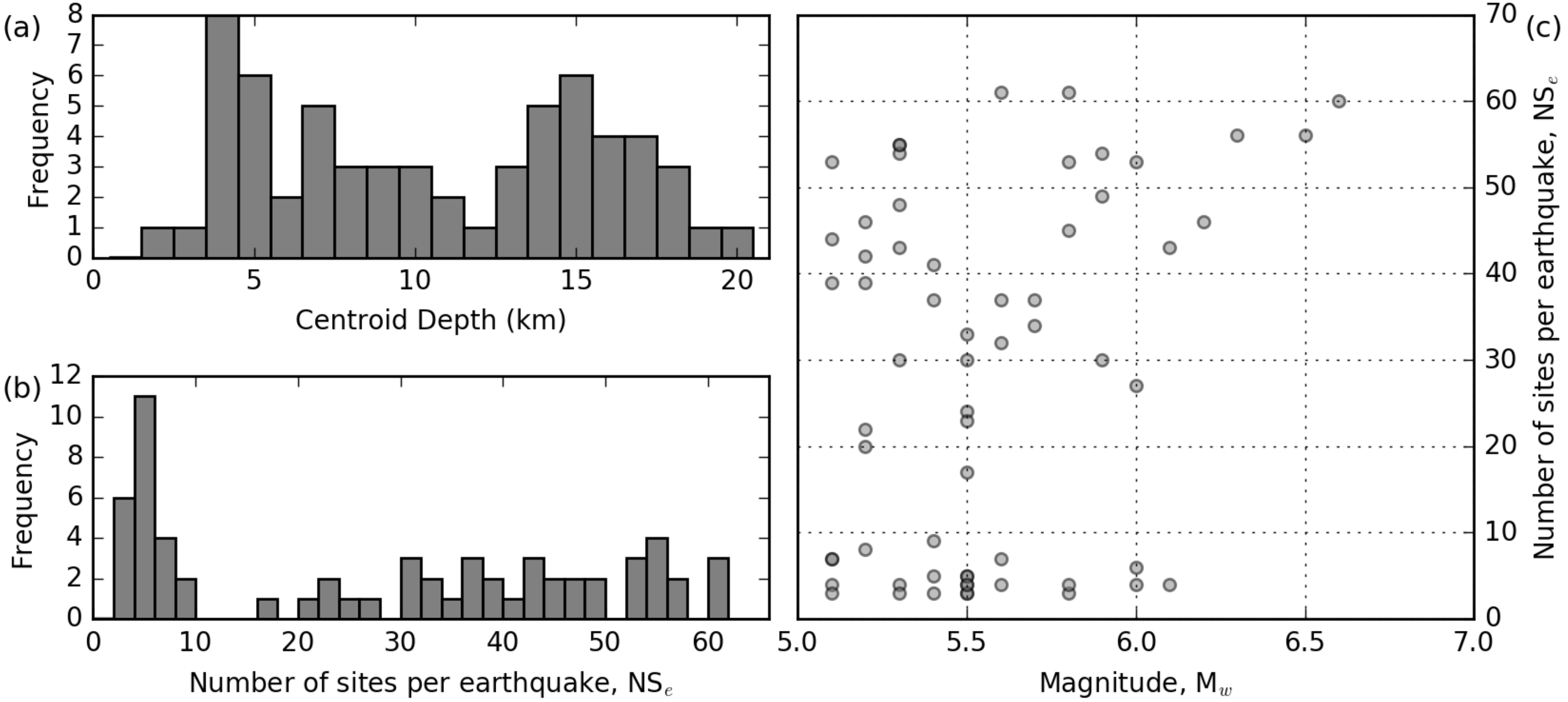
Earthquake Events

- 62 earthquakes.
- 1738 high quality records across 203 stations from an initial set of over 4000.
- Quality of records determined from neural network trained against small M_w earthquakes.
- Enforced 3 HQ records per event and per station.
- Largest is M_w 6.6 which is 2013 Lake Grassmere EQ.



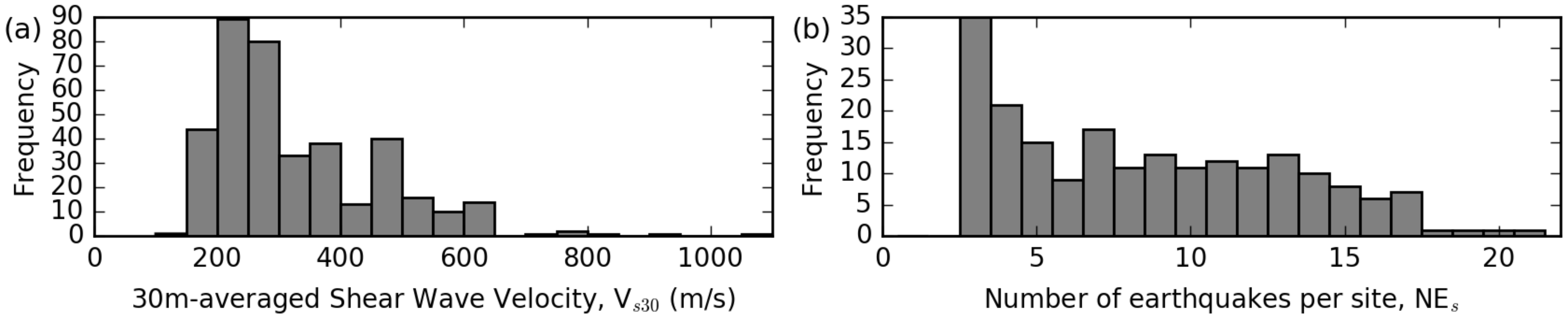
Earthquake Events

- Limited to events with centroid moment tensor solutions with centroid depth ≤ 20km.
- Larger M_w on average more records.

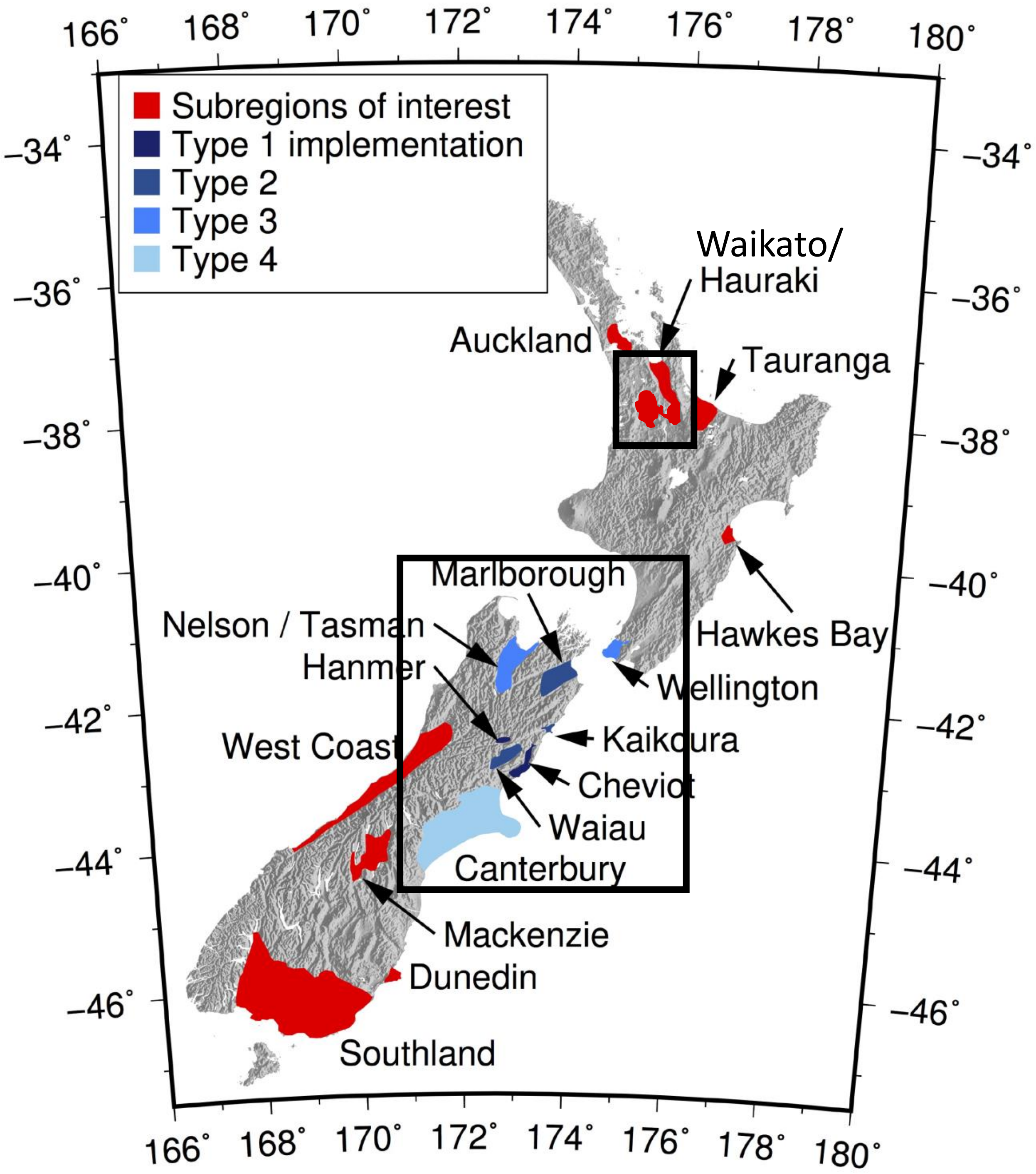


Recording Stations

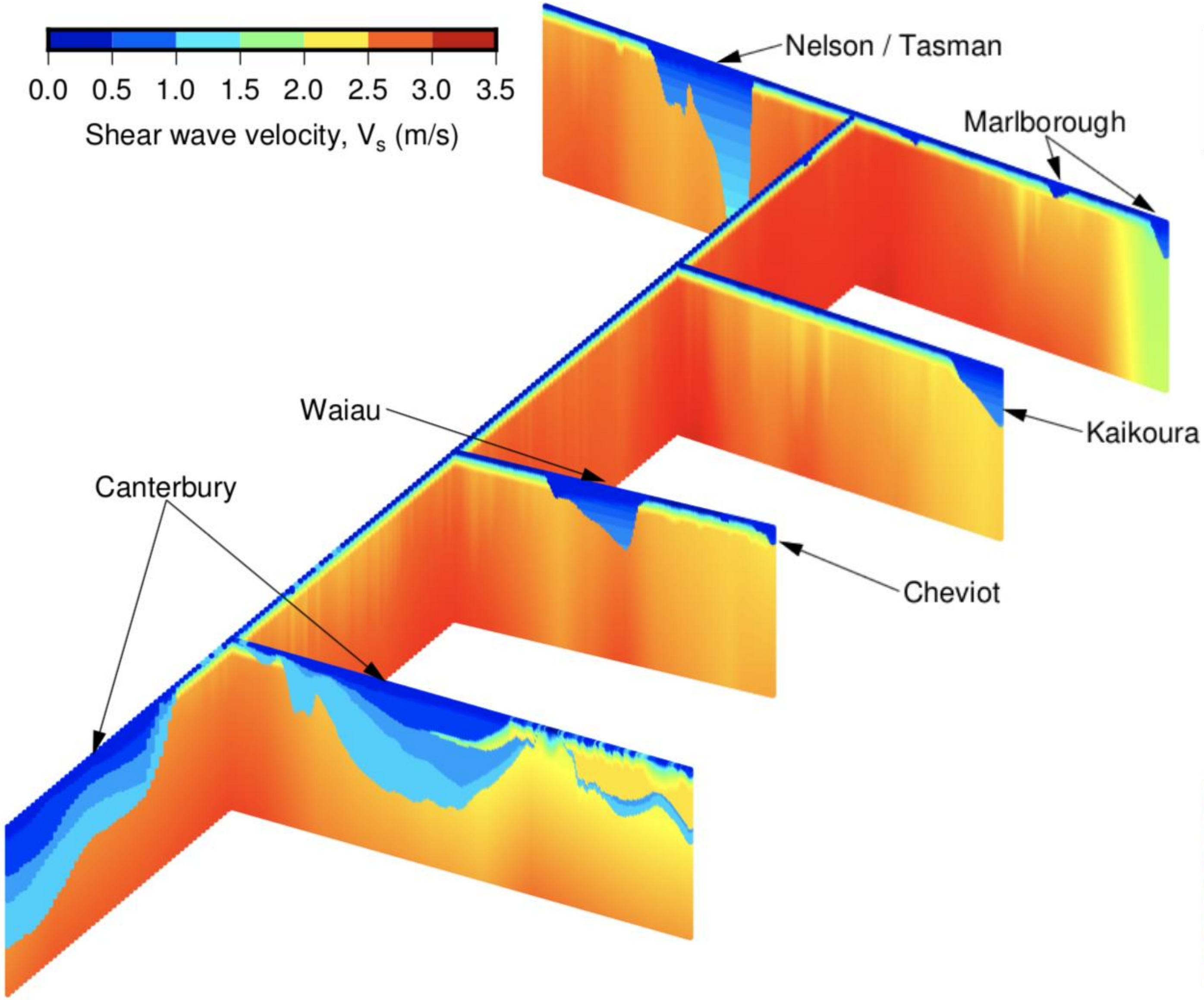
- Broadband and strong motion stations across NZ.
- V_{s30} values from Foster et al. (2019) NZ-wide V_{s30} map.
- A variety of site conditions as shown by range of V_{s30}.
- Previous validation showed many sites appeared to have V_{s30} too low.
- Model currently being modified.

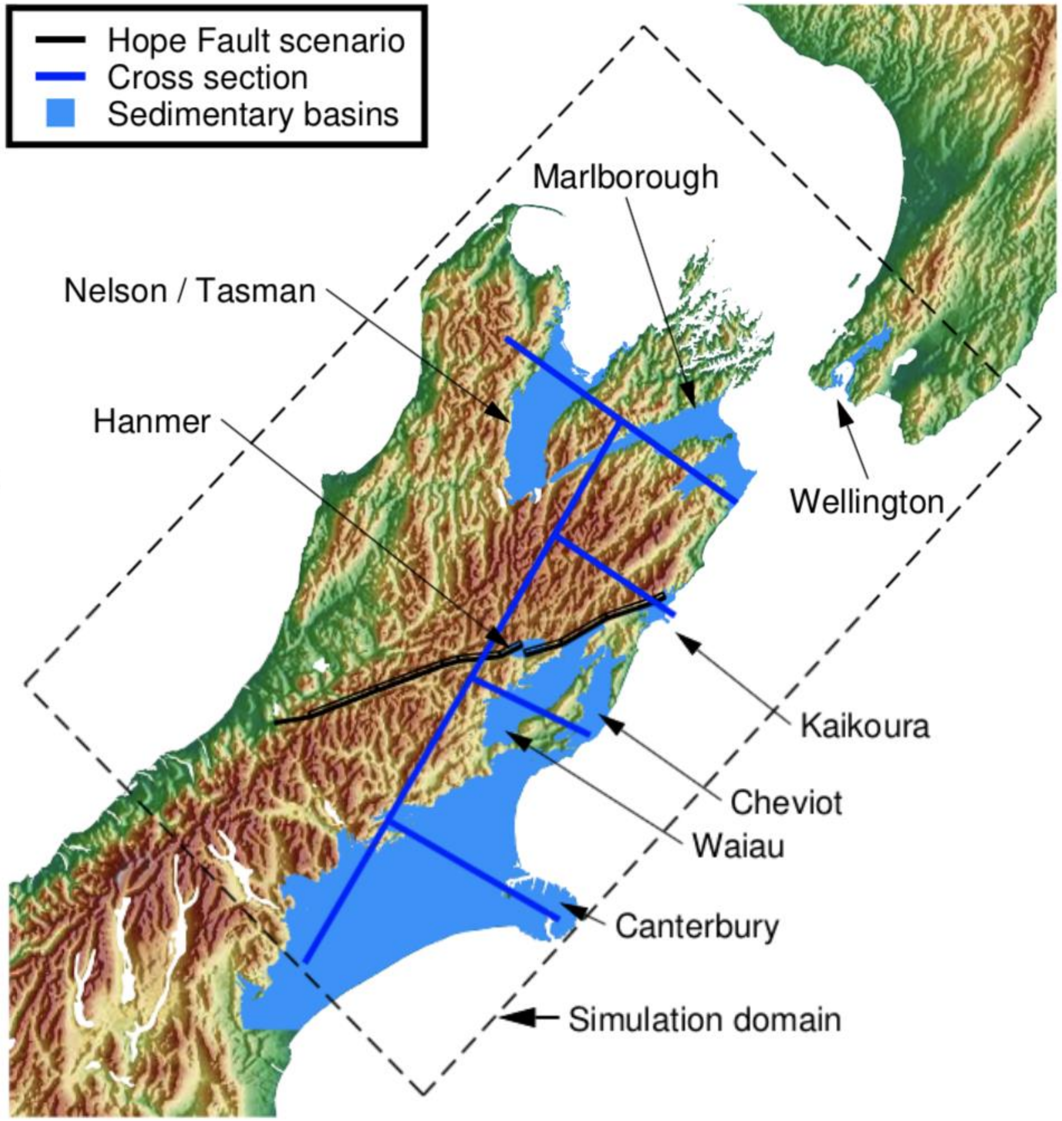


Velocity Modelling



Velocity Modelling





Source Modelling

- Sources for small M_w can be reasonably approximated as point sources.
- Not reasonable for moderate Mw.
- Need to model as finite fault.
- Additional complexities.
  - Rupture geometry.
  - Slip, rise time and rake distribution.
  - Temporal evolution of slip.
  - Hypocentre location (currently set as centre of rupture plane).

Rupture Geometry

- Source description from geonet centroid moment tensor catalogue.
- To get a finite fault we use M_w-Area scaling relationship.
- Use Leonard (2010).

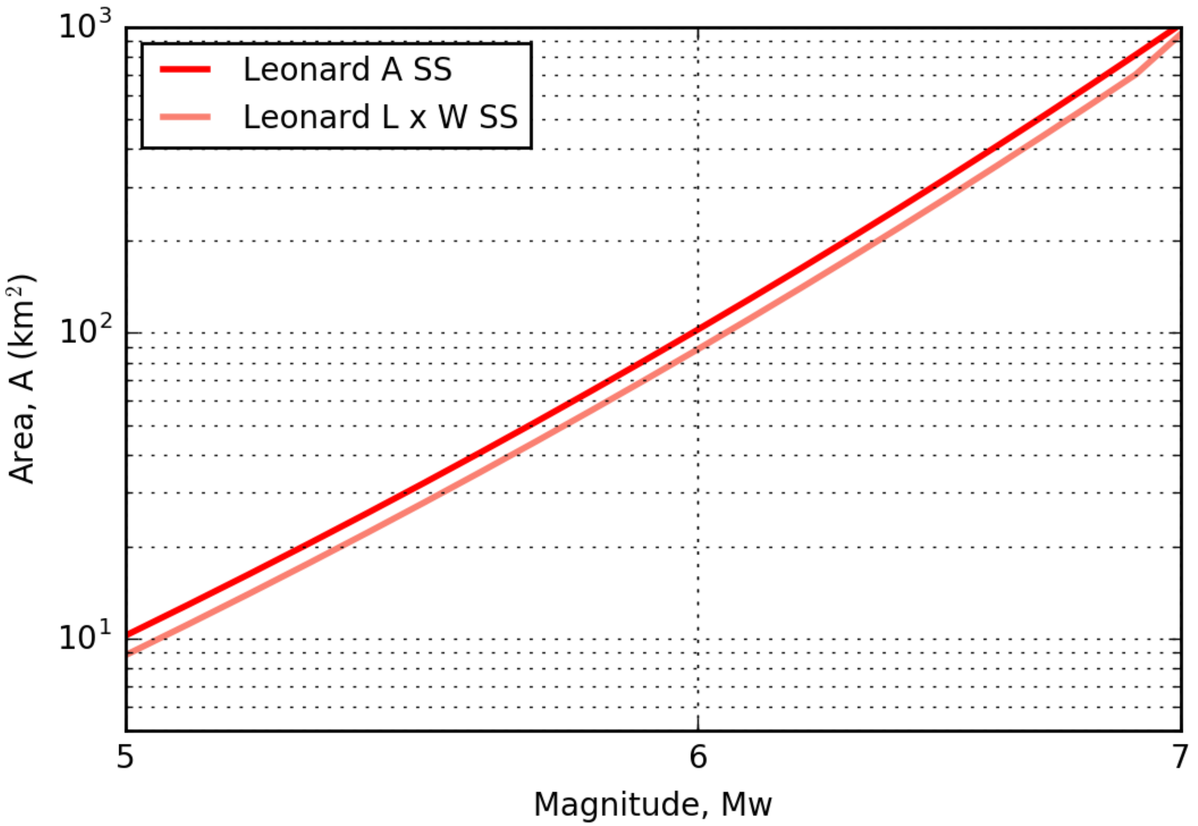
Table 4

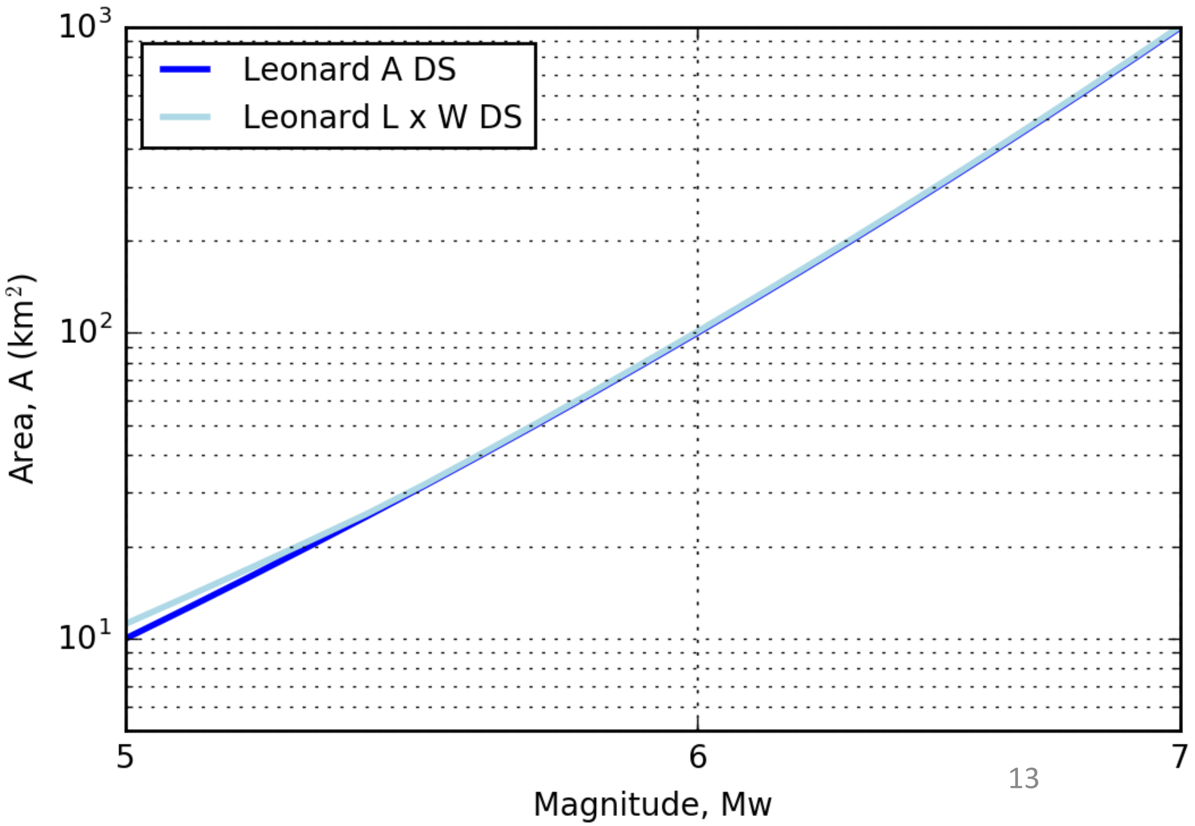
Summary of the More Commonly Used Magnitude-Based Fault-Scaling Relations

Fault Type	Relation	b	a	$S(a)$	Range A(km^2), L(km), W(km), D(m)*
Interplate DS	$M_w = a + b \times \log(A)$	1.0	4.00	3.73–4.33	>0
	$M_w = a + b \times \log(L)$	2.0	4.00		
		1.667	4.24	3.81–4.73	>5.4
	$M_w = a + b \times \log(W)$	2.5	3.63	3.61–3.73	>5.4
	$M_w = a + b \times \log(D)$	2.0	6.84	6.17–7.38	>0
Interplate SS	$M_w = a + b \times \log(A)$	1.0	3.99	3.73–4.25	>0
	$M_w = a + b \times \log(L)$	1.667	4.17	3.77–4.55	3.4–45.0
		1.0	5.27		>45
	$M_w = a + b \times \log(W)$	2.5	3.88	3.82–3.95	3.4–19.0
	$M_w = a + b \times \log(D)$	2.0	6.85	6.34–7.38	>0.13

Magnitude-Area Scaling Relationship

- Predicted A does not equal product of predicted L and W.
- I won't rule out an error or misunderstanding on my end but I checked this very rigorously. Has anyone else checked this before?





Magnitude-Area Scaling Relationship

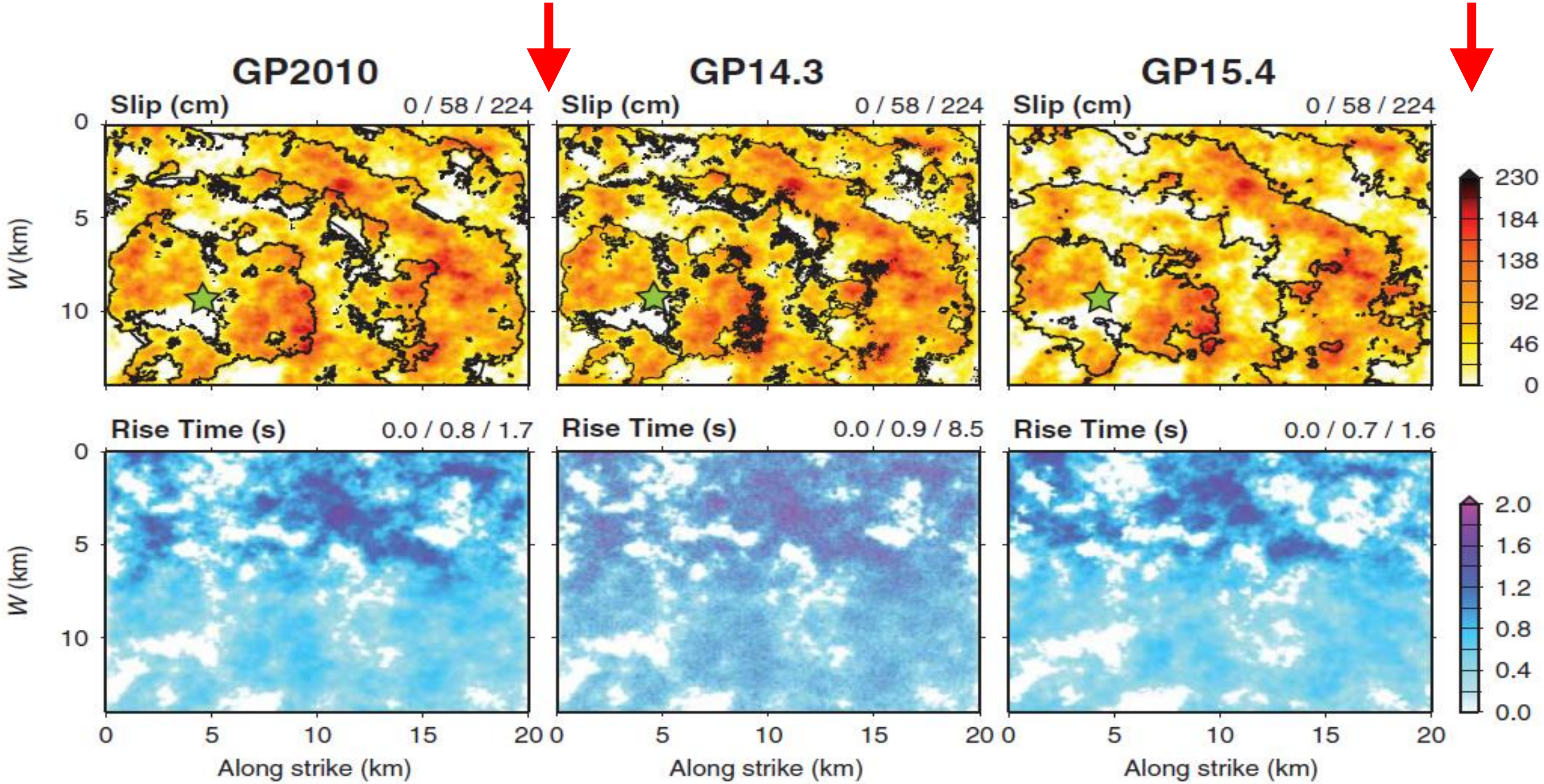
- We consider two options:

1. L and W are equal so L = W =$\sqrt{A}$
2. L and W are have a ratio r=L/W equal that predicted by Leonard (2010) equations while preserving the A predicted by Leonard.
   - Example:
   - For a M_w 5.0 strike slip earthquake:
   - Leonard gives us A = 10.2, L = 3.1, W = 2.8
   - L x W = 3.1 x 2.8 = 8.8 ≠ 10.2
   - Instead use L = 3.4 and W = 3.0
   - L x W = 3.4 x 3.0 = 10.2

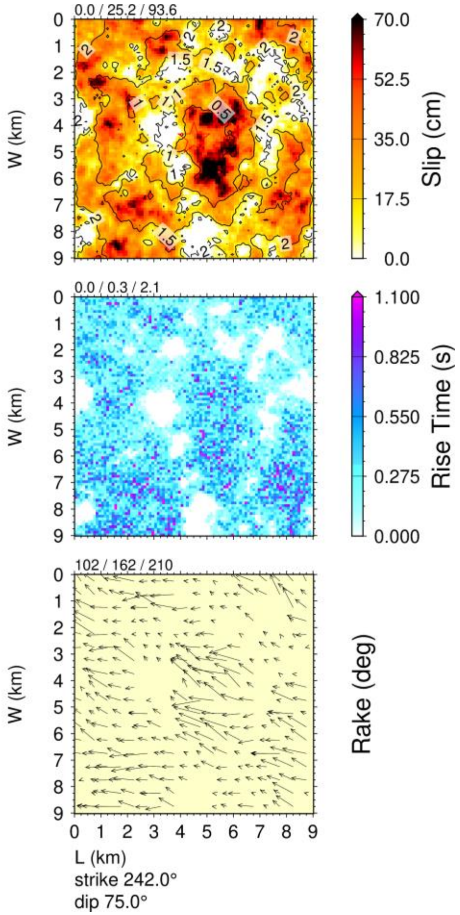
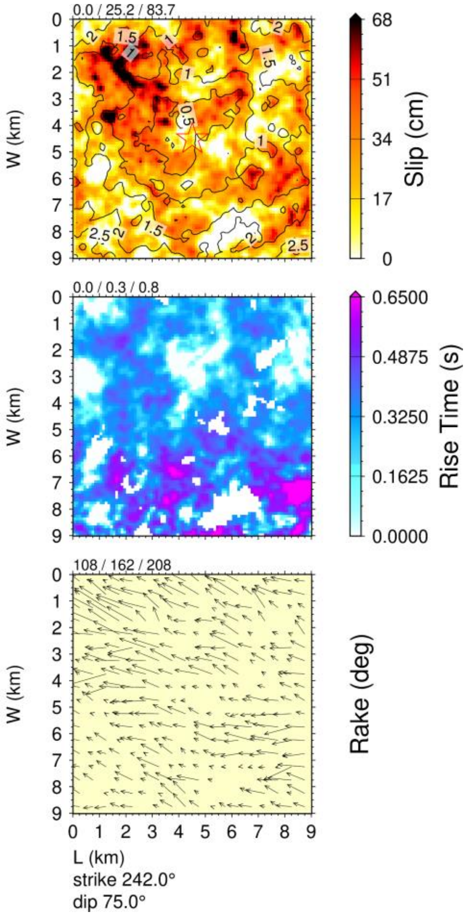
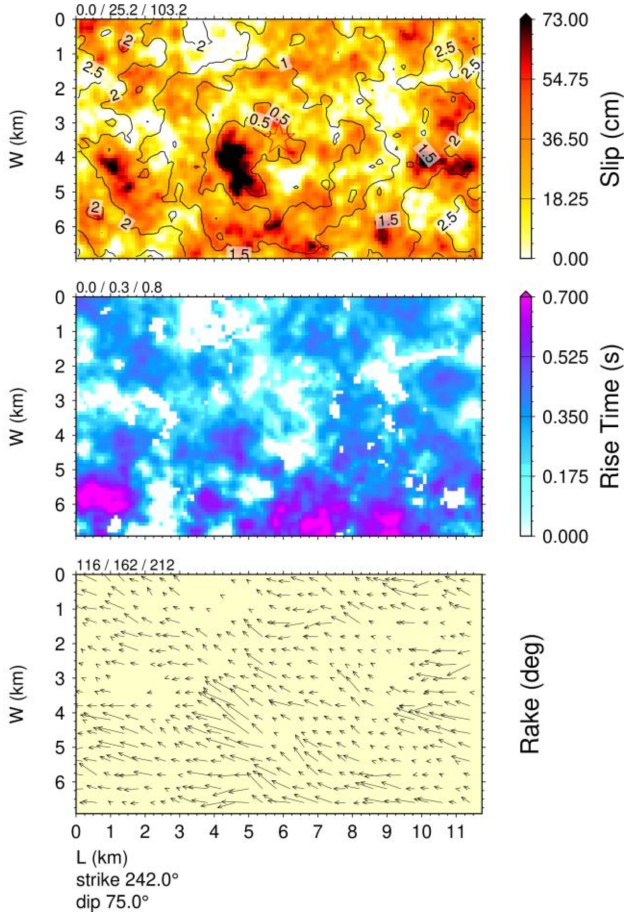
Rupture Generator

- Graves and Pitarka rupture generator.

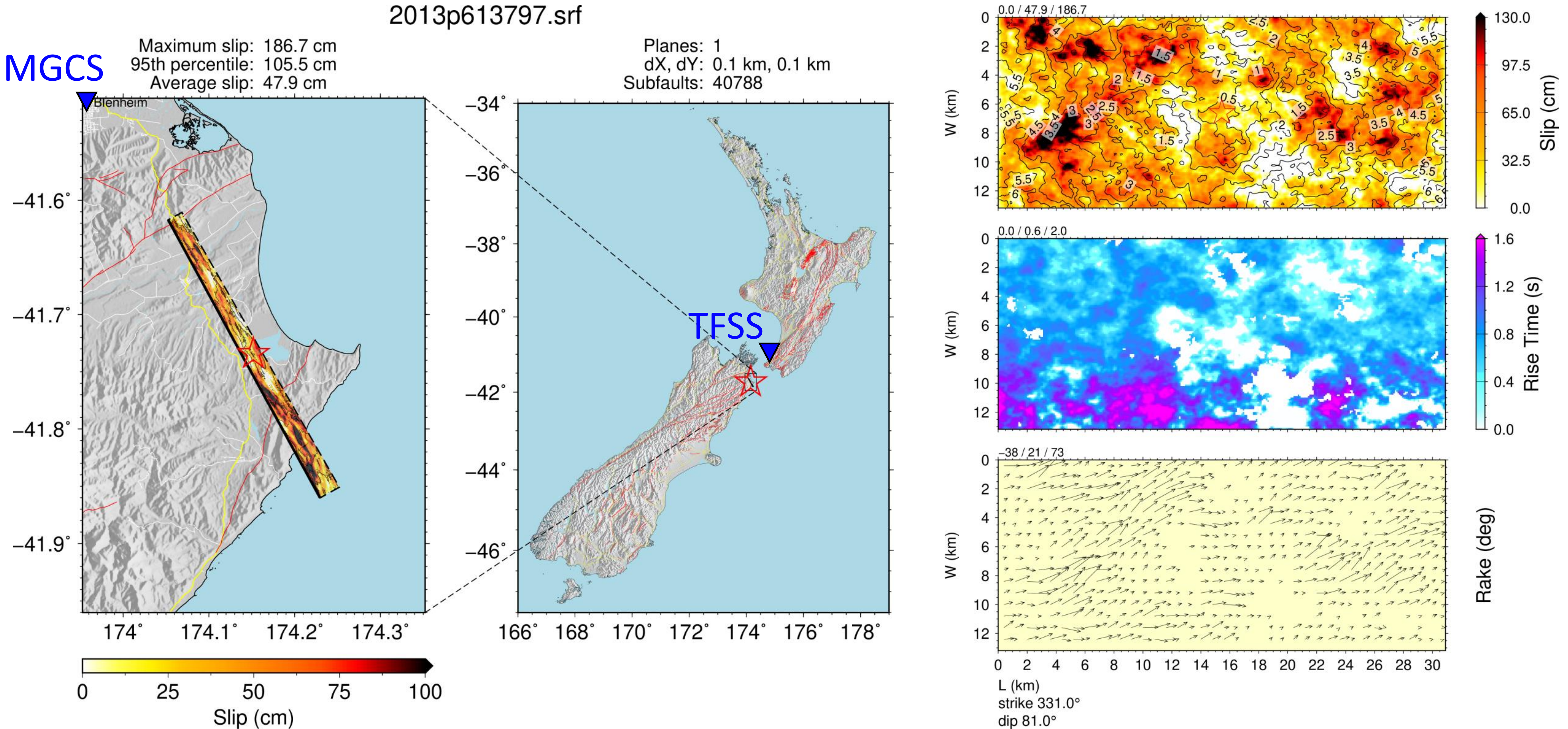
genslip_v3.3 genslip_v5.4.2



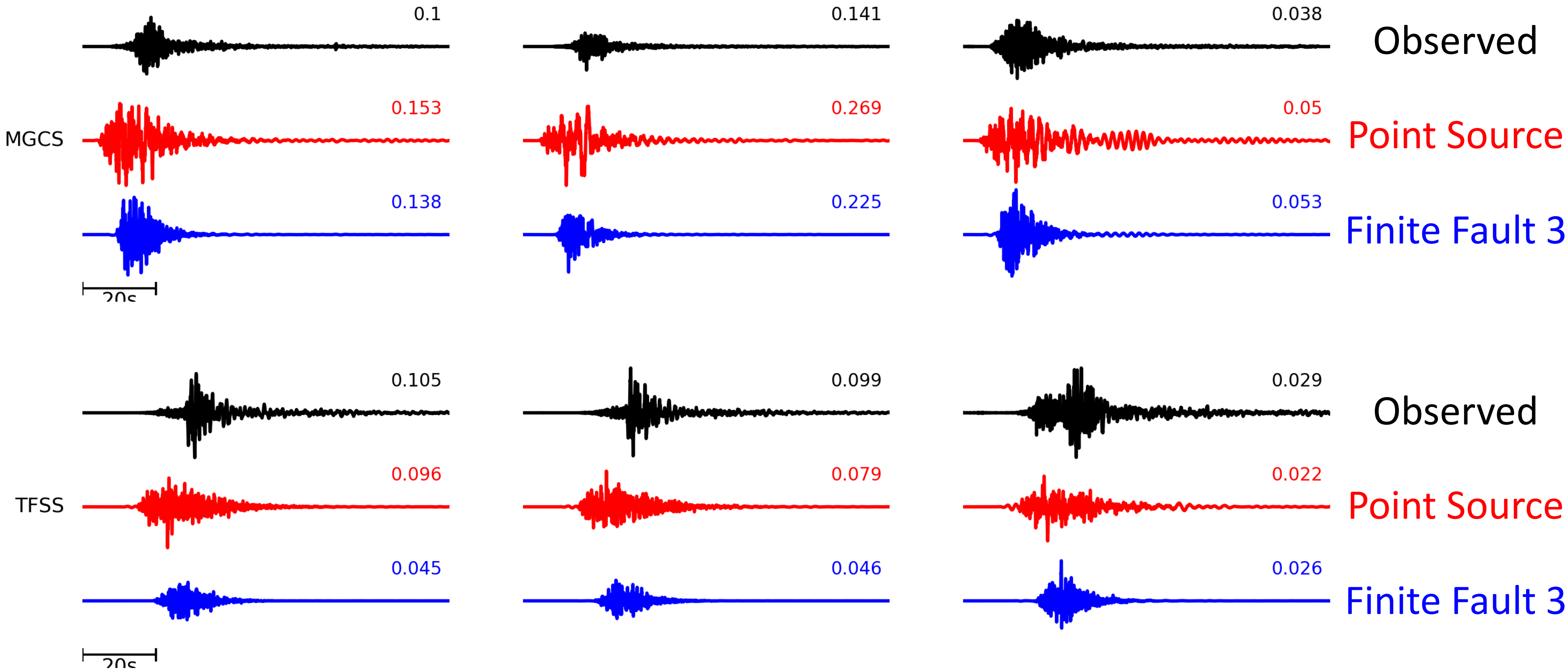
Source Modelling

Method	Point Source	Finite Fault 1	Finite Fault 2	Finite Fault 3
Slip gen	N/A	genslip_v3.3	genslip_v5.4.2	genslip_v5.4.2
Aspect Ratio	N/A	1.0	1.0	$\propto L/W$ (Leonard)
Slip	One slip value			
Rise Time	0.5s			
Rake	One rake value			

Example Simulation: 2013 Lake Grassmere

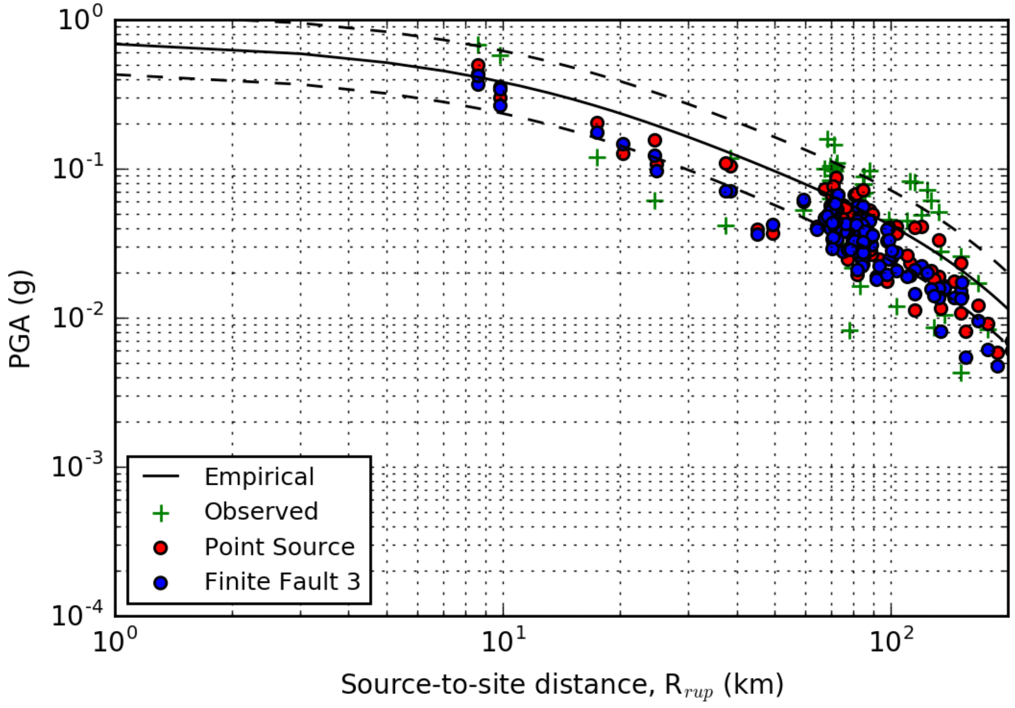


Waveforms

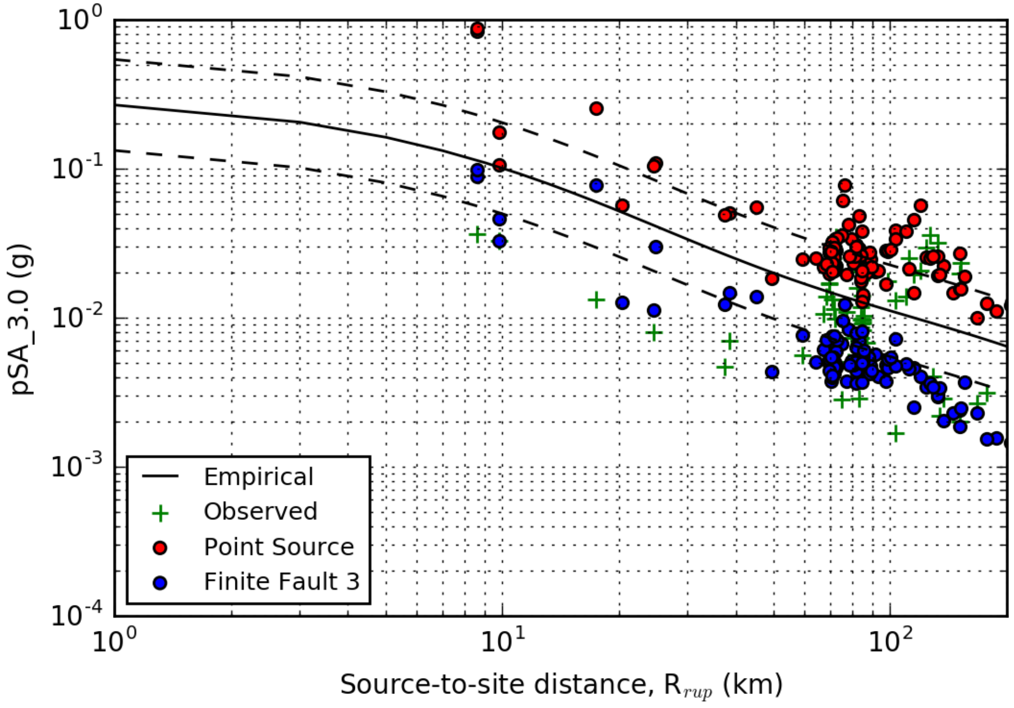

MGCS
0.1
0.141
0.038
Observed
0.153
0.269
0.05
Point Source
0.138
0.225
0.053
Finite Fault 3
20s
TFSS
0.105
0.099
0.029
Observed
0.096
0.079
0.022
Point Source
0.045
0.046
0.026
Finite Fault 3
20s

Intensity Measures vs R_{rup}

PGA



SA(3.0s)



Analysis of Entire Dataset

- Mixed-effects regression framework to identify systematic biases.
- General form of a ground motion model for event *e* and station *s*:

$$\ln IM_{es} = f_{es} + \Delta$$

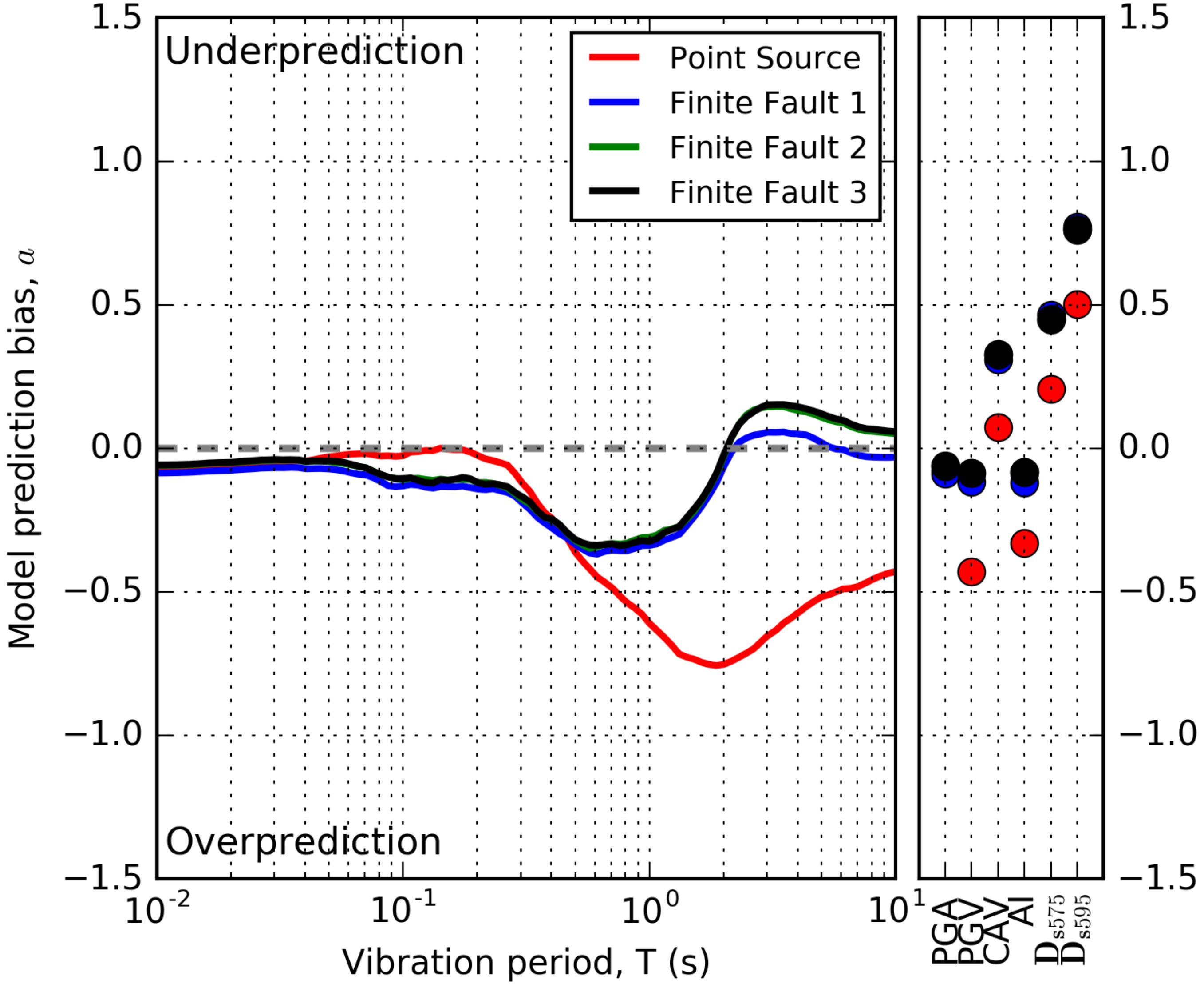
Observation = Median prediction + Total residual

$$\ln IM_{es} = f_{es} + (a + \delta S2S_s) + \delta B_e + \delta W_{es}^0$$

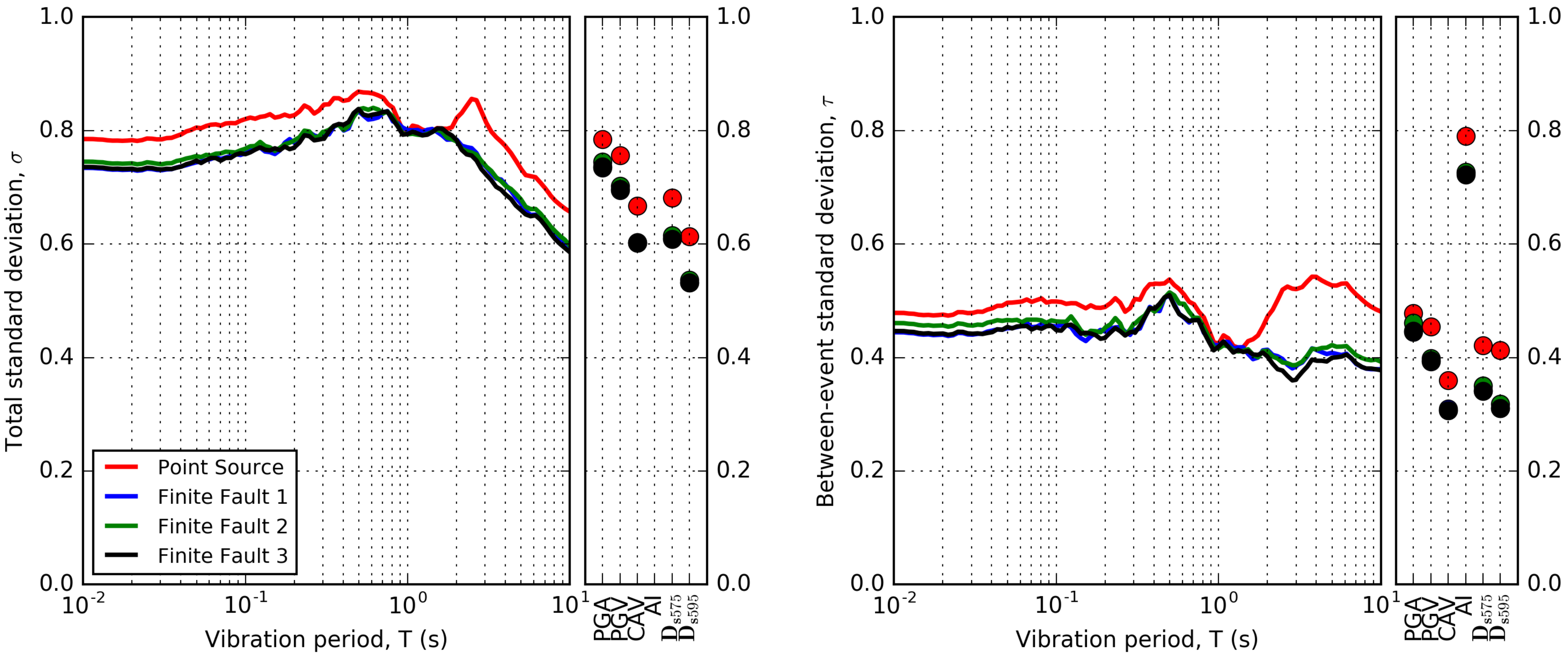
Observation = Median prediction + Model bias + Systematic site residual + Between-event residual + Remaining within-event residual

Standard deviations: ϕ_{S2S} τ ϕ_{SS}

Model Prediction Bias



Standard Deviations



Future Work

- Modified V_{s30} model built on the Foster et al. (2019) model.
- More investigation and analysis of 200m results.
- 100m grid run.
- Improvement of ground motion quality classification neural network.
- Subduction earthquakes.
- Uncertainty characterisation.