Source Parameters from Generalized Inversion and Their Spatial Pattern

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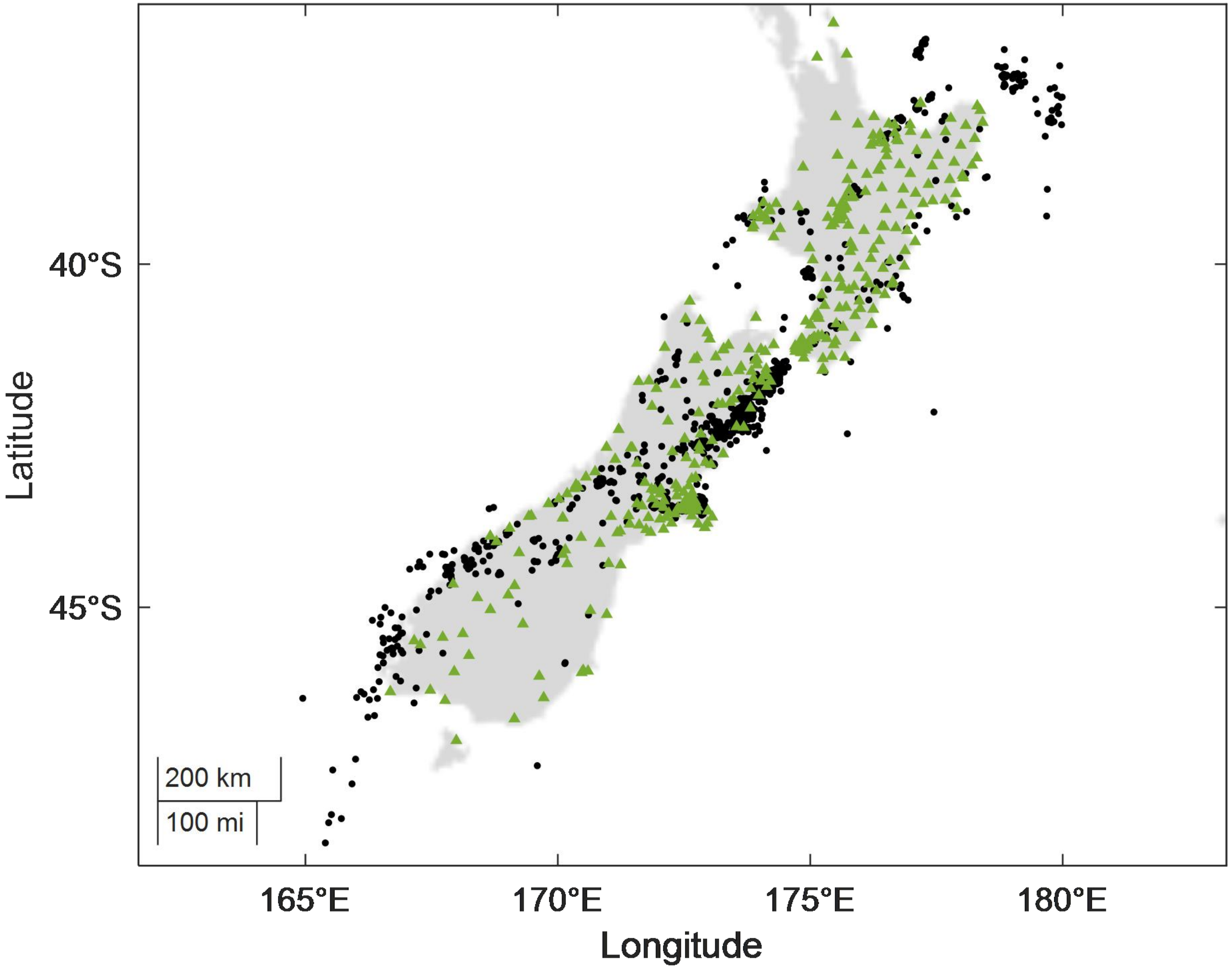
Shallow Crustal Events

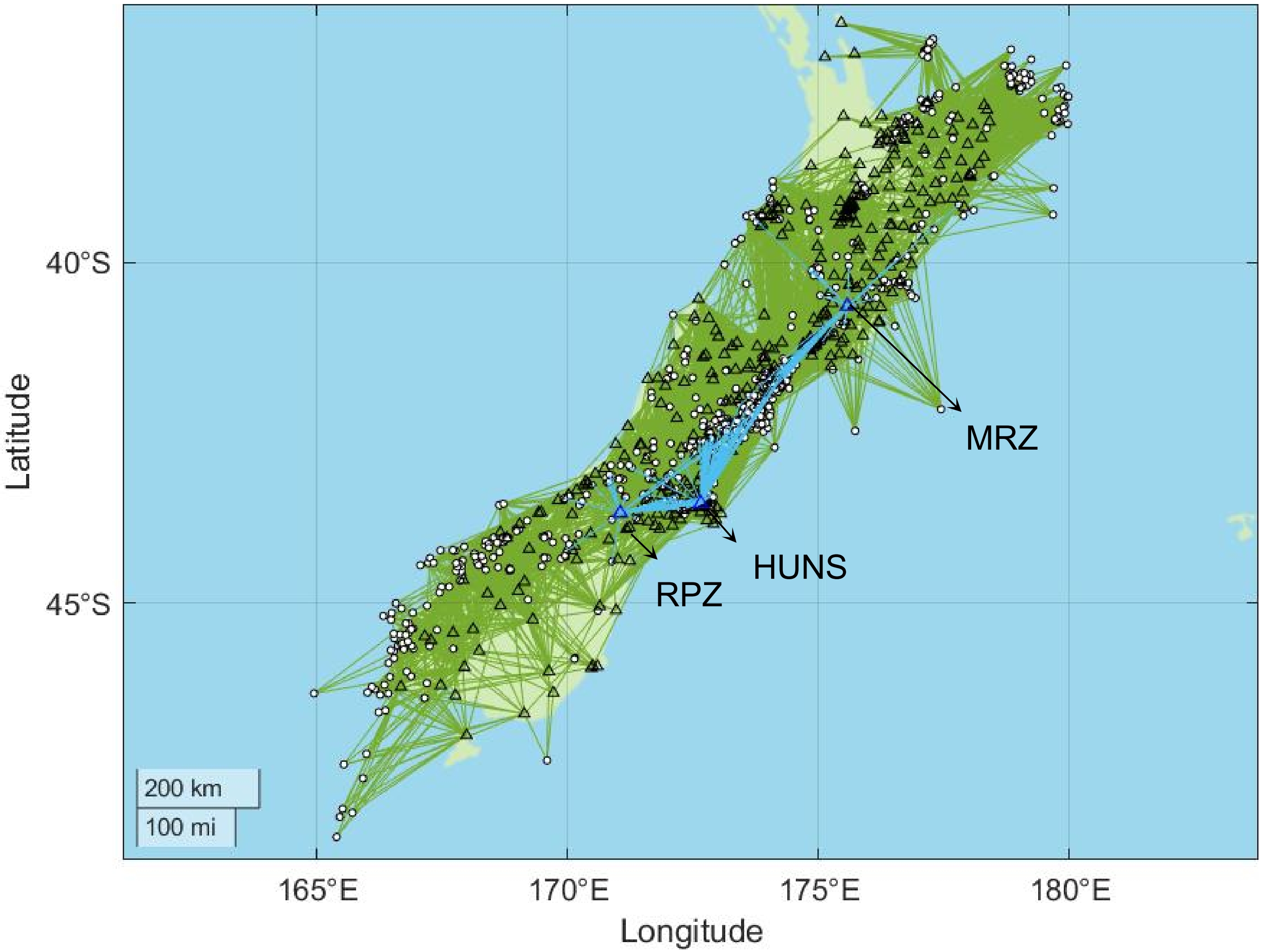


Data selection from NZGMDB (Hutchinson et al., 2023; Gerstenberger et al., 2022):

- ❑ *Mw>= 3.0*
- ❑ $R_{hypo} \leq 300.0$ *km*
- ❑ *D ≤ 30 km*
- ❑ *0.0002g ≤ PGA ≤ 0.2g*
- ❑ *no. of stations >=3 & no. of recordings>= 3*
- ❑ ***Usable frequency range***
- ❑ Other quality metrics

20, 813 ground motions from **1200** crustal events (dots) recorded by **693** sensors at **439** unique locations (triangles).

Non-Parametric Generalized Inversion



Generalized inversion (Andrews, 1986; Castro et al., 1990):

Event-specific | Tectonic class-(and region) dependent | Site-specific

$$lnH_{1,1}(f) = lnE_1(f) + lnP_{1,1}(f) + lnS_1(f)$$

$$\vdots$$

$$\boldsymbol{lnH_{i,j}(f) = lnE_i(f) + lnP_{i,j}(f) + lnS_j(f)}$$

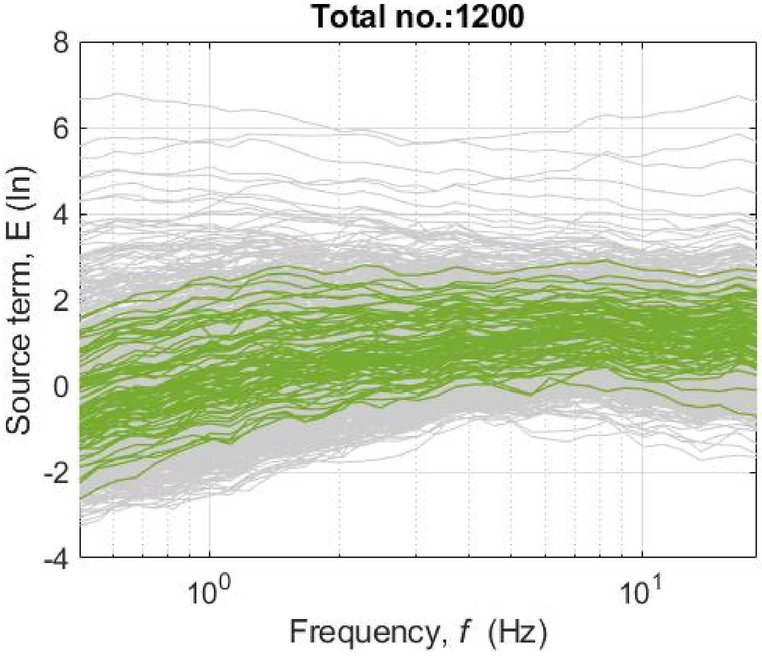
$$\vdots$$

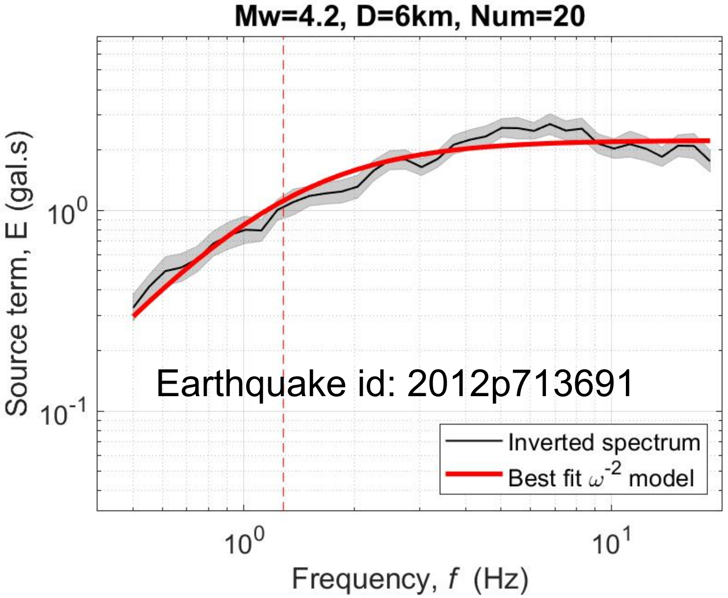
$$lnH_{N,n}(f) = lnE_N(f) + lnP_{N,n}(f) + lnS_n(f)$$

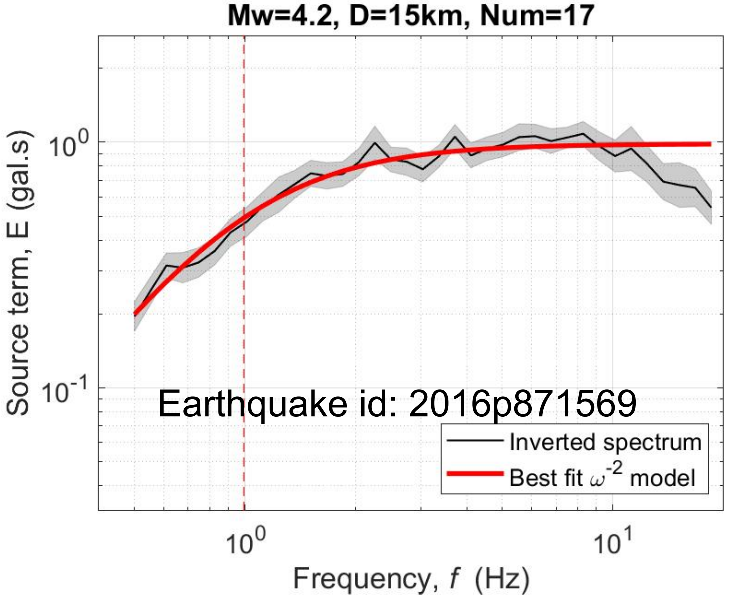
$$\boldsymbol{b = A \cdot x}$$

Non-parametric scheme: no pre-defined functional forms;

Parameterize Source Spectra







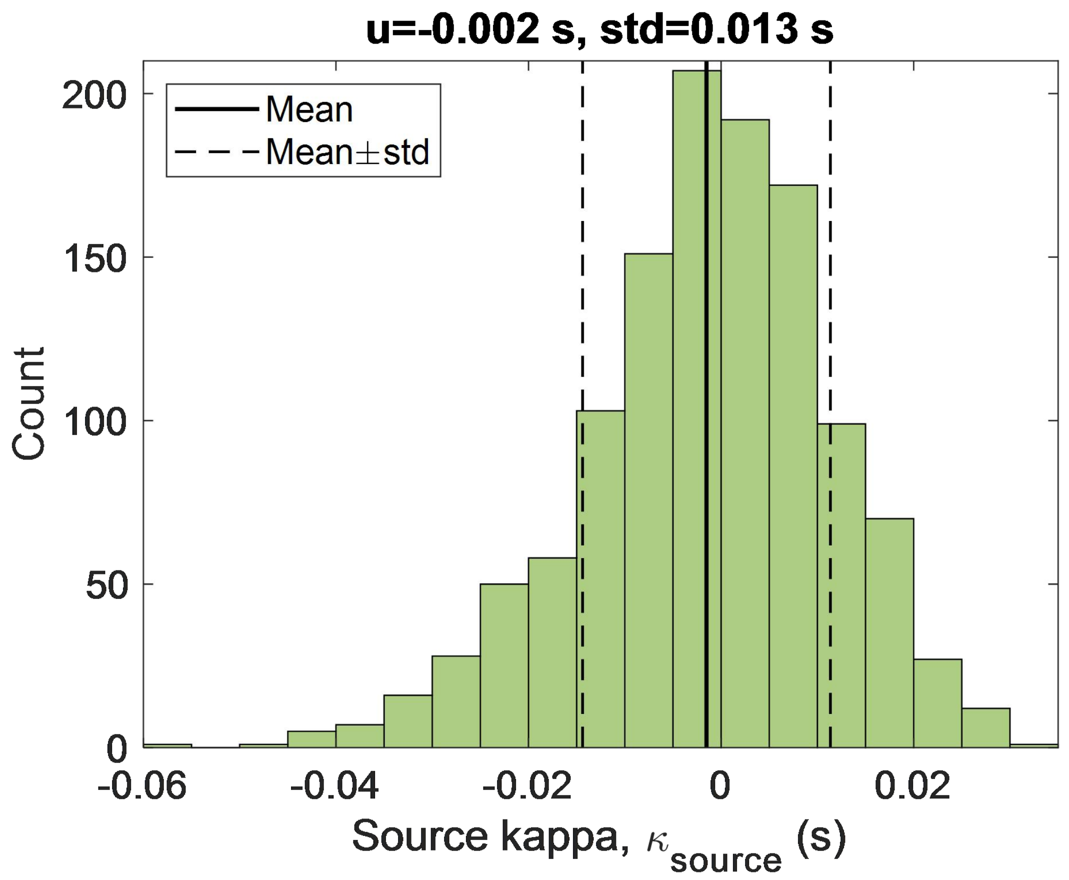
The theoretical source model used herein, $E'(f)$, consists of both the standard ω^{-2} model (Brune, 1970 and 1971) and a κ_{source} filter:

$$E'(f) = (2\pi f)^2 \frac{R_{\theta\emptyset} V F}{4\pi\rho\beta^3 R_{ref}} \times \frac{\boldsymbol{M_0}}{1+\left(\frac{f}{\boldsymbol{f_c}}\right)^2} e^{-\pi\boldsymbol{\kappa_{source}}(\boldsymbol{f}-f_k)}$$

standard ω^{-2} model — high-frequency fall-off

Source Kappa κ_{source}

Inverted κ_{source} for each of the 1200 events:



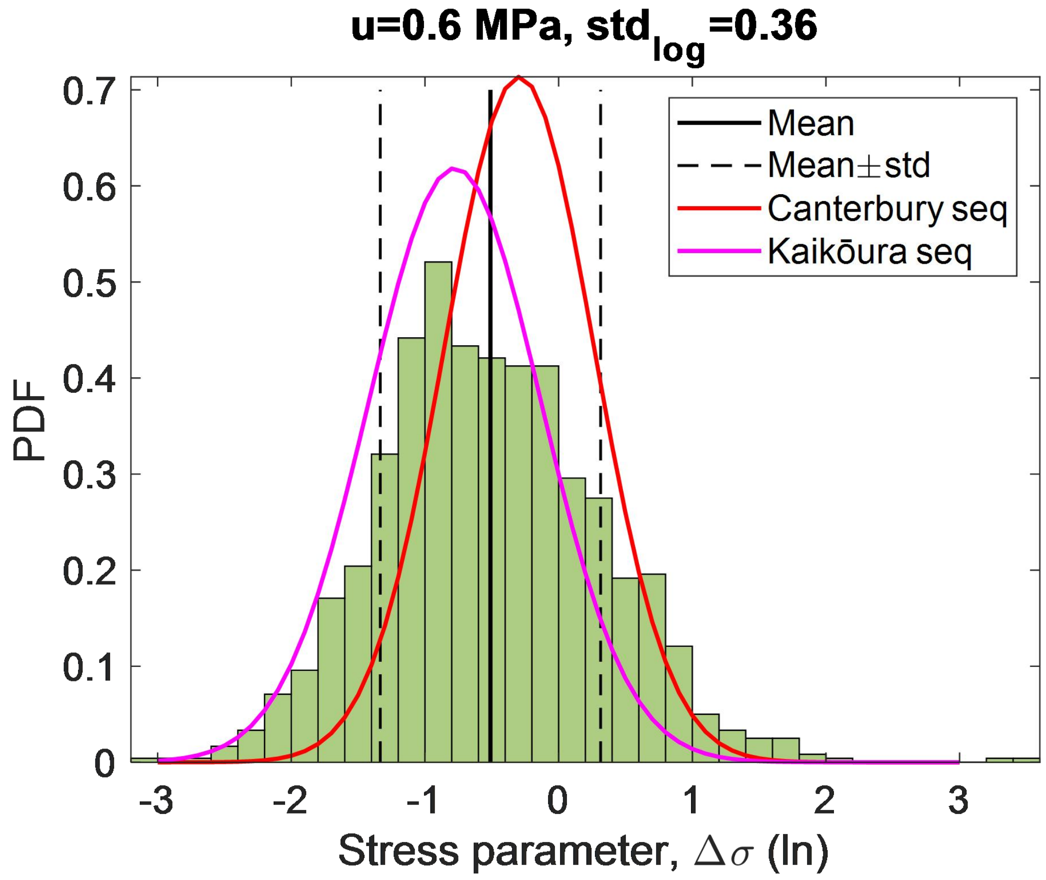
- Source spectra, on average, follow ω^{-2} model;
- Some individual events may not;
- Origin debatable, e.g., source and site effects (Hanks, 1982; Papageorgiou and Aki, 1983);
- Instead of $\left(\frac{f}{f_c}\right)^2$, using $\left(\frac{f}{f_c}\right)^{2.5}$ (Beresnev, 2019);

$$E'(f) = (2\pi f)^2 \frac{R_{\theta\phi} V F}{4\pi\rho\beta^3 R_{ref}} \times \frac{\boldsymbol{M_0}}{1+\left(\frac{f}{f_c}\right)^2} e^{-\pi\kappa_{source}(f-f_k)}$$

Stress Parameter Δσ

Stress parameter Δσ (unit: Pa) can be obtained from inverted M_0 and f_c, assuming a circular fault rupture with uniform stress drop (Eshelby, 1957; Keilis-Borok, 1959; Brune, 1970):

$$\Delta\sigma = 8.5 M_0 \left(\frac{f_c}{\beta}\right)^3$$



- Mean: similar to that in Japan (Nakano et al., 2015);
- Std: consistent with other regions, e.g., Japan and California (e.g., Baltay et al., 2013; Oth et al., 2017; Trugman, 2019);
- The 2010-2011 Canterbury sequence has a mean $\Delta\sigma$ higher than the national average whereas the 2016 Kaikōura sequence has a lower mean $\Delta\sigma$.

Stress Parameter Δσ & Between-Event Term δB_e

Lee, Bradley et al. (2022) partitioned the total residual between observation (y_{es}) and prediction (f_{es}) from hybrid broadband simulations of 479 small magnitude (Mw 3.5-5.0) active shallow crustal (< 20 km) earthquakes:

$$\ln y_{es} - \ln f_{es} = a + \boldsymbol{\delta B_e} + \delta S2S_s + \delta WS_{es}$$


Research Paper

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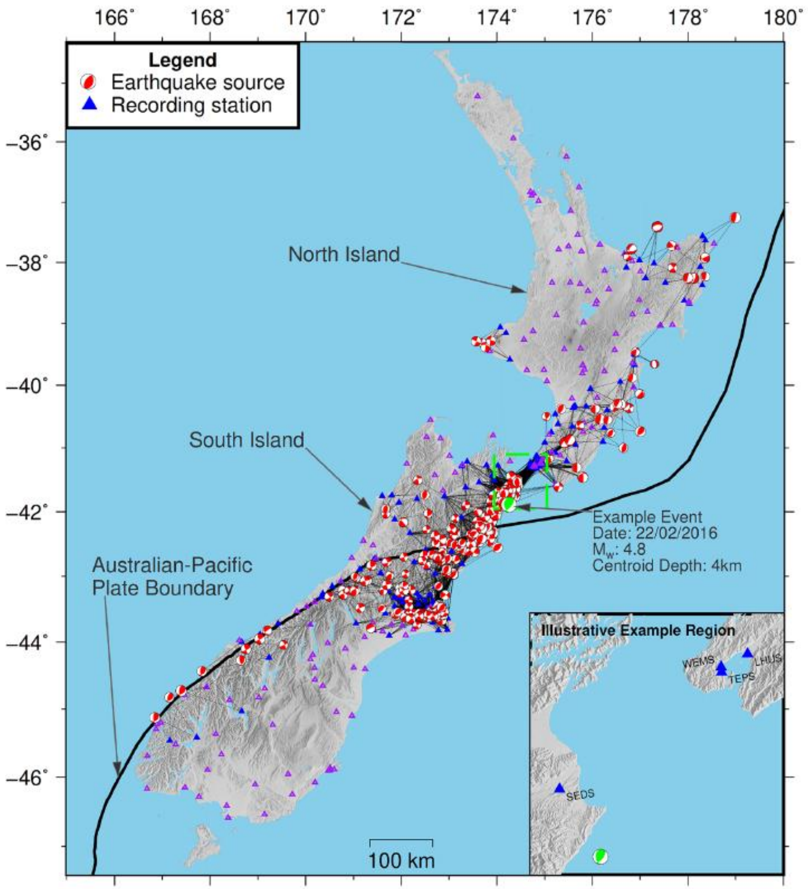
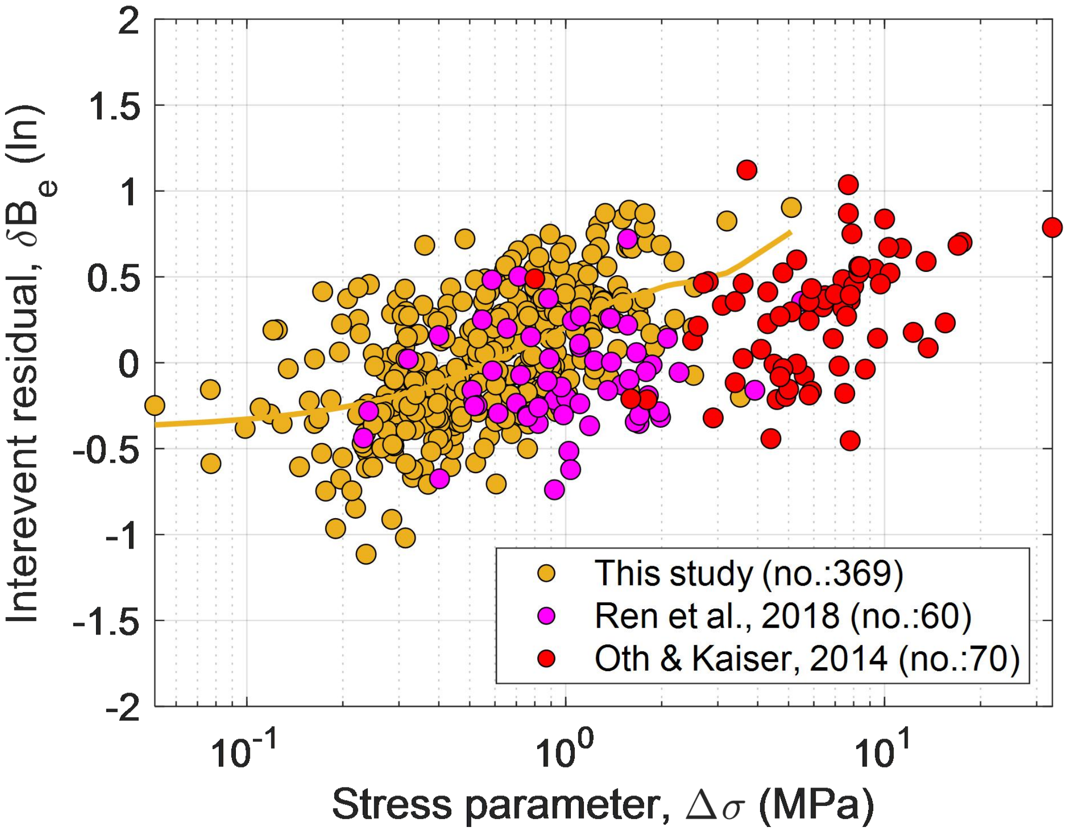
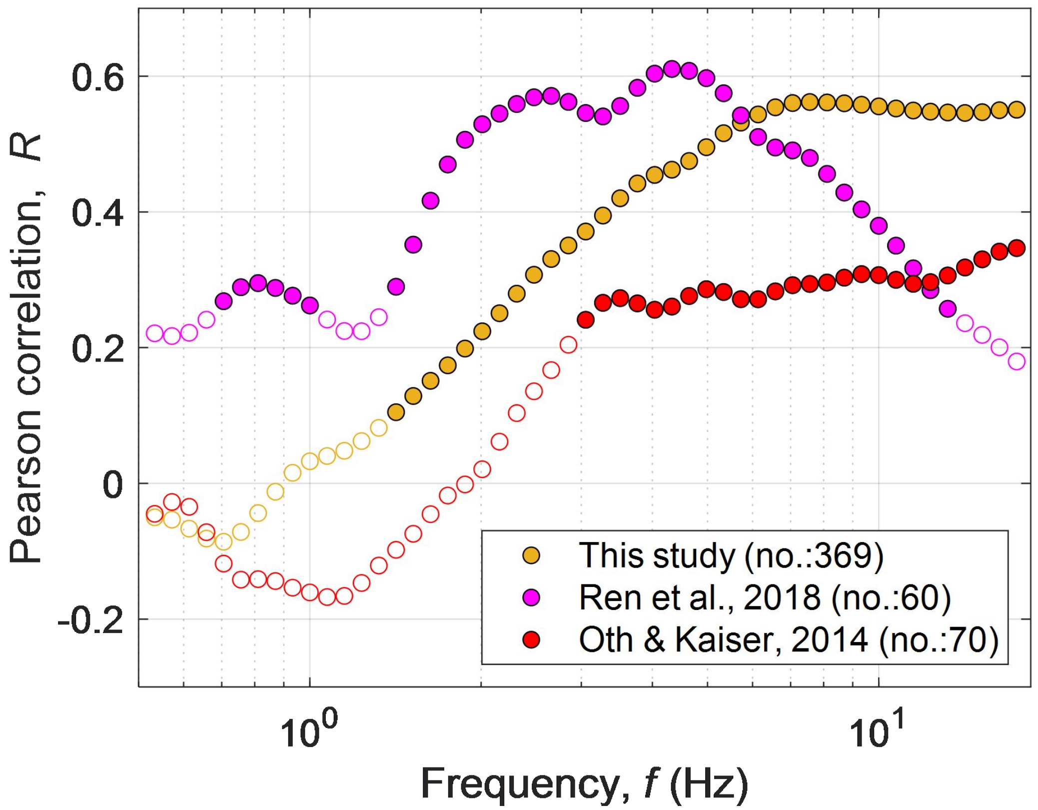
Hybrid broadband ground-motion simulation validation of small magnitude active shallow crustal earthquakes in New Zealand

Robin L Lee, M. EERI[1], Brendon A Bradley, M. EERI[1], Peter J Stafford, M. EERI[2], Robert W Graves, M. EERI[3], and Adrian Rodriguez-Marek, M. EERI[4]



Stress Parameter Δσ & Between-Event Term δB_e



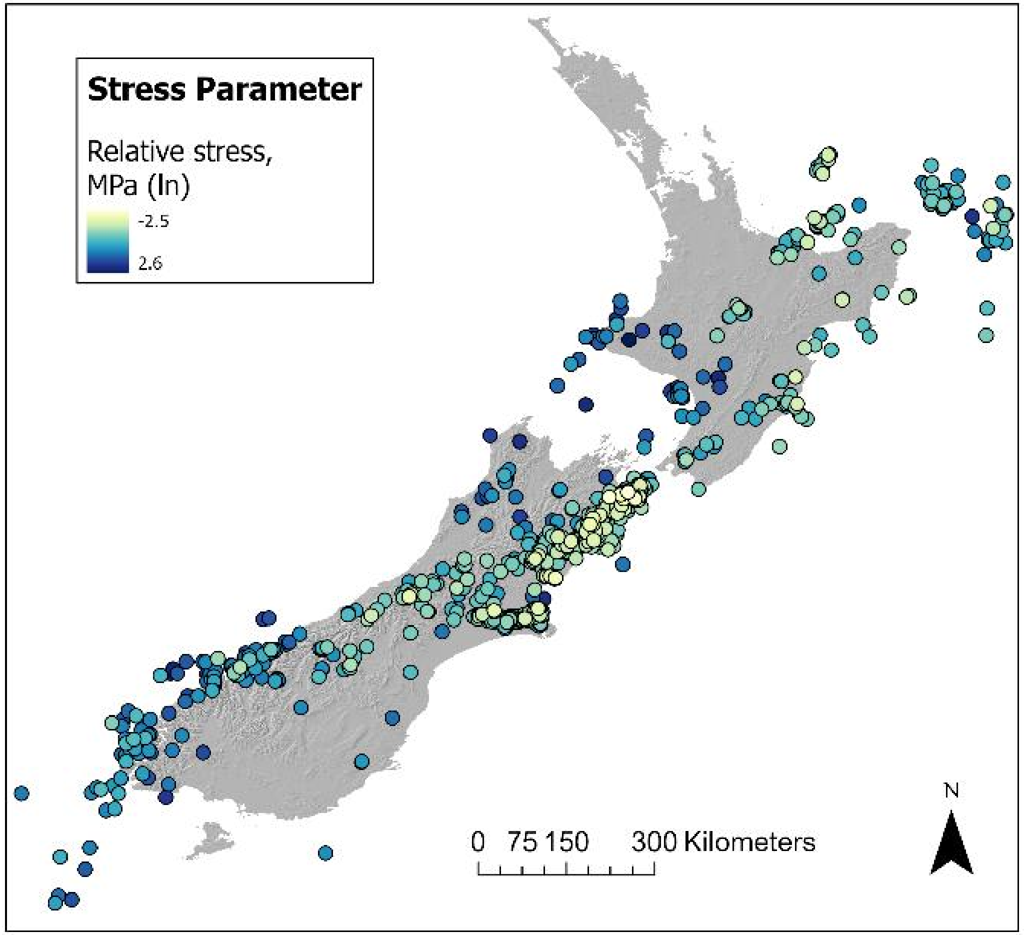


- ❑ δB_e at f=18.5 Hz;
- ❑ Positive correlation with Pearson's R = 0.56;

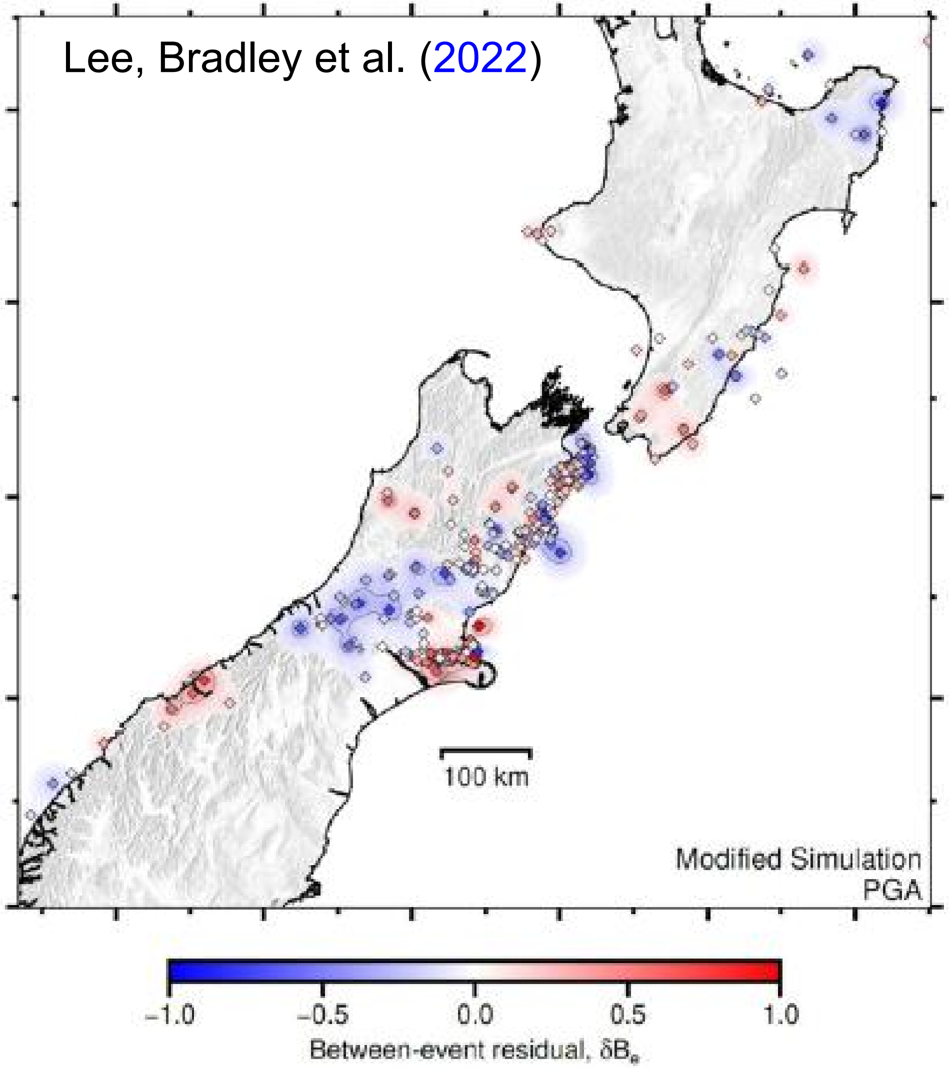
- ❑ Open circles represent those with p-value>0.05;
- ❑ At relatively low frequencies, weak dependence of $\Delta\sigma$ on Fourier amplitudes for $f < f_c$;
- ❑ This study is for crustal events across NZ.

Stress Parameter Δσ & Between-Event Term δB_e

Mean-adjusted relative Δσ

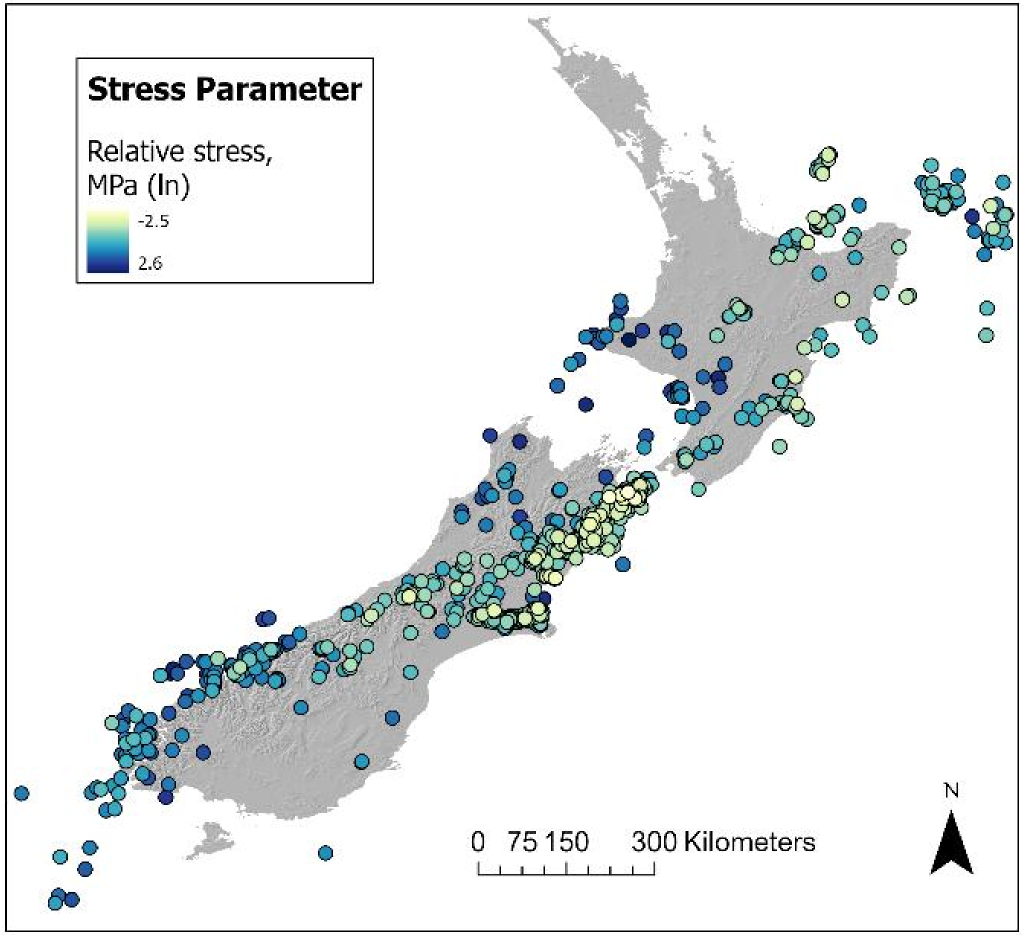


Between-event residual δB_e



Spatial Dependence of Stress Parameter Δσ

Mean-adjusted relative Δσ



Global Moran's *I* test (Moran, 1950) via *ArcGIS Pro* gives a Moran's *I* Index of 0.31.

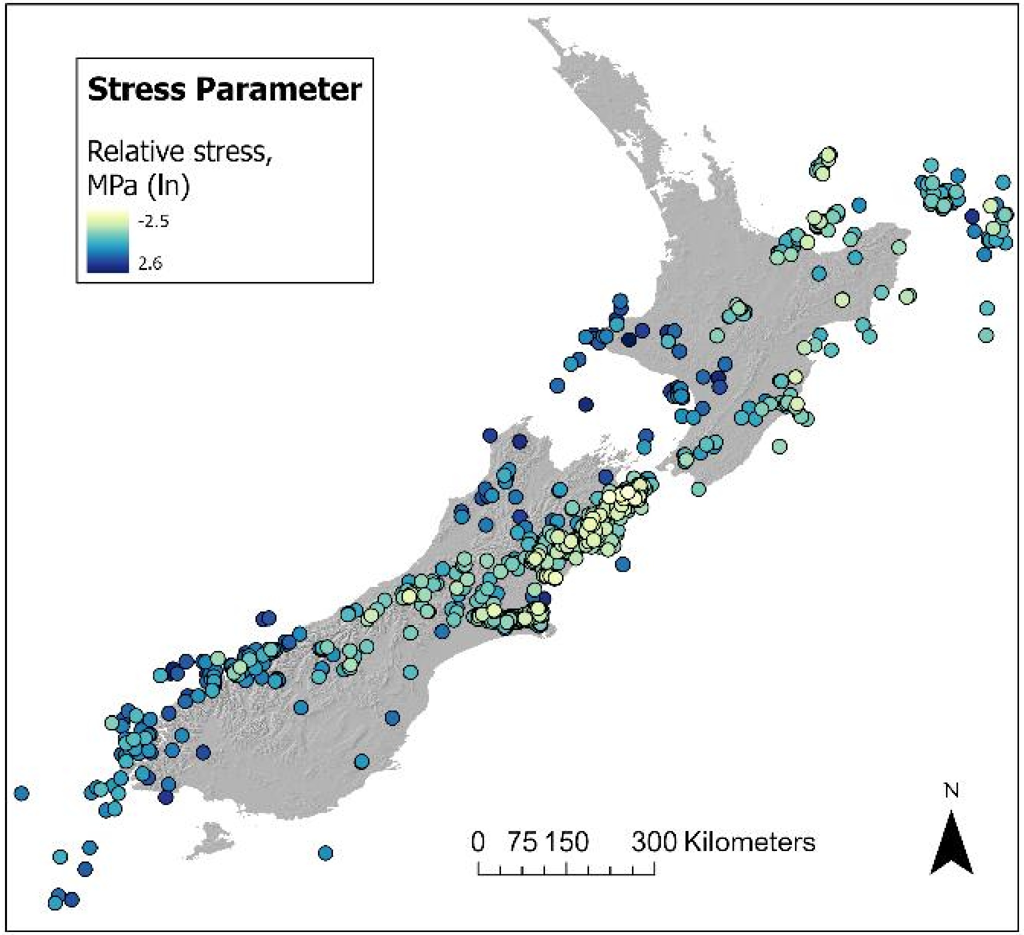
The *I* Index ranges between -1.0 and 1.0:
- ❑ +: tendency toward clustering,
- ❑ -: tendency toward dispersion.

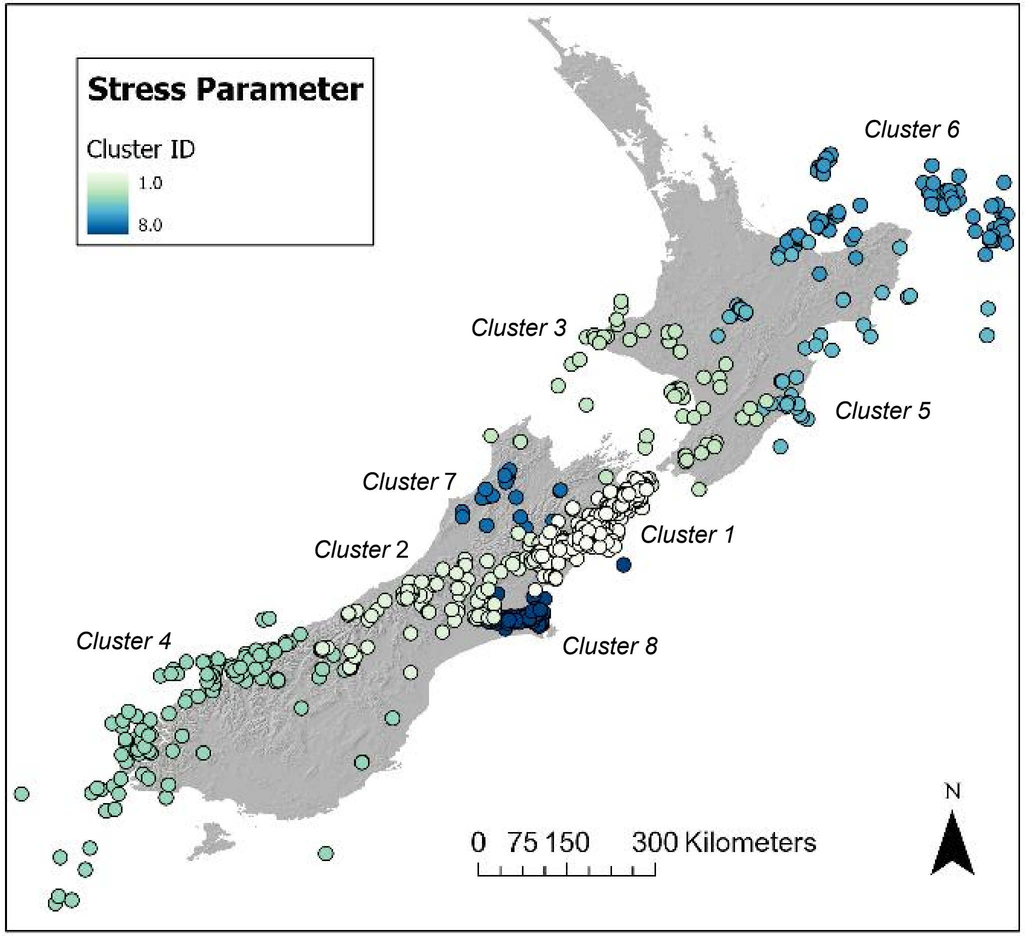
Statistical significance measures:
- ❑ z-score=2.46 and p-value =0.01,
- ❑ reject the null hypothesis (randomly distributed).

Spatial clustering

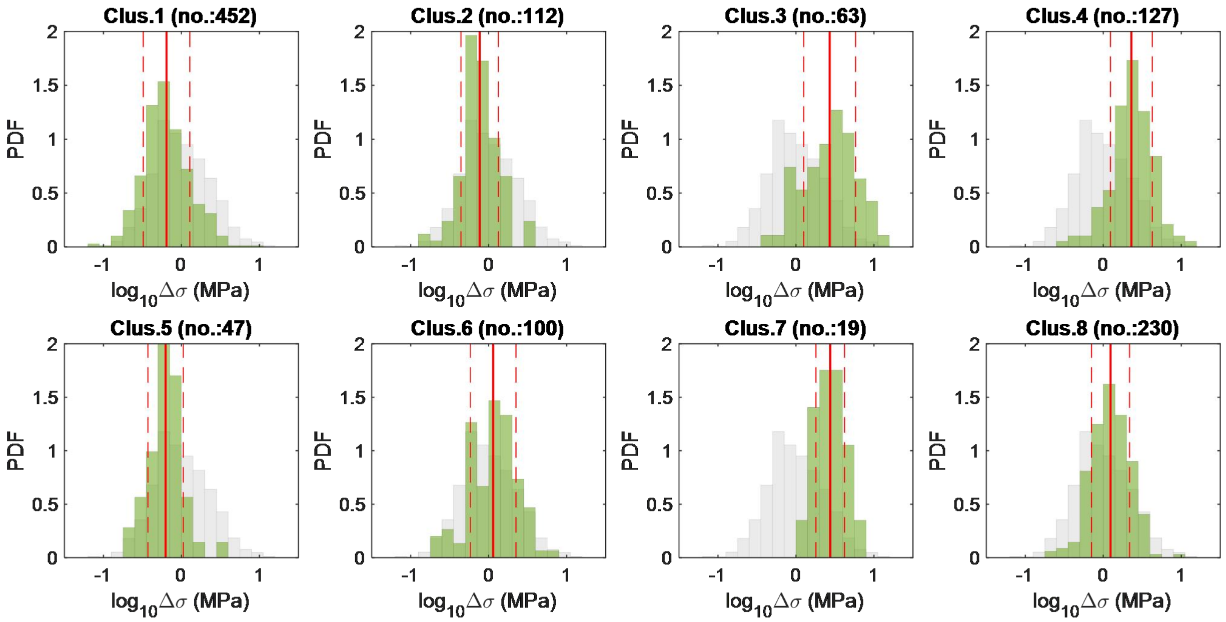
Spatial Dependence of Stress Parameter Δσ

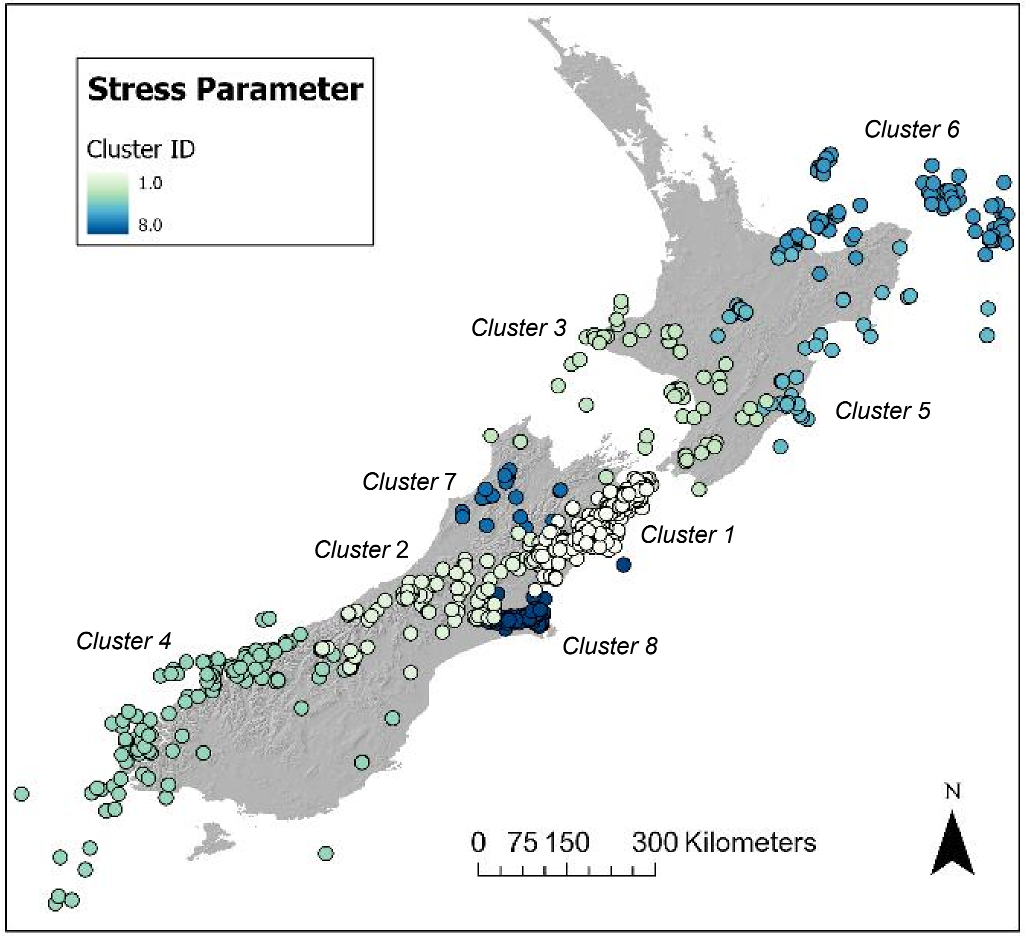
Mean-adjusted relative Δσ



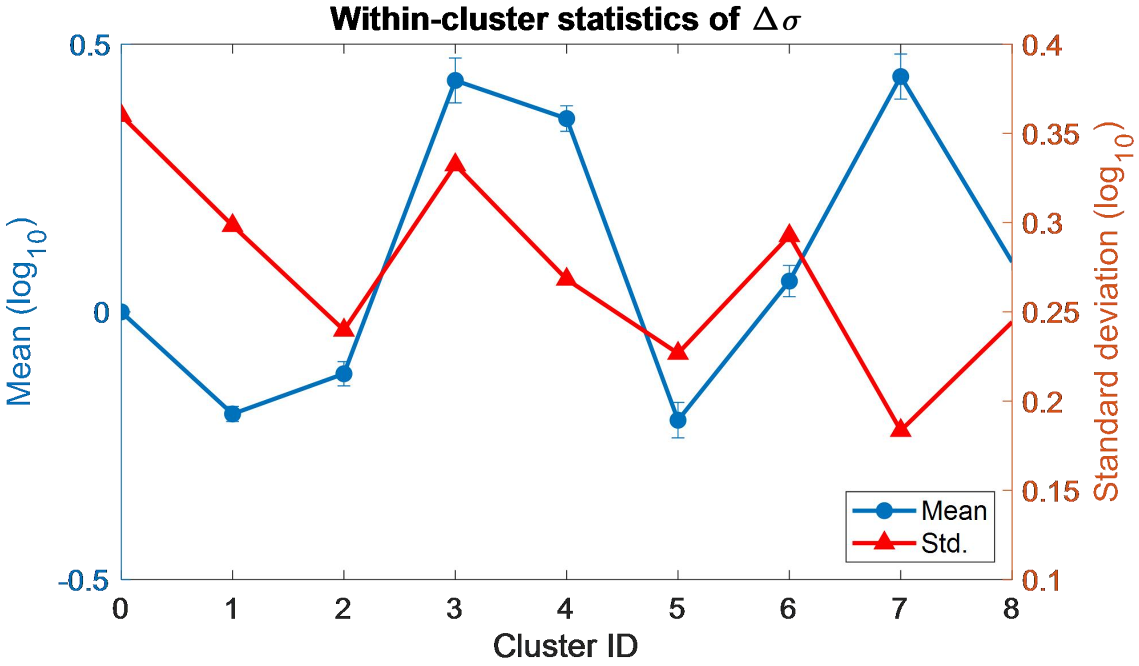


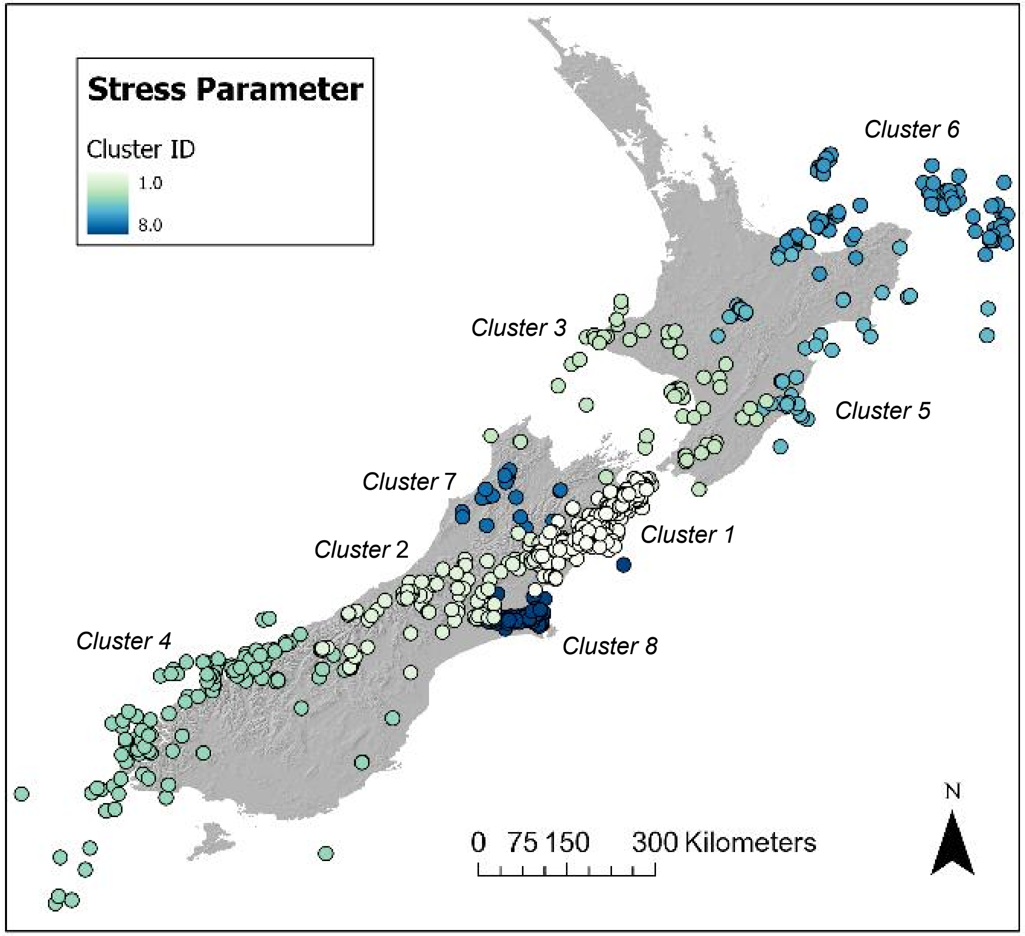
Spatial Dependence of Stress Parameter Δσ





Spatial Dependence of Stress Parameter Δσ





- Std$_{log10}$ for Cluster 1-8 is 0.30, 0.24, 0.33, 0.27, 0.23, 0.29, 0.18 and 0.24, respectively;
- Reduction of 17%, 33%, 8%, 25%, 37%, 19%, 49%, and 32% relative to Cluster 0 (the entire dataset, i.e., 0.36).

Summary

- ❑ $\Delta\sigma$ displays a statistically significant spatial clustering, which can explain a sizable portion of its variability.

Next steps:

- ❑ To what extent the portion of $\Delta\sigma$ variability explained via spatial clustering can be translated to improvement in ground-motion prediction?

- ❑ Refine Q structure in NZ;

Thank you !

- Big data;
- Advanced algorithm;
- HPC;
- Automate and iterate;