USING FORESHOCKS, AFTERSHOCKS AND SEQUENCES TO PROBE EARTHQUAKE NUCLEATION

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1. MOTIVATION

We observe that earthquakes are clustered in space and time.

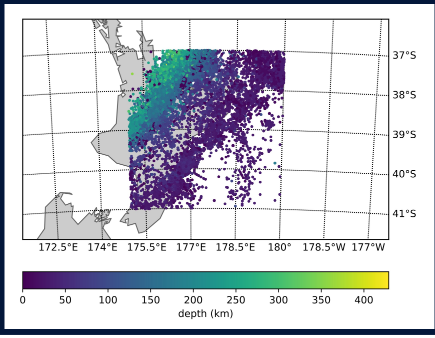
- There are two main hypotheses for this
    - **Single mode nucleation:** series of earthquakes occur, each triggering another event. One of these happens to grow much bigger.
    - **Complex extended nucleation:** earthquakes triggered by aseismic slip or pore pressure changes.
- Currently, the main limitation is a lack of high quality observations of foreshocks.
- We wanted to test which of these is happening by examining the timing of numerous earthquakes.

2. PHASE COHERENCE METHOD

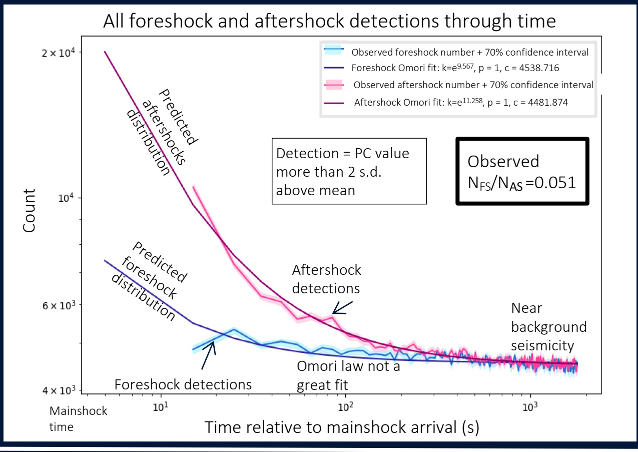
Rationale

- Looking for foreshocks and aftershocks close to the mainshock in space and time.
- Compares the seismograms produced by two sources, recorded at multiple stations → allows the identification of similar co-located sources.
    - Must be on same fault plane and have similar focal mechanisms.
- Use the mainshock as a template, and calculate the phase coherence for different time windows along the record.
- Peak in phase coherence where there is a good match between mainshock template and part of the signal being considered.
- See *Hawthorne and Ampuero (2017)*

- Used **11236 M3+ earthquakes** on the Hikurangi subduction zone, NZ.



3. DETECTIONS WITH PHASE COHERENCE



3a. PREDICTED RATIO

1. Find ETAS parameters using *BayesianETAS* r package.

2. Use *Shearer (2012)* equations for $\frac{dN_{AS}^{obs}}{dm}$ and $\frac{dN_{FS}}{dm}$.
Correct for aftershocks of smaller events in the sequence, and of earlier events.

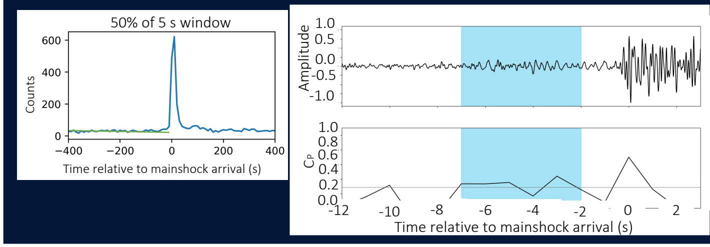
2a. Find branching ratio with *Seif et al (2017)* → r = 0.643

3. Using mainshock numbers, work out total expected numbers of foreshocks and aftershocks for all mainshocks in the catalogue.

4. Expected foreshock/aftershock ratio found! → N_{FS}/N_{AS}=0.163

4. SEQUENCES

- Search our detections for densely spaced foreshock sequences.
- Have previously occasionally been observed before mainshocks, suggesting externally driven processes are at play.
- We find sequences by looking at proportion of time window with detections in it
- We find a statistically significant (but hard to see) increase in sequences before the mainshock, but these are much less obvious than those found previously.



5. CONCLUSIONS

- We find a foreshock:aftershock ratio of 0.051 using phase coherence.
- This is lower than expected from single-mode triggering nucleation (0.163).
- See an increase in sequences just before the mainshock.

- Foreshocks not as well fitted by Omori law
- Detected events down to M0.7! So unlikely to have missed lots of foreshocks.
- If we take aftershocks as being explained by single-mode triggering, need some external process to explain reduced foreshock numbers and poorer fit by Omori's law.
- Nucleation is more complex than single mode triggering implies → external processes likely involved.
- Increase in sequence detections before mainshock also suggests more complex nucleation
- Fits with *Shearer (2012)* results in California.