Exploring the Increasing Prevalence of Swarms and Foreshocks in Tiny Earthquakes as Detected by Recent High-Sensitivity Earthquake Catalogs

Taiga Morioka[1], Peter Shearer[1], Wenyuan Fan[1]

1. Scripps Institution of Oceanography, University of California San Diego, La Jolla, CA, USA

2026 SCEC Annual Meeting
Poster 143

1. Is aftershock triggering self-similar with respect to mainshock's magnitude?

- Many triggering models (ex. [4]) assume the average number of directly triggered aftershocks by mainshock is scaled by mainshock magnitude:
  - $N = Q10^{\alpha(m-m_1)}$
    - Q: aftershock productivity
    - α: constant
    - m, m_1: mainshock & minimum triggering event magnitudes
- These models predict **self similarity** where **event rates within ΔM are**, on average, **constant** regardless of mainshock magnitude.

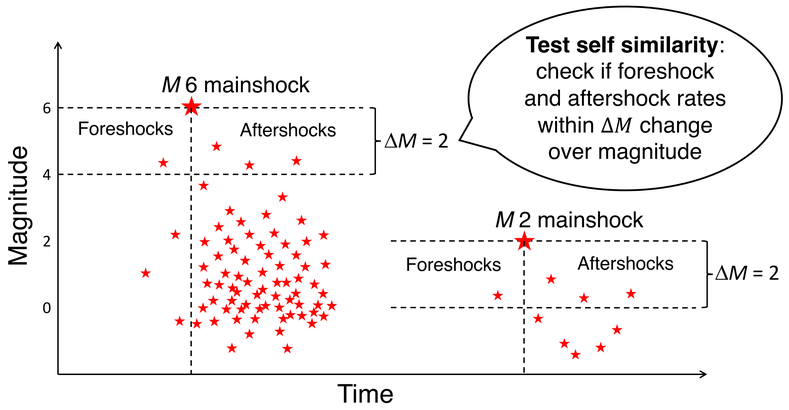


Figure 1: Illustration of self similarity. M 6 mainshocks have the same average rate of $M > 4$ foreshocks and aftershocks as M 2 mainshocks have of $M > 0$ foreshocks and aftershocks.

2. Our experiment: locating small events with multiple arrays

- Deployed **5 nodal arrays** around the San Jacinto Fault from **November 6th, 2024**, to **February 9th, 2025**

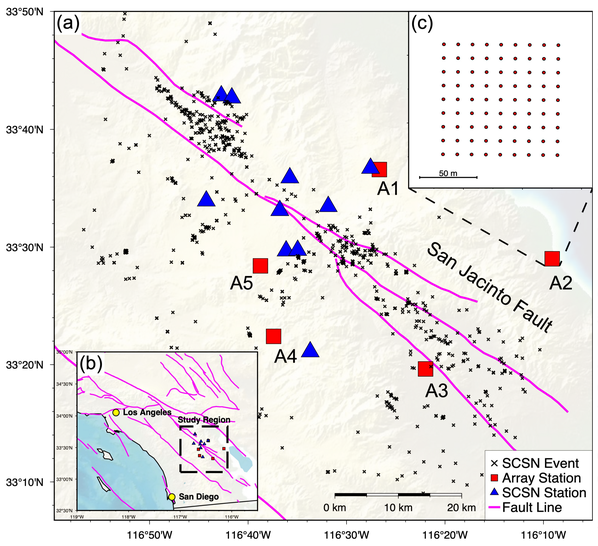
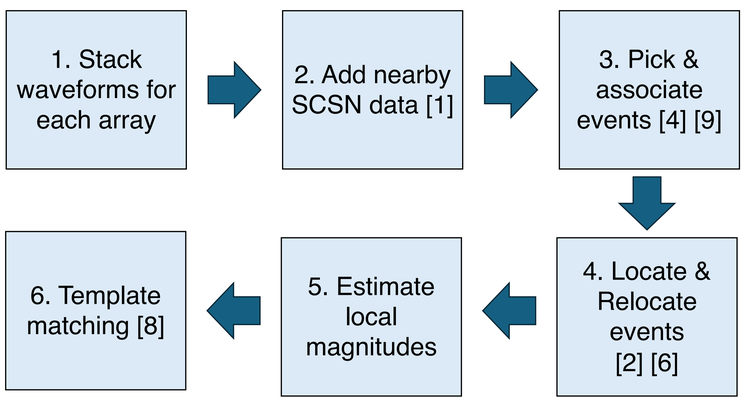


Figure 2: (a) Map of nodal arrays (red squares) deployed in our experiment and the SCSN stations added in the catalog creation procedure (blue triangles) with nearby fault lines (pink lines) and seismicity from the SCSN standard catalog (black crosses). (b) Overview map of the study region shown in a black dashed square, and the nearby major cities are indicated as yellow dots. (c) Close-up map of A2 array, one of the five arrays deployed for this study. Red dots show seismometer locations.

3. Enhance our catalog by machine-learning (ML) and template-matching (TM) detection methods

- **Catalog creation workflow**



4. Our catalog contains 10 times more events than standard regional catalog.

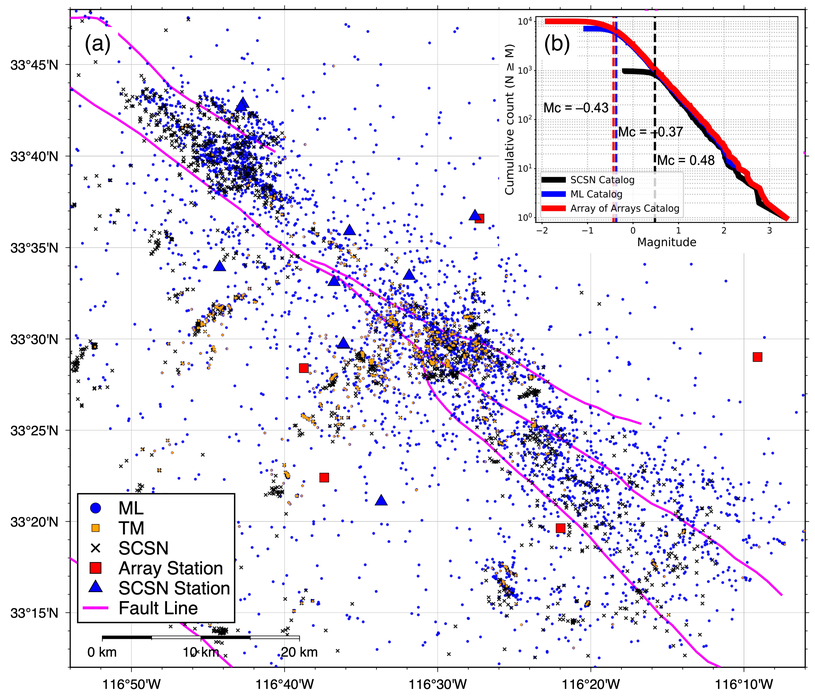


Figure 3: (a) Map of detected seismicity in our catalog (blue dots for events detected by ML method and orange squares for ones from TM method) and SCSN events (black crosses) overlaid on Figure 2. (b) Cumulative number of detected events versus local magnitude, along with magnitude of completeness (M_c) for the SCSN catalog (black curve and vertical dashed line; $N = 975$ and $M_c = 0.48$), our catalog based on only ML-based detection steps (blue; $N = 7{,}183$ and $M_c = -0.37$) and our catalog based on both ML and TM-based detection steps (red; $N = 10{,}126$ and $M_c = -0.43$). The magnitude of completeness for each catalog is estimated by the goodness-of-fit method with 90% confidence interval [7].

5. Compare our catalog with larger scale catalogs

- **QTM Catalog** [5]:
  - Template-matching enhanced SCSN catalog (Southern California)
  - 2008-2018
  - Mc = 0.3
  - N = 1.8 million
- **GENIE Catalog** [3]:
  - Deep-learning enhanced NCEDC catalog (Northen California)
  - 2000-2024
  - Mc = 0.8
  - N = 1.9 million

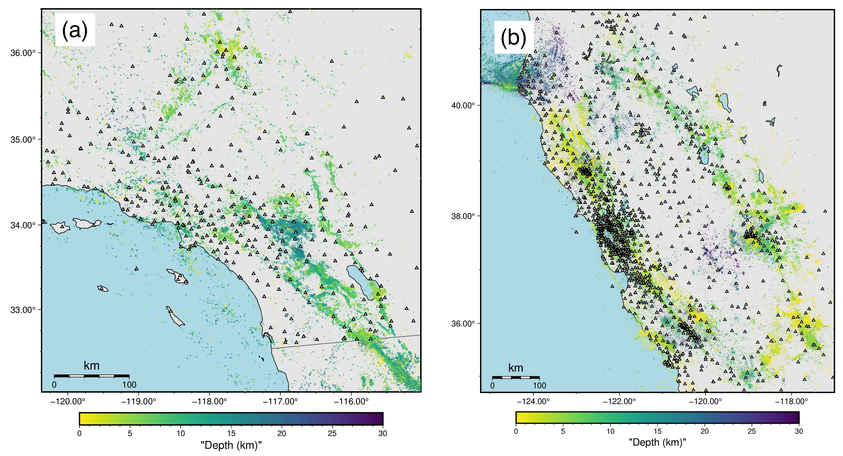
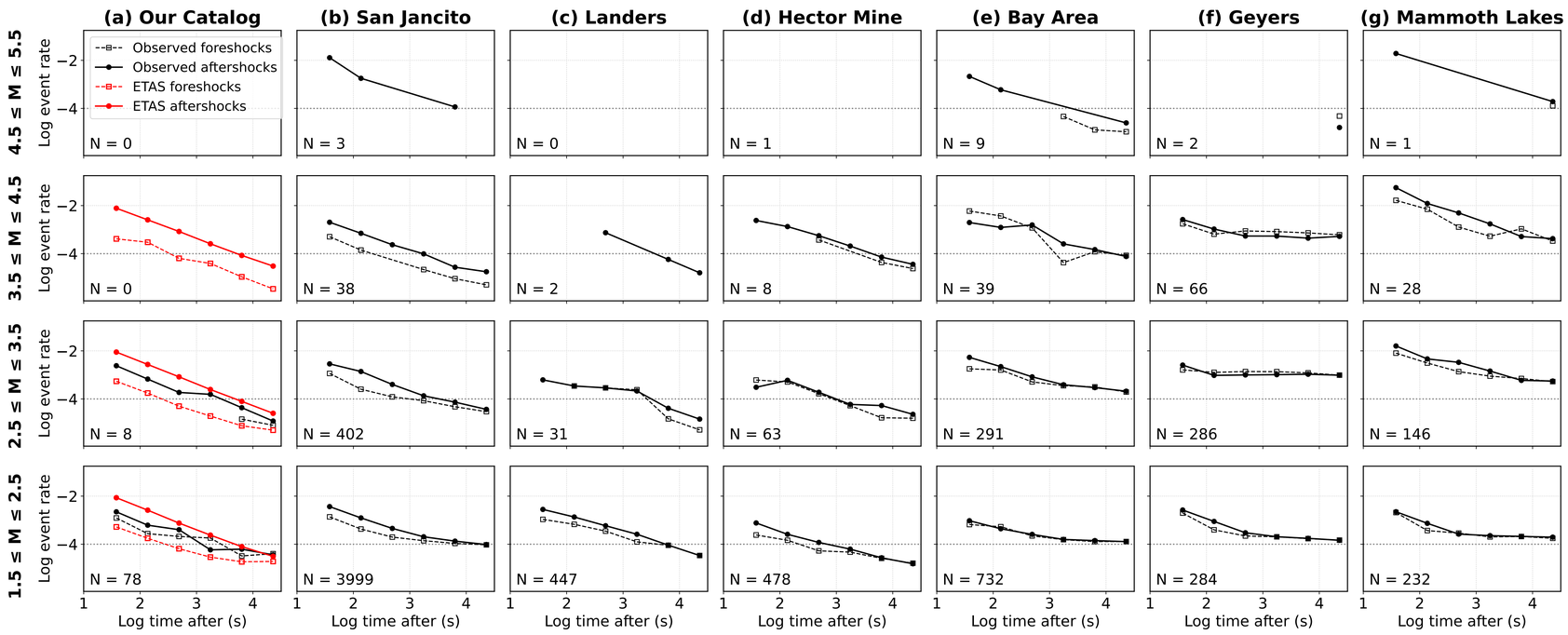


Figure 4: (a) Map of seismicity from QTM catalog. Each event is color-coded by depth. Triangles show the stations used to create the catalog. (b) Map of seismicity from GENIE catalog.

6. Is self similarity preserved in seismicity from different regions in California? Probably not.

- Obtain "**mainshock**" events by choosing **the largest event within 12 hours and 5 km nearby** (1 km for Geysers)
- Compute "**event rate**" = **(number of foreshocks and aftershocks within $\Delta M = 2$ w.r.t. "mainshock") / (number of "mainshocks" × width of time bin)**



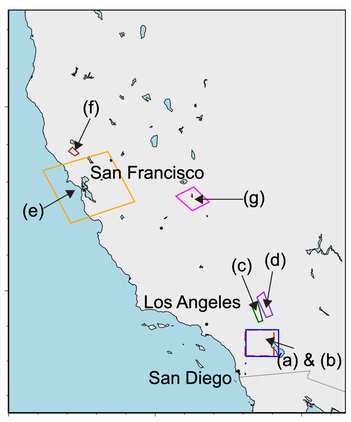


Figure 5: **(Above)** Computed mirrored foreshock rates (unfilled squares) and aftershock rates (filled circles) for different mainshock-magnitude ranges and regions. *N* indicates the number of sequences associated with the selected mainshocks. Red markers show event rates from ETAS simulations with 5 million background events. Observed aftershock rates increase with mainshock magnitude in most regions (e.g., panels (d)–(g)), whereas the ETAS predictions remain approximately constant across the magnitude ranges. The observed event rates are approximately symmetric in time around the mainshock, whereas ETAS predicts asymmetric foreshock and aftershock rates. **(Left)** Map showing the regions used in the above panels. Each colored box indicates the area from which seismicity is selected to compute the event rates.

7. Summary and Future Work

1. Our nodal arrays, combined with SCSN stations, machine-learning detection, and template matching, detected **~10x more earthquakes** than the standard catalog.
2. Analysis of event rates reveals that **aftershock rates depend on mainshock magnitude** in most regions.
3. This finding suggests that seismicity may **deviate from self-similar behavior** at smaller magnitudes.
4. Our results indicate that studying hidden small earthquakes may provide **a clearer picture of earthquake interactions**.

Acknowledgements: Special thanks to Ian McBrearty for providing the GENIE catalog.

References [1] California Institute of Technology, Southern California seismic network, 1926. [2] Lin & Shearer, *Seismological Research Letters*, 2006. [3] McBrearty et al., Stanford Digital Repository, 2025. [4] Mousavi et al., *Nature Communications*, 2020. [4] Ogata, Journal of the American Statistical Association, 1988. [5] Ross et al., Science, 2019. [6] Trugman & Shearer, *Seismological Research Letters*, 2017. [7] Wiemer and Wyss, Bulletin of the Seismological Society of America, 2000. [8] Zhang and Wen, Geophysical Journal International, 2015. [9] Zhu et al., *Journal of Geophysical Research: Solid Earth*, 2022.