Earthquake Forecasting Using Single-Station Waveform Detection Without Reliance on Event Catalogs

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One-sentence summary:

Earthquake forecasting can be effectively achieved using detections from single-station waveforms, highlighting the potential of employing the waveform itself to enhance predictive capability.

Introduction

Neural temporal point process models, RECAST, surpass ETAS given sufficient data (Dascher-Cousineau et al., 2023)

- Predictive skill depends on catalog quality.
- Small earthquakes can together yield predictive power comparable to larger events.

Waveform-based methods should detect small events and enhance prediction.

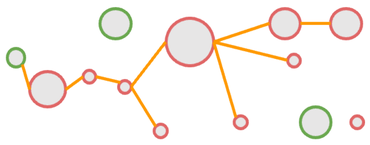


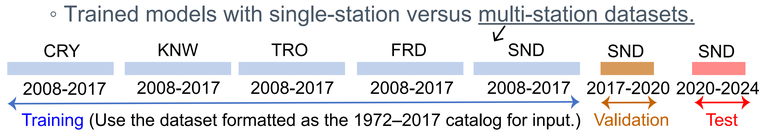
Figure 1. Schematic view of history-based earthquake forecasting strategies.

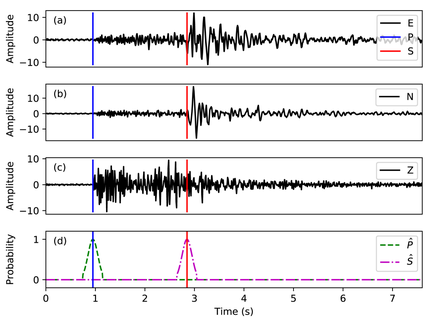
Data and Methodology

1. Constructed event catalogs from single-station waveforms (Anza) using PhaseNet (Zhu and Berroza, 2019; Guo et al. 2024)
2. Input the catalog into RECAST for earthquake prediction.

Experiments:

- Varied the P/S detection probability threshold (0.1–0.7).
- Compared performance with the ETAS model (Ogata et al., 1988).
- Trained models with single-station versus multi-station datasets.





Event criteria

- Both P- and S-wave arrivals
- S–P interval < 5 s (~40 km from the station)

Data period

- Training: 2008-2017
- Validation: 2017-2020
- Test: 2020-2024

Figure 2: Waveforms and Associated Probability of P and S wave picks from PhaseNet (Figure from Zhu & Beroza, 2018)

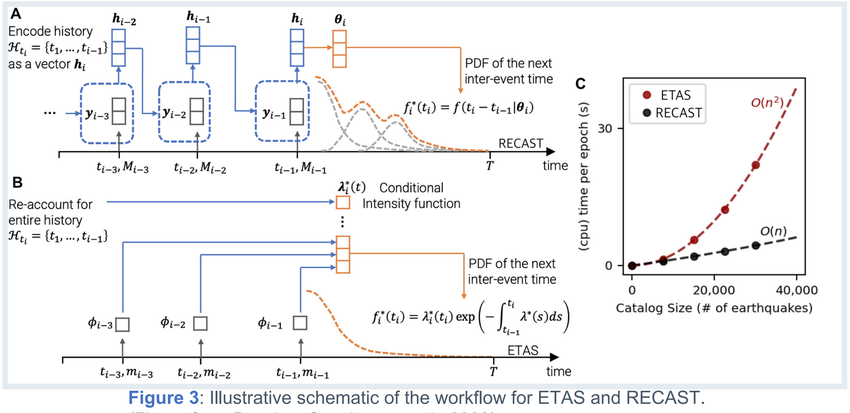


Figure 3: Illustrative schematic of the workflow for ETAS and RECAST. (Figure from Dascher-Cousineau et al., 2023)

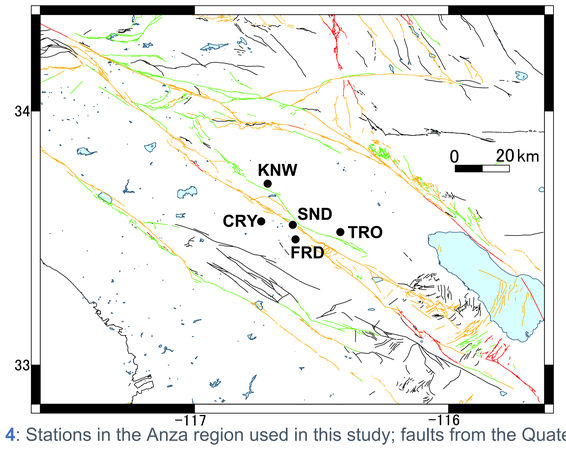


Figure 4: Stations in the Anza region used in this study; faults from the Quaternary Fault and Fold Database.

Results

Single-station prediction is effective.

- RECAST surpasses ETAS.
- Multi-station training outperforms single-station training
  - Even when the stations are in close proximity

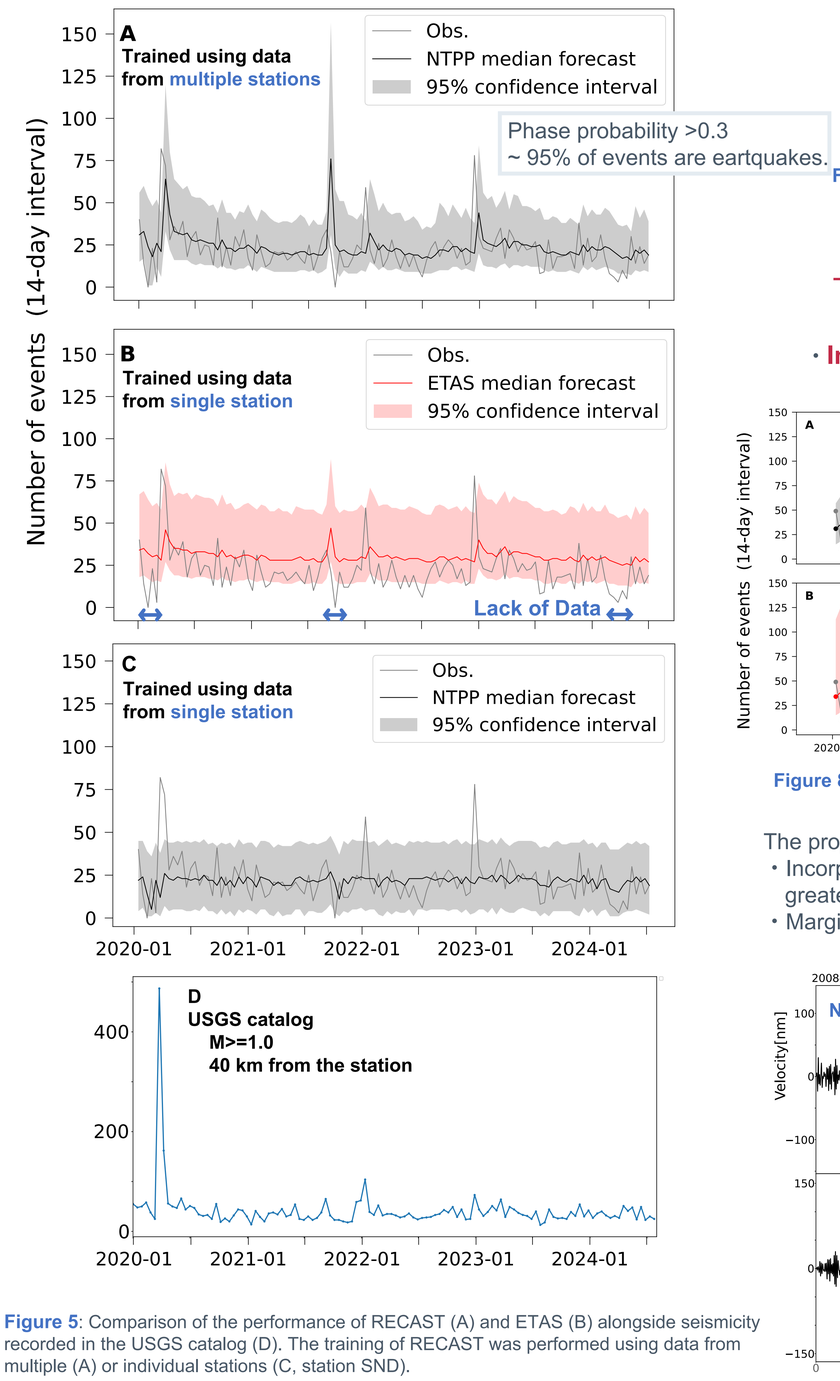


Figure 5: Comparison of the performance of RECAST (A) and ETAS (B) alongside seismicity recorded in the USGS catalog (D). The training of RECAST was performed using data from multiple (A) or individual stations (C, station SND).

- The catalog derived from a single station effectively reproduces both Omori's Law and the Gutenberg-Richter statistics.

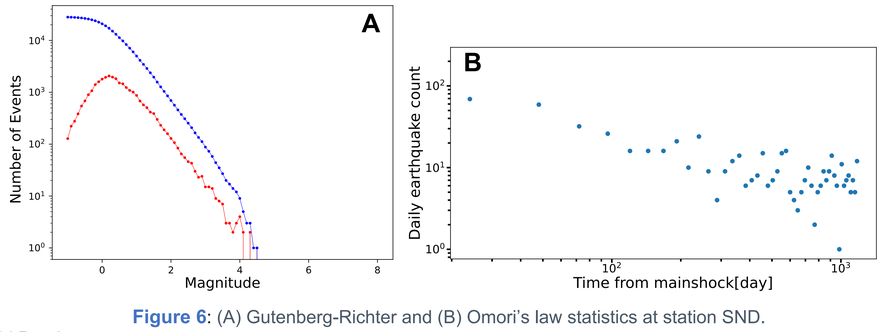


Figure 6: (A) Gutenberg-Richter and (B) Omori's law statistics at station SND.

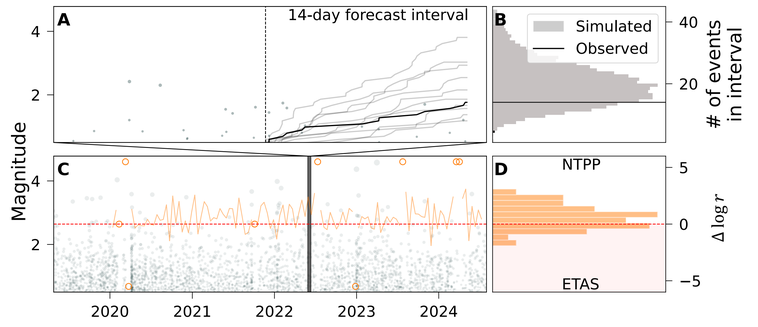


Figure 7: Simulated trajectories over forecast intervals and evaluation of earthquake forecasts.

$$\log r = \log\left(\sum_{k=1}^{N_{tot}} I(n_k = n_{obs})/N_{tot}\right) \qquad \Delta \log r = \log r_{RECAST} - \log r_{ETAS}$$

Discussion

- **Input P/S phase probabilities with magnitude and time into RECAST**
  →Weighted by data quality

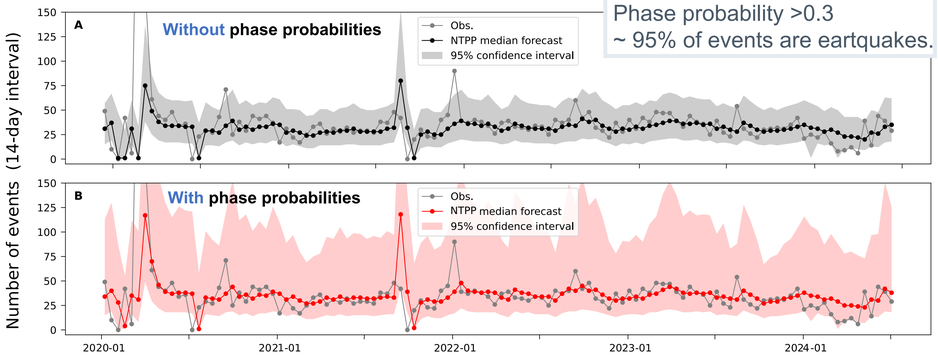


Figure 8: Comparison of RECAST performance without(A) and with(B) phase probability incorporation (station KNW).

The proportion of noise is relatively minor (~5%).

- Incorporating probabilities introduces greater uncertainties.
- Marginal improvement?

Future work:

- **Direct utilization of the waveform**

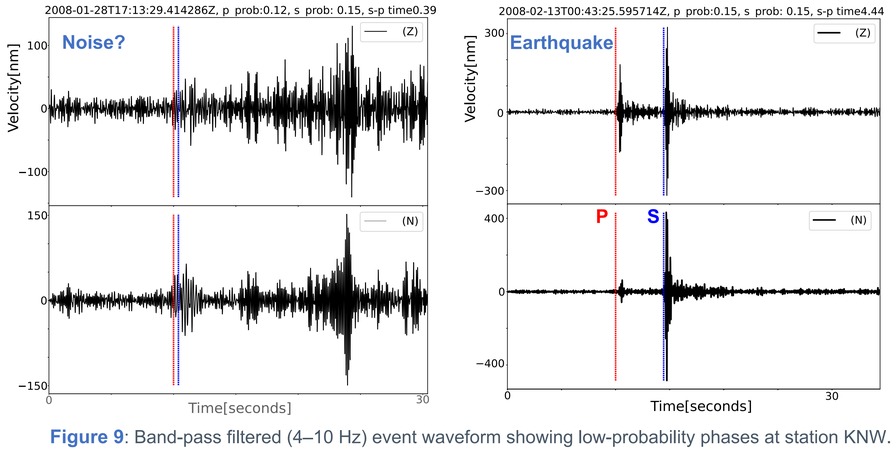


Figure 9: Band-pass filtered (4–10 Hz) event waveform showing low-probability phases at station KNW.

References

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Acknowledgements

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