Employing the Full Joint Hypocenter Covariance for Identification of Repeating Earthquakes

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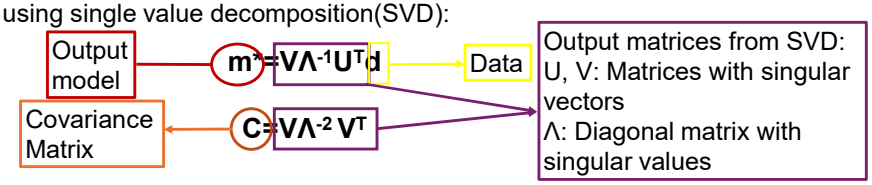
Introduction

- Discrimination of true repeating earthquakes from those that are only neighbors requires careful attention to hypocenter and hypocentroid uncertainty (e.g. Uchida and Burgmann, 2018).
- Assessment of source overlap, rather than simply waveform similarity is the critical step for determining if events are true repeaters or not (Gao et al., 2023)
- Because location uncertainties are correlated between events, accounting only for individual location variance may lead to both false positive and false negative results.
- Here, we show how to properly resample the full covariance matrix for assessment of candidate repeaters.

Methods

Simple Synthetic Test Set Up

- Set up the basic equations from the double difference problem in a single layer using single value decomposition(SVD):



- Applied small amounts of random noise to the arrival times used as "data"
- Allowed arbitrary station locations and event locations relative to the stations: Consider output covariance and correlation matrices
- Cases at the center, edge, and degraded networks

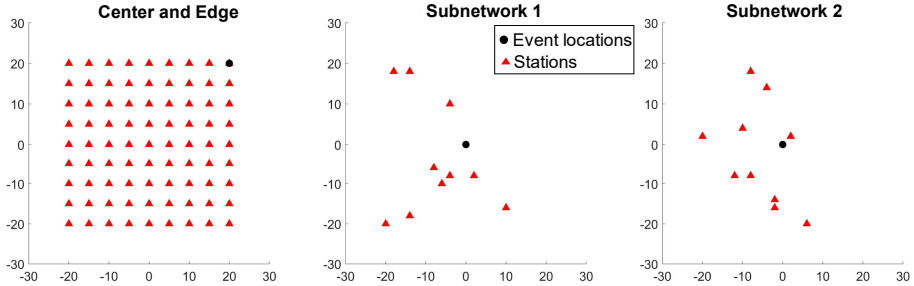
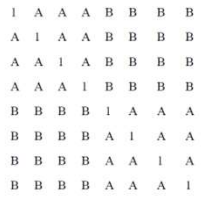


Figure 1: Station networks for synthetic tests

- Compare output correlation matrices with constructed simple ones of this form:
  - A: Covariance within event
  - B: Covariance between events



Cases:
A=0.9, B=0.9 (positively correlated)
A=0.9, B=-0.9 (negatively correlated)
A=0.9, B=0.25 (weakly correlated)
A=0, B=0 (independent)

Sampling With Covariance

- As in Ries et al. (2025) stress drops are independently sampled for both events from distributions in Figure 4
- Select location perturbations based on location covariances by applying the Cholesky decomposition such that: $C=LL^T$
- Allow for the location perturbations (X) to be produced from mean location (μ) modifying standard normal random values (Z): $X= \mu+LZ$
- Apply to scaled amounts of location error from 5 m to 250 m over a range of magnitudes

Results and Discussion

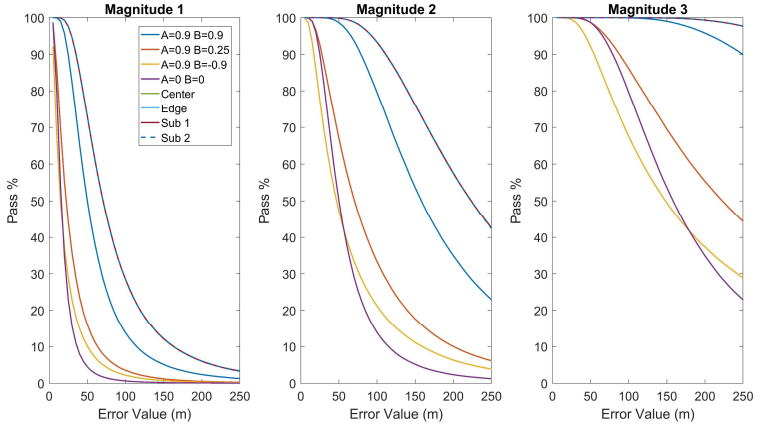


Figure 2: Results from randomized location perturbation as %pass (percent of trials sufficiently overlapped to be called repeaters) vs. error value starting from complete overlap

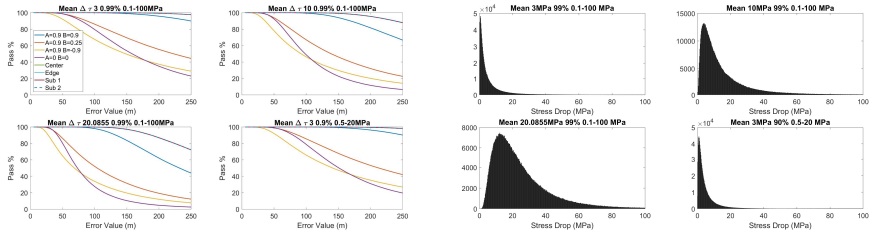


Figure 3:Comparisons with different stress drop distributions, all showing magnitude 2 starting completely overlapped

Figure 4: Stress drop distributions used for the random selection of stress drop values for each event

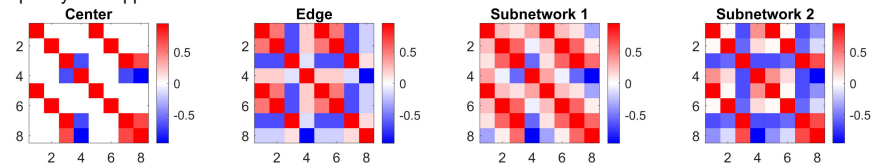


Figure 5: Correlation matrices from synthetic tests with station geometries shown in Figure 1

- Location errors can be important to identification of repeating earthquakes
- Because location uncertainties are correlated, accounting for only variance may influence results for repeating earthquake identification
- Covariance between events is an important factor for these synthetic cases, particularly X1-X2 correlation
- Negatively correlated events (B<0) appear to have potential to be less likely to produce repeaters though none of the single layer synthetic locations gave negative values for the X1-X2, Y1-Y2, or Z1-Z2 components

Conclusions

- Based on the synthetic experiments we've conducted, including the covariance between events can change the assessment of potential repeating earthquakes

Future Work

- Apply this to real earthquakes in the Caldwell Kansas sequence featured in Ries et al. (2025)
- Further investigate origins/controls of covariance matrix in hypoDD

References

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Waldhauser, F., and W. L. Ellsworth (2000). A double-difference earthquake location algorithm: method and application to the northern Hayward fault, California, Bull. Seismol. Soc. Am. 90, no. 6, 1353–1368.
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Gao, D., H. Kao, and J. Liu (2023). Identification of Repeating Earthquakes: Controversy and Rectification, Seismol. Res. Lett. 94 (6), 2655-2665.