Poster 81

Systematic Measurements of Rupture Directivity for Small-to-Moderate Earthquakes in California

NEVADA SEISMOLOGICAL LABORATORY

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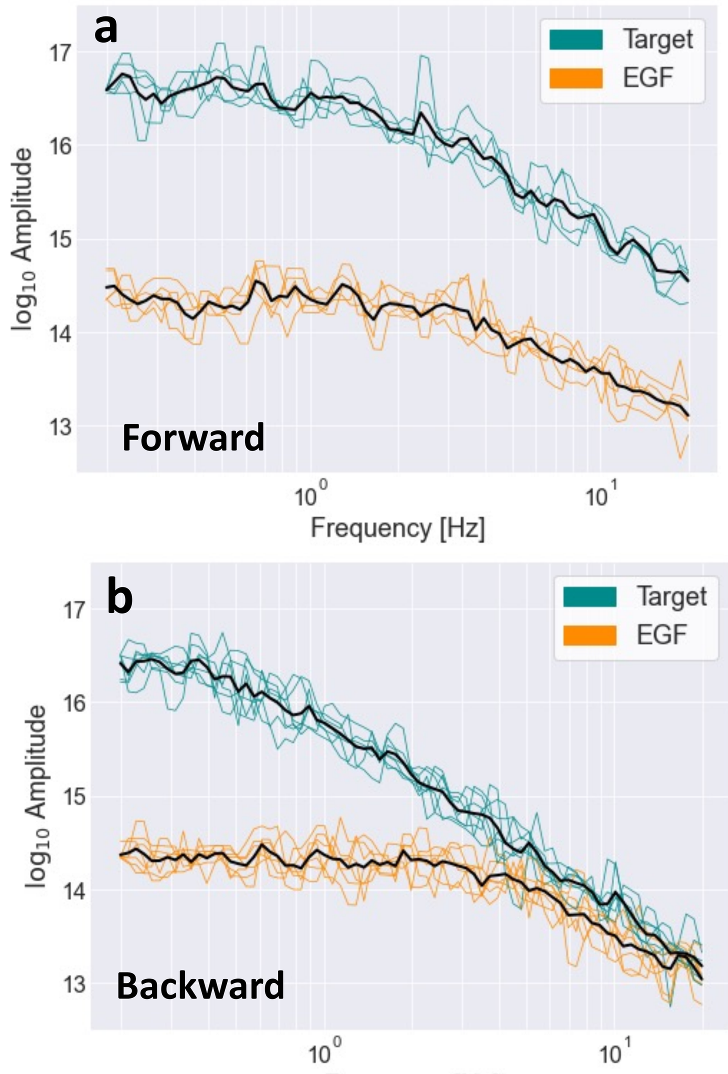
Background & Method

Rupture directivity is the tendency of some earthquakes to exhibit azimuthal variations in shaking duration and intensity due to a Doppler-like motion of the rupture front. This variation tends to increase ground motion in along-fault directions. In addition to azimuth, the degree of directivity is dependent on two main factors:

- Normalized rupture velocity
- Distance from the hypocenter to the nearest end of the rupture



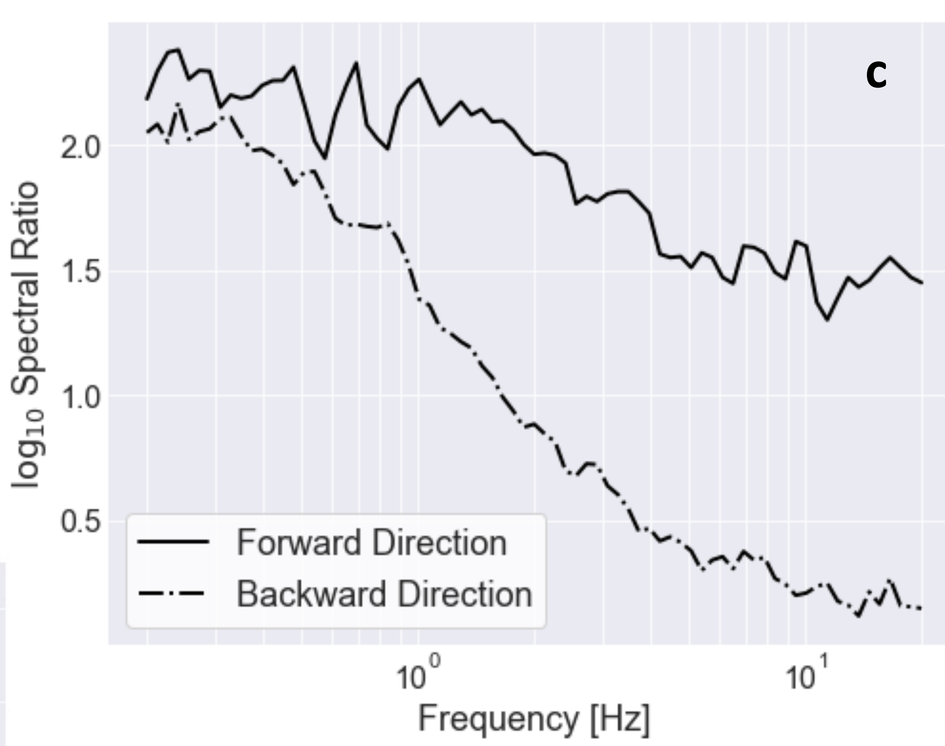


Figure 1. Synthetic tests showing strong directivity in the forward direction. **(a)** Synthetic spectra at all "stations" in the forward direction. **(b)** Synthetic spectra at all "stations" in the backward direction. **(c)** Spectral ratios averaging all "stations" in the forward and backward directions.

To calculate directivity, we use an Empirical Green's Function method. EGFs are needed to cancel out path and site effects, thereby reducing the seismogram to only the source signal. For each target event, EGFs must:

- Be 1-2 magnitude units smaller than the target
- Be close to the target event
- Have a similar focal mechanism (i.e., Kagan angle)
- Be recorded by 10+ of the same stations as the target event, ideally in all directions

We use the directivity index (DI) method of Ross & Ben-Zion (2016) and Calderoni *et al.* (2023). The DI method finds the difference in spectral ratio amplitude averaged across stations at all azimuths. Then, we weight DI for each event based on the quality of each EGF (Figure 2).

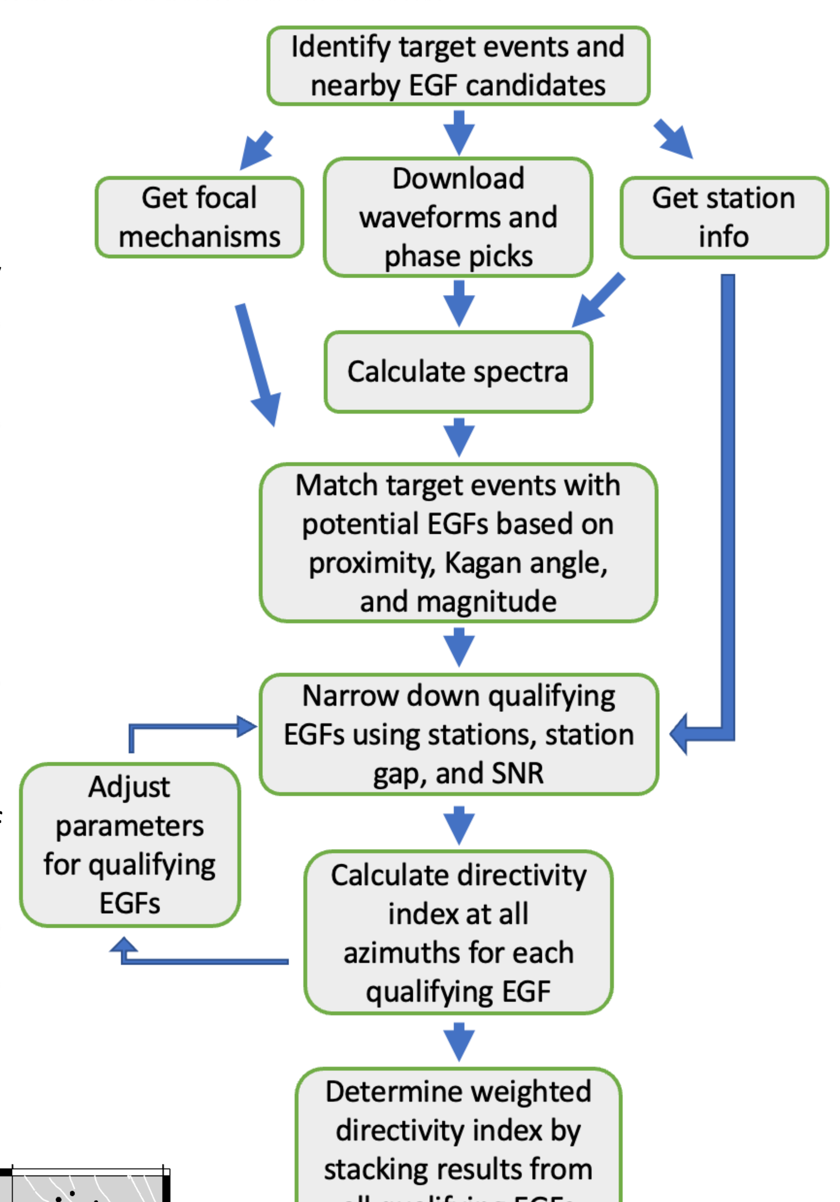


Figure 2 (above). Workflow for calculating directivity index, beginning with choosing potential target and EGF events, and concluding with weighting DI for a single event.

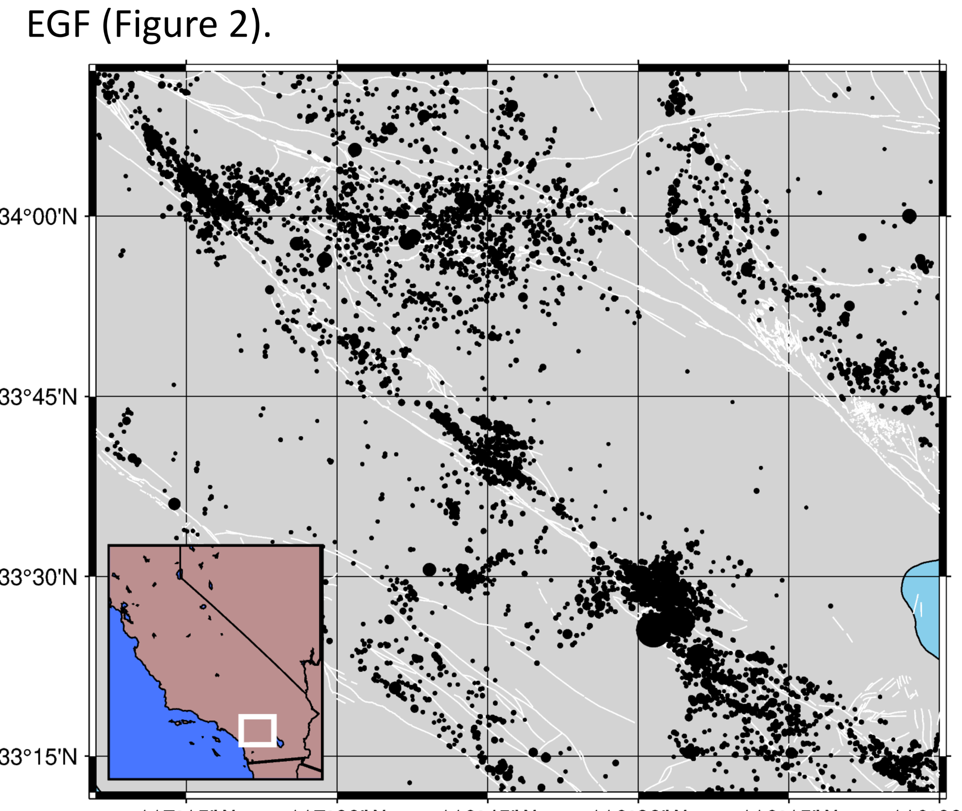
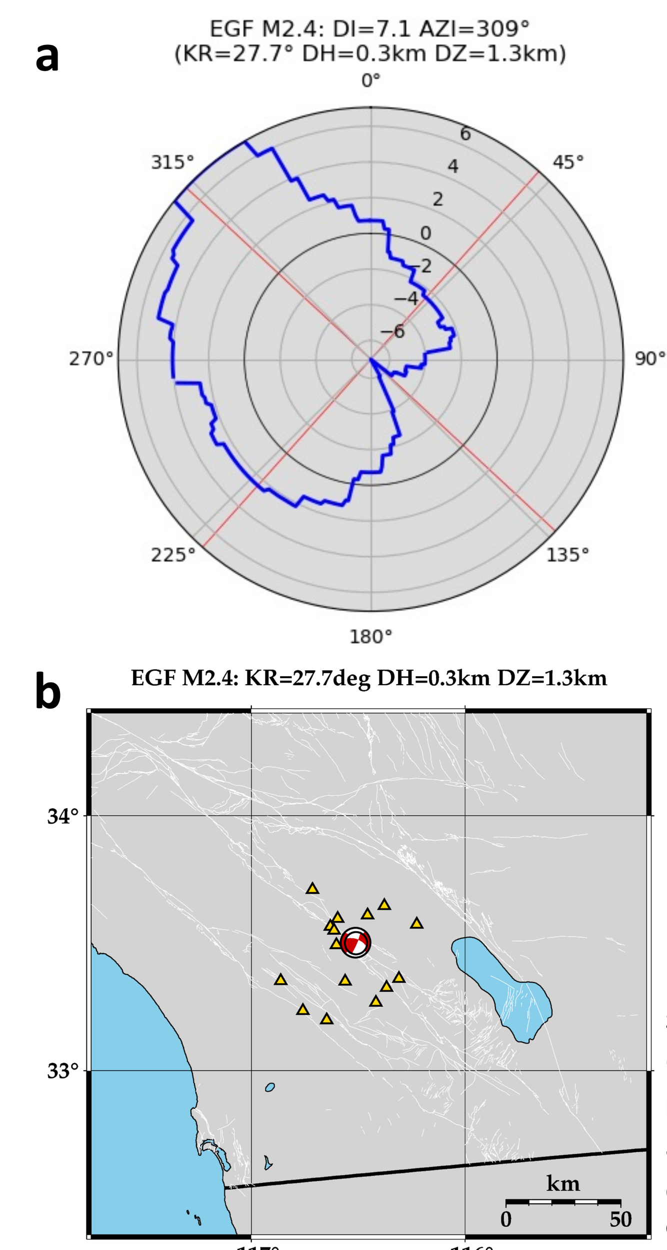


Figure 3 (left). Our initial study area was the San Jacinto Fault Zone (SJFZ) and the surrounding region. We began with all events M1.5+ that occurred between 2008 and 2022 (black, sized by magnitude). We then narrowed down the dataset to only keep strike-slip events that had focal mechanisms (Cheng et al., 2023), allowing for easy determination of the similarity between the target and EGF events.

Results

We measured rupture directivity for all M3+ earthquakes with qualifying EGFs in the SJFZ and surrounding area, resulting in directivity measurements for 56 events. Of these events, 36 had significant directivity based on our EGF weighting scheme. As expected, rupture directivity in the SJFZ is primarily oriented northwest or southeast, aligned with the main fault trace (Figures 5 and 6).



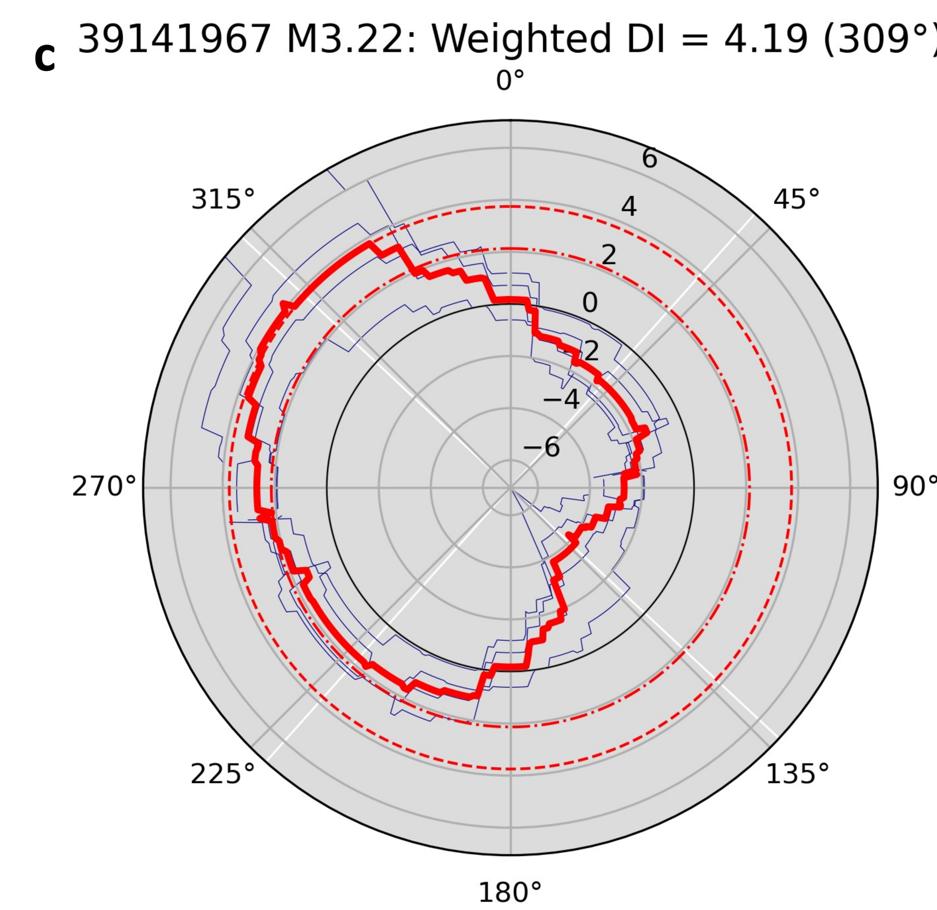
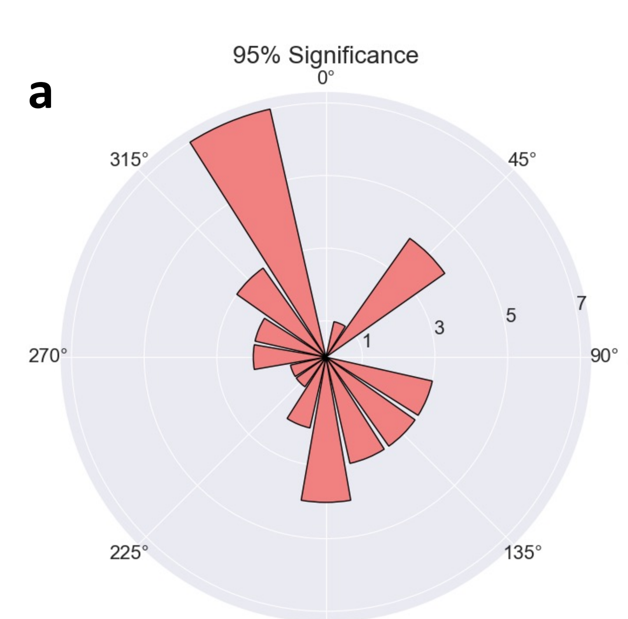


Figure 4. Example of strong rupture directivity measurements for a M3.2 earthquake. **(a)** Azimuthal variation in DI for a single EGF showing peak DI to the northwest (blue) with focal plane strikes (red). **(b)** Map of target and EGF focal mechanisms and the stations that recorded both events. **(c)** Azimuthal variation of weighted DI (red) along with DI of all qualifying EGFs (blue). The strike of the target event's focal planes are plotted in white, and red dotted lines indicate 95% and 99% t-statistic significance.



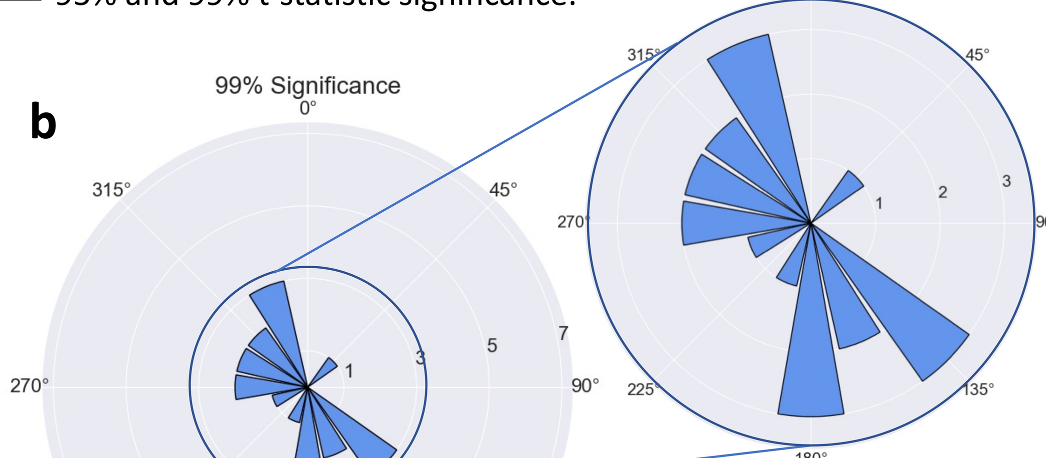
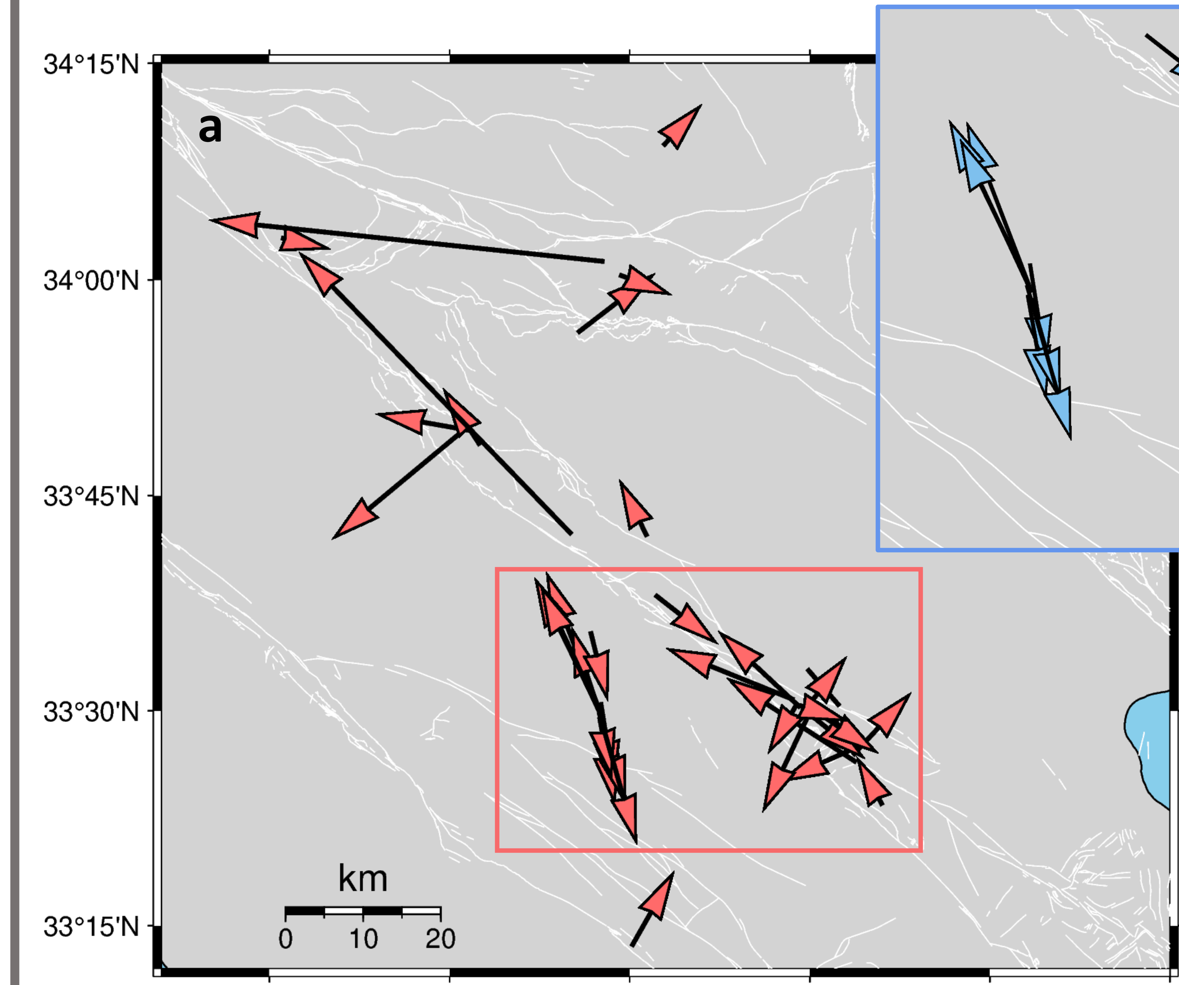


Figure 5. Rose diagram showing azimuthal distribution of maximum DI for events with **(a)** 95% significance and **(b)** 99% significance.



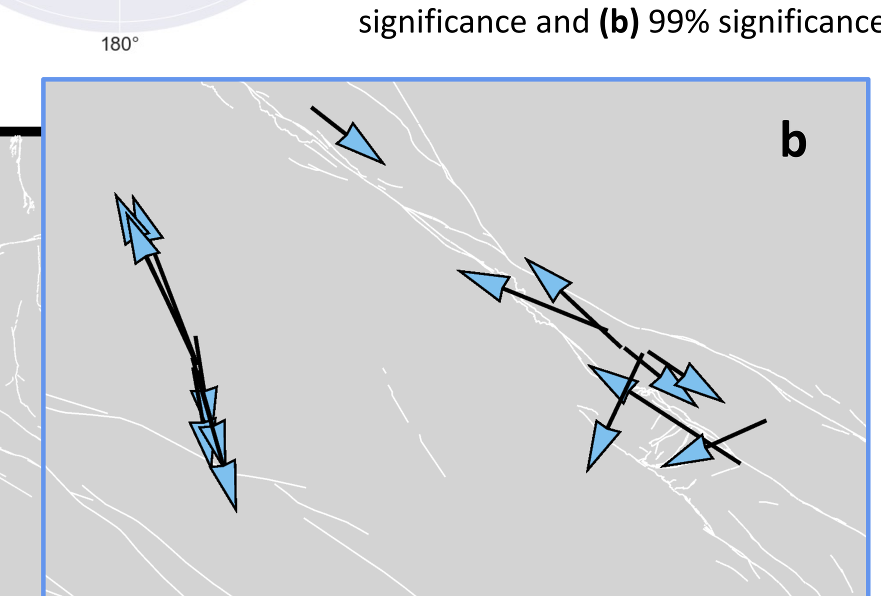
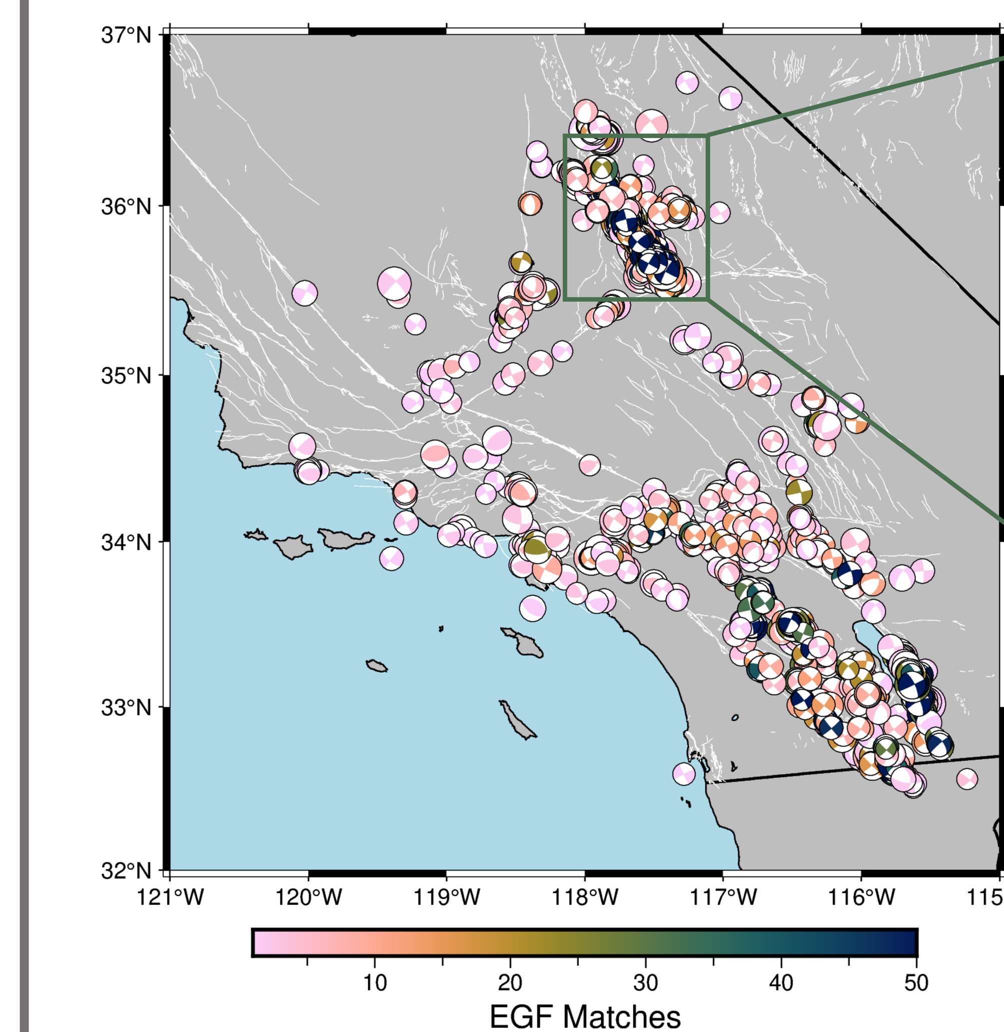


Figure 6. Direction and DI of events with significant rupture directivity in the SJFZ (Figure 3). **(a)** DI of events with 95% significant directivity. **(b)** DI of events with 99% significant directivity, focused on the SJFZ trifurcation zone and the 2016-2019 Cahuilla earthquake swarm.

Discussion & Next Steps

We show that some events as small as M3 have measurable rupture directivity. Now that we have tested the DI method on a small area, we can expand our study area to the rest of California. Because of network differences, we will begin with southern California and include dip-slip events in addition to strike-slip events (Figure 7).



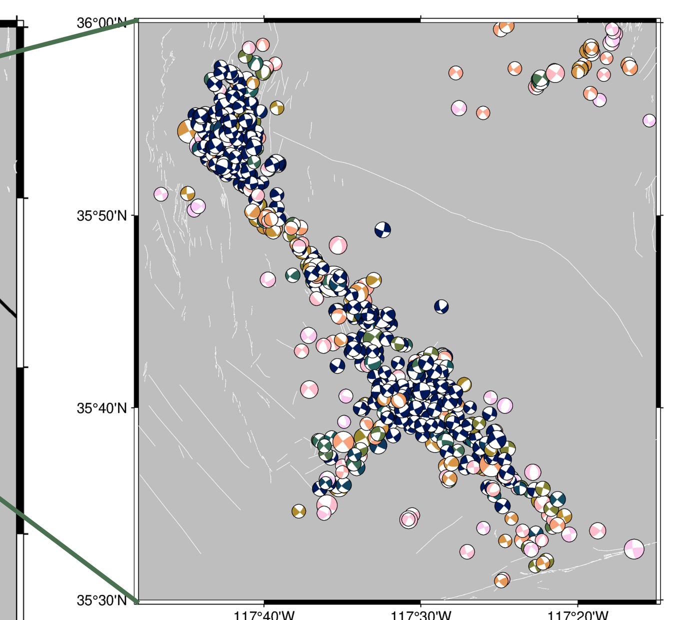
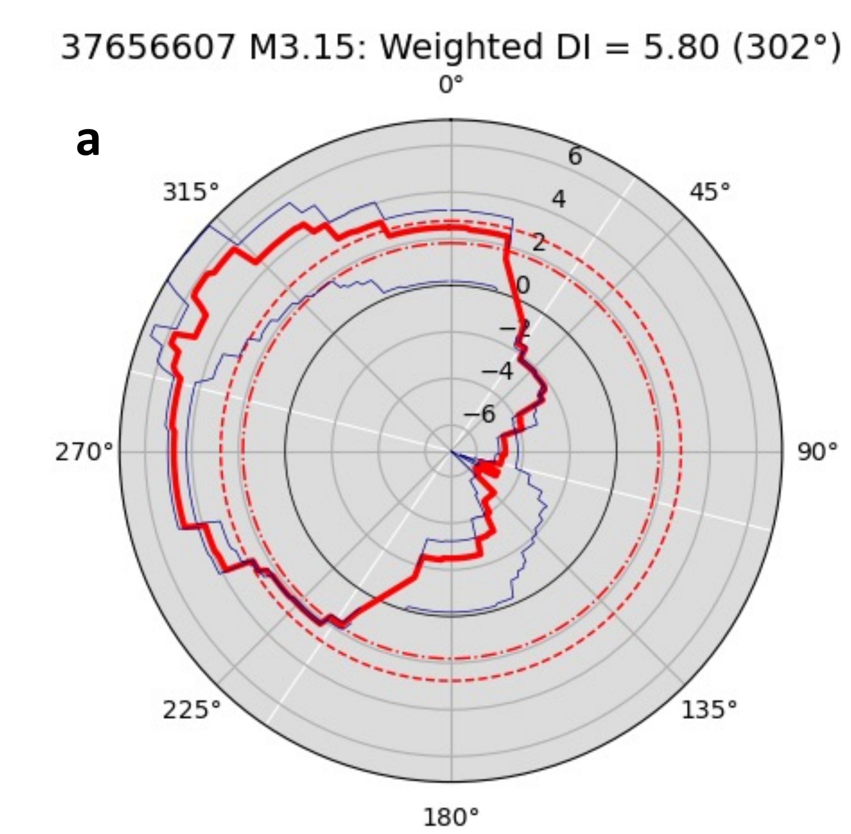


Figure 7. (left) Focal mechanisms of southern California earthquakes colored by the number of matching EGFs. EGF matches have a maximum Kagan angle of 45°, maximum horizontal and vertical distances of 3 km, and a minimum of 10 matching stations. This dataset will include dip-slip earthquakes as well as strike-slip. **(above)** Ridgecrest is another promising study area, with many earthquakes having over 40 matching EGFs.

Despite there being few dip-slip earthquakes in the SJFZ, one thrust event showed strong rupture directivity along the San Jacinto Fault to the north-northwest (Figure 8). A limiting factor for obtaining more robust measurements of the other dip-slip events was likely a lack of qualifying EGFs. Expanding this technique to more transpressional tectonic regions will likely resolve this issue.



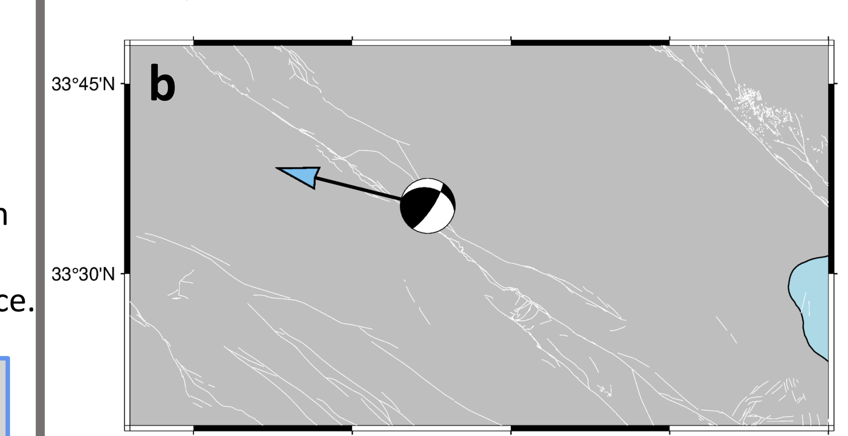


Figure 8. **(a)** Rose diagram of azimuthal variation of directivity for Event 37656607 using results from two EGFs. **(b)** Focal mechanism and directivity vector for Event 37656607.

Key Findings

- Many M3 earthquakes in the SJFZ have measurable rupture directivity trending to the NW and SE along the San Jacinto Fault Zone
- There is no clear directional preference of rupture directivity in the SJFZ
- The 2016-2019 Cahuilla swarm has consistent rupture directivity to the NW and SSE

Next Steps

- Expand our study area to include all M3+ earthquakes in California
- Re-evaluate method of determining EGF quality for the weighted directivity index
- Use our results to assess the extent of increased ground motion along active faults in high-risk areas

References

Calderoni, G., R. Di Giovambattista, and G. Ventura (2023). A Reliable Procedure to Estimate the Rupture Propagation Directions from Source Directivity: The 2016–2018 Central Italy Seismic Sequence, *Seismological Research Letters*, doi: 10.1785/0220220318.

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