Estimating Earthquake Source Parameters from S-Wave Maximum Amplitudes: Application to the 2019 Ridgecrest Sequence (#33)

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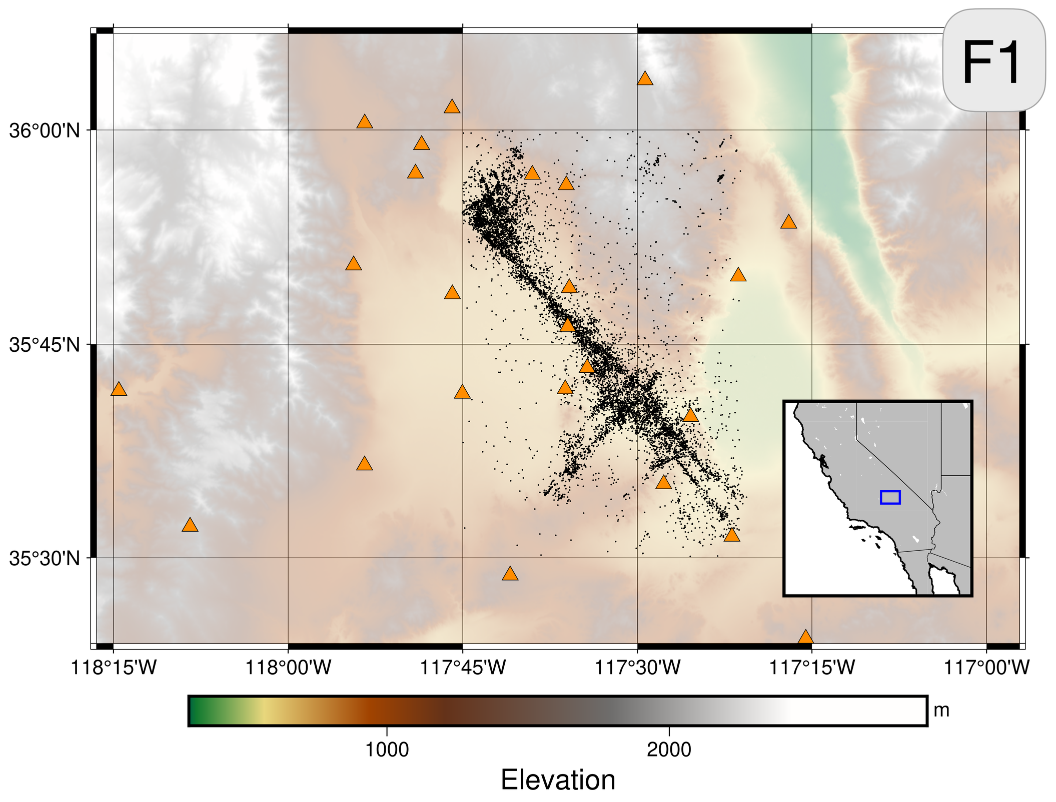
Stress Drop Reveals Earthquake Dynamics

Earthquakes radiate a wide spectrum of seismic energy, from which we can estimate source properties in an attempt to answer: **are small and large earthquakes fundamentally different?**

- **seismic moment** M_0 - related to earthquake energy release
- **corner frequency** f_c- the frequency where displacement spectrum begins falling off, and related to high-frequency ground motion
- **stress drop** $\Delta\sigma$ - change in average shear stress across a fault area due to an earthquake, and related to rupture dynamics. Higher stress drops correlate with stronger ground motion and may cause more damage

Using the Ridgecrest earthquake sequence dataset (**F1**), we design a new method, **amplitude decomposition** (**F2**), to estimate earthquake source spectra using measurements obtained in the time domain.

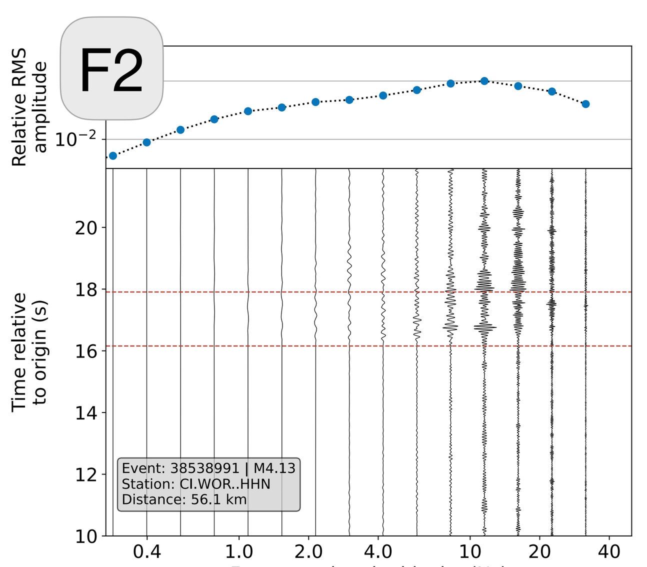


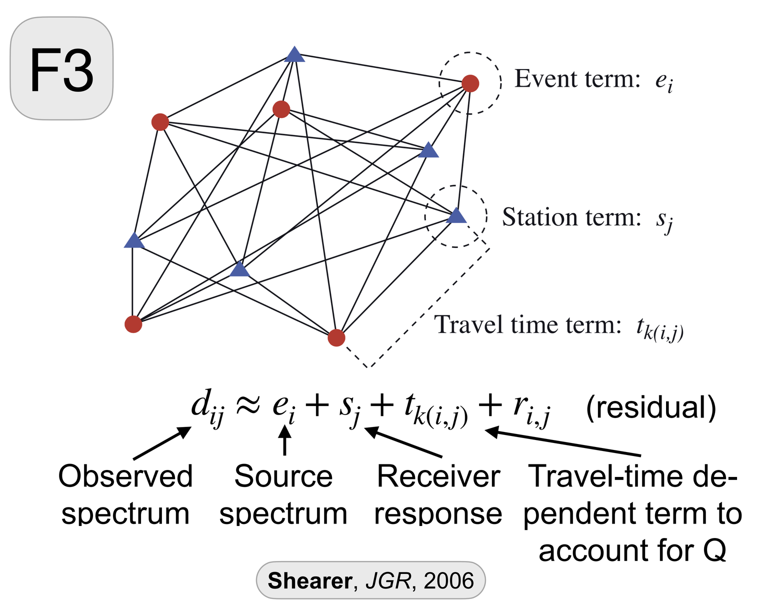
F1: Ridgecrest seismicity is shown as black dots, M>1.0, 4-18 July 2019, with a total number of 12,943 events. Orange triangles are some of the seismic stations used in the study.

Time-Domain Stress Drop Estimation

Step 1: We estimate S-wave spectra by measuring the maximum S-wave amplitude at different frequency bands (**F2**).

Step 2: We apply a general inversion technique to extract an uncorrected source spectrum for each event. Our method is similar to the ones used in spectral decomposition (**F3**).



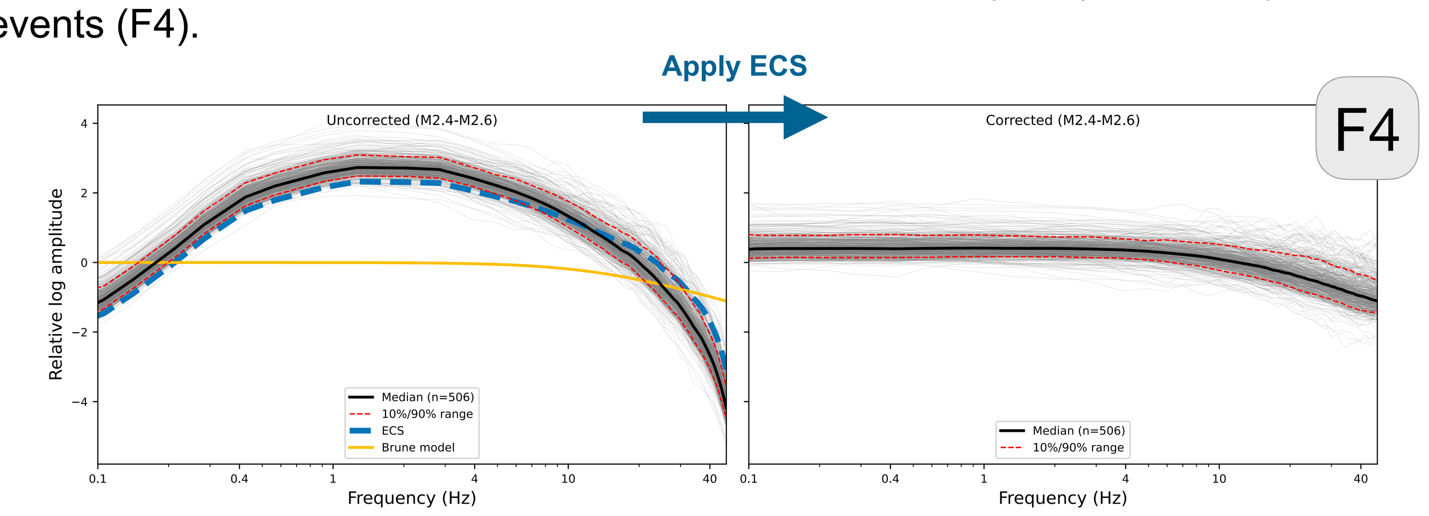


F2: Time-domain spectrum calculation example. The maximum amplitude is measured in the dashed red line window for each trace, which is then used to obtain an uncorrected spectrum. Each seismogram is filtered separately using narrow overlapping bandpass filters with midpoints ranging from about 0.05 - 40 Hz.

F3: Cartoon depicting the general inversion technique used in amplitude and spectral decomposition to calculate the event terms, e_i.

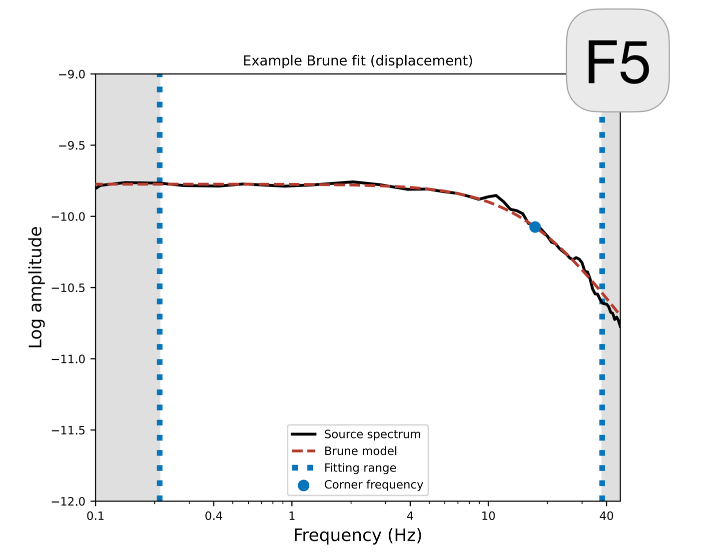
Time-Domain Stress Drop Estimation (continued)

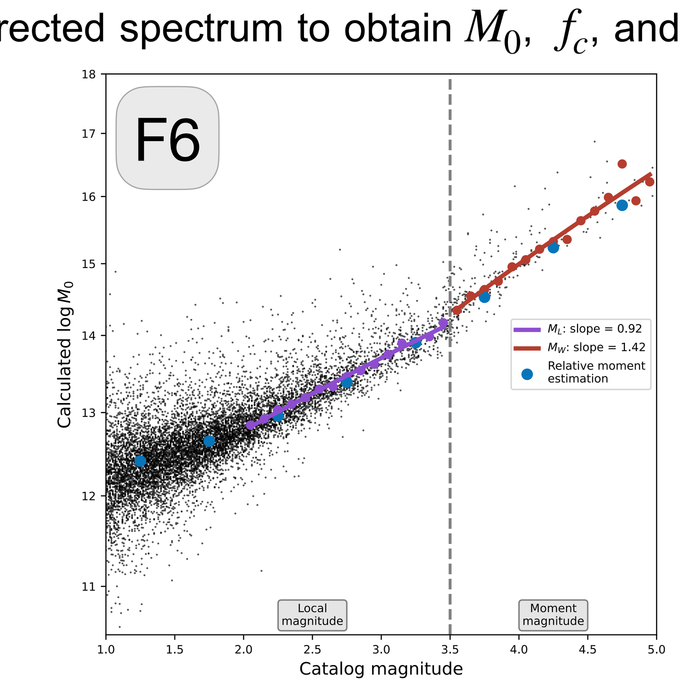
Step 3: We calculate an empirical correction spectrum (ECS) and apply it to all events (F4).



F4: (Left) Calculation of the ECS by fixing f_c of M1.9-M2.1 events to 13.6 Hz, following the findings of borehole studies (Abercrombie, 1995) and the methods in Shearer et al. (2022). The obtained ECS term is applied to all events. (Right) The ECS is applied to the M1.9-M2.1 event terms to force the median to have a Brune model.

Step 4: We fit a Brune model to each corrected spectrum to obtain M_0, f_c, and $\Delta\sigma$ estimates for each event (**F5**)





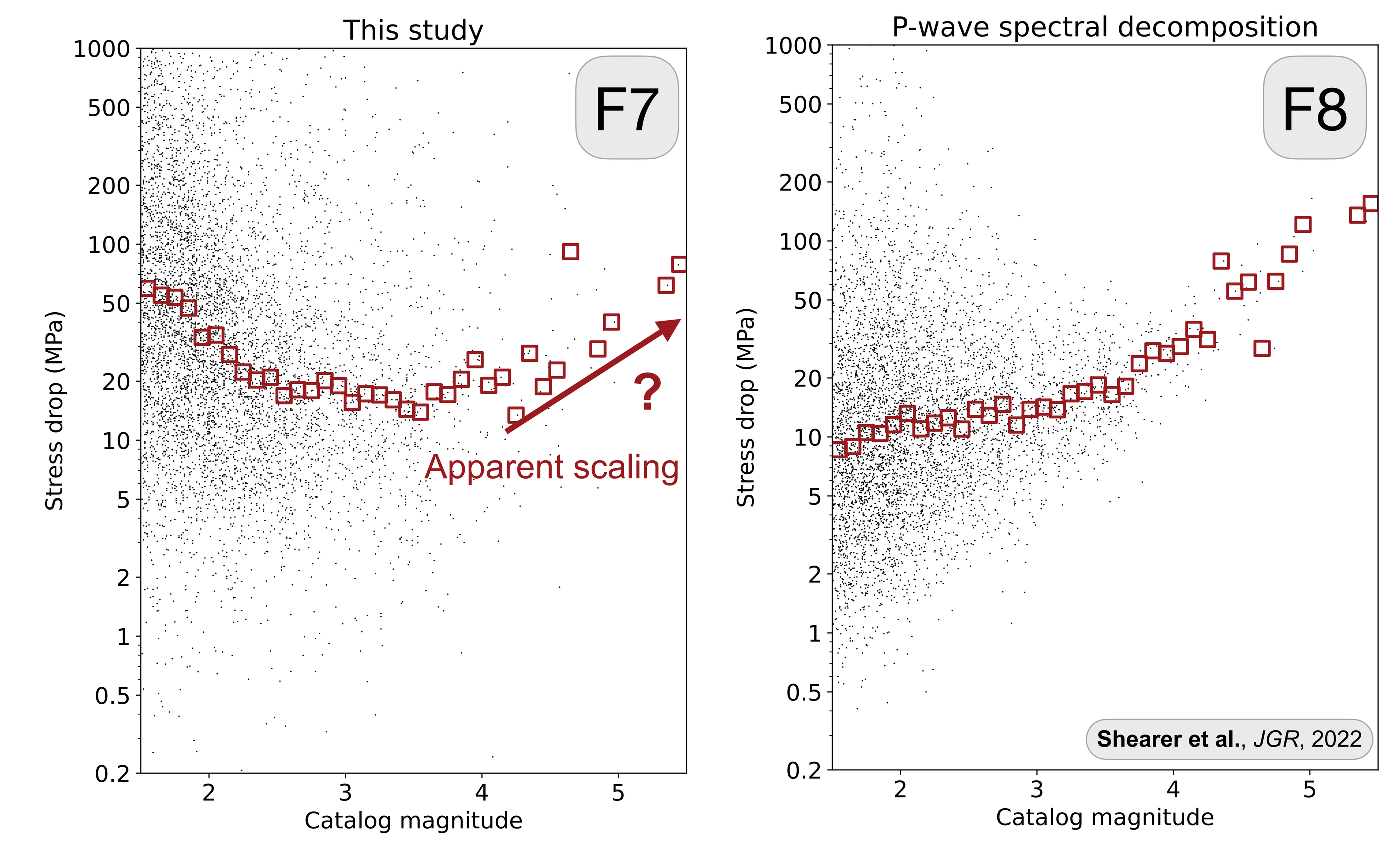
F5: Example of fitting a Brune model to a corrected event term, from which we obtain the relative moment and associated corner frequency of the earthquake.

F6: Comparison of the catalog magnitudes and the moment estimates obtained from the amplitude decomposition method. Note the median moments scale with the catalog magnitudes for earthquakes with a slope of ~1 for M<3.5 earthquakes. The slope changes to ~1.5 at around M3.5.

Robust Measurement at Lower Frequencies

- We observe a **slope change in log M_0 versus catalog magnitude near M3.5** when applying the amplitude decomposition method (**F6**). This slope change is less obvious in the spectral decomposition methods.
- This method can **resolve spectra at low frequency** with high fidelity because we filter the entire time series and then measure the peak amplitudes.
- The amplitude decomposition method has the potential to **better estimate source parameters** of moderate magnitude earthquakes.
- Our preliminary results suggest an apparent increase in stress drop with magnitude (**F7**).
- The stress drop estimates of events with magnitude less than 2.5 are likely artifacts (**F7**).
- The true stress drop is challenging to resolve uniquely because of tradeoffs between the ECS, the assumed high-frequency falloff rate, the assumed f_c of small events, and scaling of stress drop with moment (Shearer et al. 2019, 2022).
- Relative stress drops among different events can be better constrained, especially for events with similar moments.
- We continue exploring the cause of the differences in the stress drop estimates between the spectral and amplitude decomposition methods.

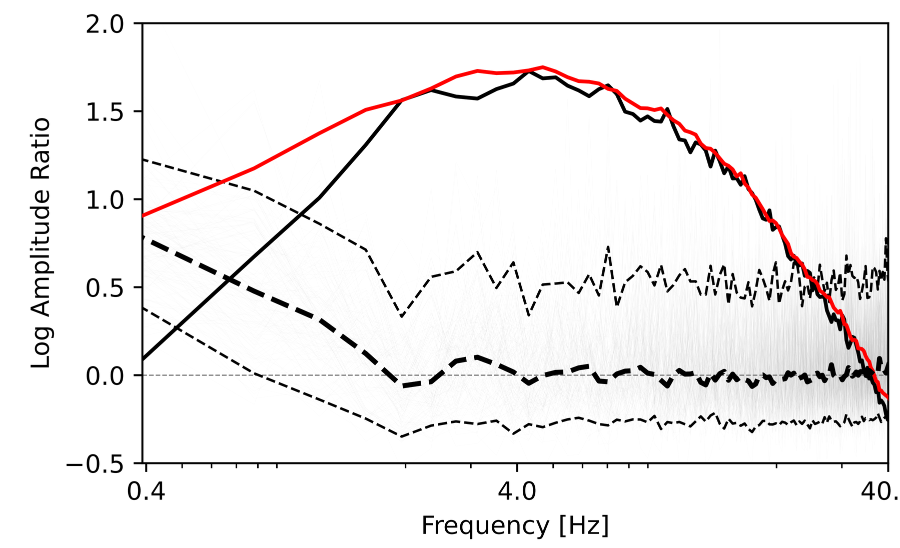
Robust Measurement at Lower Frequencies (cont.)



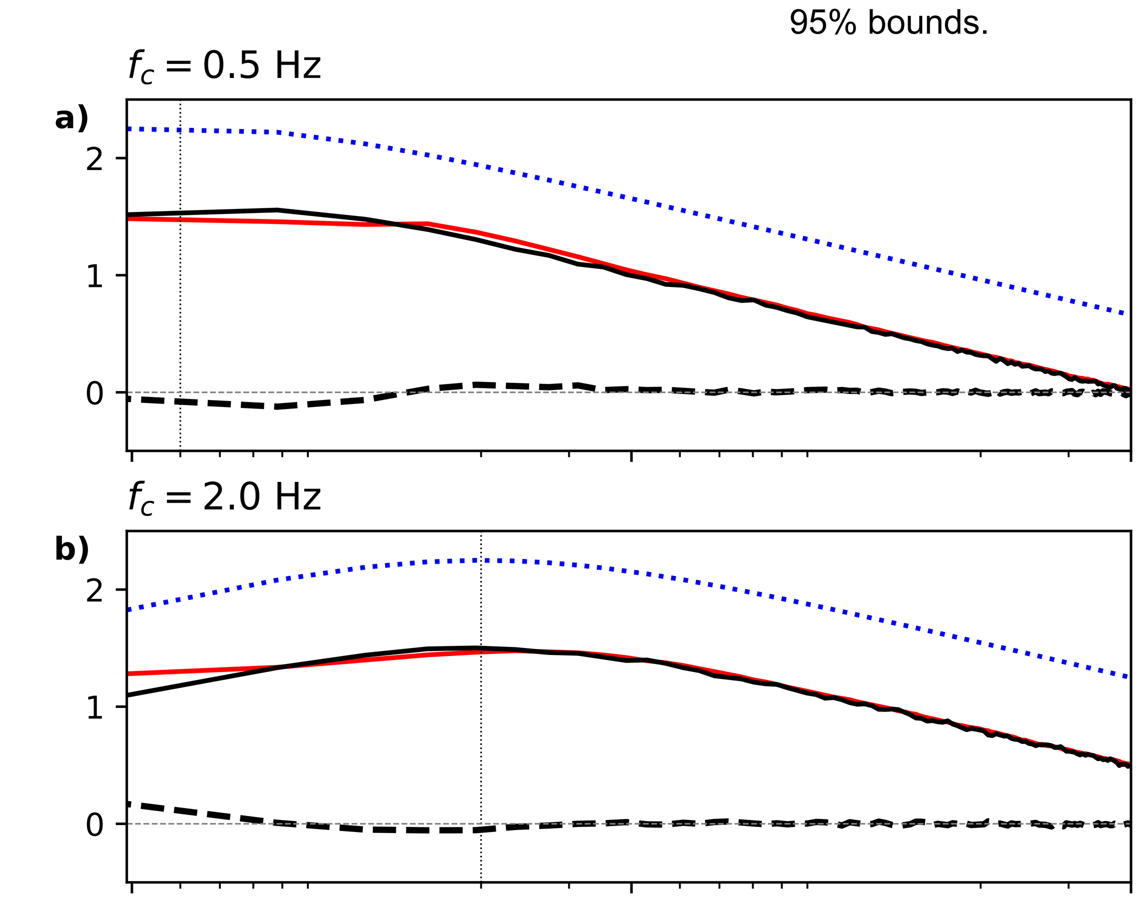
F7: Stress drop estimate versus magnitude from this study, and **F8**: From Shearer et al., 2022. Median stress drop estimates for each catalog bin of width 0.1 magnitude are plotted as red squares.

Multitaper influences on spectra at low frequencies

We find that in some cases multitapered spectra can be biased at very low frequencies. While Hann-taper estimates have higher uncertainty over the spectrum, they seem to be more accurate on average at these low frequencies (**F9**, **F10**). Our results suggest that earthquake moment and corner frequency estimates obtained using Hann-tapered spectra are likely more reliable than those obtained from multitapered spectra.



F9: Comparison of the taper effects on spectrum calculation. Uncorrected median log velocity amplitude spectra are computed for ~200 events between M3.0 and M3.2 that are from the same region using a Hann taper (solid black) and a set of multitapers (solid red). The difference between the two taper methods is shown as the heavy dashed black line. Thin dashed black lines indicate the 5% and 95% bounds.



F10: Synthetic test of the taper effects. Median log velocity spectra of 1000 synthetic seismograms are generated following a Brune velocity model with corner frequencies of 0.5 and 2 Hz. Multitaper spectra are shown in red, Hann-taper spectra are shown in solid black, their differences are shown as dashed black lines, and the Brune velocity models used to generate the synthetic data are shown as a blue dotted line.

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References

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