Earthquake Source Spectra Estimates Obtained from S-wave Maximum Amplitudes: Application to the 2019 Ridgecrest Sequence

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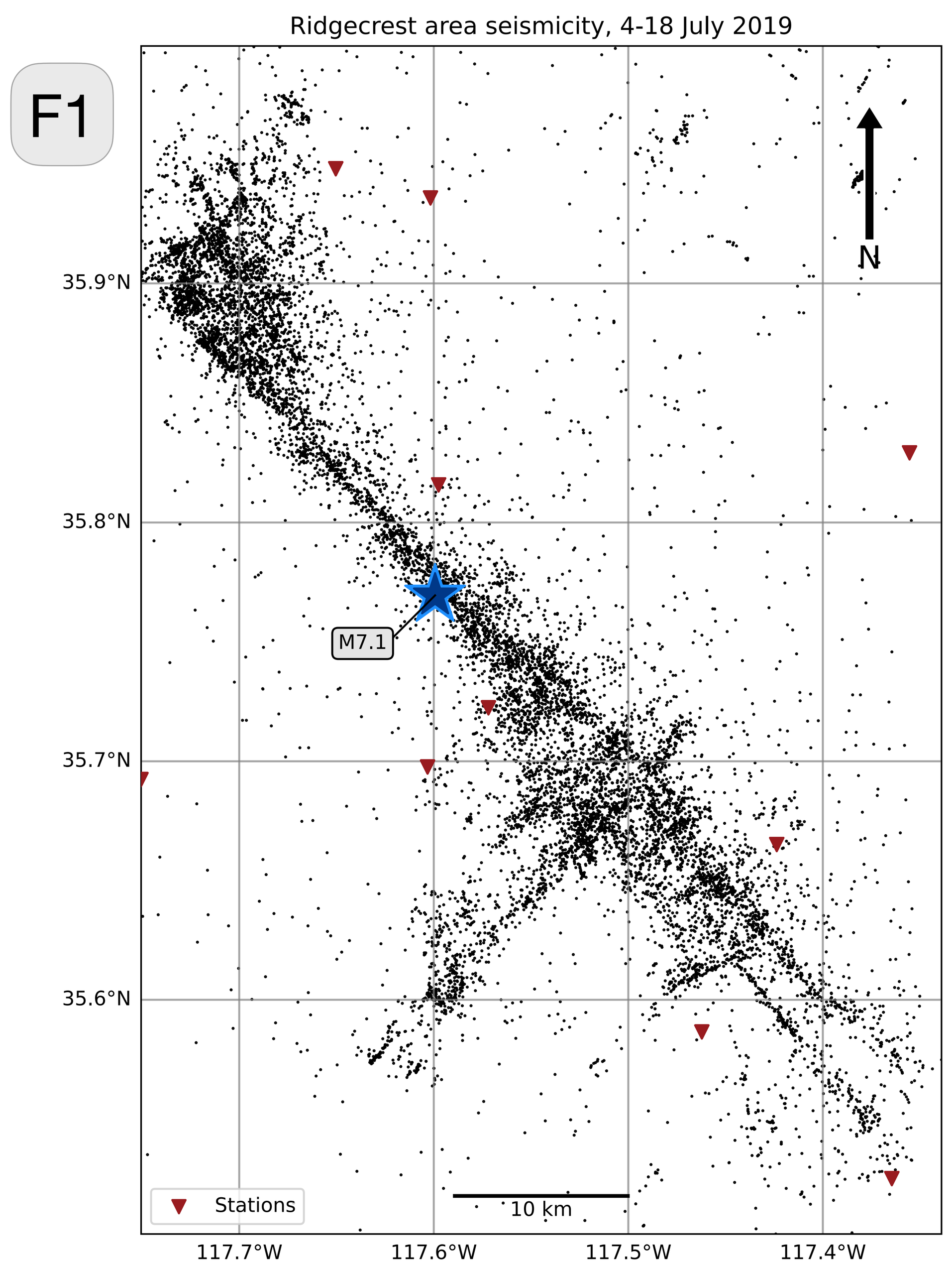
Introduction

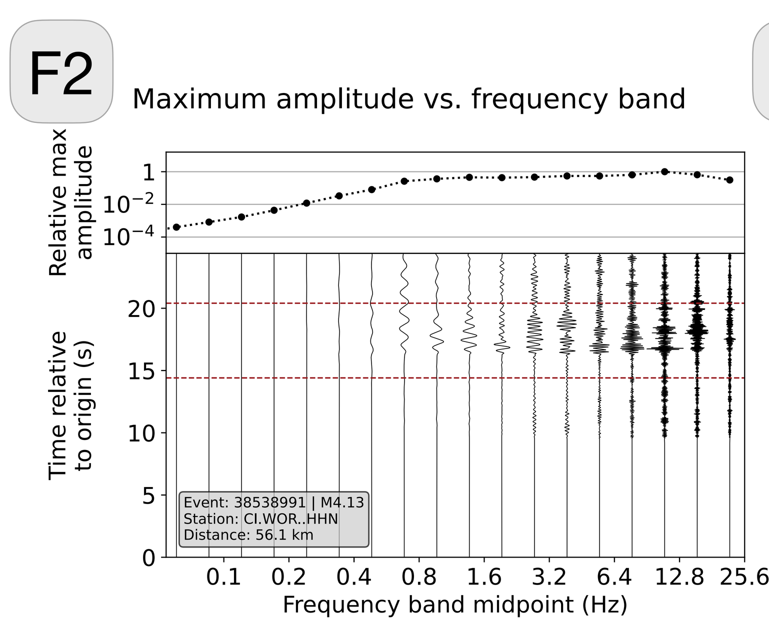
Earthquakes radiate a wide spectrum of seismic energy, from which properties like seismic moment and stress drop can be estimated. These are important for questions regarding the self-similarity of earthquakes, i.e., whether the source physics changes between small and large events. A common approach to large data sets of local earthquakes with many sources and receivers is spectral decomposition, which first separates event terms from station and other path terms and then solves for a best-fitting source model. A problem in spectral decomposition is poor signal-to-noise ratios for smaller earthquakes at low frequencies, which prevents setting the lower frequency limit low enough to accurately measure the moments and corner frequencies of the largest earthquakes.

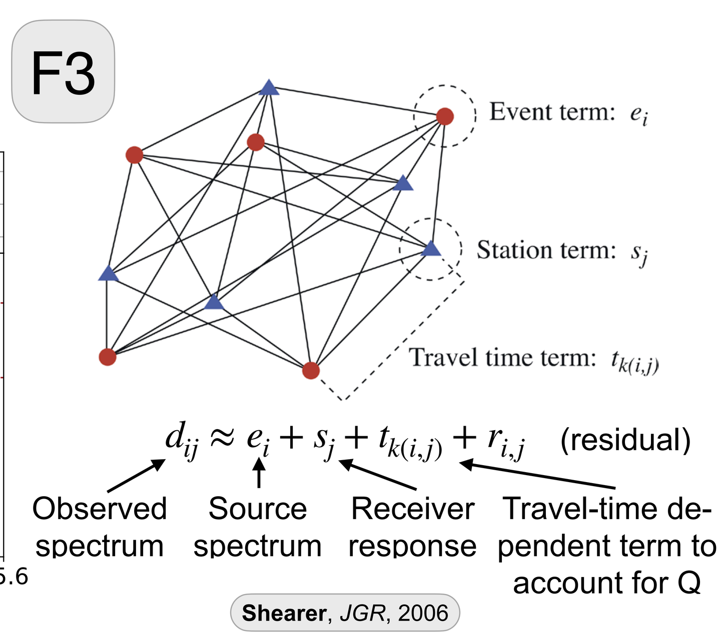
Here we experiment with a new method for amplitude decomposition, which measures the maximum shear-wave amplitude of bandpass-filtered seismograms in the time domain to calculate spectra in the frequency domain. This method has the benefit of having better signal-to-noise ratios at low frequencies when compared with P-wave spectral decomposition.

We apply this method to seismic data generated during the 2019 Ridgecrest earthquake sequence (**F1**), and compare our preliminary results with previous spectral decomposition studies.



F1: Ridgecrest M7.1 mainshock (blue star) and nearby >M1 events (black dots)



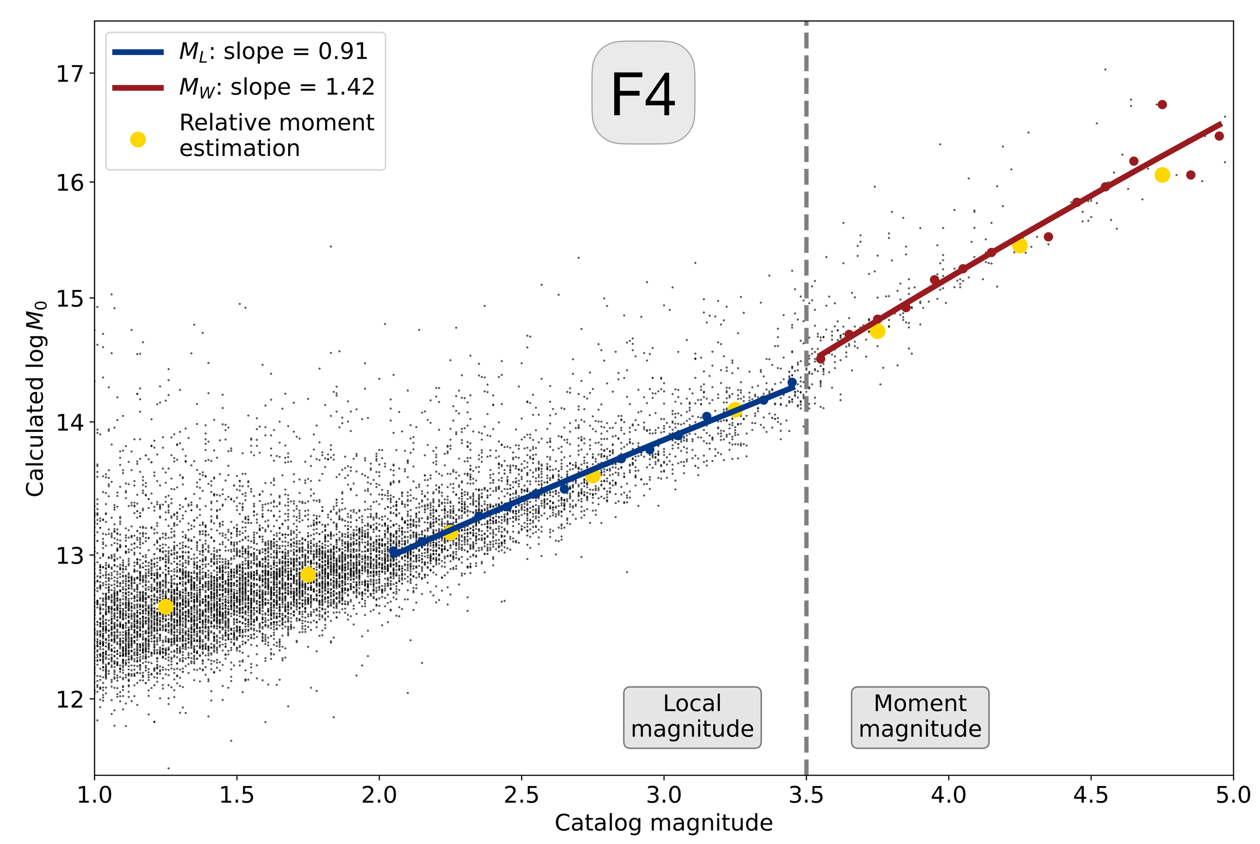


F2: Amplitude decomposition example, where maximum amplitude is measured in the dashed red line window; **F3:** Cartoon depicting spectral decomposition

Methods

Step 1: We filter seismograms containing S-wave arrivals using different bandpass filters, measure the maximum arrival amplitude in that frequency band, and use the results to construct spectra for each seismogram (**F2**). These spectra are then decomposed into the source spectrum, receiver response, and path dependent terms to obtain one source spectrum for each event (**F3**).

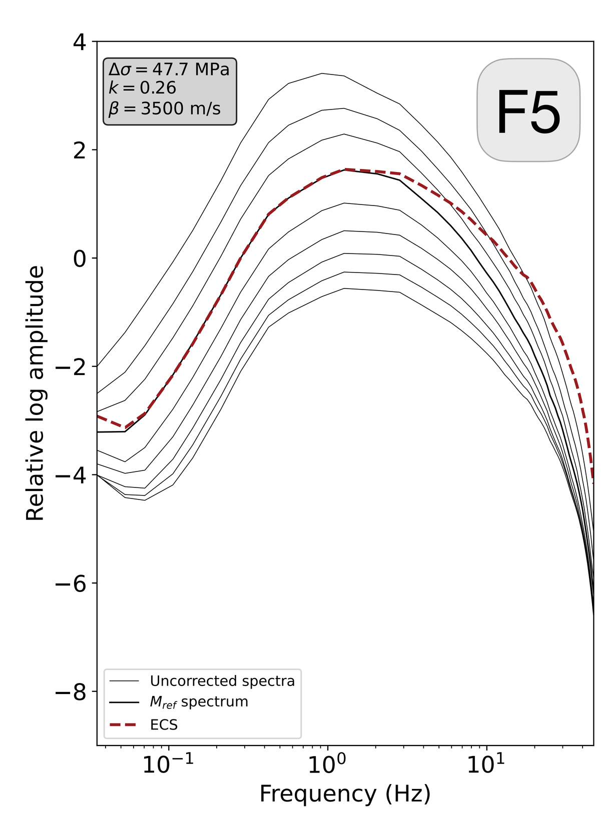
Step 2: The event source terms are binned and averaged by magnitude to form uncorrected spectra, and their spacing at low frequency is used to estimate relative moments (**F4**). The uncorrected spectra are compared to theoretical Brune models for varying stress drop, and the median difference between model and uncorrected spectra becomes the empirical correction spectrum (ECS, **F5**), which is subtracted from each observed spectrum to obtain the corrected spectra (**F6**). The best-fit stress drop value is chosen where the misfit between model and corrected spectra is at a minimum.

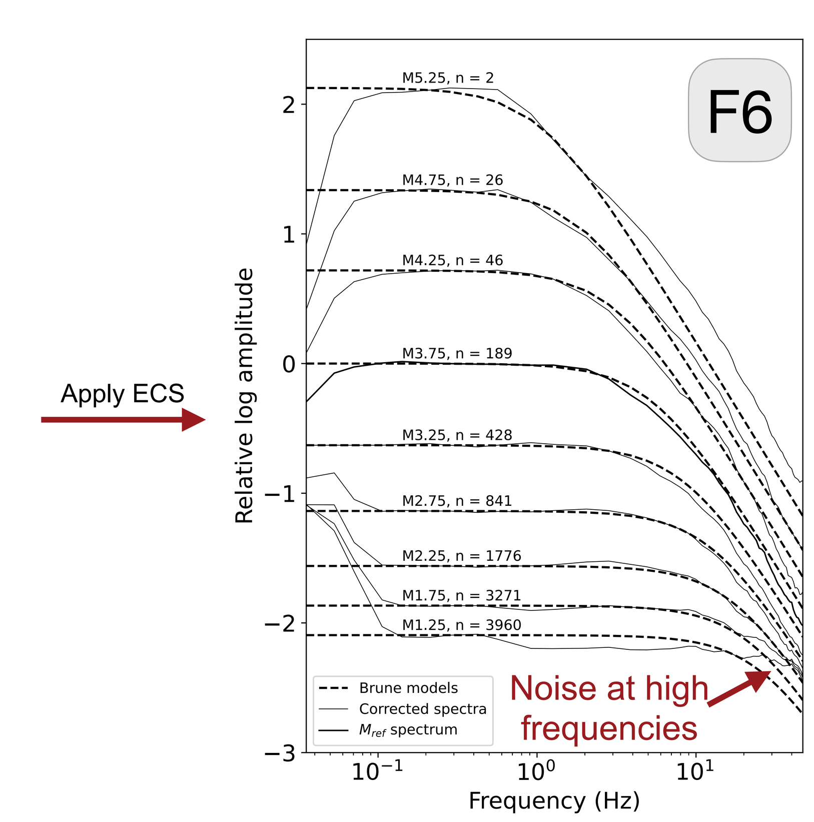


F4: Calculated log moment vs. catalog magnitude for all events (black dots). Relative moments estimated from binned spectra spacing are plotted as gold circles. Color lines represent the best-fit line to median log moments (color dots) for their respective magnitude range.

Step 3: For each event spectrum, a Brune model using the best-fit stress drop value is fit to solve for corner frequency, which is used to estimate the event's stress drop. Spectra with low signal-to-noise ratios are thrown out, and the results are plotted in **F7**.

It should be noted that this method makes no assumptions of absolute stress drop values of small events, whereas some methods of spectral decomposition assume a fixed value for stress drop for smaller events; the calculated best-fit stress drop is purely derived from smallest misfit.





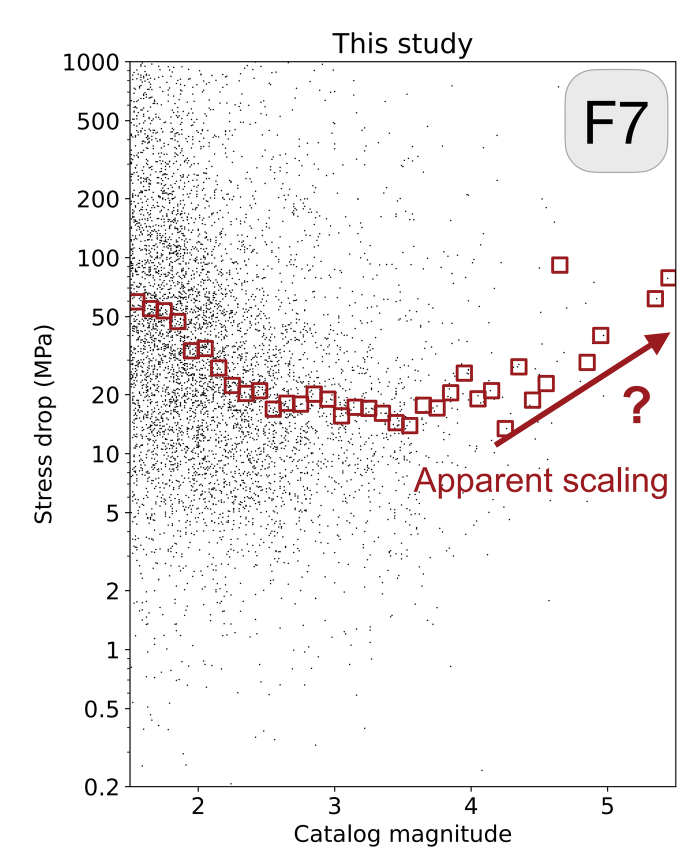
F5: Uncorrected binned spectra and the calculated ECS; **F6:** Corrected binned spectra and their best-fit Brune models.

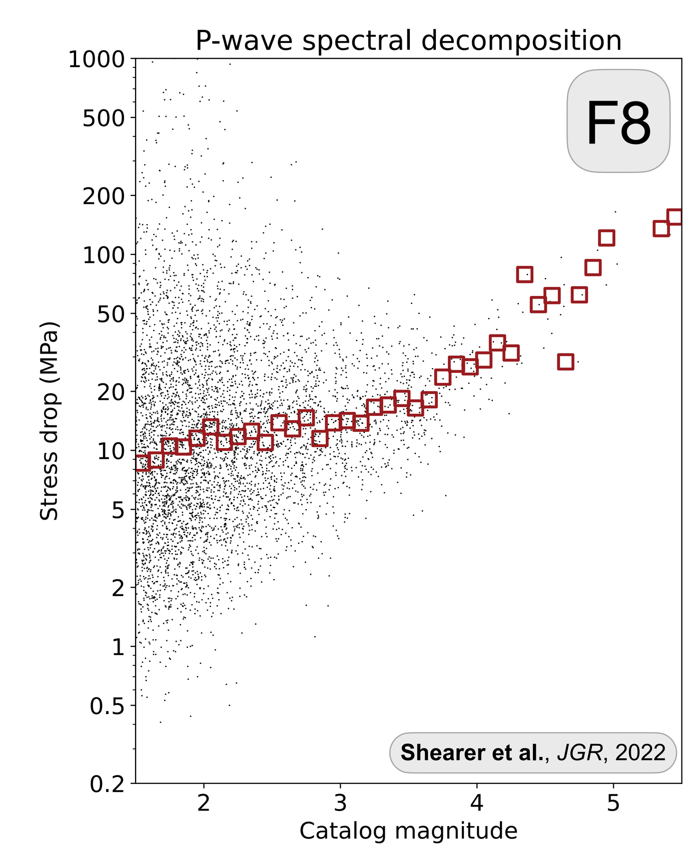
Results

Using the 2019 Ridgecrest dataset, the log moment vs. catalog magnitude is plotted for each event (**F4**). We find a clear change in slope at M3.5 where the magnitude type changes. The slope in the local magnitude range is 0.91, and the slope in the moment magnitude range is 1.42, which roughly agree with theoretical values of 1.0 and 1.5 respectively.

Using shear-wave amplitude decomposition, our preliminary best-fit stress drop value is about 48 MPa, higher than previous P-wave spectral decomposition studies (e.g. Shearer et al., 2022). Our results seem to show an increase in stress drop with magnitude (**F7**), a characteristic seen in other studies and one that would imply the non-self-similarity of earthquakes. However, there is still considerable uncertainty for these events. In particular, as discussed in Shearer et al. (2019, 2022), there are likely tradeoffs among the model parameters (i.e., the ECS, the assumed high-frequency falloff rate, the median stress drop for the smallest events, and any scaling of stress drop with moment) that prevent unique determination of the true event stress drops. However, for a given ECS, such as that used here, the relative stress drops among the different events are much better constrained, particularly for events of similar moment.

Spectra of small events are noisy, especially at high frequencies (**F6**). This could account for higher uncertainty in stress drop estimates for smaller events (**F7**) since the corner frequency cannot be reliably determined with high frequency noise. Further exploration of this method is required to minimize uncertainty in stress drop.





F7: Stress drop vs magnitude from this study, and **F8:** from Shearer et al., 2022. The median stress drops in bins of width 0.1 magnitude are plotted as red squares.

Summary

- As the estimated moment vs. magnitude slopes roughly agree with theoretical values, we find that our approach to amplitude decomposition has potential in the study of source mechanics like stress drop.
- Using this method, spectra appear reliable at frequencies about an order of magnitude lower than with P-wave spectral decomposition applied to the same events. For a Nyquist frequency of 50 Hz, this method seems to resolve spectra down to about 0.1 Hz, compared to about 1 Hz for spectral decomposition. This should allow for better estimates of both corner frequency and low-frequency amplitude.
- Preliminary results seem to show an increase in stress drop with increasing magnitude, which would agree with some recent P-wave spectral decomposition studies.
- Recent P-wave spectral decomposition studies use multiple localized ECS to account for path differences. Future work on this method may explore the use of multiple ECS.

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References

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