Looking at Low-Frequency Earthquakes through the Perspective of Two Different Models

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What are LFEs?

Low-frequency earthquakes (LFEs) are recurrent seismic events characterized by a lack of high-frequency seismic energy. They are found in swarms along subduction plate boundaries in the transitional zone between major earthquakes and deeper continuous creep.

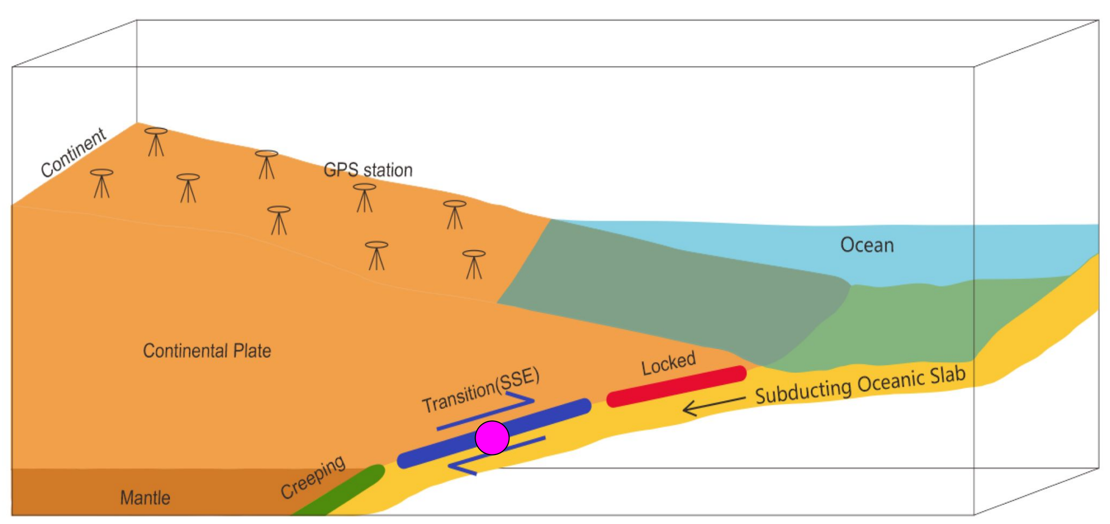


Figure 1: Cross Section of a Subduction Zone (Yan et al., 2023). *Transitional zone where LFEs are located is marked in pink.*

LFE Source Characterization

LFEs offer crucial insights into the frictional transition zone and its relevance to major earthquakes, but the source of LFEs is still unknown. Classical earthquake modeling techniques, like the Brune Source Model, fail to capture the source of LFEs due to a lack of high frequencies captured in the seismic recordings of these events. They also predict scaling relations that are inconsistent with observed LFEs.

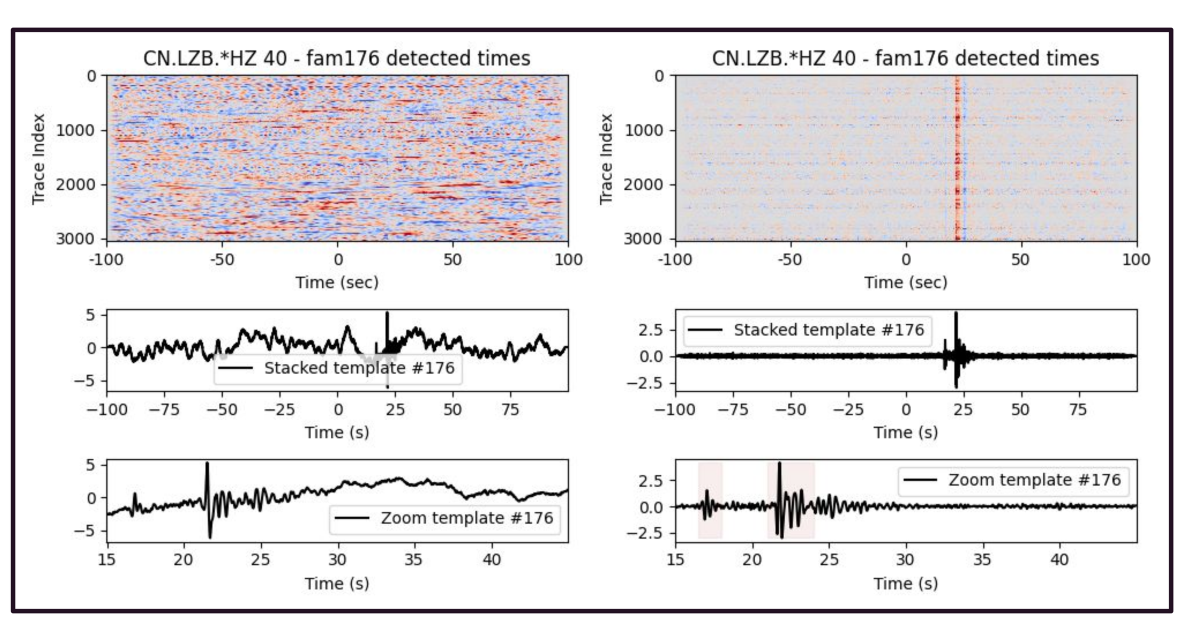


Figure 2: *This sample catalog of waveforms show processed event data. Due to their low signal to noise ratios, proper analysis of LFEs require "stacking" of multiple captured events to minimize noise and obtain information.*

The focus of this research is to potentially extend the amount of usable bandwidth and explore whether different models can better explain the LFE source. Properly characterizing LFEs would add nuance to future analyses of the dynamics of the plate boundary where they reside.

Source Models Compared

$$\tilde{\Omega}(\omega) = \frac{M_0}{1+\omega^2/\omega_0^2}$$

Equation #1: Brune's Source Model *- Brune's is a simplified method used to represent the complex process of an earthquake by relating corner frequency (ω_0) to earthquake size through the assumption that the earthquake originates from a circular fault area where the stress is released. The model introduces the concept of "stress drop" (the difference in stress before and after an earthquake), which helps in understanding the amount of energy released in a given seismic event.*

$$|\Omega(\omega)| = \frac{48\Delta\tau}{7}(R-R_0)R_0R\,\mathrm{sinc}\left(\frac{\omega R\sin\theta}{c}\right)\frac{1}{\sqrt{\omega^2 t_0^2+1}}$$

Equation #2: Earthquake Source Model near the Nucleation Dimension (Cattania) *- Cattania's source model is an improvement on models like Brune's that only account for one parameter (rupture dimension). Cattania's model, which notably uses two corner frequencies rather than one, accounts for two parameters: finite nucleation dimension and finite rupture dimension, as well as variation in spectral properties with observation angle.*

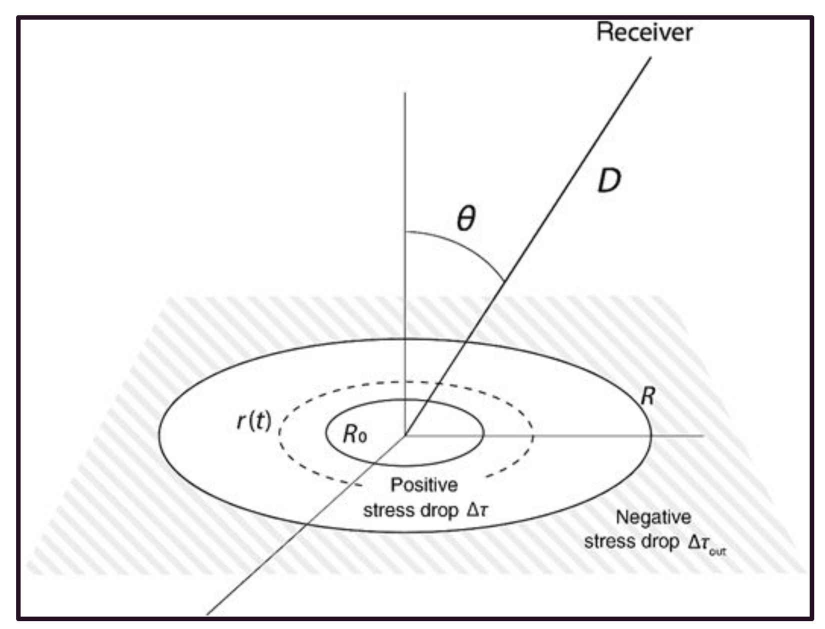
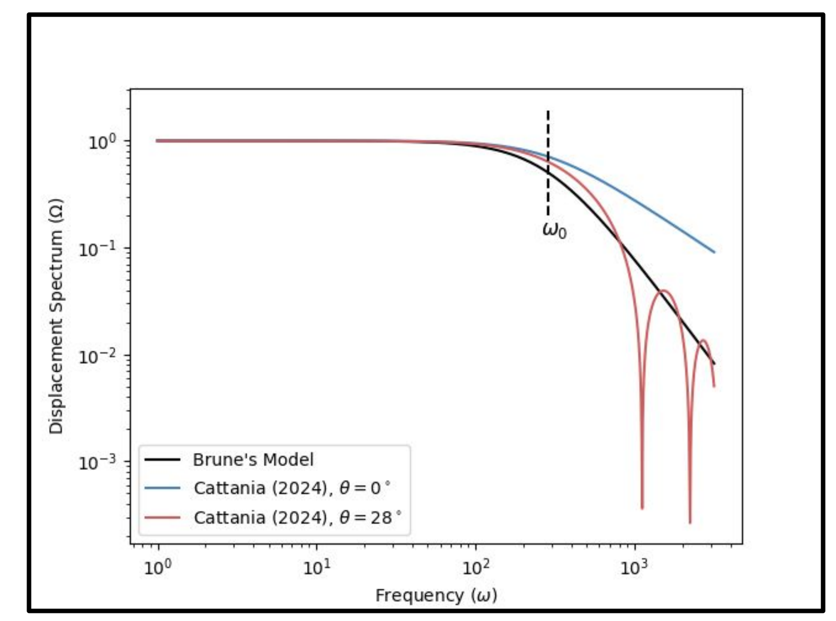


Figure 3: Earthquake Rupture Propagation sketch (Cattania, 2023) *- Slip and rupture speed accelerate over a finite nucleation dimension, and then grow self-similarly over the rupture patch. The angle of observation impacts the apparent observed rupture speed.*



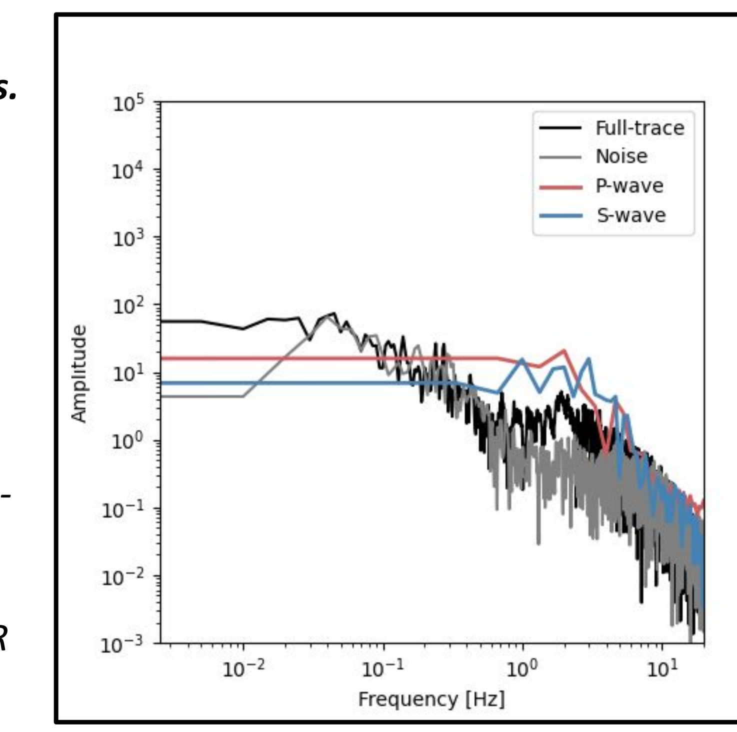


Figure 4 (left): Forward Model of Brune vs. Cattania *- Spectrum at $\Theta = 0°$ follows a Boatwright ($1/\omega_0$) spectral fall-off at high frequencies and a Brune ($1/\omega_0^2$) spectral fall-off for other viewing angles, with additional spectral features reflecting the travel-time difference between seismic waves at each end of the rupture.*

Figure 5 (right): Noise and Signal Spectra *- a spectral fitting. Signal to Noise ratio (SNR) is helpful in determining usable bandwidth for spectra fitting. A higher SNR makes for high quality data.*

Results

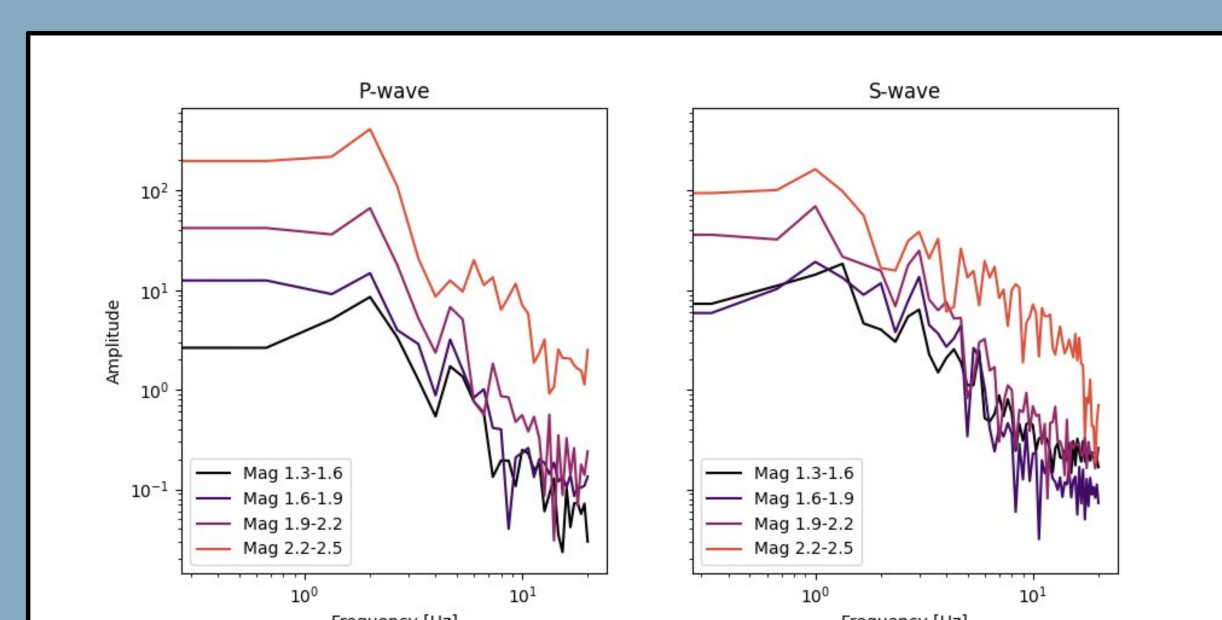


Figure 6: Stacked Spectra Sorted by Magnitude *- There is a clear change in the spectra as moment magnitude is increased (Magnitudes gathered from Bostock et al. (2015)).*

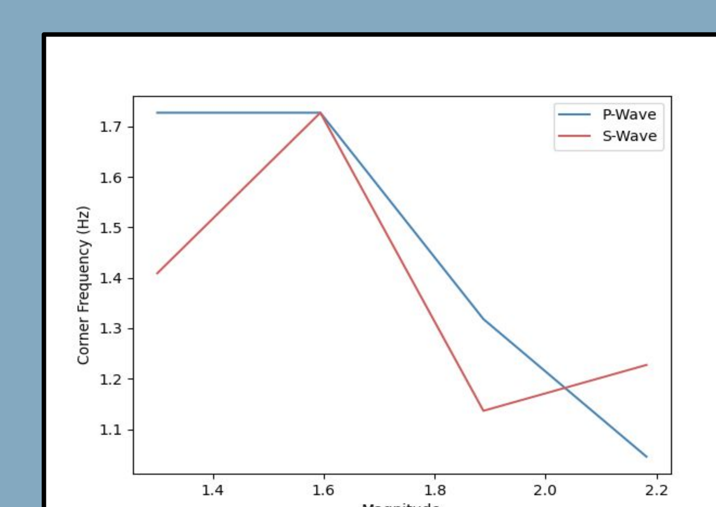


Figure 7a: Best Corner Frequency vs. Magnitude of Brune's Model *- Lower magnitude events tend to have higher corner frequencies, suggesting smaller source dimensions.*

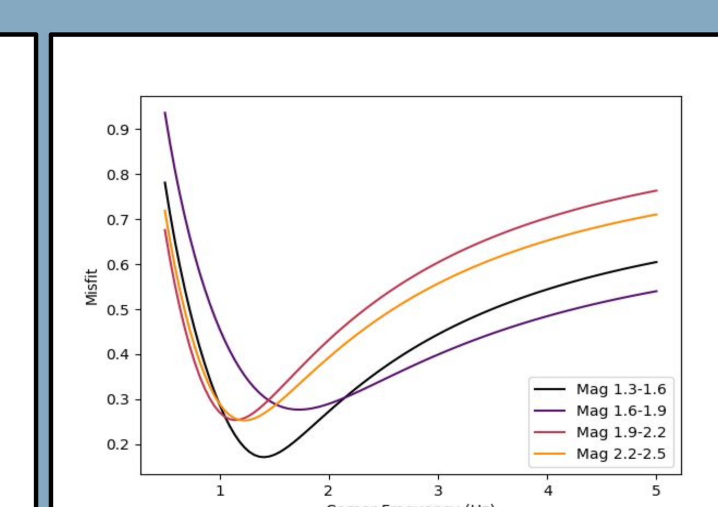


Figure 7b*: Brune's Model misfit plot estimating misfit between Brune's model and provided data. The plot's estimated corner frequency coincides with estimate in figure 7a.*

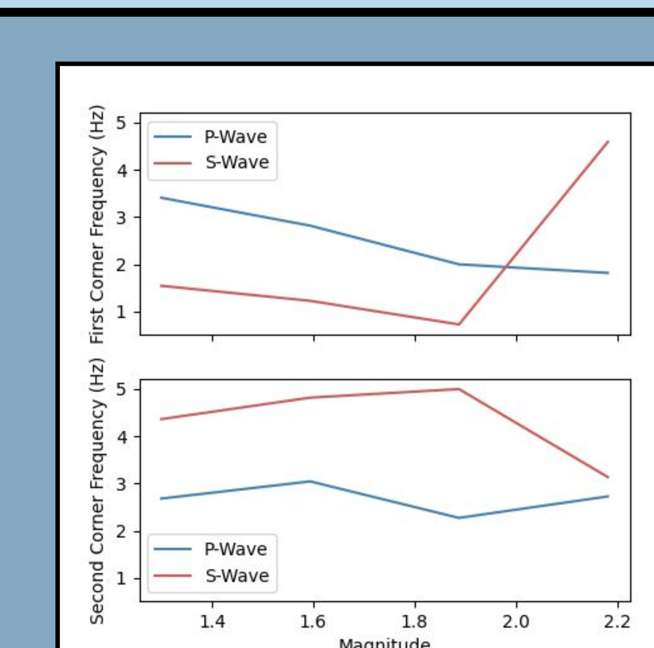


Figure 8: Best Corner Frequency vs. Magnitude of Cattania's Model *(both corner frequencies shown).*

Implications and Conclusions

Conclusions: Where we would be able to distinguish between the two models, we lack the the resolution to do so due to the noise levels.

- The models differ in their prediction of the high-frequency falloff rate via the addition of a second corner frequency.
- The noise spectrum is noticeably of comparable amplitude to the signal around 10Hz, which is likely lower than our second corner frequency.

Implications: Lower magnitude events could have higher corner frequencies, but we can't tell for sure due to noise.

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