Using a Simple High- to Low-Frequency Spectral Ratio to Distinguish Spatial Variations in Earthquake Source Properties

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What makes earthquakes *different* from each other?

Stress drop is a fundamental earthquake source parameter related to the amount of damaging high-frequency waves due to an earthquake. Studies over the past few decades have found that **estimates of stress drop have large uncertainty**; even a slightly different estimation technique can change values greatly (see Baltay, et al., 2024).

For equal magnitude events, **some variation in stress drop is due to relative amounts of high- and low-frequency amplitudes**. Here, we define the parameter, β, simply as the ratio of high-frequency spectral amplitude (A_{HF}) to low-frequency spectral amplitude (A_{LF}):

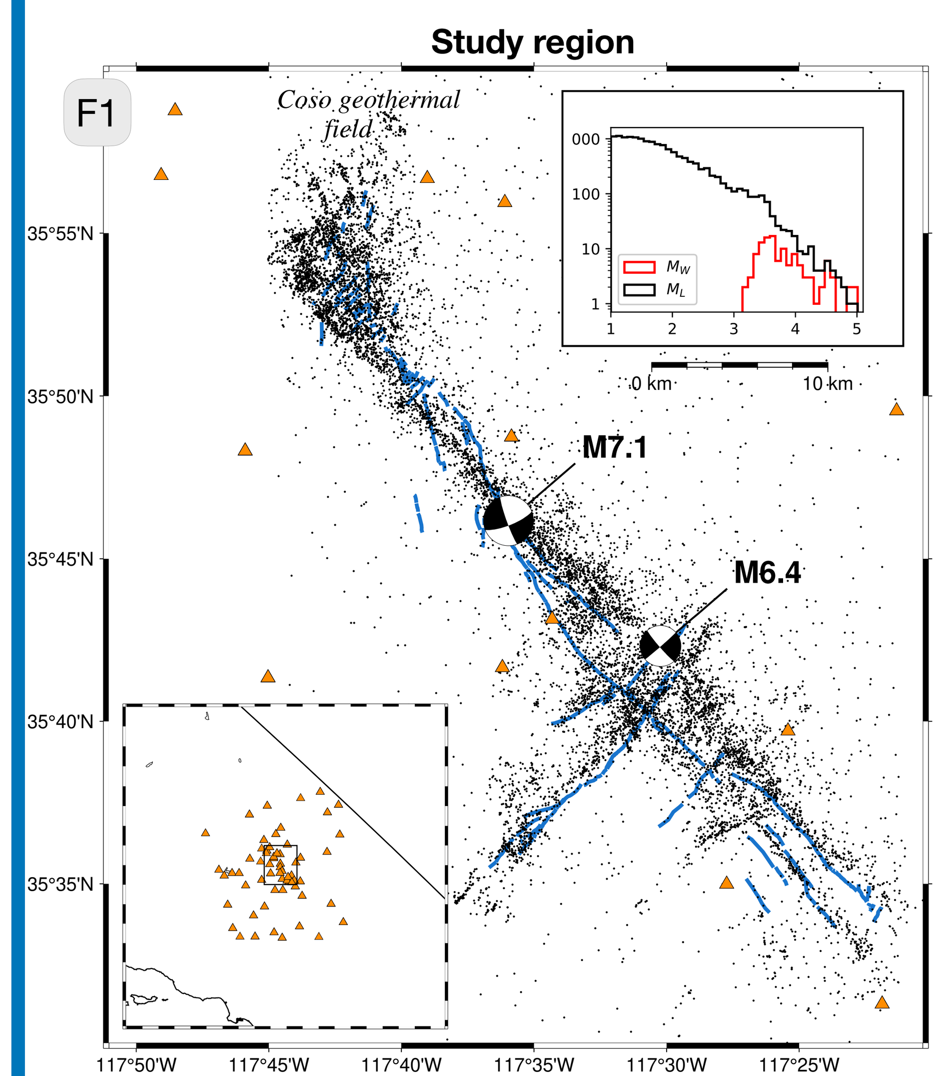
$$\beta = \frac{A_{HF}}{A_{LF}},$$

and in the log domain,

$$\log \beta = \log A_{HF} - \log A_{LF}$$

We find that, after applying station and magnitude corrections, this value is **correlated with corner frequency and stress drop**.

We apply this method to **P-wave spectra** of the 2019 Ridgecrest earthquake sequence (**F1**), and compare our preliminary results with spatial variation in stress drop obtained using P-wave spectral decomposition.

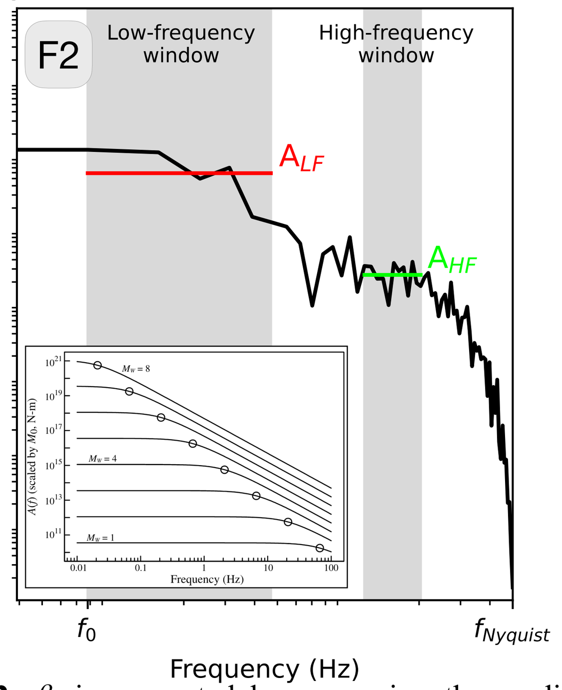


F1: Map of dataset, including earthquakes (black dots), seismic stations (orange triangles) and existing faults (blue lines). The upper-right inset shows the number of each magnitude type versus magnitude, and the lower-left inset shows the greater southern California region. From Vandevert, et al. (2024)

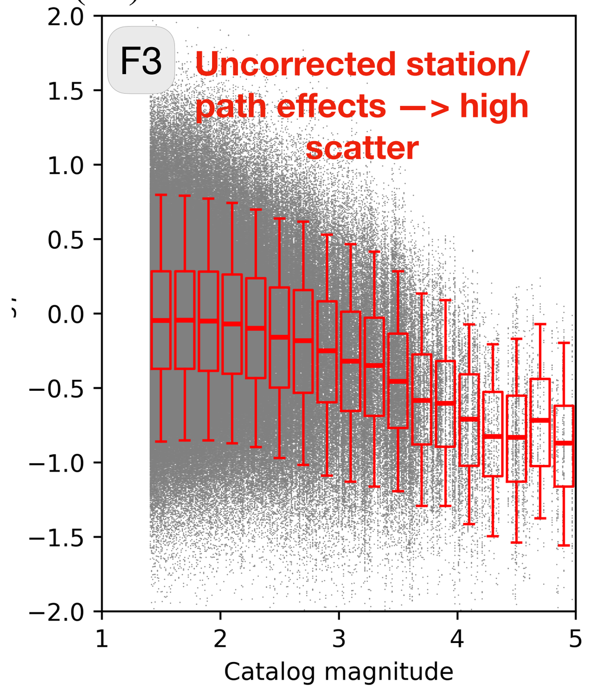
How does it work?

Step 1

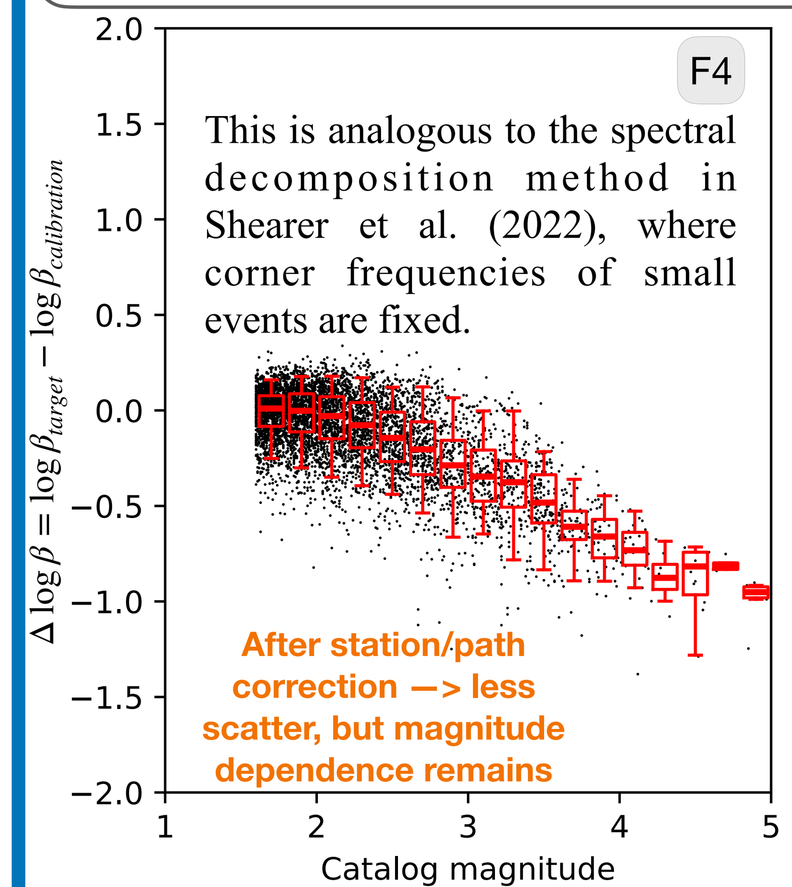
Compute β for all earthquake-station pairs where the spectrum's signal-to-noise is above some threshold (F2).



F2: β is computed by measuring the median low-frequency amplitude (A_{LF}) and median high-frequency level (A_{HF}). We found that using a low-frequency band of about 1-5 Hz and a high-frequency band of about 12-20 Hz provided a good correlation with previously-computed stress drop.



F3: $\log \beta$ values for all records passing signal-to-noise threshold (n=561,843)



Step 2

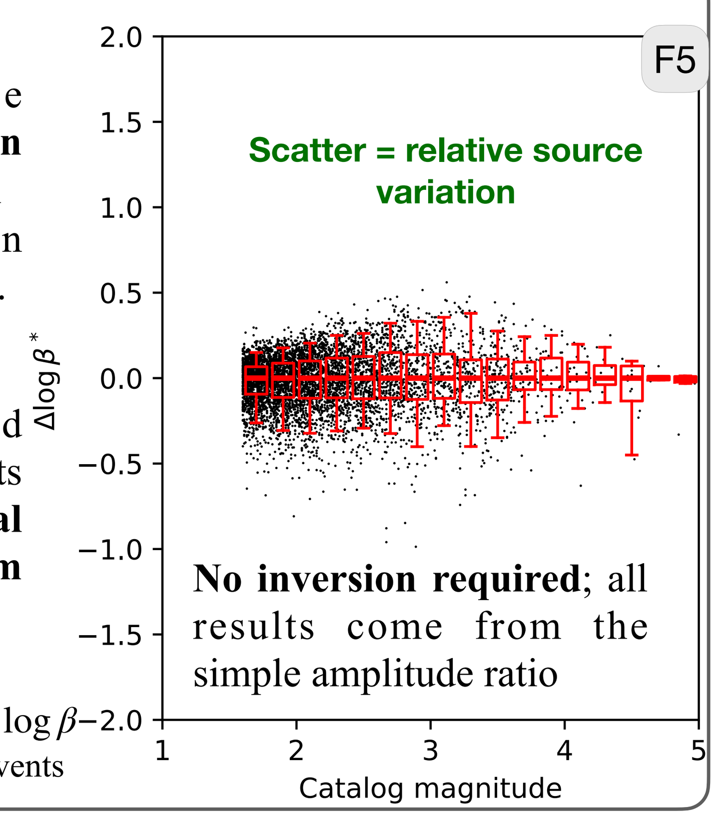
For each "target" event, find small, nearby **"calibration" events that have roughly the same path**. Compute the difference between target and calibration β records:

F4: $\Delta \log \beta$ values for all target events (n=6,106)

Step 3

Apply a magnitude correction to **shift median $\Delta \log \beta$ to zero** for all magnitudes, so we can analyze relative differences.

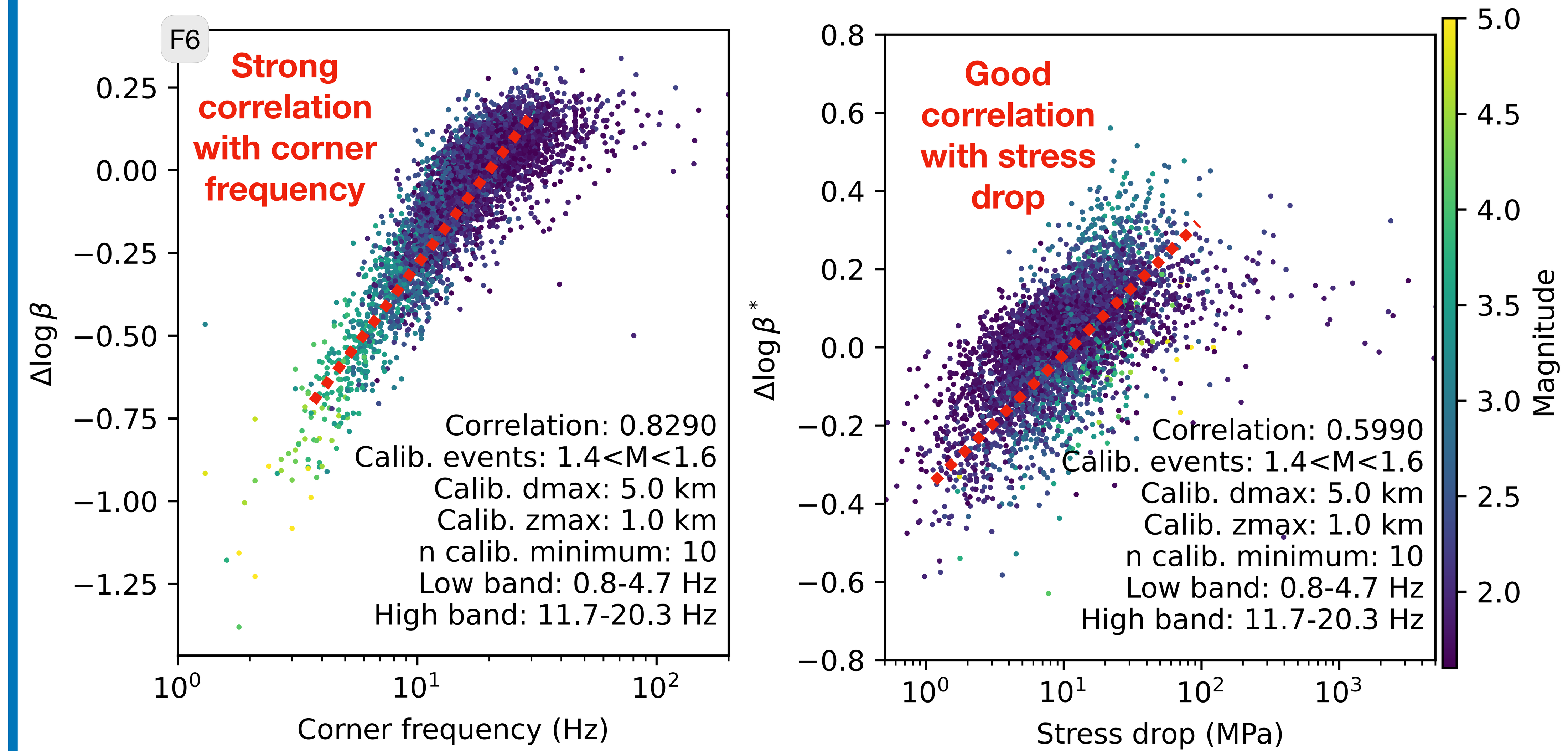
Path, station, and magnitude-dependent effects are removed —> **Spatial variation results from source differences**



No inversion required; all results come from the simple amplitude ratio

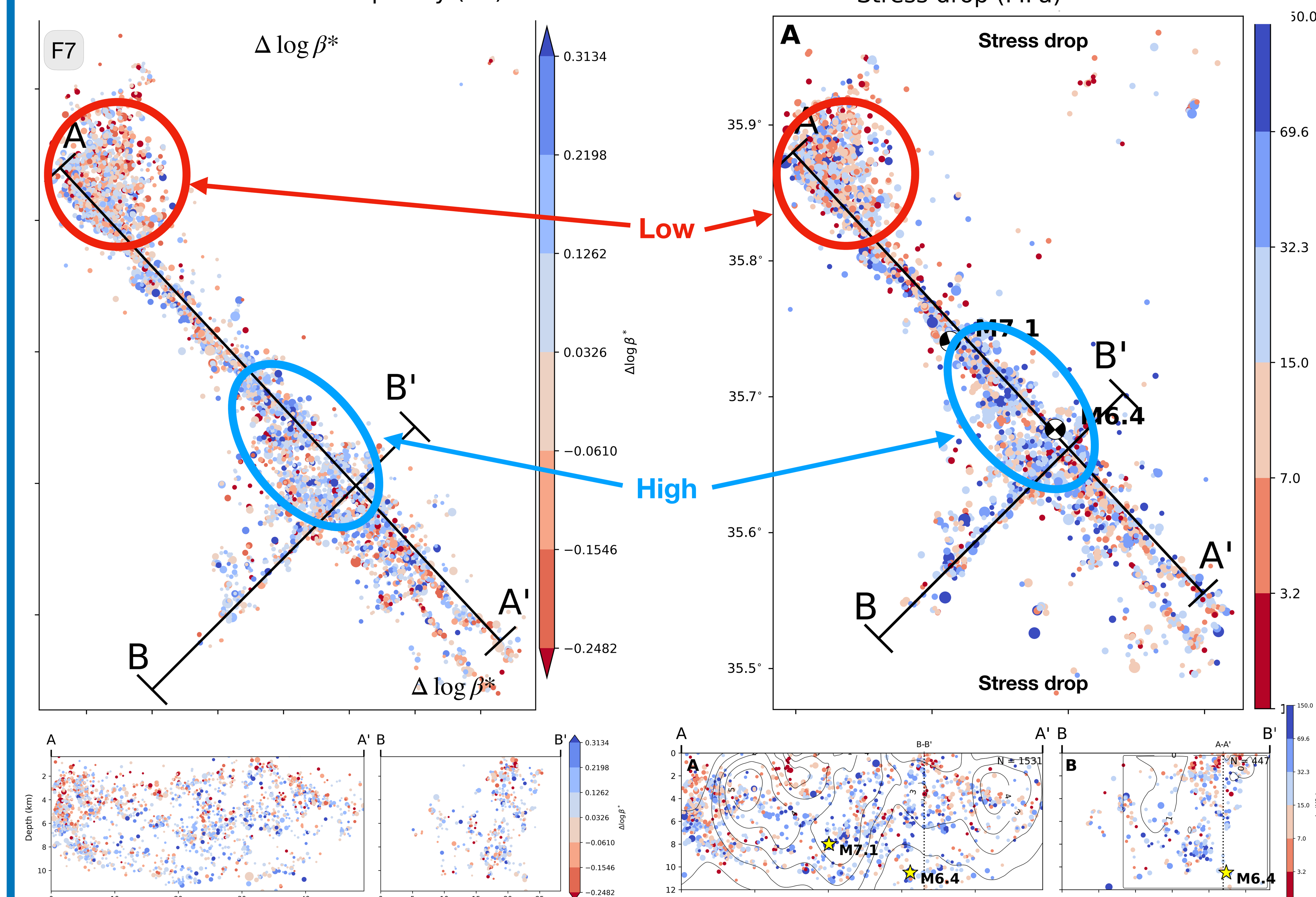
F5: Magnitude-corrected $\Delta \log \beta$ values ($\Delta \log \beta^*$) for all target events

$\Delta \log \beta$ characterizes earthquake source properties



Good correlation with source parameters

F6: Comparison with corner frequencies and stress drops from Shearer et al. (2022)



$\Delta \log \beta^*$ and stress drop have similar spatial patterns

F7: (left) Map and cross-section of $\Delta \log \beta^*$ from this study, and (right) map and cross-section of estimated stress drop from Vandevert et al. (2024)

Discussion and conclusions

- $\Delta \log \beta$ has **strong correlation with corner frequency** estimated using spectral decomposition
- $\Delta \log \beta^*$ has **good correlation with stress drop** from spectral decomposition
- **Variations** in $\Delta \log \beta^*$ are **due to differences in source**, since path, station, and magnitude-dependent effects are removed
- **Effects from structure are removed** by measuring $\Delta \log \beta$ relative to calibration events
- These results are from P-wave spectra, but the method can **easily be applied to S-waves**
- The origin of spatial variation of $\Delta \log \beta^*$ is unclear, as they are not correlated with mainshock slip models (Vandevert et al., 2024). Understanding why $\Delta \log \beta^*$ and stress drop vary spatially is important for **better understanding strong ground motion.**
- We plan to release open-source code soon to perform this method on other datasets
- This method can be applied to larger datasets and ones in other locations

References

- **Baltay, A., Abercrombie, R., Chu, S., & Taira, T.** The SCEC/USGS community stress drop validation study using the 2019 Ridgecrest earthquake sequence. Seismica, 2024
- **Shearer, P. M., R. E. Abercrombie, and D. T. Trugman**, Improved stress drop estimates for M 1.5 to 4 earthquakes in Southern California from 1996 to 2019, *J. Geophys. Res.*, 2022.
- **Shearer, P. M.**, Introduction to Seismology, *Cambridge University Press*, 2019
- **Vandevert, I. C., Shearer, P. M., & Fan, W.**, Ridgecrest Aftershock Stress Drops from P- and S-Wave Spectral Decomposition. *BSSA*, 2024.

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