Ridgecrest Aftershock Stress Drops from P- and S-wave Spectral Decomposition

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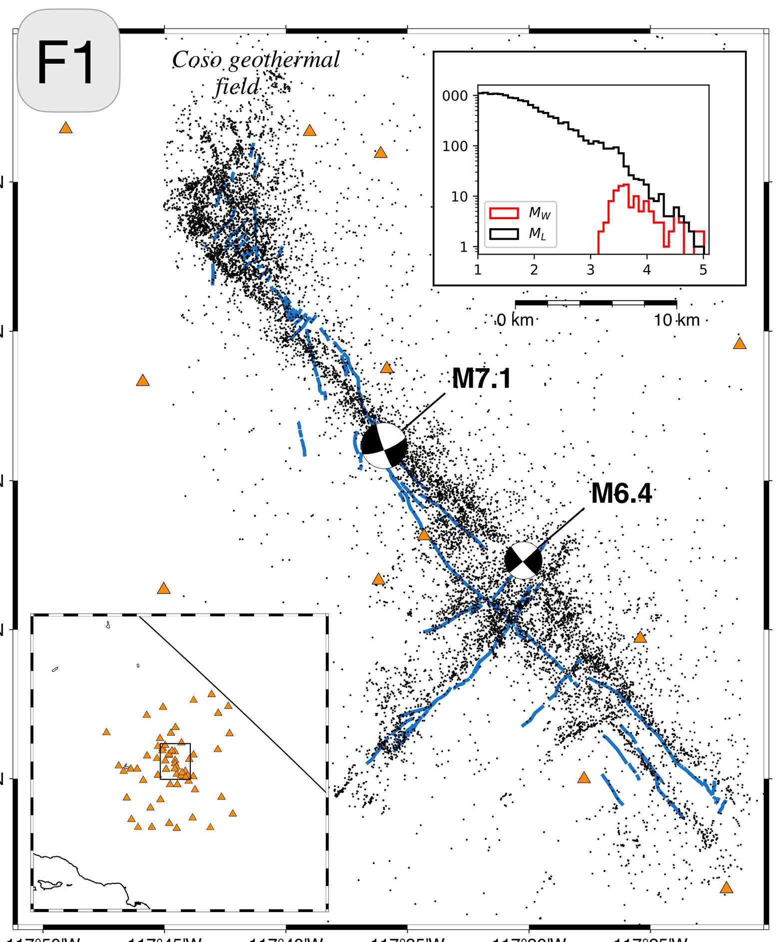
Source parameters have large uncertainties

- **Seismic moment** (M_0) and **stress drop** ($\Delta\sigma$) are crucial for understanding rupture processes, but their estimates often have large uncertainties for small earthquakes.
- Poorly constrained path corrections and model assumptions limit their accuracy, especially for $\Delta\sigma$.
- We apply P- and S-wave spectral decomposition to the 2019 Ridgecrest sequence (**F1**) and adjust the model parameters to achieve consistent $\Delta\sigma$ results between the two.



F1: Ridgecrest seismicity (black dots), M>1.0, 4-18 July 2019, with a total number of 12,943 events. Seismic stations are shown as orange triangles. The upper-right inset depicts the number of records by magnitude type versus magnitude.

This is our contribution to the **Community Stress Drop Validation Study** (**Baltay et al.**, 2024), in which many groups apply different techniques of source parameter estimation to the 2019 Ridgecrest dataset, with the goal of better understanding their uncertainties.

Abercrombie et al. (2024) compares these results, including the results of this study, to each other.

Spectral decomposition

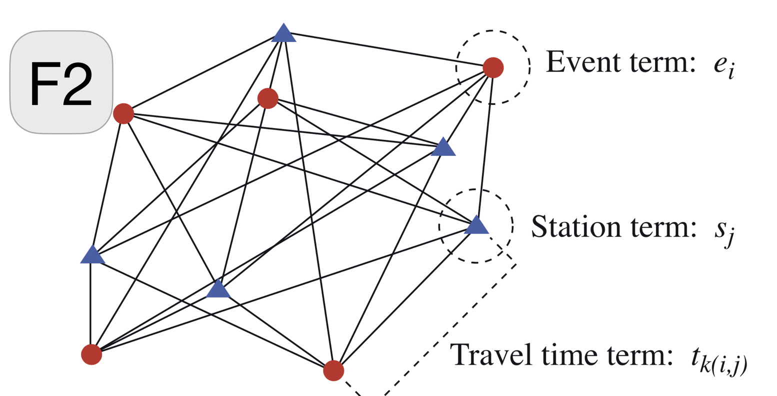
Step 1: We estimate displacement spectra for the station-event pairs, and discard those with a low signal-to-noise ratio.

Step 2: Observed spectra are 'decomposed' into event-specific source spectra (**F2**)

Step 3: We correct for path effects using a similar method as in Shearer et al. (2022), where an empirical correction spectrum (**ECS**) is computed by assuming the corner frequency of small earthquakes to a fixed value (**F3**):

P-waves: $f_c(\mathrm{M}1.5 \pm 0.1) = 30$ Hz

S-waves: $f_c(\mathrm{M}2 \pm 0.1) = 17$ Hz

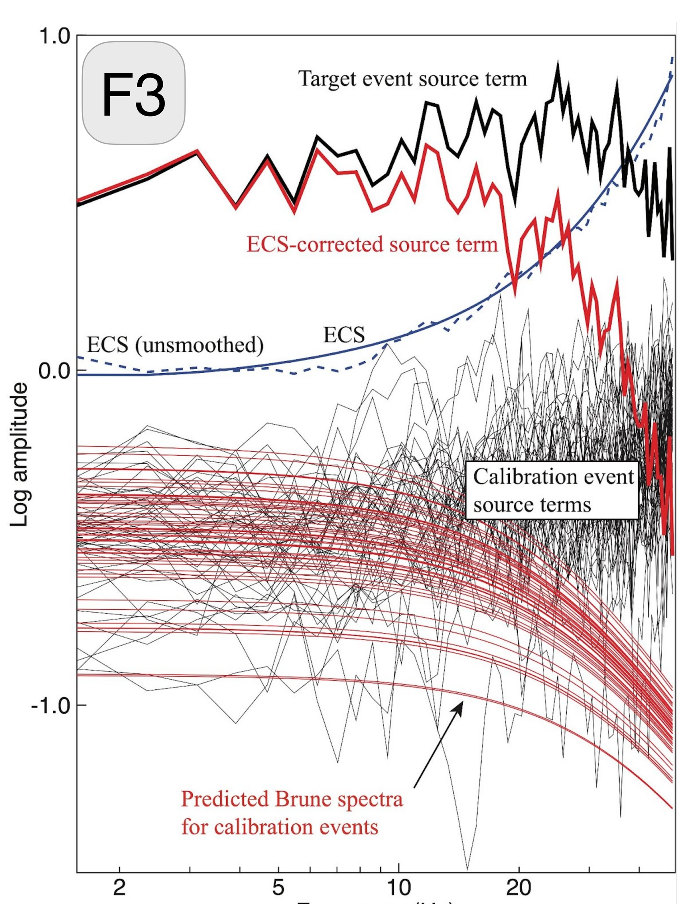


$$d_{ij} \approx e_i + s_j + t_{k(i,j)} + r_{i,j} \quad \text{(residual)}$$

Observed spectrum · Source spectrum · Receiver response · Travel-time dependent term to account for Q

Shearer et al., 2006

F2: Cartoon depicting the general inversion technique used in amplitude and spectral decomposition to calculate the event terms, e_i.



F3: Empirical correction spectrum estimation, correcting for path effects

Spectral decomposition (cont.)

Step 4: A theoretical source model (**Eq. 1**) is fit to the ECS-corrected source term, with long-period spectral amplitude $\Omega_0 \propto M_0$, and $n^P = 2;\ n^S = 1.8$

$$u(f) = \frac{\Omega_0}{1 + \left(\frac{f}{f_c}\right)^n} \qquad \textbf{Eq. 1}$$

Step 5: We obtain stress-drop estimates using **Eq. 2**

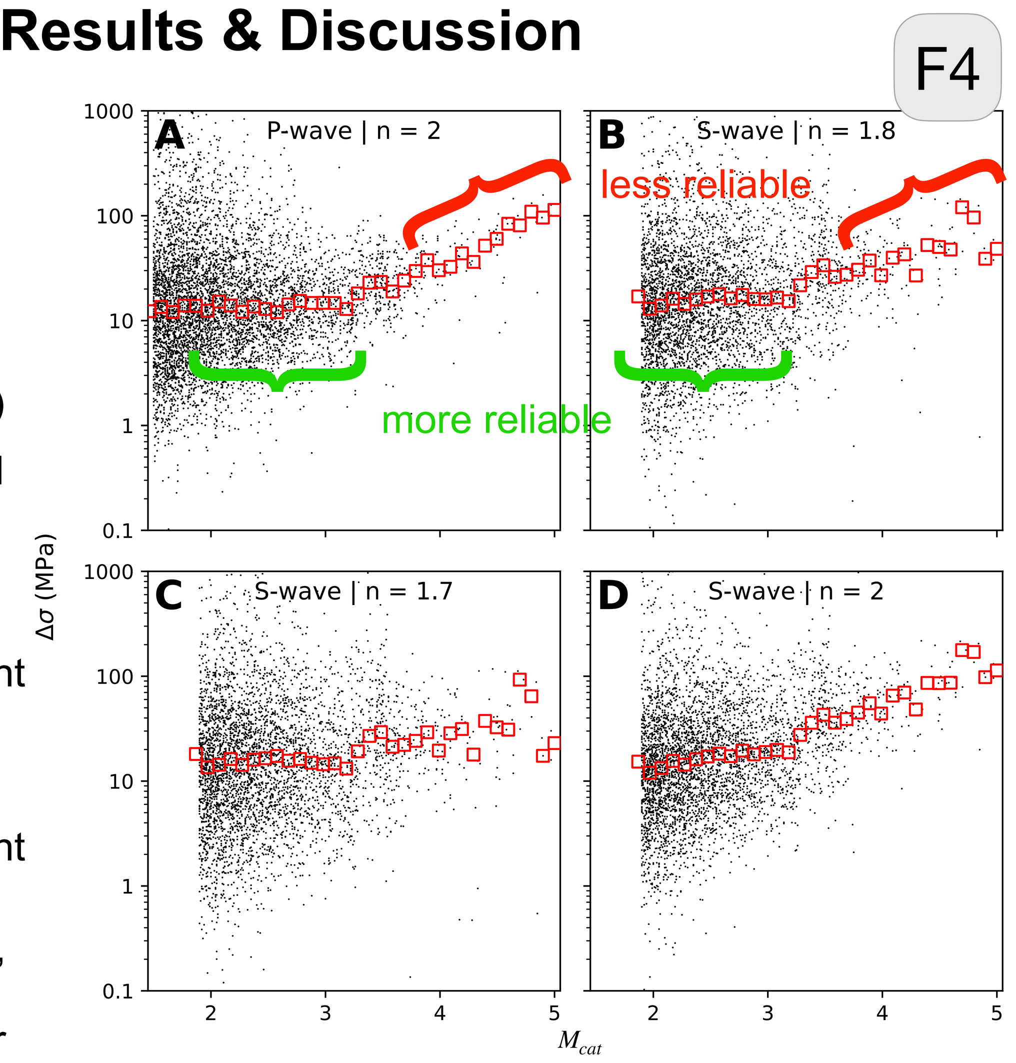
$$\Delta\sigma = \frac{7}{16}\left(\frac{f_c}{k\beta}\right)^3 M_0 \qquad \textbf{Eq. 2}$$

$k^P = 0.38;\ k^S = 0.26$ (**Kaneko and Shearer**, 2014)

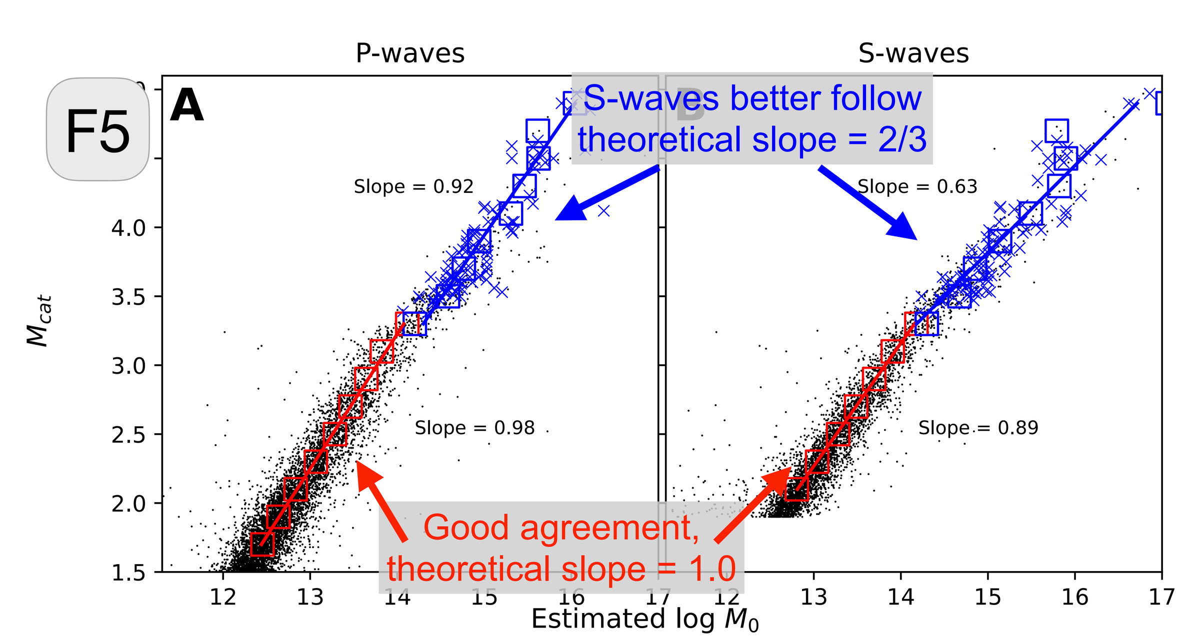
$\beta = 3.464$ km/s

Results & Discussion

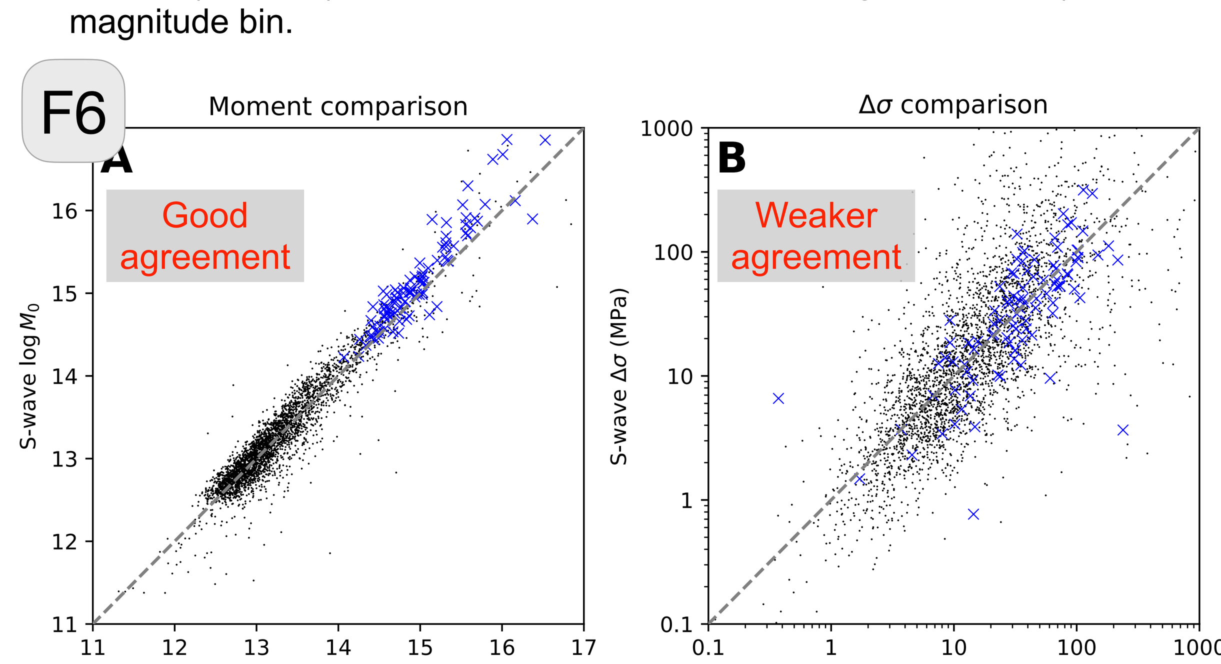
- $\Delta\sigma$ estimates using $n = 1.8$ for S-waves agree better with P-wave estimates (**F4**)
- We observe self-similarity in both datasets for <M3.5 (**F4**)
- M_0 is **better estimated using S-waves** for the larger events (>M3.5, **F5**)
- We find good agreement for M_0 and weaker agreement for $\Delta\sigma$ (**F6**)
- We observe an apparent increase in $\Delta\sigma$ with magnitude above M3.5, however this is likely unrealistic for the larger magnitudes (**Shearer et al.**, 2022)



F4: Comparison of the P-wave results (**A**) and S-wave results for n = (1.7, 1.8, 2.0) (**B-D**)



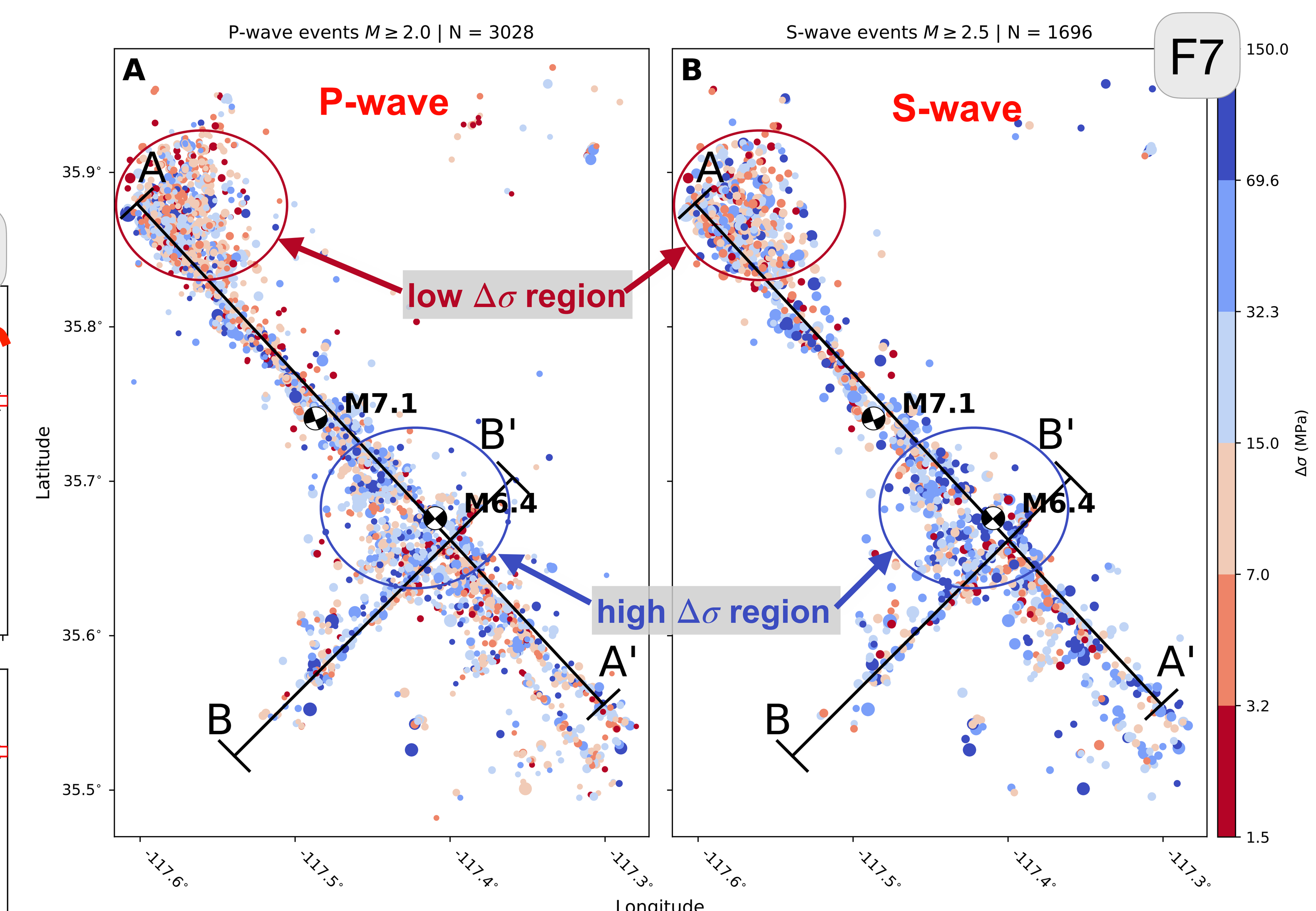
F5: Catalog magnitude versus estimated log moment for P-wave (left) and S-wave (right) datasets, for **local magnitude** (M_L) events (black dots) and **moment magnitude** (M_W) events (blue Xs). Lines are fit to the median log moments (color squares) for each magnitude bin.



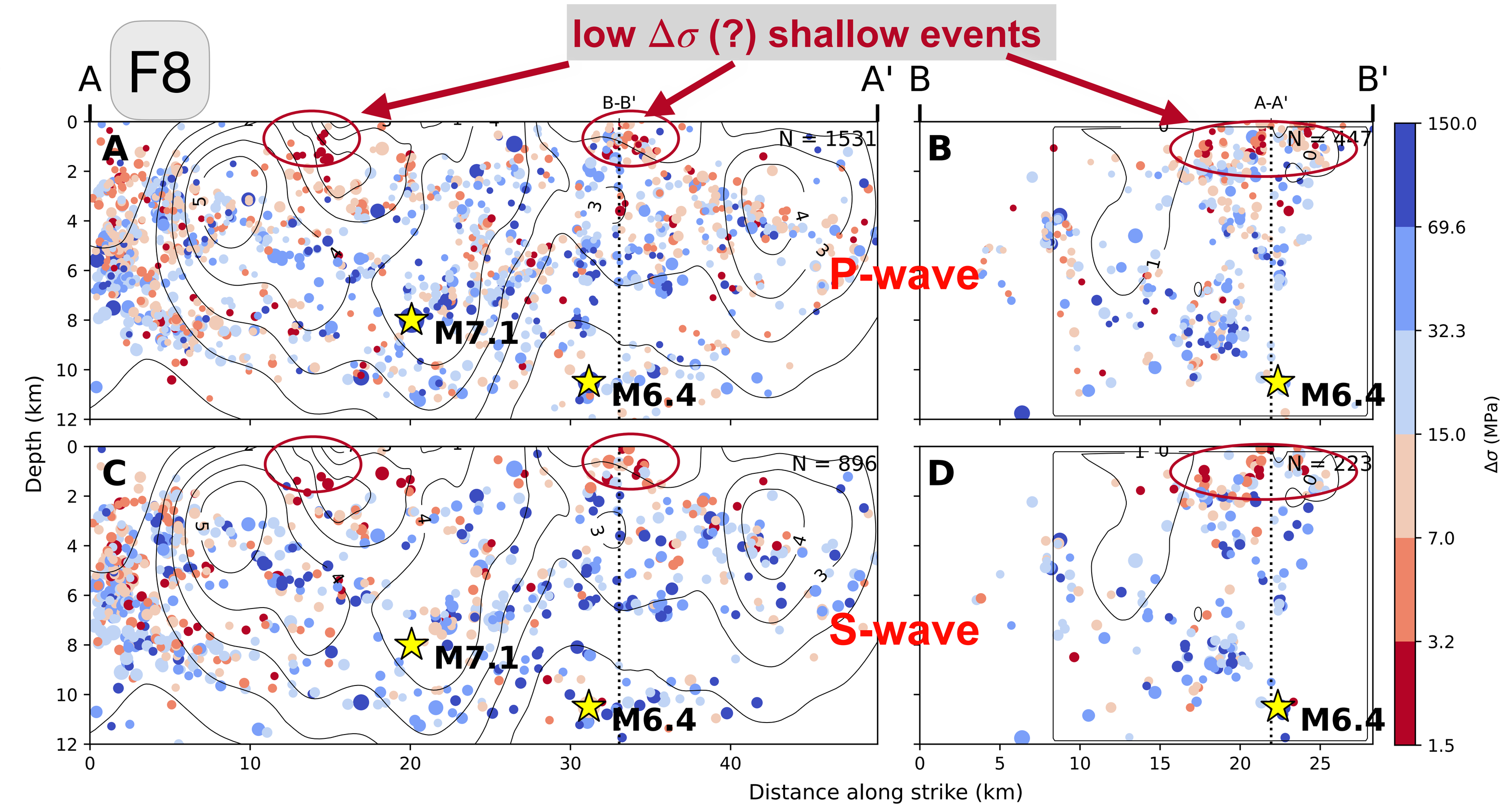
F6: Comparison of S-wave versus P-wave results for M_0 (left) and $\Delta\sigma$ (right). Blue Xs depict events with a catalog M_W.

Results & Discussion (cont.)

- We find **coherent spatial variation** consistent between P- and S-wave results (**F7, F8**)
- We find low $\Delta\sigma$ for many shallow events, but this could be an artifact of the ECS calculation (Abercrombie et al. 2021)
- We find no clear correlation between $\Delta\sigma$ and the slip model contours shown in **F8**.



F7: Spatial distribution of $\Delta\sigma$ for P-waves (**A**) and S-waves (**B**). Marker size is proportional to magnitude. Earthquakes within 1.5 km of each cross section (depicted by the tick lengths) are plotted in cross-section in **F8**.



F8: Cross-sections A-A' and B-B' depicting $\Delta\sigma$ at depth. Depths are vertically exaggerated. Slip contours are derived from Wang et al. (2020); slip data from the M7.1 mainshock is projected onto the cross section and interpolated onto an equally-spaced grid.

Takeaways

- We compute $\Delta\sigma$ for the Ridgecrest dataset using **P- and S-wave spectral decomposition.**
- We find that the results are most consistent when using a **lower high-frequency falloff rate for the S-wave spectra.**
- We find **coherent spatial variation** in $\Delta\sigma$ for both datasets.
- We find no clear correlation between our $\Delta\sigma$ results and a slip model of the M7.1 mainshock.
- The observed stress-drop distributions likely result from either **heterogeneous fault environments** or the effects of **3D seismic velocity structures.**

Acknowledgements

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