Dominant strike-slip faulting and near-constant stress drop of induced earthquakes in the Kiskatinaw area, northeastern British Columbia, Canada - supplement material

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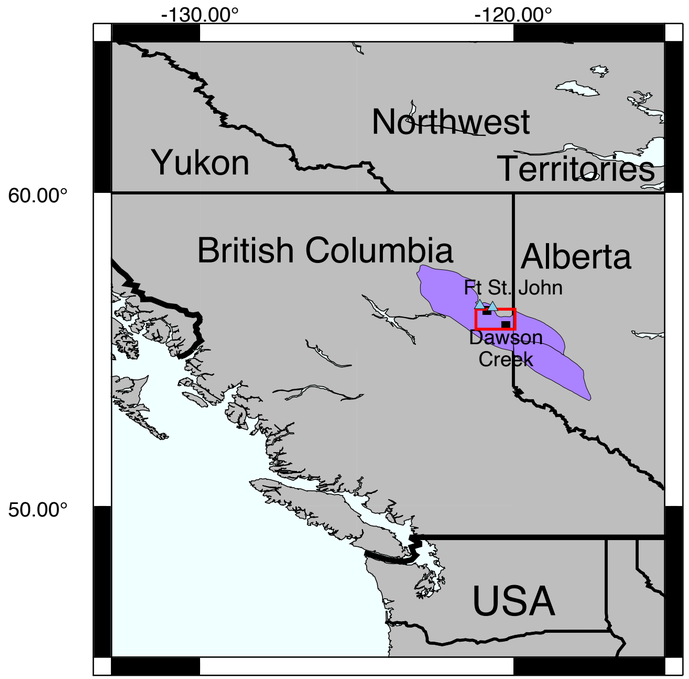
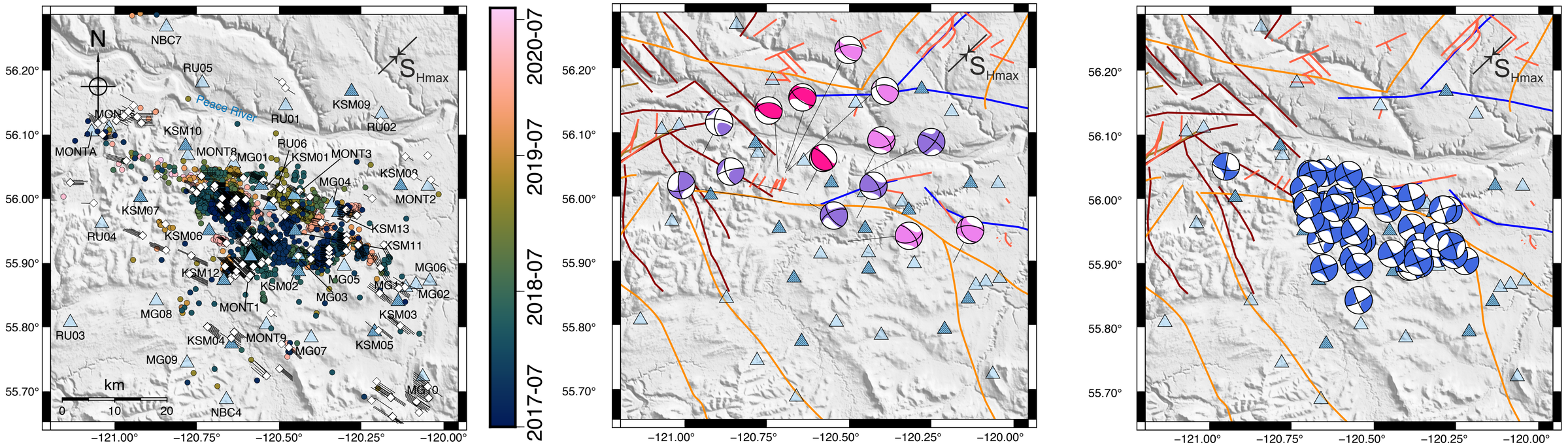
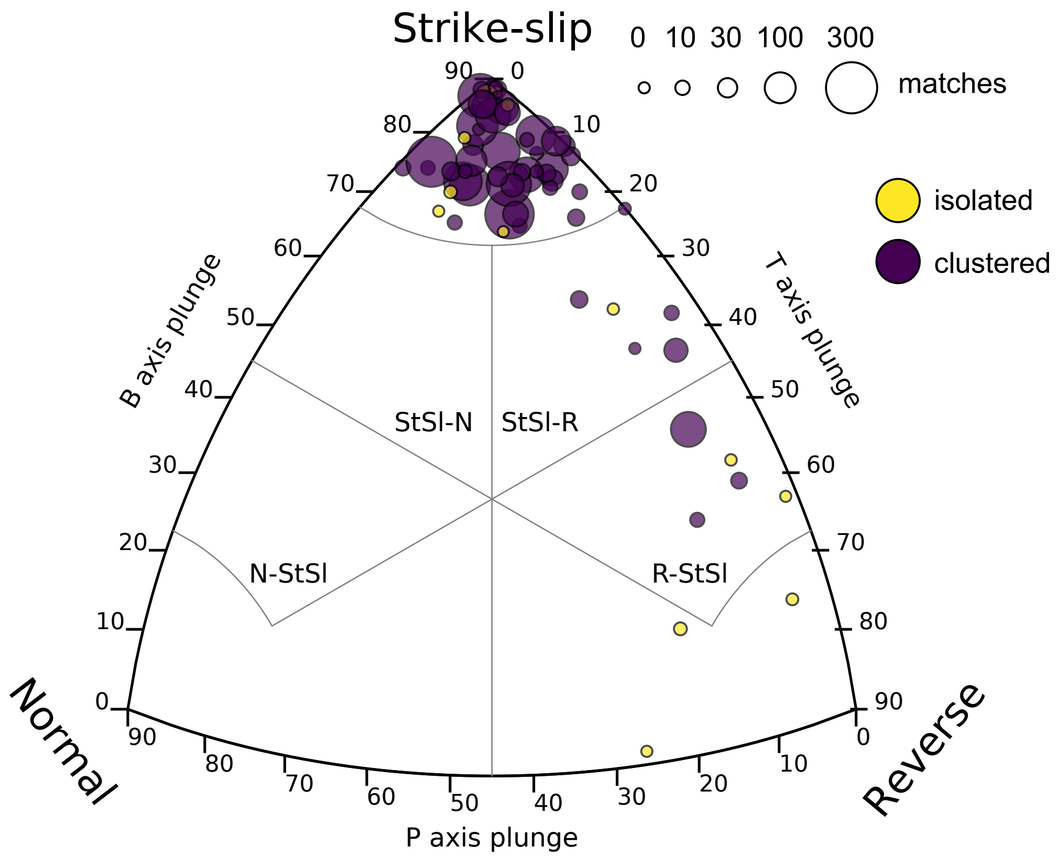


Waveform based clustering and template selection



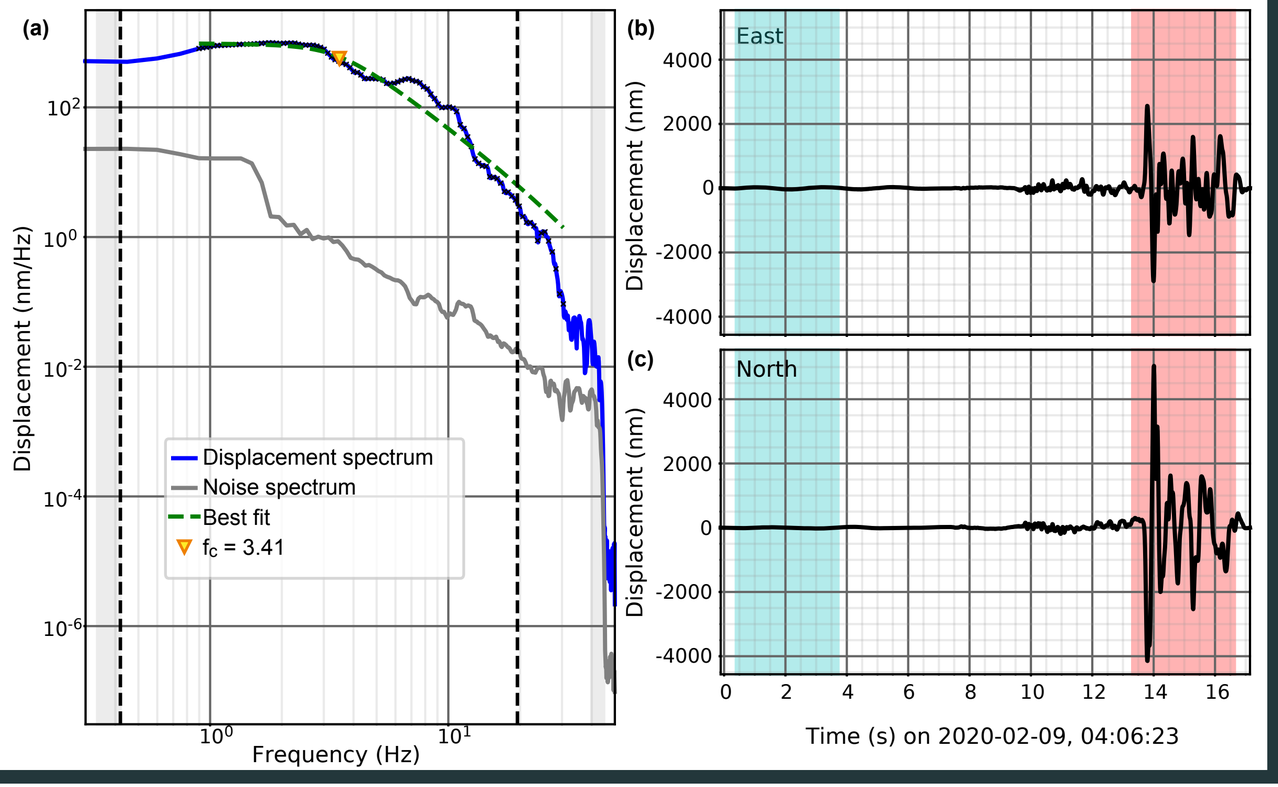
- Waveform based clustering of 8285 hydraulic fracturing induced events (circles) leads to 52 event families highly correlated to hydraulic fracturing operations (diamonds)
- A template selection of 51 clustered events (ML 1.5+) and 13 additional isolated events (ML 2.5+) results in 50 (78%) strike-slip events (StSl), 6 (9%) strike-slip events with non-negligible thrust-faulting component (StSl-R), 5 (8%) thrust-faulting events with strike-slip component (R-StSl), and 3 (5%) thrust faulting events (R).

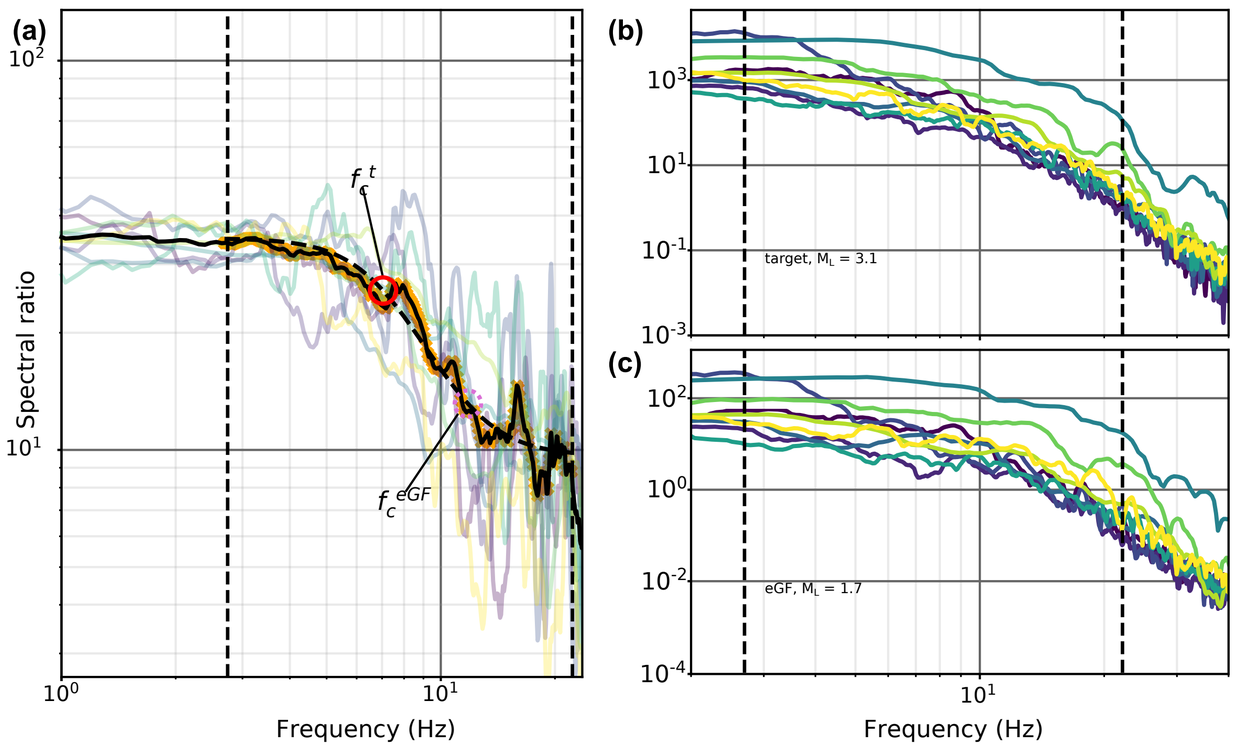
Template matching to enhance the FMS catalog



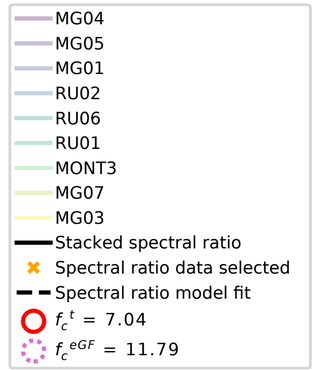
- Template matching on three stations indicates an additional 3500 out of the 8285 events to have cross-correlation coefficient (CCC) > 0.8 with at least one of the templates.
- We build and expanded focal mechanism solution (FMS) catalog by assuming matching events to be co-located with a similar FMS:
  - StSl: 3306 events (93%)
  - StSl-R: 87 events (2%)
  - R-StSl: 161 events (5%)
  - R: 10 events (<1%)
- The majority of strike-slip events occur in predefined event families
- Thrust-faulting events are isolated

Source parameter estimation

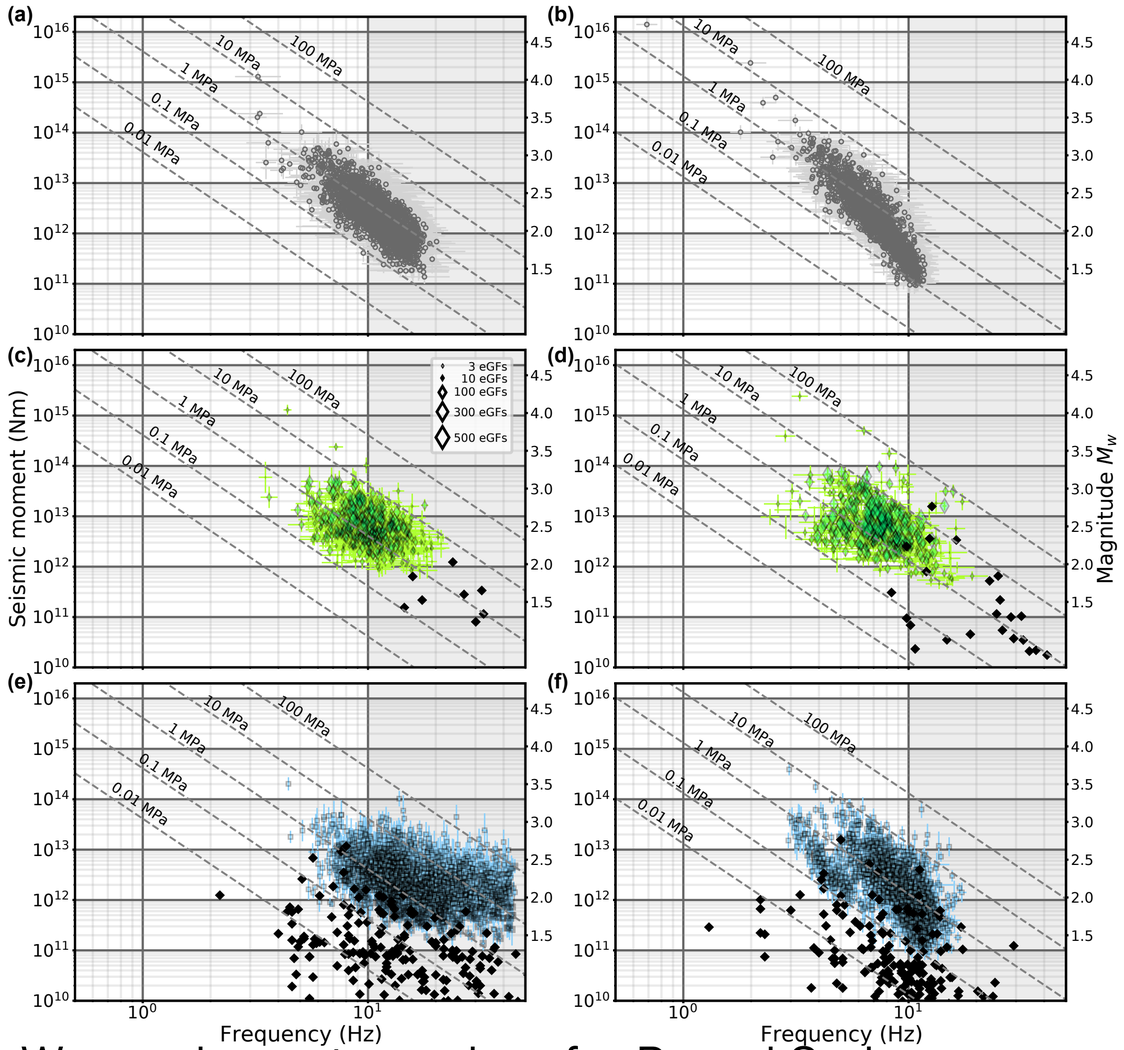




- We estimate source parameterusing three methods: single spectrum fitting (using the Boatwright model, a fixed Q = 850 and n = 2.5), spectral ratio fitting (with a fixed n = 2.5), and a clustered event method (CEM)[1].
- We estimate the spectral corner frequency, seismic moment and static stress drop for 2360 P-phases, and 1981 S-phases using single spectrum fitting; 559 P-phases, and 448 S-phases using spectral ratio fitting; 2150 P-phases, and 1784 S-phases using CEM.



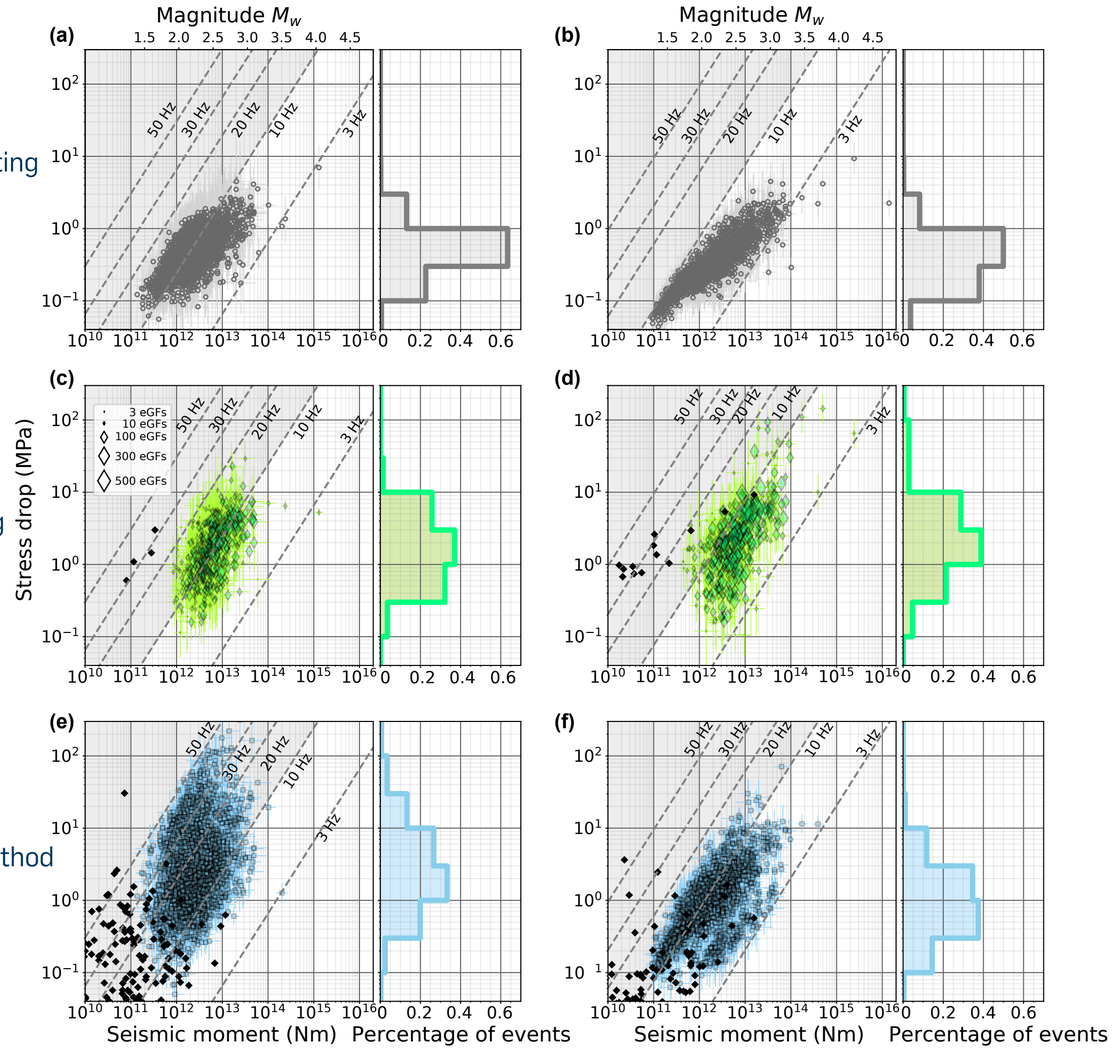
Source parameter estimation



Single spectrum fitting

Spectral ratio fitting

Clustered event method



- We receive a stress drop for P- and S-phases, respectively, of
  0.59 ± 0.02 MPa / 0.47 ± 0.02 MPa (single spectrum, grey circles);
  2.44 ± 0.28 MPa / 4.92 ± 1.15 MPa (spectral ratio fitting, green diamonds);
  7.14 ± 0.67 MPa / 1.66 ± 0.13 MPa (CEM, blue squares)

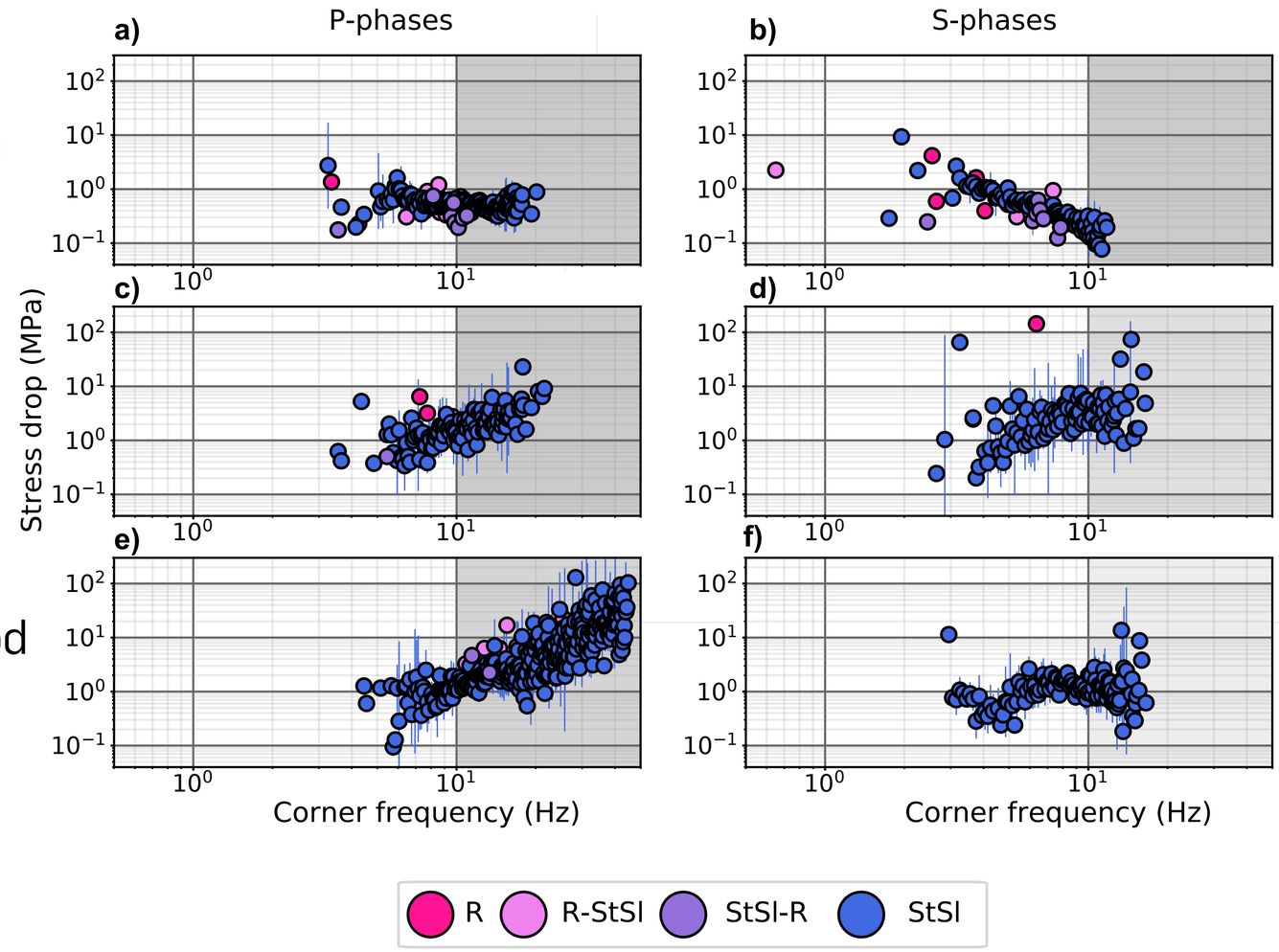
(black diamonds are from Yu et al., (2020)[2])

Source parameter estimation

Single spectrum fitting

Spectral ratio fitting

Clustered event method



- Mean stress drop estimate per 0.1 Hz-binned corner frequency range and faulting style
- Strike-slip and thrust faulting events exhibit roughly the same stress drop

Summary

- Seismicity in the Kiskatinaw area is strongly coupled to HF operations
- FMSs confirm two faulting styles, consistent with activation of optimally oriented faults:
  - Strike-slip faults at low angles to S_H
  - Thrust faulting events perpendiculat to S_H
- Strike-slip faults occur in event families, thrust faulting events on isolated faults
- Induced events in the Kiskatinaw area exhibit constant average stress drop of ~1-10 MPa, simmilar to tectonic earthquakes

[1] Ko, J. Y.-T., Kuo, B.-Y., & Hung, S.-H. (2012). Robust determination of earthquake source parameters and mantle attenuation. Journal of Geophysical Research: Solid Earth, 117(B4). doi: 10.1029/2011jb008759

[2] Yu, H., Harrington, R. M., Kao, H., Liu, Y., Abercrombie, R. E., & Wang, B. (2020). Well proximity governing stress drop variation and seismic attenuation associated with hydraulic fracturing induced earthquakes. Journal of Geophysical Research: Solid Earth, 125(9). doi: 10.1029/2020jb020103

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Figures in this presentation are part of a manuscript in preparation.