Stress Drops from Trench to Depth in the Northern Chilean Subduction Zone

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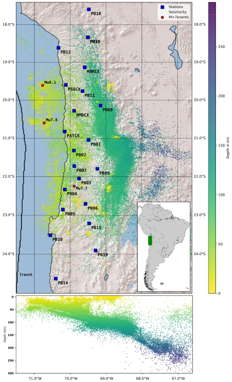
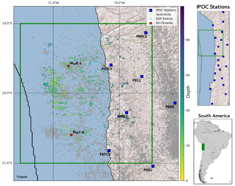
Data Basis - Northern Chile Seismicity Catalog

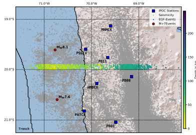


Research area northern Chile. Seismicity catalog from Sippl et al. 2018 color coded with depth from top and side view. Red circles are the 2014 Iquique main event and its largest aftershock; blue squares are IPOC stations.
The data set constitutes a great data base for a comprehensive stress drop analysis covering all seismic active regions within a subduction zone from trench to a depth of over 200km including both inter-plate and intra-plate events.

Template Selection for Template Matching

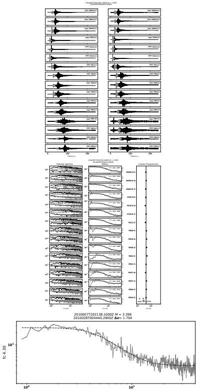


In a recent study 2610 templates from the rupture area of the Iquique event were selected to perform template matching, yielding about 9950 possible EGFs.



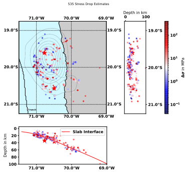
We are currently applying a template matching approach to the entire catalog for the full time period of 2007 to today to a) find previously unidentified events and b) select appropriate EGFs to perform a comprehensive spectral raio based stress drop analysis.
Here, a a first test run of 2543 events is shown limited between 19.9 and 20 Deg South. Approx. 15956 potential event pairs were found.

Data Example

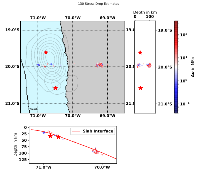


Exemplary velocity waveform data for one EGF pair with cc above 0.80 at minimum 3 stations. P phase is highlighted. Corresponding spectra are computed showing noise levels as thinner lines. Spectral ratios of main to EGF events are shown station wise. A Boatwright based spectral ratio model is fitted to the stacked data to obtain the corner frequency of the main event which is used to compute the stress drop.

Resulting Stress Drop Distributions

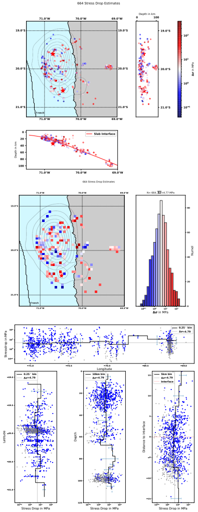


Stress drop distribution on map and side views. Stress drop ranges mostly from 0.1 to 100 MPa with an median of 4.16MPa. Some areas show patches of higher some of lower stress drop. No dominant trend is apparent.
The published results of this study can be found here.



Same as above but with the test data set. Stress drop estimates are spatially separated into two groups, here. Those of shallow and those of intermediate depths events (which where excluded in the previous study). The deeper group seems to show slightly elevated median stress drops.

Joined Results



First results reveal increased stress drop with distance to the interface. The intermediate depth events also appear to have increased stress drops. The increase, however, is only small compared to overall stress drop variability in the data.

Motivation - Pilot Study of the Interface Seismicity of the Rupture Area of the Iquique EQ

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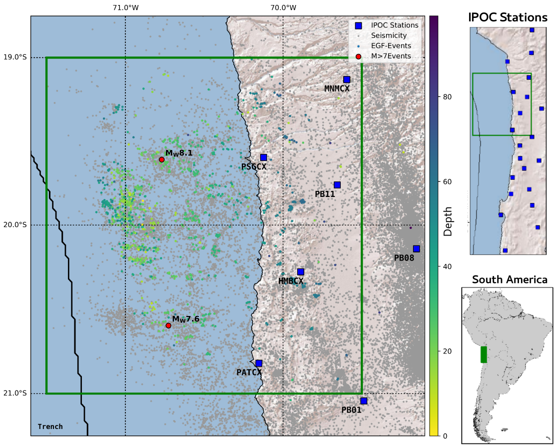
- Earthquake source parameter scaling is fundamental for understanding the mechanics of earthquake rupture.
- The parameter **stress drop** relates rupture dimension to seismic moment which makes it a central parameter for source description.
- The Northern Chilean subduction zone has been monitored by the IPOC network for more than ten years. The subduction zone produced a vast amount of seismic activity and a **huge catalog** was compiled including over 100000 events, published by Sippl et al. 2018.
- We apply the **spectral ratio approach** to investigate stress drop of interface seismicity in the rupture region of the 2014 $M_W 8.1$ Iquique event.



Research area northern Chile. Seismicity catalog from Sippl et al. 2018, highlighted are 2610 events which were selected for this study color coded with depth. Red circles are the 2014 Iquqiue main event and its largest aftershock; blue squares are IPOC stations.

Stress Drop - Computation

Brune type stress drops are computed using:

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

β is shear wave velocity at the source

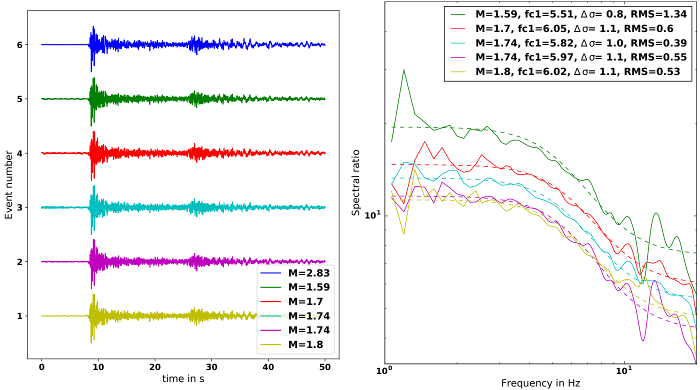
$k = 0.32$ is a standard value by Madariaga, 1979

M_0 is seismic moment

We estimate f_c with the **spectral ratio** approach (e.g., Abercrombie, 2014):

$$\frac{u(f)}{u_{EGF}(f)} = \frac{\Omega_0}{\Omega_{0EGF}}\left(\frac{1+(f/f_{c_{EGF}})^{\gamma n}}{1+(f/f_c)^{\gamma n}}\right)^{\frac{1}{\gamma}}$$

where n is spectral falloff, γ is model dependent ($\gamma = 1$: Brune,1970, $\gamma = 2$: Boatwright,1981).



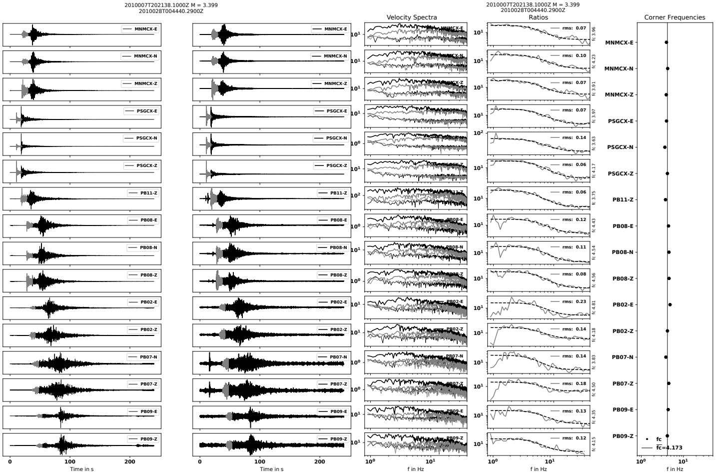
Empirical Green's function family. One target event on top with five EGFs found by template matching. Spectral ratios computed with corresponding colors. From the ratio f_c is computed and stress drop can be calculated. Note the consistency of f_c and stress drop estimates using the different EGFs. Figures taken from Rakau, 2019.

Processing and Examples

Event selection
→ 9950 templates from catalog by Sippl et al., 2018
→ Template matching at IPOC stations PB 01,02,08,11,12
→ Time span 2008-2016
→ $cc \geq 0.8$, $\Delta M \geq 1$
→ 2610 event pairs found

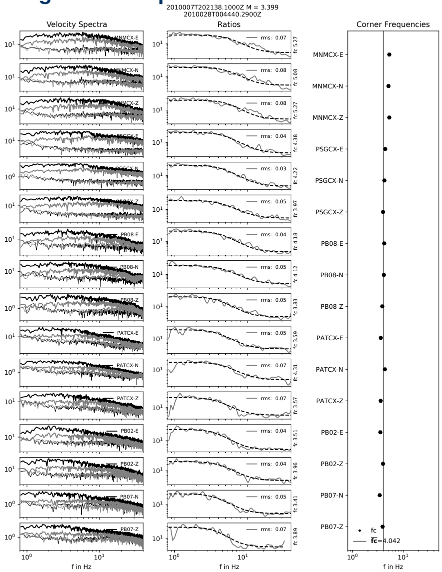
Processing
→ Detrend
→ Bandpass filter (0.8–40Hz)
→ Spectral Ratio
→ Averaging of trace spectra using the median of all traces
→ Boatwright spectral model fit to average spectrum to obtain fc
→ Computation of stress drop

→ Repeat for all events, P and S phase
→ Average redundant results with median

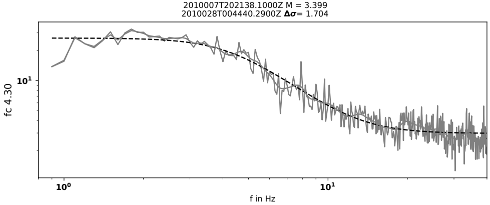


From left to right: Seismic traces from target event and one of its EGF events. Selected P phase is highlighted. Spectra and spectral ratios with Boatwright fit. Estimated f_C for each station. Spherical average using median, indicated by vertical line gives $f_C = 4.17\ Hz$.

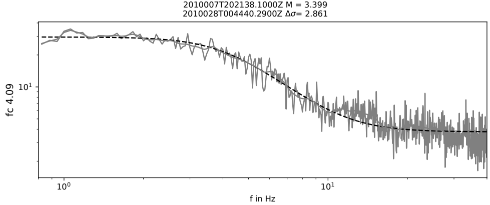
Processing and Examples



(Left) Spectra and spectral ratios with Boatwright fit for **s phase**.

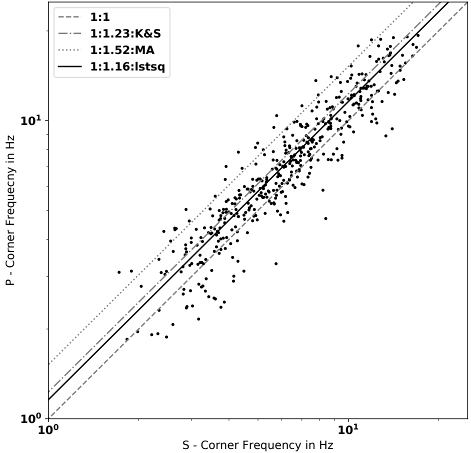


Stacked **p phase** spectra (using median at each frequency point) to estimate fc.



Stacked **s phase** spectra (using median at each frequency point) to estimate fc.

Computing k and β

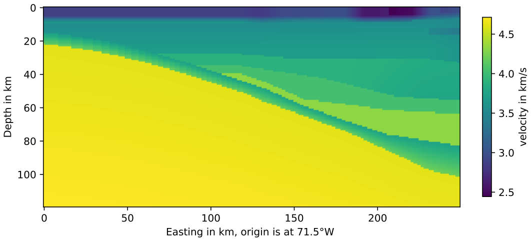


Because event specific k is not known k is obtained via a cross plot of estimated f_{c_p} and f_{c_s}.

Remember:

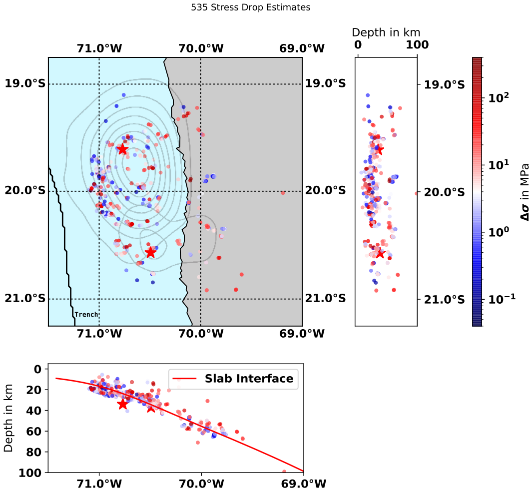
$$\Delta\sigma = \frac{7}{16}\left(\frac{f_c}{k\beta}\right)^3 M_0$$

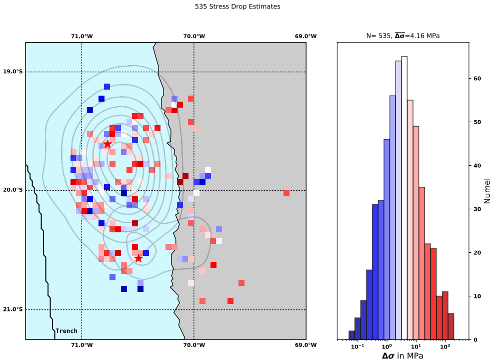
Velocity model at approx 20°S



β is taken from the pseudo 3D velocity model from Bloch et al., 2014, for each event individually
M_0 is computed from a magnitude catalog by Müchmeyer et al., 2020, for each event individually

Results

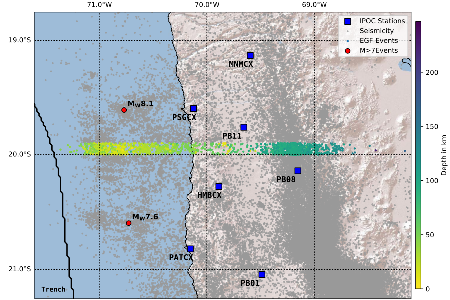




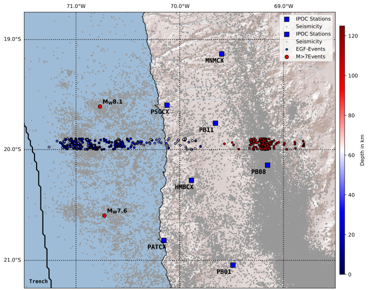
left: Stress drop distribution in map view and side views. Color indicates magnitude of stress drop. Red stars indicate the hypocenters of the $M_W 8.1$ Iquqiue event and its biggest aftershock ($M_W 7.6$). Slip distribution from Schurr et al 2014 is underlain in grey.

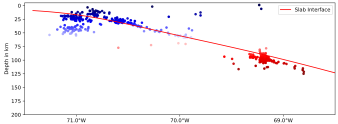
right: Cell wise averaged stress drop distribution and histogram. Note the log–normal distribution with the overall median of 4.16MPa.

Full Data Set - Test Run



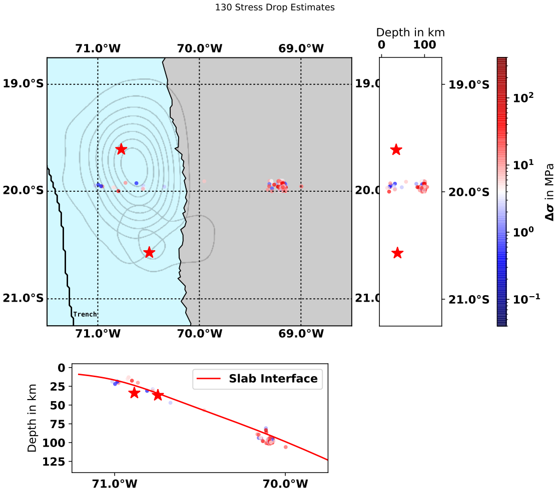
Test set for template matching run for the entire catalog. A strip between 19.9 to 20° South is selected. It contains about 2543 events and we find 15956 matches, i.e. event pairs that are possibly suitable for a spectral ratio analysis.

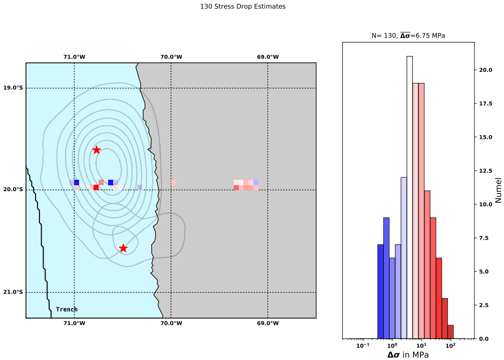




After applying restrictions by cc $>$ 0.8 and a minimum amplitude ratio of five, 2528 event pairs remain for stress drop analysis (shown here). In the next steps, data availability, picks and SNR are checked. These are strong limitations as is the maximal sampling rate of 100Hz, effectively limiting the study to events with a main event of M$>$2.5. Consequently, event numbers reduce significantly to only 130 events.

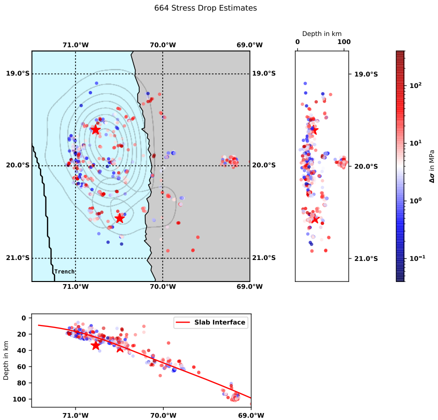
Results - Test Run



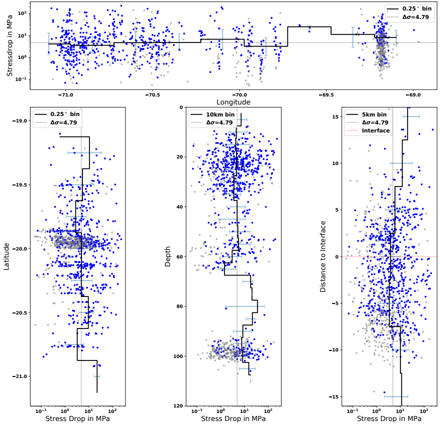


left: Stress drop distribution in map view and side views. Color indicates magnitude of stress drop. Red stars indicate the hypocenters of the $M_W 8.1$ Iququie event and its biggest aftershock ($M_W 7.6$). Slip distribution from Schurr et al 2014 is underlain in grey.
right: Cell wise averaged stress drop distribution and histogram. Note the log–normal distribution with the overall median of 6.75MPa. Note that the deeper events show more reddish colors than the shallow events indicating higher stress drops.

Joined Results



Combined data from Interface and Test Run data.



Detailed stress drop variation in four spatial sections (W–E, N–S, depth, distance to interface) with overlain median binning. Note the increased median values to the east, corresponding to the deeper events below 70km. Also note a similar increase of values when receding from the interface into the plates.

Interface Data set

- Spectral ratio method provides reasonable stress drop estimates for a large group of events.
- Estimates span a range from 0.1 to 100 MPa and show log–normal distribution with a reasonable median value.
- Slight spatial dependencies are observed such as increased stress drop with distance to interface.
- **No** increase of stress drop with depth was identified.

Test Run Data Set

- A distinction between shallow and intermediate depth events is apparent with deeper events having larger stress drops
- The overall median stress drop is increased compared to the above data set

Joined Data

- Two trends of stress drop variability stick out:
- The median stress drop is elevated for deeper events.
- The stress drop increases with larger distances to the plate interface.

Whats next?

- Actually, the entire catalog is used as template data base to obtain previously missed events and potentially find events suitable for the spectral ratio approach.
- We expect new insights from the intermediate depth seismicity band which includes the majority of events from the original catalog. Especially because first results indicate a distinction in stress drop from other shallower events.

Acknowledgments and Bibliography

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