

Empirical Green's Functions (EGF) Techniques

Meichen Liu

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AN NSF+USGS CENTER

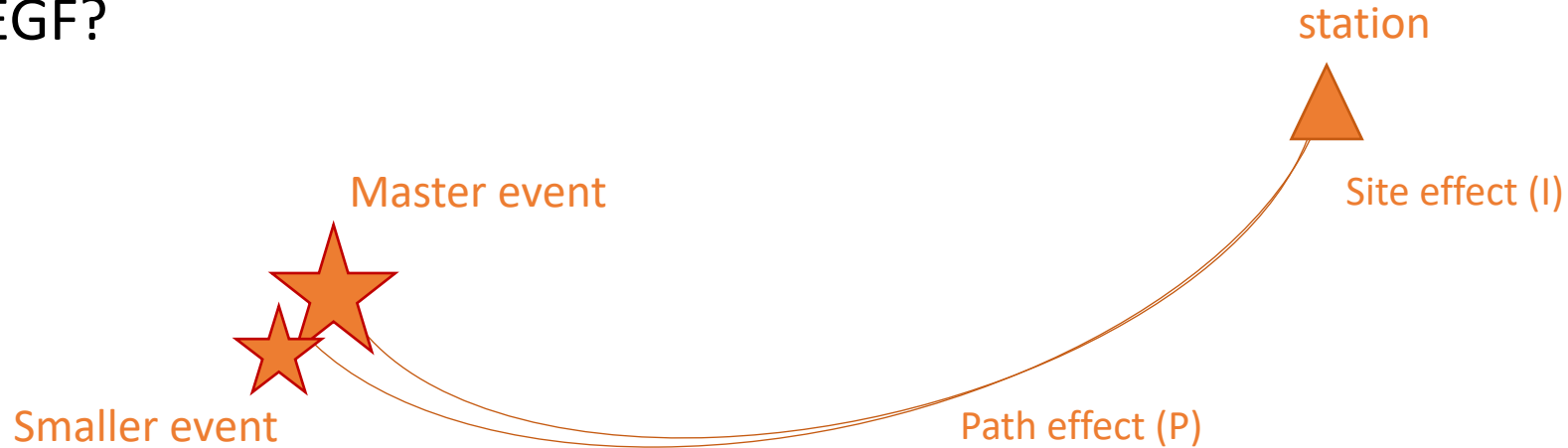
Community Stress Drop Validation Study Workshop

Outline

- Introduction to EGF technique.
- Hands-on exercise
- Discussions

Empirical Green's Function (EGF)

➤ what is EGF?



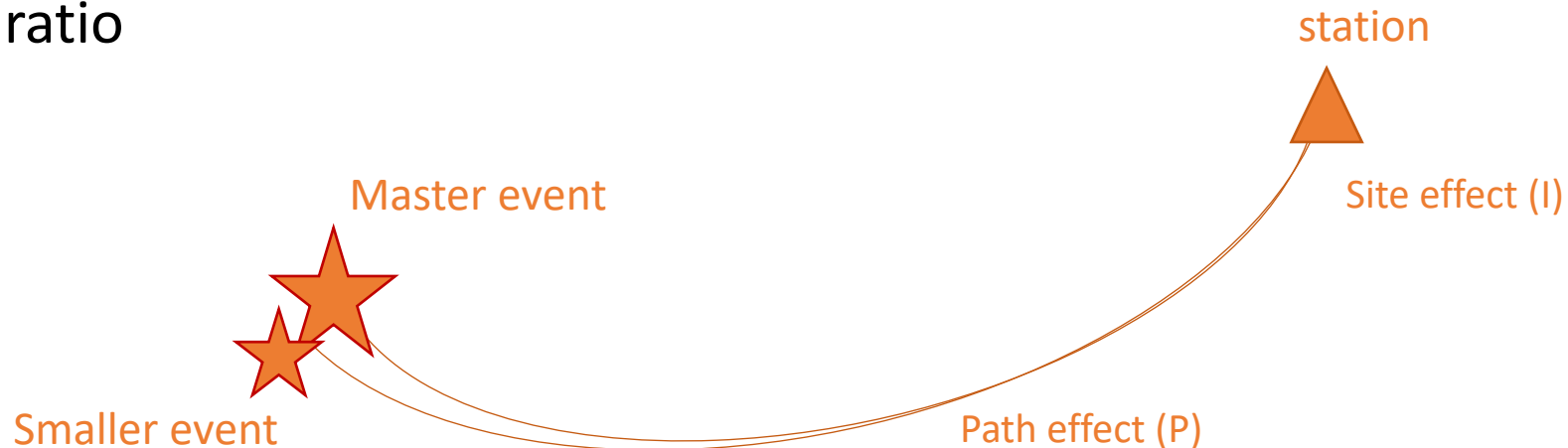
Green's function: the response of the medium to an impulsive point source.

In ambient noise tomography: the stacked cross-correlation wavefield of ambient noise.

In earthquake source studies: A smaller event that approximate the seismic path and site effects of the nearby large event.

Empirical Green's Function (EGF)

➤ Spectral ratio



$$\begin{array}{c} \text{Displacement spectrum} \rightarrow u(f) = S(f)P(f)I(f) \\ \begin{array}{ccc} \uparrow & \uparrow & \uparrow \\ \text{Source} & \text{Path} & \text{Site} \end{array} \end{array} \quad \Rightarrow \quad \frac{u_{master}}{u_{EGF}} = \frac{S_{master} \cdot \cancel{P} \cdot \cancel{I}}{S_{EGF} \cdot \cancel{P} \cdot \cancel{I}} = \frac{S_{master}}{S_{EGF}}$$

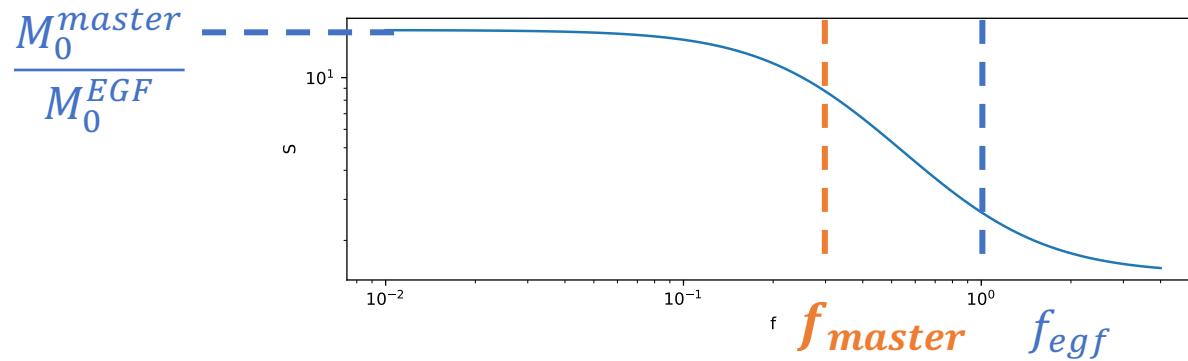
Empirical Green's Function (EGF)

- Corner frequency and stress drop

Brune's source model:

$$S(f) = \frac{M_0}{1 + \left(\frac{f}{f_c}\right)^2}$$

$$\frac{u_{master}}{u_{EGF}} = \frac{S_{master}}{S_{EGF}} = \frac{M_{master}}{M_{EGF}} \cdot \frac{1 + \left(\frac{f}{f_{EGF}}\right)^2}{1 + \left(\frac{f}{f_{master}}\right)^2}$$



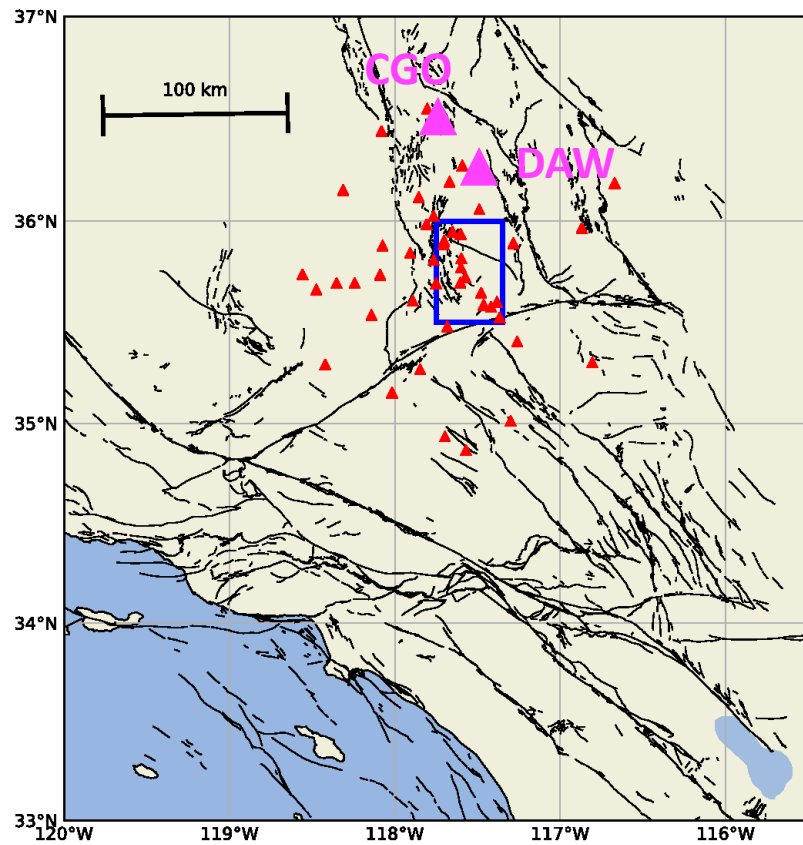
Stress drop $\Delta\sigma$ of circular crack: $\Delta\sigma = \frac{7}{16} \frac{M_0}{r^3}, r = \frac{k\nu}{f_{master}}$

Hands-on exercise

Link for jupyter notebook and data:

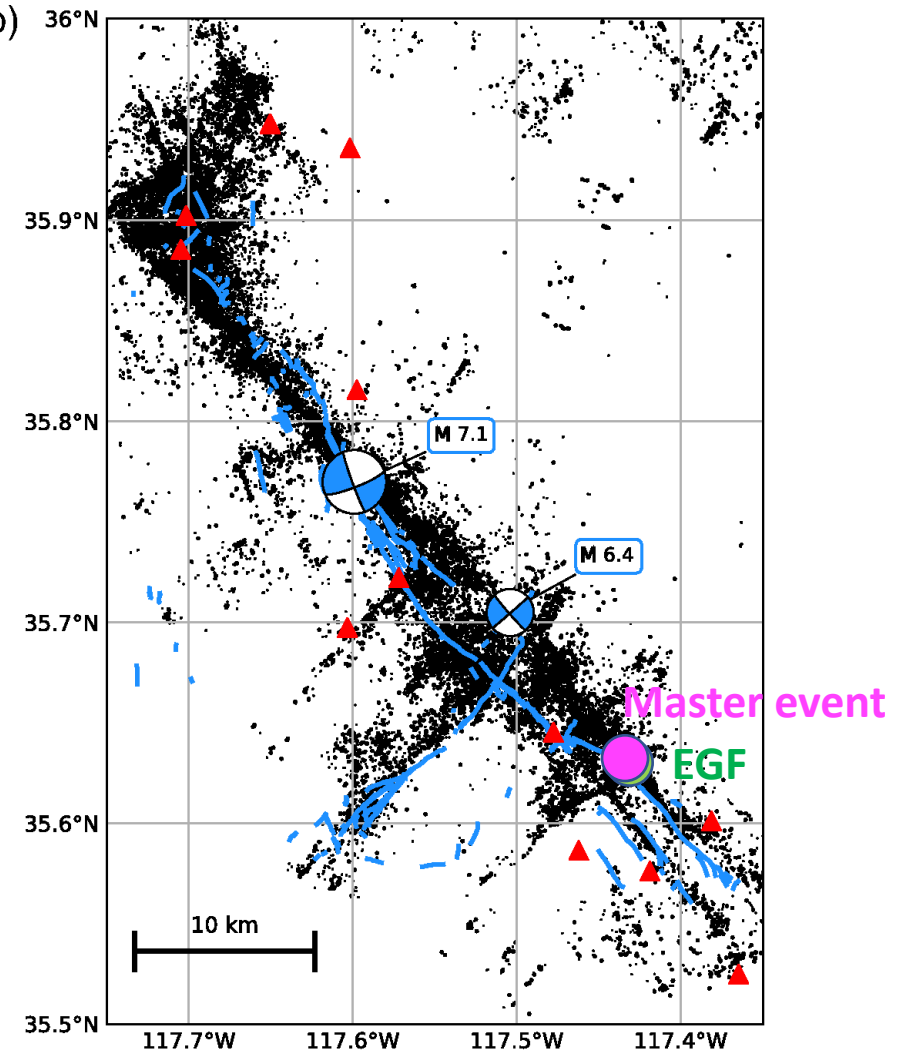
<https://drive.google.com/drive/folders/1FFSs0XzW6wqknI3ljGysH9WAZad7lBfb?usp=sharing>

(a)



(Trugman, 2020)

(b)



Hands-on exercise

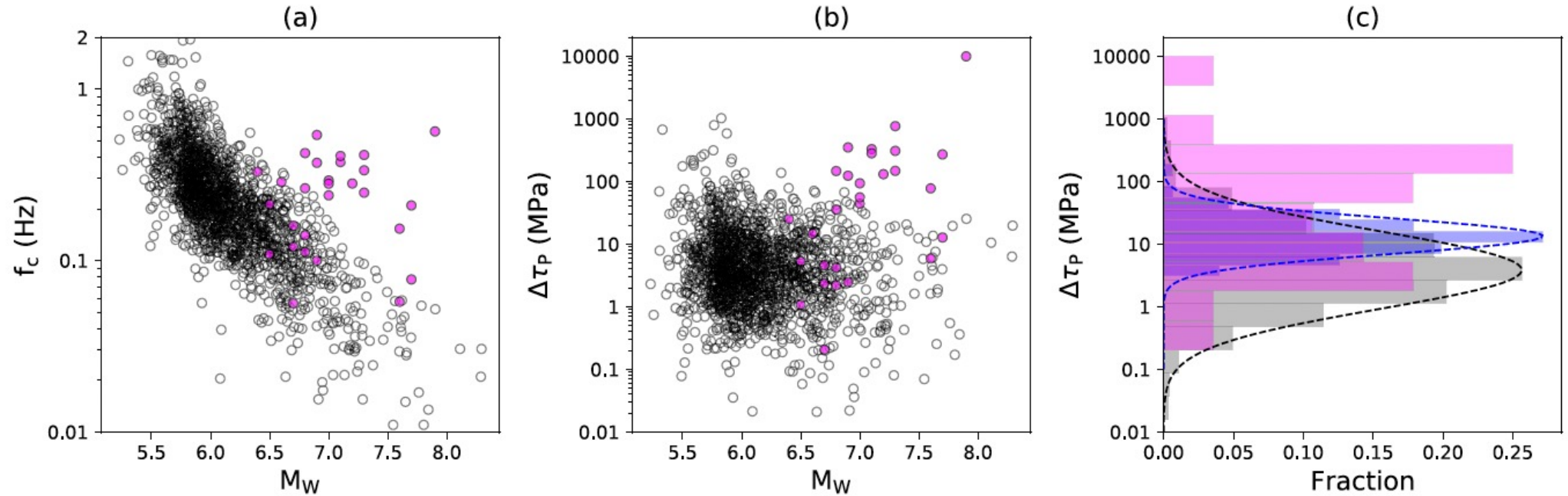
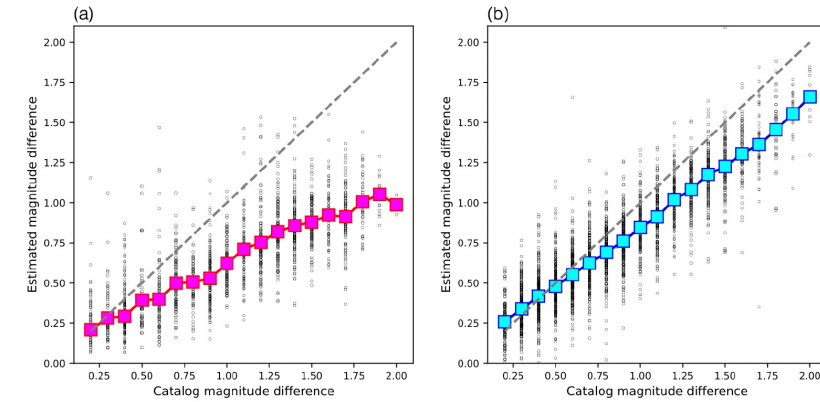
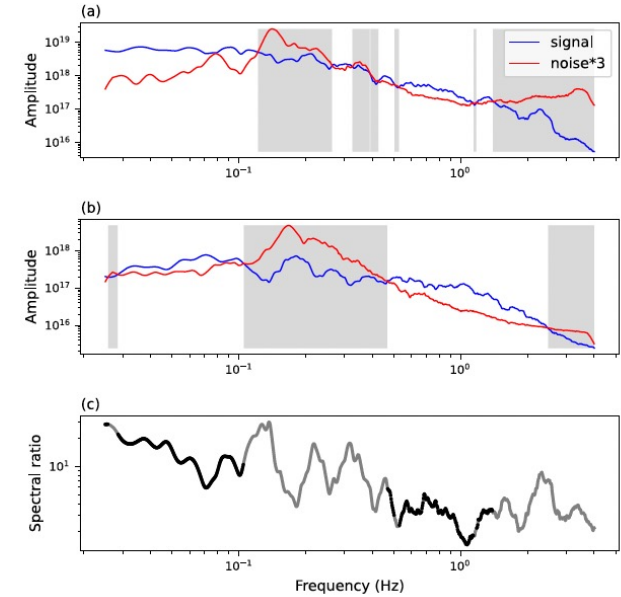


Figure 4. (a) Corner frequencies and (b) stress drops of shallow earthquakes (white circles) by Allmann and Shearer (2009) and estimates for deep-focus earthquakes in this study (magenta circles). (c) Histograms of the stress drop distributions corresponding to data in (a) and (b). The blue histogram shows the stress drop distribution of deep-focus earthquakes determined by Poli and Prieto (2016). Dashed lines are Gaussian contour fitting to histograms. The median stress drops of magenta, blue, and gray histograms are 50.0, 13.4, and 4.0 MPa.

Discussions: Data selection and analysis

The selection criteria and analyzing processes could also cause a large difference, especially if there is not enough data.

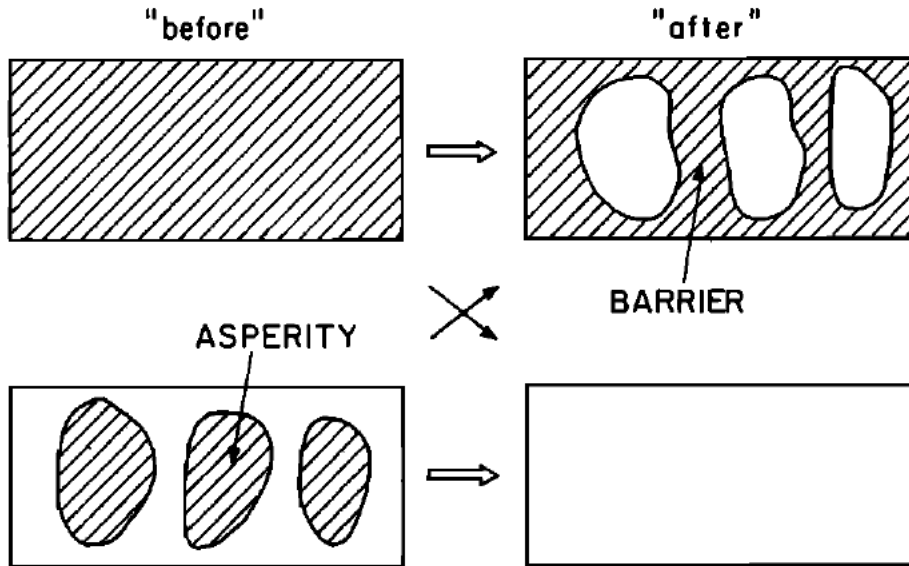
- Magnitude difference between master event and EGF: > 0.5
 - Distance between master event and EGF: < 1 source dimension
 - SNR: trade off between data size and quality,
 - Average > 3
 - > 2 in each subset frequency ranges
 - Window length for spectra calculation: $>$ source duration
 - Frequency bandwidth: lower bound $\times 1.5 < f_{\text{master}} < \text{high bound} / 1$.
 - FFT: multi-moving window vs. multitaper
 - Stacking method: trace-wise vs. point-wise
-
- EGF selection criteria: > 5 stations
 - Master event selection criteria: > 2 EGFs
 - ...



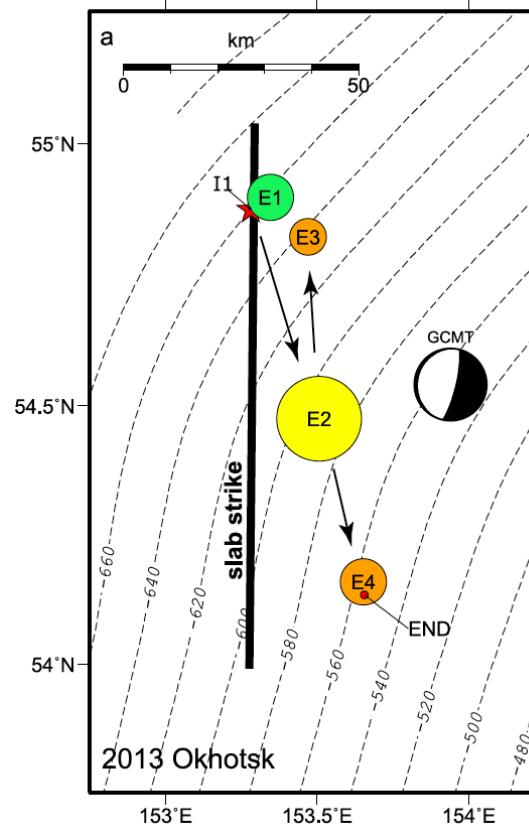
(Liu et al., in prep)

Discussions: Source complexity (time domain)

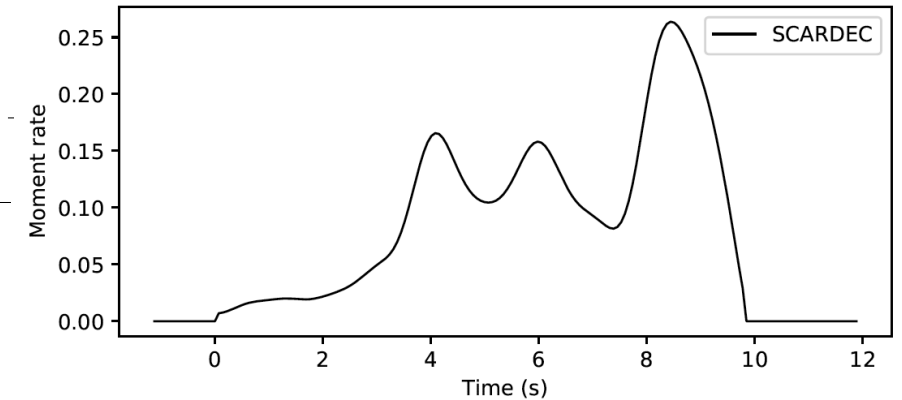
(Aki, 1984)



(Zhan et al., 2014)

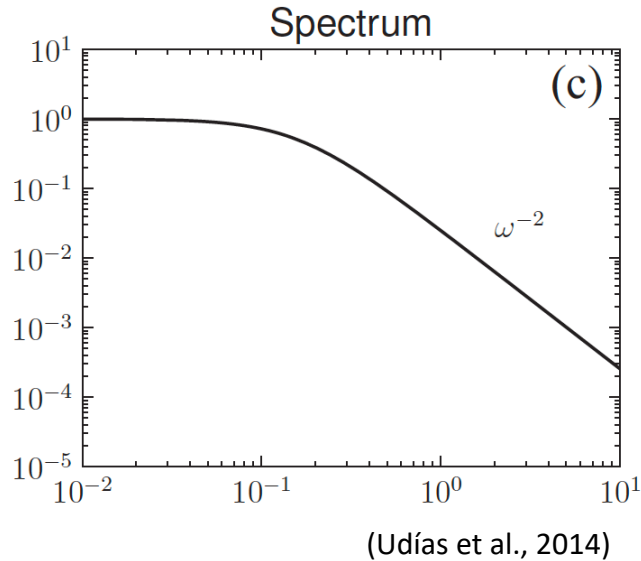


Source time function complexity

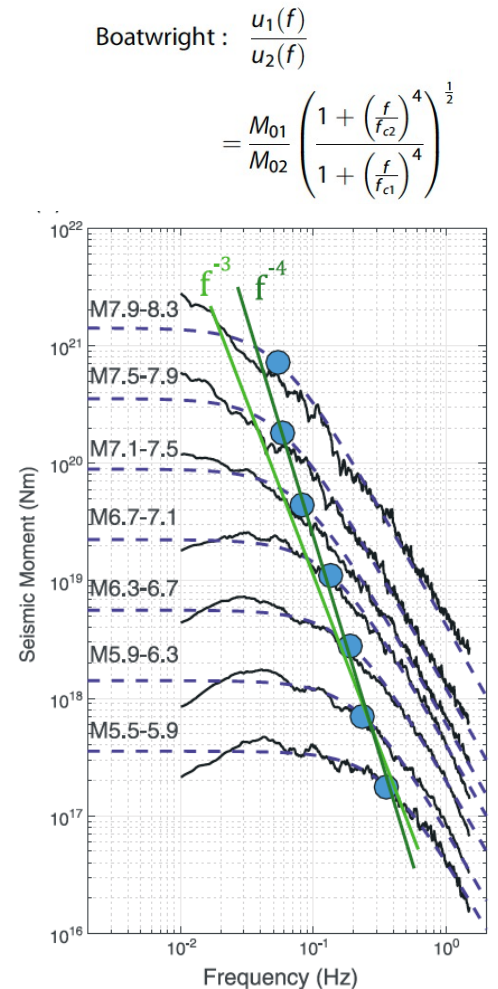


- Non-circular fault, unilateral and bilateral propagation, focal mechanism, fault geometry...

Discussions: Source complexity (spectrum)



- Brune (1970) source model: The entire circular crack simultaneously experiences a shear dislocation due to a constant stress change.

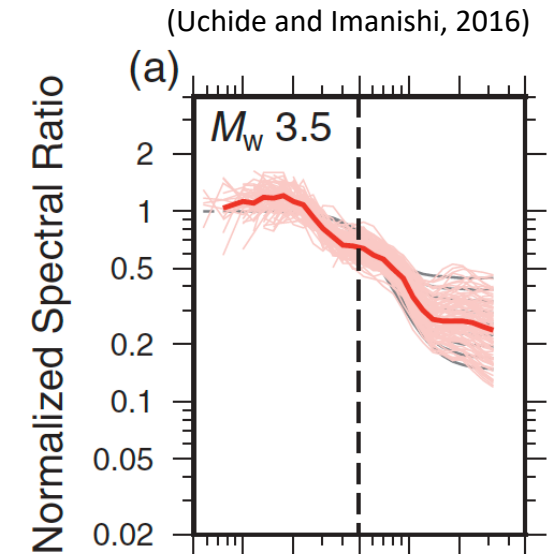


(Denolle and Shearer, 2016)

- Deviation from omega-squared shape

$f_c^1 \sim$ source duration;
 $f_c^2 \sim ?$

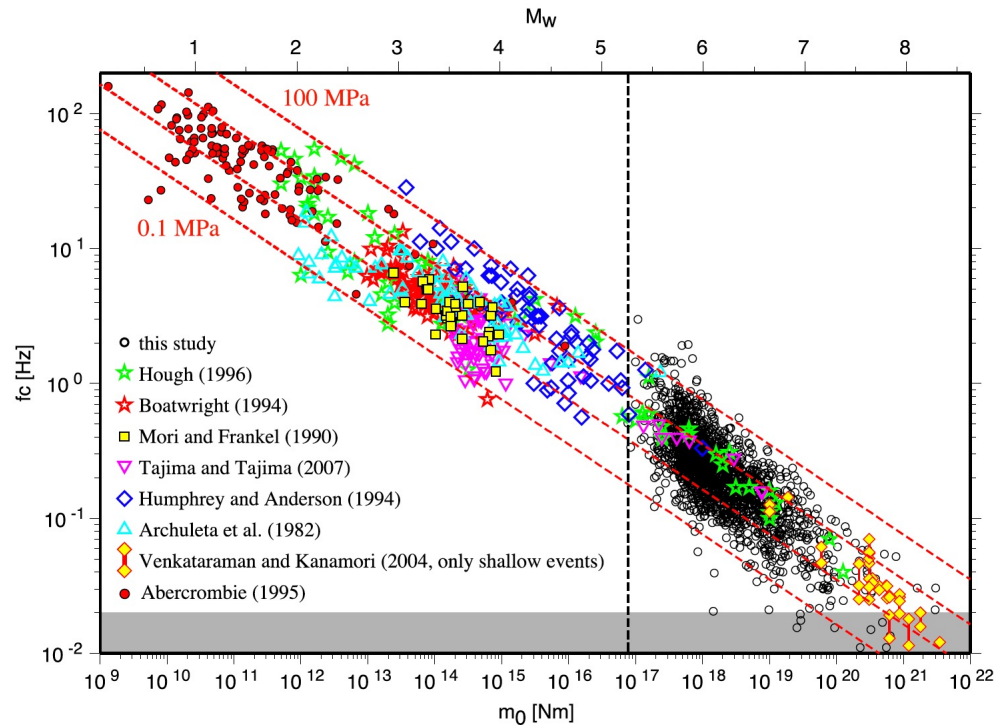
Slip rise time; Spacing of barriers or asperities; Starting and stopping phases...



- A double-corner frequency model

Discussions: Interpretation of stress drop estimated by EGF techniques

(Allmann & Shearer, 2009)



➤ Stress drop estimates have 3 orders of magnitude variation using different methods and processing.

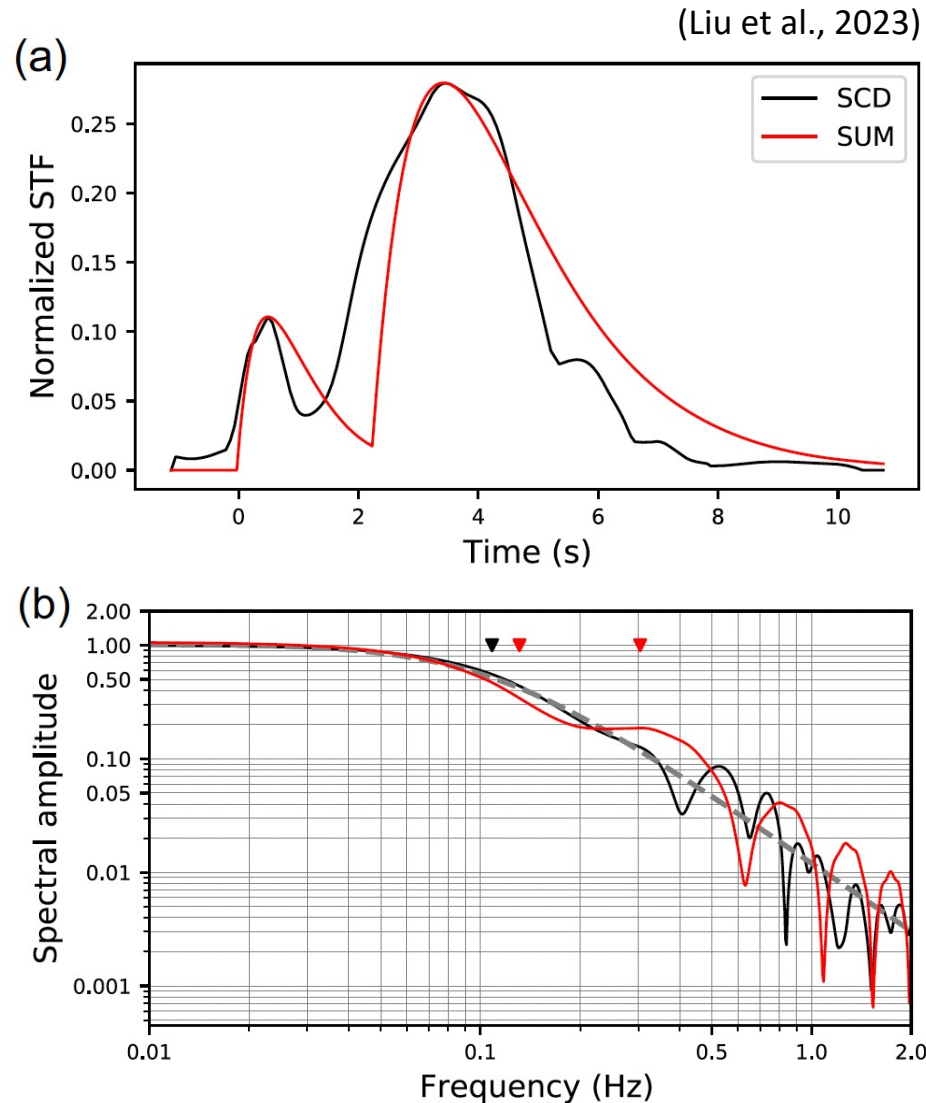
- Uncertainty in r is cubed in stress drop.

$$\Delta\sigma = \frac{7}{16} \frac{M_0}{r^3}, r = \frac{kv}{f_{master}}$$

- Stress drop definition: Average stress drop over the fault plane.

Average by area, energy, or slip distribution (Noda et al., 2013)?
How does the source complexity affect estimates?

Discussions: Interpretation of stress drop estimated by EGF techniques



Assuming the Brune source model and using the EGF techniques, though source time function decomposition and synthetic tests of 2-subevent sources, we found

- the estimated stress drop is dominated by the largest subevent.
- ➔ This can partially explain the large variation of stress drop estimates.
- ➔ A lot more to explore on stress drop and EGF techniques.

Thanks!
Q&A