SCEC Statewide California Earthquake Center

Community Stress Drop Validation Workshop

January 20, 2026

Session III: Synthetic Datasets

1:30 - 3:00 pm Pacific

Tuesday January 20, 2026

Virtual

Rachel Abercrombie rea@bu.edu

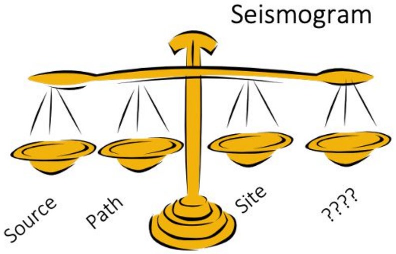
Annemarie Baltay abaltay@usgs.gov

Agenda

10:45 - 11:00	*Break*	
11:00 - 12:30	**Session II: New Data Sets** *Presentations from community members on new empirical datasets and regions, with a discussion and perhaps a vote on what data to choose.*	
	Source time functions from repeating earthquakes off Tohoku	Keisuke Yoshida
	Presentation of candidate datasets and group discussion	Colin Pennington, Rob Skoumal, Elizabeth Cochran, Peter Shearer, Daniel Trugman, Hao Guo
12:30 - 13:30	*Break*	
13:30 - 15:00	**Session III: Synthetics and looking forward** *We will hear about previous synthetic data analysis for earthquake stress drop or source parameters, and then a discussion of several stochastic and other simplistic datasets we will use for the Community Project.*	
	Ongoing/completed synthetic dataset study	Ian Vandevert, Jamie Neely, Chen Ji, Xiaowei Chen, Dino Bindi
	Discussion of community synthetic datasets	Dino Bindi, Annemarie Baltay, Peter Shearer, Rachel Abercrombie
	Looking forward: SCEC, NSF, international	Rachel Abercrombie
15:00 - 15:30	**Wrap up and review of morning for those joining from other timezones and commitments**	Rachel Abercrombie, Annemarie Baltay

Problem

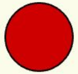
Inverting seismic data for Earthquake Source and Attenuation Structure



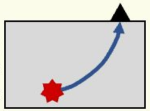
Source | **Path + Site** | **Instrument**

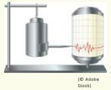
Simple Models

Circular source



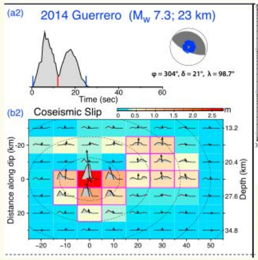
1D (or constant) attenuation structure

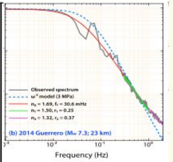




Known – hopefully

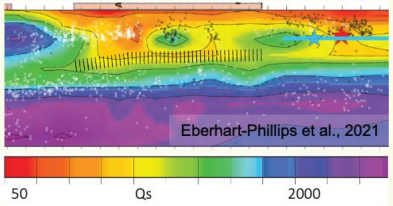
Real Earth is far more complex





Ye *et al.*, 2016

Large and Small earthquakes are complex when data are good enough to observe



Attenuation heterogeneity

Trade-offs and uncertainties from forcing the real earth into simple models

Biased outcomes

Studies using different assumptions disagree

BUT data inadequate to resolve fully complex problem…

…How do we provide end users with reliable numbers?

What do we do?
Depends on BOTH the problem we are trying to solve, AND the quantity and quality of data.

Strategy to use Synthetics to Understand and Improve Source Characterization

How can we as stress droppers best utilize simply synthetic data to resolve known parameters?

Goals of Session:

Hear previous work - what have they done? What have we learned?
What is missing?

Step 1: Benchmark methods on simple synthetics to ensure consistency/accuracy between methods

Step 2: Address potential causes of uncertainty and trade-off in our current methods:

Source: Brune/Boatwright? Vary n? 1 or 2 corners? subevents?
Path: homogeneous frequency independent Q? Depth dependent Q, Spatially (azimuthally) varying Q? Frequency dependent Q?
Site: high frequency attenuation (kappa0)? Frequency-dependent amplification and resonance? Other site variability - ensure realistic site uncertainty is included

Designing new data sets - need to focus on parts in stages

Start simple, gradually add a single type of complexity, then combine
Start with a set of synthetic spectra.

(Long term: use sophisticated dynamic/kinematic models, including complexity of source, path and site)

Possible Implementation Plan

Design individual Synthetic Data sets of kinematic source spectra to address problems in turn:

Question 1: If source, path, site are simple, how well can methods resolve the input values?

Question 2: If source and site are relatively simple, what uncertainty/bias do you get from depth-dependent variation in attenuation?

Question 3: If path is simple, how does including source complexity affect uncertainty?

Question 3: Site???

Question n: Allow everything to be complex!!

Question n+1: use sophisticated dynamic/kinematic models, including complexity of source, path and site

Ongoing/completed work

- Dino Bindi
- Jamie Neely
- Ian Vandevert
- Xiaowei Chen
- Chen Ji

Name: Dino Bindi

Example of numerical experiment reproducing the geometry of an empirical data set to evaluate the GIT performance

Reliability of Source Parameters for Small Events in Central Italy: Insights from Spectral Decomposition Analysis Applied to Both Synthetic and Real Data

Dino Bindi; Daniele Spallarossa; Matteo Picozzi; Paola Morasca

+ Author and Article Information

Bulletin of the Seismological Society of America (2020) 110 (6): 3139–3157.
https://doi.org/10.1785/0120200126 | Article history

Synthetic FASs were generated considering the same event location, event magnitude, station location, event-station combinations of the actual data set used for the spectral decomposition (GIT) (**data and synthetics shared the same design matrix**)

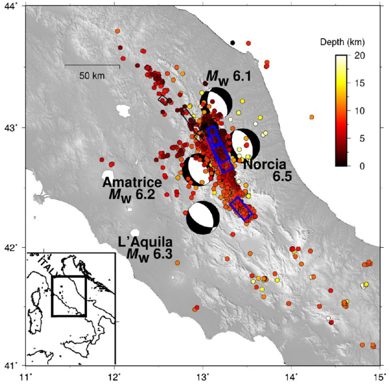
Name: Dino Bindi

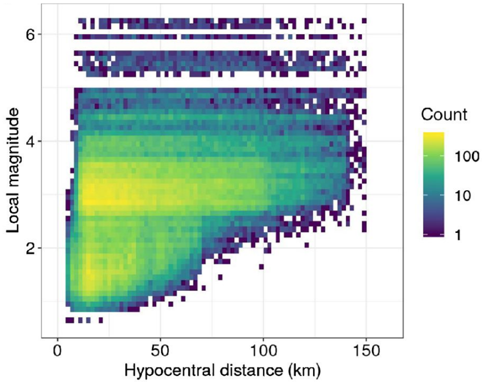
Data geometry

~4100 events

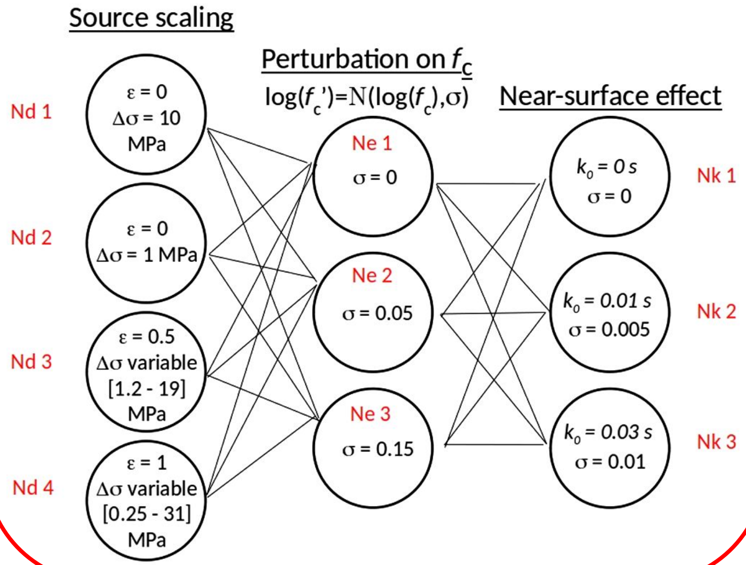
~400000 FASs

(a)





Simulation schema

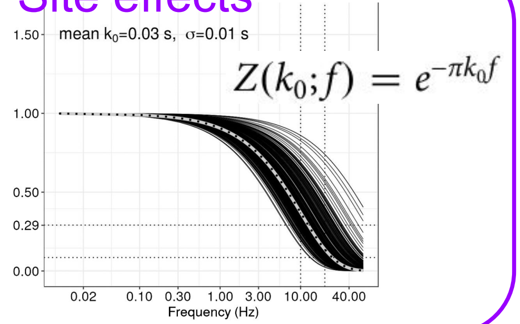


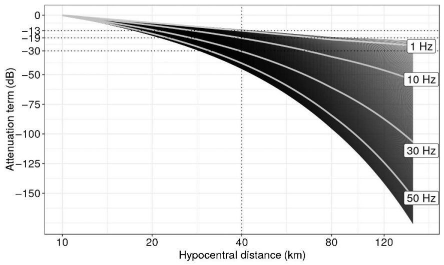
Source spectra

$$S(M_0, f_c; f) = \frac{F_V R^{\theta,\phi}}{4\pi\rho\beta^3} \frac{1}{R_{\rm ref}} \frac{M_0 f^2}{1 + \left(\frac{f}{f_c}\right)^2}$$

$M_0 \propto f_c^{-(3+\epsilon)}$ Different scalings

Site effects





$$G(n_1, n_2, R_h; R) = \begin{cases} \left(\frac{R_{\rm ref}}{R}\right)^{n_1} & \text{for } R \le R_h \\ \left(\frac{R_{\rm ref}}{R_h}\right)^{n_1} \left(\frac{R_h}{R}\right)^{n_2} & \text{for } R > R_h \end{cases}$$

$$A(Q_0, \alpha; R, f) = e^{\frac{-\pi R f^{1-\alpha}}{Q_0 \beta}}$$

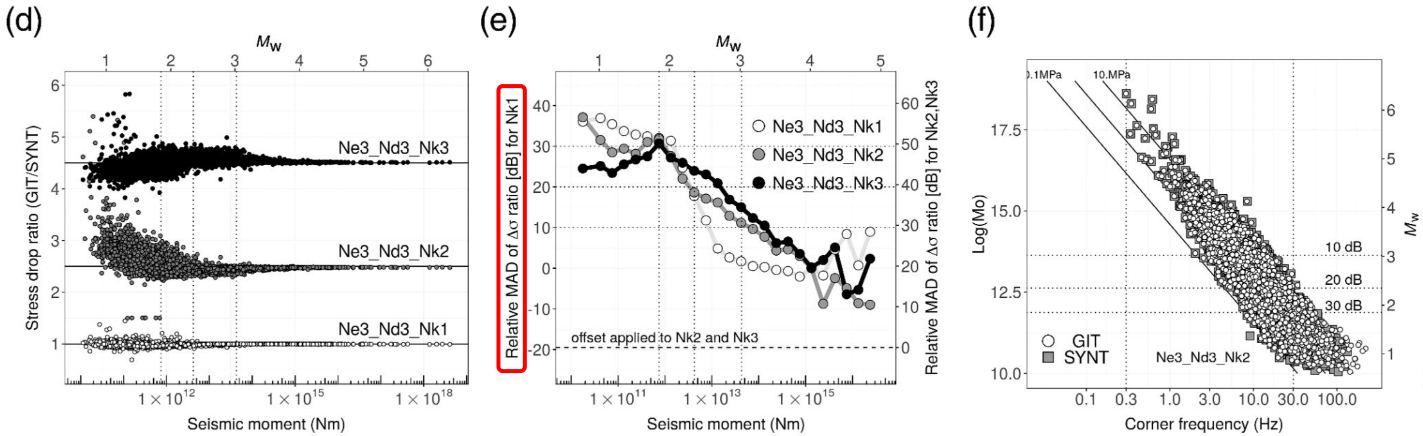
- Piecewise linear G(R)
- $Q=Q(f)=Q_o f^{\alpha}$

Attenuation Model

(the same for all simulations)

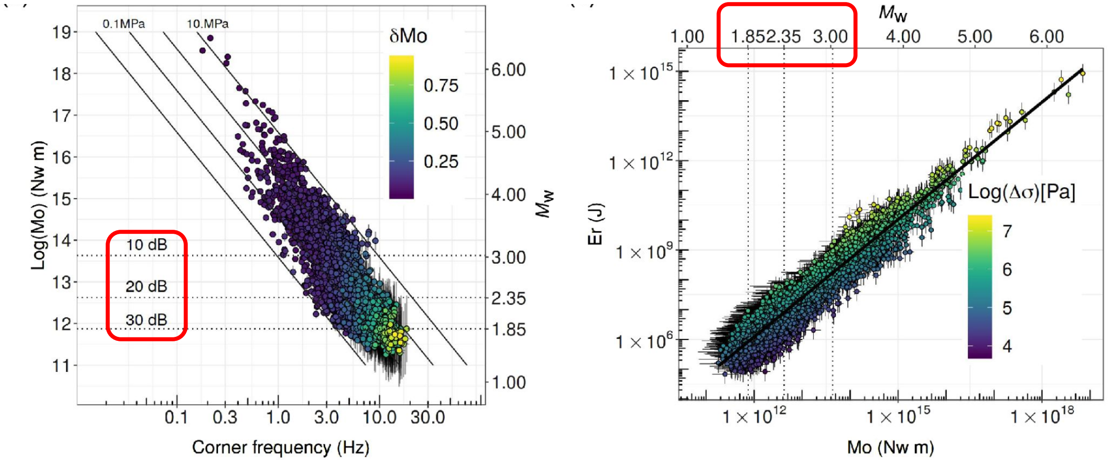
Name: Dino Bindi

Results (example)



Synthetics

$$\text{RelativeMAD} = 20 \log \frac{\text{MAD}(k_0)}{\text{MAD}(k_0 = 0)} + \delta,$$



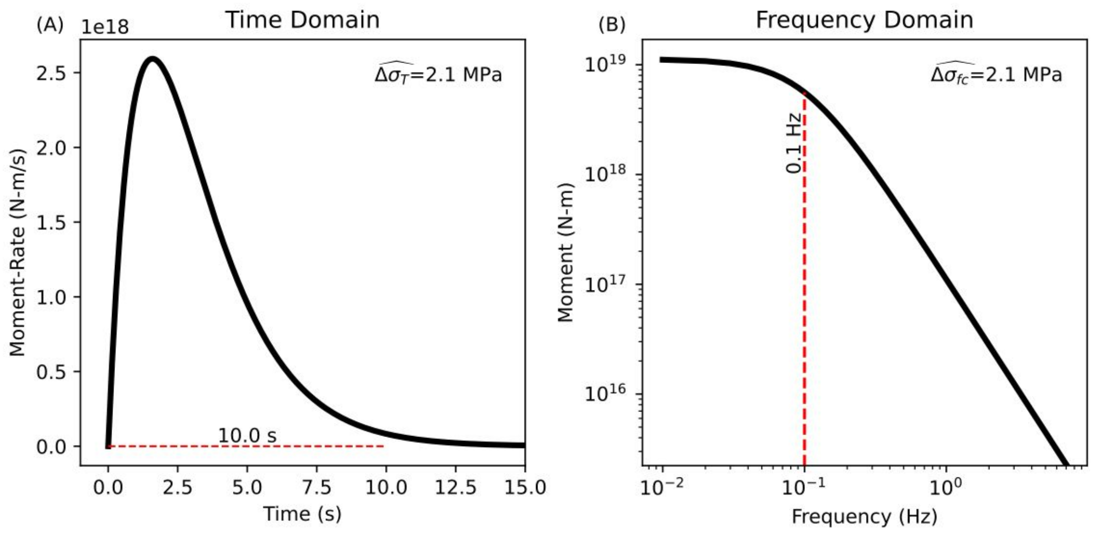
Recorded data

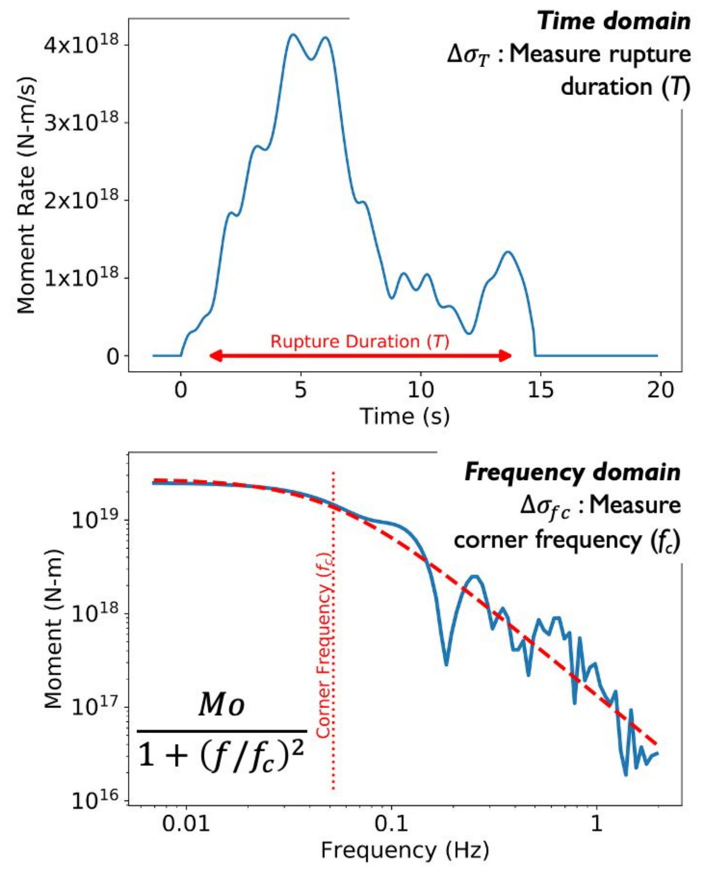
https://doi.org/10.1785/0120200126

Name: Jamie Neely, Sunny Park, Annemarie Baltay, Rachel Abercrombie

Stress drop estimation methods ***assume source simplicity***

What impact does ***source complexity*** have?





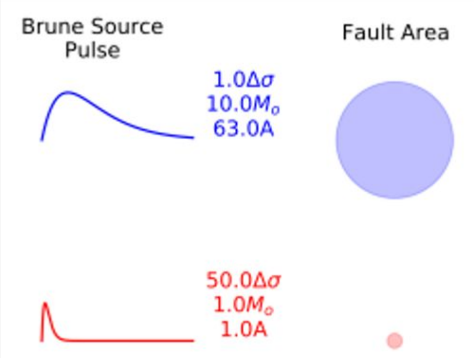
If simple Brune rupture:

$$\Delta\sigma_T \propto \frac{M_0}{T^3} = \Delta\sigma_{fc} \propto M_0 f_c^3$$

Name: Jamie Neely, Sunny Park, Annemarie Baltay, Rachel Abercrombie

Construct 5000 complex eqs from Brune pulses

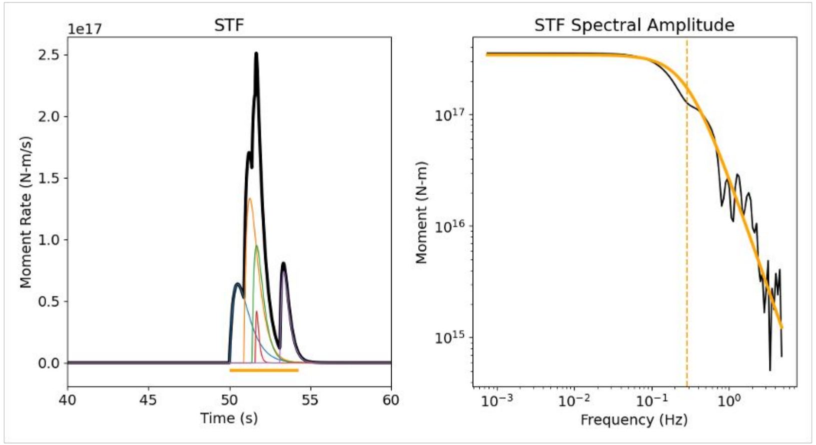
1) Randomly select ***number of Brune pulses*** between 2 and 5
2) Randomly assign ***each pulse a stress drop*** by selecting from lognormal distribution
3) Randomly assign ***each pulse a seismic moment***
4) Randomly select ***start time of each pulse*** so pulses overlap
5) ***Sum the pulses*** to create complex earthquake
6) ***Estimate*** rupture duration *T* and corner frequency f_c for complex earthquake to calculate stress drops

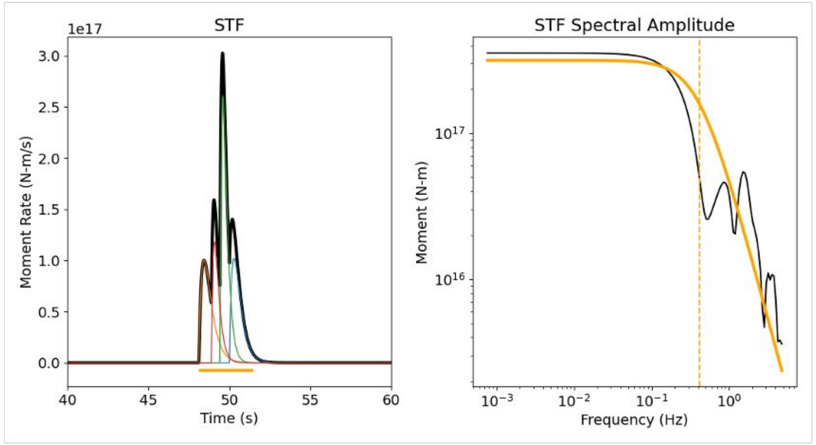


2 "True" Stress Drops

$$\overline{\Delta\sigma_{Area}} = \left(\frac{63}{64} * 1\right) + \left(\frac{1}{64} * 50\right) = 1.8 \text{ MPa}$$

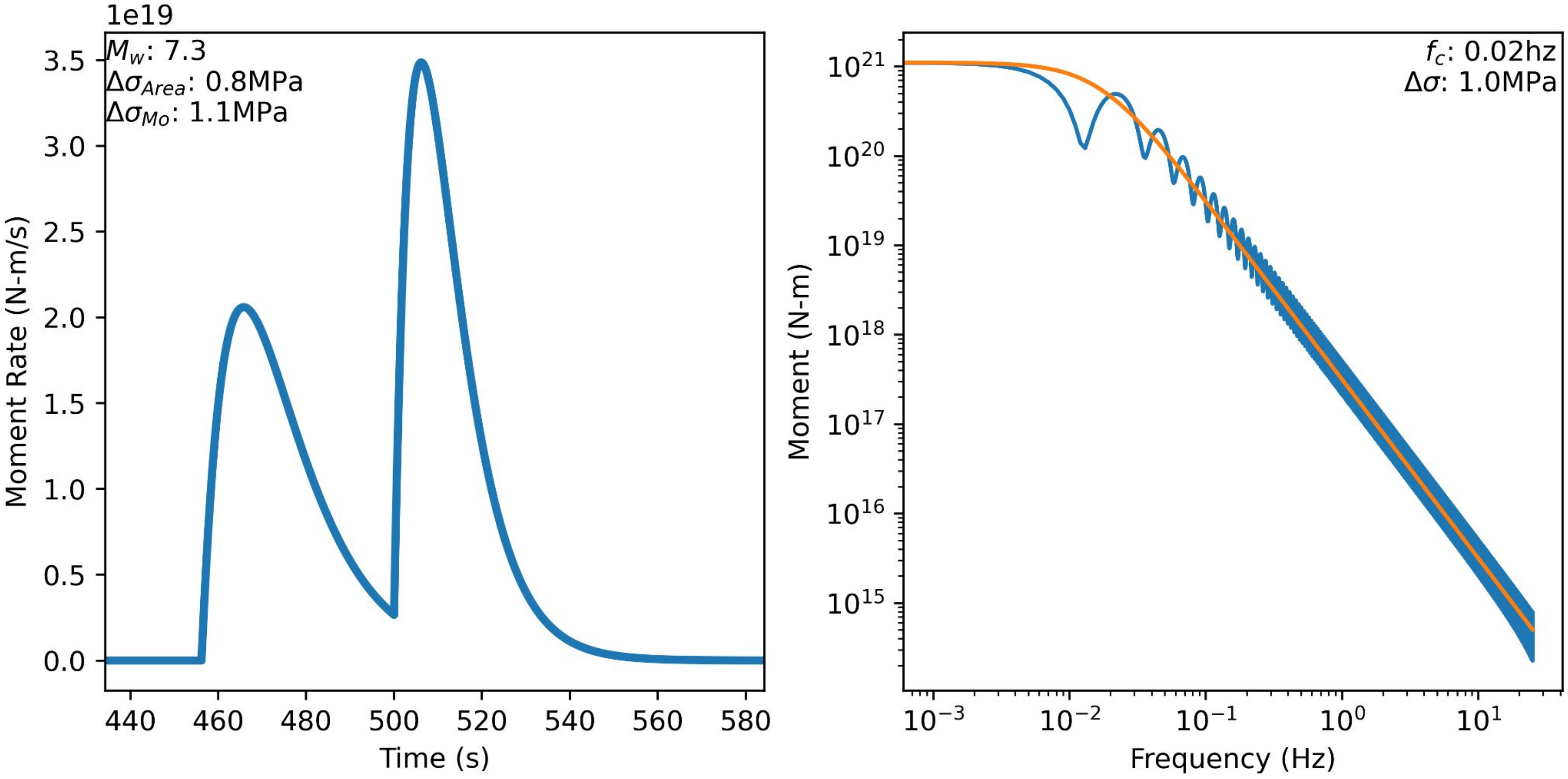
$$\overline{\Delta\sigma_{Mo}} = \left(\frac{10}{11} * 1\right) + \left(\frac{1}{11} * 50\right) = 5.5 \text{ MPa}$$





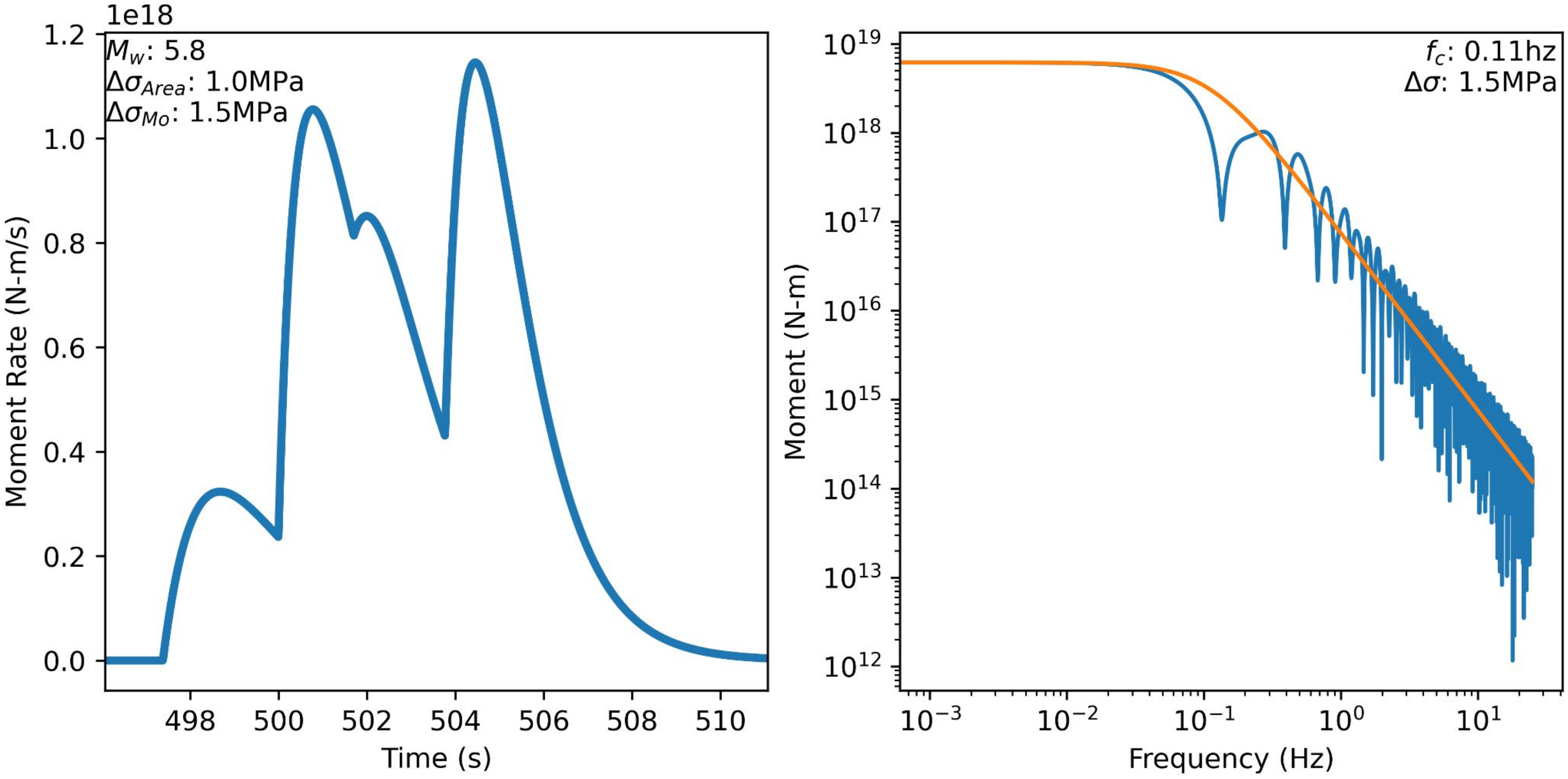
Name: Jamie Neely, Sunny Park, Annemarie Baltay, Rachel Abercrombie

Example Synthetics



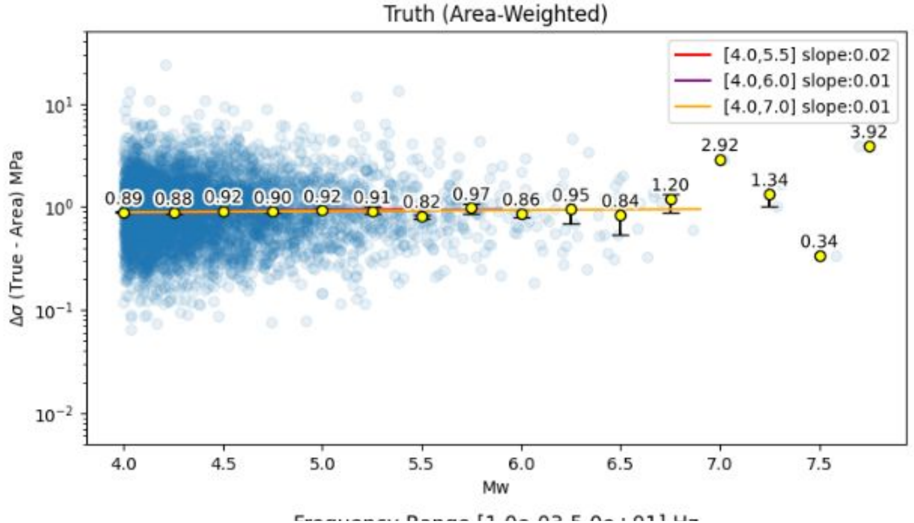
Name: Jamie Neely, Sunny Park, Annemarie Baltay, Rachel Abercrombie

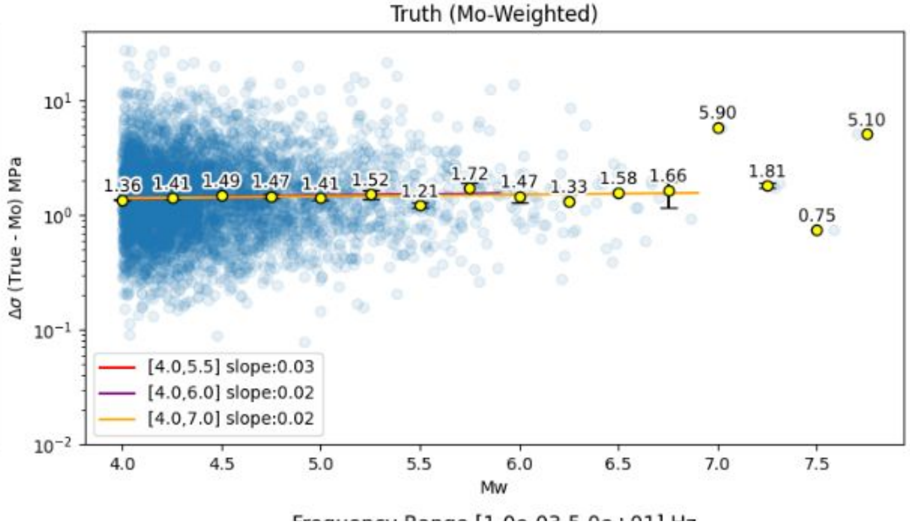
Example Synthetics



Name: Jamie Neely, Sunny Park, Annemarie Baltay, Rachel Abercrombie

What are we actually measuring?

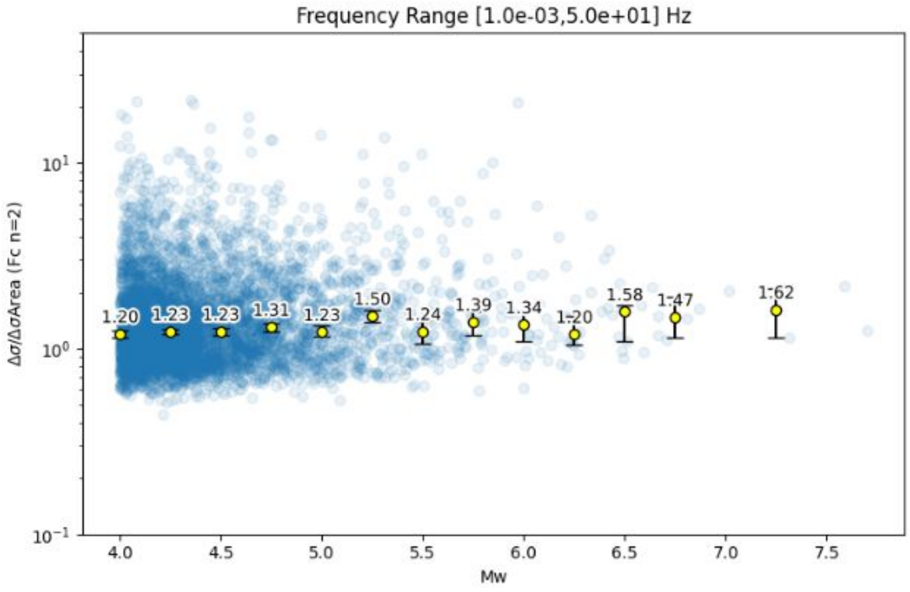




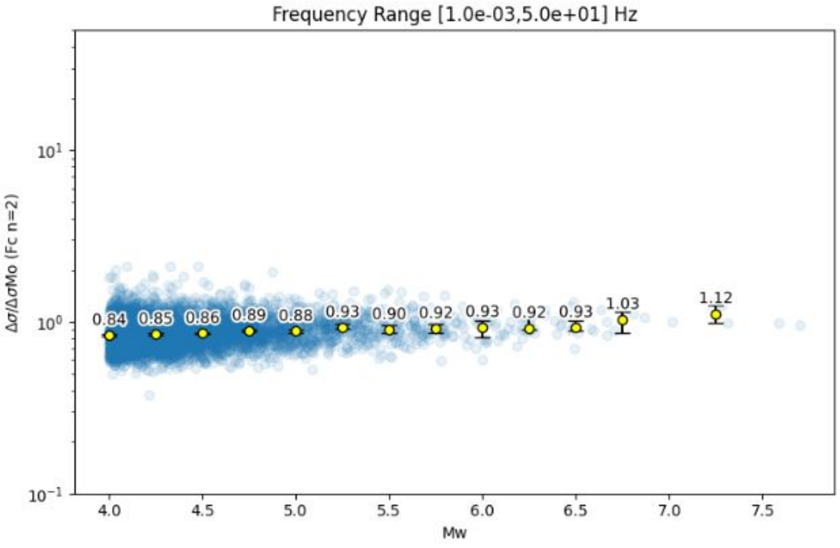
Name: Jamie Neely, Sunny Park, Annemarie Baltay, Rachel Abercrombie

What are we actually measuring?

Estimate/Area-Weighted Avg.

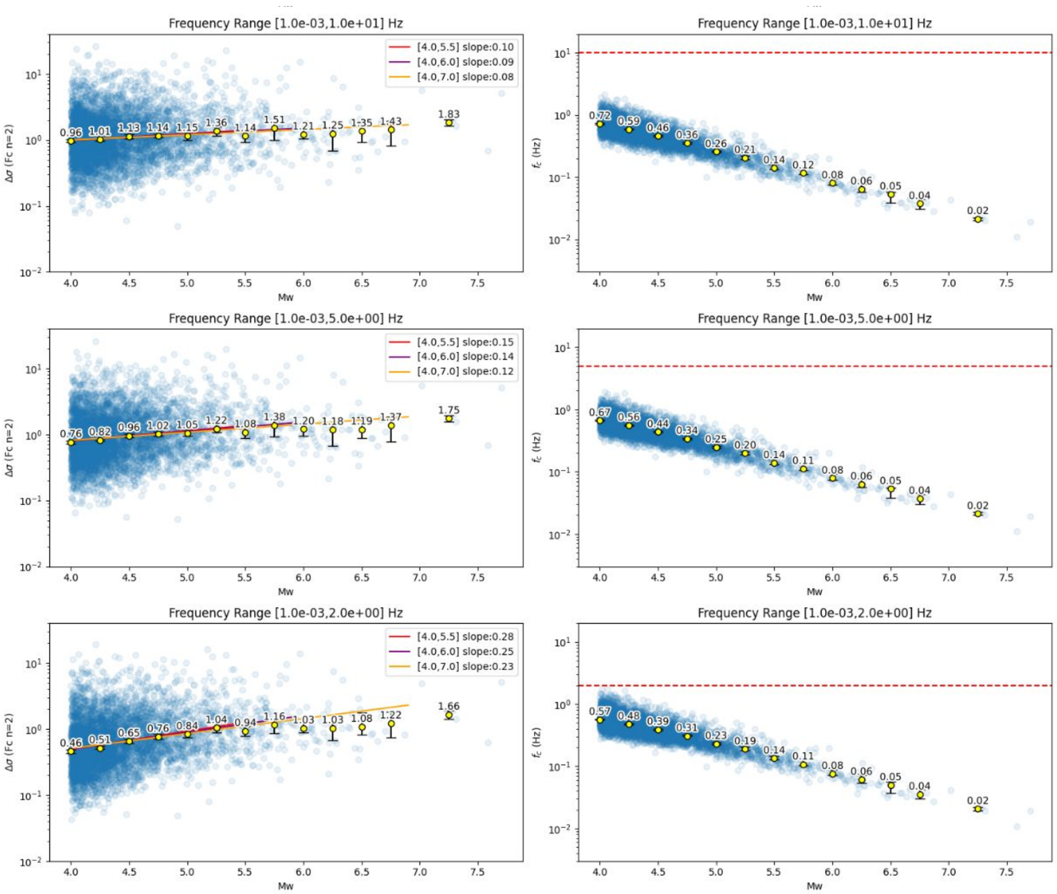


Estimate/Mo-Weighted Avg.



Name: Jamie Neely, Sunny Park, Annemarie Baltay, Rachel Abercrombie

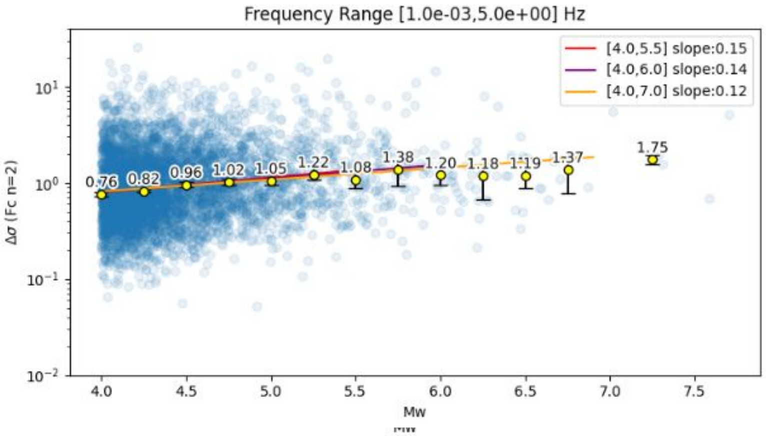
How do frequency-band limitations impact estimates?

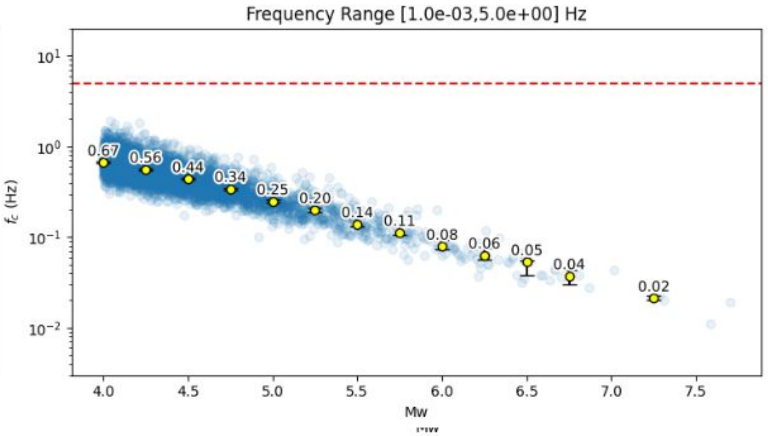


Name: Jamie Neely, Sunny Park, Annemarie Baltay, Rachel Abercrombie

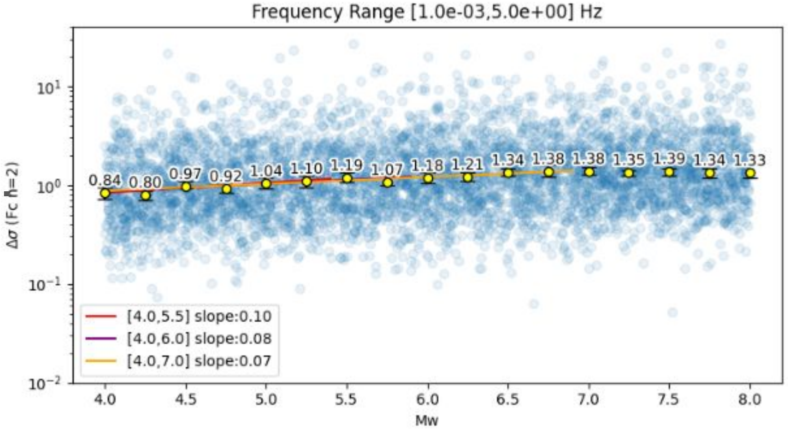
How does magnitude distribution impact trends?

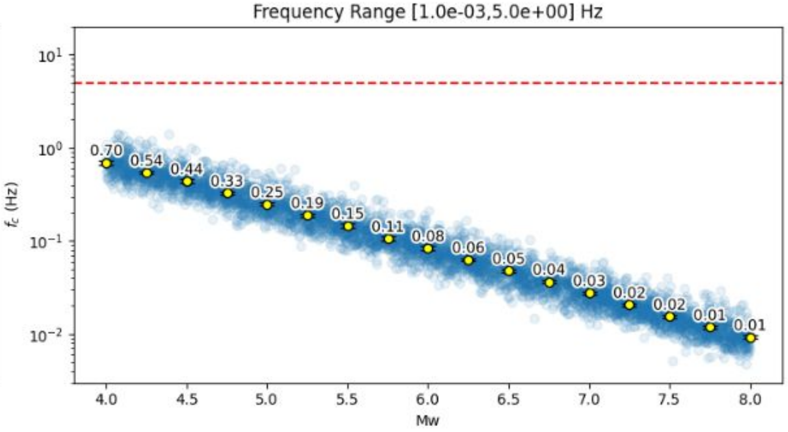
GR Mag.
Dist.





Uniform Mag
Dist.

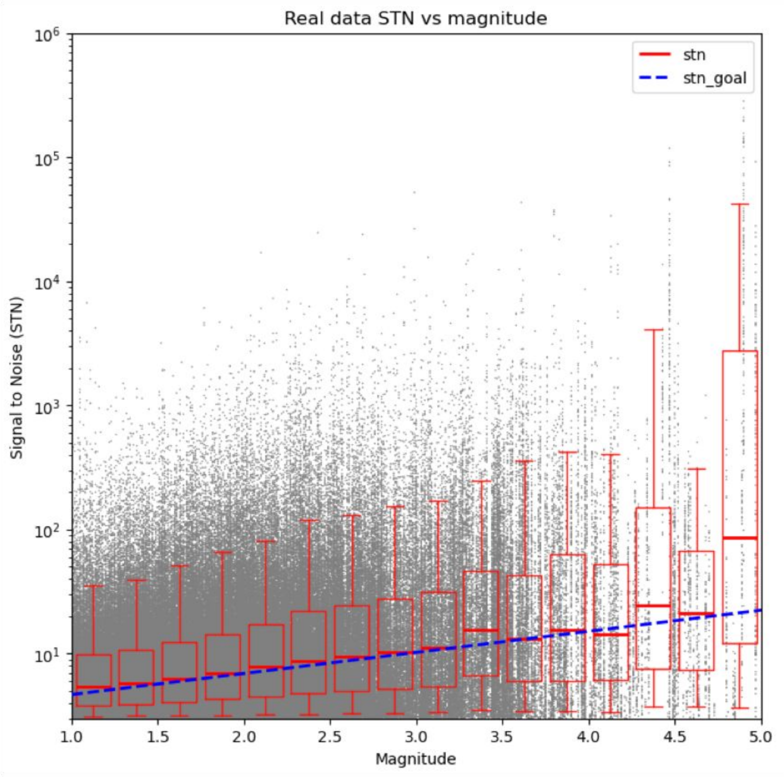




Name: Ian Vandevert, Peter Shearer, Wenyuan Fan

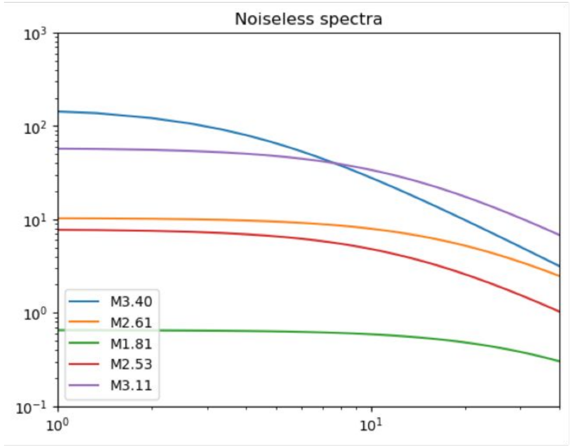
Idea: generate spectra using some model $M(f)$ and add **real seismic noise**, scaled so that the resulting spectrum $S(f)$ has a set signal-to-noise ratio (STN)

- Median STN ratio increases with magnitude in real dataset
- Simple line fit to median STN for records binned by magnitude to generate desired STN for a given magnitude
- Note: **no path effects or attenuation** simulated for our use case



Name: Ian Vandevert, Peter Shearer, Wenyuan Fan

$M(f)$



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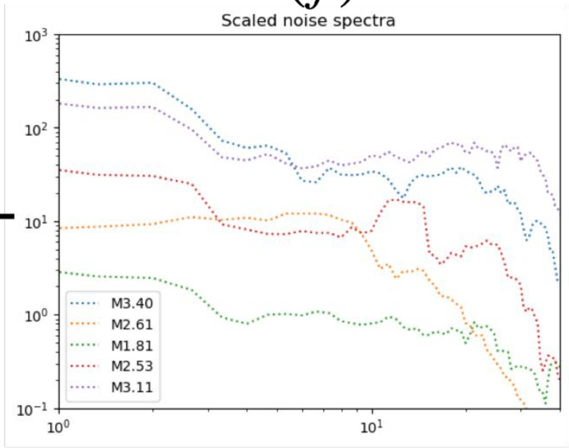
$N(f)$



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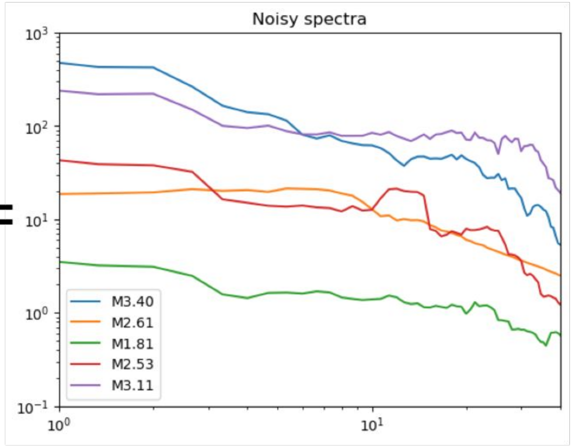
$S(f)$



Brune, n-falloff, etc.

Real seismic noise spectra

Synthetic spectra with real seismic noise

In this case:
n=1.7
median $\Delta\sigma = 5$ MPa

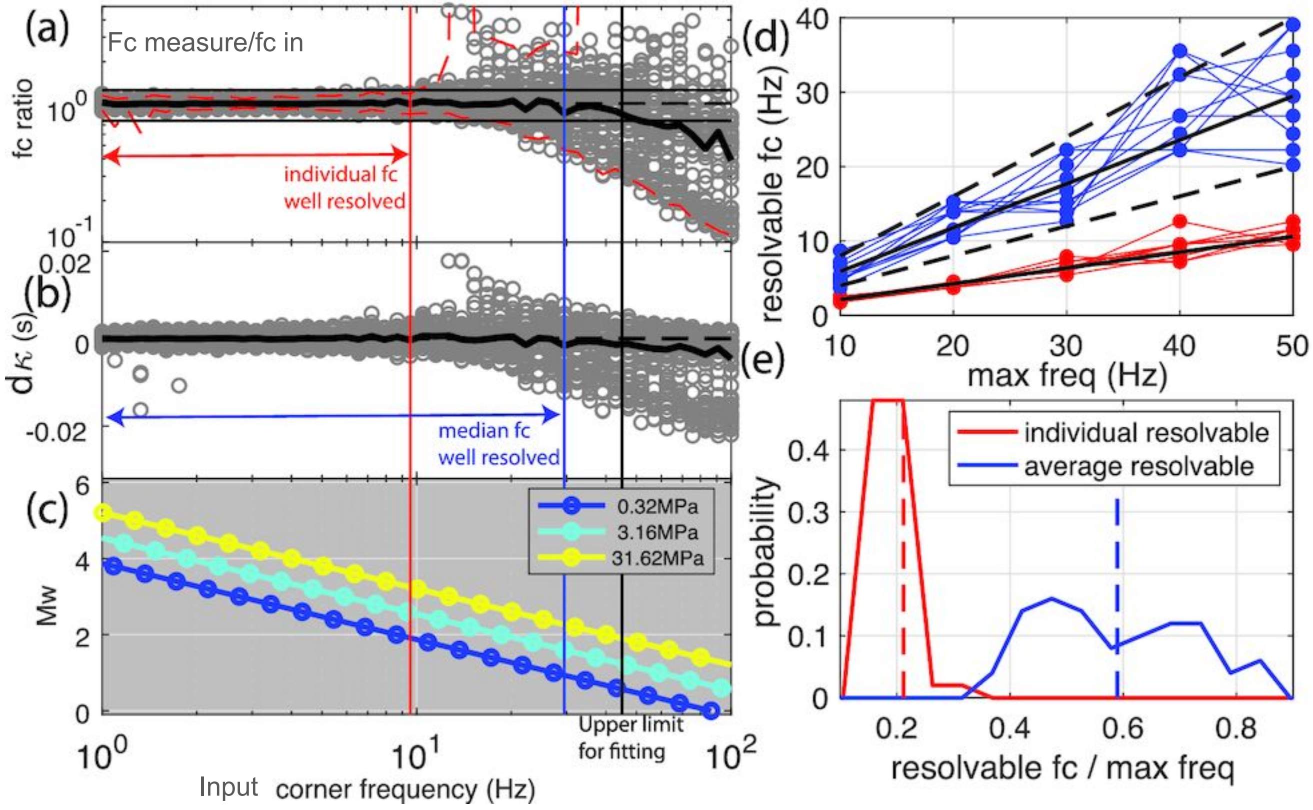
Scaled such that:

$$STN[S(f)] = STN_{desired}$$

Smaller events have lower STN

Xiaowei Chen and Rachel Abercrombie

Improved approach for stress drop estimation and its application to an induced earthquake sequence in Oklahoma
Chen and Abercrombie, GJI 2020



We use synthetic tests based on a joint spectral-fitting method to define the resolution limit of the corner frequency as a function of the maximum frequency of usable signal, for both individual spectra and the average from multiple stations.

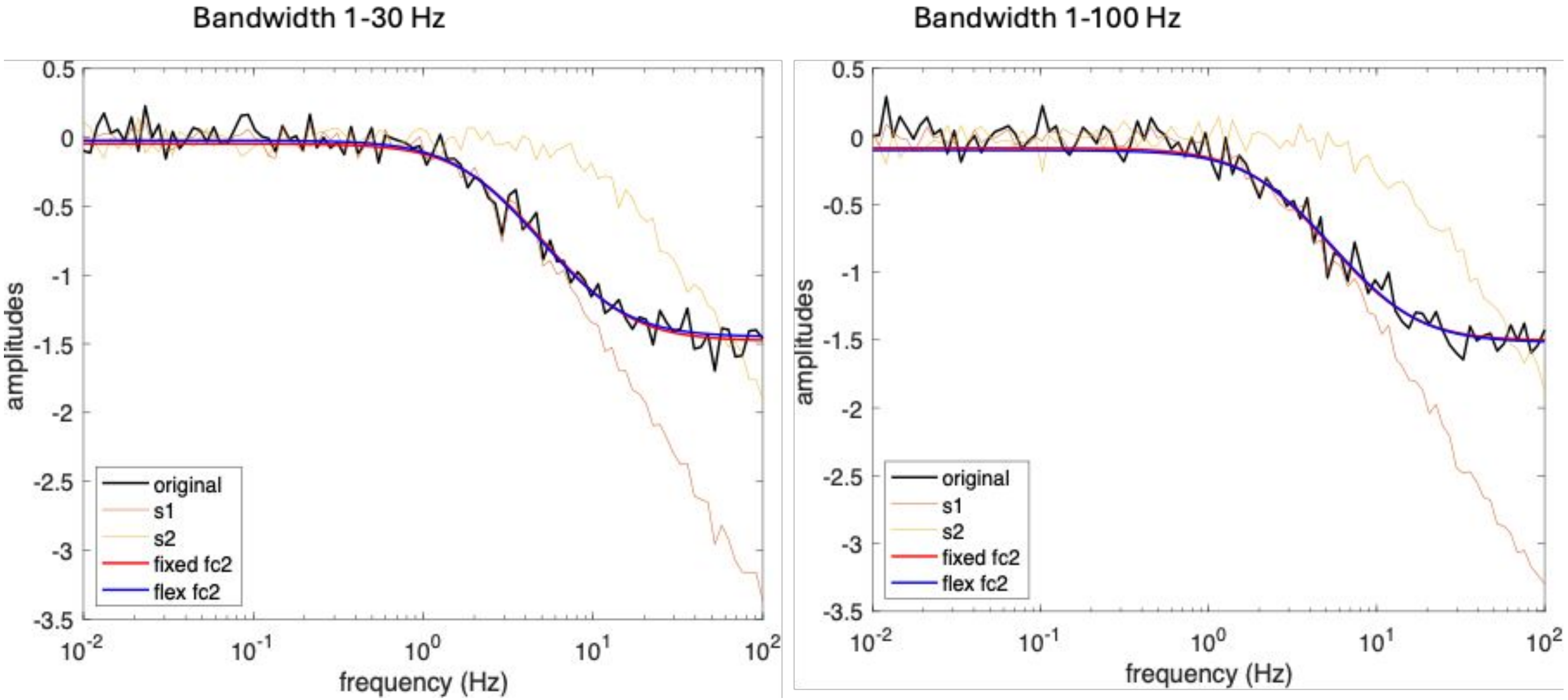
Synthetic tests based on stacking analysis find that an improved stacking approach can recover the true input stress drop if the corner frequencies are within the resolution limit defined by joint spectral-fitting.

Xiaowei Chen

Synthetic experiment for spectral ratio fitting

Step 1. Generate two synthetic Brune spectral: fc1 = 2.1 Hz, fc2 = 11.8 Hz.

Similar results for “simultaneous fitting of fc1, fc2” or “fixed fc2”



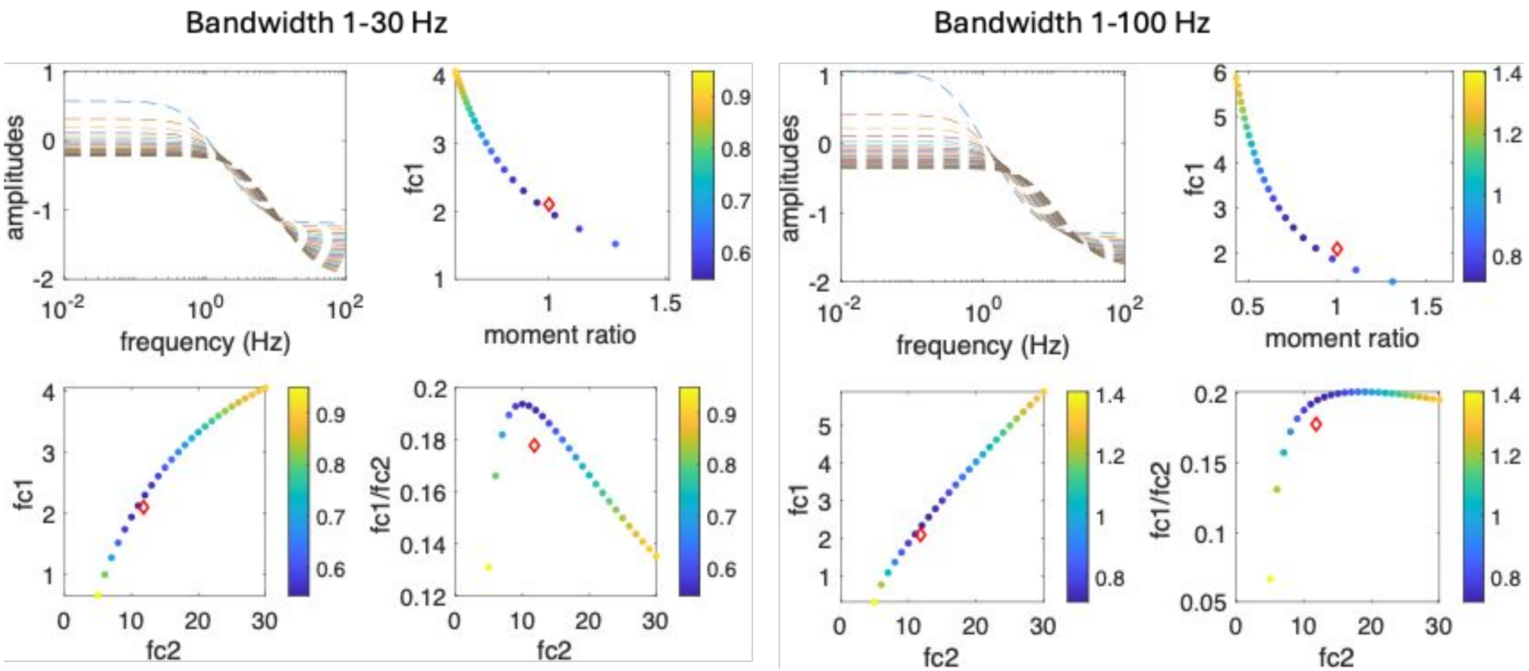
Xiaowei Chen

Synthetic experiment for spectral ratio fitting

Step 2. Check the influence of fixed fc2. Jointly fitting fc1 and moment ratio.

Strong tradeoff between fc1 and moment ratio. Also, fc1 increases when “fixed fc2” increases

But somehow the “ratio” between “best-fitting fc1” and “fixed fc2” becomes stable when bandwidth is sufficient.



Xiaowei Chen

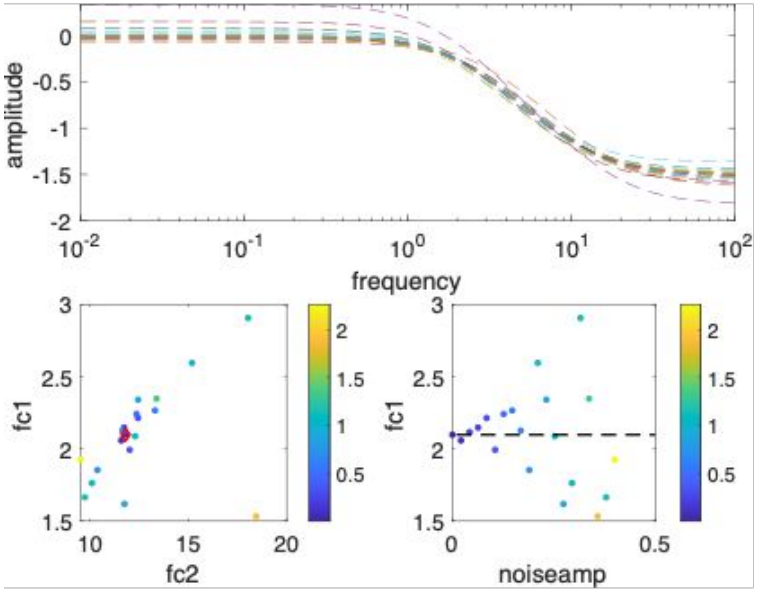
Synthetic experiment for spectral ratio fitting

Step 3. Check the influence of noise on simultaneous fitting (fc1, fc2, moment ratio).

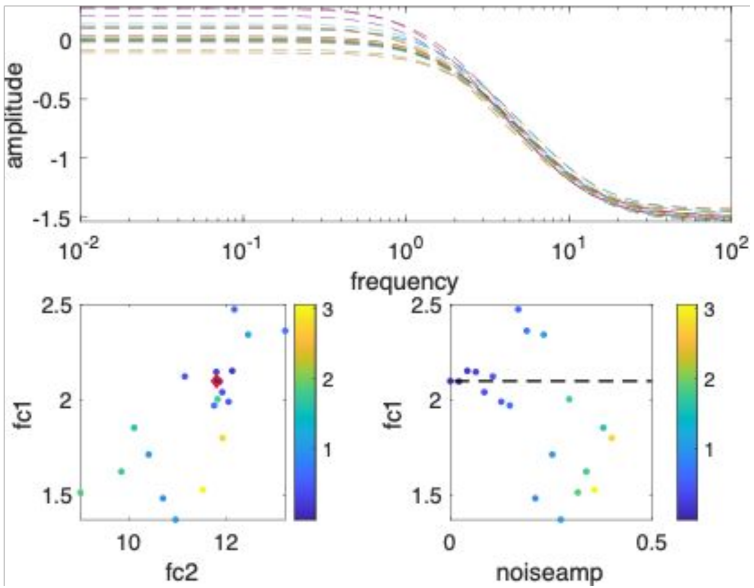
fc1 scatter increases with increasing noise amplitude.

When bandwidth is high, the scatter is small for both fc1 and fc2.

Bandwidth 1-30 Hz



Bandwidth 1-100 Hz



Chen Ji

Ridgecrest Synthetic Experiment (UCSB)

$$syn_{ij}(f) = s_i(f) \cdot path_{ij}(f) \cdot site_j(f)$$

Geophysical Journal International

Geophys. J. Int. (2020) **221,** 1029–1042
Advance Access publication 2020 January 23
GJI Seismology

doi: 1

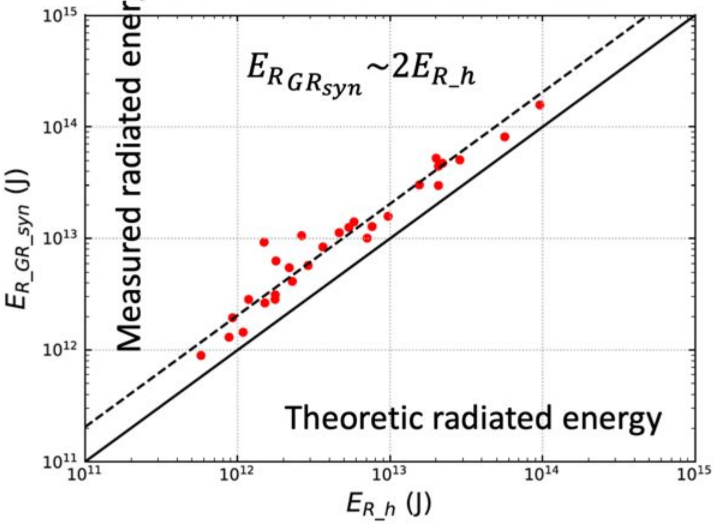
Estimation of radiated energy using the KiK-net downhole records—old method for modern data

Hiroo Kanamori,[1] Zachary E. Ross[1] and Luis Rivera[2]

[1] *Seismological Laboratory, California Institute of Technology, Pasadena, CA 91125, USA. E-mail: hiroo@gps.caltech.edu*
[2] *Institut de Physique du Globe de Strasbourg; UMR7516, University of Strasbourg-CNRS, Strasbourg, France*

Accepted 2020 January 13. Received 2020 January 6; in original form 2019 August 26

Fig. 4



- Absolute values of apparent stress and stress parameter
- Depth dependence of stress measurements

Synthetic algorithm: I. source s_i + path $path_{ij}$

Source response

- Brune spectrum $s_i(f_c^i, f)$
- Corner frequency f_c, using $f_c \propto M_0^{1/3+\epsilon}$
- Radiation patterns are considered (Wang and Zhan, 2020)

Crustal response (fk algorithm of Zhu and Rivera, 2002)

1. 1D velocity model (without Q): 1/R decay?
2. 1D velocity model (with Q)

Stations

- $\Delta \leq 50$ km

Synthetic S wave response are extracted using the same workflow as the observations (Ji et al., 2024)

Chen Ji

Synthetic algorithm: II Site response

$$site_{ij}(f) = Amp_j(f)\exp\left(-\pi\kappa_0^{ij} f\right)$$ [Boore and Joyner, 1997]

$Amp_j(f)$

1. $\boldsymbol{amp_j(f)} = \sqrt{\dfrac{\boldsymbol{\rho_0\beta_0}}{\boldsymbol{\rho_s(Vs30_j,f)\beta_s(Vs30_j,f)}}}$
2. $amp_j(f)$ (Ji and Ralph, in preparation)

κ_0^{ij}

1. $\boldsymbol{\kappa_0^{ij} = \kappa_0^{j}}$
2. $\kappa_0^{ij} = \kappa_0^{j} + \boldsymbol{\delta\kappa_0^{i}}$, $\delta\kappa_0^{i} \sim N(0, 0.005^2)$

Note: $\boldsymbol{\delta\kappa_0^{i}}$ here can be interpreted as the with-event variation of source spectra

Summary

UCSB Ridgecrest Synthetic Experiment considers

- 8 possible scenarios
- 120 Mw 3.5-5.4 Ridgecrest earthquakes
- 18 stations

Proposed Community Synthetic Study

Question: How well can different methods separate source, path, site, all with known inputs?

Plan: Run relatively simple synthetics in which we can specifically control spectral stress drop, attenuation, site spectra, before moving on to larger dynamic, kinematic simulations

Implementation: Annemarie, Rachel, Peter, Dino, Elizabeth develop several sets of simplistic data, and test. Within next ~2 months, distribute to community.

Mimic *new* empirical dataset in magnitude, location, station distribution?

Statewide California Earthquake Center

Question: How well can different methods separate source, path, site, all with known inputs?

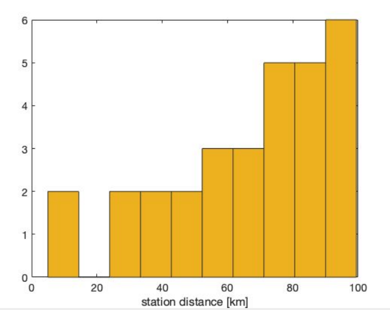
USGS science for a changing world

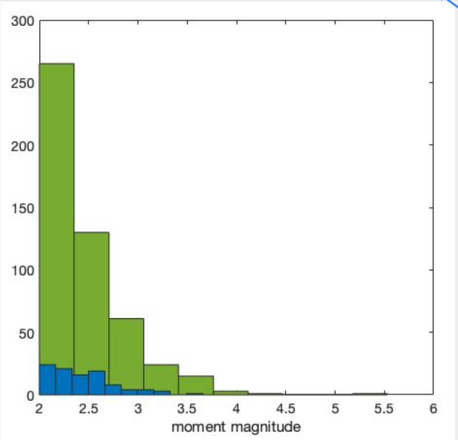
Initial runs:

- 1D set up.
- 100 earthquakes
- 30 stations
- All earthquakes at all stations
- Distance is prescribed for each station
- Single regional Q/velocity - given.
- ? noise
- S waves

Stations:

- 30 stations
- Named A1 - A30
- Distances from 0-100, distributed as R^2
- For all: stlat = 0; stlo = R
- Each station has a random "station term" (k0 + amplifications, known only to "developers")





Sources:

- 100 earthquakes
- Named EQID 0001 to 0100
- Source model (some complexity?)
- Exactly co-located sources
- M2 - 6, GR distribution
- Random fc from distribution (known only to developers)
- Moment magnitude given
- All have depth of 8km

Records:

- 200 sps
- Given window length
- ~~Time series, velocity in m/s~~
- FAS.

Data format:

- Text format

Strategy to use Synthetics to Understand and Improve Source Characterization

How can we as stress droppers best utilize simply synthetic data to resolve known parameters?

Goals of Session:

Hear previous work - what have they done? What have we learned?
What is missing?

Step 1: Benchmark methods on simple synthetics to ensure consistency/accuracy between methods

Step 2: Address potential causes of uncertainty and trade-off in our current methods:

Source: Brune/Boatwright? Vary n? 1 or 2 corners? subevents?
Path: homogeneous frequency independent Q? Depth dependent Q, Spatially (azimuthally) varying Q? Frequency dependent Q?
Site: high frequency attenuation (kappa0)? Frequency-dependent amplification and resonance? Other site variability - ensure realistic site uncertainty is included

Designing new data sets - need to focus on parts in stages

Start simple, gradually add a single type of complexity, then combine
Start with a set of synthetic spectra.

(Long term: use sophisticated dynamic/kinematic models, including complexity of source, path and site)

Possible Implementation Plan

Design individual Synthetic Data sets of kinematic source spectra to address problems in turn: First using very simple geometry, then repeat with geometry matching *new* empirical dataset [*New: Add Noise, Vary Frequency range, Vary M distribution*]

Question 1: If source, path, site are simple, how well can methods resolve the input values?

Question 2: If source and site are relatively simple, what uncertainty/bias do you get from depth-dependent variation in attenuation?

Question 3: If path is simple, how does including source complexity affect uncertainty?

Question 4: Site???

Question n: Allow everything to be complex!!

Question n+1: use sophisticated dynamic/kinematic models, including complexity of source, path and site

Dino's group contributions

Non-peer reviewed **Software Report** to be submitted to SEISMICA

Numerical Experiments to Assess the Limitations and Biases of Spectral Decomposition in Estimating Earthquake Source Parameters

D. Bindi
GFZ-Potsdam
A. Oth (ECGS), M. Picozzi (OGS), D. Spallarossa (UniGe)
+ ……………………….

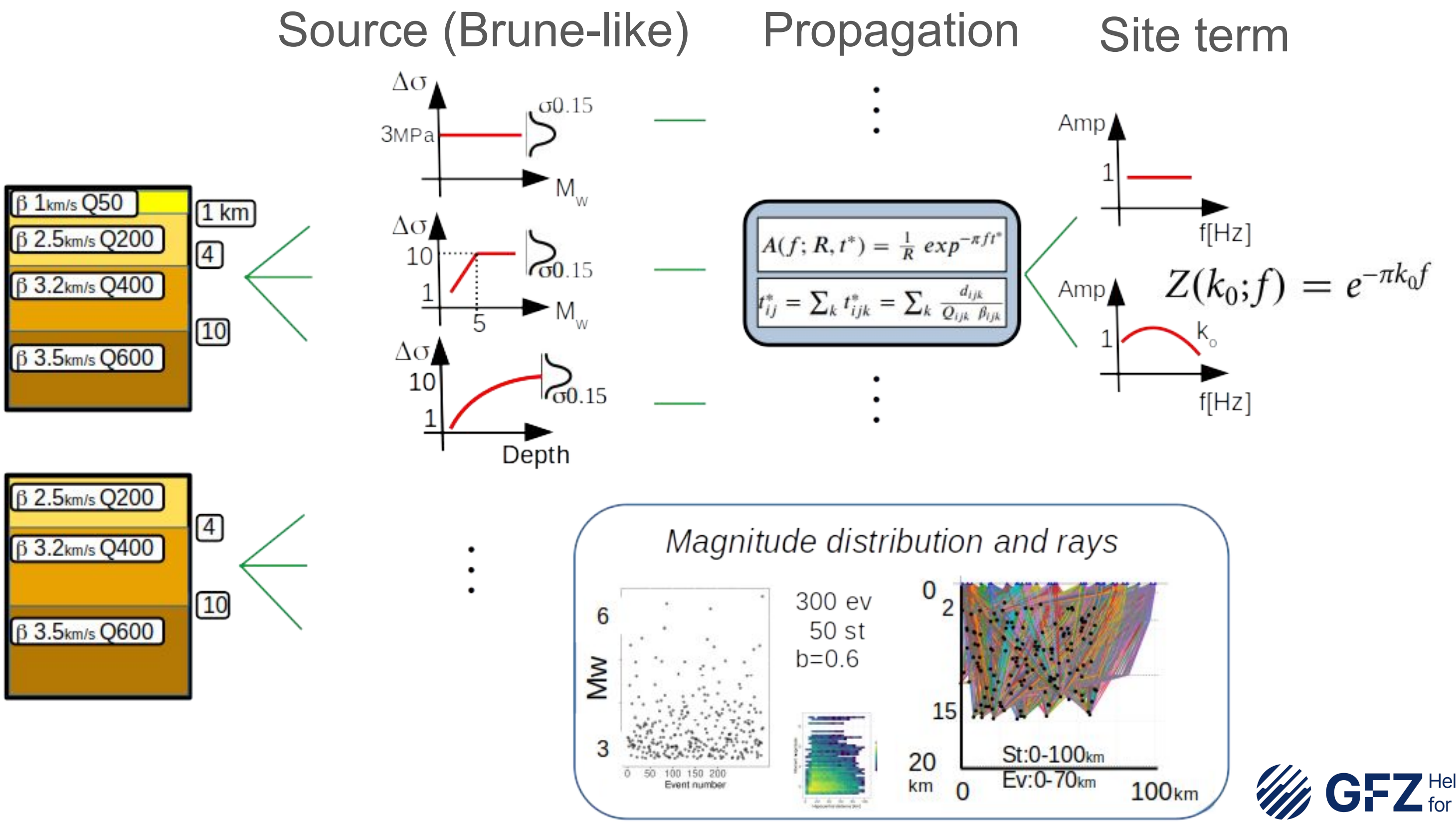
GFZ Helmholtz Centre for Geosciences

Dino’s group contributions

- The study adopts a **decomposition-based framework** that separates source, propagation, and site effects to test how well the method distinguishes their contributions when **one term is imperfectly modeled**.
- The current numerical experiment **focuses on propagation**, examining how inaccuracies in attenuation modeling affect the reconstructed source and site terms
- We apply the **spectral decomposition GIT** to numerical FASs generated for different source scaling (i.e., self-similar, $\Delta\sigma$ moment dependent, $\Delta\sigma$ depth dependent), two different layered models, different site amplifications, and evaluate its performance when simplified description of attenuation is used.

Dino’s group contributions

Simulation logic-tree



Helmholtz Centre for Geosciences

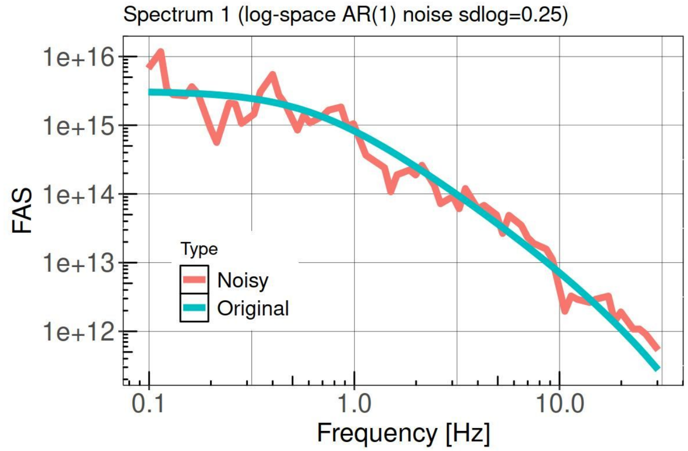
Dino's group contributions

An example of generated noisy FAS is shown in Figure 14. Table 1 summarizes the main choices made to generate the synthetic spectra.

Object	Choices	Comments
2D model	3 layers 4 layers	0-4km Q200; 4-10km Q400; 10-20km Q600 +1km Q50 layer at surface
Source	$< \Delta\sigma >= 3$ MPa $\Delta\sigma = \Delta\sigma(Mo)$ $\Delta\sigma = \Delta\sigma(h)$	Self-similar scaling + perturbations Constant for M>5 + perturbations fixed MPa/km gradient + perturbations
Attenuation	$(1/R; t^*)$	info extracted from 2D ray paths
Site	$1 \ \forall f$ (C_{amp}, k_0)	no site effects high-frequency filtering effect

Table 1 Summary of the choices made to construct the synthetic FASs.

Summary of the FAS simulations



FAS = Source Propagation Site +noise

(correlated noise)

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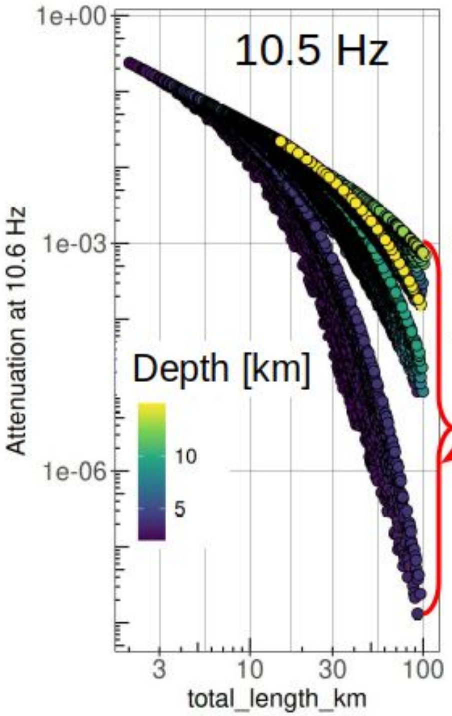
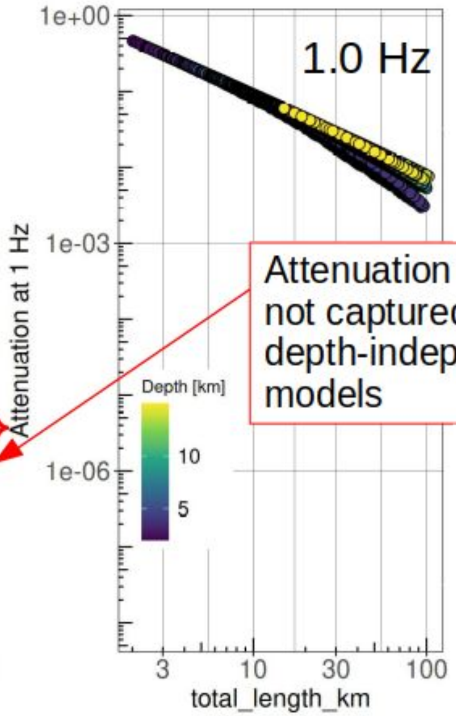
4-layers



4-layers

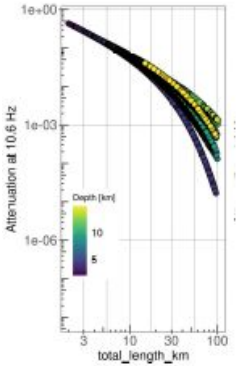


$$A(f; R, t^*) = \frac{1}{R}\ exp^{-\pi f t^*}$$

$$t^*_{ij} = \sum_k t^*_{ijk} = \sum_k \frac{d_{ijk}}{Q_{ijk}\ \beta_{ijk}}$$

Attenuation variability not captured by depth-independent models

3-layers



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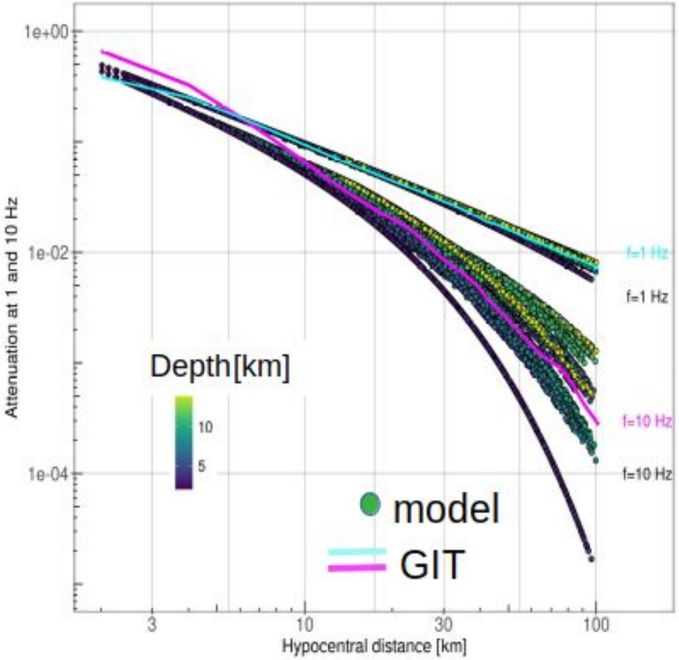
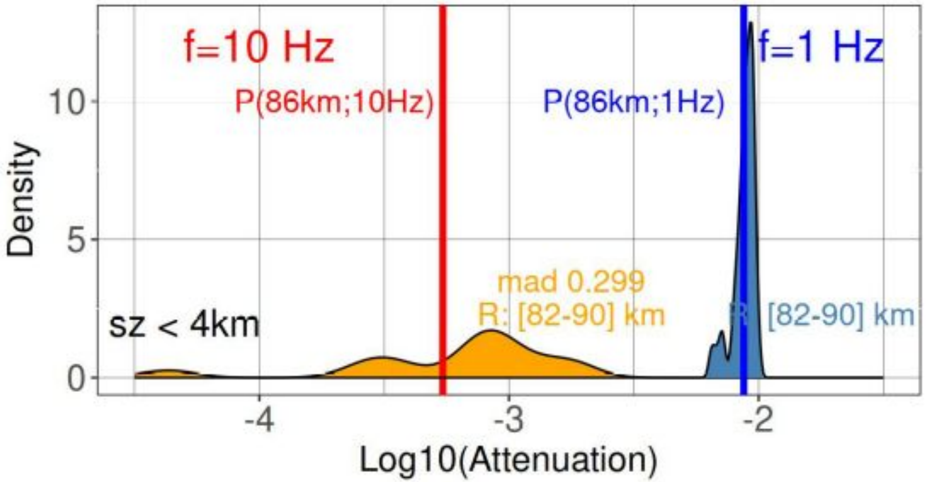
(preliminary) Example of analysis and results



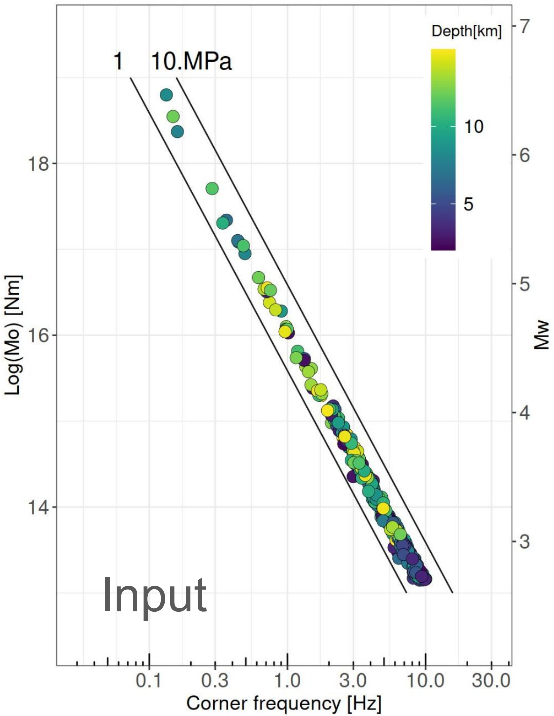
Spectral attenuation

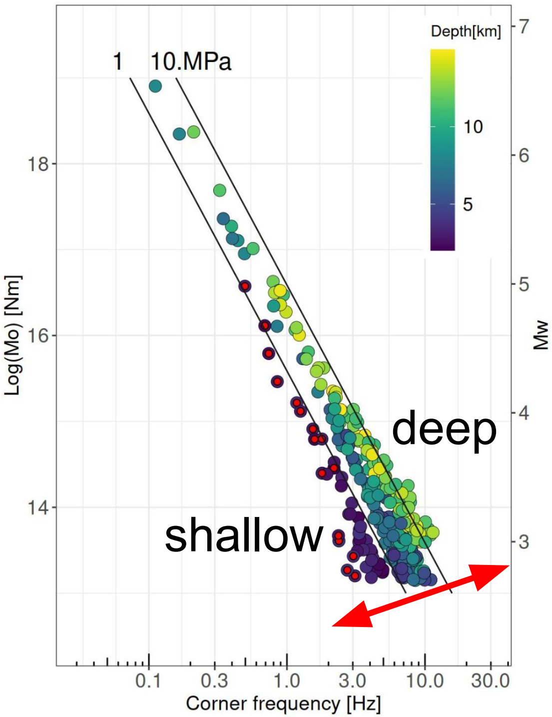
Missed attenuation variability
(mostly moved to source)

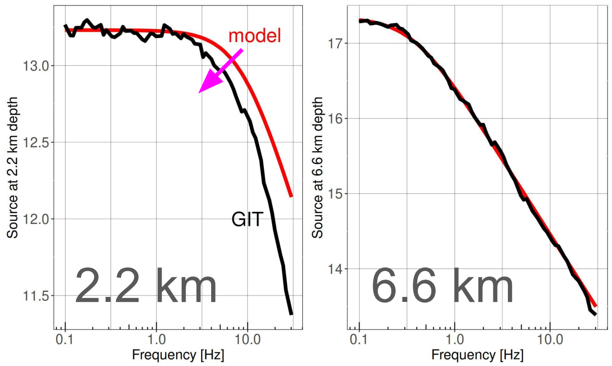


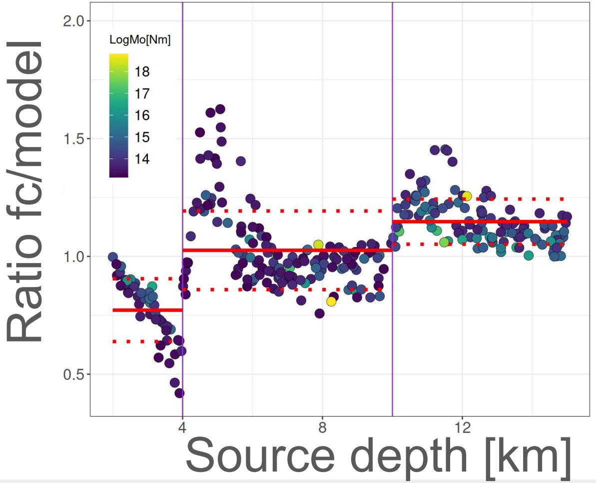
Dino's group contributions

Example of preliminary results









More is coming…..soon!

Feel free to contact us if you are interested to participate (dino.bindi@gfz.de)

2:55 pm Pacific: Wrap up

Thanks for coming!
Review (including Introduction)

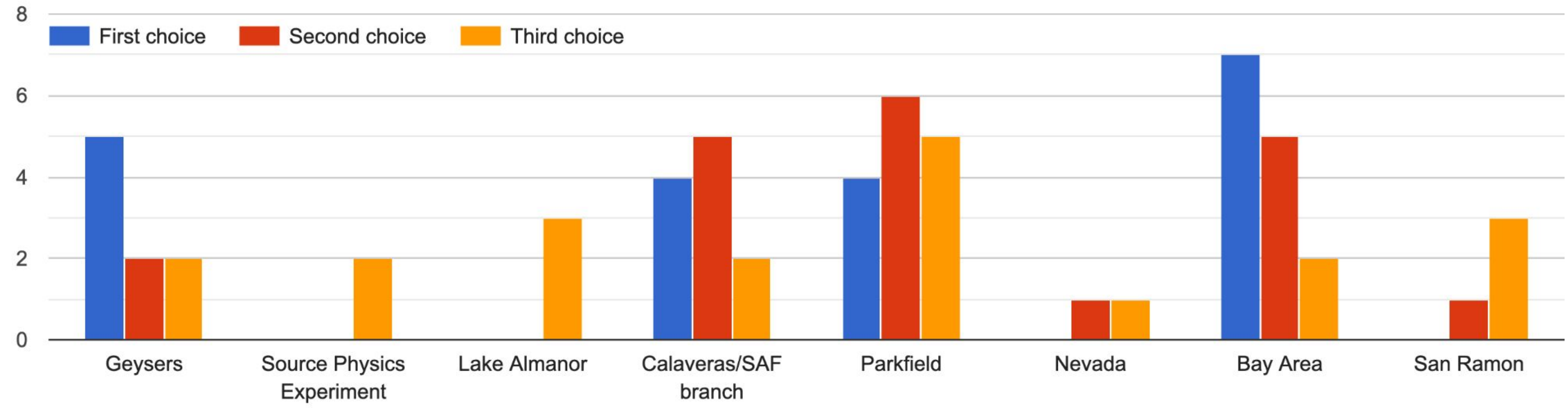
https://www.scec.org/events/2026-community-stress-drop-validation-workshop/

ALL LINKS FOR TODAY: https://tinyurl.com/49m7w4ys

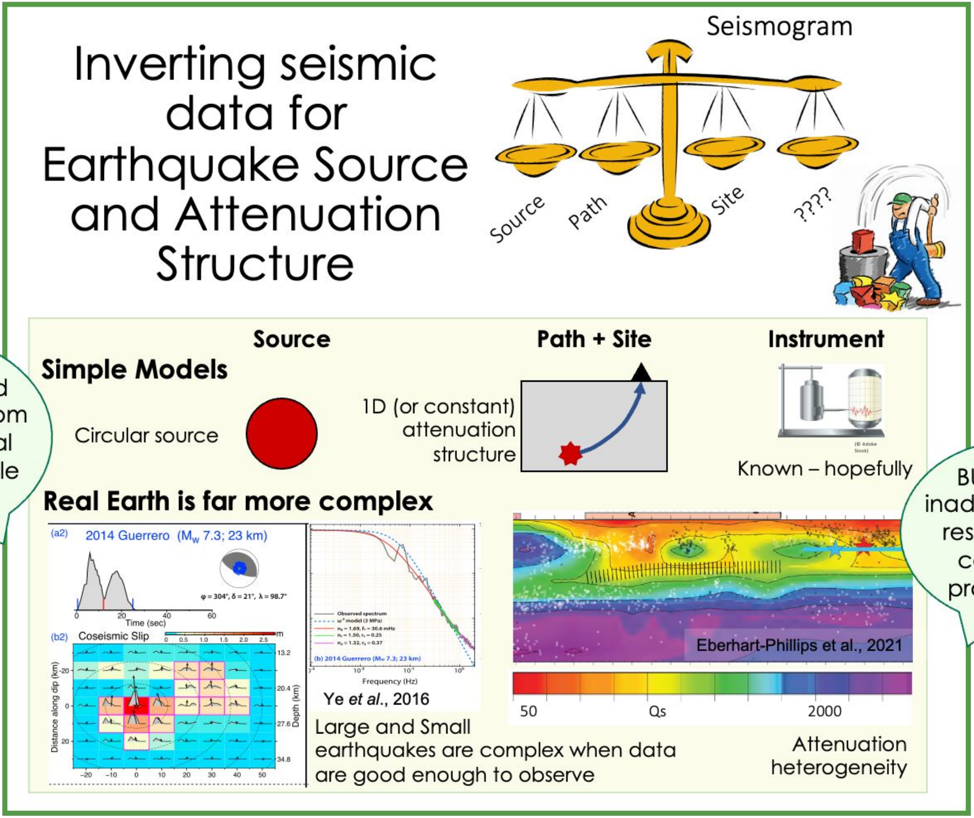
Choosing a Northern California Data set for a second Community comparison

Bay Area with different subsets (regional, large magnitudes…)

Rank your top three datasets!



Step 1: Likely Causes and How Bad is it?



Trade-offs and uncertainties from forcing the real earth into simple models

BUT data inadequate to resolve fully complex problem…

First Community Validation experiment -

2019 Ridgecrest Earthquake Study

REPORT
doi:10.26443/seismica.v3i1.1009
SEISMICA

The SCEC/USGS Community Stress Drop Validation Study Using the 2019 Ridgecrest Earthquake Sequence

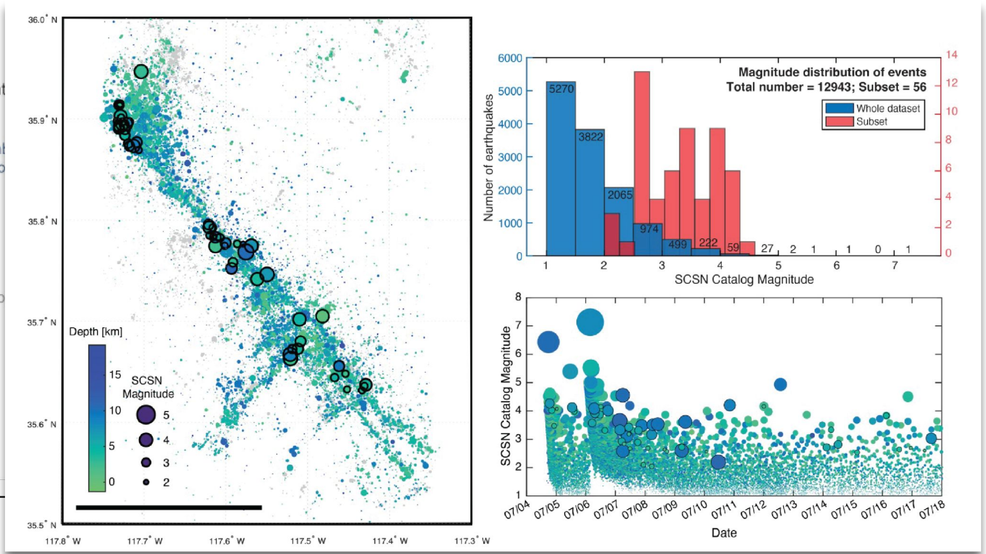
Annemarie Baltay *[1], **Rachel E. Abercrombie** [2], **Shanna Chu** [1], **Taka'aki Taira** [3]

[1]United States Geological Survey, Earthquake Science Center, Moffett Field, CA, USA, [2]Department of Earth & Environment
Boston, MA, USA, [3]Berkeley Seismological Laboratory, UC Berkeley, Berkeley, CA, USA

Author contributions: *Conceptualization*: A. Baltay, R.E. Abercrombie. *Data Curation*: T. Taira. *Formal Analysis*: A. Baltay, R.E. Abercromb *Acquisition*: A. Baltay, R.E. Abercrombie, T. Taira. *Project Administration*: A. Baltay, R.E. Abercrombie,. *Visualization*: A. Baltay, R.E. Abercro *original draft*: A. Baltay, R. E. Abercrombie. *Writing – review & editing*: A. Baltay, R.E. Abercrombie, S. Chu, T. Taira.

Abstract We introduce a community stress drop validation study using the 2019 Ridgecrest, California, earthquake sequence, in which researchers are invited to use a common dataset to independently estimate comparable measurements using a variety of methods. Stress drop is the change in average shear stress on a fault during earthquake rupture, and as such is a key parameter in many ground motion, rupture simulation, and source physics problems in earthquake science. Spectral stress drop is commonly estimated by fitting the shape of the radiated energy spectrum, yet estimates for an individual earthquake made by different studies can vary hugely. In this community study, sponsored jointly by the U. S. Geological Survey and Southern/Statewide California Earthquake Center, we seek to understand the sources of variability and uncertainty in earthquake stress drop through quantitative comparison of submitted stress drops. The publicly available dataset consists of nearly 13,000 earthquakes of M1 to 7 from two weeks of the 2019 Ridgecrest sequence recorded on stations within 1-degree. As a community study, findings are shared through workshops and meetings and all are invited to join at any time, at any interest level.

https://seismica.library.mcgill.ca/article/view/1009



BSSA 2025: Special Issue + 1

Introduction to the Special Section on Improving Measurements of Earthquake Source Parameters

Annemarie Baltay; Rachel E. Abercrombie; Adrien Oth; Takahiko Uchide

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Overview of the SCEC/USGS Community Stress Drop Validation Study Using the 2019 Ridgecrest Earthquake Sequence

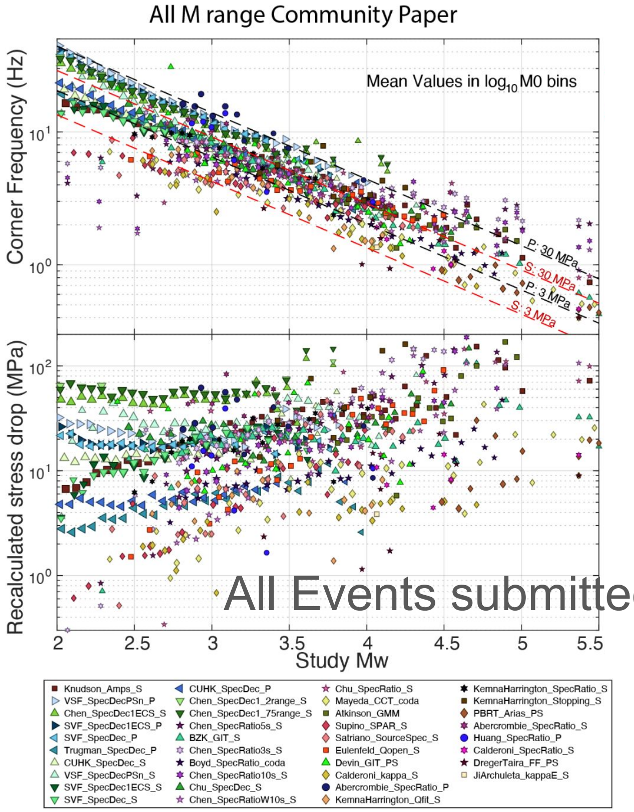
Rachel E. Abercrombie; Annemarie Baltay; Shanna Chu; Taka'aki Taira; Dino Bindi; Oliver S. Boyd; Xiaowei Chen; Elizabeth S. Cochran; Emma Devin; Douglas Dreger; William Ellsworth; Wenyuan Fan; Rebecca M. Harrington; Yihe Huang; Kilian B. Kemna; Meichen Liu; Adrien Oth; Grace A. Parker; Colin Pennington; Matteo Picozzi; Christine J. Ruhl; Peter Shearer; Daniele Spallarossa; Daniel Trugman; Ian Vandevert; Qimin Wu; Clara Yoon; Ellen Yu; Gregory C. Beroza; Tom Eulenfeld; Trey Knudson; Kevin Mayeda; Paola Morasca; James S. Neely; Jorge Roman-Nieves; Claudio Satriano; Mariano Supino; William R. Walter; Ralph Archuleta; Gail Marie Atkinson; Giovanna Calderoni; Chen Ji; Hongfeng Yang; Jiewen Zhang

Contact Authors, or rea@bu.edu for access if you need it

Abercrombie and Baltay: **Magnitude, Depth, and Methodological Variations of Spectral Stress Drop Within the SCEC/USGS Community Stress Drop Validation Study Using the 2019 Ridgecrest Earthquake Sequence**
BSSA 2025 https://doi.org/10.1785/0120250056

https://docs.google.com/document/d/1tiDZ2F8pc6kkBN22zY3tcVBw2T7NMZsLQkQ7XpOWXF0/edit?tab=t.0

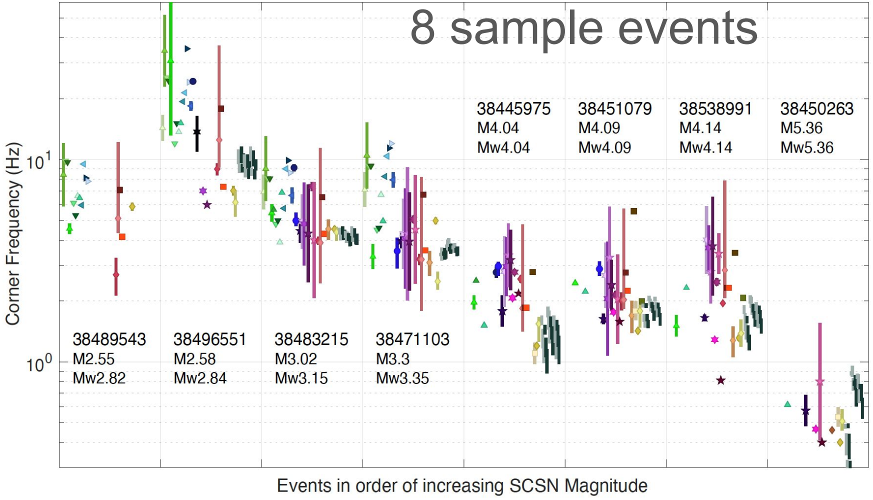
Abercrombie, Baltay et al. 2025
Overview of Community Study



All Events submitted

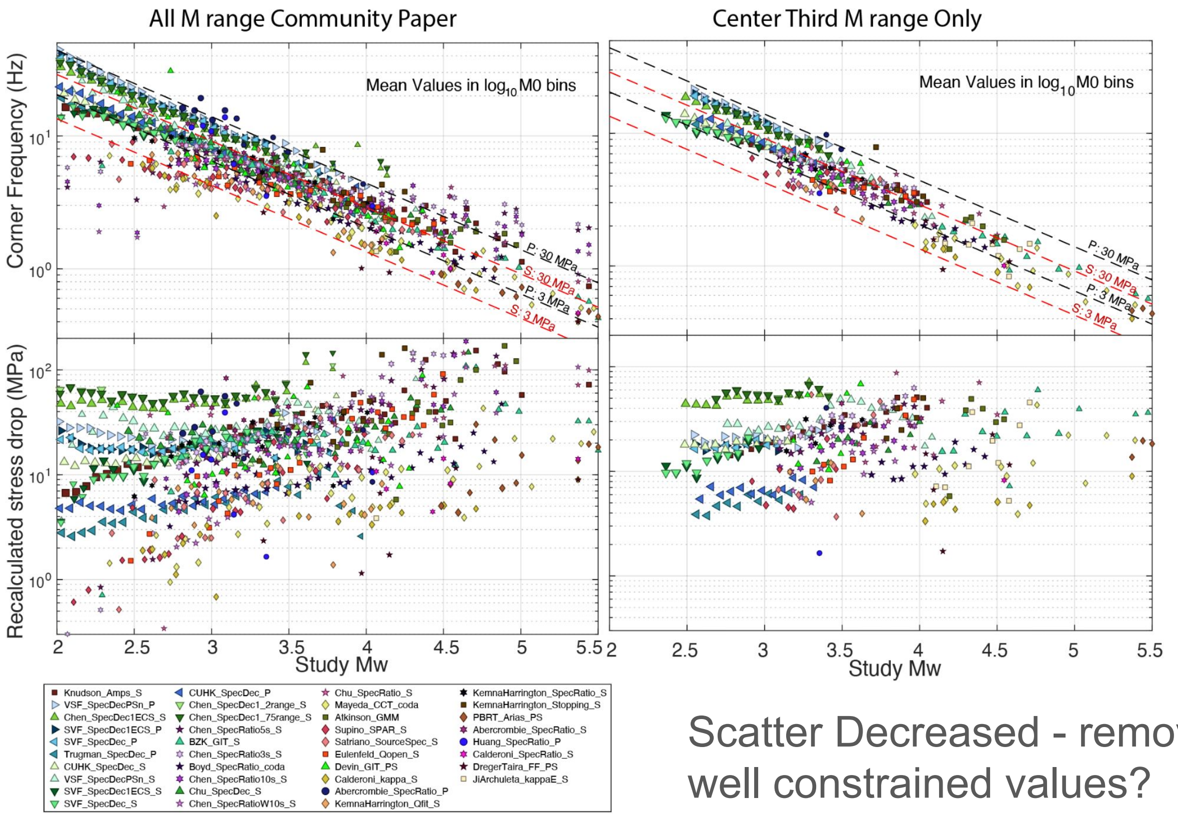
56 estimates from 20 independent groups - A lot of scatter

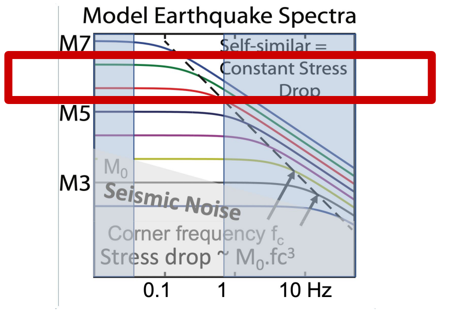
Direct Comparison of 8 sample events

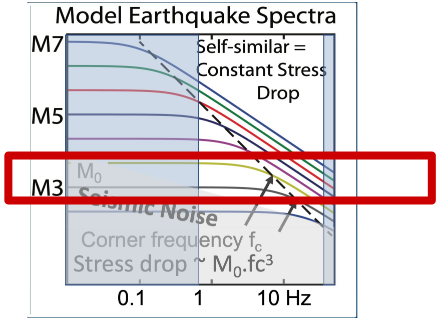


Much systematic and random variation, error bars do not overlap

Maybe we should use stronger quality control?
Only include very best constrained estimates



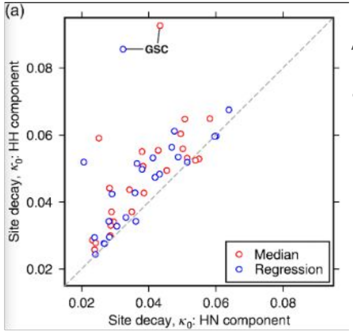




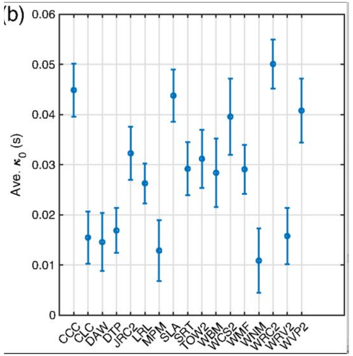
Scatter Decreased - removes less well constrained values?

Effect of different kappa values

Submitted Results: **Absolute** Values kappa ~ 0.015 - 0.06 s

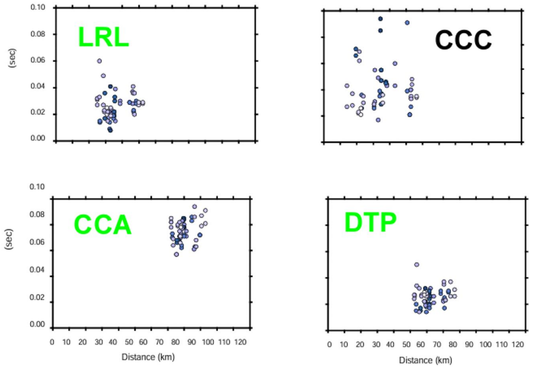


Ahn et al. 2025



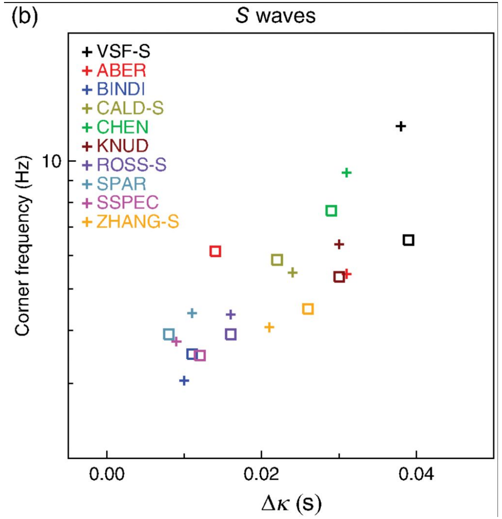
Ji et al. 2024

Calderoni & Abercrombie 2024



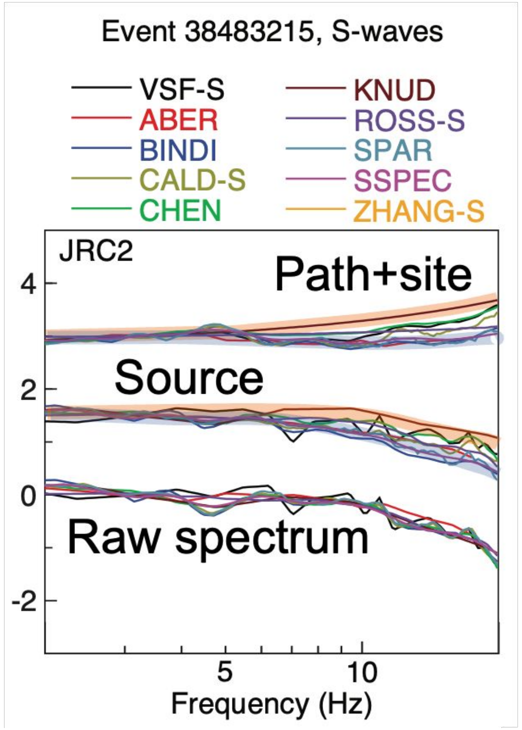
Site and Path attenuation

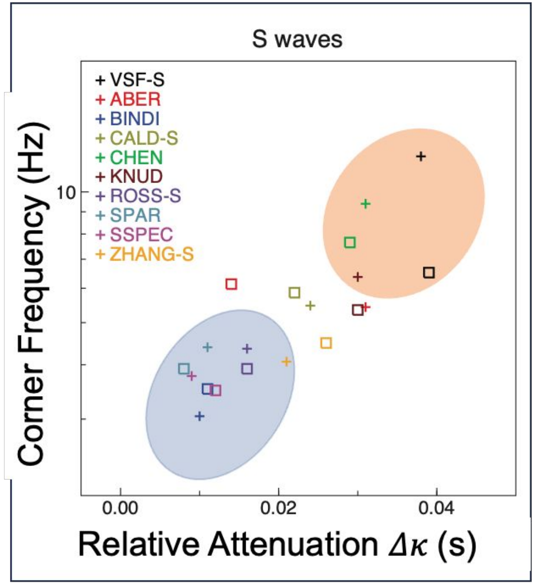
Shearer et al. 2024 DIFFERENCE between values for different studies



Difference between Values Δkappa ~ 0.01 - 0.04 s

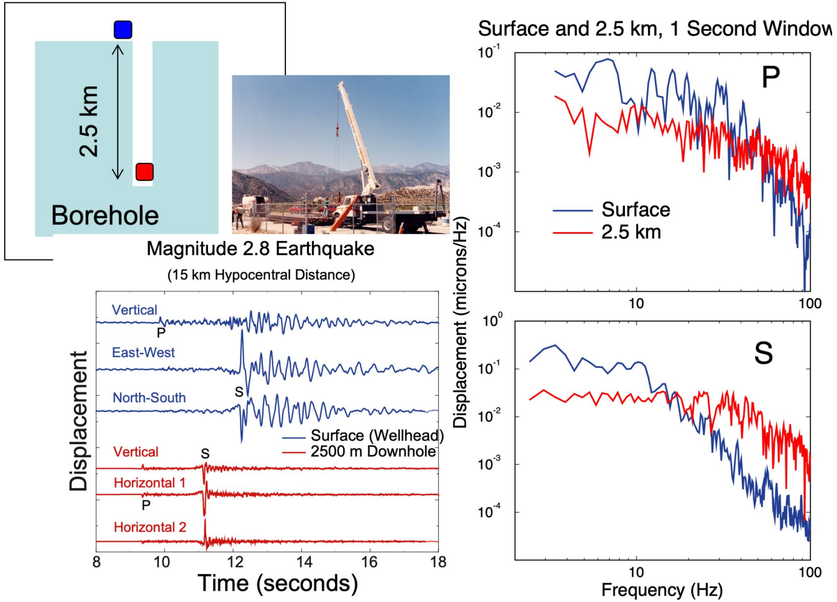
Site Effect: Amplification, Resonance, Attenuation



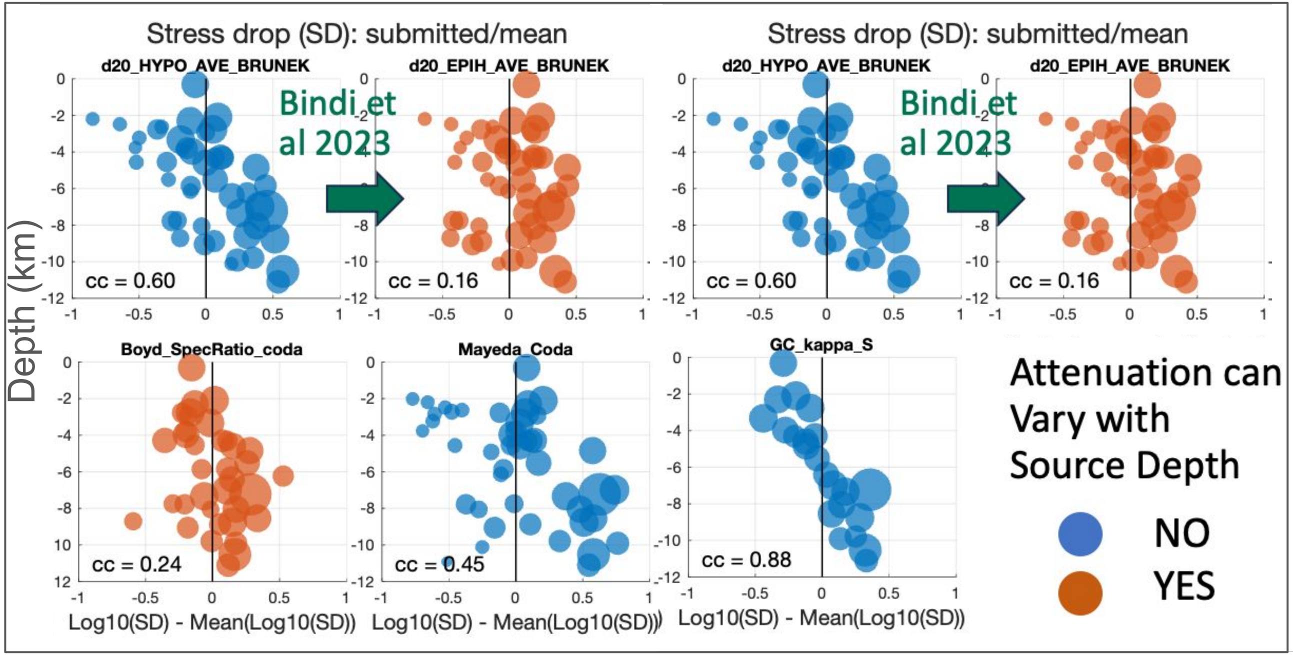


Shearer et al. 2024

Abercrombie 1995, 1997 - Cajon Pass Deep Borehole



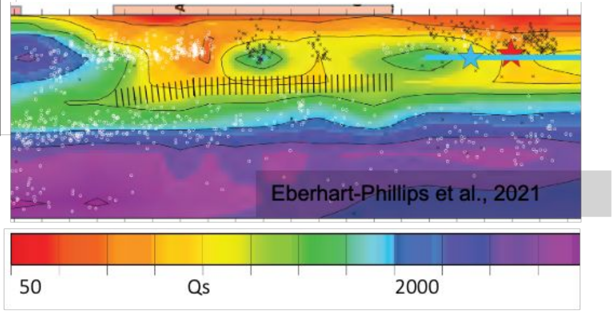
Over-simplified Attenuation Structure



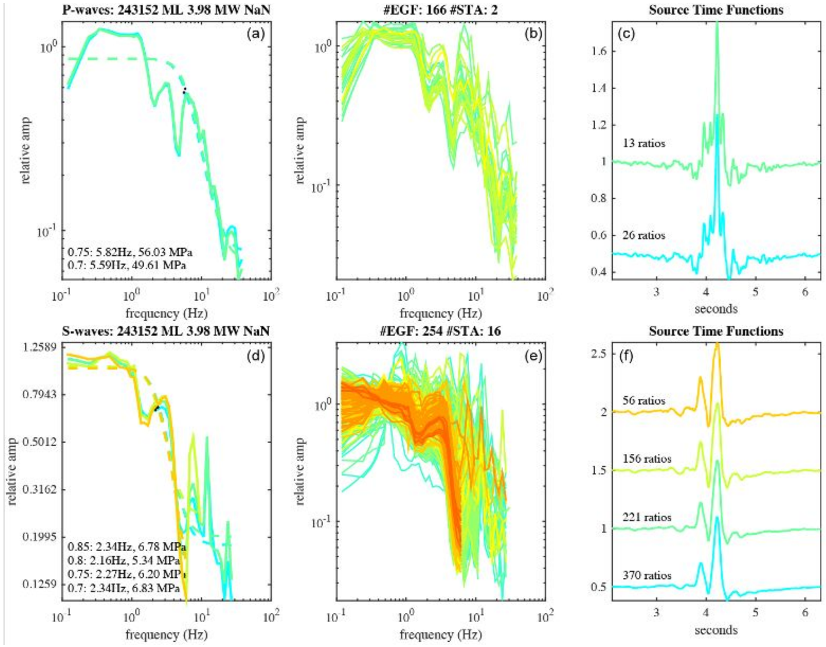
Trade Off between attenuation and source varying with source depth

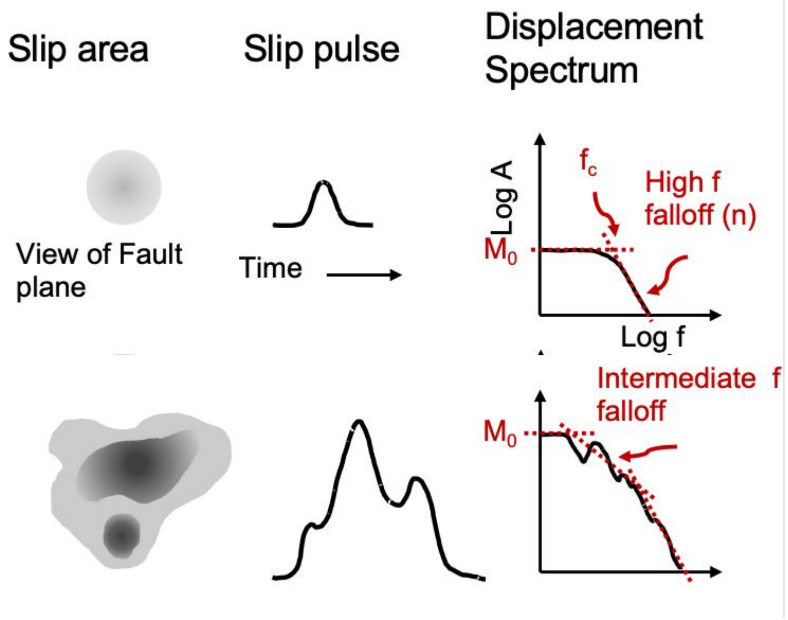
Abercrombie & Baltay (2025), also Abercrombie et al. (JGR 2021).

Dino Bindi will present new synthetic results later.



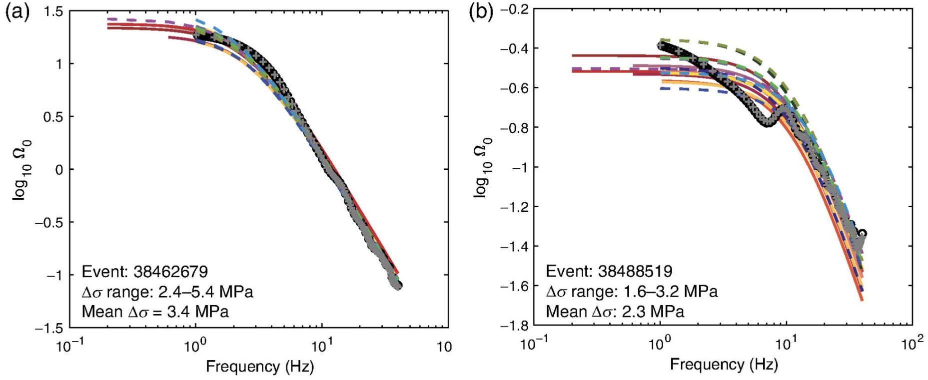
Assumption of Simple Source Model

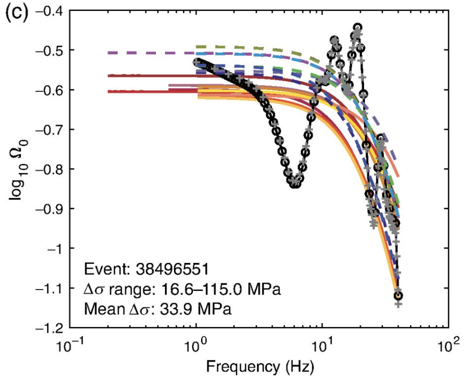


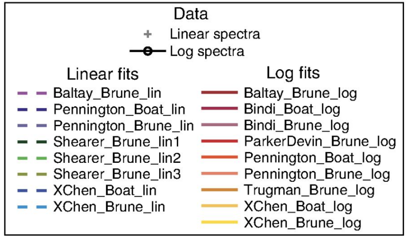


Even small earthquakes are often NOT simple circular sources e.g. Pennington et al. BSSA 2022, GJI 2023; Abercrombie et al. GRL 2020 and many more

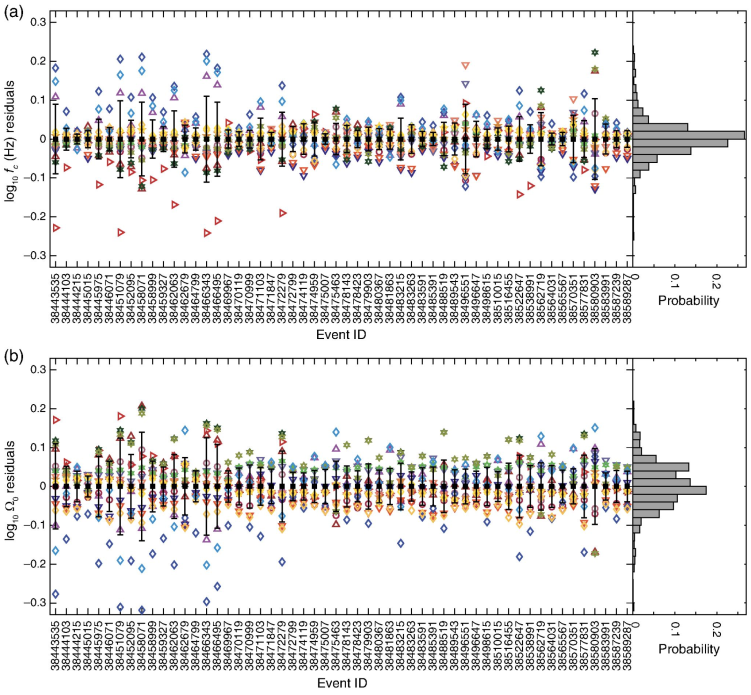
Cochran *et al.* 2025: Simple Source models do not converge for complex spectra





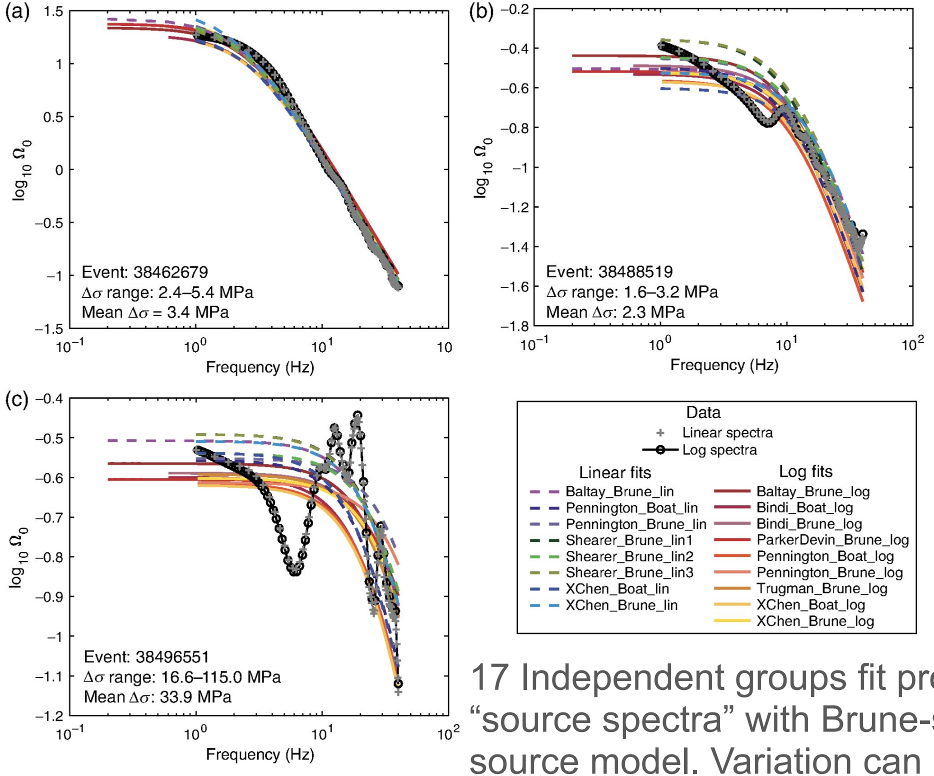


17 Independent groups fit provided "source spectra" with Brune-style source model. Variation can reach an order of magnitude.

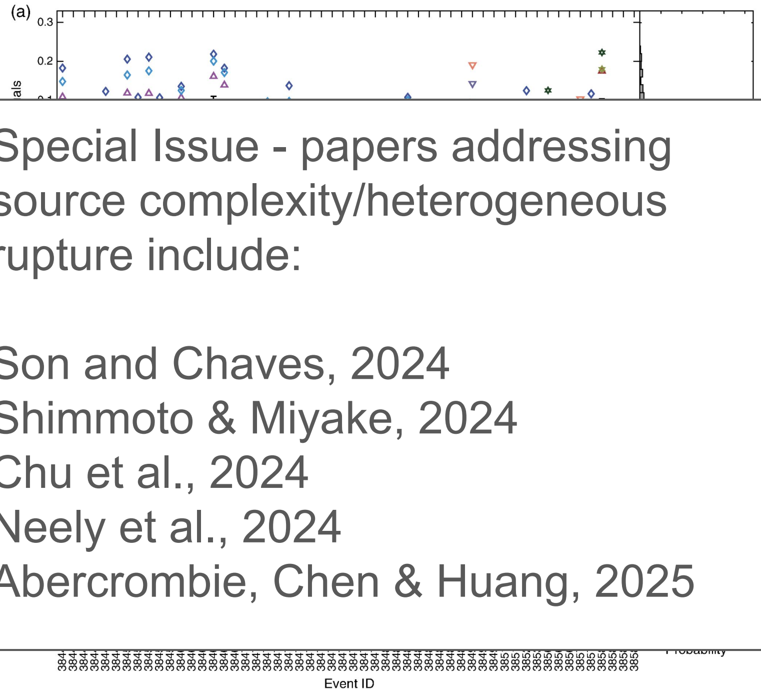


Some is likely real source variation. Some from inaccurate path and site correction to make "source spectra" ?

Cochran *et al.* 2025: Simple Source models do not converge for complex spectra



17 Independent groups fit provided "source spectra" with Brune-style source model. Variation can reach an order of magnitude.



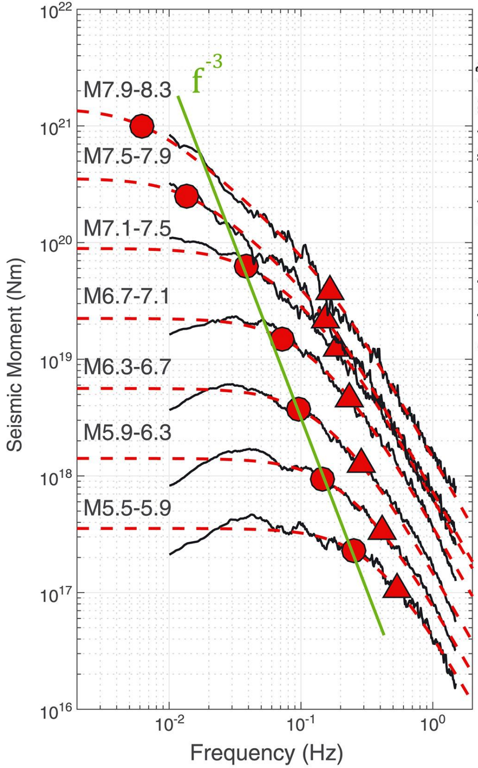
Special Issue - papers addressing source complexity/heterogeneous rupture include:

Son and Chaves, 2024
Shimmoto & Miyake, 2024
Chu et al., 2024
Neely et al., 2024
Abercrombie, Chen & Huang, 2025

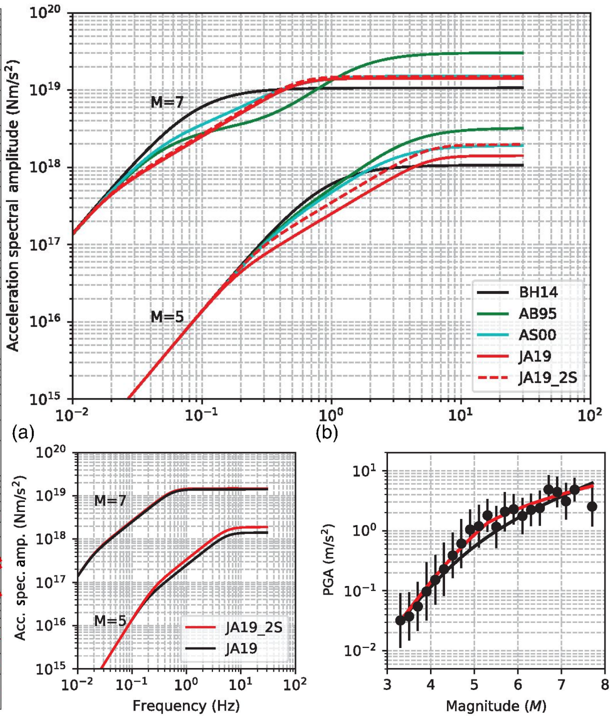
Some is likely real source variation. Some from inaccurate path and site correction to make "source spectra" ?

Two Corners? Crack v Pulse? Sub-events?

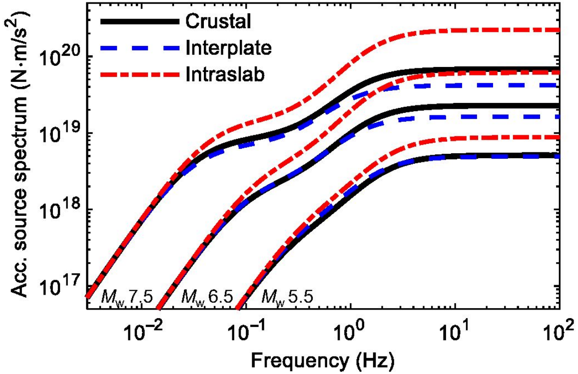
Denolle & Shearer, 2016



Ji & Archuleta, 2021



Shimmoto, 2025



Two Corners - More free parameters so fit data better.

But how well constrained?

How do they scale? Are smaller earthquakes less “complex”, or resolution issue?

Crack v Pulse - Kano et al. 2025 JGR

- ✔ Crack-like rupture: Local slip continues until the rupture reaches the fault edge.
- ✔ Pulse-like rupture [Heaton, 1990]:

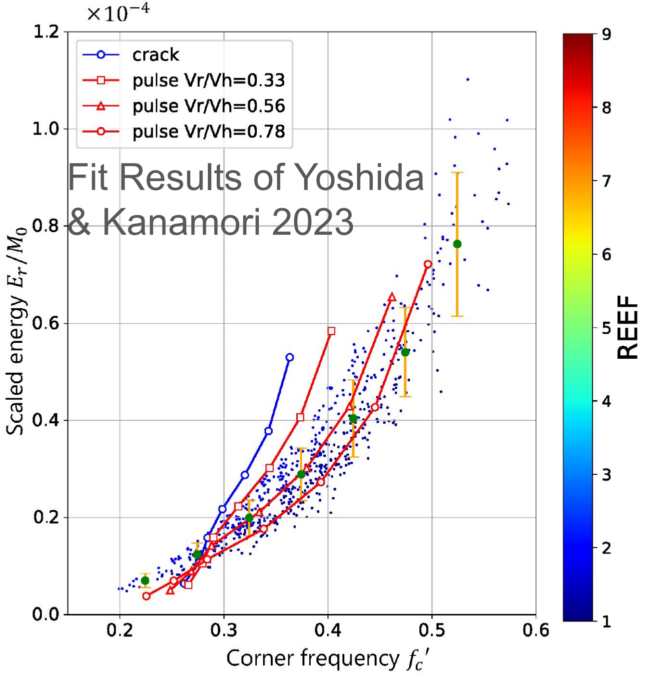
Local slip duration is shorter than the total rupture duration (and duration expected from stopping phases produced at the fault edge).

- ✔ Large EQs are typically pulse-like [e.g., Melgar and Hayes, 2017].
- ✔ Small EQs are often assumed to be crack-like.
- ✔ If the self-similarity holds between small and large EQs, do most small EQs exhibit pulse-like behavior?

Note: The reasons behind pulse-like rupture are still debated (e.g., enhanced velocity-weakening friction, stopping phases, fault heterogeneities, etc)

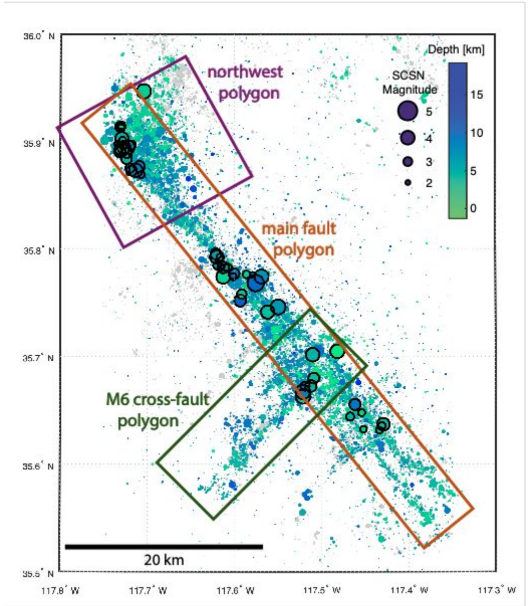
We develop **a self-similar pulse model** by extending the approach of Kaneko and Shearer [2015], which was based on a self-similar crack model.

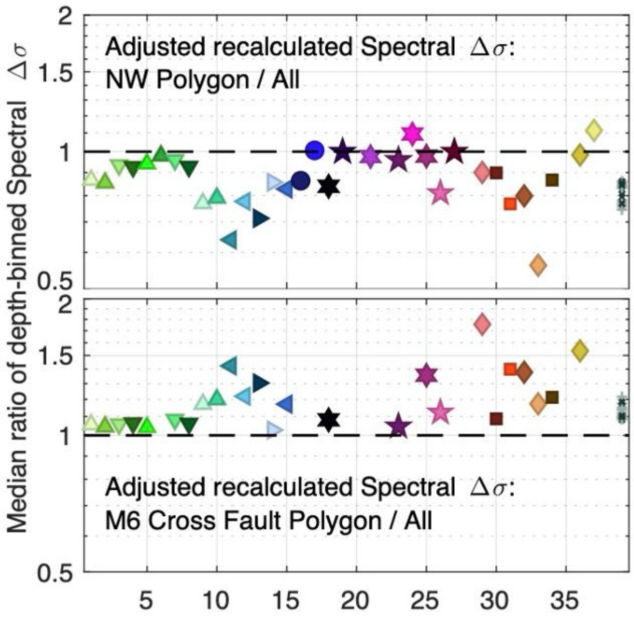
- ✓ A circular fault of radius a embedded into an infinite elastic medium.
- ✓ Self-healing slip pulse with shear strength first decreasing, then increasing at the tail.
- ✓ Rupture speed V_r and healing speed V_h are prescribed; fracture energy comes out as a solution.
- ✓ Each simulation, based on spectral element method, takes ~4 hours on HPC.



Main result: Pulse-like ruptures better match observed seismic energy patterns than crack-like ruptures.

But there is some real variation if only we can decrease the random and systematic uncertainties





Abercrombie and Baltay 2025

Better agreement between relative values after removing systematic offsets and large scale (Mag. and depth) trends.

All studies show similar spatial variation - there is some real signal within the noise.

Summary of Current Status

We have a problem

Source is more complicated than simple models

Earth structure & attenuation are more complicated than assumed in most inversions

Site effects - amplification & attenuation are complicated and significant

Data are limited - resolution very variable depending on quantity and quality of recordings and quantity & magnitude of earthquakes

Towards a Solution?

A follow-up comparison:
Are method developments following initial comparison helping??

Synthetic experiments:
Design carefully to isolate each issue at a time to quantify and explore
Consider alternative approaches for different goals

High frequency ground motions v. source physics
Regions with higher/lower quantity/quality of recording

Statewide California Earthquake Center

science for a changing world

INVITED TALKS on NEW AND ONGOING WORK

Gian Maria Bocchini: *Earthquake Stress Drop values delineate spatial variations in maximum shear stress in the Japanese forearc lithosphere*

Sara Beth Cebry: *Source parameters from fully constrained laboratory earthquakes*

Hilary Chang: *Microearthquake stress drop and attenuation from borehole DAS at Cape Modern*

Mariano Supino: *Bedretto micro-earthquakes*

Keisuke Yoshida: HiNET *Source time functions from repeating earthquakes off Tohoku*

SCEC new TAG Letter of Intent (LOI) *submitted*

- Ideas sprouted from in-person discussions at SCEC AM
- (now) LOI is reviewed by SCEC
- (spring 2026) We write a longer (5-page?) TAG proposal
- More folks always welcome to join as key participants

2025 Letter of Intent: New SCEC TAG

Proposed TAG Name:	Community Stress Drop Validation TAG
Lead Investigator:	Annemarie Baltay, USGS Moffett Field, abaltay@usgs.gov Rachel Abercrombie, Boston University, rea@bu.edu
Project Title:	Integration of observational, theoretical, and engineering approaches to improve spectral stress drop estimates for advancing earthquake source physics and ground motion modeling.
Confirmed Key Participants:	D. Trugman, P. Shearer, C. Pennington, E. Cochran, Y. Huang, X. Chen, C. Ji, A. Oth, E. Tinti, M. Son, R. Harrington, M. Supino, O. Boyd, O.-J. Ktenidou, Z. Jia

TAG Overview:

The SCEC/USGS Community Stress Drop Validation TAG was formed in 2021 to address the wide discrepancy in reported spectral stress drop ($\Delta\sigma$) estimates, arising even when the same earthquake is studied with similar methods. Spectral $\Delta\sigma$ is estimated from the corner frequency that distinguishes the flat, moment-controlled portion of the spectrum from the high-frequency decay associated with radiated energy. Because spectral $\Delta\sigma$ captures this high-frequency transition, it is key for earthquake source physics as well as for hazard and ground motion studies. Since 2021, we have built a global community of over 100 people, including observational seismologists developing methods as well as practitioners from other fields (ground motion, rock mechanics, dynamic rupture) who use $\Delta\sigma$ measurements in their own work. To date, the group has collected more than 20 submissions of spectral $\Delta\sigma$ and other source parameters for the 2019 Ridgecrest study, and coordinated a BSSA special issue on the topic. Overall, we have resolved both random and systematic method variability, found improvements to many approaches, and identified the primary problems needing more research.

Now we seek to create a new, broader TAG to build on the interest and collaborations that arose in the last 5 years. Beyond ongoing methods development and validation, we will enhance our

Five Pillars for new TAG (proposed):

1. **New empirical data set.** The community will discuss and decide on a new focus region for comparative study, likely in northern California at the funded January 2026 virtual workshop.
2. **Simulations/Synthetics.** Produce simulated datasets that match the earthquake magnitudes, locations, and station distribution of the empirical dataset to test model resolution and isolate sources of tradeoffs and uncertainties.
3. **Ridgecrest Study.** Continue analysis to understand the large variability still apparent in the published results, including comparisons with GMM methods and detailed models of regional structure. Use additional data (e.g., nodal arrays, DAS) to improve constraints.
4. **Site response.** Study site response and kappa to clarify trade-offs between amplification and attenuation with source spectral features. Ambiguity in correcting for near-surface effects was identified as a major source of discrepancies in the original Ridgecrest comparative study.
5. **Other/novel estimates of source parameters.** Examine band-limited energy, time-domain approaches, magnitude-related properties, and any connection of spectral $\Delta\sigma$ to other physical parameters, specifically other “stress parameter” measurements.

SCEC in-person workshop

- Awarded $20,000 to hold an in-person workshop!
- In-person 1-day workshop at USGS Moffett Field, CA with hybrid option.
- Planning for ~50 people.
- Award will cover travel for participants: 2 nights lodging for ~25 people and airfare for ~8 (will consider need-based)

When??? We want ***your*** input.

May 11-15; June 22-26; June 29-July 1

August 12 - September 3

https://forms.gle/YeGshCvf6Hjio4ur5

Summary

VOTE for your preferred dataset!
https://forms.gle/f857XgwPRtQwWQsJA

region	M range	# EQs	f range	Depth	# of Sensors	comments	Science implications
Geysers Small area	0-5	23 M>4 since 2009 Thousands of small	4.5 Hz phones	2-4km	32 in 20x10 km	Are any large events clipped? summer/winter attenuation varies?	Fluid-driven effects, several stress drop studies
SPE Small area	M<3	Short duration	High f	< 1km	Very dense close-in recording	Known sources, aftershocks of explosions	Very specific focused study.
Lake Almanor	M<5.7	57 > M2.5 with nodals	Nodals + a few BB, SM	crustal. ~2 - 10 km	Little for 10 years (2 in 25 km); dense for 2 months	34 station Nodal deployment	Hazard implications for dams
Calaveras larger area	M<5	Since 2000: 6 M4.5+; 1869 M2/5+	Similar to Ridgecrest	crustal.	81 in study area, Spacing ~10 km	Similar scale and recording to Ridgecrest?	Hazard in the bay area, spatial variations
Parkfield medium area (small within HRSN)	M1-6	5000+	Surface: 1-20, HRSN 1-60Hz.	crustal. ~2 - 12km	Dense surface, and shallow borehole. Very short term deep SAFOD	Very well studied. DAS, SAFOD borehole. Comparison with	What is causing spatial variations? What is stress drop for small EQs? Temporal changes following M6
Nevada Medium scale	M2+ catalogued	**Monte Cristo**- lots of EQs, 9 Mile, Antelope Valley, Parker Butte, **Reno-Carson area**	Similar to Ridgecrest		Sparse, big azimuthal gaps, short nodal deployment for Monte Cristo	Novel! Not well studied. Station coverage is sparse. May need relocations? No previous Best coverage probably Reno/Carson area	Could test limits of methods! Site measurements available for Reno/Carson
Bay Area (large area)	<6 (Napa)	~800>M3, 55>M4 since 2003	Similar to Ridgecrest, Hayward borehole 4-55 Hz	crustal	Lots, approx 10 km?	Velocity and attenuation models exist, good geology. Could focus on Hayward area? (borehole)	Seismic hazard to Bay Area.
San Ramon (small, within Bay area)	< 4.4	~250+ since 2000 M2+			Quite dense		Why ongoing clusters? Why move around?

Choosing a Northern California Data set for a second Community comparison

Rank your top three datasets!

Bay Area with different subsets (regional, large magnitudes…)