Welcome! and thank you!

- Official SCEC TAG
- Launched spring 2020
- PIs: Baltay, Abercrombie, Taira, Ruhl, Ellsworth, Yoon, Pennington, Cochran

- Common dataset available
- Only beginning! Still time for everyone to get involved
- 11 groups submitted results for today, woohoo!
Community Stress Drop Validation Study

Thank you….
  … to everyone for participating today, and those who are presenting and moderating
  … to everyone who quickly calculated things, and was willing to share.
  … to our brainstorming and proposal team
  … to Tran and Edric and the SCEC Team
  … to SCEC and USGS for their support
  … to Taka’aki Taira for creating and monitoring the dataset
  … to Rachel for being my co-conspirator!
Agenda

09:00 - 10:30 Session 1: Introductions and Comparisons of Initial Results
Moderators: Rachel Abercrombie, Annemarie Baltay
09:00 - 09:20 Welcome and Overview of Workshop, Datasets Annemarie Baltay, Taka’aki Taira, Rachel Abercrombie
09:20 - 10:00 Lightning Talks: Methods by Different Research Groups who submitted preliminary results
10:00 - 10:15 Initial Results Rachel Abercrombie
10:15 - 10:30 Group Discussion

10:30 -11:00 Break

11:00 - 12:30 Session 2: Method Comparisons —Breakouts and Discussion
Moderators: Oliver Boyd, Natalie Schaal
11:00 - 11:15 Comparisons of Stress Drop Results: a Focus on the Prague, OK Sequence Colin Pennington
11:15 - 11:35 Breakout Discussion #1
11:35 - 11:55 Breakout Discussion #2
11:55 - 12:15 Breakout Discussion #3
12:15 - 12:30 Group Discussion

12:30 - 13:30 Break

13:30 - 15:00 Session 3: User needs lightning talks and looking forward
Moderators: Ahmed Elbanna, Christine Goulet
13:30 - 13:40 Introduction
13:40 - 13:45 Stress Drop in Ground Motion Behzad Hassani
13:45 - 13:50 Static Stress Drop - UCERF/M-logA Bruce Shaw
13:50 - 13:55 Stress Drop in Dynamic Rupture Simulations Ruth Harris
13:55 - 14:00 Stress Drop in Source Physics Valère Lambert
14:00 - 14:20 Breakout Discussion #4 - with previous speakers
14:30 - 15:00 Group Discussion: Looking Forward

15:00 Adjourn
15:00 + Bonus Happy Hour
Workshop Today: Planning + Preliminary Results

Lots of time for discussion, less time for presentations. Community effort, we are just facilitating.

We don’t have a concrete overarching plan. We don’t know what’s going to happen next! So we YOU to get involved, get excited, get talking.

Preliminary - both the results and the organization. This has given us a chance to see how to organize (logically and scientifically) so we can improve for the next round. Ideas?

Think forward! What should we focus on as a community - a few specific events? A simplified method? Reducing magnitude uncertainty?

Next Year! SCEC proposals? Workshop! Monthly calls? Round up of similar methods?

Throughout today, leave us constructive feedback! (chat, email, etc.) Moderators have a shared Google doc in which to leave feedback, too.
Upcoming Meetings

AGU Session: *S45A - Community Stress Drop Validation, Focused on the 2019 Ridgecrest Earthquake Sequence I Poster*. Thursday December 16, 2021. 16:00 - 18:00 Central Time.

SSA 2022 Bellevue, WA. *Earthquake source processes at various scales: Theory and observations.*

JpGU May-June 2022 in Chiba, Japan, hybrid…

2nd official TAG Workshop! Spring 2022???
JpGU Meeting 2022 Session (just proposed)
“Seismic Spectra for Source, Subsurface Structure, and Strong-motion Studies”

Conveners

Takahiko Uchide
(Geological Survey of Japan, AIST, Japan)

Rachel E. Abercrombie
(Boston University, USA)

Kuo-Fong Ma
(Academia Sinica, Taiwan)

Kazuhiro Somei
(Geo-Research Institute, Japan)

Abstract Deadline:
8:00, Feb. 17, 2022 (UTC)

Hybrid Meeting:
May 22 – 27, 2022

Online Poster Sessions:
May 29 – Jun. 2, 2022

Makuhari Messe, Chiba, Japan
Data Set

- Earthquake Catalog and Waveform Data
  - Minimum magnitude: 1.0
  - Time window (UTC): 2019/07/04 00:00 - 2019/07/18 00:00
  - 12,943 events (M≥1)
  - Available for download at
    - [https://scedc.caltech.edu/data/stressdrop-ridgecrest.html](https://scedc.caltech.edu/data/stressdrop-ridgecrest.html)
    - If problems, please send emails to me (taira@berkeley.edu)

- Meta Data:
  - Earthquake catalog with SCSN magnitudes.
  - Relocations from Trugman (2020, SRL)
  - P- and S-wave phase picks for each waveform
    - SCSN analysis pick and synthetic travel time with SOCAL 1D model
  - Vs30 estimates at all stations
Introduction to General Problem

*Constant Stress Drop varies over 3+ Orders of Magnitude*

Combining Smaller scale studies

M trends within individual studies?

Spatial variability?

Depth dependence?

Uncertainties? Resolution? Simplifying Assumptions?

e.g. Yoshimitsu *et al.*, GRL 2015
Measurements from Frequency of Seismic Waves

1960s and 1970s Aki, Brune, Kanamori, Madariaga etc.
(pre digital recording and big computers..)

Source spectrum has simple shape:

Peak in velocity spectrum
= corner frequency \((f_c)\) in displacement
\(\sim 1/\text{source dimension}\)

Brune Model:
\[ n = 2 \quad M_0(f) = \frac{M_0}{1 + \left(\frac{f}{f_c}\right)^n} \]

Seismic Moment: \(M_0 = \text{rigidity} \times \text{slip} \times \text{area} = \text{Long period level}\)

Stress Drop \(\sim\) strain \(\sim\) slip / \(\sqrt{\text{area}}\)

Rachel Abercrombie, 4 November 2021
Seismic waves are attenuated as they travel through the Earth (path and site effects).

For example: Two M6 earthquakes were felt very differently in different parts of the USA.

Because attenuation is higher in warmer, higher strain rate west.

Are the earthquake sources different too?
Introduction to Methods

First Problem: how separate source and path in recorded seismograms

**Simple Models**

- Circular source

**Real Earth is far more complex**

1D (or constant) attenuation structure

**Source**

- 2014 Guerrero (Mw 7.3, 23 km)
- Ye et al., 2016

**Path + Site**

- Known – hopefully
- Large and Small earthquakes are complex when data are good enough to observe

**Instrument**

**Seismogram (X):**

\[ X(t) = S(t) \times G(t) \times I(t) \]

**Frequency spectrum:**

\[ X(f) = S(f) \times G(f) \times I(f) \]

In practice: Trade-offs.

Hard to resolve with limited frequency range data - in either frequency OR time domain

Rachel Abercrombie, 4 November 2021
Introduction to Methods

Simple Individual Spectral Fitting – Separation of source and path is Ambiguous

\[ M_0(f) = \frac{Ce^{-\pi ft/Q}}{1 + \left(\frac{f}{f_c}\right)^2} \]

\( t^* = t/Q \)

Large trade-offs in limited frequency range of typical data

Fit synthetic data for Q and fc

x5 stress drop difference

Ko et al., JGR 2012

Rachel Abercrombie, 4 November 2021
Introduction to Methods
Various Alternatives Developed to Improve Resolution

Large Scale Inversion: Using multiple earthquakes recorded at multiple stations to separate source, path and site effects

Empirical Green’s Function (EGF) – use small, co-located earthquake to remove path and site effects

Inversion for Spectral Components

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

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

Solved with iterative least-squares method with outlier suppression

And many variations and combinations ... as you will see!

Rachel Abercrombie, 4 November 2021
Ridgecrest: Comparison of Published Results

ABSTRACT
Stress drop, while difficult to measure reliably and at scale, is a key source parameter for understanding the earthquake rupture process and its relationship to strong ground motion. Here, we use a P-wave spectral decomposition approach, designed for large and densely sampled datasets, to measure earthquake stress drop in the region surrounding the 2019 Ridgecrest, California, earthquake sequence. With more than 11,000 measurements of earthquake stress drop in the 20-yr time period from 2000 through 2019, this dataset provides an opportunity to understand how coseismic stress changes and how other geophysical factors relate to the distribution of stress drop and its evolution in space and time. We observe a mild but persistent deviation from self-similar scaling, with larger events having systematically higher stress drops, though this trend depends on the assumption of an omega-square source spectral model. Earthquake stress drop increases with hypocentral depth in this study region, and the Ridgecrest aftershocks tend to have higher stress drops than the pre-event seismicity. This is in part due to their deeper hypocenters. Coherent spatial patterns of stress drop in the aftershock sequence correlate with the slip distribution of the M 7.1 mainshock, whose northwest rupture tip terminated in a long-lived zone of enervated stress drop. Although physical interpretation of these results is complicated by the trade-offs between the timing, depth, and location of these earthquakes, the observations provide new insight into the physics of the earthquake source in an area of renewed seismic activity in southern California.

Repeatable Source, Path, and Site Effects from the 2019 M 7.1 Ridgecrest Earthquake Sequence

ABSTRACT
We investigate the dependence of event-specific ground-motion residuals in the Ridgecrest region, California. We focus on the impact of using either local (M L) or moment (M w) magnitude, for describing the source scaling of a regional ground-motion model. To analyze homogeneous M w, we compute the source spectra of about 2000 earthquakes in the magnitude range 2.5-7.1, by performing a nonparametric spectral decomposition. Seismic moments and corner frequencies are derived from the best-fit or p2 source models, and stress drop is computed assuming standard circular rupture model. The Brune stress drop varies between 0.62 and 24.63 MPa (with median equal to 3.0 MPa), and values for M w > 5 are mostly distributed above the 90th percentile. The median scaled energy for M w < 5 is 4.57, and the low values obtained for the M w 6.4 and 7.1 mainshocks (~5 and ~5.2, respectively) agree with previous studies. We calibrate an ad hoc nonparametric M L scale for the Ridgecrest region. The main differences with the standard M L scale for California are observed at distances between 30 and 100 km, in which differences up to 0.4 magnitude units are obtained. Finally, we calibrate ground-motion models for the Fourier amplitude spectra, considering the M L and M w scales derived in this study and the magnitudes extracted from Comprehensive Earthquake Catalog. The analysis of the residuals shows that M L better describes the interevent variability above 2 Hz. At intermediate frequencies (between about 3 and 8 Hz), the interevent residuals for the model based on M w show a correlation with stress drop; this correlation disappears, when M L is used. The choice of the magnitude scale has an impact also on the statistical uncertainty of the median model: for any fixed magnitude value, the epistemic uncertainty is larger for M L below 1.5 Hz and larger for M w above 1.5 Hz.
Comparison of Published Results

Using catalogue ML as default for comparisons. Not ideal, but unclear yet what should be preferred.

Some consistency, some variability of $M_0$, $f_c$, and $\Delta \sigma$.

ML dependence of stress drop not the same.

Rachel Abercrombie, 4 November 2021
Comparison of Published Results

Bindi et al., 2020 BSSA
Trugman, 2021, BSSA

Both show similar depth and spatial variability, with stress drop increasing with depth.
Comparison of Published Results

Do they correlate? Is correlation a function of M or depth dependence?

Bindi *et al.*, 2020 BSSA
Trugman, 2021, BSSA

Correction for ML Dependence

Correction for Depth Dependence

Removing ML and depth dependence of each has negligible effect on correlation.

Rachel Abercrombie, 4 November 2021
Is Depth dependence real?

Abercrombie, Trugman, Shearer, Chen, Zhang, Pennington, Hardebeck, Goebel & Ruhl, 2021 JGR

Spectral Ratios:
deep large / deep small
Shallow large / shallow small

Remove significant depth dependence to spectral shape.
Some (most) is probably depth dependent attenuation.
Brief Introduction to Methods

1. GIT/Spectral Decomposition Inversion

Combined inversion for source, path and site terms e.g. Oth, Bindi, Shearer and many others.
- Assumes Brune (or similar) spectral shape to obtain source parameters
- Typically inverts for travel-time dependent path term, and make assumptions about source, or reference site to remove site ambiguity.

Inversion for Spectral Components

Event term: $e_i$
Station term: $s_j$
Travel time term: $t_{k(i,j)}$

$d_{ij} = e_i + s_j + t_{k(i,j)} + r_{ij}$ (residual)

Needs large number of stations and earthquakes for stability
Is path correction too simple?
Is source shape too simple?
Reference site assumption?

Frequency range limits resolution

Each panel shows a different global EGF, and MEAN $\Delta \sigma$. Cannot resolve self-similar scaling or not with these data (Shearer et al. 2019 JGR).

Rachel Abercrombie, 4 November 2021
Brief Introduction to Methods

2. Spectral Ratios: EGF

Assumes co-located small event (or events) remove all path and site effects. No modeling or other assumptions for path required. Assumes Brune (or similar) spectral shape to obtain source parameters.

- Can also Stack multiple EGFs.
- Or do combined inversion (Hough 1997).

Complex sources and limited bandwidth make omega-square model fitting for spectral ratio unstable (Abercrombie, 2021).

- Needs EGF for each event – how good is EGF?
- Is source shape too simple?
- Needs independent M0

Rachel Abercrombie, 4 November 2021
Brief Introduction to Methods

3. Source Time Functions: EGF

Assumes co-located small event (or events) remove all path and site effects. No modelling or other assumptions required. Either performs complex deconvolution, or calculates synthetics for large event by convolving model source time function with EGF waveforms. Uses second moment formula, or finite fault modeling to obtain spatial distribution of slip and rupture duration. Estimate corner frequency for comparison from 1/duration.

Co-located
Same focal mechanism

Frequency Spectra
Spectral Ratio
Time

EGF required – as for spectral ratios
What source complexity is well-resolved?

Frequency range limits resolution

M2 Parkfield: Dreger et al., 2007
Preliminary Comparison of Preliminary Results

11 groups submitted results.
Now let’s hear from each about their methods.
Return to look at this in more detail.

Remember – very preliminary results without usual levels of quality checking.