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The characteristic of source spectra and stress drop of earthquakes in the Bucaramanga nest

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Outline

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- Data and Resources
- Empirical Green Function (EGF) Method to Extract Seismic Spectra and Estimate Stress Drop
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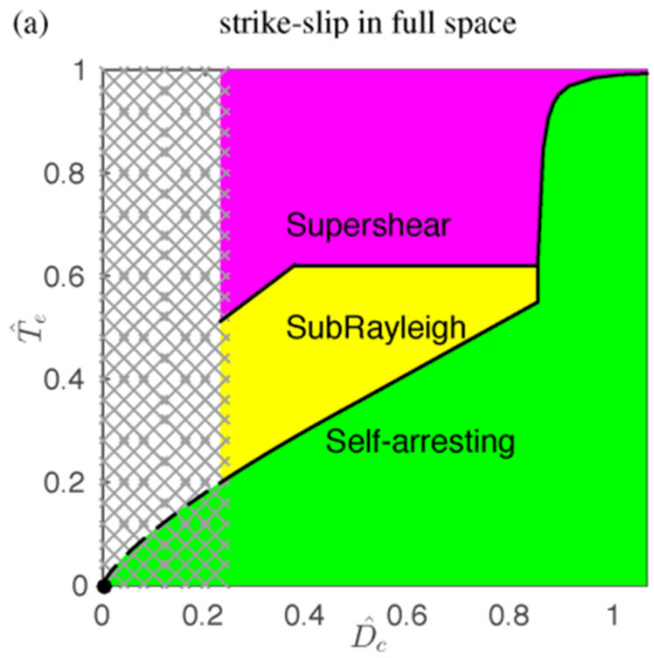
- Conclusions and Discussion

Introduction to Rupture Phase Diagrams

As we know, the behavior of dynamic rupture varies with slip-weakening law, the size of nucleation asperity and initial stress condition. Based on the vast number of simulation using BIEM, Xu Jiankuan and Chen Xiaofei (2015) obtained rupture phase diagrams.

There are three kind of rupture styles. Supershear rupture with supershear speed and SubRayleigh rupture will subshear speed will keep propagation going until they arrive outside interference, so these two kind of rupture styles are called runaway rupture. Self-arresting rupture can be autonomously arrested by itself without any outside interference.

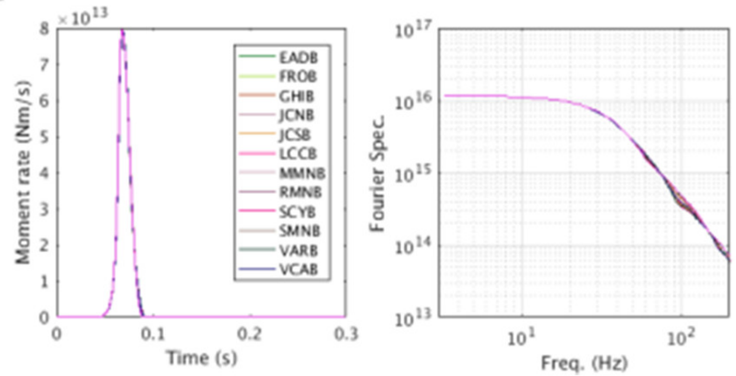


Rupture phase diagrams in full-space
(Xu Jiankuan and Chen Xiaofei, 2015)

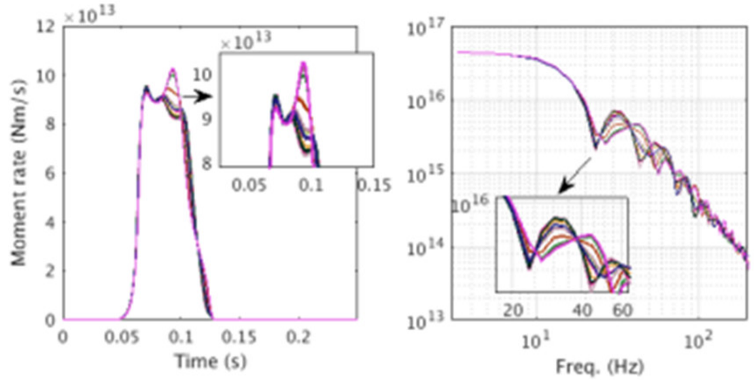
Wen Jian and Chen Xiaofei (2018) investigated seismic spectra of different rupture earthquake and found that the seismic spectra of runaway rupture and self-arresting rupture have different characteristic.

self-arresting rupture has smooth seismic spectra and simple source time function (STF). However, runaway rupture has complicated STF, and holes exist on seismic spectra at specific frequency.

Next, we will calculate seismic spectra and source time function of many earthquakes to support it .



self-arresting rupture

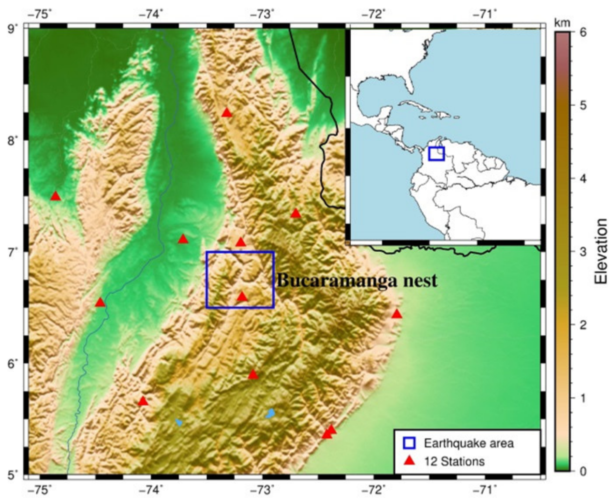


runaway rupture

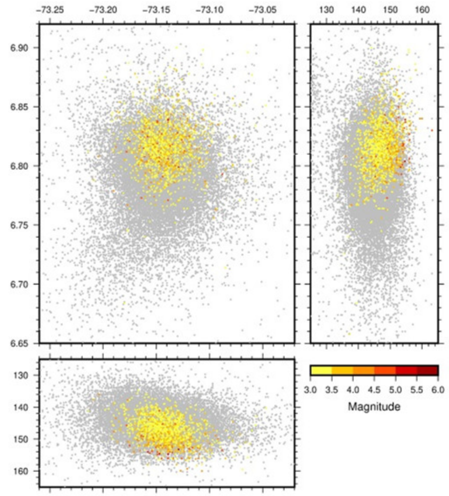
Source time function and seismic spectra (Wen Jian and Chen Xiaofei, 2018)

Data and resources

We totally use waveform data of more than 30000 earthquakes (about 135-165 km depth)from 2012 to 2018 happened in Bucaramanga nest . Seismic spectral and stress drop of 1545 earthquakes with 3-5.7 Ml as target earthquakes are calculated, and others with 1.5-2.9 Ml are as potential EGF earthquakes.



Bucaramanga nest location
(red triangles are 12 stations,
earthquakes are in blue rectangle)



Earthquake distribution
(color circles are 1545
earthquakes, gray circles
are all earthquakes)

The primary source of data for this study comes from the catalog and waveform data from the Red Sismológica Nacional de Colombia (RSNC). The catalog data and waveforms data are available at https://www2.sgc.gov.co/sismos/sismos/ultimos-sismos.html

Empirical Green Function (EGF) Method to Extract Seismic Spectra and Estimate Stress Drop

The basic theory: two collocated earthquakes of different magnitudes are assumed to experience identical propagation and site effects. So the smaller earthquakes can be used to cancel out these effects as the bigger earthquake' Green function empirically.

Earthquake seismogram, u(t), is the convolution of the radiation from the earthquake source, s(t), with the combined propagation effects, G(t), along the path and the instrument response, r(t).

$$u(t) = s(t) * G(t) * r(t)$$

In frequency domain

$$u(f) = s(f) \cdot G(f) \cdot r(f)$$

The spectra ratio

$$\frac{u_l(f)}{u_s(f)} = \frac{s_l(f) \cdot G_l(f) \cdot r_l(f)}{s_s(f) \cdot G_s(f) \cdot r_s(f)} = \frac{s_l(f)}{s_s(f)}$$

Using Brune (1970) or Boatwright (1980) source model, we can obtain

$$\frac{u_l(f)}{u_s(f)} = \frac{M_l}{M_s} \left(\frac{1 + \left(\frac{f}{f_{cs}} \right)^{\gamma n}}{1 + \left(\frac{f}{f_{cl}} \right)^{\gamma n}} \right)^{\frac{1}{\gamma}}$$

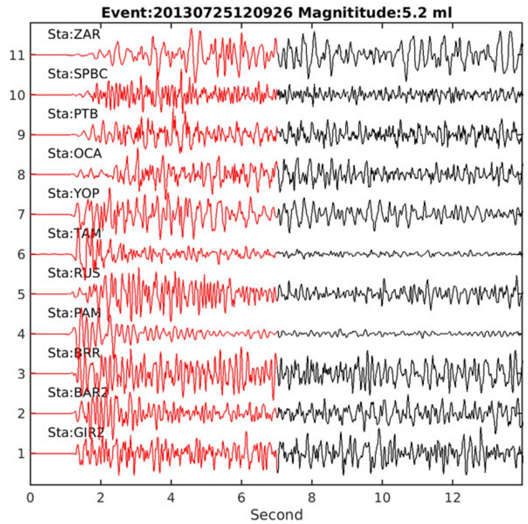
In general, $\gamma = 2$

Boatwright model, $n = 2$

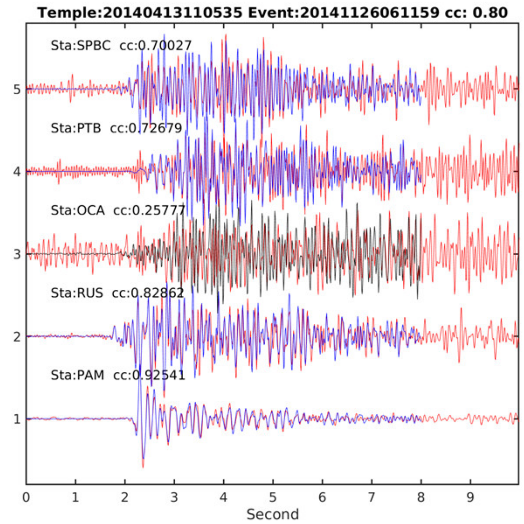
Brune model, $n = 1$

Because the earthquake location is not very precise, especially depth parameter, we apply mean cross-correlation coefficient of all station recording waveform to select proper EGFs.

In Bucaramanga nest, we only select P wave recordings in 12 stations with same length, 7s, starting from 1s before P phase arrival time. The frequency bandwidth is 2-20Hz.



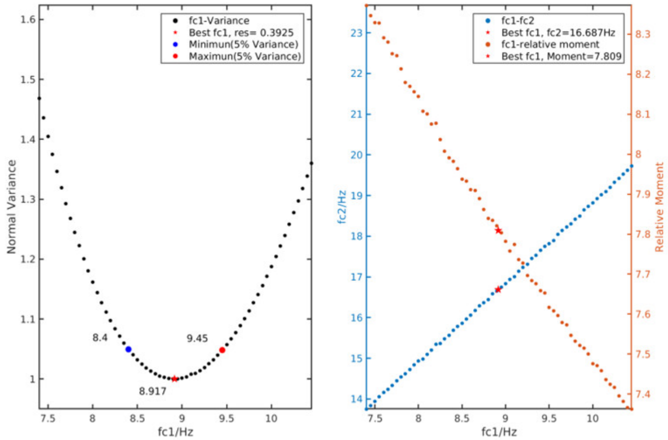
P wave recording



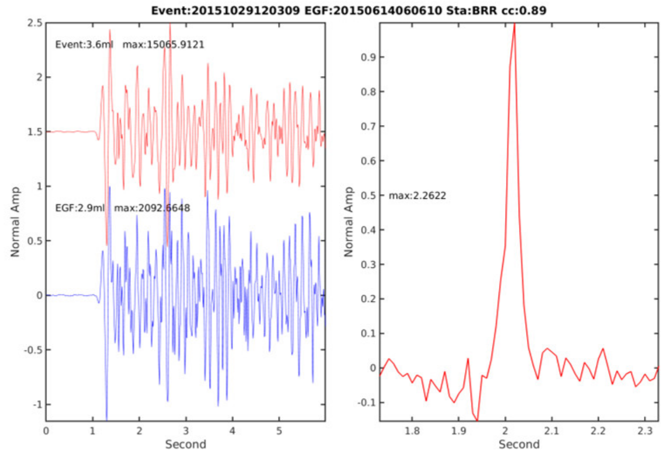
cross-correlation coefficient (black line is bad cross-correlation coefficient)

We calculated steady mean cross-correlation coefficient . For each recording, if mean cross-correlation coefficient minus its cross-correlation coefficient is more than 0.35, we won't use this recording and recalculate mean cross-correlation coefficient. (before calculating cross-correlation coefficient, we already selected high SNR recording)

We use multi-taper spectral analysis method to obtain stable seismic spectra and Nelder-Meade method to fifing seismic spectra. We refer to Viegas (2010) and Abercrombie (2014) to obtain more stable results.

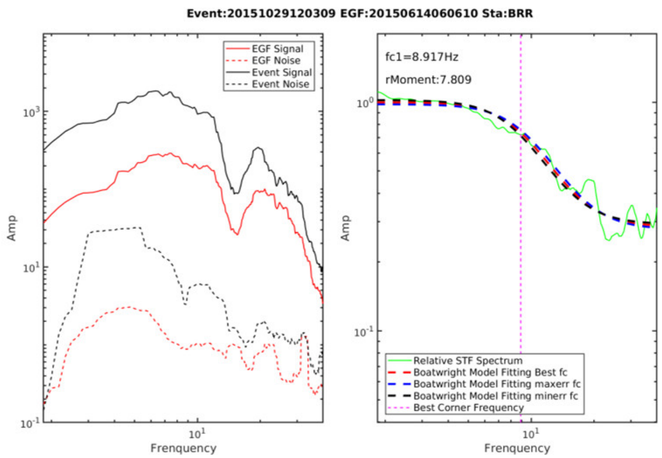


Left: target corner frequency - fitting error
Right: target corner frequency - EGFs corner frequency(blue) and relative moment(orange)



Left:
target earthquake (red line) and EGFs (blue line) P wave

Right:
Relative source time function



Left:
target earthquake (red line) and EGFs (blue line) waveform spectra

Right:
Relative seismic spectra

We also refer to Abercrombie (2014) to obtain the weighted mean of corner frequency and the standard deviation of the weighted mean.

The weighted mean of corner frequency

$$\hat{f}_c = \frac{\sum_i f_{ci} \big/ \mathrm{var}_i^2}{\sum_i 1 \big/ \mathrm{var}_i^2}$$

The standard deviation of the weighted mean

$$\hat{V}ar_c = \sqrt{\frac{1}{\sum_i 1 \big/ \mathrm{var}_i^2}}$$

We use Eshelby (1957) to calculate stress strop and the standard deviation of stress strop

Stress strop

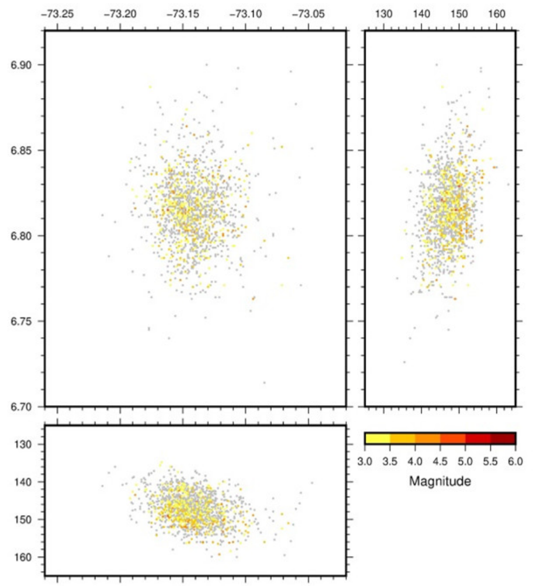
$$\Delta\sigma = \frac{7 M_0 f_c^3}{16 k^3 \beta^3}$$

The standard deviation of stress strop

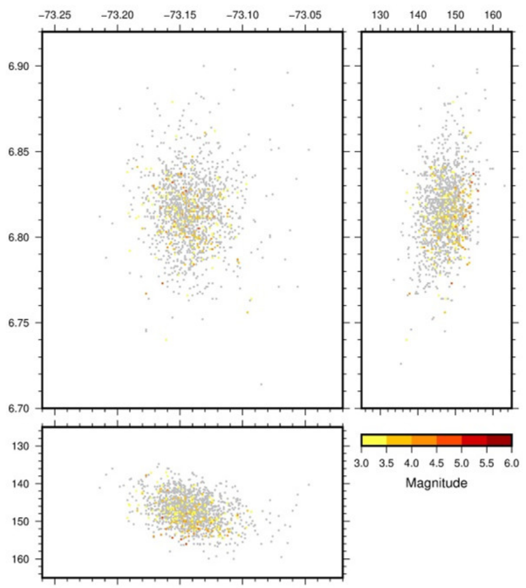
$$\hat{V}ar_\sigma = \left|\Delta\sigma'\right| \hat{V}ar_c = \frac{21 M_0 f_c^2}{16 k^3 \beta^3} \hat{V}ar_c$$

Results

In Bucaramanga nest, we finally obtain seismic spectra and STF of 633 earthquakes, 433 of which are self-arresting rupture and 295 of which are runaway rupture.



Self-arresting rupture earthquakes



Runaway rupture earthquakes

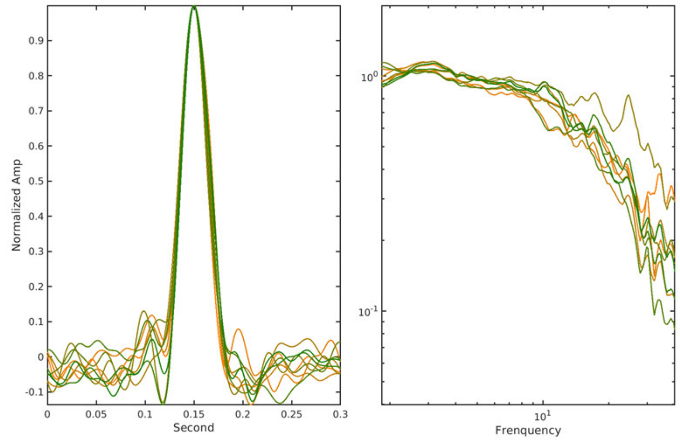


Fig a. Self-arresting rupture (different color lines are different EGF earthquake results)

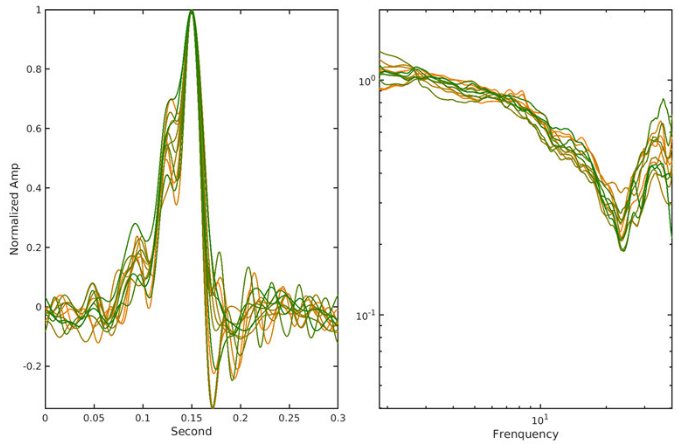


Fig b. Runaway rupture

Seismic spectra of self-arresting rupture earthquakes fitted well by omega-square model are smooth and its source time function are simple (Fig. a). Runaway rupture earthquakes has complicated source time function and holes exist on seismic spectra at specific frequency(Fig. b).

The source time function of a few runaway rupture earthquakes appear two separate peeks(Fig c). This kind of earthquakes maybe be caused by simultaneous slip on two close rupture zone.

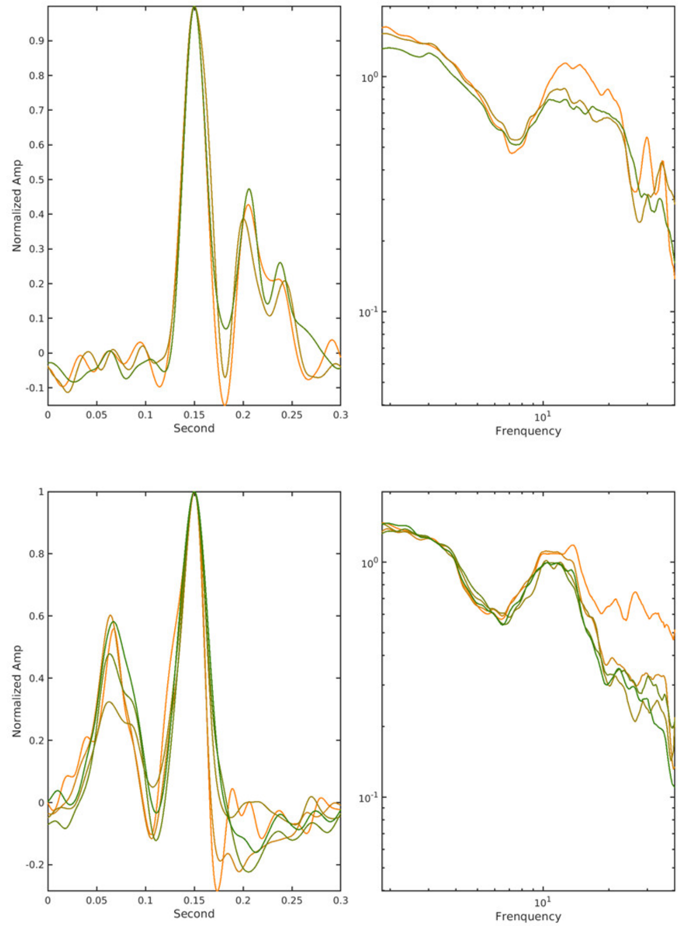
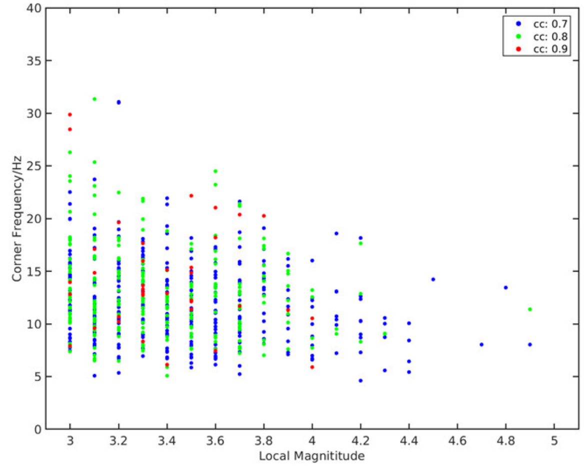


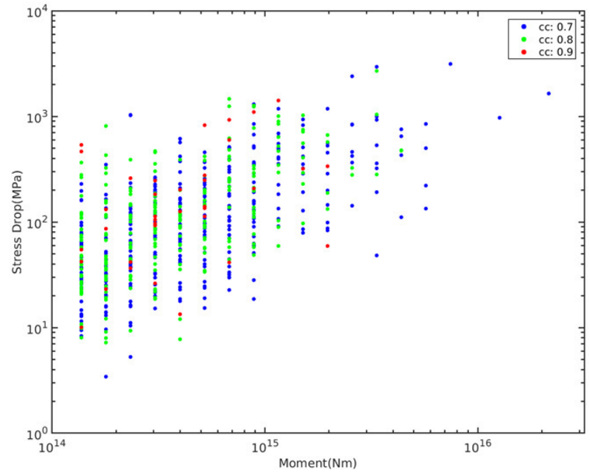
Fig c. Runaway rupture

Because corner frequency and stress drop are based on source model, we only calculated corner frequency and stress drop of self-arresting rupture earthquakes.

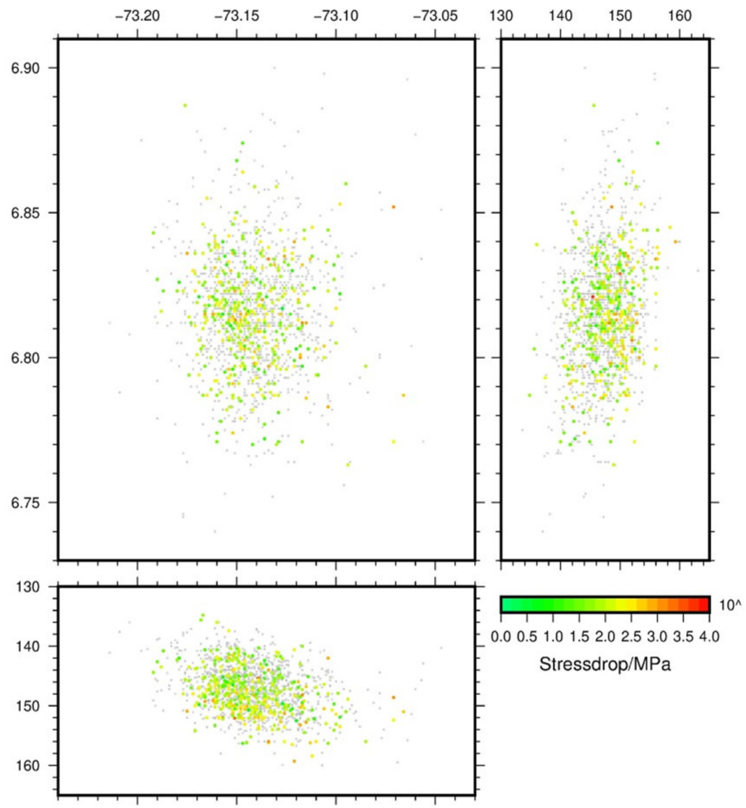
In Bucaramanga nest, the highest corner frequency decrease with magnitude and corner frequency of same magnitude earthquakes vary a lot. Stress drop increase with seismic moment and the range variation of earthquake's stress drop with same seismic moment is up to 2 order of magnitude. Most of earthquakes' stress drop are between tens and hundreds Mpa and only a few earthquakes' stress drop is over 1000 Mpa, median stress drop of which is about 100 Mpa and spatial distribution of which has no obvious characteristics.



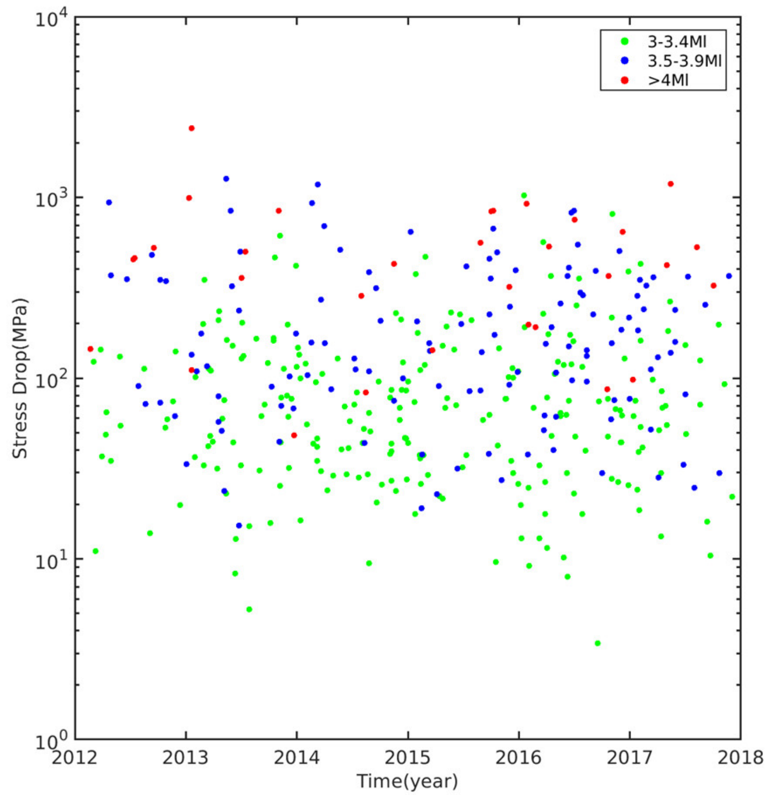
Magnitude – Corner frequency



Moment – Stress drop



Spatial distribution of stress drop



Temporal distribution of stress drop

Conclusions and Discussion

- In Bucaramanga nest, there are two kind of rupture styles earthquakes. self-arresting rupture earthquakes fitted well by omega-square model are smooth and its source time function are simple. Runaway rupture earthquakes has complicated source time function and holes exist on seismic spectra at specific frequency

- In Bucaramanga nest, Stress drop increase with seismic moment and the range variation of earthquake's stress drop with same seismic moment is up to 2 order of magnitude. Most of earthquakes' stress drop are between tens and hundreds Mpa and only a few earthquakes' stress drop is over 1000 Mpa, median stress drop of which is about 100 Mpa.

Reference

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