Earthquake sub-event scaling: new perspective for rupture determinism

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We take advantage of global databases of source time functions (SCARDEC, Vallee et al. 2011, over 2,500 events and USGS, Hayes 2017, over 180 events) to explore earthquake source complexity. We use a sub-event detection method in each source time function to decompose the earthquake into sub-events that each carry a seismic moment and a duration. The number, the size, and the duration of sub-events grow with the earthquake magnitude. We use dynamic modeling of earthquake rupture to explain our observations and propose a fault strength distribution to explain our observables. This allows us to estimate the final size of the earthquake with 0.28 uncertainty in moment magnitude before 20% of the event duration.

Source Time Function subevent analysis

We use an iterative - forward sub-event detection similar to Zhan et al., (2014).

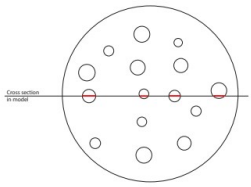
1- Find the first STF peak that is at least 10% of STF maximum.

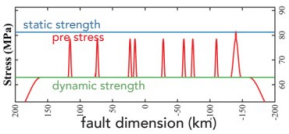
2- Scale a Gaussian to it and grid search the Gaussian width to best fit the growth. Integrate under the Gaussian curve to get a subevent moment.

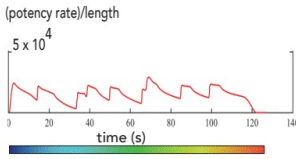
3- Substract the previous sub-event Gaussian function and got back to step 1.

This method allows us to extract a catalog of subevent with their moment, duration. The fit is good at low frequencies and will fail at high frequency due to the use of a smooth Gaussian.
and we explore how many subevents.

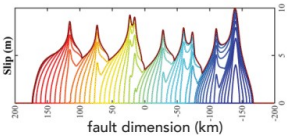
Conceptual framework







slip evolution on the fault and with time

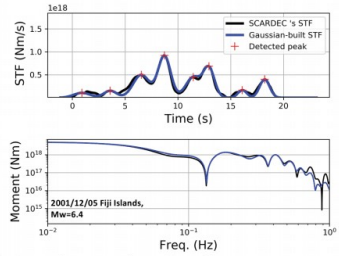


Observations suggests subevents stress drop are about 10-20 MPa.
moment scaling: $M_A \sim 0.1\ M_0$

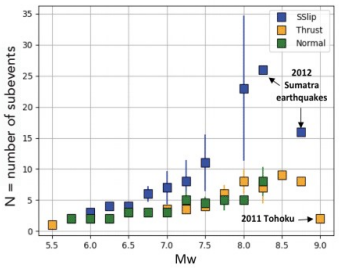
stres drop scaling: $\tau_a \sim 10\ \tau_o$
We find that asperities may occupy 4% of the fault area and be of about 10 MPa.
We set this up in a 2D, place asperities randomly on a fault and use linear slip weakening friction (software: SBIEMLAB, Ampuero). Parameters:
Normal stress is 120 MPa static friction: 0.677 (uniform)
Fault length 300 km dynamic friction: 0.525 (uniform)
Dc = 0.4 m (uniform)

Observations

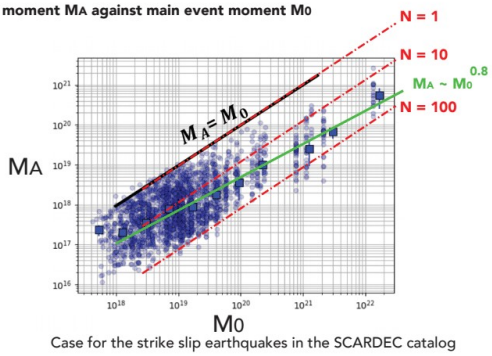
Individual STF and their best-fit reconstruction from sub-events:



Median number of subevents per main earthquake

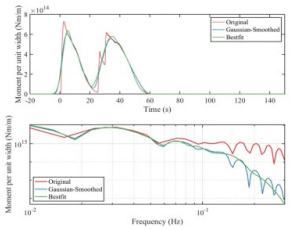


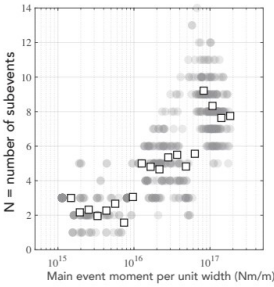
Sub-event moment M_A against main event moment M_0

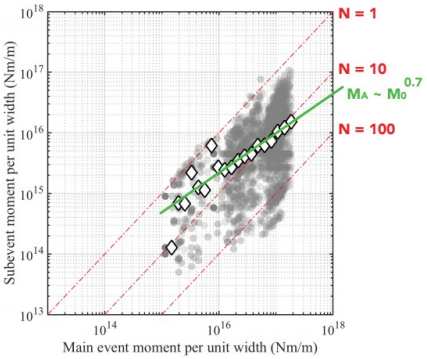


Case for the strike slip earthquakes in the SCARDEC catalog

Simulations

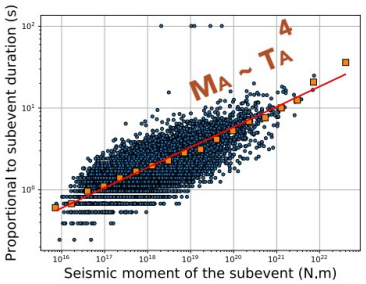




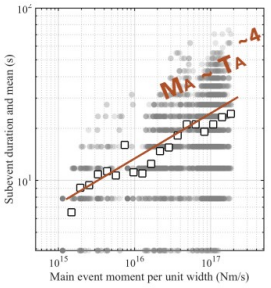


Observations

sub-event duration-moment scaling (approximate values)



Simulations



Application to Earthquake Early Warning

Provided that one can estimate STF in real-time, the scaling we find allows us to estimate the earthquake magnitude using only the first few sub-events of the STF. Therefore, a magnitude estimate of earthquakes can be done with a good precision before the rupture ends: Moment magnitude uncertainty is 0.28 at 10% of the rupture duration.