Earthquake stress drop: what can we resolve from observations, and what can we infer about earthquake triggering processes

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The average stress drop during an earthquake is a parameter fundamental to ground motion prediction and earthquake source physics, but it has proved hard to measure accurately. This has limited our understanding of earthquake rupture, as well as the spatiotemporal variations of fault strength. In this study, we investigate the resolution limits of spectral analysis based on synthetic spectra with similar magnitude range, average stress drop and frequency bands to a fluid-injection induced earthquake sequence in Oklahoma near Guthrie.

Synthetic tests using joint spectral fitting method define the resolution limit of corner frequency as a function of maximum frequency for both individual spectra and averaged spectra from multiple stations. Synthetic tests based on stacking analysis find that the improved stacking approach can recover the true input stress drop if the corner frequencies are within the resolution limit defined by joint spectral fitting.

The improved approach is applied to the Guthrie sequence, different wave types and different signal-to-noise criteria are examined to understand the stability of the stress drop distributions. The results suggest no systematic scaling relationship for stress drop for M≤3.1 earthquakes, but larger events M≥3.5 tend to have higher average stress drops. Results with lower signal-to-noise ratio requirement and direct P-wave tend to have higher scaling factor compared to results with high signal-to-noise ratio and S-waves.

Comparison of results from several different methods suggest that the average stress drop is well resolved and not subject to tradeoff with attenuation. Some robust spatiotemporal variations can be linked to triggering processes and indicate possible stress heterogeneity within the fault zone. Tight clustering of low stress drop events at the beginning stage of the sequence suggests that pore pressure influences earthquake source processes. Events at shallow depth have much lower stress drop compared to deeper events. The largest earthquake occurred within a cluster of high stress drop events, and involved cascading failure of several sub-events.