Understanding the spatial variation of high frequency radiation from earthquakes in Southern California

Technical Report for SCEC Award # 21082

Investigators: Rachel Abercrombie (BU) and Peter Shearer (UCSD)

Abstract:

Earthquakes of similar moment often radiate very different amounts of high-frequency radiation, and quantifying this variation and resolving its causes are vital to understanding the underlying rupture physics and producing reliable ground motion prediction equations (GMPEs). These energy variations are commonly modeled in terms of earthquake stress drop, a fundamental source parameter implicit in many of the science goals of SCEC5, but challenging to measure. During our SCEC collaboration, the PIs have investigated the origins of the large uncertainties and scatter in stress-drop estimates by comparing different approaches to analysis of P-wave spectra from small to moderate earthquakes in Southern California. We have gained an understanding of the limitations of the methods and how they can be improved, most recently identifying biases in the calculation of the spectra and the correction for path attenuation. One of our insights is that stress-drop estimates rely heavily on certain modeling assumptions, which are difficult to verify from observations even with high-quality regional network data. Thus, we favor measures of high-frequency radiation that are closer to the data and rely less on specific theoretical rupture models or poorly-constrained empirical corrections.

Progress to date:

This project is a continuation of work funded by SCEC for several years. Our main recent accomplishment was completion of a study examining the question of whether median stress drop increases with depth in the crust. We plan to build on these results as we examine questions such as possible lateral variations or moment dependence of earthquake stress drop.

Our previous collaboration to compare analysis methods exposed the potential for significant tradeoffs between depth-dependent source and path effects in spectral decomposition and related large-scale inversion approaches. To investigate this, we combined the spectral decomposition and traditional EGF approaches and compiled and re-analyzed a database of consistently calculated event spectra from over 50,000 earthquakes (M0-5) from 12 studies in southern California (Chen & Shearer, 2011; Trugman & Shearer, 2017; Shearer *et al*., 2019, Trugman, 2020; Goebel *et al*., 2015), northern California (Hardebeck & Aron, 2009; Trugman & Shearer, 2018; Zhang *et al*., 2019), Kansas (Trugman *et al*., 2017), Oklahoma (Chen & Abercrombie, 2020; Pennington *et al.,* 2021) and Nevada (Ruhl *et al.,* 2021). After presenting the results at conferences (including SCEC Annual Meeting, 2020) we completed the analysis and published the outcome (Abercrombie *et al*., 2021). For different magnitude bins, we compared the ratio of the high- to low-frequency amplitudes and found that the relative high-frequency content (and corner frequency) systematically increases with increasing earthquake depth (Figure 1).

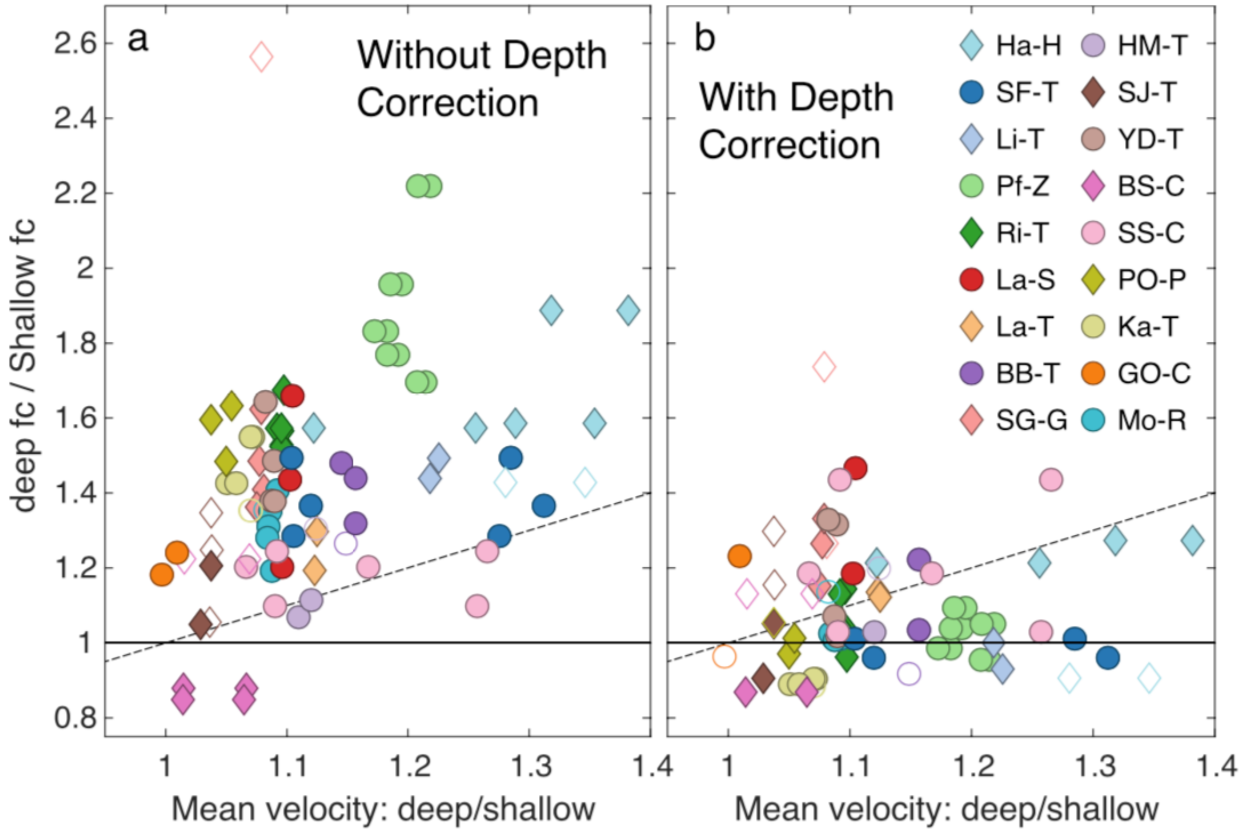

Figure 1. Comparison of relative source parameters vs. *P* velocity, with and without depth correction (Abercrombie *et al*., 2021). The ratios of re-calculated corner frequencies between the deep and shallow earthquakes from 18 regions (colors and symbols, multiple symbols represent different magnitude bins, and alternative velocity models.), are plotted against the ratio of the average P-wave velocity at the depths of the respective deep and shallow event populations. The black dashed line represents a constant stress drop with depth, if rupture velocity is proportional to P-wave velocity.

By analyzing spectral ratios between large and small events as a function of source depth, we were able to constrain better the source and attenuation contributions to the observed depth dependence in high-frequency radiation and corner frequency. Without any correction for depth-dependent attenuation, we find a systematic increase in stress drop with depth (or increase in rupture velocity), as has previously been observed. When we add an empirical attenuation correction, the depth dependence of stress drop systematically decreases, often becoming negligible; Figure 1a shows that without correction for depth-dependent attenuation, the corner frequencies and hence stress drops appear to increase with depth. In Figure 1b, the measurements include the empirical correction for depth-dependent attenuation, and the results from most regions are consistent with negligible increase in stress drop with depth. The largest corrections are observed in regions with the largest velocity increase with depth. We conclude that source parameter analyses, whether in the frequency or time domains, should not assume path terms are independent of source depth, and should more explicitly consider the effects of depth-dependent attenuation. Just because a solution involving depth dependent stress drop is possible does not mean it is required (*c.f.* Abercrombie *et al.,* 2021; Bindi *et al*., 2020, 2021).

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