**O-14**

# Dynamic ruptures on rough faults: Incoherent high frequency ground motion and frequency-dependent far-field radiation patterns

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A particularly challenging aspect of generating synthetic broadband seismograms is to accurately capture, in a single model, both the coherent low frequency wavefield and incoherent high frequency radiation. Toward this end, we seek to identify the fundamental source processes responsible for exciting high frequency waves and incorporate these processes directly into spontaneous rupture models. Our focus is on fault roughness, which we investigate using a high-order finite difference method featuring strongly rate-weakening fault friction and off-fault plasticity. The latter tames otherwise unreasonable stress concentrations and prevents fault opening. Natural fault surfaces exhibit slight deviations from planarity with amplitude-to-wavelength ratios of roughness $\alpha$ between $10^{-3}$ and $10^{-2}$ (see Figure 1). Such roughness exists at all scales, providing a means of exciting waves of all frequencies. Our two-dimensional plane strain models assume a uniform, isotropic medium, such that all complexity in the source process and resulting incoherent high frequency ground motion emerges naturally as ruptures interact with stress perturbations induced by slip on the nonplanar faults. Synthetic seismograms feature have a flat acceleration spectrum at high frequencies in both the near- and far-field (see Figure 2).

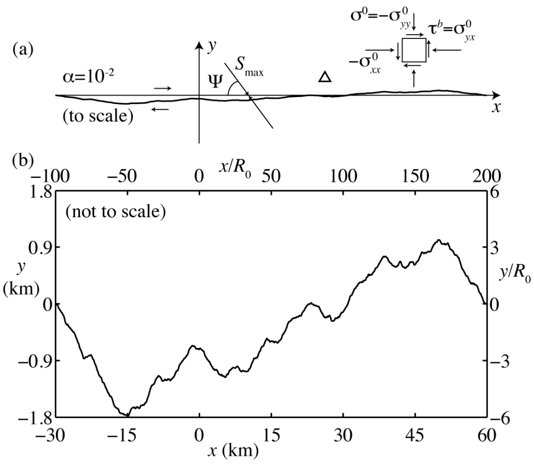


Figure 1: Self-similar fault profile. Ruptures are nucleated at the origin and propagate in a primarily unilateral manner to the right. Synthetic seismograms are calculated at the station indicated with the triangle in (a).

We also investigate the far-field radiation pattern. Primarily unilateral earthquake rupture propagation causes a pronounced directivity effect, where ground motion in the direction of propagation is of larger amplitude than that in the opposite direction. Observations suggest that directivity effects are generally only present at frequencies less than about 1 Hz, and that at higher frequencies, the directivity effect vanishes and the far-field radiation pattern changes from the usual double-couple pattern to an isotropic one. Differences between high and low frequency ground motion could be either a source effect (with the source losing coherence at short wavelengths) or a path effect (with high frequency waves being preferentially scattered by crustal heterogeneities). In this work, we isolate the contribution of source effects to the frequency dependence of far-field ground motion. We construct approximate three-dimensional source models by projecting the rupture history of our two-dimensional models onto a high-aspect-ratio fault under the assumption that the rupture process and nonplanar fault topography are everywhere the same across the smaller dimension. We then calculate far-field body wave seismograms and Fourier spectra using the representation theorem. The radiation pattern transitions from a clear double couple pattern with strong directivity effects at low frequencies to a more isotropic pattern with diminished, but not completely absent directivity effects at high frequencies (see Figure 3).

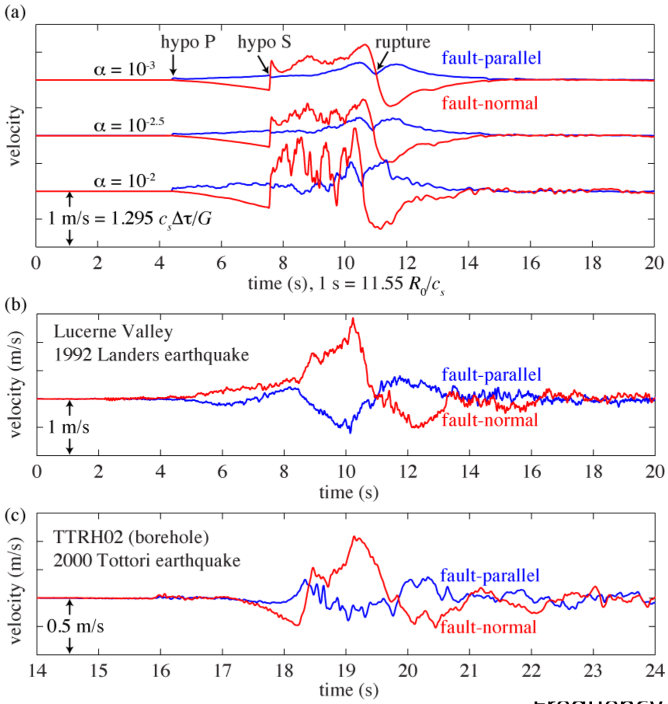


Figure 2: (a) Synthetic seismograms for different amplitude-to-wavelength ratios of roughness α. Hypocentral P and S wave arrivals and passage of the rupture are marked; strong shaking commences with the arrival of the direct S wave and persists until the rupture passes; note incoherent high frequency motions during this interval. (b), (c) Typical near-field strong motion records from strike-slip earthquakes for comparison.

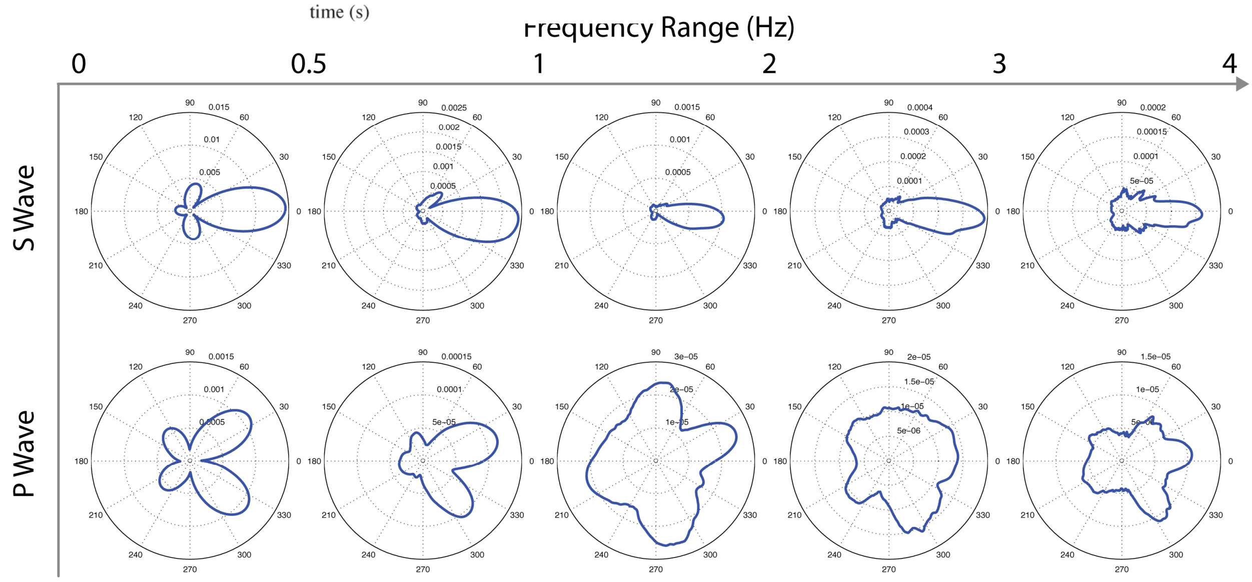


Figure 3: S- and P-wave radiation patterns as a function of frequency. Standard representations of source heterogeneity (spatially variable initial stress or friction parameters on flat faults) cannot capture fluctuations in local radiation pattern on rough faults that causes radiation pattern to become more isotropic at high frequencies.