Poster #246

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3D Dynamic Rupture Simulations along Dipping Faults, with a focus on the Wasatch Fault Zone, Utah

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Abstract

Studies have found that the Wasatch Fault has experienced successive large magnitude (>M_w 7.2) earthquakes, with an average recurrence interval near 350 years. To date, no large magnitude event has been recorded along the fault, with the last rupture along the Salt Lake City segment occurring ~1300 years ago. Because of this, as well as the lack of strong ground motion records in basins and from normal-faulting earthquakes worldwide, seismic hazard in the region is not well constrained. Previous numerical simulations have modeled deterministic ground motion in the heavily populated regions of Utah, near Salt Lake City, but were primarily restricted to low frequencies (~ 1 Hz). Our goal is to better assess broadband ground motions from the Wasatch Fault Zone. Here, we work to extend deterministic ground motion prediction to higher frequencies (~ 5 Hz) in this region by using physics-based spontaneous dynamic rupture simulations along a normal fault with characteristics derived from geologic observations to simulate ruptures > Mw 6.5. We use a summation by parts finite difference code (Waveqlab3D) that can handle rough-fault topography (following a self-similar fractal distribution), surface topography, off-fault plasticity, and frequency-dependent attenuation with both slip-weakening and rate and state friction laws.

Study Area, Fault Geometry, and Surface Topography

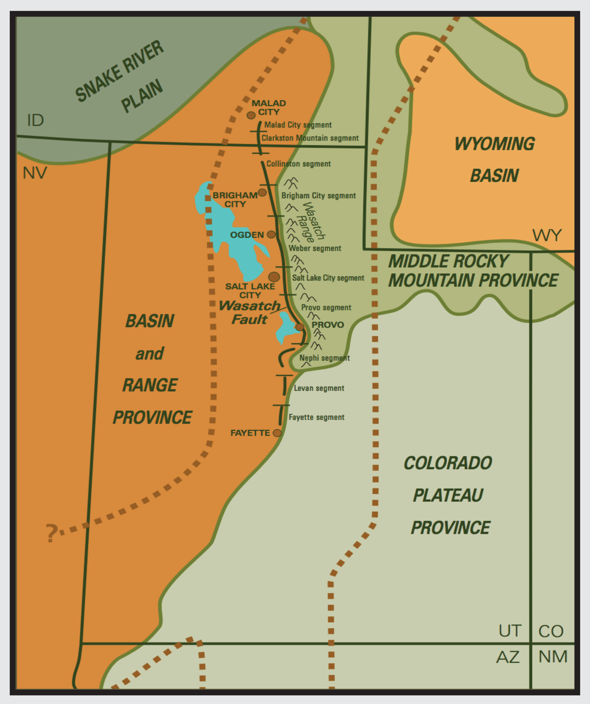


Figure 1. Our focus is on dipping normal faults, specifically matching that of the geometry of the Wasatch Fault zone. We start with the Salt Lake City segment, where the majority of previous simulations have been performed, and where the largest density of urban population exists. Additionally, this is where the most accurate community velocity model is present in the Utah region. We incorporate a version of the Salt Lake City segment by modeling the Cottonwood Canyon, East Bench, and Warm Springs Fault as one single fault trace. (Left) The Wasatch Fault zone, detailing the geographic perspective, including the ten segments that make up the fault as well as the region encompassing the Intermountain seismic belt. Extracted from "Utah Geological Survey Public Information Series 40: The Wasatch Fault."

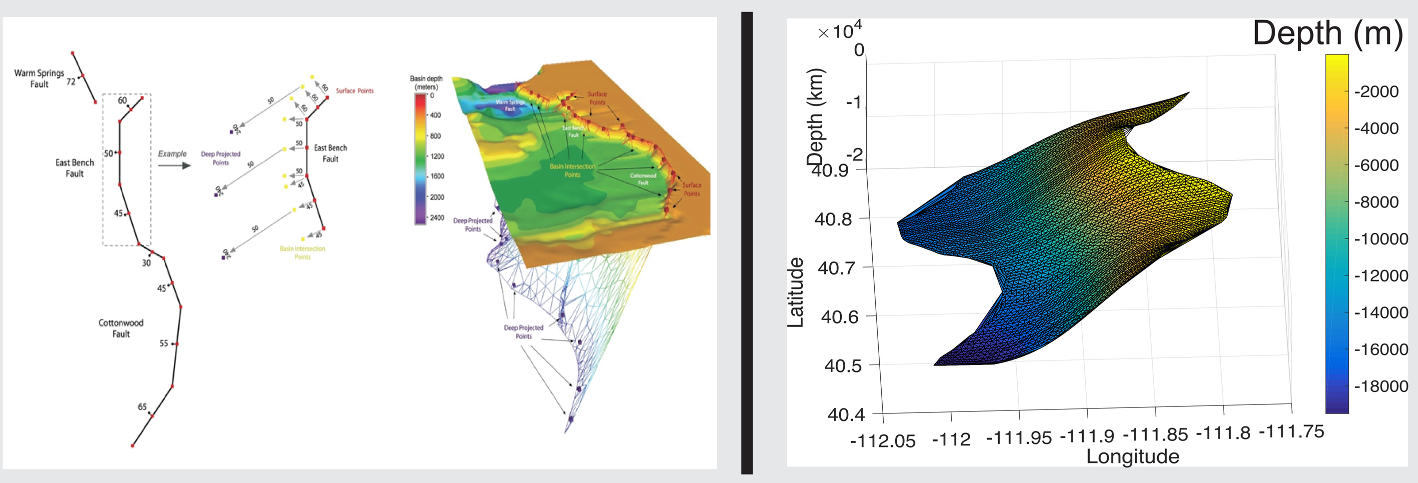


Figure 2. (Left) Development of the 3-D fault representation along the Salt Lake City segment of the Wasatch Fault. (From Moschetti et. al., 2017). (Right) Mesh of fault plane used as the background (long-wavelength) fault surface.

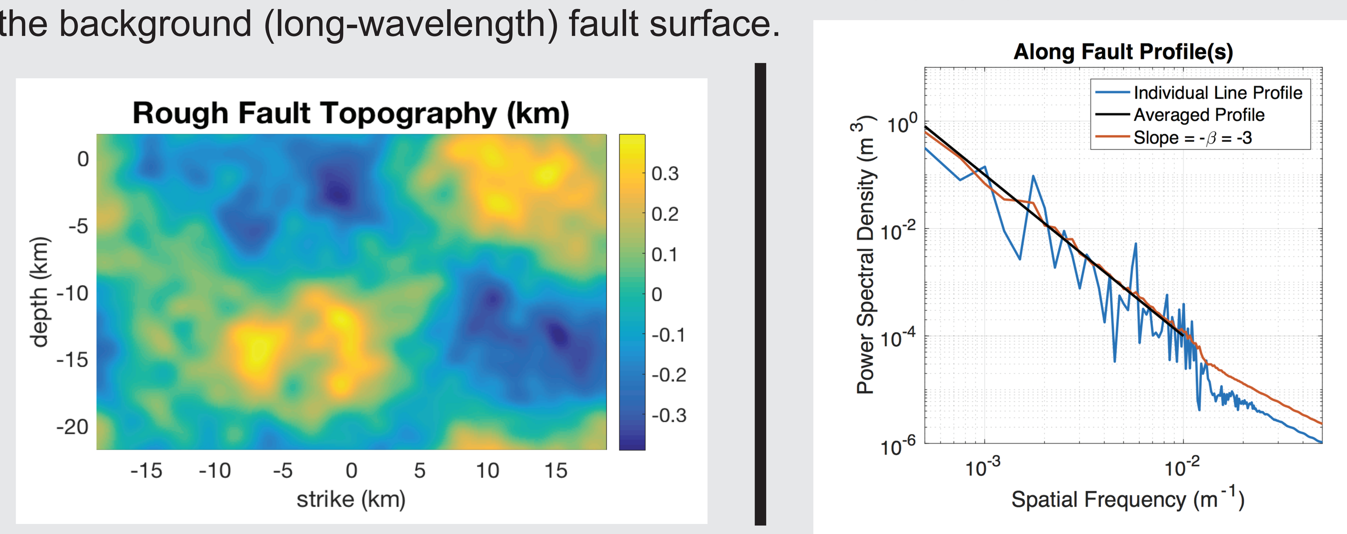
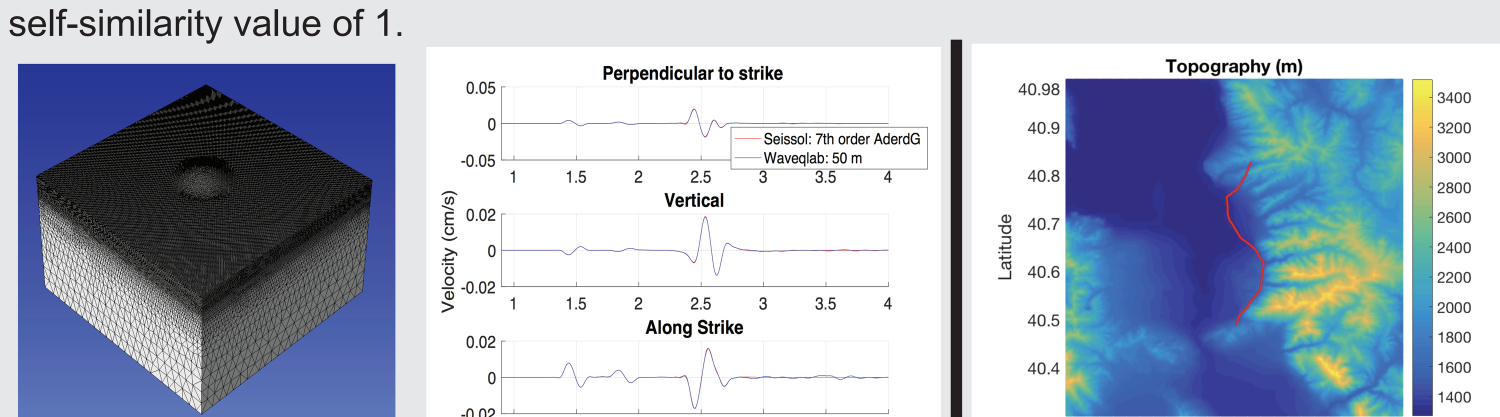


Figure 3. In addition to long-wavelength fault geometry, we superimpose stochastic variation (from wavelengths of 100 m up to the length of the fault) on the background model to generate high-frequency energy, as a technique to generate broadband ground motion. (Left) Stochastic roughness added onto background long-wavelength fault topography (Right). Fourier power spectra line profiles. The values of the Hurst number estimated from the slope of power spectra in the designed wavelength range is very close to the self-similarity value of 1.



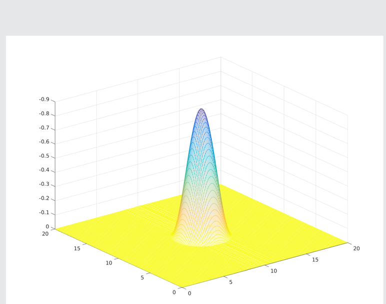


Figure 4. Free-surface topography will likely play an important role in ground motion characteristics along the Wasatch Fault, particularly at higher frequencies. Waveqlab3D was recently modified to handle free-surface topography, in addition to fault-topography. (Left) Validation with Seissol for a simple Gaussian hill model at an example station. (Right) Topography across our simulation domain.

Dynamic Rupture Simulations

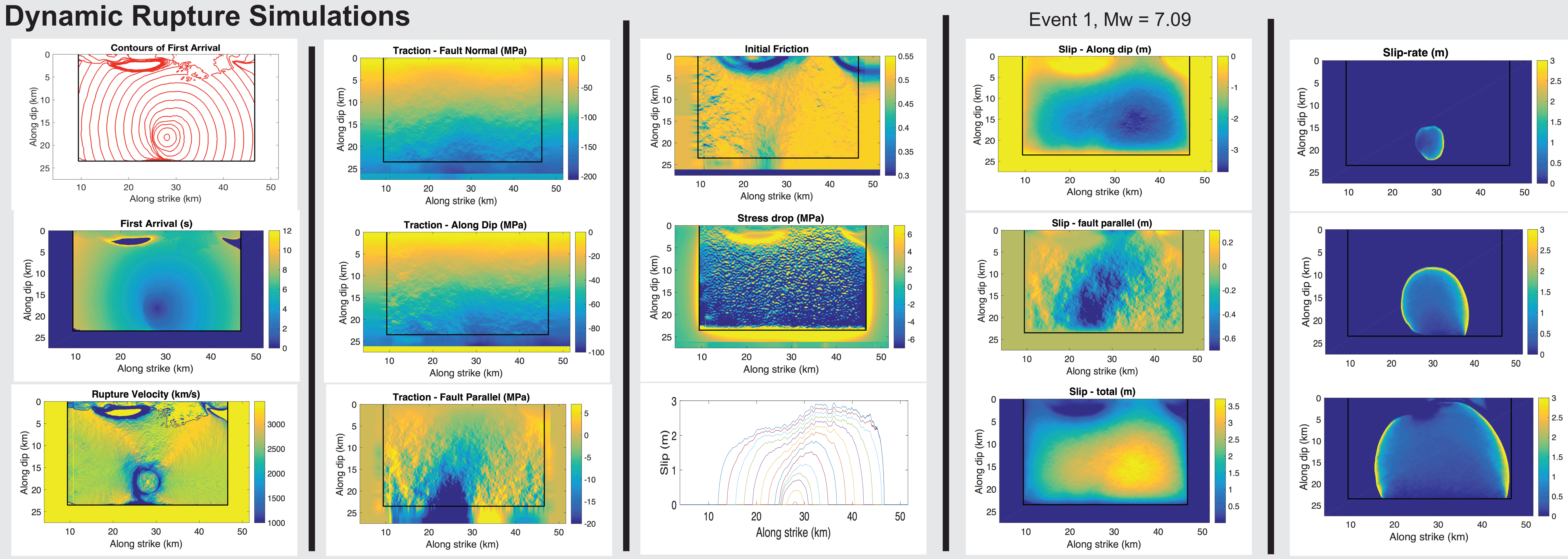
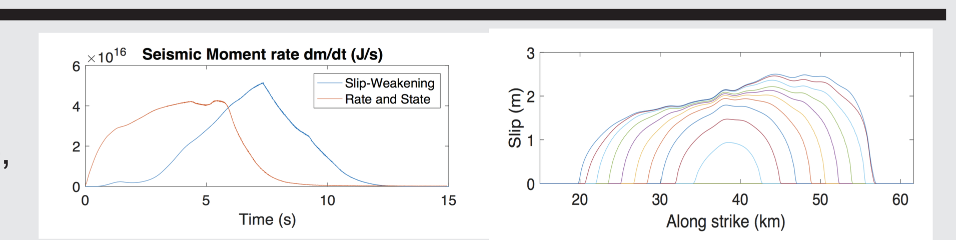
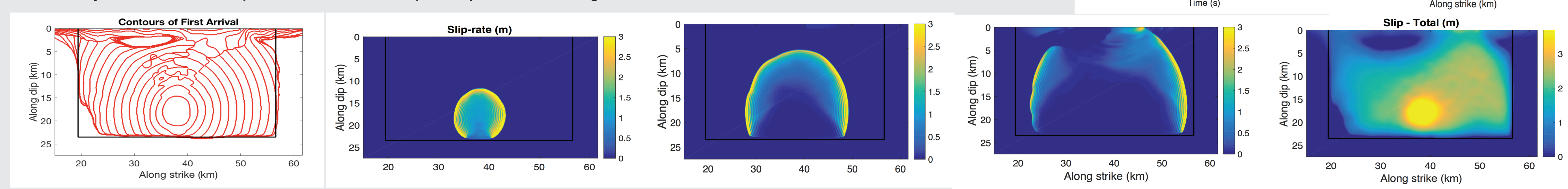


Figure 5. These simulations use slip-weakening, with a static and dynamic coefficient of friction of 0.6 and 0.44, respectively, and slip-weakening distance of 0.3 m. We apply a regional stress tensor that matches that of an extensional regime (minimum stress direction of 270˚, with φ = (S2-S3)/(S1-S3) = 0.5 with lithostatic stress conditions assuming hydrostatic pore pressure. Nucleation is achieved by a forced rupture in a small region surrounding the hypocenter.

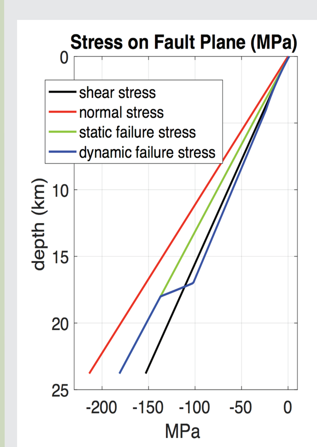
Rate and State

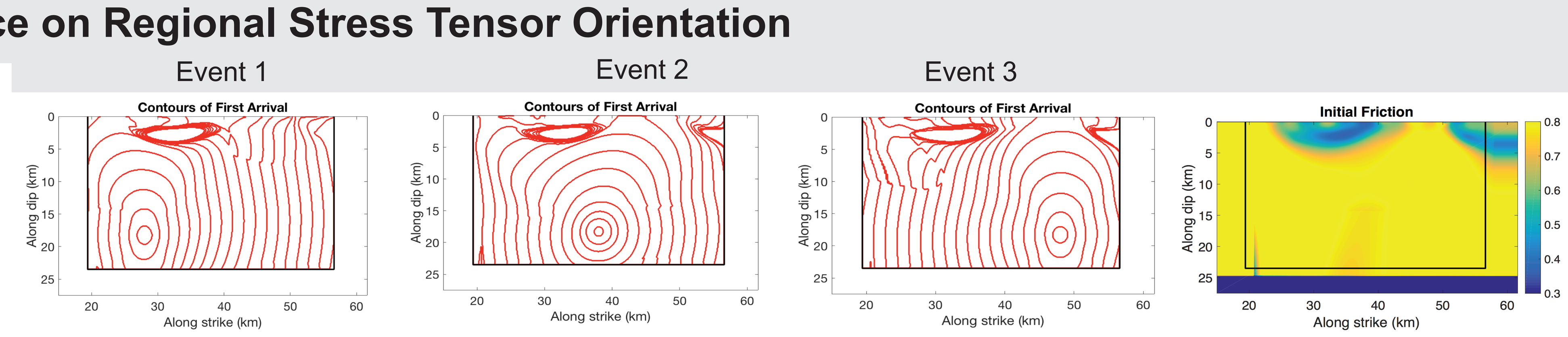
Figure 6. These simulations use a rate and state friction law, targeted to match the slip-weakening conditions as closely as possible. We find similar characteristics to the slip-weakening law, with a more distinct pulse-like rupture, indicated by the minimal slip after the initial rupture passes through a fault location.





Dependence on Regional Stress Tensor Orientation





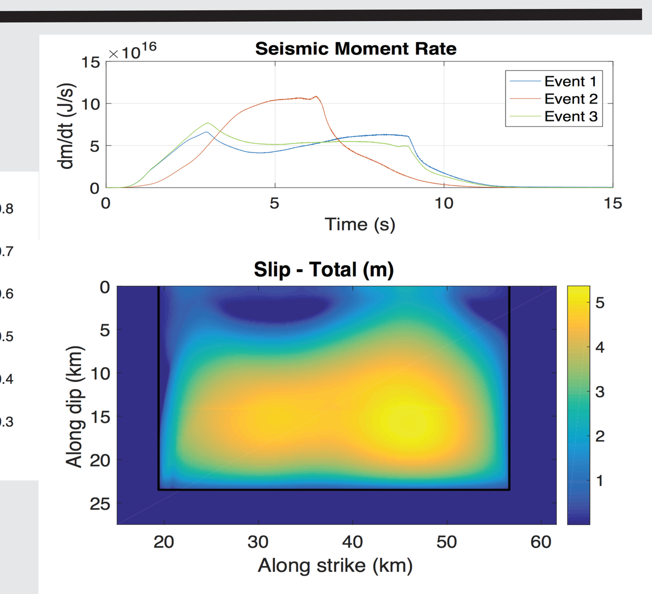


Figure 7. These simulations (low-frequency, without fault roughness) use a regional minimum stress direction of 240˚, with φ =0.2, near that implied by mesoscopic fault population data (Bruhn et. al., 1987). Friction and rupture conditions have been adjusted to allow failure along this fault plane.

Ground Motion

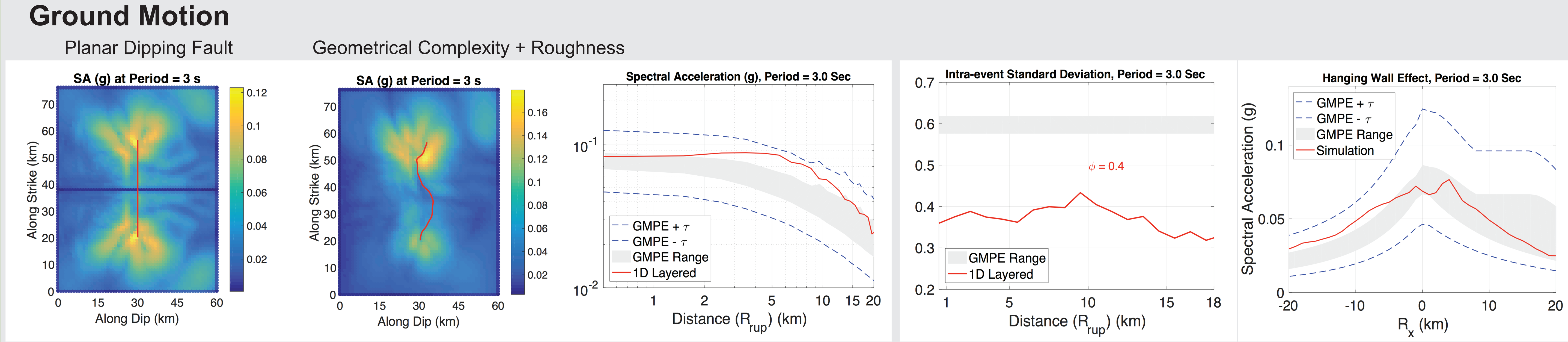
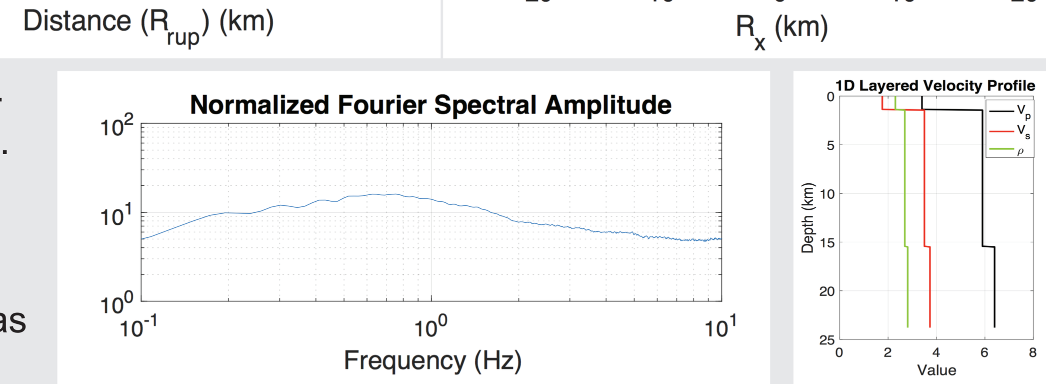


Figure 8. We compare our synthetic ground motion (both median and intra-event variablity) with that of 4 leading GMPE relations using a 1D layered velocity profile as a function of closest distance to the fault plane (R_{rup}). A commonly observed feature of ground motion from dip-slip earthquakes is the hanging wall (HW) effect, where increased ground motion is present on the HW side of the rupture (Donahue and Abrahamson, 2014). (Above) GMPEs and synthetic data SA along a cross-section perpendicular to strike, averaged along profiles lying within the fault strike (R_{y0} = 0). We use R_x, the horizontal distance from the top of the rupture to the site, as the distance parameter (with positive values of R_x defined as on the hanging wall side).



Conclusions

We study dynamic rupture and ground motion from dip-slip faults in regions that have high-seismic hazard, such as the Wasatch fault zone, Utah. We run dynamic rupture simulations along a dipping normal fault, with geometry matching that of the Salt Lake City segment. Our goal is to extend deterministic prediction of physics-based scenarios and resulting ground motion to frequencies of interest to structural engineers. The simulations include rough-fault topography following a self-similar fractal distribution (over length scales from ~100 m to the size of the fault) in addition to off-fault plasticity. We compare the effect of both slip-weakening and rate and state friction laws have on rupture propagation. Long-wavelength fault geometry imparts a non-uniform stress distribution along both dip and strike, influencing the final slip, as well as slip-rates and moment-release with time. Ground motion (median and intra-event variability) is in the range predicted by GMPE's and has a noticeable hanging-wall effect.