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Sierra Advances Resolution of Hayward Fault Earthquake Simulations

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Short Summary

Title for short summary:

Resolving higher frequency seismic waves from damaging earthquakes
Or *Rapidly computing higher frequency seismic simulations of damaging earthquakes*

The character of strong earthquake shaking within a few kilometers of a fault is highly variable and poorly constrained by relatively few empirical recordings. Supercomputers enable simulation of earthquake motions to investigate the hazard and risk to buildings and infrastructure before damaging events occur. However, they require meter scale resolution to capture fine details in high frequency waves (5-10 Hz) on regional scales (~100 km).

Using SW4-RAJA, a 3D seismic simulation code ported to GPU hardware, LLNL researchers are able to increase the resolution of earthquake simulations to frequencies of engineering interest on regional domains with rapid throughput to enable sampling of various rupture scenarios and sub-surface models.

Quote

"Sierra's thousands of GPU-accelerated nodes allow SW4-RAJA to compute earthquake simulations with 100's of billions of grid points with shorter run times so we can resolve high-frequency waves and investigate different rupture scenarios or earth models."

Details

We modeled ground motions for a magnitude 7.0 Hayward Fault earthquake on a regional scale covering the greater San Francisco Bay Area. We used SW4, a fourth-order finite difference code for seismic simulations developed at LLNL. SW4 was recently enhanced to take advantage of Sierra's GPU architecture using the RAJA portability package. This resulted in SW4-RAJA which runs on Sierra and other GPU-accelerated platforms.

The computational domain includes fully three-dimensional (3D) sub-surface material properties following the geology and surface topography from the United States Geological Survey (USGS, 2018). The latest run on Sierra used a grid spacing of 6.25 m and resolved waves as short as 50 m corresponding to frequencies of 10 Hz. Inclusion of these short wavelengths (high-frequencies) is important for engineering and risk applications. Homes, buildings, and critical infrastructure (e.g. electricity generation and delivery, water, gas, transportation, hospitals) are sensitive to frequencies of motion above 1 Hz, in the 5-10 Hz range and higher.

Figure 1 shows snapshots of the shaking intensity (shown as the magnitude of the ground velocity) at different times. The spatial pattern of shaking intensity is highly variable due to variations in the slip distribution on the fault and wave propagation through 3D earth structure. In particular, softer soils in sedimentary geology amplify shaking relative to hard rock. Differences in rock type across the Hayward Fault result in different character of shaking.

Figure 2 shows the resulting peak ground velocity for the duration of the simulation across the region. The red colors correspond to motions at or exceeding 1 m/s and likely to cause damage to structures.

The recent simulation on Sierra was able to resolve short wavelengths corresponding to frequencies of 10 Hz, which is unprecedented resolution for regional-scale domains. Earlier simulations resolved frequencies of about 1 Hz (Aagaard et al., 2008; 2010; Harmsen et al., 2008). Recent simulations on Department of Energy National Lab supercomputers have enabled resolution of 2.5-5 Hz (Johansen et al., 2017; Rodgers et al., 2018ab). The recent 10 Hz simulation on Sierra doubles the resolved frequency of seismic waves compared to a calculation run earlier this summer on a large CPU platform.

Figure 3 illustrates the impact of higher resolution on the resulting seismograms, shown as ground acceleration time-histories, at a range of resolutions: 1.25, 2.5, 5.0 and 10.0 Hz. Accelerations are composed of high frequency motions and are important for engineering analyses because they impart forces to buildings and structures. The waveforms are shown for two locations: Oakland near the Hayward Fault and Livermore, about 38 km from the fault. The higher frequency waveforms resolve higher amplitudes and more complex response resulting from fine details in the earthquake rupture and scattering by 3D geologic structure, including amplification in sedimentary basins.

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Figures

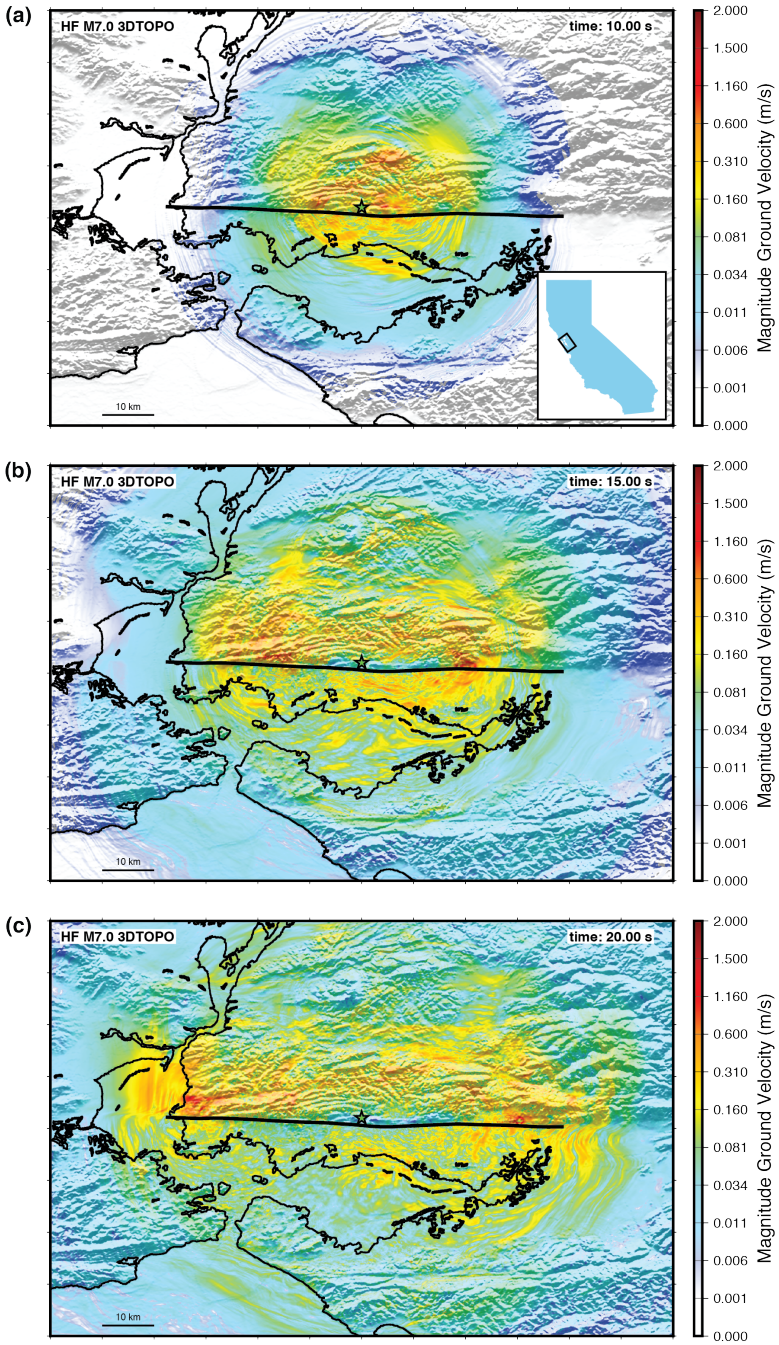

Figure 1. Snapshots of the shaking intensity at three times: 10, 15 and 20 seconds **(a)-(c)**, respectively. Each panel shows the magnitude of the three-component ground velocity according to the color bar with shaded relief and coastlines. The domain within the State of California is shown in the inset **(a)**.

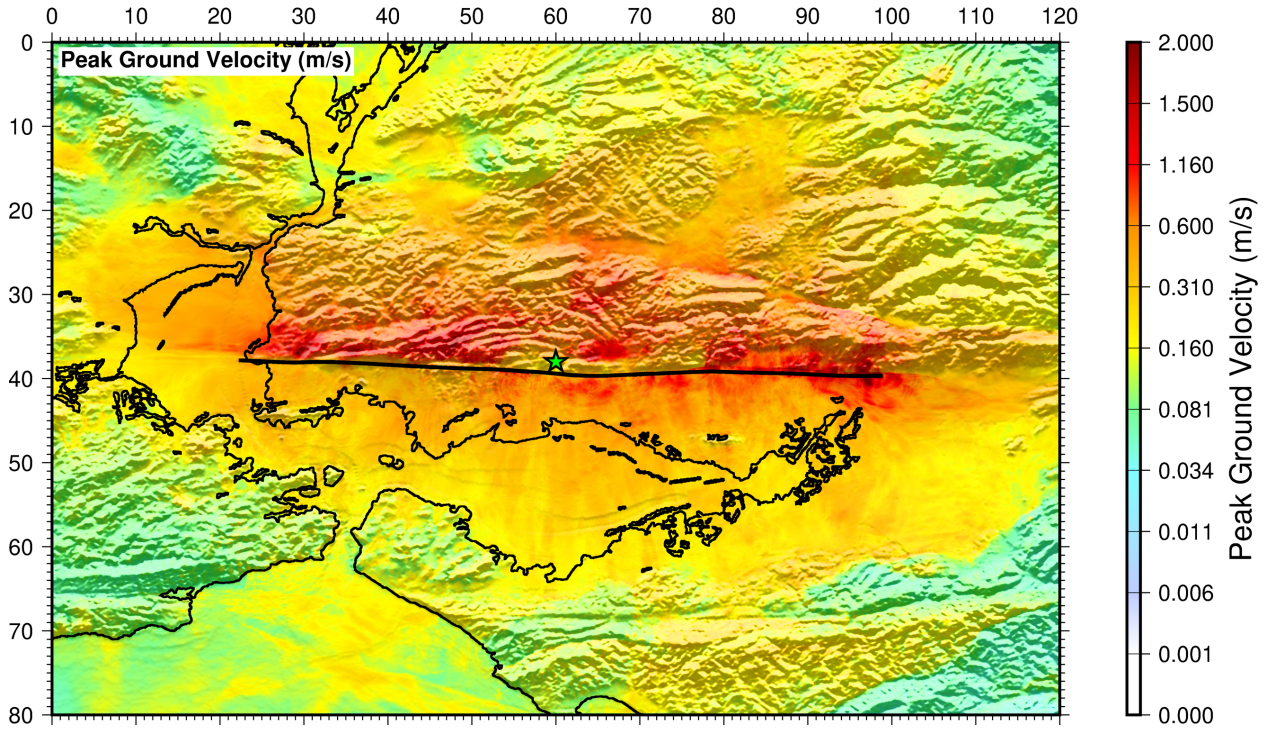

Figure 2. Peak ground velocity (color bar) for a magnitude 7.0 earthquake on the Hayward Fault, San Francisco Bay Area. The top of the fault surface is indicated by the thick black line and the rupture starts at the green star. Shaded relief and coastlines are shown, similar to Figure 1.

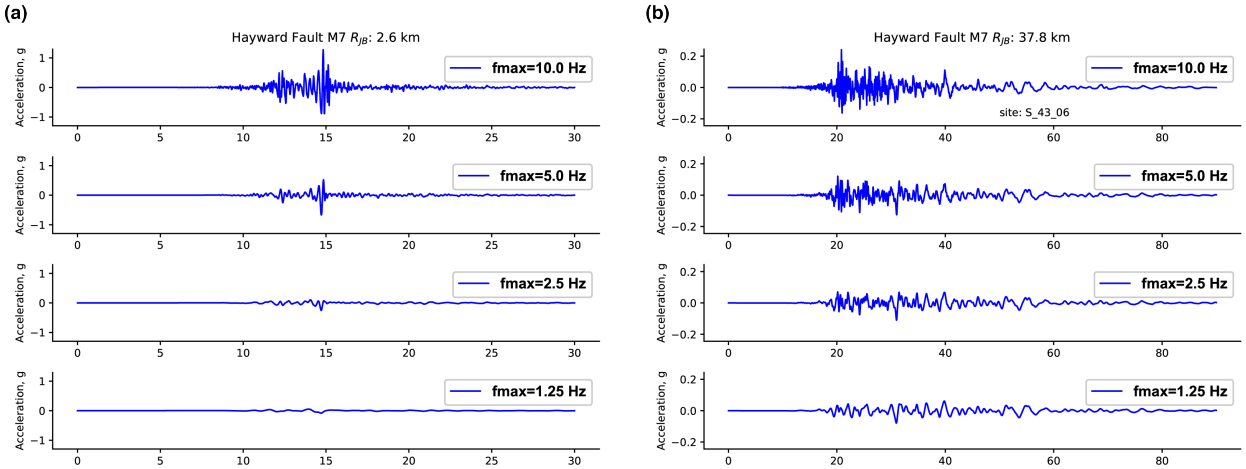

Figure 3. Acceleration waveforms for two locations **(a)** Oakland and **(b)** Livermore for a range of resolutions: 1.25, 2.5, 5.0 and 10.0 Hz. Note different time scales. The recent Sierra simulation resolved to 10 Hz and provides more realistic motions.