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A CyberShake-Based System for Operational Forecasting of Earthquake Ground Motions

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The goal of operational earthquake forecasting (OEF) is to provide authoritative information about the time dependence of seismic hazard to help communities prepare for earthquakes. Seismic hazards change dynamically in time, because earthquakes suddenly alter the conditions within the fault system that will lead to future earthquakes. Statistical and physical models of earthquake interactions have begun to capture many features of natural seismicity, such as aftershock triggering and the clustering of seismic sequences. In some situations, seismicity-based forecasting methods can achieve short-term probability gain factors of 100-1000 relative to long-term forecasts. Unifying long-term and short-term earthquake probability models into a single time-dependent Uniform California Earthquake Rupture Forecast (UCERF3) is the goal of the current Working Group on California Earthquake Probabilities.

The UCERF models forecast the occurrences of earthquake sources in the form of fault ruptures. However, from an OEF perspective, forecasts are better represented in terms of the strong ground motions that constitute the primary seismic hazard. Moreover, the prospective testing of ground motion forecasts against observations—an essential requirement for OEF— has certain advantages relative to the more indirect testing of rupture forecasts. This approach has been applied in the Short-Term Earthquake Probability (STEP) model of Gerstenberger et al. (2007), an operational system that forecasts ground motion exceedance probabilities in California at modified Mercalli intensity VI. A major limitation is that empirical ground motion prediction equations (GMPEs) used by STEP to compute the probability of shaking intensity conditional on the source do not properly account for the source directivity and basin-coupling effects for individual fault ruptures.

We show how this limitation can be overcome by the coupling of probabilistic rupture forecasting models with large ensembles of physics-based simulations of ground motions that can now be generated using petascale supercomputers. In particular, we have developed a framework for OEF based on SCEC’s CyberShake simulation platform, which can simulate ground motions in geologically complex environments for rupture ensembles large enough (~600,000) to sample adequately the statistical variability represented in the UCERF forecasts (Graves et al., 2010). Figure 1 illustrates how local increases in earthquake rupture probabilities can be mapped into regional ground motion probabilities using the low-frequency CyberShake 1.0 model for the Los Angeles region. Maps of exceedance probabilities for 0.3 Hz spectral acceleration at 0.2 g are shown for five recent earthquakes that could have been (though were not) foreshocks to larger ruptures. For this demonstration, a nominal probability gain factor of 1000 relative to the NSHMP-2008 forecast—the time-independent version of UCERF2 (Field et al., 2009)—was applied to all ruptures with epicenters within 10 km of the candidate foreshocks, more-or-less consistent with the Agnew-Jones foreshock probability method. Significant gains in the ground motion probabilities relative to a STEP-type model are obtained for events near the San Andreas fault, primarily because the CyberShake model accounts for the rupture directivity and basin effects associated with all individual ruptures; e.g., the strong directivity-basin coupling previously inferred from the TeraShake and ShakeOut simulations.

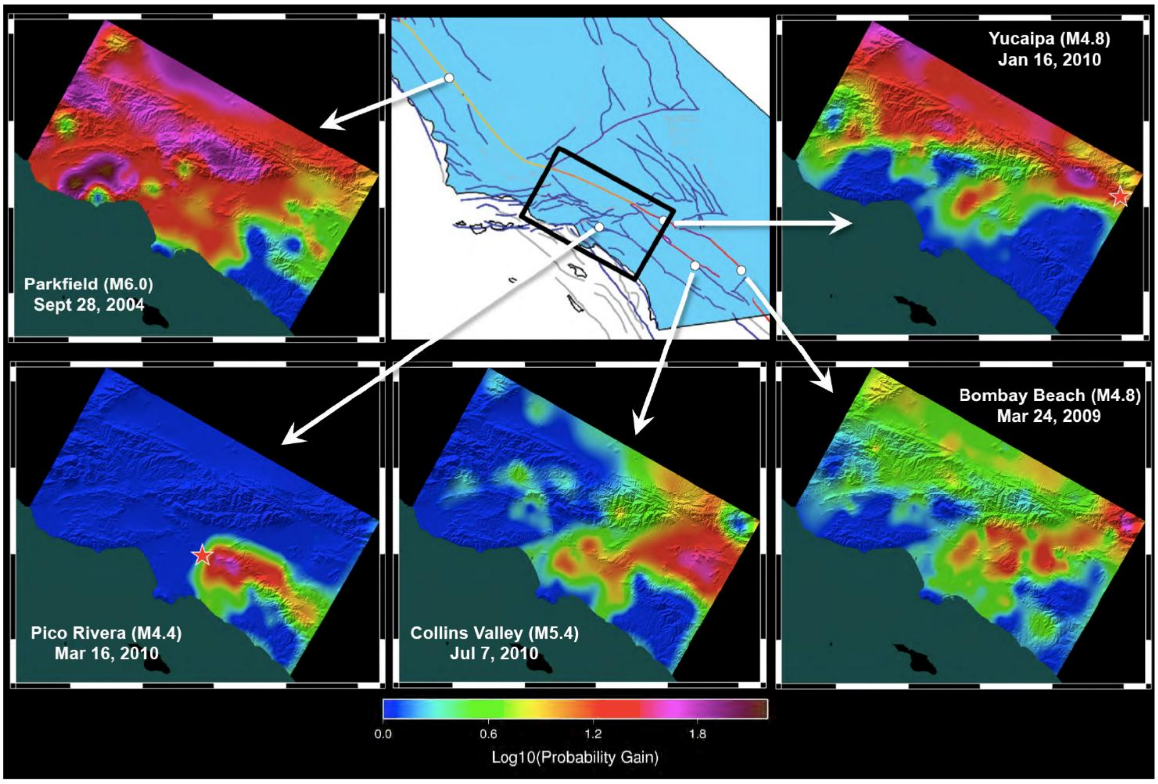

Figure 1. Maps of the Los Angeles region showing the gains in ground motion probabilities on the day following five small to moderate earthquakes. The probability gains were computed relative to the time-independent NSHMP (2008) forecast for 0.3 Hz spectral accelerations exceeding 0.2 g using the CyberShake 1.0 simulation-based hazard model. For the demonstration calculation, the probabilities of ruptures with epicenters less than 10 km from the events were arbitrarily increased from their NSHMP (2008) values by a nominal gain factor of 1000. The model accounts for rupture directivity and basin effects not adequately represented by standard GMPEs.

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