SOLVING PREDICTION PROBLEMS IN EARTHQUAKE SYSTEM SCIENCE ON BLUE WATERS

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EXECUTIVE SUMMARY:

A major goal of earthquake system science is to predict the peak shaking at surface sites on the scale of a few days to many years. The deep uncertainties in these predictions are expressed through two types of probability: an aleatory variability that describes the randomness of the earthquake system, and an epistemic uncertainty that characterizes our lack of knowledge about the system. Standard models use empirical prediction equations that have high aleatory variability, primarily because they do not model crustal heterogeneities. We show how this variance can be lowered by simulating seismic wave propagation through 3D crustal models derived from waveform tomography. SCEC has developed a software platform, CyberShake, that combines seismic reciprocity with highly optimized anelastic wave propagation codes to reduce the time of simulation-based hazard calculations to manageable levels. CyberShake hazard models for the Los Angeles region, each comprising over 240 million synthetic seismograms, have been computed on Blue Waters. A variance-decomposition analysis indicates that more accurate earthquake simulations may reduce the aleatory variance of the strong-motion predictions by at least a factor of two, which would lower exceedance probabilities at high hazard levels by an order of magnitude. The practical ramifications of this probability gain for the formulation of risk reduction strategies are substantial.

INTRODUCTION

The Southern California Earthquake Center (SCEC) coordinates basic research in earthquake science using Southern California as its principal natural laboratory. The CyberShake method produces site-specific probabilistic seismic hazard curves, comparable to Probabilistic Seismic Hazard Analysis (PSHA) hazard curves produced by the U. S. Geological Survey (USGS) that are used in national seismic hazard maps.

If the CyberShake method can be shown to improve on current PSHA methods, it may impact PSHA users including scientific, commercial, and governmental agencies like the USGS. For seismologists, CyberShake provides new information about the physics of earthquake ground motions, the interaction of fault geometry, 3D earth structure, ground motion attenuation, and rupture directivity. For governmental agencies responsible for reporting seismic hazard information to the public, CyberShake represents a new source of information that may contribute to their understanding of seismic hazards, which they may use to improve the information they report to the public. For building engineers, CyberShake represents an extension of existing seismic hazard information that may reduce some of the uncertainties in current methods, which are based on empirical ground motion attenuation models.

METHODS AND RESULTS

SCEC has used Blue Waters to perform CyberShake computational research, a physics-based, computationally intensive method for improving PSHA. We have calculated several new PSHA seismic hazard models for Southern California, exploring the variability in CyberShake seismic hazard estimates produced by alternative 3D earth structure models and earthquake source models.

SCEC's CyberShake workflow system produced a repeatable and reliable method for performing large-scale research calculations in record time. The tools used work within the shared-computer resource environment of open science HPC resources including Blue Waters. These tools have helped our team increase the scale of the calculations by two orders of magnitude over the last five years without increasing personnel .

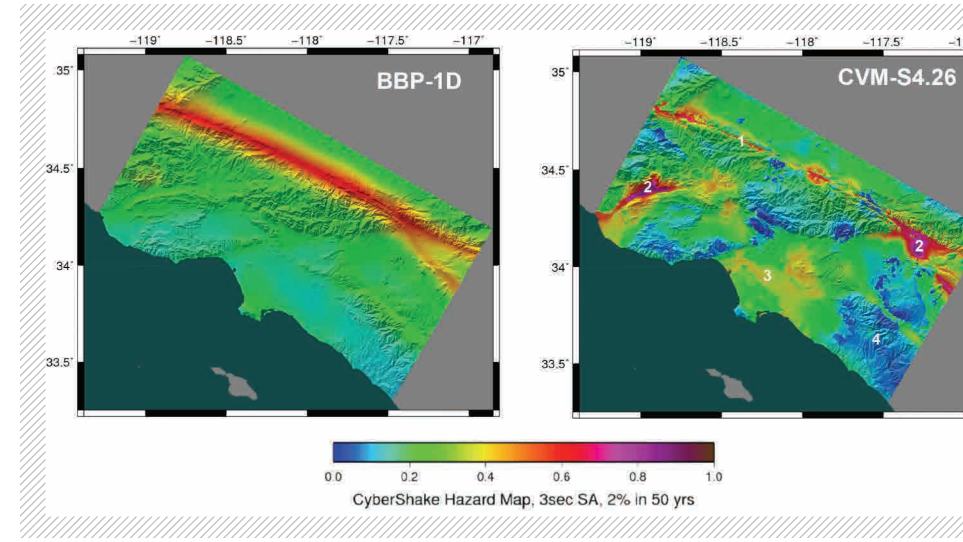

FIGURE 1: Two CyberShake hazard models for the Los Angeles region calculated on Blue Waters using a simple 1D earth model (left) and a more realistic 3D earth model (right). Seismic hazard estimates produced using the 3D earth model show lower near-fault intensities due to 3D scattering, much higher intensities in near-fault basins, higher intensities in the Los Angeles basins, and lower intensities in hard-rock areas.

Our scientific contributions to PSHA have the potential to change standard practices in the field. Models used in PSHA contain two types of uncertainty: aleatory variability that describes the intrinsic randomness of the earthquake-generating system, and epistemic uncertainty that characterizes our lack of knowledge about the system. SCEC's physics-based system science approach can improve our understanding of earthquake processes, so it can reduce epistemic uncertainties over time. As an example of the potential impact, we used the averaging-based factorization (ABF) technique to compare CyberShake models and assess their consistency with Next Generation Attenuation (NGA) models. ABF uses a hierarchical averaging scheme to separate the shaking intensities for large ensembles of earthquakes into relative (dimensionless) excitation fields representing site, path, directivity, and source-complexity effects, and it provides quantitative, map-based comparisons between models. CyberShake directivity effects are generally larger than predicted by the NGA directivity factor [1,2], and basin effects are generally larger than those from the three NGA models that provide basin effect factors. However, the basin excitation calculated from CVM-H is smaller than from CVM-S, and shows stronger frequency dependence primarily because the horizontal dimensions of the basins are much larger in CVM-H. The NGA model of Abrahamson & Silva [3] is the most consistent with the CyberShake CVM-H calculations, with a basin effect correlation factor >0.9 across the frequency band 0.1-0.3 Hz.

WHY BLUE WATERS

SCEC uses Blue Waters to perform large-scale, complex scientific computations involving thousands of large CPU and GPU parallel jobs, hundreds of millions of short-running serial CPU jobs, and hundreds of terabytes of temporary files. These calculations are beyond the scale of available academic HPC systems, and, in the past, they required multiple months of time to complete using NSF Track-2 systems. Using the well-balanced system capabilities of Blue Waters CPUs, GPUs, disks, and system software, together with scientific workflow tools, SCEC's research staff can now complete CyberShake calculations in weeks rather than months. This enables SCEC scientists to improve methodology more rapidly as we work towards CyberShake calculations at the scale and resolution required by engineering users of seismic hazard information.

PUBLICATIONS

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