SIMULATING ALTERNATIVE CALIFORNIA EARTHQUAKE HISTORIES USING RATE AND STATE FRICTION

Allocation: NSF PRAC/9,620 Knh
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EXECUTIVE SUMMARY

The Southern California Earthquake Center (SCEC) is using Blue Waters to develop physics-based earthquake forecasts for broad impact users including the U.S. Geological Survey, California State emergency planning authorities, and civil engineering organizations. During the last year, we used the physics-based earthquake cycle simulator code known as RSQSim to produce several million-year California earthquake catalogs to investigate how fault complexities affect the probabilities of large, multifault ruptures and multievent sequences. This research is improving our understanding of earthquake processes, which will improve probabilistic seismic hazard analysis in the United States and benefit earthquake system science worldwide.

RESEARCH CHALLENGE

SCEC conducts an earthquake system science research program developing physics-based, predictive models of earthquake processes to improve probabilistic seismic hazards assessments. SCEC researchers use physics-based computational models, observation-based 3D earth structure models, and high-performance computer resources to improve probabilistic seismic hazard forecasts for California. Our research is leading to improved Probabilistic Seismic Hazard Analysis (PSHA) methods and results. Our computationally intensive CyberShake seismic hazard models estimate peak ground motions using 3D wave propagation simulations. Blue Waters enables SCEC seismic hazard modelers to benefit from significant advances in computing and storage capabilities. By improving PSHA and ground-motion simulations, this project contributes to improved seismic design and safety because PSHA ground motion estimates guide the long-term construction of a seismically safe built environment.

METHODS & CODES

SCEC's earthquake system science research requires an integrated collection of earth structure models and physics-based simulation codes. SCEC has developed a seismic hazard software ecosystem that includes traditional probabilistic seismic hazard analysis software (OpenSHA), California velocity models (UCVM), finite difference wave propagation software (AWP–ODC), finite element wave propagation software (Hercules), and physics-based probabilistic seismic hazard software (CyberShake). The computational scale of our seismic hazard studies has led to close collaborations with the Blue Waters technical groups, who have helped us identify and remove technical roadblocks in our large-scale research calculations.

RESULTS & IMPACT

This year, the SCEC team used a physics-based code, RSQSim [1], to produce long-term (one million+ years) synthetic earthquake catalogs that comprise dates, times, locations, and magnitudes for earthquakes in the California region. RSQSim simulations impose stresses upon a representation of the California fault systems. These stresses are then distributed throughout a complex system of faults, generating cascades of earthquakes during the simulations. The RSQSim output is an earthquake rupture catalog that represents a sequence of earthquakes of various magnitudes expected to occur on the San Andreas Fault over a given time range. These catalogs represent a possible history of California earthquakes over the last million years.

After using RSQSim earthquake catalogs to estimate California seismic hazards, SCEC compared the RSQSim hazard estimates to seismic hazard estimates from traditional, empirically derived California Earthquake Rupture forecasts, called UCERF2 and UCERF3, which were designed and developed by SCEC and the U.S. Geological Survey. These California seismic hazard estimate comparisons (Fig. 1) show that the physics-based RSQSim model can replicate the seismic hazard estimates derived from the empirical models, but with far fewer statistical assumptions. This agreement gives researchers confidence that the seismic hazard models for California are consistent with what we know about earthquake physics.

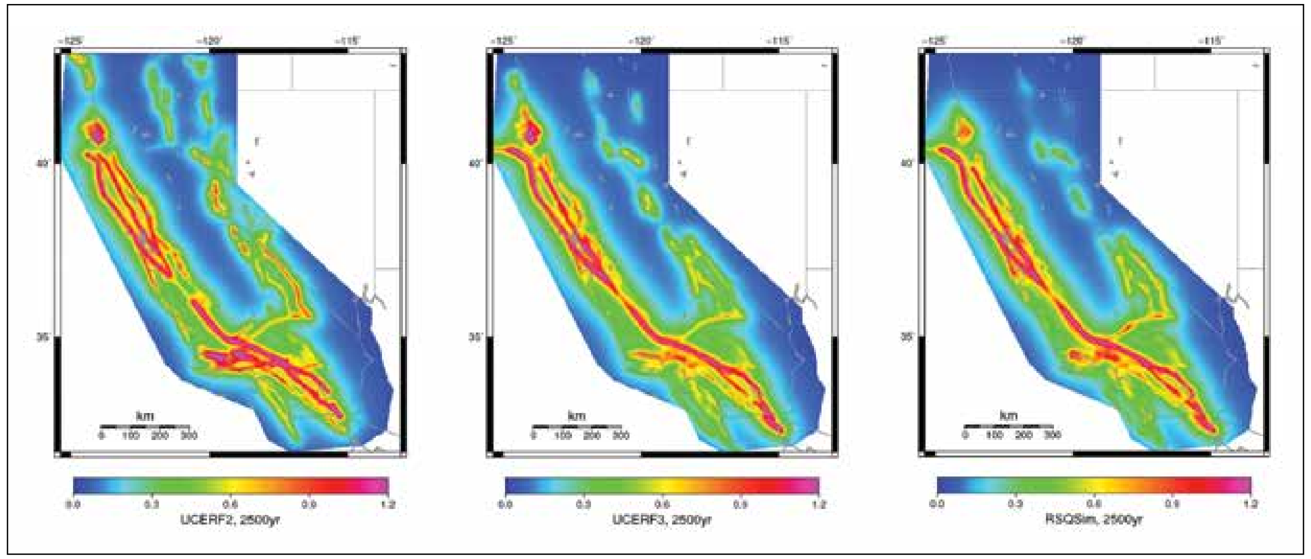

Figure 1: These maps show estimated shaking hazard produced using the RSQSim earthquake catalog as compared to the UCERF2 and UCERF3 hazard models. Maps show Peak Ground Acceleration with a probability of exceedance of 2% in 50 years. Units are in fractions of the acceleration of gravity, g. (a) UCERF2, (b) UCERF3, (c) RSQSim model.

WHY BLUE WATERS

SCEC's large-scale seismic hazard studies would not be possible without Blue Waters. Blue Waters is a highly productive research environment due to its variety and large number of computing nodes, the large filesystem, the fast I/O system and network, and the science-friendly system administration policies. Blue Waters makes it possible to perform the large-scale physics-based seismic hazard simulations that can reduce the uncertainties in long-term seismic hazard forecasts and improve risk assessments for critical facilities such as large dams, nuclear power plants, lifelines, and energy transportation networks.

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EXTREME CONVECTIVE STORMS UNDER CLIMATE CHANGE

Allocation: Blue Waters Professor/240 Knh
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EXECUTIVE SUMMARY

One projected impact of human-induced climate change is an increase in the intensity of landfalling hurricanes. In our work, we have found that these more intense hurricanes also appear likely to be more hazardous in terms of inland flooding and tornado generation.

RESEARCH CHALLENGE

The future impact of thunderstorms and thunderstorm systems such as hurricanes under a globally warmed climate are still uncertain. Part of this uncertainty is related to the fact that thunderstorm hazards—tornadoes, hail, damaging straight-line winds, lightning, and localized flooding—have spatial scales that fall well below the effective resolution of typical climate models. Modeling approaches such as dynamical downscaling have begun to address this resolution issue. However, their applications thus far have generally been unconcerned with the basic question of whether significant events in the current climate will be more or less significant in the future. The answer to this question is important from the perspective of basic science but will also help to inform decision-makers such as emergency managers on how to prepare for future disasters.

METHODS & CODES

We used an event-based implementation of the pseudo-global warming (PGW) methodology. Modified atmospheric states drawn from global climate model (GCM) output were applied to constrain Weather Research and Forecasting (WRF) model simulations at high resolution. We supplemented these PGW simulations with idealized simulations using Cloud–Model 1 (CM1). Both WRF and CM1 are community codes.

RESULTS & IMPACT

Hurricane Ivan (2004) is the historical case of interest here, in part because of its relative intensity, but also because it generated a record-setting 118 tornadoes as well as considerable inland flooding. Thus, we were motivated to determine if such extreme tropical cyclone tornado (TCT) generation would be further enhanced in a future climate. Our basic approach was to compare a control simulation of Ivan to simulations in an atmosphere modified by PGW. The PGW simulations involved future climate conditions over the late (2080–2090) twenty-first century period under Representative Concentration Pathways 8.5, as extracted from three Coupled Model Intercomparison Project phase 5 GCMs (National Center for Atmospheric Research, Model for Interdisciplinary Research on Climate, and Geophysical Fluid Dynamics Laboratory). Changes in tropical cyclone (TC) intensity and TCT generation for the PGW-modified Ivan were documented and analyzed.

Compared to the control, all three PGW simulations exhibited more intense TCs. The TCs under PGW also produced significantly more accumulated rainfall over the course of Ivan's inland progression. In addition, each of the PGW TCs generated more prelandfall TCTs than did the control simulation; more numerous and also more intense postlandfall TCTs resulted from PGW in some of the simulations. These and other experiments lend support to the hypothesis that an increase in sea surface temperature due to human-induced climate change will intensify landfalling TCs, which in turn will result in more numerous tornadoes.

In our forthcoming work, these PGW results are being used in a county-level event-based assessment of the risk of inland TC hazards, particularly TCTs.

WHY BLUE WATERS

The relatively small size of thunderstorms and the ranges of relevant scales within tropical cyclones, coupled with their episodic occurrence, necessitate a research approach that can account for temporal scales from minutes to decades and spatial scales of hundreds of meters to thousands of kilometers. In other words, we require very large geospatial domains that have fine gridpoint spacings and long-time integrations with high rates of model output. Moreover, quantifications of uncertainty require that such realizations be repeated over multiple experiments. The Blue Waters allocation is providing us with the resources needed to achieve this unprecedented level of climate simulation.

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