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THE VIRTUAL QUAKE THAT COULD SAVE LIVES

With supercomputers at Argonne National Laboratory, SCEC creates fault behavior models that translate into life-saving measures

Catastrophic earthquakes are rare, and so is the hard data surrounding them. It makes them difficult to study and even harder to predict. The Southern California Earthquake Center (SCEC) is transforming the study of massive temblors by using supercomputers to extrapolate what is known into realistic projections of what could happen. It's research that aims to find its way into city, county, and state building codes, and ultimately keeps transportation lines, critical resources, and people safer.

Understanding the unpredictable

Of all the types of catastrophes that occur on our planet, earthquakes are the most difficult to predict. Most disasters come with tangible warning signs days, hours, or minutes before they strike. Earthquakes are different.

In fact, no organization has ever successfully predicted an earthquake. So, scientists do the next best thing—they project the probability of major fault activity over a span of decades.

Several groups of researchers at SCEC, headquartered at the University of Southern California are going one step further, using supercomputers to model virtual earthquakes to see what damage is likely for a given fault rupture.

"It's not a prediction of an earthquake—it's a predictive model of how an earthquake could impact a region in terms of shaking," explains Christine Goulet, executive director for applied science at SCEC. Specifically, she and the SCEC teams are looking at critical infrastructure around faults to see how it might be affected.

Argonne NATIONAL LABORATORY

SCEC AN NSF+USGS CENTER Southern California Earthquake Center

INDUSTRY: RESEARCH

REGION: UNITED STATES

VISION

Study the potential effects of catastrophic earthquakes to predict real-world outcomes

STRATEGY

Leverage supercomputing to build realistic, multi-magnitude simulations of fault behavior

OUTCOMES

- Predicts ground movement possibilities for given faults at different magnitudes
- Creates accurate, physics-based simulations to aid in regional earthquake preparedness efforts
- Influences government agencies and building codes to keep people and resources safer

Science that reduces uncertainty

"The first thing we think of is shaking," she says. "When an earthquake occurs, there is slip along a fault causing permanent displacement somewhere within the crust. As it does, it generates waves." In fact, Goulet is fairly obsessed with quakes. "I keep a seismometer in my basement, and I have a knack for feeling the first earthquake wave arrivals before most people notice," Goulet says. Just like lightning appears seconds before the thunderclap, Goulet can detect the first jolt of a quake.

"I can usually estimate how far away the epicenter is just by counting until the stronger shaking starts," Goulet says. "That's how earthquake alerts work: by capturing the first waves near a fault and computing when it's going to move elsewhere."

Goulet and her team look at the kinds of infrastructure that could potentially be damaged by shaking and by that displacement when it reaches the surface. "Complex systems like gas lines, roads, bridges, electrical distribution systems, and aqueducts—those are the ones we're especially concerned about. With a single building you can usually avoid known faults, but with distribution infrastructure that span hundreds of miles, you're bound to cross faults. It's especially an issue in Southern California. If this region is suddenly cut off from its water supply, that's an event that would cause a lot of suffering, far beyond the shaking and displacement in the area of the fault itself."

To get a better idea of the kind of damage a quake could cause—and how to protect against it—the center has developed digital models of regional faults and software tools to test them. "Simulating earthquakes on known faults can help us reduce uncertainty," Goulet says. This reduction of uncertainty allows communities to better prepare and protect themselves.

Simulating the "big one"

The bigger the quake, the harder it is to simulate. But those are the events SCEC is most interested in. "We're interested in the rare large events—anything with low probability but large consequence," Goulet explains. "Because those are the events we need to keep in mind when we're building cities."

Goulet and team know where many of the fault lines are. In fact, SCEC has a 3D model of all the known active faults in southern California—comprising close to 200 faults defined in many sections. When projected to the surface, they look a little bit like the greater Los Angeles freeway system.

"Since this is all based on physics, we create simulations by identifying the fault, applying stress, and letting virtual quakes happen on the whole system over long periods of times—hundreds of thousands of years, or on a specific fault modeled in more details," Goulet explains.

Not all quakes will cause damage or visual displacement. "Think about what happens when a rock hits your windshield—the force of the rock exceeds the resistance of the glass at that point and dents it. You might end up with a hairline crack in the glass. Sometimes, cracks propagate out from that point, but sometimes nothing happens," says Goulet. "It's a lot like a fault. The Earth is a dynamic system, and the forces within eventually exceed the rock resistance at the weakest point. Sometimes the rupture stops quickly, sometimes it continues for a while, creating larger magnitude events. That's what we study—the conditions that lead to slip and especially slip near the surface."

> With more realistic earthquake simulations, we can reduce suffering and build a more resilient society."
>
> – **CHRISTINE GOULET**, EXECUTIVE DIRECTOR FOR APPLIED SCIENCE, SOUTHERN CALIFORNIA EARTHQUAKE CENTER

Many faults, many factors

That's when the computation-intensive modeling and the need for supercomputing really begins for Goulet. By looking at the material near the fault and studying how it reacts, the team can then make educated guesses about how a quake of a certain magnitude will impact an area.

"When there's displacement during a quake, it's not just a clean break along a line—we capture what happens to the material from tens to hundreds of meters around the fault and look at how this can impact everything from buildings to buried infrastructure," Goulet says.

Because not all the material around faults is the same—some is more brittle, some has more plasticity—the model parameters vary based on the geology of each fault and the characteristics of the lands that surround it.

Orders of magnitude for quakes and compute

To simulate the kind of quakes that SCEC wants to study, the computations can become enormous. "The largest magnitude events trigger movement on the longest faults, so we're making our 10 to 100-meter material calculations along several hundreds of kilometers," Goulet explains. "And to truly capture the behavior realistically, we actually need even smaller grid sizes."

Creating statistically meaningful simulations also means making models of different magnitudes of quakes. "Large events above a magnitude of 6.5 are important for us to capture because they tend to control the design dictated by the building code, but we also need to see what happens gradually up to 8.2 or so, the upper-end of what we expect to see on most of the continent," Goulet says.

> The computational demands are huge at that magnitude (8.0), but we want to be able to continue to push for more complex, high-resolution simulations."
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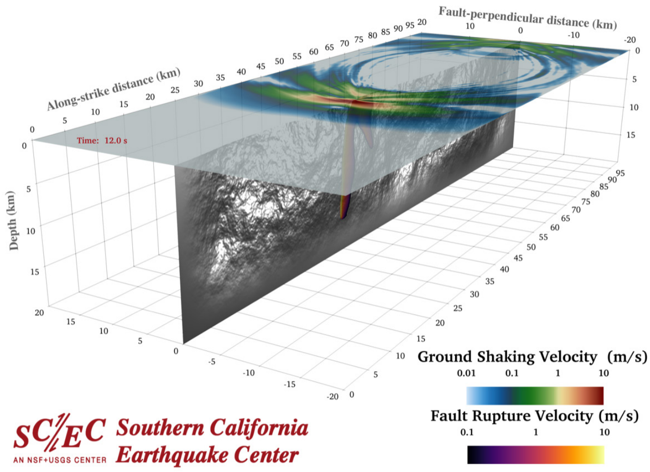

FIGURE 1. Snapshot of a magnitude 7.6 earthquake with rupture propagation and resulting wavefield. **Credit:** Y. Wang and C. Goulet, University of Southern California

Goulet and her team leverage some of the nation's most powerful supercomputers, including Theta at the the Argonne Leadership Computing Facility (ALCF)—a U.S. Department of Energy Office of Science User Facility. Theta is a Cray XC40,[1] 11.7 petaflop system based on Intel® CPUs.

Theta has supported SCEC and its research into ground motions since it came online in 2017. Right now, the team is pushing what it can do with magnitude 8.0 simulations. "The computational demands are huge at that magnitude," Goulet says. "But we want to be able to continue to push for more complex, high-resolution simulations. We're getting better at modeling the plasticity of different rocks, and we want to ultimately create models based on more realistic physics."

Exascale: the next era

It's why Goulet is looking forward to running her calculations on exascale computers soon. Argonne has been working with Intel and Hewlett Packard Enterprise to deploy an exascale system called Aurora that could transform the types of research humans can perform.

Aurora is an HPE Cray EX supercomputer designed with a sustained performance of one exaflop and peak performance of two exaflops. Exascale is defined as one quintillion (a billion-billion) floating point calculations per second. For purposes of scale, it would take 40,000 years for one quintillion gallons of water to spill over Niagara Falls.[2]

Building a more resilient society

"At SCEC, we are always excited to jump onto new systems to keep our research as relevant as we can. We're excited about building larger, more complex models on Aurora," Goulet says.

[1] A legacy offering prior to the HPE acquisition.

[2] hpe.com/us/en/insights/articles/here-comes-exascale-and-its-about-to-change-everything-2010.html

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"We can currently run a 7.8 magnitude 'ShakeOut' earthquake with simple material plasticity on an existing system. A goal is to go to higher frequencies that are relevant to engineering design; these require finer grid resolutions and more complex nonlinear plasticity models. Using an HPE exascale machine, we will be able to run an earthquake simulation with a resolution 3.3–10m, depending on depth, by using our advanced nonlinearity-enabled software to complete a ShakeOut scenario run in less than a day."

Ultimately, Goulet's aim is for the center's research to find its way into local building codes and state-wide recommendations. "We've gotten pretty good at building away from faults, but there's still a lot of important infrastructure at risk. That's why we work with a broad range of stakeholders in the community—utility companies and state transportation organizations as well as geologists, engineers, and hazard modelers. With more realistic earthquake simulations, we can reduce suffering and build a more resilient society."

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