Can We Predict

By Katie Neith

In April 2009, the Italian city of L'Aquila suffered a devastating magnitude 6.3 earthquake that toppled ancient buildings and left nearly 300 people dead. Dozens of significant aftershocks rocked the region, causing more damage and leaving tens of thousands of locals without homes. The main quake was preceded by a swarm of smaller temblors that caused general anxiety in the region. An official committee of scientists and emergency managers sought to calm this anxiety by saying that the swarm was a reassuring sign—pent-up energy was being relieved, thereby decreasing the chance of a larger earthquake. Two years later, even as the area was being rebuilt, six Italian earthquake scientists and a former government official were found guilty of manslaughter for their scientifically unjustified statement. They were sentenced to six years in jail.

The trial, which focused on the foreshocks and other natural phenomena that had occurred prior to the major quake, sparked outrage and debate among scientists around the globe. One question was whether earthquakes are predictable; another, whether scientists who advise the public are criminally culpable. Tom Heaton, a seismologist at Caltech who has dedicated his career to earthquake research, has a short response to the first question: no.

"Personally, I think you are only fooling yourself if you think you can predict an earthquake in detail," he says. "The reports of signs that seem to point to an oncoming earthquake are typically versions of what I call 'Texas sharp shooting.' Someone shoots the side of the barn and then draws the target *after* they shoot."

That said, Heaton does believe it's possible to build systems that can give people a warning mere seconds to a few minutes—max—before shaking from an earthquake is about to occur in a specific area. In fact, he's been working on such earthquake early warning (EEW) systems since the late 1970s, and he was the author of the first paper on the concept in a 1985 issue of the journal *Science*.

Although EEW research stood relatively still for nearly two decades after Heaton's seminal paper, the past 10 years have seen enthusiasm for EEW systems begin to grow.

"Things have really turned around," says Heaton. "The world just had to await the invention of Internet communication. In the '70s or '80s, we would have had to build our own rapid communication system. But now one of the key elements already exists."

Those advances have made it possible for fully functioning EEW systems to be built and implemented in Japan, Taiwan, Mexico, Turkey, and Romania in just one decade. And thanks to a recent $6 million award from the Gordon and Betty Moore Foundation, Caltech—along with UC Berkeley, the University of Washington, and the U.S. Geological Survey (USGS)—has been able to advance a West Coast EEW system.

"We're at the point where we are beta-testing a system that sends seismic-event information to us scientists and a few test users at the beginning of an earthquake," Heaton says. "It's currently being used to get other places—like emergency response agencies or power plants—accustomed to what they might do with the technology."

For instance, thanks to the system, Caltech seismologist Kate Hutton received a 40-second warning ahead of the waves from a 4.7 quake in Anza, California, on March 11 of this year. If this means what Heaton and others hope it does, that beta system—called ShakeAlert—might soon be the difference between preparedness and chaos.

GROWING ALERT

ShakeAlert utilizes a network of seismometers—instruments that measure ground motion—widely scattered across the western states. In California, that network of sensors is called the California Integrated Seismic Network (CISN) and is made up of computerized seismometers that send ground-motion data back to research centers like the Seismological Laboratory at Caltech.

"When an earthquake occurs, seismic waves radiate away from the source, like the waves on a pond after you've thrown a rock into the water," explains Maren Boese, a senior research fellow in the Seismo Lab. "Our computer algorithms can analyze these waves and can predict where

Earthquakes?

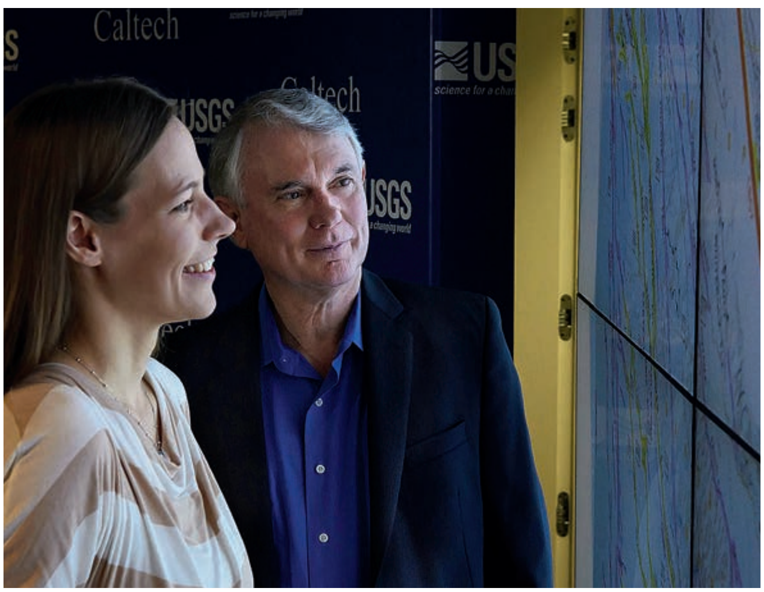
strong shaking will occur so quickly that an automated warning can be sent to more distant sites before the waves—and the shaking they cause—arrive. It's mainly a very fast information system."

Here's how the current ShakeAlert works: a user display opens in a pop-up window on a recipient's computer as soon as a significant earthquake occurs in California. The screen lists the quake's estimated location and magnitude based on the sensor data received to that point, along with an estimate of how much time will pass before the shaking reaches the user's location. The program also gives an approximation of how intense that shaking will be. Since ShakeAlert uses information from a seismic event in progress, people living near the epicenter do not get much—if any—warning, but those farther away could have seconds or even tens of seconds' notice, says Boese.

The hope is that an improved version of ShakeAlert will eventually give schools, utilities, industries, and the general public a heads-up in the event of a major temblor.

"You can use early warning to trigger a public alert and warn people to take protective steps, such as drop, cover, and hold on," Boese says. "But I think it's just as important to get psychologically ready for the shaking. Many people are really confused at the beginning of a quake and that's how they lose time. But if they already know that it *is* an earthquake—and they know that in a couple of seconds it will be over—that's really useful information that will reduce panic."

For many applications, like trains or elevators, actions will be initiated automatically after a warning is received. To be effective, the system must be reliable; you don't want to stop trains unless it really is a significant earthquake. On the other hand, the regions near the epicenter will have the strongest shaking and the shortest warning times, if any at all. Unfortunately, these are competing goals, Heaton says. While it may be feasible to get the first messages out very quickly, those messages will be based on minimal data and will not be as reliable. In order to determine the best trade-off between speed and reliability, James Beck, an engineer at Caltech, is working to design a type of cost-benefit analysis that can be applied to automated decision-making processes.



Above: Maren Boese and Jim Beck

Above right: Tom Heaton

"When you're dealing with earthquakes, there is enormous uncertainty," he says, "and only a few seconds in which to make a decision. So we quickly realized that we have to take humans out of the loop and somehow capture the essence of human decision making in a computer."

To do this, Beck and his lab are developing a probability-based automated decision-making earthquake application called ePAD. Its focus is on making fast and reliable decisions about whether the system should initiate a mitigation action—such as slowing a train or halting surgery—or not.

"One of the biggest challenges is that all earthquakes, in some sense, start out nearly the same," says Beck, who envisions that ePAD, when ready, will one day be incorporated into the ShakeAlert system. "A large earthquake is big simply because it ruptures a fault over a longer distance—there's not much else about it at its onset that signals that it's different from a smaller quake. When you're trying to determine whether it's worth sending out a warning, there is a real trade-off: you want the system to be quick in sending an appropriate response, but you also want it to be reliable, only raising an alarm when it's absolutely needed. It's very hard to get both."

The task of improving the speed and dependability of the ShakeAlert system is something that Boese and Heaton are undertaking as well.

"Some people think it's just a trivial problem of knowing that it's a certain sized earthquake and figuring out when the waves will get to you and that's it," says Heaton. "There is far more to making intelligent decisions than just that simple level of information."

FIGURING OUT FINDER

Making use of more complex data, Heaton—along with Boese and Egill Hauksson, a senior research associate in the Seismo Lab—has developed an algorithm called a Finite Fault Rupture Detector (FinDer), which can deconstruct an earthquake rupture in real time and provide additional data to the ShakeAlert system.

Although a rupture begins at a point, it can spread over tens of kilometers in a larger earthquake. FinDer works by looking for stations with intense, high-frequency shaking that is typically seen only very close to a rupture. The algorithm then compares the spatial pattern of near-source stations with patterns determined from a suite of already-understood large-earthquake scenarios. This provides more detailed information about which direction the quake might be heading and how quickly.

"I think it's really a big step forward," Boese says. "With FinDer, you can really keep track of the rupture as it is evolving."

The FinDer group is taking its ideas one step further by tapping into a huge database of 3-D simulations of seismic waves that will provide information about how seismic waves act based on location—leading, the team hopes, to better ground-motion predictions. For example, there is a deep basin below Los Angeles in which seismic waves seem to become trapped, reverberating for long periods during a rupture and making the shaking stronger. But, simulations show, bedrock yields less shaking. Incorporating this information into ShakeAlert, then, would mean that people living on bedrock would receive a different level of alert than those on softer soil.

"Once you know there is a major earthquake, the system should be able to immediately tell you how strong the shaking will be at your particular site," Boese says. "This database of simulations already exists, so it's nothing new, but now we're applying it to EEW."

Still, while significant strides have been made to improve the current EEW prototype, many challenges remain before scientists will be able to bring a statewide, public-access system to fruition.

Beck feels that one of the biggest technological challenges is to make the software more discriminating when it comes to detected events that aren't really California earthquakes—such as sensor malfunctions or local man-made ground shocks—or small earthquakes that are perceived as large earthquakes because they are part of a complex sequence of quakes that produce overlapping signals.

Boese expects that educating the public about EEW systems will be an additional hurdle. "People need to know what early warning is, its benefits, and—most importantly—its limitations," she says. "We need to be able to explain that it's only an additional tool they can use to get information; it does not replace seismic retrofitting or other precautions."

One of the final—and possibly highest—hurdles will be finding someone to operate a statewide EEW system. The obvious candidate would be the USGS—but because its budget, which comes from the federal government, has steadily decreased over the past 30 years, it would require a lot more resources in order to take on this expanded role. In April, the federal government did pledge $5 million to improve the EEW system in Southern California, but the USGS says that this is just a fraction of what will be needed to implement a statewide system.

"It's possible that the right politicians could make that happen, and certainly an adequate seismic tragedy could make that happen," says Heaton. "Unfortunately, the reality of our business is that seismic tragedies are often among the most important instigators of new developments. I guess it's a little like war in that respect."

Nonetheless, the researchers agree that the benefits of putting an EEW system in place are worth the tackling of its technological and political challenges.

"As a scientist, it's very exciting that our research is now allowing us to make a prediction and then test it within seconds," Heaton says. "Usually, in our business, we do a study that includes a guess about something that could happen in the future, and *maybe* in your lifetime you could test it, but probably not. Early warning is different. And that's extremely satisfying."

All three researchers also agree that, on a broad societal scale, an EEW system could give the public a few seconds to take actions that might greatly reduce losses in the case of a severe earthquake, including the much-discussed Big One.

"Earthquakes will still occur, and there will be damage," says Boese. "But we hope that, with an early warning, we can protect property, shorten recovery times, and, most importantly, save lives." E&S

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