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Gravity signals could detect earthquakes at the speed of light

Algorithm set for deployment in Japan could identify giant temblors faster and more reliably

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An aerial image of a fire caused by tsunami flooding in Iwaki City, Japan, after a magnitude 9 earthquake

Warning systems underestimated the scale of Japan's magnitude 9 Tohoku earthquake. A new algorithm will help determine the size of these large events faster. *THE ASAHI SHIMBUN* VIA GETTY IMAGES

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Two minutes after the world's biggest tectonic plate shuddered off the coast of Japan, the country's meteorological agency issued its final warning to about 50 million residents: A magnitude 8.1 earthquake had generated a tsunami that was headed for shore. But it wasn't until hours after the waves arrived that experts gauged the true size of the 11 March 2011 Tohoku quake. Ultimately, it rang in at a magnitude 9—releasing more than 22 times the energy experts predicted and leaving at least 18,000 dead, some in areas that never received the alert. Now, scientists have found a way to get more accurate size estimates faster, by using computer algorithms to identify the wake from gravitational waves that shoot from the fault at the speed of light.

"This is a completely new [way to recognize] large-magnitude earthquakes," says Richard Allen, a seismologist at the University of California, Berkeley, who was not involved in the study. "If we were to implement this algorithm, we'd have that much more confidence that this is a really big earthquake, and we could push that alert out over a much larger area sooner."

Scientists typically detect earthquakes by monitoring ground vibrations, or seismic waves, with devices called seismometers. The amount of advance warning they can provide depends on distance between the earthquake and the seismometers, and the speed of the seismic waves, which travel less than 6 kilometers per second. Networks in Japan, Mexico, and California provide seconds or even minutes of advance warning, and the approach works well for relatively small temblors. But beyond magnitude 7, the earthquake waves can saturate seismometers. This makes the most destructive earthquakes, like Japan's Tohoku quake, the most challenging to identify, Allen says.

Recently, researchers involved in the hunt for gravitational waves—ripples in space-time created by the movement of massive objects—realized that those gravity signals, traveling at the speed of light, might also be used to monitor earthquakes. "The idea is that as soon as mass moves anywhere, the gravitational field changes, and ... everything feels it," says Bernard Whiting, a physicist at the University of Florida who worked on the Laser Interferometer Gravitational-Wave Observatory. "What was amazing was that the signal would be present even in seismometers."

Sure enough, in 2016, Whiting and his colleagues reported that regular seismometers could detect these gravity signals. Earthquakes result in large shifts in mass; those shifts give off gravitational effects that deform both existing gravitational fields and the ground beneath seismometers. By measuring the difference between these two, the scientists concluded they could create a new kind of earthquake early warning system. Gravitational signals show up on seismometers before the arrival of the first seismic waves, in a portion of the seismogram that's traditionally ignored. By combining signals from dozens of seismometers on top of one another, scientists can identify patterns to interpret the size and location of large events, Whiting says.

Now, Andrea Licciardi, a postdoc at Côte d'Azur University, and his colleagues have built a machine-learning algorithm to do that pattern recognition. They trained the model on hundreds of thousands of simulated earthquakes before testing it on the real data set from Tohoku. The model accurately predicted the earthquake's magnitude in about 50 seconds—faster than other state-of-the-art early warning systems, researchers report today in *Nature*.

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"It's more than the seed of an idea—they've shown that it can be done," Whiting says. "What we showed was a proof of principle. What they're showing is a proof of implementation."

The gravity signals are too weak to be used for detecting earthquakes smaller than magnitude 8.3 with current technology, and the system is unlikely to provide much extra advance warning in earthquake zones that are already blanketed in seismometers. But it could deliver more reliable size estimates of large-magnitude earthquakes, which is crucial, particularly for predicting tsunamis, which often take an extra 10 or 15 minutes to arrive, Allen says. With this technique, seismologists in Japan could have accurately determined Tohoku's magnitude and issued proper alerts "1 or 2 minutes after the beginning of the earthquake," says Jean-Paul Ampuero, a seismologist also at Côte d'Azur University and co-author on the paper. "In 2011, it took hours. It would have been fantastic."

But the technology isn't operational yet: It hasn't processed data in real time. The model is set to be deployed in Japan—but only for earthquakes generated by a specific fault zone likely to generate "big ones." The algorithm needs to be trained separately for use in different regions, and the researchers are currently doing so for seismic networks in Peru and Chile, Licciardi says. Still, "We have a first-generation algorithm … that's a huge step forward," Allen says. "Now let's go and figure out if it actually works."

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