Quake Prediction Tool Gains Ground

Seismologists don't fully understand a controversial Greek prediction scheme, and some think its "successes" are just luck. But it is enticing many researchers

Each time researchers have flirted with a possible scheme for predicting earthquakes, they have ended up regretting it when the scheme failed to live up to expectations. Now they are being tempted again. This time, the attraction is strange electrical signals in the ground that, according to proponents, heralded three large earthquakes in a row this spring in Greece. And, in spite of those past disappointments, some researchers are wondering whether this might be the real thing.

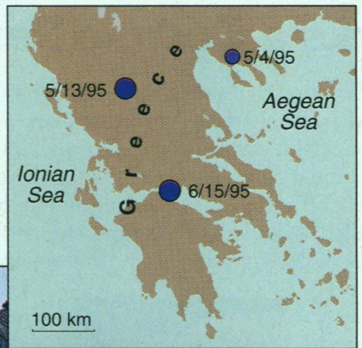
Although long disparaged by Greek seismologists, a prediction scheme based on those signals is now attracting interest, and some enthusiasm, in Japan and the United States, after the Royal Society of London and the University of California (UC), Berkeley, recently held workshops examining it. "It's bedevilingly intriguing," says Berkeley's Thomas McEvilly.

Most seismologists are still skeptical, arguing that the apparently successful predictions are just lucky guesses, aided by the vagueness of the predictions and the abundance of earthquakes in Greece. "But you just keep getting sucked back toward the apparent—though fuzzy—successes, especially those in the last year," says McEvilly. Hiroo Kanamori of the California Institute of Technology, a prominent seismologist and a longtime skeptic of simplistic approaches to earthquake prediction, adds that the statistical criticism "is probably valid. But that doesn't mean the whole thing is invalid," he says. "My feeling is there is something to it."

Geophysicists who study the electromagnetic properties of the crust tend to think so too, in part because they have been working along the same lines. For decades Chinese researchers have been searching for electrical precursors that might signal changes in fluid flow or rock properties leading up to an earthquake. And in the United States, researchers have been looking for magnetic precursors, especially since Antony Fraser-Smith of Stanford University detected a striking burst of magnetic noise just before the Loma Prieta earthquake of 1989 in California (*Science*, 22 December 1989, p. 1562).

Solid-state physicist Panayiotis Varotsos of the University of Athens and his colleagues got into the business in the mid-1980s as a result of laboratory experiments in which they squeezed dry rocks while monitoring their electrical properties. Just before fracturing, the rock would generate a transient electrical current as crystal imperfections caused a separation of charges. Because earthquakes are much larger versions of rock fractures, Varotsos and his colleagues reasoned, they should generate precursory electrical signals in the crust.

Greece has more than its share of earthquakes, making it a good testing ground for the idea. So Varotsos and his physicist colleagues began setting up what amount to giant voltmeters—wires as long as 3 to 4 kilometers connected to electrodes stuck in the ground—intended to record the changing electrical state of the crust. And sure enough, they recorded signals before earthquakes. Soon, Varotsos (V) and colleagues K. Alexopoulos (A) and K. Nomicos (N) were making public earthquake predictions using the "VAN" method.



SOURCE: LANL

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Threesome foretold? VAN came close to predicting three quakes, including a 15 June event in southern Greece *(photo).*

Few seismologists were seduced by the VAN group's early claims that they were successfully predicting quakes. "The experiment was not convincing, say 10 years ago, that Varotsos was measuring anything but electrode noise or some other problem with the sensors," says electrical geophysicist Stephen Park of UC Riverside. But since then, say Park and others, Varotsos has altered his equipment to compensate for instrumental noise and the crustal currents induced by fluctuations in Earth's own magnetic field. "Now we're convinced that it is a signal from the Earth," says Park.

That still leaves the question of whether these signals, dubbed "seismic electric signals," or SES, actually have anything to do with earthquakes. Varotsos believes they do, although he notes that the connection isn't simple. He has learned that SES aren't always detected at the location of an impending earthquake but often are recorded at distances of up to 100 kilometers and more. The reason, he says, is that the current has to reach the surface by way of conductive channels in the crust, which may carry it long distances.

Park and other geophysicists think such long-distance transmission is unlikely, because it would require too much energy at the source. And most geophysicists are skeptical of Varotsos's belief that crustal rock on the verge of fracturing generates current. Instead, speculates Kanamori, the signals might be generated as water and gas surge through the crust, triggering electrical changes and other precursors over a wide area and weakening a major fault until it ruptures.

But whatever their genesis, Varotsos converts the signals into a prediction based on the distribution of sites detecting them, the number of signals, and their amplitudes. And the results, Varotsos told *Science*, have been consistently successful. In the past 9 years, he says, 14 earthquakes of magnitude 5.8 or larger have struck Greece, three of which fell outside his network. Of the remaining 11, 10 were predicted weeks in advance, he says; only one prediction failed, and there were one or two false alarms.

Park sees it a little differently. When he and Richard Aceves and statistician David Strauss of UC Riverside include smaller, more abundant quakes in the magnitude range covered by VAN, the picture looks less impressive. "Varotsos has only issued predictions for 10% of the earthquakes that have actually occurred," he says. But of the predictions issued, "he's had a success rate of about 65 to 70%. Our results have shown it's very unlikely this could be produced by random chance. To me, that says that this is a physical phenomenon worth studying."

Seismologist David Jackson of UC Los Angeles disagrees. "I think [VAN] has gotten a lot more attention than it deserves," says Jackson. "The statements themselves—I won't call them predictions—are so vague." He points out that they predict the timing only to within some weeks, specify the location only to within 100 kilometers or so, and give the magnitude to within 0.7 units. With UCLA colleague Yan Kagan, Jackson has "come to the conclusion the results aren't any better than random chance," he says.

"I can understand why people are complaining about the VAN method," says seismologist Kanamori. But when it comes to the rarer, larger quakes, where the odds of succeeding by chance are smaller, Kanamori's "subjective judgment" is favorable. Because Varotsos has been faxing VAN predictions around the world as they are made, Kanamori has a feel for the correlation between predictions and larger earthquakes. In the past, "when I received several faxes in a relatively short time," says Kanamori, "there were almost always large events in Greece."

That was the case when a series of three large quakes—magnitude 5.2, 6.5, and 6.4—struck Greece last May and June. "This year Varotsos sent out three predictions for big earthquakes," notes Stanford's Fraser-Smith, "and there were three big earthquakes. There have been no predictions since." The predictions "have never been exactly right," notes Fraser-Smith—two of the quakes arrived days past the windows set by the predictions—but they have sent Fraser-Smith "more into the favorable column" on VAN. He and colleagues in California are now mounting a study of the SES phenomenon there. Likewise, Seiya Uyeda of Tokai University will be expanding his electrical network in Japan, which he and other researchers set up in recent years to emulate the Greek system.

But even as VAN attracts supporters outside Greece, a nagging question remains: Even if it works, how useful will it ever be? If Kanamori is right that the signals are generated not at the eventual epicenter but over a broad area, he says the VAN method wouldn't be any better than past attempts at prediction based on the broad swarms of smaller quakes that tend to precede large ones in some areas. At best, the predictions could only pinpoint an impending quake to an area 200 kilometers or so across—large enough to include both Los Angeles and San Diego. "I don't think that's very useful for earthquake prediction in a place like California or Japan," says Kanamori.

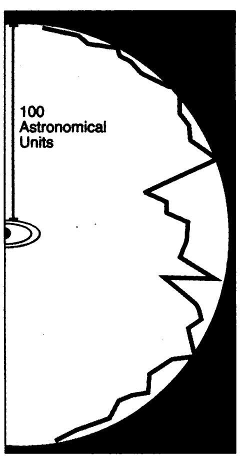
Such musings are reminding researchers like Park, Fraser-Smith, Uyeda, and others not to embrace the VAN group's technique too eagerly. But it's too enticing to ignore, says McEvilly: "These guys aren't quacks."

–Richard A. Kerr

SPACE PHYSICS

Ulysses Cracks a Cosmic Peanut

It was an elegant picture: Enclosing the sun and all its planets is a vast, mostly spherical cocoon of plasma and magnetic fields, carved out of the thin gases of interstellar space by the wind of charged particles from the sun. But the heliosphere, as it's called, is not looking quite so elegant anymore. If space physicists are right in their interpretations of data from the spacecraft Ulysses, our cocoon in interstellar space actually looks more like a peanut, with its "waist" in the same plane as the solar system.



Shape of space. The heliosphere, an envelope of plasma 100 times wider than Earth's orbit, bulges at the poles *(red line)*.

At a workshop held last month at the Jet Propulsion Laboratory in Pasadena, California, investigators reported Ulysses measurements showing that the solar wind carries more momentum at the sun's poles than it does along the ecliptic—the plane of space in which Earth and the other planets orbit. The effect, they said, is to balloon the heliosphere north and south of the ecliptic. Ulysses also picked up hints that the heliosphere is not only a peanut, it's probably a lopsided one at that.

Charting the shape of the heliosphere takes a unique vantage, which is just what Ulysses has. "I don't believe there is any other measurement technique that could've done it," says John Phillips of Los Alamos National Laboratory, leader of the Ulysses team studying solar-wind plasma. Launched 5 years ago as a joint project between the National Aeronautics and Space Administration and the European Space Agency, the $1.1 billion spacecraft swung past the sun's south pole last year, sped back across the ecliptic plane and, in September, crossed the north pole.

During this passage, the sun has been near the minimum of its 11-year cycle of activity, a time when its behavior changes only slowly. And that slow pace of change, combined with Ulysses' swift reconnaissance, makes the observations "the closest thing we've ever had to a global snapshot of the heliosphere," says Phillips. Although the heliosphere's boundary has not yet been observed directly, it is thought to lie 100 times farther from the sun than Earth's own orbit. But the exact distance now seems to vary with direction.

Even before Ulysses, says Phillips, it was known that during the minimum of the solar cycle, the solar wind is both faster and more tenuous over the sun's poles. It meets less resistance there, because the sun's magnetic field lines wander away into space instead of forming arches over the surface, as they do at lower latitudes. But it wasn't known how the faster speed and lower density would balance out—whether they would combine to deliver more or less momentum, or "push." Ulysses showed that the rise in speed more than compensates for the drop in density, so that the heliosphere should have a peanut-shaped cross section when viewed along the sun's direction of travel through interstellar space. (Seen from the side, the heliosphere is thought to be stretched into an oval or teardrop shape.)

What's more, the momentum carried by the wind at the two poles differed slightly, which may inflate the two lobes of the peanut unequally and affect its ability to screen out cosmic rays. Because of the open magnetic field lines at the sun's poles, researchers had suspected that charged cosmic rays have an easier time getting into the heliosphere at both poles than they do at lower latitudes. Ulysses confirmed that the flux rises slightly with increasing solar latitude—although, as University of Arizona theorists Randy Jokipii and Joseph Kota predicted before the flight, the overall increase is limited by waves that jiggle the magnetic field like clotheslines, blocking some of the rays.

But such processes should have the same effect at both poles, resulting in a symmetrical flux increase north and south of the sun's equator. Yet a Ulysses team led by John Simpson of the University of Chicago found that the cosmic ray flux falls to a minimum not at the sun's equator, as expected, but about 10 degrees south of it. Adding to the puzzle, the flux also turned out to be higher at the north pole than at the south. "The explanation is unknown," says Chicago collaborator Ming Zhang, but some of his colleagues speculate that the asymmetries in the wind might create unequal barriers to the cosmic rays.

What all researchers agree on is that the heliosphere will look even less symmetrical when Ulysses makes its next southern and northern passes in 2000 and 2001. The sun will then be at the peak of its activity cycle, and how the heliosphere will react to the gusts of solar wind, flares, and other unruly behavior of the sun at solar maximum is anyone's guess. Says Jokipii, "The next time Ulysses goes by the poles it's not gonna be so simple."

–James Glanz