Perestroika Comes to Earthquake Forecasts

But is the novel Soviet technique that predicted the Loma Prieta quake useful or just lucky?

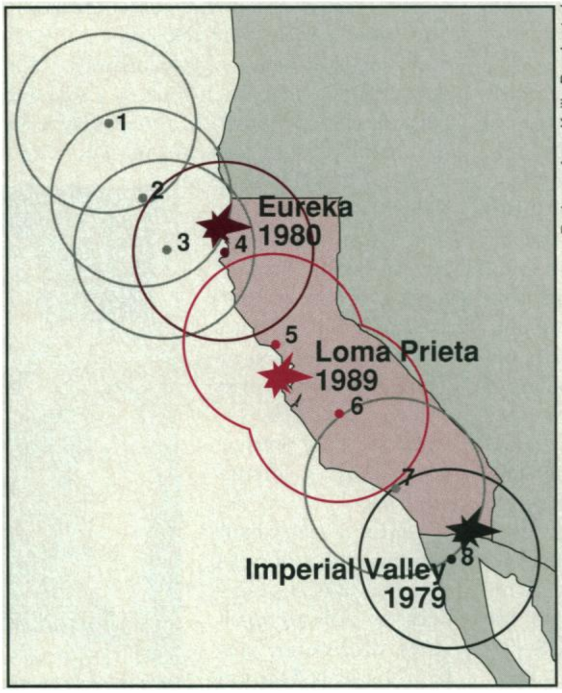
EARTHQUAKES ARE NOT THE USUAL STUFF of superpower summitry, but in Geneva in 1985 President Mikhail Gorbachev had some geophysical news for his newfound American friend, Ronald Reagan: Using a newly developed technique, Soviet scientists were predicting that a massive quake would probably strike Southern California sometime in the next 3 years. The White House took Gorbachev's warning seriously. Within a few days U.S. geophysicists were huddling to see what they could make of the prediction. In the end, these experts took a wait-and-see attitude. They waited, but the predicted quake failed to materialize.

Five years later, however, Soviet scientists are again prodding their U.S. colleagues to consider seriously their prediction method—and in the intervening years they've rung up some successes. They claim to have predicted the destructive Loma Prieta earthquake in 1989, another large one in Armenia in 1988, and five others around the world.

Still, for most U.S. researchers, it seems too good to be true. "I'm skeptical," says John Filson, who until last year was head of the U.S. Geological Survey's (USGS) earthquake office in Reston, Virginia. "I just don't know how robust [the Soviet method] is for predicting into the future."

The method's tentative reception in the United States may be due in part to its unfamiliar approach. Unlike American seismologists, who focus primarily on short segments of specific faults, the Soviet method looks at the pattern of seismic activity over a broad area, at least 165,000 square kilometers. The American approach has yielded intermediate-term forecasts—within a few years to a decade—for the major California faults, but most are rather vague. The U.S. estimate for the Loma Prieta fault segment was a 30% chance of a large earthquake in the next 30 years and for the Bay Area it was a better than 50-50 chance in the same 30-year period. The Soviets couldn't be as specific about the site for the next large California quake, but their method claims a success rate of 70% to 80% and narrows the time window from 30 years to 5 years.

The leader of the Soviet effort is academician Volodya Keilis-Borok, director of the Institute of Earthquake Prediction Theory and Mathematical Geophysics in Moscow. He and his colleagues have developed a computer algorithm that searches for patterns of unusual seismic activity that he and his group believe precede most large earthquakes. An early version of such an algorithm produced their failed Geneva summit prediction, but a revised algorithm saw a good chance of something big hitting northern California by 1990. Loma Prieta struck in October 1989.



Redrawn from Keilis-Borok *et al.*

Three hits in California. *Three times a computer algorithm developed by Soviet researchers has predicted California earthquakes. Twice, the successes were tests done in hindsight, but Loma Prieta was in advance.*

"This is the most promising method we have in this intermediate time scale," says Leon Knopoff of the University of California, Los Angeles, the recent recipient of the Medal of the Seismological Society of America. And Knopoff isn't the only prominent American sympathetic to Keilis-Borok's work. Such luminaries as Clarence Allen of Caltech, a past chairman of the National Earthquake Prediction Evaluation Council, and Frank Press, president of the National Academy of Sciences, have coauthored papers with the Soviet team.

Keilis-Borok attributes the method's accomplishments to its ability to recognize changes in the character of seismic activity that are harbingers of large quakes. Most of these changes have long been proposed for one quake or another, but a learning process went on for more than 15 years as the algorithm was designed, tuned, and redesigned to search for possible precursors such as heightened seismic activity, unusual quiescence, changes in the size of small quakes, and the increased clustering of events.

The algorithm is, to the say the least, complex. An early version looked at 12 traits of the seismic record each characterized by 6 or 7 parameters, but later versions did as well with fewer variables. In addition to this welter of parameters, there had to be rules that said when enough changes have accumulated to warrant a warning. These warnings, dubbed "times of increased probability" or TIPs, cover the particular region searched for precursor patterns, and the magnitude of the predicted quake is proportional to the area searched. The duration of the warning is usually 5 years. Recently, the Soviet group and Stuart Smith of the University of Washington have developed a method they believe can localize a warning to an area between 7% and 25% of the TIP area.

So if the technique is that powerful, why aren't American scientists flocking to adopt it? Part of the reason is that they don't entirely understand it. John Healy of the USGS in Menlo Park is the only outsider who has dissected the latest version of the algorithm—dubbed M8—and recoded it to run on a U.S. computer. It took him a year of close cooperation with the Soviets to get that far, and even he isn't entirely sure how it works.

"I don't understand the reasons for" the particular rules that determine a TIP, Healy says. "Many choices are quite arbitrary, and I think they may change from time to time. I think [the Soviets] worked on a lot of data over the years and just adjusted things until they worked." Such data fitting is fine by Americans; that is how an algorithm is refined to do a better job of explaining the data. It's just that many Americans aren't sure yet where the data fitting stops and prediction begins.

Another complaint among seismologists in the United States is that the algorithm may have been adjusted to work well on past large quakes that it was trained on, but, despite the claims of success, it may not work on future earthquakes. The Keilis-Borok group counters that the method has been tested as rigorously as it can be. After being trained on a given set of earthquakes, an algorithm was tested to see how well it could do in the same geographic area but at a different time or in an entirely different area. According to Keilis-Borok's estimation and published results, 70% to 80% of the TIPs produced in these hindcasting tests are successful. About 20% to 30% of the time a TIP is a false alarm, and there is no earthquake. Between 15% and 20% of the time TIPs miss large earthquakes that actually occur.

Knopoff has called such hindcasting results "phenomenal," but many U.S. researchers remain unimpressed. Statistician Mark Matthews of Stanford has worked with the M8 algorithm, and he says the abundance of adjustable parameters inevitably leads to a suspicion that the Soviet group "might do things that seem natural at the time but would introduce a bias" toward an unrealistic success rate in hindcasting.

American suspicions have only been aggravated by what is seen as the Soviet style of science. "Americans are almost pathological about requiring a clear documentation of a forecast," says tectonophysicist Wayne Thatcher of the USGS in Menlo Park. "The Russians don't do that." Thatcher's USGS colleague, seismologist Allan Lindh, complains that questions to Keilis-Borok and his associates about specifics of the algorithm too often elicit "smoke and mirrors. But they're extremely nice people, they're your guests, so it's hard to hammer on them the way you would an American." Matthews also cites the "Soviet style of giving circuitous answers to simple questions. There's a difference in perspective. As a statistician, I can't see why they don't publish certain figures and statistics. I ask them and they act like they don't see why I'm interested."

This less than ideal communication has contributed to much of the confusion over how well the algorithm works. For example, the first Soviet warning for northern California called for a magnitude 7.5 or greater quake before 1988, but by June of 1988, when the National Earthquake Prediction Evaluation Council had Keilis-Borok in for a talk, the warning had been extended until the end of 1991. Despite a prior request for "a written record of the actual prediction presented to the council and of the scientific basis for it," it took a full day for council members just to figure out what the prediction was. And now, according to Keilis-Borok, that TIP has been superseded by the results of a subsequent run of a slightly reconfigured M8 that produces a TIP ending in 1989. Minster, who reviewed a voluminous paper on TIPs for the council, found that "there is still too much black magic for comfort in the descriptions of M8."

Stanford's Matthews has been trying to sort out the science from the magic in the M8 algorithm. For one thing, he wondered which moderate earthquakes actually led to the Loma Prieta warning. He found that without the magnitude 3 earthquakes in a spot 225 kilometers north of the Loma Prieta epicenter, a TIP warning would not have been issued for the area. Such a large separation between precursor and eventual rupture would be enough to dismay many U.S. researchers (see box), but Matthews found a bigger problem—the crucial precursor earthquakes were in all likelihood manmade. They fall squarely in the Geysers geothermal area, where virtually all quakes large enough to have an impact on the algorithm's predic-

Earthquake Mind Set Shaken?

If a Soviet earthquake prediction method based on broad patterns of seismicity proves to be valid, American scientists are in for some serious rethinking of how earthquakes work. "If you look at the American point of view on earthquake prediction," says seismologist John Healy of the U.S. Geological Survey in Menlo Park, "we're very attached to the idea that each earthquake is an individual entity. If you want to predict it, you should look [for precursor activity] on or very close to the fault. For 20 years our program has been premised on this mind set." The reason is simple: According to conventional wisdom, the stress transmitted through the crust by distant events is presumably damped out within a few kilometers by the earth's crust.

Some Soviet researchers, and a few Americans, are urging that their colleagues look much farther afield. In order to predict the Loma Prieta earthquake of 1989, for example, Soviet seismologist Volodya Keilis-Borok and his colleagues at the Institute of Earthquake Prediction Theory and Mathematical Geophysics in Moscow searched for harbingers of the quake over circular areas 560 kilometers in diameter.

"It would be very strange if the precursors of a coming earthquake were to be concentrated in one place," Keilis-Borok told *Science*. "We started with this presumption" that they would not be localized. "It was obvious; it seems to be natural with me and my colleagues," he says. "When we processed the data, they confirmed it." While Americans trying to predict quakes cluster their instruments within one fault length of the incipient rupture, or even pierce the fault itself with instrumented drill holes, Keilis-Borok recommends looking for precursors out to five to ten times the length of the expected rupture.

Keilis-Borok bases his broad view of the earthquake process on his concept of a hierarchy of blocks that make up the outer rigid shell of Earth. The largest blocks are the tectonic plates: The boundaries between them, such as the San Andreas fault, are often the sites of large earthquakes. The plates "are divided into smaller blocks, like shields or mountain chains," he writes. "After 15-20 divisions, we come to the grains of rock of millimeter scale, if not less." No block is an island, according to Keilis-Borok. Each feels the motion of its neighbors, even if they do not touch directly.

Most American theorists have trouble with the long-range interactions that the Soviet prediction method implies. James Rice of Harvard University, a theoretician in the mechanics of faults, notes that the stress change induced by a fault rupture, even one as large as Loma Prieta, attenuates to insignificance within a distance equal to a few fault lengths. That would have put the Loma Prieta fault segment well out of range of the small to moderate quakes that the Soviet method assumes are precursors. He also sees no clear evidence in geodetic measurements that an entire region could be activated—both large and small faults at once—by a broad, deep-seated deformation of the crust. However, in both cases, Rice cannot rule out the possibility that the deep crust can behave in a way that produces such long-range interactions without being clearly detected from the surface. It's just that he has no good theoretical reason to think that it does.

Theoretical support or not, the crust now and again acts as if perhaps it does indeed make long-distance connections. Its latest hint is the behavior of the Old Faithful Geyser in Calistoga, California. Paul Silver of the Carnegie Institution of Washington Department of Terrestrial Magnetism and his colleagues report that the intervals between eruptions of the geyser began to increase sharply 60 hours before Loma Prieta struck, presumably when straining of the crust reduced the geyser's water supply. But Calistoga is 180 kilometers from the epicenter. That's hardly the place most American researchers would have looked for clues to the coming quake. ■ **R.A.K.**

tions are produced by the withdrawal of steam for electric power production and the injection of steam condensate back into the ground.

If the Geysers quakes are manmade, notes David Oppenheimer of the USGS in Menlo Park, they should not be connected with a TIP. They could not be induced by the buildup of strain at Loma Prieta, but conversely, given conventional views of how the crust behaves, it is unreasonable to suggest they helped trigger the distant earthquake.

Matthews' discovery is not a fatal flaw in M8: Two overlapping TIP regions both predicted the Loma Prieta earthquake. But it's the kind of problem most skeptics feel the Soviets haven't done a very good job of explaining.

Both American and Soviet researchers agree that to prove the usefulness of the prediction method, it will have to forecast more earthquakes successfully. Healy, in cooperation with Keilis-Borok and his group, is setting up a version of M8 at Menlo Park that will never be altered as it cranks out forecasts of earthquakes around the Pacific rim. Then it will be a question of time, probably 5 to 10 years, until matters of style become irrelevant and unassailable results decide whether a broad view of earthquakes really works.

■ RICHARD A. KERR

ADDITIONAL READING

V. I. Keilis-Borok *et al.*, "Intermediate-term prediction in advance of the Loma Prieta earthquake," *Geophys. Res. Letts.* 17, 1461 (1990).

Radioastronomers Seek a Clear Line to the Stars

The chatter of voices and data beamed to Earth from communications and surveillance satellites is beginning to drown out whispers from the cosmos, radioastronomers say. Navigational satellites such as the United States' Navstar and the Soviets' Glonass—as well as radio broadcasts, airplane telephones, and even taxi dispatches—have been interfering with radio signals from distant galaxies. And radioastronomers expect the problem to get worse. The chief reason: since the mid 1980s it has become easier and cheaper to make equipment that transmits radio waves at frequencies of interest to astronomers.

There are, however, two recent indications that the astronomers' concerns are being heard. Scientists struggling to protect threatened radio space have persuaded at least two encroaching organizations, the U.S. Customs Service and Motorola Communications Inc., to back off.

Motorola could have created a major new headache in 1994 with its planned launch of Iridium, a communications network of 77 satellites that will connect people with cellular phones who live or work in remote areas untouched by existing cellular phone networks. Lawrence Moore, a public affairs officer with Motorola's Government Electronics Group, said the company is seeking approval from the Federal Communications Commission to operate the Iridium network at frequencies ranging from 1610 to 1626.5 megahertz. Unchecked broadcasts in this range, astronomers say, would interfere with the radio waves emitted by hydroxyl radicals—electrically charged molecules that signal the presence of hydrogen and oxygen, and, potentially, developmental shifts in the formation of stars. Astronomers detect the spectral lines of hydroxyl radicals in four bandwidths, one of which falls between 1610.6 and 1613.8 MHz.

After learning of astronomers' concerns, however, Motorola is modifying its satellite. Company scientists, Moore said, aim to program the Iridium system to switch bandwidths whenever the satellites come within range of a sensitive radioastronomy antenna.

"Legally they don't have to do this, but morally they probably feel like they should," said A. Richard Thompson, a radioastronomer at the National Radio Astronomy Observatory (NRAO) in Charlottesville, Virginia. Thompson and Tomas E. Gergely of the National Science Foundation negotiated with Motorola to preserve researchers' access to stellar radio waves. The astronomers had no legal leverage because the FCC is poised to give Motorola primary user status, entitling it to exclusive use of this frequency band, while radioastronomy would be relegated to secondary status. However, a footnote in the International Telecommunications Union regulations states that primary users should try to "take all practicable steps to protect the radioastronomy service from harmful interference."

"We're just trying to preserve useful frequencies for as long as we can."

—RICHARD THOMPSON

Similar problems arose recently with transmitters belonging to the U.S. Customs Service. Since the mid 1980s, Customs has installed six "aerostat" surveillance balloons around the southern perimeter of the continental United States to watch for small planes that may be smuggling drugs across the border. The aerostats, tethered helium-filled blimps that hover about 10,000 feet in the air, transmit radio waves in the 1215 to 1350 MHz range.

It is in this range, however, that radioastronomers detect atomic hydrogen spectra emitted by distant galaxies whose radio waves are greatly red-shifted. Some of the farthest galaxies from the Milky Way are detected by atomic hydrogen spectra in the low 1300s MHz, Thompson said, and "these spectra have been enormously important for mapping out the structure of galaxies."

Recently, radioastronomers were concerned that interference from the SOWRBALL aerostat, located above Fort Huachuca, Arizona, might interfere with their observations at Kitt Peak. However, they discussed the problem with Customs officials before SOWRBALL was deployed and agreed that whenever its swivelling radar pointed toward the telescope, the signal would be cut off, unless the radar was tracking a plane. On the other hand, according to NRAO scientist Pat Crane, an aerostat above Marfa, Texas is close enough to a research antenna in Fort Davis that the radioastronomers there must use a special filter to "clean up" the signal they get from space.

Despite these compromises, Thompson foresees a future in which an increasing demand for the radio waves erodes the ability of radioastronomers to collect data. Said Thompson, "We're just trying to preserve useful frequencies for as long as we can." Over the long term, astronomers fear their prospects for halting the spread of commercial transmissions are about good as King Canute's in the 11th century, when he set his throne on the beach and commanded the tide to withdraw. ■ RICHARD STONE

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