MEETING AMERICAN GEOPHYSICAL UNION

Earthly Circuitry, Breathing, and Shakes

SAN FRANCISCO—When 9000 geophysicists gathered here last month for the annual fall meeting of the American Geophysical Union, they heard the usual potpourri of earth and planetary sciences. Subjects included predicting eruptions and earthquakes in Iceland, piggyback monitoring of atmospheric electrical circuits, and odd annual pulsations of the solid earth.

Predicting Icelandic Fire and Shakes

Geophysicists have had a decidedly mixed record predicting the future. Successful warnings of volcanic eruptions, such as the 1991 Mount Pinatubo catastrophe, did not save 14 volcanologists from sudden death in five incidents over 10 years. Most seismologists have given up predicting earthquakes after failing to find any reliable warning signs preceding quakes. But the news out of Iceland is decidedly upbeat. Last year, Icelandic geophysicists issued successful and surprisingly specific predictions for the eruption of the Hekla volcano in February and a magnitude 6.6 earthquake in June. The successes, although not unqualified, point up the virtues of patient monitoring.

Icelandic researchers had been waiting 9 years since the last small eruption of Hekla 120 kilometers east of Reykjavík, geophysicist Kristjan Agustsson of the Icelandic Meteorological Office (IMO) in Reykjavík told those attending the meeting. Although the volcano had been erupting about every 10 years, "we almost believed Hekla was unpredictable" in the short term, says seismologist Páll Einarsson of the University of Iceland. But seismometers had caught a burst of small earthquakes in the hour before the previous eruption in 1991, so when tiny quakes were observed beneath the normally quiescent volcano shortly after 5:00 p.m. on 26 February, workers at IMO and the university took note. By 5:29 p.m., the intensifying swarm prompted the IMO to warn the Civil Defense of Iceland of a "possible imminent" eruption.

IMO predictors weren't finished. About half an hour before the 1991 eruption, a strainmeter in a borehole about 15 kilometers from the volcano recorded an increasing crustal squeeze as magma pushed its way upward from a chamber 4 kilometers beneath the volcano. After nearly identical compression began on the same instrument at about 5:45 p.m., IMO issued a prediction at 5:53 that "an eruption was certainly to be expected within 20 minutes." The eruption began at 6:17.

"They really nailed it," says volcano seismologist David Hill of the U.S. Geological Survey in Menlo Park, California. The warning from the rising magma dike should be broadly applicable, says geophysicist Alan Linde of the Carnegie Institution of Washington's Department of Terrestrial Magnetism, who helped operate the strainmeter. "Will we see something like this before eruptions at other volcanoes?" he asks. "I'm optimistic we will. You can't escape physics."

No surprise. Hekla volcano gave a clear warning of its latest eruption, allowing a precise prediction.

PHOTO CREDIT: H. SIGURJON

Although geophysicists don't yet understand the far more complex physics of a quake, Icelandic researchers have made some progress with the South Iceland Seismic Zone. A broad, 70-kilometer-long region on the southwest coast between Hekla and Reykjavík, the zone contains about 10 parallel, north-south–trending faults. They tend to fail in a sequence of magnitude 6 to 7 quakes, starting in the east and progressing westward as the rupture of one fault transfers stress to its neighbor (*Science*, 22 October 1999, p. 656). From historical records, researchers knew that two narrow north-south segments of the zone had not failed in 300 years and that the last sequence swept through the zone almost 100 years ago. Since the 1980s, Icelandic researchers have agreed that the zone in general and those two gaps in particular were due for renewed activity.

That long-term forecast panned out on 17 June when a magnitude 6.6 quake struck the easternmost "seismic gap." But hopes for a short-term prediction, based on extensive monitoring systems installed in the zone, were frustrated. "We didn't recognize any precursors before that earthquake," seismologist Ragnar Stefánsson of the IMO told the meeting attendees. However, all eyes did turn to the west, where the next gap lay. By 20 June, it was obvious that the small earthquakes triggered in that gap by the mainshock 15 kilometers to the east were continuing rather than petering out as normal aftershocks do. IMO notified national and local civil defense authorities that another earthquake of similar size would probably strike soon, most likely in the nearby gap. Twenty-four hours later, the predicted quake hit. There were no deaths or injuries, but "people have been very grateful," says Stefansson, having been alerted to secure their breakables.

In hindsight, says Stefansson, "there are some signs that increase our optimism we will be able to detect precursors before even the first earthquake in a sequence occurs." In the months to hours before the first quake, shifting patterns and orientations of microearthquakes, a pulse of radon gas in the ground, and changing water levels in a borehole all pointed toward an impending quake, he says, conceding that "this is always easier to see afterwards." Although many seismologists have been repeatedly disappointed by similarly promising observations, geodesist Roger Bilham of the University of Colorado, Boulder, is encouraged. "If you persist in looking where you expect an earthquake," he says, "you'll see precursors. This [event] is what we need to renew interest in short-term prediction."

–RICHARD A. KERR

Atmosphere's Power Grid Exposed

Storms from the sun spark an electromagnetic frenzy in Earth's upper atmosphere. Some of that intense activity appears as curtains of shimmering auroras, but the rest of the electrical currents are invisible. Now, thanks to a surprising use of an array of costly communication satellites, researchers have devised a way to map the electrical power flowing through the planet's ionosphere. The new technique could lead to better warnings of surges that can zap utility lines. "This is a great piece of work," says space physicist William Lotko of Dartmouth College in Hanover, New Hampshire. "It's at the intersection of science, technology, business, and society."

Earth's magnetic field carves a comet-shaped cavity in the solar wind, a constant stream of charged particles from the sun. When the sun acts up, changes in the wind's intensity can ripple this vast bubble "like a wind sock," says atmospheric physicist Brian Anderson of the Johns Hopkins University Applied Physics Laboratory in Laurel, Maryland. Those clashes drive millions of amperes of currents over Earth; most of that energy funnels toward the poles.

To calculate the strength and direction of those currents, researchers must measure both the electric and magnetic fields far overhead. Combining the two fields yields a map of the electric power, which usually streams down toward the planet along narrow, curved bands. A network of a dozen auroral radars, called SuperDARN, tracks the electric fields near the North Pole. Magnetic fields at high latitudes, however, have been elusive, because few scientific satellites travel in polar orbits that carry them through those regions.

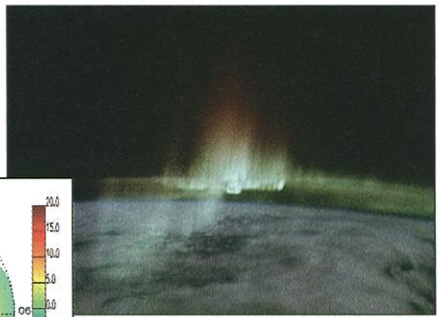
The solution came from an unexpected source: the Iridium network, a $5 billion constellation of 72 satellites that provided global telephone service to customers of Motorola. The operating company declared bankruptcy last year, when the pricey service failed to attract enough users. In December, however, a new company revived Iridium with a 2-year, $72 million contract from the Defense Department. That's good news for Anderson and his colleague Colin Waters of the University of Newcastle in New South Wales, Australia, who figured out how to use Iridium data to chart the polar magnetic fields.

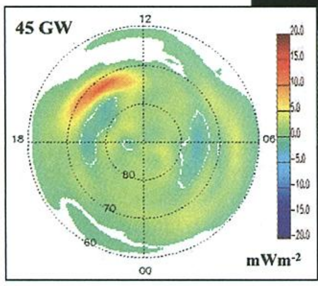
Each satellite orbits from pole to pole at an altitude of 780 kilometers and carries a magnetometer to help engineers monitor conditions in orbit. By combining the hourly magnetic field readings with the SuperDARN data, Anderson and Waters derived the first dynamic maps of the electrical power flowing into and out of the ionosphere. Typical power levels are 40 billion watts for the region northward of 60 degrees latitude, although they flicker wildly depending on the sun's mood. Much of the power focuses within "hot spots" that ebb and flow from hour to hour. "We can see the currents generated throughout an entire solar event, and we can handle the peak intensities," Anderson says. "Before, it was like trying to measure a hurricane with an anemometer that only goes to 10 miles [16 km] per hour."

Anderson and Waters are pushing for even faster data transfer to create new power maps every 10 minutes or so. That capacity could lead to a system to warn electric utilities about the movements of intense hot spots. Severe electrical fluxes in the atmosphere induce currents in the ground and along high-power transmission lines, Lotko notes. With just a short warning, he says, utility companies could prevent dangerous surges.

Other scientists hope to gain new insights into the interactions between the sun and Earth's protective magnetic sheath. "This shows that data from commercial and military satellites can give the space science community a huge boost," says space physicist Lie Zhu of Utah State University in Logan. "We should push the government hard in that direction."

–ROBERT IRION





Colorful current. This aurora *(above)* traces invisible currents that pulse above Earth's poles. Scientists have now mapped electric power flowing into the atmosphere *(left)*.

Earth's Breathing Lessons

Earth is never still. Any large earthquake sets it ringing like a bell for hours and days. The wind, apparently, causes it to "hum" continually at a high pitch. Now, some suspect that Earth is also "breathing," compressing its crust and extending it once each year. This cycle is most evident in Japan, geophysicists told the meeting, where it may be responsible for that country's "earthquake season." Elsewhere, it may lead some volcanoes to erupt almost solely between September and December.

Detecting heavy breathing takes some extremely sensitive instrumentation. Geodesist Makato Murakami of the Geographical Survey Institute in Tsukuba, Japan, and volcano seismologist Stephen McNutt of the University of Alaska, Fairbanks, reported that a network of 50 Global Positioning System (GPS) stations across northeast Japan is detecting 30 millimeters of east-west crustal shortening a year as the diving Pacific tectonic plate snags on the bottom of the island nation. But the compression isn't steady: The squeeze builds 15% faster than average in the fall and 15% slower in the spring. Although GPS instruments must weather all sorts of environmental insults, such as heating by the sun, Murakami and McNutt believe they have eliminated all the likely culprits besides real breathing of Earth.

Geodesist Kosuke Heki of Japan's National Astronomical Observatory in Mizusawa told the meeting attendees that he has independent data showing similar seasonal changes in northern Japan. He analyzed observations of a strainmeter installed in a 150-meter-long tunnel dug into granite bedrock in northeast Japan and found much the same rhythmic squeezing and release as seen by GPS.

GPS and strainmeters aren't the only things that seem to pick up planetary breathing. McNutt reported identifying four volcanoes—Pavlof in Alaska, Oshima and Miyake-jima in Japan, and Villarica in Chile—that have a strong preference for erupting between September and December, a preference significant at better than the 99% level in the case of Pavlof. At the well-studied Pavlof, an autumnal squeeze is presumably forcing magma out of the volcano's magma chamber late in the year, says McNutt, like toothpaste squeezed out of a tube, and easing the pressure in the spring to discourage eruptions then. And in 1999, seismologists Masakazu Ohtake and Hisashi Nakahara of Tohuko University in Sendai, Japan, confirmed that since 684 A.D. the great earthquakes of central Japan have without exception struck from August to February. The right kind of squeeze at the right time might alternately encourage or discourage quakes, notes Heki.

Geophysicists have traditionally shied away from making such connections. "In the past, we've tended to dismiss things without an obvious physical mechanism," says volcano seismologist David Hill of the U.S. Geological Survey in Menlo Park, California. But after California's 1992 Landers earthquake reached out hundreds of kilometers to trigger quakes by some still mysterious means, Hill, for one, became more receptive. At the meeting, he says, "I was struck that there may be something" to Earth breathing and eruptions or earthquakes.

Geophysicists will first have to confirm the reality of breathing in Japan and search elsewhere, then pursue the matter of mechanism. McNutt had originally suggested that an added load of wind-blown coastal water might be forcing magma out of Pavlof. In Japan, Heki sees signs that the weight of a winter's snowfall on the western mountains of northern Japan may suffice. McNutt allows that the snow load may play a role, but he wonders if that would be enough. Perhaps more than one mechanism, he says, is needed to unsettle Earth.

–RICHARD A. KERR

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