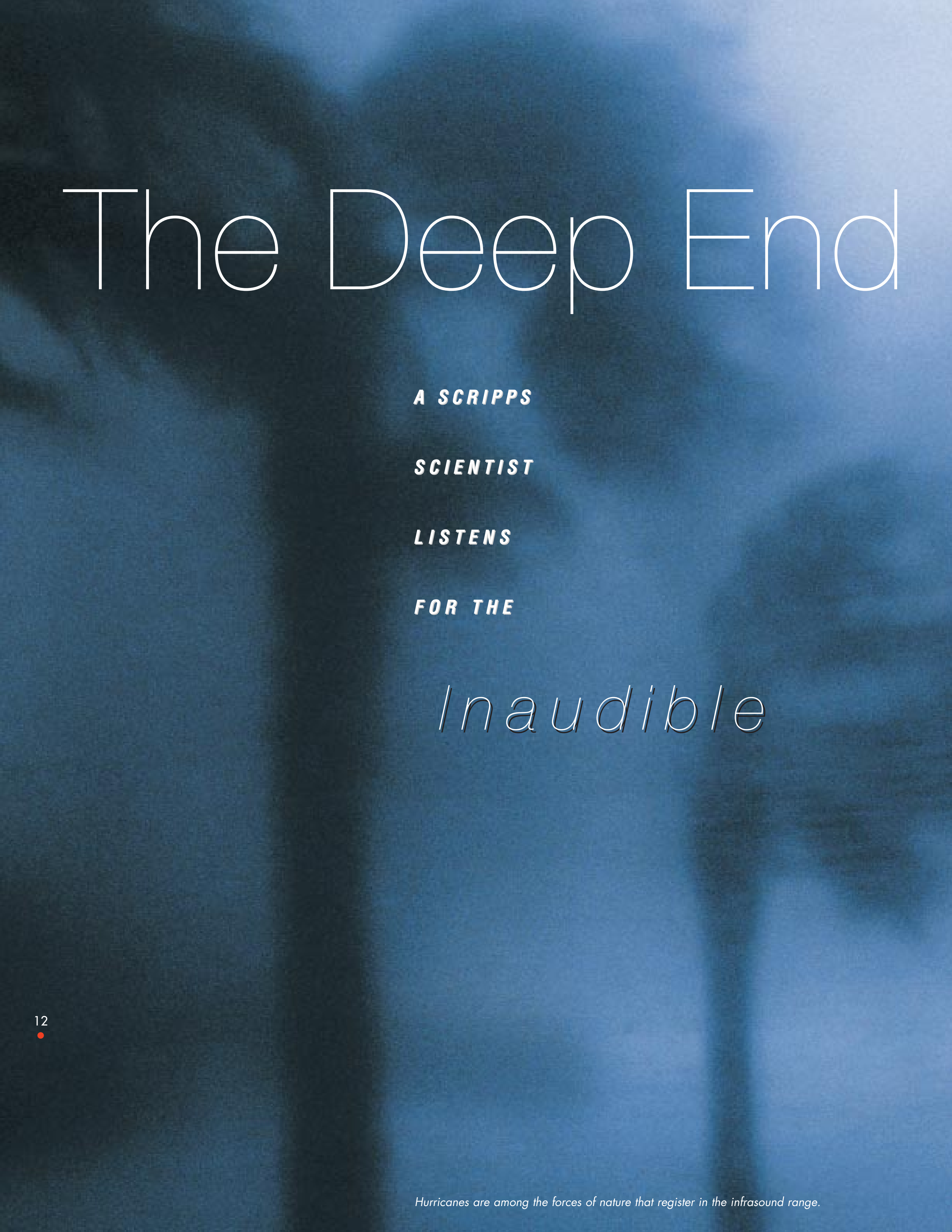
The Deep End

A SCRIPPS SCIENTIST LISTENS FOR THE

Inaudible



Hurricanes are among the forces of nature that register in the infrasound range.

# of Sound

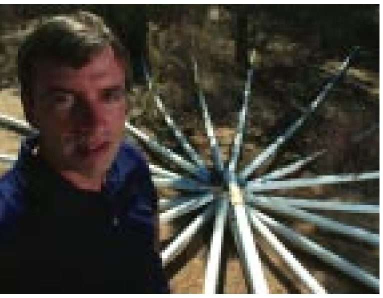
BY ROBERT MONROE

On April 23, 2001, a meteor struck Earth's atmosphere over the Pacific Ocean between California and Hawaii. The force of the impact was comparable to that of the atomic bomb dropped on the city of Hiroshima in Japan.

Few people heard it, however, because the audible part of the explosion dissipated before it reached Earth's atmosphere. But the blast was "heard" at low frequencies—and not just in the Pacific Rim. Sound from the crashing meteor traveled 11,000 kilometers (6,835 miles) to Germany, and sensors in India picked up something that day as well in an acoustic range long recognized by scientists but barely explored until now.

This range is called "infrasound," and after decades of relative silence, infrasound research is making a comeback at places like Scripps Institution of Oceanography. What infrared is to the eyes, infrasound, which registers below 20 hertz, is to the ears. Both exist in ranges humans cannot detect without help from sensitive instruments. Infrasounds are created almost exclusively by the biggest forces in nature, like last year's crashing meteor.

For decades, scientists have been interested in listening for subtle signals made by volcanoes about to



burst and tornadoes about to touch down, but the field of natural infrasound research originated from that first atomic bomb during World War II. Infrasound sensors are now used to listen for nuclear bombs detonated in secret.

To help governments and scientists monitor both natural and anthropogenic phenomena, Scripps researchers are participating in a project to build a worldwide infrasonic monitoring system consisting of infrasonic microphones as well as seismic, hydroacoustic, and radiation sensors. The network has primarily been funded to scan low frequencies for nuclear explosions, but the first beneficiaries will be the researchers who can now hear planet Earth's outbursts with unprecedented clarity.

ON SEPTEMBER 11, 2001, AN INFRASOUND STATION IN THE CENTRAL CANADIAN PROVINCE OF MANITOBA PICKED UP THE COLLAPSE OF THE WORLD TRADE CENTER TOWERS.

"As a rule of thumb, for something in the atmosphere to generate such long-period acoustic energy, it has to be significant," said geophysicist Michael Hedlin, a lead scientist in Scripps's infrasound project. "It has to be large, pushing a lot of air such as a hurricane or tornado, or it has to move very fast like a rocket or supersonic aircraft, or it has to be explosive. Anything that significant happening in the atmosphere is important to us."

This page, *In the brush-covered desert south of Palm Springs, a Scripps microbarometer element is identified by its distinctive spokelike sound filters.*

Below, *Scripps geophysicist Michael Hedlin surveys part of the array at the Scripps Cecil H. and Ida M. Green Piñon Flat Observatory.*

detected 160 kilometers (100 miles) away. With distance, the sound's energy is absorbed because of the viscosity of air. In contrast, the infrasound waves generated by Krakatoa slowly propagated around the world—and not just once, but several times.

Since then, infrasounds generated by many natural and human-made events have been discovered and studied. Hurricane researchers like Scripps alumnus Milton Garces, now at the University of Hawaii, listen for the collisions of ocean waves that accompany brewing storms, for instance. Infrasounds from certain nuclear bomb tests have traveled all the way around the world. And on September 11, 2001, an infrasound station in the central Canadian province of Manitoba picked up the collapse of the World Trade Center towers.

INFRASOUND'S STORMY HISTORY

Scientists' fascination with the deep end of sound is well documented since the nineteenth century. In 1883, the volcanic eruption of Krakatoa in Indonesia killed an estimated 36,000 people. On the other side of the world, scientists picked up its infrasonic signals by detecting short-lived changes in air pressure caused by the explosion. They were using barometers similar to those a meteorologist uses to identify changes in atmospheric pressure associated with weather systems.

The sounds audible to the human ear squeeze and push air molecules as do infrasonic waves, but they are relatively short lived. As a consequence, they travel shorter distances than volcano-sized growls. Only the loudest sounds, such as a sonic boom or major explosion, can be

Above, *The International Monitoring System network is scheduled to include some 60 stations across the globe.*

Between midnight and 6 a.m., when local atmospheric turbulence dies down, the Piñon Flat Observatory is one of the quietest places in the world, infrasonically speaking. Between 2 and 3 p.m., it is one of the noisiest.

Scripps geophysicists Jon Berger (left) and Mark Zumberge use special machinery to spool fiber-optic cable that can sense changes in air pressure.

HEARING WITH LIGHT

THE NEXT GENERATION of infrasonic sensors probably won't hear infrasound at all but will "see" it through optical fiber.

Geophysicists Jon Berger and Mark Zumberge of the Cecil H. and Ida M. Green Institute of Geophysics and Planetary Physics (IGPP) at Scripps are experimenting with optical interferometry, which uses laser light to measure tiny fluctuations in a fiber-optic cable. The amount of strain on the cable, which is carefully wrapped around flexible hose, is influenced by ambient temperature, composition of the fiber in the cable, and air pressure. If the first two factors can be accounted for, all that's left is the influence of acoustics.

Berger said that the new sensors should be less expensive than microbarometers and, because of the way they detect infrasounds, will be less vulnerable to local turbulence and other distortions. Microbarometers pick up sound fed through long filtering pipes. Portions of the sound can be lost during the travel time from one end of the filter to the microbarometer. Fiber-optic cable, on the other hand, uses a distributed sensor, reading air pressure all along the length of the pipe. Researchers then average out those readings to come up with a single, accurate recording.

The Defense Advanced Research Projects Agency, a division of the U.S. Department of Defense, is just one party interested in this technology. The agency is intrigued by the interferometer's use as a high-powered microphone for subaudible and audible sounds. "Because we're using light, there's nothing that limits this to infrasound," Berger said.

Berger and Zumberge claim that "at certain frequencies, [the interferometer] is an order of magnitude better" than microbarometers when tested in head-to-head competition. "This is theoretically superior. Whether we can build something superior in practice remains to be seen," Berger said.

Infrasound initially became important to the U.S. government when the Soviet Union detonated its first atomic bomb in 1949. The search was on to find a reliable way to spy on the developing Soviet atomic arsenal, and the United States began using infrasonic monitors in the atmosphere, the oceans, and the solid earth. Scripps played an important role by monitoring seismic signals for possible underground tests.

Use of infrasound technology, however, was hobbled for a number of reasons. The U.S. government classified most of its infrasound records, making information sharing among scientists difficult. Meanwhile, other technologies used to monitor nuclear explosions were gaining favor. The Limited Test Ban Treaty, signed by 108 countries in 1963, banned nuclear weapon tests in the atmosphere, oceans, and space but not in the earth, literally driving the nuclear arms race underground. As a result, seismic monitoring became the treaty's most important tool for measuring nuclear explosions. By the late 1960s, improved satellite technology, which could scan the

Below, *Underground nuclear testing in the state of Nevada.*

atmosphere for bomb flashes, eclipsed infrasound as the primary atmospheric monitor.

Infrasound monitoring continued, though, said Alfred Bedard, an aerospace engineer at the National Oceanic and Atmospheric Administration, and was supported by institutions and governments that commissioned research, such as the state of Colorado's recent commission for the study of infrasounds generated by avalanches.

"We managed to just chug along," said Bedard, who has been researching infrasound since the late 1950s. "We kept our hardware intact. We kept our diagnostic equipment intact. Every once in a while we'd make an improvement."

REVIVAL OF THE FITTEST

It would take a renewed interest in nuclear testing to spark the field's renaissance. That came about in the 1990s, when the world realized that nukes were not just for the world's superpowers and that satellites were not an infallible surveillance tool.

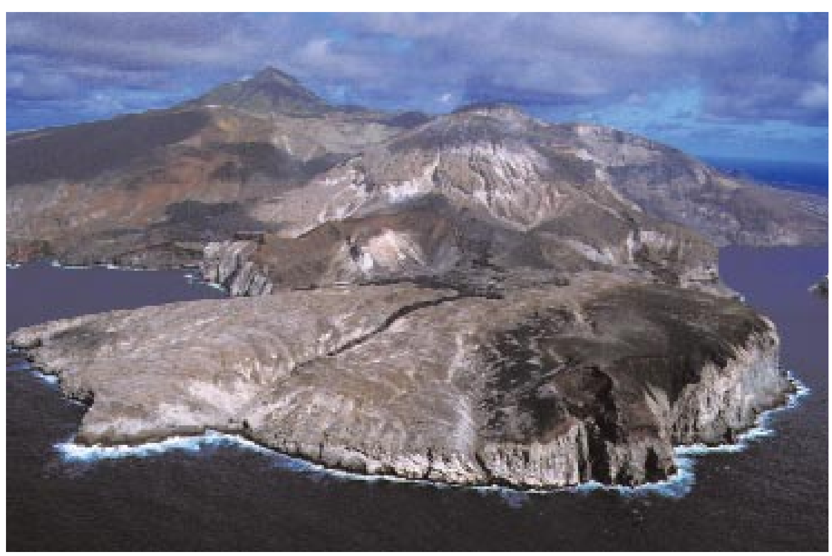
By the middle of the decade, nearly 2,000 nuclear tests had been conducted worldwide and 44 countries possessed nuclear power of some sort. Israel and South Africa were rumored to have joined the club of countries possessing weapons. India and Pakistan proved to each other and to the rest of the world that they, too, were members of this club when they publicly tested nuclear weapons as a show of power.

Based on the original 1963 treaty, the Comprehensive Test Ban Treaty first took shape in 1993. Three years later, the United Nations General Assembly adopted a final document banning testing of nuclear weapons anywhere in the world. To enforce compliance, the treaty organization created the International Monitoring System (IMS) despite a still unmet requirement that all 44 nuclear countries ratify the treaty.

The IMS network consists of geophysical sensor stations located around the world that monitor seismic signals, release of radioactive materials into the atmosphere, hydroacoustic readings, and infrasounds.

Infrasound was chosen because of the limitations and cost of

Top, *A solar-powered antenna beams infrasound readings from microbarometers to computers for analysis.* **Middle,** *Sound filter arrays are buried, if possible, to further reduce unwanted noise.*



Above, *A monitoring array is scheduled to be built on Ascension Island, located in the so-called "nursery" of Atlantic hurricanes off Africa's west coast.*

satellites, a technology that has the potential for false readings and is difficult to share among countries with limited coverage capabilities. In addition, infrasound monitoring acts as a deterrent to a country that might test weapons under violent weather systems, in which a mysterious flash could be attributed to a number of sources such as lightning or related phenomena known as "sprites." It's difficult to say, said Bedard, whether that's actually happened.

"There's been some evidence of suspicious things in the atmosphere that has never really been resolved," he said.

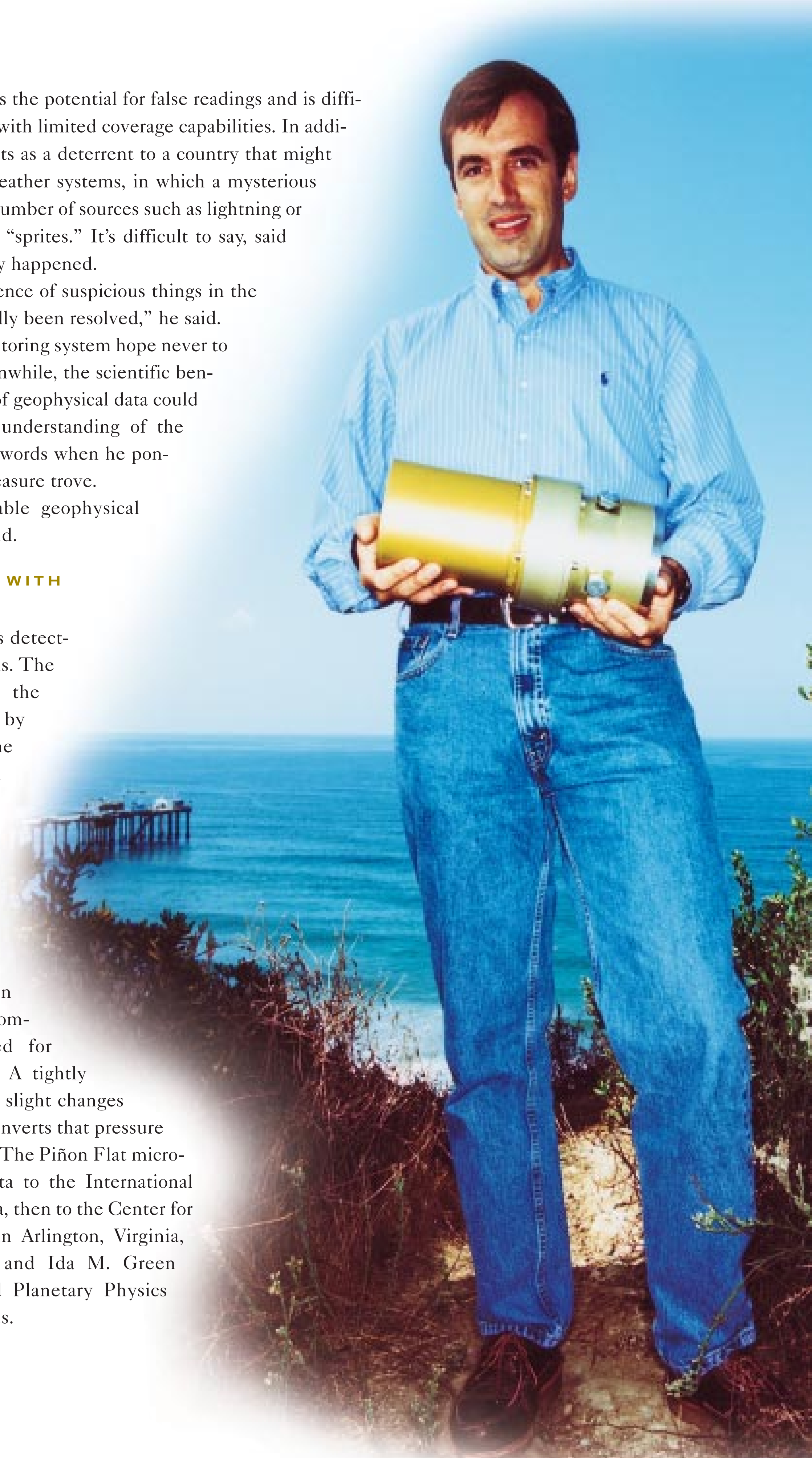
The architects of the monitoring system hope never to hear a nuclear explosion. Meanwhile, the scientific benefits of continuous collection of geophysical data could greatly advance researchers' understanding of the planet. Bedard doesn't mince words when he ponders the potential of such a treasure trove.

"This is the most valuable geophysical resource ever created," he said.

AROUND THE WORLD WITH EIGHT ARRAYS

To date, the IMS network has detected no secret nuclear explosions. The 2001 meteor strike rates as the biggest event yet recorded by Scripps's array, located at the Cecil H. and Ida M. Green Piñon Flat Observatory south of Palm Springs. Around midnight on April 23, infrasound waves reached the array, a series of microbarometers installed on the desert floor.

The devices are similar in basic operation to aneroid barometers, tools commonly used for meteorlogical measurements. A tightly sealed chamber reacts to very slight changes in air pressure, and a sensor converts that pressure change into an electric signal. The Piñon Flat microbarometers transmit their data to the International Data Center in Vienna, Austria, then to the Center for Monitoring Research based in Arlington, Virginia, and back to the Cecil H. and Ida M. Green Institute of Geophysics and Planetary Physics (IGPP) on the Scripps campus.



An individual microbarometer cannot tell much about the magnitude or location of an infrasonic event. Hence, Scripps's desert facility includes not one but eight microbarometer stations spread out across two kilometers (one mile). Each station consists of spokes of filtering pipe, which radiate from each barometer and help solve infrasound's biggest problem: discriminating important sounds from unimportant ones. The largest station measures about 70 meters (230 feet) across.

The hollow PVC pipes are fitted with metal mesh at the end to keep out animals and debris that might distort or muffle signals. There are still ambient sounds that bounce around inside the pipe (think of what you hear when you put a seashell up to your ear). The Scripps team, through some complex engineering feats, has found a way to keep those sounds from reaching the microbarometer, Hedlin said.

A native of Saskatoon, Saskatchewan, Hedlin came to Scripps in 1986 and earned his Ph.D. in 1991. After exploring for oil in Canada, he returned to Scripps about the time the test ban treaty was becoming international law. He has taken a six-year detour from his career in seismology to concentrate on infrasound.

> "ANYONE WHO WOULD CONSIDER CONDUCTING A TEST [HAS] TO BE VERY CAREFUL, BECAUSE WE'RE LISTENING."
>
> —MICHAEL HEDLIN, SCRIPPS GEOPHYSICIST

American representatives of the Comprehensive Test Ban Treaty Organization invited Scripps to help build and operate the monitoring network. Researchers at the institution, like Hedlin and IGPP's Jon Berger, had already established Scripps as an infrasound center, and had conducted site surveys to validate the appropriateness of locations for infrasound stations around the world. In addition to the Piñon Flat site, Scripps has built a microbarometer array near Spokane, Washington, and has proposed to build others on Ascension Island and Cape Verde off Africa's west coast, a region where many Atlantic Ocean hurricanes are born.

As part of the larger IMS, eight arrays are planned for construction in the United States, which is one of the countries that has not ratified the test ban treaty. Several U.S. institutions will install them in places as far away as Antarctica. In all, the IMS will have 60 such infrasound arrays around the world. Just as eight microbarometers are better than one at Piñon Flat, such an unprecedented number of infrasonic micro-

Left and above, *Hedlin shows off a microbarometer, inside and out.*

Backdrop, *The April 23, 2001 meteor strike as plotted by six of the elements in the Piñon Flat Observatory.*

phones will make possible much finer analysis of the infrasonic range.

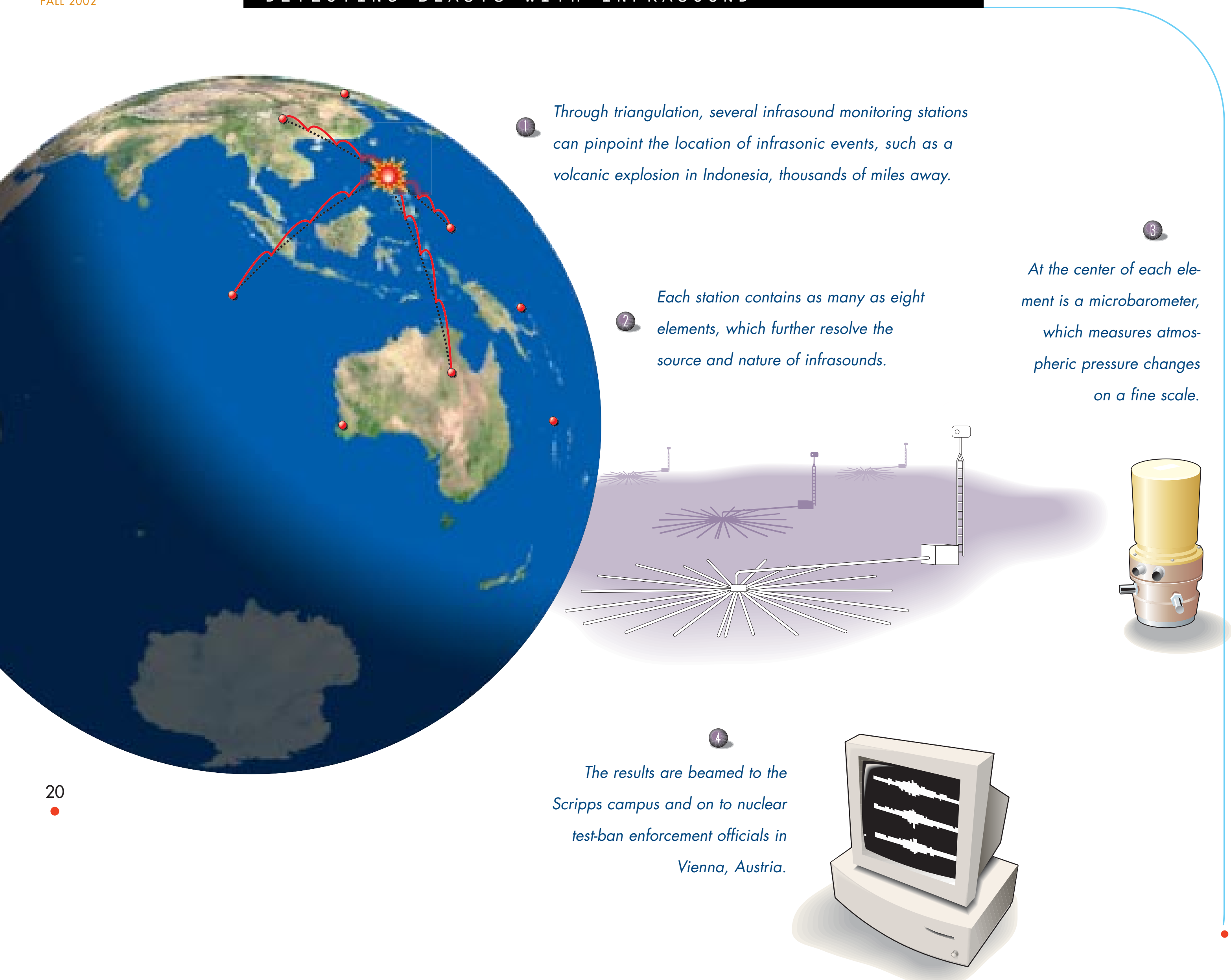
By processing array recordings, researchers are able to increase the amplitude of faint signals from storms on land or at sea, relative to the constant din that results from turbulence in the atmosphere, and estimate the direction of a storm. Through basic techniques like triangulation, multiple arrays can be used to track the location and intensity of the storm.

When the infrasound signals of the IMS are cross-referenced with the network's continuous seismic readings, the system becomes even more sensitive.

"Now we can hear the smallest things," said Garces, whose Hawaiian array can hear Antarctic storms if there is no severe weather in between. "Imagine seismology 30 or 40 years ago. That's where we are in infrasound today."

Hedlin agrees, saying researchers are just beginning to understand infrasound's potential. For example, using archived infrasonic data from IMS, scien-

DETECTING BLASTS WITH INFRASOUND



"This is the most valuable geophysical resource ever created."

—Alfred Bedard, NOAA Aerospace Engineer and infrasound veteran

The Laboratory for Atmospheric Acoustics at Scripps Institution of Oceanography, otherwise known as L2A, conducts research into human-made and natural atmospheric phenomena that generate sound in the atmosphere. A prerequisite for studying these sources is understanding what has happened to the sound as it propagates to the receiver.

For this reason, the group studies the propagation of sound through the moving, turbulent atmosphere. The group also studies how the signals can be recorded clearly amid interference from atmospheric noise.

tists could learn about the frequency of meteor strikes never before detected and determine the probability of dangerous ones.

As for the stated purpose of the worldwide network as a sentinel for nuclear testing, Hedlin believes it might never stop terrorists from detonating a small "dirty bomb" of nuclear material. They would be working on too small a scale and probably wouldn't be too concerned about testing. That only leaves as potential perpetrators established national programs "that would like to make sure they get it right the first time," Hedlin said. Possibly all that will come of the deterrence program is years of incredible scientific data.

"Anyone who would consider conducting a test realizes that there are these listening posts worldwide, and if they want to get away with it, they have to be very careful," Hedlin said, "because we're listening."

This page, *Low brush and high technology meet at the Piñon Flat Observatory.*