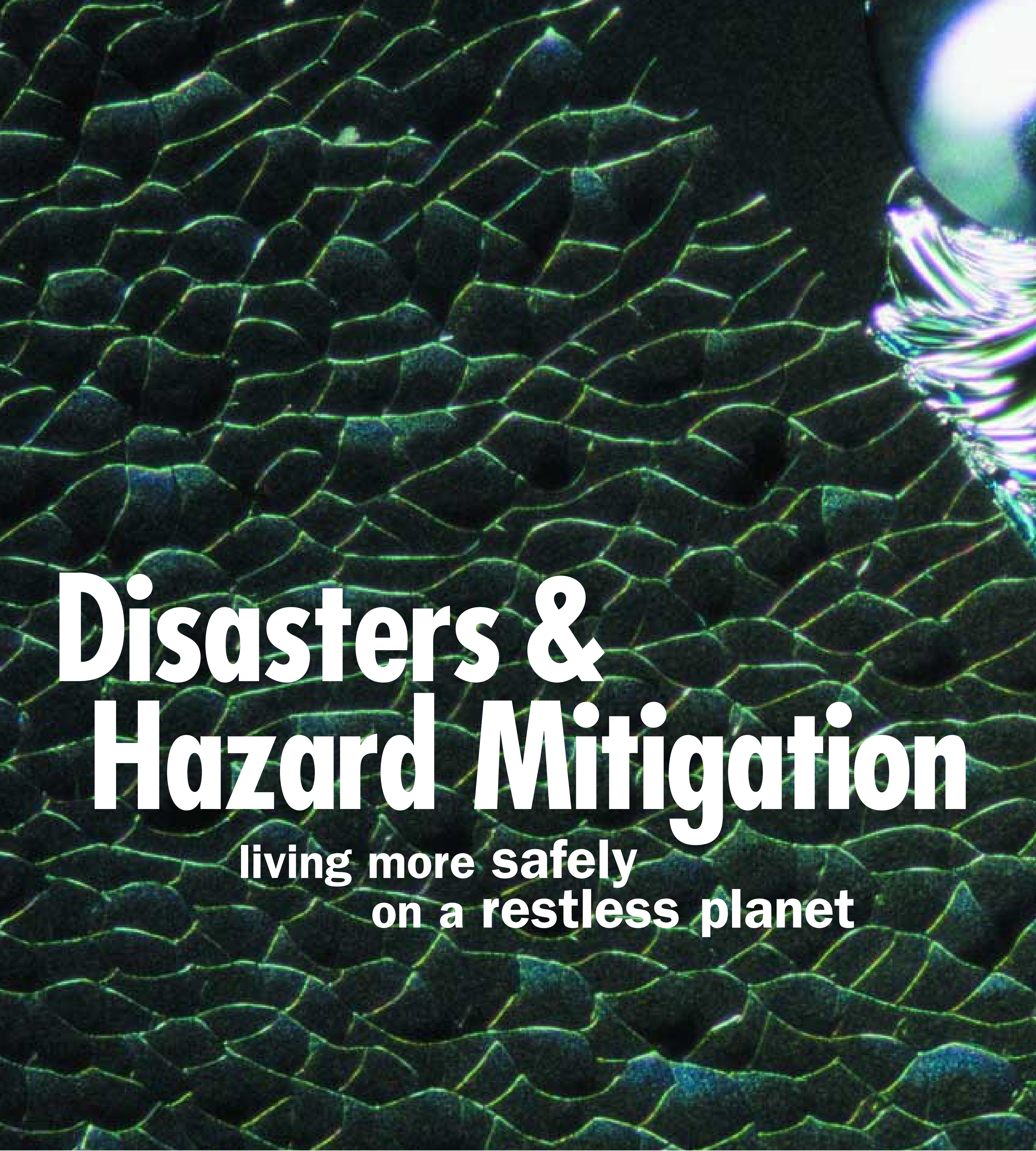
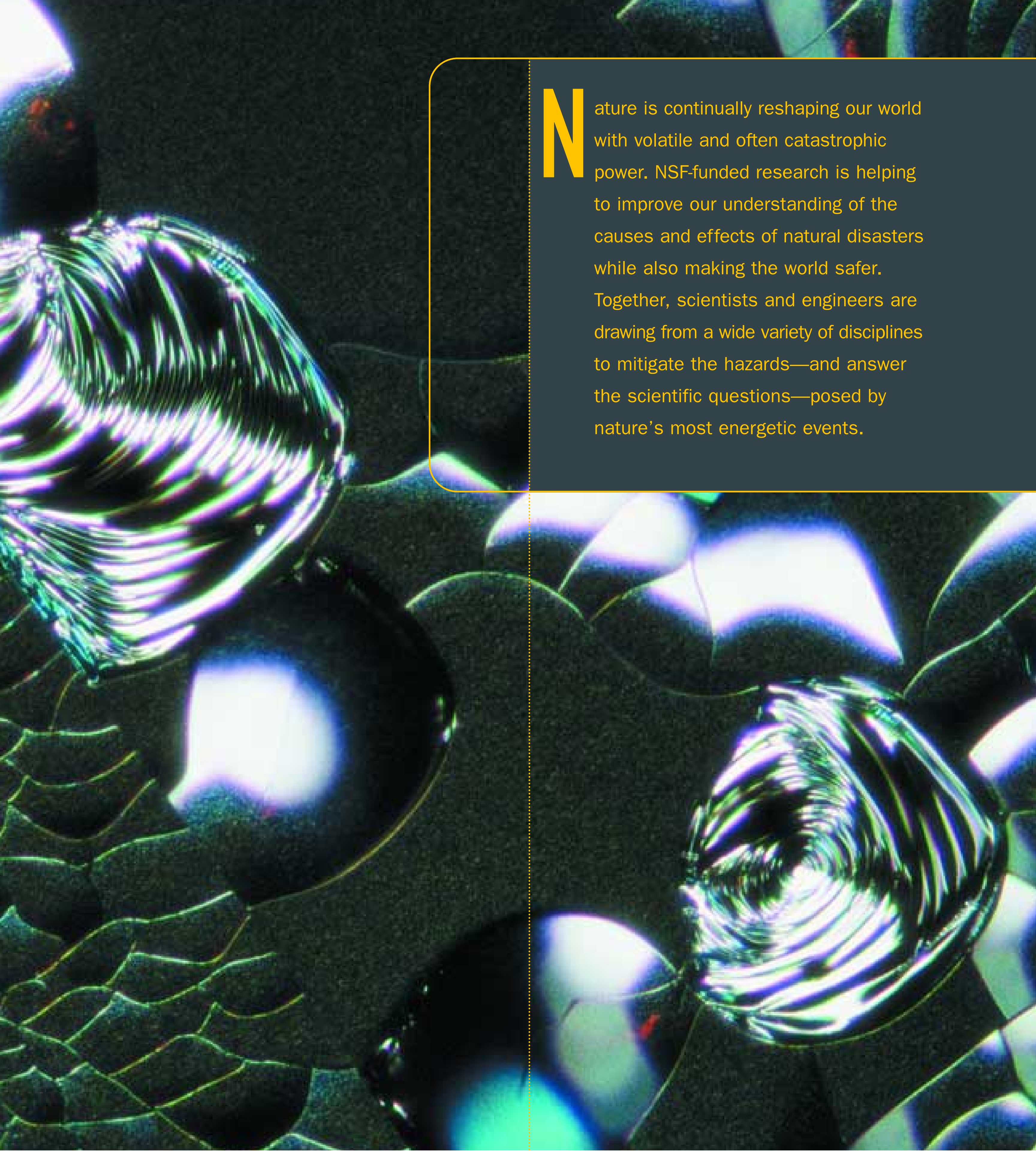


Disasters & Hazard Mitigation

living more safely on a restless planet



Nature is continually reshaping our world with volatile and often catastrophic power. NSF-funded research is helping to improve our understanding of the causes and effects of natural disasters while also making the world safer. Together, scientists and engineers are drawing from a wide variety of disciplines to mitigate the hazards—and answer the scientific questions—posed by nature's most energetic events.

Natural disasters are complex and often global in their effects. That is why the hallmark of NSF's long involvement in disaster research has been to encourage the exchange of ideas across national boundaries as well as scientific disciplines. To find answers in this high-stakes field, NSF programs marshal a wide range of researchers, including atmospheric scientists, engineers, geologists, sociologists, economists, seismologists, biologists, political scientists, and others. Their work takes them to wherever nature is in turmoil—earthquakes in Japan, volcanoes in the Philippines, hurricanes in the Atlantic, and floods on America's Great Plains. The resulting discoveries about the inner workings and human risk associated with nature's most extreme events are making both warning and mitigation increasingly possible.

The Forces Und lying the Fury

The economic cost of natural disasters in the United States has averaged as much as $1 billion a week since 1989—and is expected to rise, according to a 1999 NSF-supported study. Because natural disasters can have such brutal consequences, it's easy to think of them in terms of human misery that, somehow, must be mitigated. But society cannot mitigate what it does not understand. Natural disasters are, after all, a part of nature, and though human activities can influence the impact of extreme events, researchers must first learn as much as possible about the basic physical forces underlying the fury. At NSF, most of the research into natural disasters and their mitigation takes place within the Directorate for Geosciences, the Directorate for Engineering, and the Directorate for Social, Behavioral, and Economic Sciences.

Take, for example, earthquakes and volcanoes. Almost from its inception, NSF has been a critical player in the global effort to understand and cope with these giant Earth-altering forces. NSF funded a series of explorations during 1957–58—dubbed the International Geophysical Year—and again in the 1960s. These explorations confirmed a wild idea that scientists had begun to suspect was true: the Earth's seafloors, rather than being congruous like the rind of a melon, were actually disparate pieces that, at least in some places, were slowly moving away from each other. These findings pushed geophysicists toward the modern theory of plate tectonics. Researchers now know that the upper part of Earth's crust is broken up into a number of rigid sections or plates, and that these plates float atop soft-solid rock kept in a molten state by an unimaginably hot inner core. As the plates drift, they not only separate but also collide and slide past each other, forming valleys and mountain ranges. Occasionally, some of the molten rock breaks through—and a volcano is born. When two plates grind past each other, the shuddering friction generates earthquakes.

With funding from the National Science Foundation, scientists have made significant advances in the accuracy of storm prediction since the first tornado forecast in 1948.

Of the one million or so earthquakes that rattle the planet each year, only a few—about one each week—are large enough to grab our attention. Predicting when and where the next "big one" will take place is still far from a certainty. Short-term forecasts are sometimes pegged to swarms of smaller quakes that may signal mounting stress at a fault. Or a sudden change in underground water temperature or composition may be significant: this type of signal led to the successful evacuation of a million people before a major earthquake struck near the city of Haicheng, China, in 1975—the first earthquake to be scientifically foretold.

NSF-funded researchers are making headway on the difficult question of earthquake prediction by narrowing their focus to specific regions of the world. Because the behavior of seismic waves is so strongly affected by the different kinds of soil and geological structures through which the waves must travel, the effects of an earthquake can vary widely from place to place, even along the same fault. A soft-soil area such as a lakebed, for example, will shake more than a rocky hill. Knowing this, scientists and engineers at the NSF-sponsored Southern California Earthquake Center in Los Angeles have reassessed the consequences of earthquakes along faults in the surrounding region. The scientists were able to simulate the anticipated effects of future local quakes by using sophisticated computer models of the Los Angeles basin that accounted for fault geometry and motion, sediment composition, and other factors that can reflect, prolong, or amplify quaking motion. Such modeling, supplemented with data from new digital seismic recorders capable of sensing a broad range of actual earthquake vibrations, can help researchers and residents of quake-prone areas to anticipate—at least in a general way—when and where the next big temblor will hit and what damage may result.

Even as local efforts to understand earthquake activity improve, scientists are finding new ways to take another look at the big picture. In June 1999, NSF-funded researchers joined an international team headed to the east coast of Japan to establish long-term seafloor observatories in one of the world's busiest earthquake zones: the so-called Japan Trench, where two of Earth's biggest tectonic plates are colliding. The international team of scientists drilled holes about one kilometer deep into the ocean floor along the trench, which itself is two kilometers underwater. They then installed instruments at the bottom of these boreholes to monitor the amount of seismic activity there. Robotically controlled vehicles similar to those used to investigate the sunken Titanic will periodically travel to and from the seafloor observatories and help provide scientists with long-term observations of one of the planet's most active quake regions.

Another way that NSF is helping researchers gather data close to the moment of seismic activity is through its funding of the Earthquake Engineering Research Institute (EERI) in Oakland, California. Besides encouraging regular communication among engineers, geoscientists, architects, planners, public officials, and social scientists concerned about natural disasters, EERI quickly assembles and deploys teams of researchers on fact-finding missions in the wake of earthquakes—anywhere in the world—soon after they occur.

Reducing the Risk

Though researchers cannot yet precisely predict the timing and location of earthquakes, NSF has long recognized that more can be done to minimize—or mitigate—the damage that quakes can cause. Toward that end, in 1977 Congress passed the Earthquake Hazards Reduction Act, which put NSF in charge of a substantial part of earthquake mitigation research efforts in the United States. Earthquake-related studies, especially with regard to structural and geotechnical engineering, now make up the bulk of NSF's natural disasters research under the guidance of the Natural Hazards Reduction Program in the Directorate for Engineering.

Why engineering? Because most of the immediate deaths from earthquakes occur when buildings collapse, and the huge economic losses associated with the biggest quakes stem from damage to the structures and infrastructures that make up cities and towns. In 1997, NSF officially charged three earthquake centers with a major portion of the responsibility for conducting and coordinating earthquake engineering research in the United States. The centers, each constituting a consortium of public and private institutions, are based at the University of California at Berkeley, the University of Illinois at Urbana-Champaign, and the State University of New York at Buffalo.

The NSF-funded earthquake centers are models of cooperation, including not only geoscientists and engineers but also economists, sociologists, political scientists, and contributors from a host of other disciplines. The Buffalo center, for example, recently studied the potential economic impact of an earthquake in the Memphis, Tennessee, area near the epicenter of several major quakes that struck in 1811-12. Participants in the study included researchers from the University of Delaware's Disaster Research Center, who examined economic, political, and social elements of the hazard. The Delaware researchers have also studied the

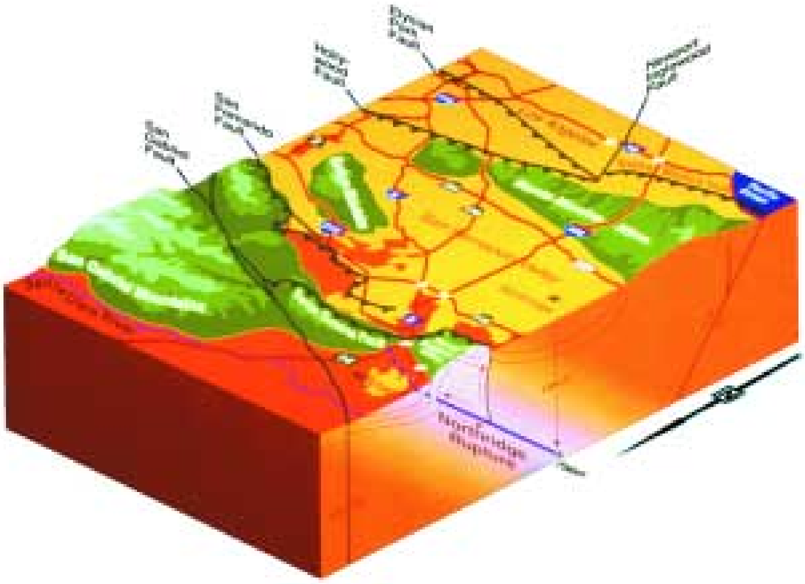
Climate Change—Disaster in Slow Motion

Before 1950, climatologists spent most of their time describing and comparing the current-day climates of different regions. Even the relatively recent climatic past remained a mystery to them, and interactions between the atmosphere and the oceans that researchers now know drive global climate change were too complex to study with the mathematical tools at hand. But then came the computer revolution, funded to a significant degree by NSF, and today much of nature's turbulence, past and present, is available for study.

With the advent of NSF-sponsored supercomputers, climatologists began building models of atmospheric change that now embrace millions of years of oceanic, atmospheric, biological, geological, and solar processes. For example, by the late 1980s NSF-supported researchers at the University of Washington were able to reconstruct the wide extremes of temperatures that existed 250 million years ago within the giant supercontinent of Pangaea.

In 1999, climate modelers at the NSF-funded National Center for Atmospheric Research in Boulder, Colorado, managed to accurately simulate a century of known climate history. The scientists then carried these simulations a century into the future. Their model suggests that if carbon dioxide emissions continue to rise at their current pace, there will likely be a boost in global temperatures as well as a 40 percent jump in winter rain and snow within the southwest region and Great Plains of the United States. The model also shows that the warming effect would be more severe in the United States than in Europe or Asia.

While global warming might not rival earthquakes and hurricanes for dramatic immediacy, such gradual but significant climate changes can indeed have disastrous consequences for human society. As ice caps melt, sea levels will rise, threatening coastal habitation and commerce. Warmer temperatures will also radically alter when, where, and whether farmers can grow certain crops. Climate models that can predict such events with a fair degree of certainty—and perhaps suggest what can be done to minimize their impact—will make an invaluable contribution to the field of natural hazards research. Accustomed to the urgency of saving lives, natural disaster researchers now face the challenge of preserving a way of life, as well.



This geological model of the 1994 Northridge earthquake was created by researchers at the NSF-funded Earthquake Engineering Research Center at the University of California at Berkeley. This three-dimensional view of the 6.7 magnitude earthquake gives scientists a better understanding of the geological forces behind earthquakes.

impact that the Loma Prieta earthquake (1989) and Hurricane Andrew (1992) had on businesses in the Santa Cruz and Miami areas, respectively. Kathleen Tierney, a sociologist at the University of Delaware and a co-principal investigator for the Buffalo earthquake consortium, says the few previous studies of long-term disaster impacts focused on individuals and families rather than on businesses. The new Delaware research should help both policymakers and business owners better understand the economic impacts of disasters and devise more effective ways of coping with them.

While understanding the economic impact of disasters is important, the heart of the earthquake centers' mission is to design safer buildings. In 1967, the University of California at Berkeley center installed what is still the nation's largest "shake table." The twenty-foot-by-twenty-foot platform reproduces the seismic waves of various earthquakes, allowing engineers to test model structures. After the Loma Prieta quake, NSF funded an upgrade of the table from two- to three-dimensional wave motions; additional digital controls and sensors will soon allow offsite researchers to monitor experiments at the shake table in real time via a computer network.

Ultimately, says William Anderson, senior advisor in NSF's Division of Civil and Mechanical Systems, the research community may be able to conceptually link geophysical and geotechnical research—such as computer models of faults and soil liquefaction—to the engineering simulations of building parts, creating a unified, integrated mathematical model of disaster.

The need for such research has been underscored numerous times in the latter part of the twentieth century. Early in the morning on January 17, 1994, southern California suddenly heaved and swayed. Deep beneath the town of Northridge, less than 25 miles from downtown Los Angeles, one giant chunk of the Earth's crust slipped over another, jolting the people and structures above with a 6.7 magnitude earthquake. (On the logarithmic Richter scale, 7.0 constitutes a major earthquake. Although the Richter scale has no upper limit, the largest known shocks have had magnitudes in the 8.8 to 8.9 range.) More than twelve thousand buildings were shaken so hard they collapsed or sustained serious damage, while many of the region's vital freeways and bridges disintegrated or were rendered impassable. Sixty people died and Californians suffered more than $25 billion in economic losses.

One year later and halfway around the world, the city of Kobe, Japan, endured its first catastrophic earthquake in a century, a 6.9 magnitude temblor. More than six thousand people died and almost two hundred thousand buildings were destroyed or damaged. Fires spread across the city while helpless firefighters failed to draw a drop of water from the shattered pipes. Besides the horrific loss of life, the devastation in Kobe cost between $100 and $200 billion.

The widespread destruction from these disasters has been especially alarming to experts because both cities sit atop a seismically active coastal region known as the Pacific Rim, which is capable of bestirring earthquakes of even greater violence. Close inspection of the rubble from both earthquake sites revealed one of the main contributing factors to the devastation: Buildings with steel frames exhibited cracks at the welded joints between columns and beams. Experts had expected old masonry and reinforced-concrete structures to crumble, but steel-framed buildings were supposed to be relatively safe. In Kobe, the steel frames failed catastrophically: more than one in eight simply collapsed. In Northridge, more than two-thirds of the multistory steel-framed buildings suffered damage.

Immediately after these disasters, NSF-sponsored researchers put new emphasis on developing better connection designs. In five short years, researchers have learned to reduce stresses on welds by altering the joints in the frames, in some cases by perforating or trimming the projecting rims (i.e., flanges) of the steel I-beams. These safer construction techniques have been included in new building code recommendations issued by the Federal Emergency Management Agency for all U.S. buildings in earthquake-prone regions.

NSF-funded researchers are finding many other ways to make buildings safer during earthquakes. Shih Chih Liu, program director of NSF's infrastructure and information systems program, says new high-performance concrete uses ash or small steel bars for better tensile strength and corrosion resistance. It took smart thinking to concoct the new concrete but other work is aimed at making the buildings themselves "smart." NSF-funded engineering professor Deborah Chung at the State University of New York at Buffalo recently invented a smart concrete that acts as a sensor capable of monitoring its own response to stress. The concrete contains short carbon fibers that lower the concrete's tendency to resist the flow of electricity (a quality that researchers call "resistivity"). Deformations to the material—as can occur during earthquakes—cause resistivity to rise, a change that can be gauged by a simple electrical contact with the concrete. The greater the signal, the greater the presumed damage. NSF-funded engineers have also developed systems such as swinging counterweights, which dampen the oscillations of buildings, and slippery foundations that are shaped like ball bearings in a bowl—the bearings allow the structure's footings to shift sideways nearly independently of the structure above.

Other NSF-supported advances include the development of smart shock absorbers for buildings, bridges, and other structures. As the structure shakes or sways, electrical signals from motion sensors in the structure cause a special fluid in the shock absorbers to become thicker or thinner (ranging between the consistency of light oil to one more like pudding), depending on what's needed to slow or speed the movement of the shock absorbers' pistons.

How well these efforts translate into saved lives and minimized economic losses depends on how widely they are shared. In the new millennium, NSF plans to develop the Network for Earthquake Engineering Simulation (NEES)—a kind of overarching cybersystem for earthquake engineering experimental research. Through NEES, researchers around the world can remotely access a complete system of laboratory and field experimentation facilities, of which there are currently more than thirty in the United States alone.

The 1995 earthquake that devastated Kobe, Japan, destroyed a section of the Nishinomiya-ko Bridge. The Kobe earthquake demonstrated the vital importance of NSF-funded research into "smart" materials and other earthquake-resistant construction techniques.

Hot Heads

Volcanoes are close cousins of earthquakes, arising as they do from the same powerful motions of the planet's tectonic plates. Despite their fiery reputation for chaos and destruction, however, only about sixty volcanoes erupt each year, usually with more bravado than brawn. What's more, most volcanoes are on the ocean floor where plate boundaries are converging or spreading over "hot spots"—large subterranean pools of magma.

This is not to say that volcanoes pose no peril. Over the last three hundred years more than 260,000 people have died from volcanic activity. The 1991 eruption of the Philippines' Mount Pinatubo killed more than three hundred people and devastated the area's economy. When Mount St. Helens blew its stack in the state of Washington in 1980, 57 people died, nearly 7,000 big game animals were killed, more than 12 million salmon perished, forests were devastated, and the economy took a nearly $1 billion hit.

On May 18, 1980, a 5.1 magnitude earthquake shook Mount St. Helens. The bulge and surrounding area slid away in a gigantic rockslide and debris avalanche, releasing pressure and triggering a major pumice and ash eruption of the volcano. Thirteen hundred feet of the peak collapsed. As a result, 24 square miles of valley were filled by a debris avalanche; 250 square miles of recreation, timber, and private lands were damaged by a lateral blast; and an estimated 200 million cubic yards of materials were deposited into the river channels.

All of this reinforces the need for better ways to model and predict volcanic activity. One way to both study and monitor a volcano is to place a gas sensing device called COSPEC along the volcano's flanks. COSPEC (for "correlation spectrometer") measures how much sulfur dioxide gas is escaping from the volcano's interior. A jump in the amount of sulfur dioxide suggests an imminent eruption. Still, a few hours' or, at most, a few days' warning is the best that scientists can manage with current knowledge and technology. And sometimes, of course, there is no discernible warning at all.

In 1993, nine members of a scientific expedition who were taking gas samples died when a sudden spasm of molten rock and ash erupted from the crater of a volcano called Galeras in Colombia. The tragedy prompted one of the survivors, Stanley Williams of Arizona State University, to organize a conference that would enable scientists to standardize their methods and make data consistent from one volcano observatory to another. The 1997 NSF-funded conference brought together virtually every scientist then working with COSPEC—some twenty-five volcanologists from fourteen countries. Williams has also developed a remote-access instrument called GASPEC that measures another early-warning gas, carbon dioxide.

Other volcano-monitoring efforts funded in part by NSF include a network of seismometers (instruments that measure ground vibrations caused by earthquakes) and an array of Earth-orbiting satellites called the Global Positioning System (GPS). The GPS can alert scientists to volcano-related ground deformations at the millimeter scale—deformations that might signal an imminent eruption.

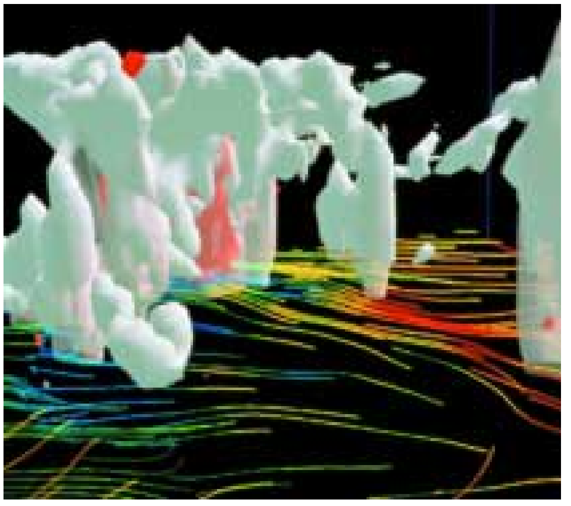
How's the Weather Up There?

In the spring of 1989, six million people in Canada, Sweden, and the United States lost electric power for up to nine hours thanks to stormy weather—not on Earth, but on the Sun. During particularly vigorous solar storms, billions of tons of plasma erupt from the Sun's gaseous outer layer (called the corona), speed toward Earth at hundreds of miles per second, and disrupt the Earth's magnetic field.

Although they also produce spectacularly beautiful auroras—those colorful atmospheric streamers known as the northern lights—"coronal mass ejections" constitute a poorly understood natural hazard of growing concern to the scientists at NSF's National Center for Atmospheric Research (NCAR). That's because the ejections are associated with features on the Sun known as sunspots, whose activity follows an eleven-year cycle. And not only is the most recent sunspot cycle expected to reach its maximum activity in the year 2000, but overall, these so-called solar maximums have become twice as powerful as they were in the early 1900s. With our civilization's well-being tied ever more closely to power stations and satellite-based communication systems, the atmospheric disturbances triggered by solar storms pose a potentially significant threat.

From 1980 to 1989, the NSF-funded *Solar Maximum Mission* satellite collected the most detailed data yet on coronal mass ejections. NCAR researchers used this data to develop a new suite of observation tools that work in space and on the ground.

For example, a special electronic camera called CHIP (for "chromospheric helium imaging photometer") perches on the volcanic flanks of Hawaii's Mauna Loa and snaps highly detailed pictures of the solar disk and corona every three minutes. These pictures are frequent enough to provide scientists with a movie loop of ejections as they develop and burst forth. Other satellite-borne instruments—some launched and retrieved by the space shuttle *Discovery* to escape distortions caused by Earth's dusty atmosphere—mine the Sun's radiation for clues about its magnetic behavior. Along with piecing together the basic science behind solar storms, these instruments should help scientists do a better job of predicting the next serious bout of bad space weather.



Researchers at the NSF-funded National Center for Atmospheric Research in Boulder, Colorado, use computer models to learn more about tornadoes, hurricanes, and other weather events. These models enable atmospheric scientists to more accurately predict when and where severe storms will hit. Greater forecasting accuracy can save lives and minimize property damage.

Stormy Weather

While earthquakes and volcanoes capture much of the public's imagination, weather-related disasters can wreak far more economic havoc. According to the Worldwatch Institute, 1998 set a new record for global economic losses related to extreme weather—$89 billion, a 48 percent increase over the previous record of $60 billion in 1996 and far more than the accumulated losses for the entire decade of the 1980s.

A major player in the world's efforts to learn about and live with extreme weather is the National Center for Atmospheric Research (NCAR) in Boulder, Colorado, funded by NSF's Division of Atmospheric Sciences. Central to NCAR's activities is the use of supercomputers to develop large-scale simulations of atmospheric and ocean dynamics. These models help to explain the formation of tornadoes, windstorms, and hurricanes, as well as more mundane climatic events. For example, in the late 1970s, NCAR researcher Joseph Klemp, working with Robert Wilhelmson of the NSF-funded supercomputing center at the University of Illinois, developed the first successful model of the most dangerous of all thunderstorms, the "supercell" storm. In a thunderstorm, air moves up and down in a turbulent mix. A single-cell storm means that there is just one updraft/downdraft component, which generally produces only moderately severe weather. A multicell storm can kick out the occasional tornado, but sometimes a main, intensely rotating updraft develops within a multicell storm and transforms it into a supercell storm capable of producing the most devastating weather, complete with violent tornadoes, raging winds, hail, and flooding.

The model developed by Klemp and Wilhelmson confirmed other researchers' observations that this special, rotating brand of thunderstorm could develop by splitting into two separate storm cells. According to their simulation, the southern storm in the pair was the most likely to concentrate its powers to make a tornado. Meteorological modelers have since improved these simulations to the point where researchers can study the ability of rotations midway up in a thunderstorm to develop tornado-like whirls at the ground. Such work, coupled with NSF-sponsored ground reconnaissance of tornadoes, may eventually solve the mystery of how tornadoes are born, which, in turn, could lead to better warning systems.

Warning systems can save lives, but whether or not a building survives a tornado's onslaught depends largely on how it was constructed. Since the 1970s, scientists and engineers at the NSF-funded Texas Tech (University) Institute for Disaster Research have been picking through the aftermath of tornadoes' fury for clues about what predisposes a structure to survival. When the researchers first began their work, it was common for emergency preparedness manuals to recommend that during a tornado building residents open their windows so that pressure inside the building could equalize with the low-pressure interior of the approaching twister. But after much dogged detective work, the Texas Tech researchers were surprised to learn that rather than exploding from unequal pressure, the walls of homes destroyed by tornadoes appeared to flatten when winds pried up the roof, just as aerodynamic forces will lift up an airplane wing. Wind was also discovered to contribute to structural damage by blowing debris from poorly built homes into homes that were otherwise sound.

The key to survivable housing—at least in all but the worst cases of tornadoes—turns out to be roofs that are firmly anchored to walls and walls

The Human Factor

Most hurricanes kill and destroy with a surge of seawater. Not Hurricane Andrew—the monster of 1992—a storm that led to at least fifty deaths and more than $30 billion in property damage in southern Florida. Sufficient warning enabled people to evacuate from dangerous beaches even as the worst of the storm miraculously skirted downtown Miami. But Andrew pummeled south Florida with particularly intense air currents that leveled well-built homes and demolished Homestead Air Force Base. The damage from the winds was more severe than expected, given that the region's building codes had been considered among the best in the country. As it turned out, however, enforcement of those codes had grown lax during the region's recent building boom.

All the science-based predictions and warnings in the world will not mitigate a natural disaster made more devastating by human folly. Ironically, improved hazard warnings in the United States may be one of the factors encouraging more and more people to move to homes on the earthquake- and hurricane-prone coasts. As noted in a 1999 report by the National Research Council's Board on Natural Disasters, 80 percent of Florida's population now lives within 22 miles of the beach—a fivefold increase since 1950. A steady rise in the migration to cities has also made more people more vulnerable to the effects of natural disasters as they live amidst aging infrastructures increasingly susceptible to the slightest ill wind or tremor. Urban growth also translates into more pavement and less exposed soil, which forces rain to run off rather than soak into the ground and tends to increase flood damage. All of this means that the sharply upward trend in the costs of natural disasters is attributable not so much to the occurrence of more hazards but rather to human choices that place more of our structures and possessions at risk.

Sometimes, too, steps taken with the best of intentions to limit the dangers of natural hazards can turn out to amplify the problem. The intense rains and flooding that occurred in 1993 along the Mississippi River provide an example. The levees and dikes that had been built along the river to protect communities from the occasional mid-level flood allowed more development in the area and also effectively eliminated the flood plain, exacerbating the damage caused by the unusually massive surge of water in 1993.

"Disasters by Design: A Reassessment of Natural Hazards in the United States," a five-year-long NSF-funded study, was released in the spring of 1999. The study compiled the thoughts of 132 experts on how communities can better prepare themselves by evaluating potential local threats up to two hundred years in the future, determining acceptable losses, and then planning for them.

Says study leader Dennis Mileti of the University of Colorado's Natural Hazards Research and Applications Information Center, "We need to change the culture to think about designing communities for our great-grandchildren's children's children."

that are firmly anchored to foundations. Wide eaves along the roofline, which can act as handles for powerful winds, should be avoided. And the researchers found that weak points in the structure, such as garage doors and opened windows, actually increase the risk of damage by inviting in winds that will blow down the opposing walls, exposing people to injury from breaking glass and flying wreckage. The advice might be simple—shut your windows during a tornado rather than open them—but it is rooted in the long investigation of complex physical forces.

Trustworthy Tools

Our ability to understand tornadoes and other natural forces is only as good as the tools researchers have to study them. One highlight in this regard is Doppler radar, developed in the mid-1970s with the help of NSF funds. Since the 1960s, meteorologists' ability to predict violent weather patterns has depended largely on two kinds of technology: an array of orbiting space satellites that observe Earth's environment on a scale not previously possible, and ground-based radar technology. Radar peers inside clouds for clues about their potential for severe weather by sending out electromagnetic pulses that bounce off particles and return with valuable information about the location and intensity of precipitation. Most weather radars send out signals with relatively short wavelengths that, while offering a precise picture of a cloud's interior, can be absorbed by the very particles they're supposed to measure. On the other hand, Doppler radar uses longer wavelengths, so that even distant weather systems will appear on the radar screen with accurately rendered intensity. What's more, Doppler radar provides additional information (such as the velocity at which precipitation is moving) that is critical to short-term forecasting.

In the last decade, the National Weather Service has installed Doppler radar systems at fixed locations across the country, improving meteorologists' ability to issue timely flash flood and severe thunderstorm warnings and cutting by more than 60 percent the number of tornadoes that strike without public notice. Recently NSF-funded scientists have also begun experimenting with more-advanced mobile Doppler instruments mounted on flatbed trucks, which allow the hardier breed of researcher to chase down storms for even more precise readings.

With Doppler radar, NCAR scientists helped a University of Chicago wind expert, the late T. Theodore Fujita, to confirm in the 1980s a whole new atmospheric hazard—the microburst. Microbursts are concentrated blasts of downdrafts from thunderstorms that have been responsible for airplane crashes killing more than five hundred people in the United States. And in 1999, NCAR researchers began testing whether Doppler radar systems installed on airplanes can detect so-called convective turbulence, associated with storms and clouds, which can rip sections off small planes and injure crew and passengers.

Another significant new observing technology developed at NCAR is a probe employed by hurricane-hunting aircraft. The probes are dropped from government planes into offshore hurricanes to profile previously hard-to-measure factors such as low-level winds, pressures, and temperatures around the storm's eye. Data from these probes have greatly improved the National Weather Service's ability to predict the course and intensity of hurricanes. Hurricanes develop over the warm tropical oceans and have sustained winds in excess of 75 miles per hour. One hundred years ago, coastal residents generally had less than a day's warning before a hurricane struck. Today, thanks to satellites and radar, these same residents know days in advance that a hurricane is maturing and moving their way.

El Niño Bears Unwanted Gifts

Hurricanes are dramatic examples of how the atmosphere and the oceans interact to drive the course of Earth's climate in sometimes perilous ways. Another example is El Niño, a weak warm current of water that appears for several weeks each Christmas off the coast of Ecuador and Peru. Every three to five years, however, this otherwise mild-mannered current becomes a real "hazard spawner," says NCAR senior scientist Michael Glantz, by growing in size and strength and lasting for many months. Unusual weather conditions result as tropical monsoons that normally center over Indonesia shift eastward, influencing atmospheric wind patterns around the world. Massive fish kills, droughts, heavy rains: These are just some of the gifts that a robust El Niño can bear.

After a particularly devastating El Niño event in 1982–83, researchers vowed not to be caught off guard again. NSF coordinated a global scientific effort to set up a network of ocean-drifting, data-gathering buoys in the Pacific Ocean. In the spring of 1997, the investment paid off when the instruments began recording abnormally high temperatures off the coast of Peru, giving scientists and policymakers their first inkling of an El Niño event that would turn out to be the most devastating in fifty years. Supplemented with satellite observations, the advance warning from the buoys allowed farmers in Central and South America to steel themselves for record-breaking drought and Californians to fix their roofs before the onset of an unprecedented rainy season that also caused life-threatening floods and mudslides. Now NCAR researchers are incorporating what they've learned about this massive El Niño event into supercomputer-based climate models designed to simulate atmospheric circulation changes over the course of decades and even centuries. And in May 1999, NCAR began working with the United Nations Environment Programme to conduct a nineteen-month study of the impact of the 1997–98 El Niño, with the goal of developing programs to help countries better prepare themselves for the day when El Niño makes a muscular comeback.

A Safer Future

In recognition of the rising dangers and costs associated with natural disasters around the world, the United Nations declared the 1990s the International Decade for Natural Disaster Reduction. At the close of the decade, NSF could look back on fifty years of sponsored programs whose aims have been—and continue to be—to better understand and prepare for the kinds of extreme natural events that can prove disastrous for human communities. While the world can never be absolutely safe, its human inhabitants can at least rest easier in the knowledge that nature's violence holds less sway in an age where scientists and engineers are working so closely together to mitigate what cannot be controlled.

To Learn More

NSF Directorate for Engineering
www.eng.nsf.gov

NSF Directorate for Geosciences
www.geo.nsf.gov/

NSF Directorate for Social, Behavioral, and Economic Sciences
www.nsf.gov/sbe

Network for Earthquake Engineering Simulation (NEES)
www.eng.nsf.gov/nees

Earthquake Engineering Research Institute (EERI)
www.eeri.org

Federal Emergency Management Agency
www.fema.gov

Mid-America Earthquake Center
(at the University of Illinois at Urbana-Champaign)
http://mae.ce.uiuc.edu

Multidisciplinary Center for Earthquake Engineering Research
(at the State University of New York at Buffalo)
http://mceer.buffalo.edu

National Center for Atmospheric Research (NCAR)
www.ncar.ucar.edu/ncar/

National Information Service for Earthquake Engineering
(at the University of California at Berkeley)
http://nisee.ce.berkeley.edu

National Weather Service
www.nws.noaa.gov

Pacific Earthquake Engineering Research Center
http://peer.berkeley.edu

Southern California Earthquake Center
www.scec.org

U.S. Geological Survey Hazards Research
www.usgs.gov/themes/hazard.html

U.S. Geological Survey Cascades Volcano Observatory
http://vulcan.wr.usgs.gov/home.html

University of Oklahoma Center for Analysis
and Prediction of Storms (CAPS)
www.caps.ou.edu