Supporting Earth Observing Science 2002

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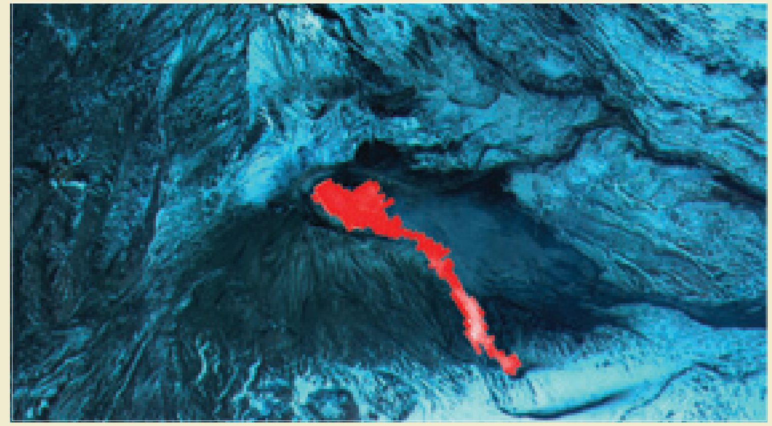

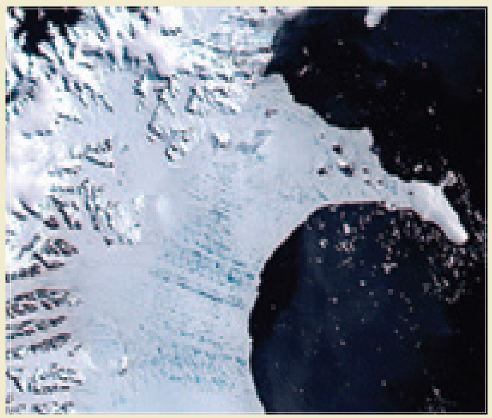
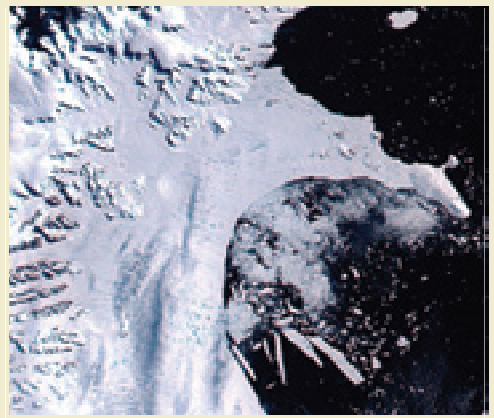
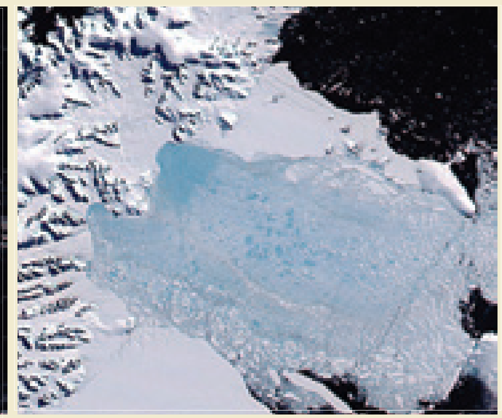
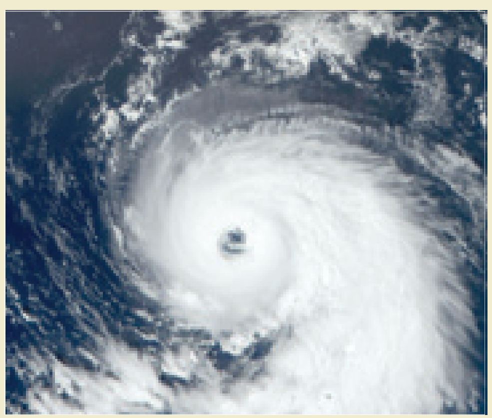
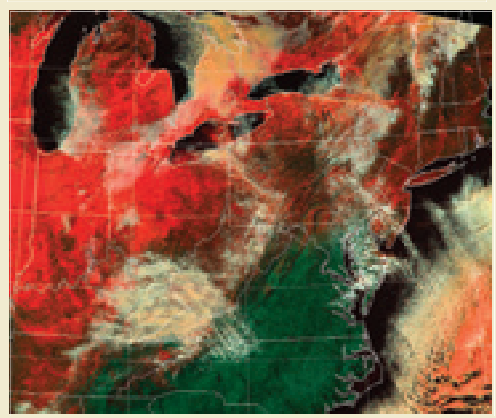

Cover Images

Front—

Left to right, from top: (1) Tai Lue farmers construct a traditional diversion dam in Sipsongpanna, Yunnan Province, Muang Long. (Image courtesy of John Hartmann); (2) Composite ASTER image, taken on December 28, 2000, shows the active Russian volcano Bezymianny. (Image courtesy of NASA); (3) Some kinds of African savanna produce palatable vegetation for natural grazers like giraffes. (Image courtesy of PhotoSpin); (4–6) MODIS captured the disintegration of the Larsen B Ice Shelf in these images taken on January 31, February 23, and March 17, 2002. (Images courtesy of NASA); (7) MODIS captured this image of Hurricane Erin east of Bermuda on September 9, 2001. (Image courtesy of NASA); (8) This false-color MODIS image, captured on January 2, 2001, shows the north-central United States (Image courtesy of NASA).

Back—

Left: This image of atmospheric vortices was captured by the MISR satellite instrument on June 11, 2000. (Image courtesy of NASA); *middle:* In this QuikSCAT image, ocean colors indicate wind speed, and white streamlines indicate wind direction. (Image courtesy of NASA's Scatterometer Climate Record Pathfinder program at Brigham Young University); *right:* A researcher takes snow measurements in the Rocky Mountains of northern Colorado (Image courtesy of NASA's Cold Land Processes Experiment).

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Earth Science Data and Information System Project-
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Dear Friends and Colleagues:-

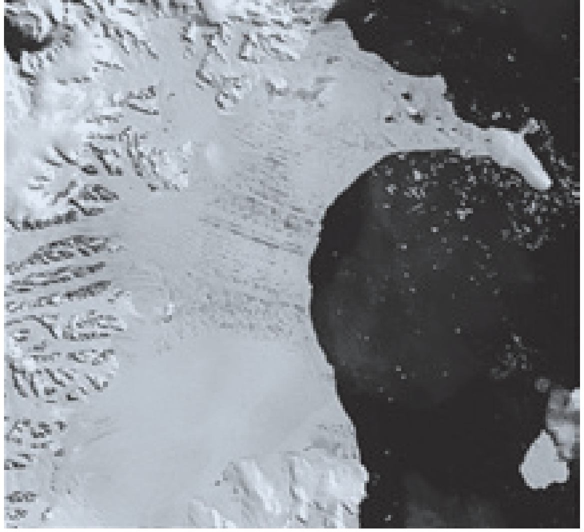
It is with great pleasure that we present the 2002 edition of *Distributed Active Archive Centers (DAAC) Alliance: Supporting Earth Observing Science*. This eighth edition illustrates the benefits and impacts of the science research - being performed using data available from the DAAC Alliance of the Earth Observing System Data and Information- System (EOSDIS). -

Science research enabled by DAAC-provided data, information, and services covers a broad spectrum of study. In this- edition, we highlight research on both fire (volcanoes and burning savanna) and ice (Antarctic ice sheets and ice- shelves). We also discuss the impact of EOSDIS data on meteorological forecasts and research related to the spread of- dangerous organisms. -

Thank you for taking the opportunity to discover the research being supported by the NASA DAACs, which continue- to play a critical role in supporting U.S. and international global change research and in providing data products and- services to a growing group of new researchers. To find out more about the DAACs and the EOSDIS, please visit the- DAAC Alliance Web site at: **http://nasadaacs.eos.nasa.gov.** I hope you find the articles in this edition to be informa™- tive.-

Vanessa L. Griffin-
Manager-
ESDIS Science Operations Office-

Supporting Earth Observing Science 2002



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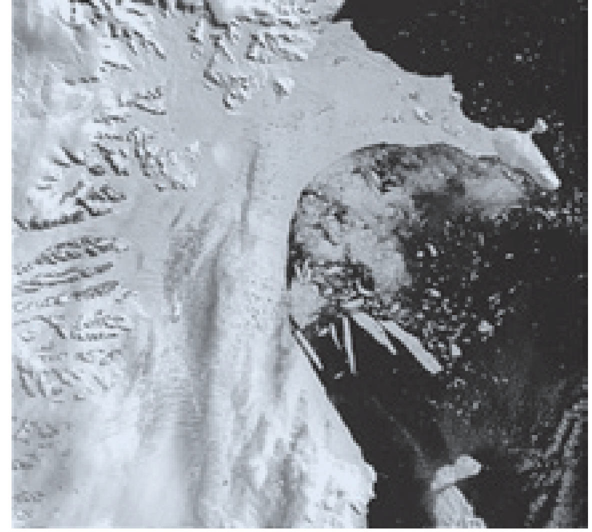


February 23, 2002

Fragment of its Former Shelf

"Climate seems to have been relatively stable on the Antarctic Peninsula for the past 1,800 years, but then 50 or 100 years ago, it began to change."

National Snow and Ice Data Center DAAC

by Laura Naranjo

FOR HUNDREDS OF THOUSANDS OF YEARS, ice shelves along the Antarctic coast retreated and advanced unobserved by the human eye. In March 2002, however, a group of scientists had a front row seat for the largest ice shelf breakup in recent history.

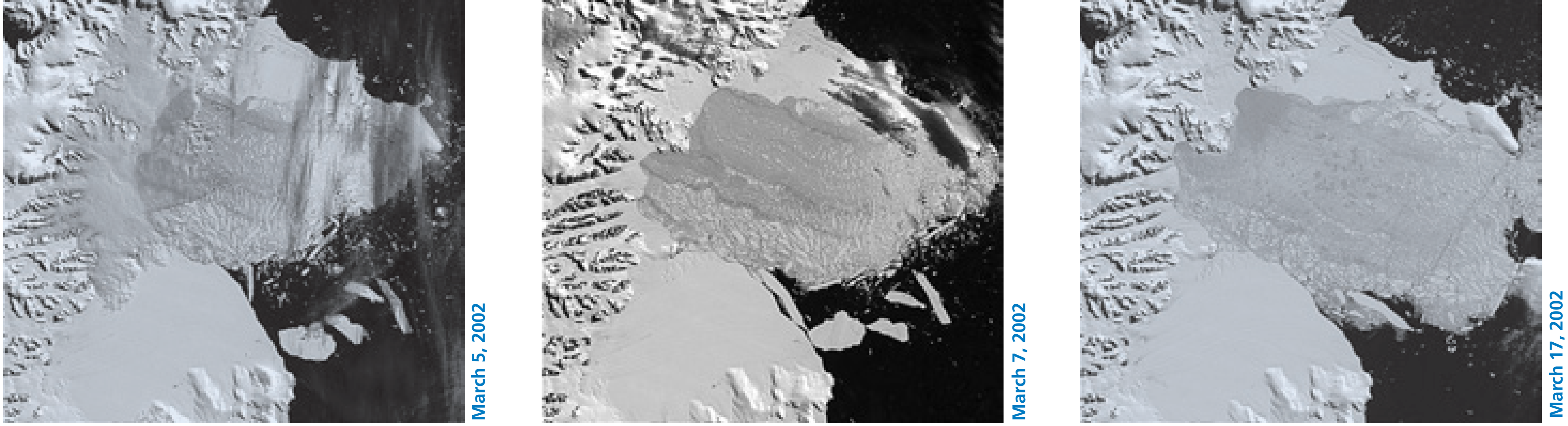
An ice shelf is a floating platform of ice, usually fed by mountain glaciers or ice sheets. Typically, ice shelves advance over the ocean for several decades until they become unstable, at which point large icebergs break off, or calve, from the ice shelf front. Advancing and retreating in this manner is a normal process for maintaining mass balance, or ice volume. However, the splintering and shattering observed in some ice shelves is unprecedented in recent history.

The Larsen Ice Shelf complex stretches along the eastern edge of the Antarctic Peninsula, a finger of land pointing crookedly toward the tip of the South American continent. Scientists have divided the shelf into three sections: the Larsen A, B, and C Ice Shelves. The Larsen A and B Shelves existed near the northern tip of the peninsula. The Larsen C Ice Shelf flows from the central portion of the peninsula and represents the southern section of the Larsen shelf complex.

Scientists had been observing the Larsen B for several years, assuming that it would eventually retreat. But they were stunned to see the ice shelf disintegrate in a mere 35 days. Between January 31 and March 7, 2002, the ice shelf lost 1,255 square miles (3,250 square kilometers)—an area somewhat larger than Rhode Island—sending a plume of icebergs into the Weddell Sea.

The disintegration of the Larsen B Ice Shelf followed several other ice shelf retreats over the past two decades. Scientists have come up with a number of theories to explain why these dramatic breakups are occurring. Some believe that various forces may compromise the internal strength of the ice shelves. Others profess that a decrease in sea ice coverage has left shelves vulnerable to ocean swells. Although many of the questions about ice shelf disintegration remain unanswered, satellite imagery is providing at least one perspective.

The recent Larsen B disintegration supports a theory developed by Ted Scambos, research scientist at the National Snow and Ice Data Center in Boulder, Colorado, and his colleagues, Christina Hulbe, associate professor at



MODIS captured the disintegration of the Larsen B Ice Shelf between January 31 and March 17, 2002. (Images courtesy of NASA)

Portland State University, and Mark Fahnestock, assistant research scientist at the University of Maryland. The researchers theorized that melt water collecting on the ice shelf surface during unseasonably warm summers might be a primary mechanism in ice shelf breakup.

Most ice shelves exhibit some surface melting each summer, but the melting is usually not widespread enough to affect the structural integrity of the ice. However, if summer temperatures are warm enough, significant amounts of melt water can accumulate on ice shelf surfaces, often forming ponds and even streams. Scambos and Hulbe suspected that excess melt water affected the structural integrity of the ice shelf, particularly in heavily fractured areas. “Melt ponds give us a mechanism that makes a nice connection between atmospheric warming and ice shelf disintegration,” said Scambos.

Scambos, Hulbe, and Fahnestock examined each new breakup event, searching for features that would account for dramatic changes in calving style among peninsular ice shelves. In 1993, Scambos began monitoring the Antarctic Peninsula using satellite imagery from the Advanced Very High Resolution Radiometer (AVHRR) sensor. AVHRR-derived images allowed him to monitor flow features, surface melt water, crevasses, and cracks developing in the ice. “The AVHRR data set enabled us to build up a pretty good record of the Antarctic coastline, and we could then start speculating about the formation of melt ponds and where the breakups were occurring,” said Scambos.

In 2001, Scambos began using NASA’s Moderate Resolution Imaging Spectroradiometer (MODIS) sensor to monitor the Antarctic Peninsula with even greater detail. The MODIS sensor is more sensitive to slight variations in reflected light, making it ideal for imaging ice surfaces. “We can see tinier cracks, smaller hills and bumps, and fainter flow features of the ice sheet, which reveal a lot about the flow history of the ice shelf and about whether a specific area is experiencing melting,” said Scambos.

While Scambos monitored the shelves using satellite imagery, Hulbe used a variety of data to model the effect of melt water on surface crevasses in ice shelves. Her results showed that melt water, which collects naturally in crevasses, could force even relatively shallow cracks to propagate, or push through, the full thickness of an ice shelf if water continually occupies at least 90 percent of the crevasse. “When a fracture cracks, it relieves the stress that caused it to crack in the first place. But the tip of that crack becomes a focus at which new stress accumulates, and when the stresses again become large enough to overcome the strength of the ice, the fracture cracks again,” said Hulbe. In the case of the Larsen B, excessive melt water was providing the constant stress needed to push fractures through the ice shelf, which was 722 feet (220 meters) thick in places.

The pressure exerted by the melt water is greater than that of the ice, especially if the crevasses are filled with water throughout most of the melt season, as they were on the Larsen B during the 2002 summer season. “If this

Ice Shelves and Sea Level Rise

The disintegration of the Larsen B Ice Shelf will not affect sea level any more than a melting ice cube would raise the level of water in a glass of ice water. However, even though disintegrating ice shelves do not contribute directly to sea level rise, they might do so indirectly. Acting more or less as a brake, ice shelves hold back the glaciers or ice sheets feeding the ice shelves. For instance, scientists have detected increased flow speeds in glaciers that previously fed the Larsen A Ice Shelf. These glaciers now feed directly into the Weddell Sea, which leads to more icebergs being discharged into the ocean. While the amount of ice in these icebergs is itself inconsequential, the Larsen A provides a model for what may happen if a larger ice shelf like the Ross Ice Shelf were to collapse. Without the Ross Ice Shelf acting as a brake, the West Antarctic Ice Sheet could disgorge an amount of ice equivalent to about 16 feet (5 meters) of sea level rise.

process continues for something on the order of a decade, the ice shelf will probably disintegrate. That's been the track record for the Larsen," said Scambos.

MODIS images of the Larsen B Ice Shelf, dating from January 31 through March 7, 2002, demonstrate the melt water fracturing theory. The first image, taken on January 31, shows extensive melt ponds. Subsequent images taken on February 17 and 23 reveal that the melt ponds disappeared, indicating that the melt water may have drained through the crevasses. Finally, a March 7 image shows that most of the ice shelf had disintegrated. The shattered areas exactly matched the locations that had been covered by melt ponds only a few weeks earlier.

Although the 2002 Larsen B disintegration supports the melt water fracturing theory, David Vaughan, a glaciologist at the British Antarctic Survey in Cambridge, England, suggests that other mechanisms might prove to be equally instrumental in ice shelf breakup.

"As the ice shelf warms up, the actual strength of the ice may change. Free water between the ice crystals could lubricate and promote fracture growth," said Vaughan. "And when temperatures are warmer, there's less sea ice protecting the ice shelf from the ocean swell." Vaughan cites several other possibilities, including possible changes in atmospheric and ocean circulation in the Antarctic region.

Unlike the melt water fracturing theory, which is easy to monitor using satellite images, other theories require *in situ* measurements that can be difficult to obtain. A crewmember of the British Antarctic Survey research vessel, *James Clark Ross,* photographed the aftermath of the Larsen B breakup. But according to Vaughan, it was pure luck that the ship happened to be in the area. "Most ship research schedules are determined years in advance, making it virtually impossible for researchers to obtain a ship on short notice. In addition, not all ships have helicopter facilities, meaning researchers can't be flown ashore," he said.

"I don't think we can look at these other processes using satellite data. If we're actually trying to see how the material properties of ice shelves change as the temperatures increase, then we actually have to go there," said Vaughan. Vaughan, Hulbe, and Scambos all cite the work of Pedro Skvarca, head of the Glaciological Division of the Instituto Antártico Argentino in Buenos Aires, who had been conducting field studies on the Larsen B Ice Shelf. "Now that the shelf is gone, the data that Skvarca collected over the last 10 or 15 years is treasure," said Vaughan. Skvarca and his team were the last people to set foot on the northern part of the Larsen Ice Shelf.

Scambos and Hulbe plan to continue monitoring Antarctic ice shelves and surface melt ponds using MODIS and AVHRR. Vaughan plans to keep an eye on the Wilkins and Larsen C Ice Shelves, both of which may retreat if warm temperatures persist. He also hopes to investigate more thoroughly how ice shelves and dense, salty Antarctic bottom water affect ocean circulation.

While hesitant to blame the disintegration on global warming, many researchers agree that summer temperatures play a role in the unusual warming trend along the Antarctic Peninsula. "Climate seems to have been relatively stable on the Antarctic Peninsula for the past 1,800 years, but then 50 or 100 years ago, it began to change," said Vaughan.

Indeed, weather records over the past 50 years show that regional air temperature increased 4.5 degrees Fahrenheit (2.5 degrees Celsius)—five times the rate of warming measured for the rest of the world. And records from Orcadas Station (located on the South Orkney Islands, northeast of the peninsula) indicate that regional warming along the peninsula occurred as early as the 1930s. "That's fairly strong evidence to suggest that this is not part of natural variability," said Vaughan.

The disintegration of the Larsen B may simply be evidence of how quickly certain regions of the world can respond to relatively small climate changes. The regional warming observed in the Antarctic Peninsula represents a small part of a much larger picture, and scientists hope to gain a better understanding of the complex interactions between ice, oceans, and atmosphere.

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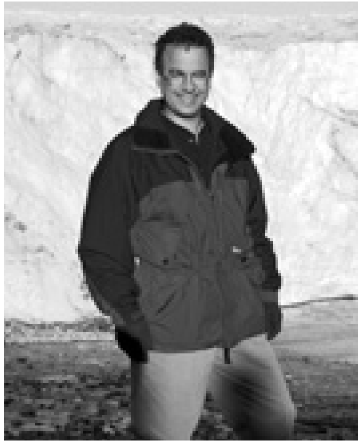

Ted Scambos, polar scientist at the National Snow and Ice Data Center in Boulder, Colorado, holds a PhD in geology from the University of Colorado. His primary research interests involve mapping Antarctic ice stream velocity and monitoring ice shelves. Scambos has developed innovative methods to observe the Antarctic continent using satellite data.

David Vaughan is a glaciologist at the British Antarctic Survey (BAS). His research focuses on Antarctica and climate, ice sheets and climate, and interactions between Antarctic ice shelves and oceans systems. Vaughan holds a master's degree in geophysics from the University of Durham and a PhD from Open University. He is principal investigator for the BAS program Global Interactions of the Antarctic Ice Sheets, and has served on the Intergovernmental Panel on Climate Change.

Christina Hulbe is an assistant professor in the Department of Geology at Portland State University where she teaches courses in glaciology, climate change, and modeling of earth systems. Her current research involves numerical modeling of the West Antarctic Ice Sheet and several of the continent's ice shelves. Hulbe earned a master's degree in geology from Ohio State University and a PhD in geophysics from the University of Chicago.

Space-Based Ice Sight

The face of Antarctica can change dramatically over decades, years, and even months.

Alaska SAR Facility DAAC

by Yarrow Axford

In August 1897, almost two decades before Sir Ernest Shackleton set sail on the ill-fated *Endurance*, an international group of sailors and scientists left Antwerp, Belgium, bound for Antarctica in a reinforced whaling ship called the *Belgica*.

The following spring their ship became stuck in the dangerous shifting pack ice. But the skipper, Adrien de Gerlache, hailed the situation as an opportunity. His crew would winter in Antarctica and make the first-ever year-round measurements of Antarctic meteorology. What de Gerlache didn't predict, however, was that his trusty ship would be trapped for an entire year, set free only after the desperate crew carved a channel through the ice to open water.

Having narrowly averted disaster, all but two of the international crew returned safely home in 1899, their ship weighted down with biologic specimens and rock samples. Theirs was the first purely scientific expedition to Antarctica.

A century of exploration and research has followed, but much remains unknown about the so-called seventh continent. Today, in response to growing concerns about global warming, attention has focused on Antarctica's most obvious feature: its ice.

The Antarctic ice sheet is the largest mass of ice in the world, storing 70 percent of the Earth's fresh water—enough to raise global sea level by more than 213 feet (65 meters), according to a U.S. Geological Survey fact sheet about sea level and climate. If the Antarctic ice sheet is shrinking, it could cause a major rise in sea level.

Before the advent of satellite data, scientists had only sparse field measurements for monitoring changes in Antarctica's ice sheet. Since the 1950s, field parties have pounded stakes into the glaciers that stream from the middle of the ice sheet to the coast, and returned each year to determine the changing locations of the stakes. Antarctica is roughly the size of the United States and Mexico combined, and the challenges of doing fieldwork on the frozen continent severely limit the number of glaciers that can be monitored.

But data from recent NASA satellite missions offer scientists new views of Antarctica, and new opportunities to understand how its enormous ice sheet might respond to future climate change. In 1997, exactly a century after the *Belgica* set sail, the Canadian satellite RADARSAT-1 orbited over Antarctica, collecting radar images of the entire continent in a spirit of international scientific cooperation similar to that of de Gerlache and his crew. In only 18 days, the Antarctic Mapping Mission (AMM-1) generated the first complete high-resolution radar map of Antarctica, giving scientists a first glimpse of the entire Antarctic ice sheet.

"The wonderful thing about radar and other satellite observations is that they provide continental-scale context at extremely high resolution, which is really unprecedented," said Ken Jezek, professor at the Ohio State University's Byrd Polar Research Center. Scientists like Jezek further capitalized on RADARSAT-1's capabilities with the Modified Antarctic Mapping Mission (MAMM) in 2000, a follow-up to AMM-1. Like AMM-1, MAMM was a collaboration between NASA and the Canadian Space Agency (CSA), with help from the Alaska Synthetic Aperture Radar (SAR) Facility,

NASA's Jet Propulsion Laboratory, Goddard Space Flight Center, the Ohio State University, and Vexcel Corporation.

MAMM had two ambitious goals: First, the mission generated high-resolution images of Antarctica's perime ter, to be used for identifying changes in the Antarctic ice sheet since AMM-1 and earlier satellite missions. Second, unique interferometric radar data from MAMM allowed scientists to measure how fast Antarctica's ice is flowing.

The highly publicized disintegration of the Larsen B Ice Shelf earlier this year provided startling evidence that Antarctica's ice shelves might be undergoing unprecedented retreat. Ice shelves, massive floating sheets of ice that hug Antarctica's coast, do not contribute directly to rising sea level when they melt, for the same reason that ice cubes melting into a glass of lemonade don't raise the fluid level in the glass. But the disintegration of an ice shelf might allow the internal ice sheet to flow faster into the ocean, no longer slowed by a mass of floating ice at its margin.

"What we don't know yet, and what we hope MAMM will help us understand, is whether the elimina tion of coastal ice shelves has an impact on the interior ice sheet," said Jezek. "If the interior ice sheet starts to slough off into the ocean, then sea level will definitely rise." This could spell trouble for residents of low-lying regions like New Orleans and the Netherlands.

To predict how the ice sheet's mass balance might change in the future, scientists must understand the current mass balance of the Antarctic ice sheet, along with the factors that influence it.

The mass balance of a glacier is a measure of its health, reflecting the balance between the amount of snow that accumulates on the glacier's surface each year and the amount of ice that melts or calves from its terminus. When a glacier accumulates more snow and ice than it discharges, it is said to have a positive mass balance, and it grows as it gains mass each year. In contrast, a glacier with a negative mass balance shrinks and, in turn, contributes to global sea level rise. Because it's difficult to measure the mass balance of the giant ice sheets that cover Greenland and Antarctica, it is unclear whether they are getting smaller.

"Mass balance is very complicated, especially trying to predict future mass balance," said Ian Joughin, a senior engineer at NASA's Jet Propulsion Laboratory (JPL). Joughin is using MAMM data and a recently developed technique called interferometry to estimate how fast

Page 6: This image shows the Lambert Glacier, one of the largest glaciers in Antarctica. The Lambert and other glaciers feed the Amery Ice Shelf, which is the bright white area in the center-right of the image. The white arrows are velocity vectors determined using Interferometric Synthetic Aperture Radar (InSAR). The image mosaic was derived from RADARSAT imagery collected during the 1997 Antarctic Mapping Mission. It shows an area approximately 560 by 415 miles (900 by 675 kilometers).

Top left: In the 1890s, the Belgica *froze fast in the Antarctic ice after a blizzard. From* Resultats du Voyage du S. Y. BELGICA en 1897–1898–1899. *(Image courtesy of NOAA)*

Bottom right: The Belgica *takes to the open water on March 5, 1898. From* Resultats du Voyage du S. Y. BELGICA en 1897–1898–1899. *(Image courtesy of NOAA)*

Antarctica's ice streams are transporting ice towards the sea. Interferometry uses extremely sensitive measurements of changes in distance between the satellite and points on the ground to calculate the velocity of slowly moving features on the Earth's surface. "Believe it or not, we can measure ice movements of just a few centimeters over a 24-day period," said Jezek.

Work by Jezek, Joughin, and colleagues has yielded some remarkable results. "Over the past five years, in part thanks to AMM-1 and MAMM, the idea of ice sheets being slow responders to climate change has been thrown out the window," said Jezek.

In fact, as the sudden breakup of the Larsen B Ice Shelf demonstrated, the face of Antarctica can change dramatically over decades, years, and even months. Research by Joughin and Jezek using MAMM data has revealed that, like the vulnerable floating ice shelves along the continent's coasts, Antarctica's fast-moving ice streams are also subject to rapid change. "It's amazing how much change we've seen in less than a decade. Some ice streams appear to be speeding up and others slowing down," said Joughin.

In a study published in the January 2002 issue of *Science,* Joughin used interferometry to measure the velocities of several ice streams that feed the enormous Ross Ice Shelf. He discovered that these ice streams are moving more slowly, and discharging less ice, than was previously indicated by field measurements. The ice streams have apparently been losing steam lately, slowing down by as much as 25 percent over the past 25 years.

Joughin concluded that the nearby region of the Antarctic ice sheet has a positive mass balance for the time being, which may be good news for residents of New Orleans, but bad news for the Texas-sized Ross Ice Shelf. If the ice streams are carrying less ice to the shelf, it could possibly collapse in the future.

Jezek's work reveals that fluctuations within ice shelves and ice streams are not unusual. Comparing AMM-1 and MAMM images with older data, Jezek has watched ice shelves retreat, advance, and then retreat again. He has also seen ice streams push far out from the coast, and then retreat inexplicably.

"The trick is figuring out the significance of observed changes," said Jezek. To understand how an event like the Larsen B's disintegration relates to global climate change, scientists must answer two difficult questions: Are the same sorts of changes occurring across Antarctica simultaneously, or does the ice sheet's behavior vary by region? And, was the Larsen B breakup part of a long-term trend toward the loss of ice shelves, or will it recover and reveal that the Antarctic ice sheet remains stable?

Jezek hopes that answers to these questions are finally within reach, thanks to a new era of satellite observation. "We're approaching a stage where we have several decades of satellite observations. What's exciting is that we're getting closer to being able to discriminate between trends and episodic or erratic events," he said.

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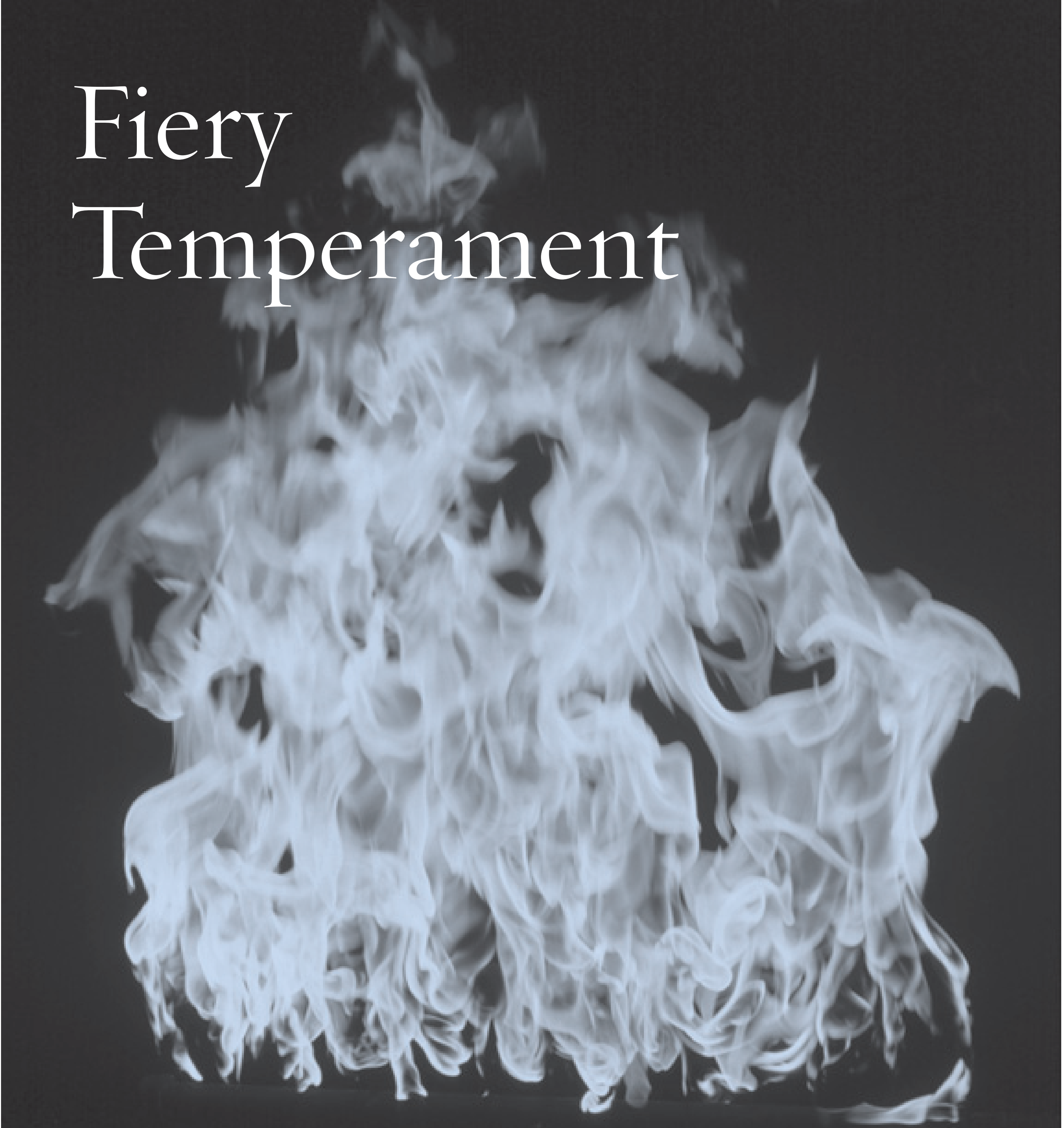
Kenneth Jezek is a professor in the Byrd Polar Research Center at the Ohio State University, where he leads a research team using satellite techniques to study the Earth's polar regions. He has worked as a researcher at the U.S. Army Cold Regions Research and Engineering Laboratory, and he served as director of the Byrd Polar Research Center from 1989 to 1999. Jezek earned a PhD in geophysics from the University of Wisconsin.

Ian Joughin is a senior engineer at NASA's Jet Propulsion Laboratory, California Institute of Technology. Joughin uses remote sensing to study the ice sheets of Greenland and Antarctica and their potential impact on sea level rise. His research efforts include the development and application of Interferometric Synthetic Aperture Radar (InSAR) for mapping ice stream and glacier flow. Joughin holds a PhD in electrical engineering from the University of Washington.

Fiery Temperament



"In a place with rich soil, if you change the ecosystem and don't like the result, you can stop, and the system will restore itself. In parts of Africa and Australia, if you change the land and see results you don't like, you might get to look at them for a long time."

Oak Ridge National Laboratory DAAC

Langley Research Center DAAC

Land Processes DAAC

by Michon Scott

On December 31, 2001, a land dispute in the Mambilla Plateau of northeastern Nigeria turned violent. The United Nations (UN) Office for the Coordination of Humanitarian Affairs reported that at least 40 people died, and hundreds were displaced after fighting broke out between local farmers and nomadic herders.

Who was at fault?

According to some analysts, the real culprit was desertification. The conflict arose after a shortage of acceptable pasture pushed desperate herders into farming regions.

French plant ecologist Andre Aubreville popularized the term desertification in a 1949 paper. He wrote that the desert "is always present in the embryonic state during the dry and hot season." Sufficient human pressure, Aubreville observed, can transform tropical rainforest into savanna, and savanna into desert. Desertification now threatens more than a billion people worldwide, although its impacts are most severe in Africa. A major impediment to food production, degraded land means roughly $42 billion each year in lost income. Outside the immediately affected areas, it can cause flooding, reduce water quality, create dust storms, and increase incidences of respiratory illness and eye infection.

"But as serious as desertification is, it's only part of the problem. The phenomenon we're concerned with is actually bigger," said Dr. Hank Shugart of the Department of Environmental Sciences at the University of Virginia. "We're interested in land systems that can change from something desirable to something undesirable, then stay that way."

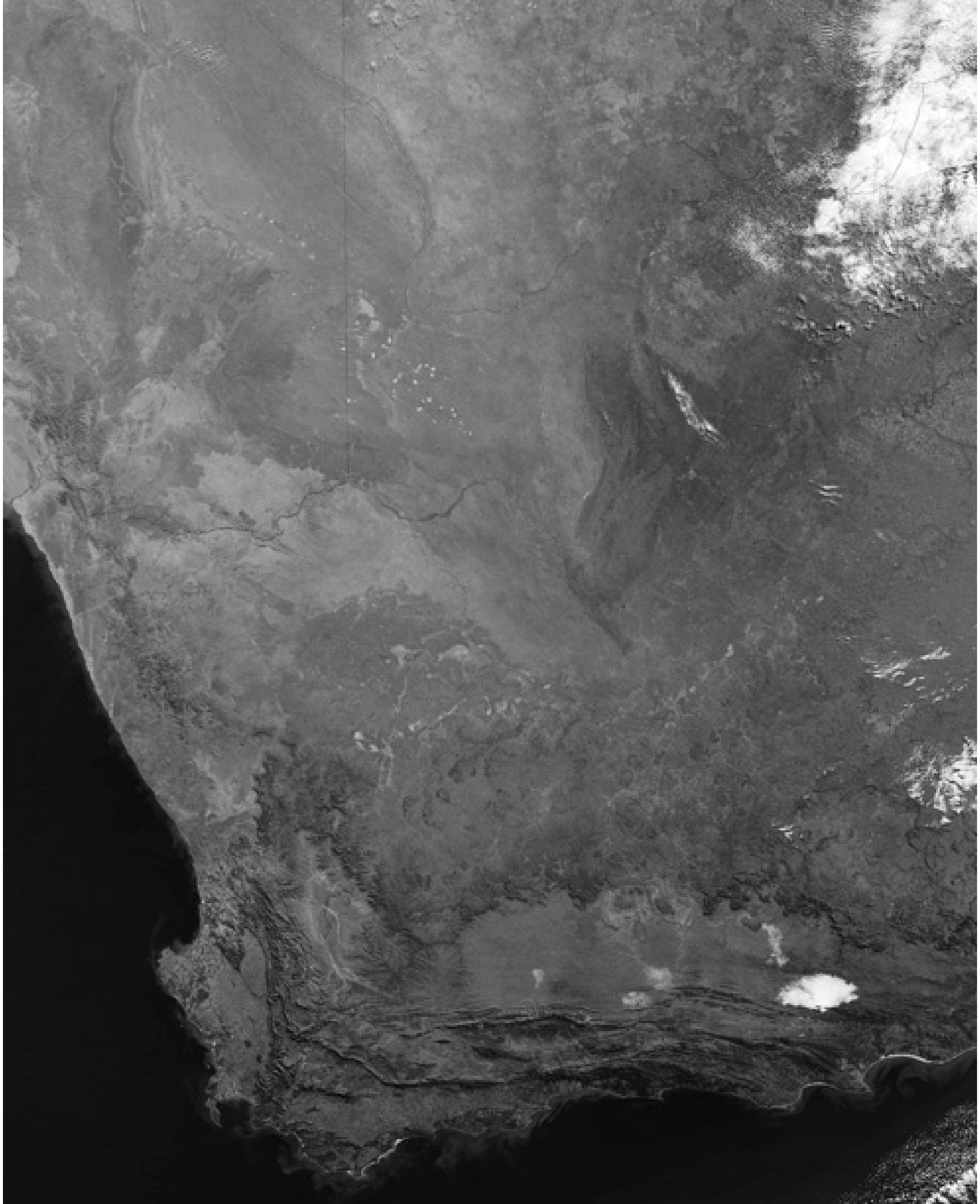
Africa's fragile ecosystems make the continent especially vulnerable to unwanted environmental changes. Shugart compared Africa to parts of the United States and Europe. "In a place with rich soil, if you change the ecosystem and you don't like the result, you can stop, and the system will more or less restore itself. In parts of Africa and Australia, if you change the land and start seeing results you don't like, you might get to look at them for a long time."

Shugart developed an interest in large-scale ecosystems as a graduate student. As a researcher in the Southern African Regional Science Initiative (SAFARI 2000), he studies the big picture by looking at interactions between the Earth, the atmosphere, and people. Shugart suspects that Africa supports two kinds of savanna. One form produces palatable vegetation that the wildlife eats and recycles locally, so the ecosystem's nutrients (nitrogen and phosphorus) remain in the system. The other form of savanna produces less palatable vegetation; rather than being consumed by animals, this vegetation accumulates, providing fuel for fires that transport nutrients somewhere else.

"If the low-nutrient ecosystems lose their nutrients, and the high-nutrient systems keep theirs, are landscape processes robbing the poor to give to the rich?" Shugart asked. If so, this reinforces a serious problem. Once an ecosystem that's easily grazed becomes an ecosystem that's easily burned, it rarely reverts to its previous grazable state. Exactly how ecosystems make this transition is not fully understood, but Shugart cites two lines of evidence that fire-adapted ecosystems exist in places that could support more benign vegetation: (1) previously forested regions have become fire-prone savanna, and (2) high- and low-nutrient communities exist on similar soils and under similar climatic conditions.

Sobering examples of unwanted ecosystem change can be found outside Africa. Introduced plant species have substantially changed ecosystems in North America. "Cheatgrass burns like crazy, and its seeds can withstand fire. It isn't good for anything else, so it's been kind of a scourge in the western United States," said Shugart.

Livestock grazing has also produced problems. "When people first encountered the Chihuahuan Desert in New Mexico, it probably had small shrubs and aridity-tolerant grasses. Once cattle grazed it, everything turned to creosote bush, which sends roots out 50 feet from the plant and sucks up all the nutrients. So now the system is either high-nutrient with a bush growing on it or low-nutrient desert. There are no nutrients between the bushes, so the grasses can't come back—even if you stop the livestock grazing."



Left: This Moderate Resolution Imaging Spectroradiometer (MODIS) image from April 16, 2002, shows three southern Africa countries: Namibia (left), Botswana (upper right), and Republic of South Africa (bottom right). The Kalahari Desert spans the southern portions of Namibia and Botswana. (Image courtesy of NASA Earth Observatory)

A variety of natural grazers can keep an ecosystem in balance, but livestock grazing has had far-reaching effects in Africa's dry regions. "Africa has a beautiful assemblage of antelope, giraffes, and other big animals that eat different kinds of plants," Shugart said. "But cattle are preferential grass eaters, so once they start grazing, the vegetation can turn thorny and shrubby. Is that a reversible condition? We'd like to know."

Ecosystems unlikely to recover from human pressures require more cautious management. Making informed land-use decisions for such unforgiving ecosystems means understanding the complicated relationship between environment and vegetation. But such studies usually involve long time periods, making controlled experiments difficult. The trick for Shugart and his fellow SAFARI 2000 researchers was to find natural experiments already in place. They found what they wanted in the Kalahari Transect.

"In most places where vegetation changes over hundreds of miles, as in the transition from the eastern forests to the Great Plains in the United States, there's a change in climate, but there's almost always a change in soil as well," Shugart said. "The Kalahari has one type of soil top to bottom—windblown sand. The rainfall changes in a very regular way. These variables are naturally controlled along this thousand-mile line."

Another controlling factor in the Kalahari Transect is land use. Much of the area Shugart is studying is devoted to farming or game preserves, where the land is essentially unused. Therefore, Shugart can compare the effects of fairly basic differences in land use. Yet studying southern Africa has presented Shugart with an uncommon problem. "Ecologists want to see how an ecosystem works naturally, and that usually means without people," he said, "but we evolved in southern Africa. The current land use patterns probably didn't evolve there, but there's been a human presence for a few million years." As humans have long known how to start fires, they have augmented naturally occurring fires.

Research conducted so far has already given Shugart valuable insights into land-atmosphere interactions. Shugart's first expedition with SAFARI 2000 started in Zambia and headed south through the Kalahari transect. Joined by members of the Moderate-resolution Imaging Spectroradiometer (MODIS) land validation team, he sampled vegetation intensively at six sites. Field data from the Kalahari Transect are available via the Oak Ridge National Laboratory (ORNL) DAAC's Mercury system.

The MODIS sensor monitors, among other factors, aerosols and land surface changes on the Earth's surface every 24 to 48 hours. For fire emission detection and vegetation mapping, Shugart uses MODIS imagery archived at NASA's Land Processes (LP) DAAC. In addition to the standard size of 1,200 by 1,200 kilometers, the ORNL DAAC has prepared 7- by 7-kilometer subsets of MODIS products over field investigation sites in southern Africa. The subsets are used for validating individual MODIS pixel values against measurements made in the field.

MODIS images vary between 500-meter and 1-kilometer resolution, so a single pixel (the smallest visible unit in the image) actually represents a large area. Five hundred square meters can easily contain a mix of grasses, bushes, trees, and bare rock, yet the pixel can only record one type of ground cover. "The satellite's going to average something out of the picture," Shugart said. So he has supplemented MODIS data with higher-resolution images and modeling techniques.

The SAFARI 2000 project obtained Airborne Multi-angle Imaging SpectroRadiometer (AirMISR) imagery by flying the sensor on an ER-2 aircraft over southern Africa during the study period. AirMISR data are archived at Langley Research Center (LaRC). For historical data, Shugart relies on newly declassified 2-meter resolution images taken by the CORONA spy satellite between 1962 and 1972, now archived by the U.S. Geological Survey (USGS). "We're trying to make comparisons between satellite imagery, aerial photos, and ground-truth data," said Shugart.

Shugart has also worked toward a model-based understanding of Kalahari vegetation. A dozen bushes might display as the same shade of green in a satellite image, regardless of their spatial distribution. Yet those bushes may behave in very different ways depending on whether they're clumped together or separated by several meters. For this reason, SAFARI 2000 researchers have begun making detailed models, known as stem maps, of fine-scale variations. Refining these stem maps will be an ongoing process for Shugart and his team.

As the study progresses, Shugart will examine fire models, burn scar models, and emissions models to better understand what nutrients are lost to the atmosphere across Africa. He is also involved in producing a special journal issue of *Global Change Biology* devoted to SAFARI 2000 research.

"It's easy to get isolated if you're a working scientist in Africa," Shugart said. "Africa doesn't have a huge number of scientists yet, and the ones doing research are under a lot of pressure because they're in the middle of the problem. SAFARI 2000 has been a remarkable project in that it's arisen through grassroots coordination among scientists. By working together, we've been able to pool our resources and share information very quickly. It has been very refreshing."

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Herman ("Hank") Shugart, Jr. is the W. W. Corcoran Professor of Environmental Sciences and the director of the Global Environmental Change Program at the University of Virginia. He has been a visiting fellow at the National University and the Commonwealth Industrial and Scientific Research Organization in Australia; a visiting fellow at the International Meteorological Institute and University of Stockholm in Sweden; and a visiting scholar at the International Institute of Applied Systems Analysis in Austria. Shugart earned his PhD in zoology from the University of Georgia in 1971 and has authored more than 250 publications.

“If we can predict upcoming eruptions, we can help mitigate potential hazards to people living below the volcano.”

Domes of Destruction

Land Processes DAAC

by Laurie J. Schmidt

In Japan, Mount Unzen is synonymous with disaster. In 1792, the volcano spawned the worst eruption catastrophe in Japanese history when its dome swelled and then collapsed, generating a massive landslide and tsunami that killed an estimated 15,000 people.

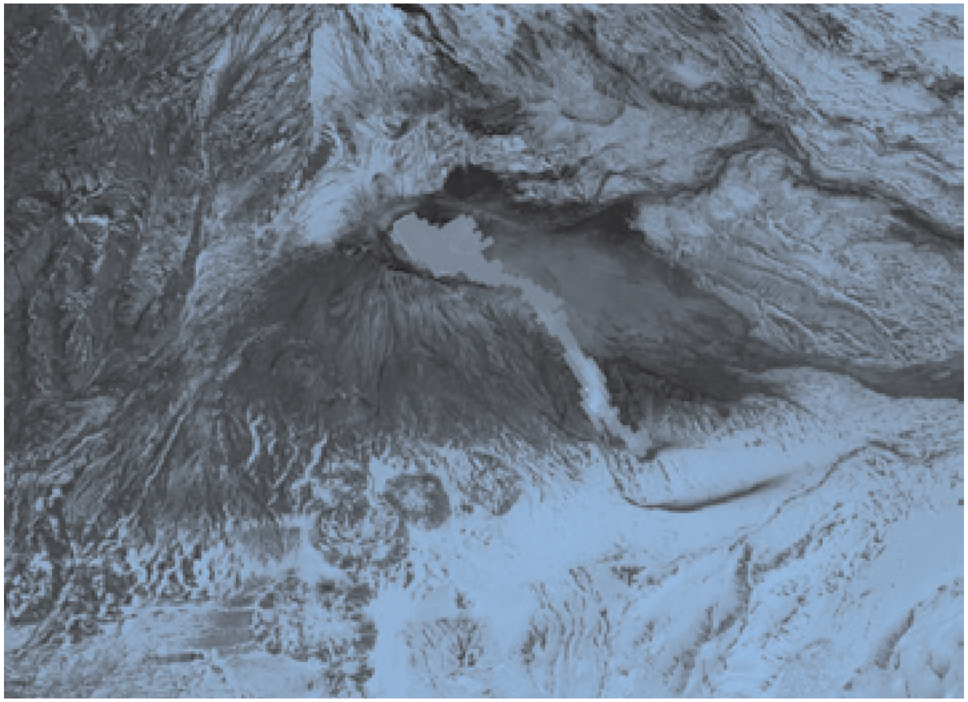
Nearly 200 years later, in 1990, Mount Unzen began sputtering again. Between 1991 and 1994, scientists recorded approximately 10,000 pyroclastic flows on Unzen’s flanks, some of which traveled up to 3.4 miles (5.5 kilometers) from the dome. By summer 1993, these surges of hot ash and gas had destroyed more than 2,000 buildings in Shimabara City, situated beneath the volcano.

Some of the most destructive eruptions have been associated with volcanic domes. To ensure public safety, Japanese officials continually work to improve warning systems and evacuation plans. But volcanic domes, which form when magma squeezes its way out of a crater vent and piles up into a muffin-shaped form, often don’t send any clues until too late. To complicate matters, domes often form quickly—geologically speaking. The dome on Mount St. Helens in the U.S. Pacific Northwest, for example, grew from 16 feet high and 82 feet in diameter to 164 feet high and 606 feet in diameter in just 24 hours.

Now, scientists are exploring the use of satellite data to monitor volcanic domes, which could lead to earlier detection of predictive changes in dome structure.

“Typically, after a large eruption, a dome develops and acts like a cork,” said Michael Ramsey, assistant professor of geology and director of the Image Visualization and Infrared Spectroscopy Laboratory at the University of Pittsburgh. “Sometimes the dome cools and that’s the end of it. But more often, the dome keeps growing and pressurizing until it collapses and generates pyroclastic flows and mudflows, which are very hazardous.”

Mount Unzen’s reawakening produced a new lava dome at its summit. “It was the worst-case scenario, where the dome actually grew up over the crater and hung off the side,” said Ramsey. “As the dome continued to grow, it became more unstable, and the front section would collapse and generate huge pyroclastic flows that



Right: This composite ASTER image, taken on December 28, 2000, shows the active Russian volcano Bezymianny. (Image courtesy of NASA) caused devastation to the homes and farms below. Then the dome would re-build itself and repeat the whole process."

According to Ramsey, pyroclastic flows are the most violent of volcanic eruptions. Highly mobile, these flows reach velocities of up to 250 miles (400 kilometers) per hour and can spread as far as 60 miles (100 kilometers) from the eruption point. In 1902, 29,000 people on the Caribbean island of Martinique were killed when a pyroclastic flow devastated the city of St. Pierre.

Pyroclastic flows also have the potential to unleash deadly lahars, or mudflows, during heavy rainstorms. Between August 1992 and July 1993, lahars from Mount Unzen damaged about 1,300 houses along the Mizunashi and Nakao Rivers, requiring the sudden evacuation of several thousand residents.

The first sign of a potentially active volcano is a hot spot—an area where hotter-than-average molten rock from the Earth's mantle begins to move upward through the Earth's crust. Where hot spots burn through the crust, volcanoes form.

NASA's newest satellite sensor, the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER), has unique capabilities that make it ideal for monitoring volcanic domes, Ramsey said. Launched aboard the Terra satellite in December 1999, the ASTER instrument captures images at a spatial resolution that ranges from 15 to 90 meters.

"ASTER is the only instrument on the Terra satellite that was designed to look at land processes involving small-scale surface change," Ramsey said. "One of its channels actually looks off in a different direction, so it images the same ground point from two different angles. This allows us to make 3D digital elevation models of the Earth's surface. What I hope to do is use ASTER in the 'zoom lens' mode, so that after initial eruptions are detected by other observatory programs, we can then schedule ASTER data to get detailed, high-resolution scenes."

Ramsey and his colleagues work with the Alaska Volcano Observatory (AVO) to regularly monitor volcanoes in the Aleutian region, as well as all of the Kamchatka Peninsula volcanoes in Russia. "These are all very dangerous to aircraft, because when they erupt the plumes head straight out over the Pacific," Ramsey said.

ASTER data, available from NASA's Land Processes (LP) DAAC, located at the U.S. Geological Survey EROS Data Center, proved their potential value during an eruptive phase of the Bezymianny volcano that occurred between June and December 2000. "There were some periods when AVO saw no activity, because the thermal anomaly was too small to be captured in an image. But ASTER detected the hot spot, pyroclastic flows, and debris flows coming off the dome," Ramsey said. "So we were able to map a lot more detail than AVO could."

"We're looking at how well we can use ASTER to monitor a volcanic dome surface, including temperature, chemistry, and texture, over a period of six months to a year. If we can predict upcoming eruptions, we can help mitigate potential hazards to people living below the volcano."

Around the globe, about 100 volcanoes erupt during any given year, and millions of people live directly below many of these volcanoes. Mount St. Helens, which towers over a large, metropolitan population, has flow paths leading directly to urban areas. Mount St. Helens' eruption on May 18, 1980, eliminated 1,300 feet of its summit, spewing ash up to 950 miles (1,529 kilometers) eastward and leaving 57 people dead.

"Mount St. Helens had a large eruption, and then for the next five to six years a lava dome grew in the crater, spawning small to moderate-sized eruptions as the dome collapsed or blew apart," said Ramsey. "If ASTER data had been available to us back then, it would have been an excellent case study."

Although detecting hot spots in the imagery is key, Ramsey takes his efforts a step farther and uses ASTER's multispectral information to study the chemistry of volcanic domes. "As a geologist, I can look at the dome and determine not only the lava type, but also whether the type is changing over time," he said. He can also determine the lava's surface texture and examine bubbles in the lava. "This is important, because those bubbles indi-

Top: Mount St. Helens' lava dome in August 1981, as viewed from a photo station 0.5 mile (0.8 kilometers) away. (Image courtesy of Lyn Topinka, U.S. Geological Survey)

Bottom: Since December 1980, eruptions of Mount St. Helens have added material to a lava dome within the crater, as seen in this 1984 view from the north. (Image courtesy of Lyn Topinka, U.S. Geological Survey)

Top: This rockslide occurred off the north face of Mount St. Helens' dome on May 14, 1986. (Image courtesy of Lyn Topinka, U.S. Geological Survey)

Bottom: Mount St. Helens' southeast crater rim with visible lava dome on May 6, 1987. (Image courtesy of Lyn Topinka, U.S. Geological Survey)

cate the potential explosivity of a future eruption. It's like shaking a champagne bottle, and the dome represents the cork on the bottle," he said.

"These are the subtle things that can't be seen from other satellite sensors, and they certainly can't be seen through ground-based monitoring," Ramsey said. "You just can't have somebody walk up to the dome to collect samples when an active eruption is going on."

Ramsey knows firsthand the dangers of monitoring a volcano on site. In July 2000, he was accompanying a team of scientists on a routine, weekly monitoring tour of Mt. Semeru in eastern Java when an eruption caught the group off guard. Although the eruption lasted only about 45 seconds, it left two Indonesian volcanologists dead and three Americans, including Ramsey, injured. Ramsey said he still has difficulty coping with the ordeal. "I'm better with it now, but for the first year after it happened, I had a hard time talking about it," he said.

Ramsey hopes that his work with ASTER imagery will play an important role in mitigating volcanic hazards. "The mitigation effort would include working with a volcano observatory that's monitoring the volcano or a series of volcanoes," he said. "The hope is that I would detect some kind of change in the ASTER imagery, then I would let them know what that change might mean. They could then broadcast the information to nearby cities or to the Federal Aviation Administration."

"We're really in a tool-building mode. It's a brand new satellite and a brand new data set that we've never had before. The question is, how well can we use these data to mitigate volcanic hazards?"

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Michael Ramsey is an assistantÄ professor in the Department ofÄ Geology and Planetary Science atÄ the University of Pittsburgh, andÄ an associate science team mem Ä ber for NASA's Advanced Space-Ä borne Thermal Emission andÄ Reflectance Radiometer (ASTER)Ä instrument. In 2000, RamseyÄ formed the Image VisualizationÄ and Infrared Spectroscopy (IVIS)Ä Laboratory, which stores imageryÄ for the ASTER program. Ramsey's varied research interests in Ä clude remote sensing of active volcanoes, urban environmentalÄ science, and natural hazards of brush fires and urban flooding.Ä He holds a PhD in geology from Arizona State University.Ä

Above: Approximately 30,000 juvenile Atlantic menhaden died when dissolved oxygen levels dropped in the Pamlico River in North Carolina. Prevailing winds then washed the fish up on Hawkins Beach near Bath, North Carolina, shown in images above. (Images courtesy of Garcy Ward, North Carolina Division of Water Quality)

Hunting Dangerous Algae from Space

Harmful algal blooms are responsible not only for adverse health effects, but also for the loss of millions of dollars from fisheries and tourist industries.

GSFC Earth Sciences DAAC

by Evelyne Yohe

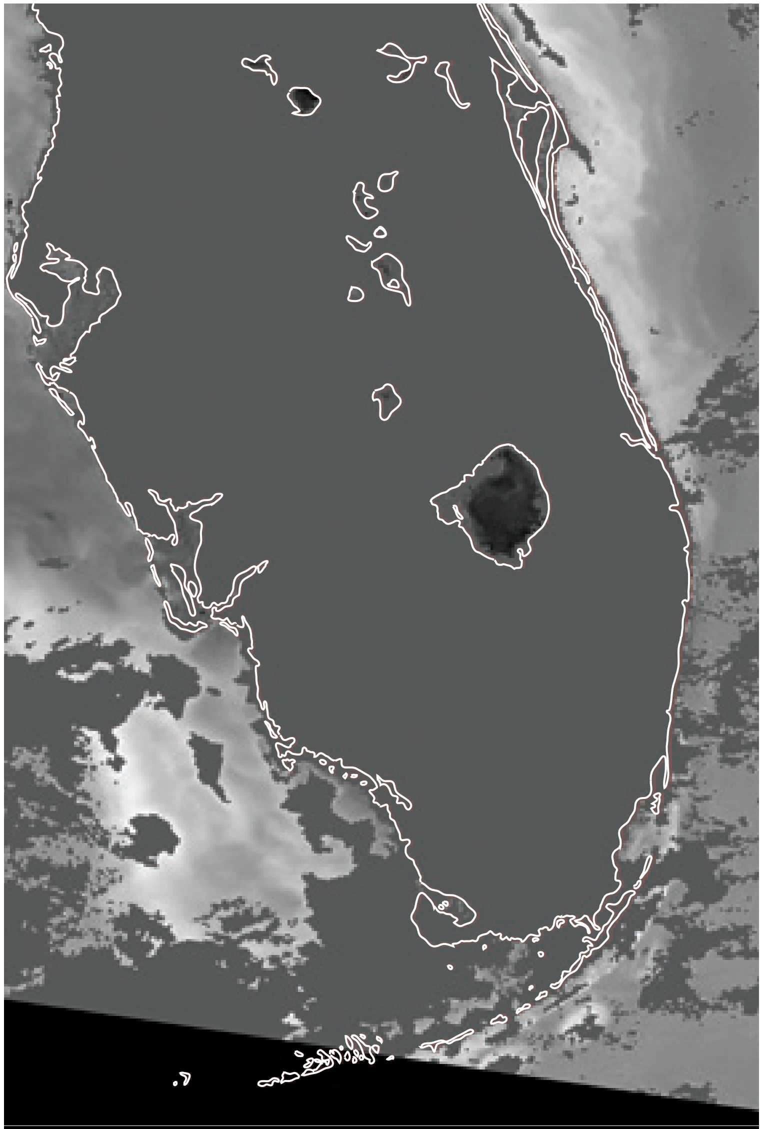
On April 2, 2002, Texas Parks and Wildlife Department staff found millions of small dead and dying menhaden fish along a 15-mile stretch of beach on North Padre Island. During February 2002, approximately 1,000 tons of rock lobsters beached themselves at Elands Bay in South Africa. And in 1996, almost 150 Florida manatee—over five percent of the estimated population—died over a two-month period, beset by a pneumonia-like respiratory syndrome. What caused these deadly events?

In each case, the cause was a microscopic aquatic plant known as phytoplankton, or algae. But not just one, or even a few, renegade algae could have been responsible for this level of destruction. Rather, millions of phytoplankton proliferated to form a harmful algal bloom (HAB), commonly referred to as *red tide*.

Harmful algal blooms occur around the world—from Florida to Maine, Norway to Africa, Japan to Oregon—and can create health problems for both animals and humans. When ocean temperature, salinity, nutrients, and light conditions are optimal, phytoplankton reproduce quickly to form blooms of millions of organisms.

Some phytoplankton, such as *Karenia brevis (K. brevis)* found off the Florida coast, contain potent toxins that are harmful to marine organisms and humans. Harmful algal blooms can kill fish, poison humans and other organisms, and cause respiratory problems in humans and marine mammals. Many of the manatees that died in 1996 had brevetoxins in their nasal and lung tissue, according to the Florida Marine Research Institute.

Harmful algal blooms are responsible not only for adverse health effects, but also for the loss of millions of



SeaWiFS captured this image of the Florida coast on September 17, 2001.

dollars from fisheries and tourist industries. Economic losses associated with blooms in the U.S. alone may exceed $1 billion over the next several decades.

Although red tides have been reported in Florida since 1530, scientists are still struggling to understand their cause, to predict their occurrence, and to find a way to lessen their impact. Early detection is key to forecasting harmful algal blooms.

Observations by volunteers and research teams at beaches and on fishing vessels can reveal when a red tide is in full bloom and is already affecting organisms. But to determine when and where a bloom is forming, scientists need to monitor large areas of ocean on an ongoing basis. Now, a group of scientists in Florida, led by Ken Carder of the University of South Florida, is using remote sensing data and offshore monitoring to find and track harmful algal blooms as they form and spread.

Carder's research team is using data from NASA's space-based SeaWiFS (Sea-viewing Wide Field-of-view Sensor) and MODIS (Moderate Resolution Imaging Spectroradiometer) instruments to detect harmful algal blooms. The satellite images provide data on ocean color (based on light intensities) and chlorophyll content. Like terrestrial plants, phytoplankton use chlorophyll for photosynthesis. Reflected light intensity and chlorophyll content can help scientists detect algal blooms.

Carder and his colleagues found that *K. brevis* has low reflectivity and high chlorophyll concentration, making it possible to detect large masses of this phytoplankton using SeaWiFS imagery. Using satellite data, hydrodynamic modeling, and biological modeling, the researchers detect, or "now-cast," red tides off the west coast of Florida. Now-casting, which refers to the detection of blooms as they occur offshore, rather than after the bloom has arrived onshore, allows researchers to alert coastline communities of approaching harmful algal blooms.

Using a combination of satellite images and data from offshore moorings, the team determines where and when phytoplankton blooms appear, and what ocean and atmospheric conditions might affect the blooms. "The satellites provide us with real-time now-casting of where things are at any given moment, and the sequence from image to image tells us quite a bit about what the ocean circulation has done. By combining that information with measurements of the hydrodynamics (ocean currents and wave action) from moorings and models, we can get an idea of where red tides have formed and where they are headed," said Carder.

Carder's group is working on revising the algorithms that help determine the presence of *K. brevis* using satellite imagery, so that they can more easily distinguish these blooms from things such as color dissolved organic material (CDOM)—decaying plants, phytoplankton, and other organic matter in the water. "If a phytoplankton bloom [detected by a satellite] is away from the coast, and we see that there is more chlorophyll than CDOM, and if it has a low backscattering per unit chlorophyll, then we have pretty strong evidence that it's red tide, and we'll send boats out to check it," said Carder.

Recently, Carder and his colleague at the University of South Florida, John Walsh, began to suspect that iron-rich dust from seasonal Saharan dust storms may lead to blooms of toxic algae in the Gulf of Mexico. The Advanced Very-High-Resolution Radiometer (AVHRR) onboard NOAA's Polar Orbiting Environmental Satellite tracks dust carried across the Atlantic Ocean and into the Gulf of Mexico by trade winds.

Walsh and Carder are finding that when levels of iron in the water increase, a bacterium called *Trichodesmium* uses the iron to convert nitrogen in the water to a form more usable for marine algae, such as *K. brevis*. Because this bacterium has high reflectivity and lower chlorophyll concentrations, it can also be classified from satellite images, allowing the scientists to correlate its presence with any subsequent phytoplankton bloom.

"If we have a lot of Saharan dust, and we begin to see a significant amount of *Trichodesmium*, there's a fair chance that we're going to have red tide showing up somewhere in or near that *Trichodesmium* bloom," said Carder. This relationship between bacteria and phytoplankton allows early detection of blooms in the Gulf of Mexico, and may be useful for detecting harmful algal blooms as they form in other coastal regions.

These methods of correlating satellite data with field data and modeling are allowing scientists to determine the causes and precursors of harmful algal blooms. With that knowledge comes the possibility of detecting the start of a bloom, alerting coastal communities earlier, and mitigating some of red tide's toxic effects, such as fish kills and neurotoxic shellfish poisoning.

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http://www.mote.org

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Kendall L. Carder is a professor in the College of Marine Science at the University of South Florida. His research interests focus on improving understanding and measurement of light propagation within the ocean and interpretation of ocean color from space. Carder has served on several spacecraft sensor and science teams. He holds a PhD in physical oceanography from Oregon State University.

"Using satellite data to map hantavirus risk gives us a good evaluation of the data's use."

Hantavirus Risk Maps

Land Processes DAAC

by Michon Scott

Page 21: Landsat 4 captured this image of the Four Corners region of the southwestern United States on June 18, 1992. The intersecting borders of Utah, Colorado, New Mexico, and Arizona appear in white. Some researchers suspect that the 1991–92 El Niño contributed to the hantavirus outbreak of 1993 by increasing precipitation and, consequently, vegetation and rodent populations. (Image courtesy of the Land Processes DAAC)

On May 14, 1993, a young, physically fit man living in the American Southwest suddenly collapsed. He was rushed to a New Mexico hospital but died of acute respiratory failure within hours. The man had been on his way to a funeral—his fiancée died a similar death just days earlier. By May 17, medical center officials identified three similar deaths in the Four Corners region where the borders of Colorado, New Mexico, Arizona, and Utah meet. All of the victims had been young and otherwise healthy.

On May 18, the New Mexico Department of Health contacted the Centers for Disease Control and Prevention (CDC) for assistance, but laboratory tests failed to find a known disease among the victims. The CDC Special Pathogens Branch began a joint investigation with the state health departments of New Mexico, Colorado, and Utah, and with the Indian Health Service, the Navajo Nation, and the University of New Mexico.

Three weeks later, the CDC identified the responsible pathogen: hantavirus.

Hantaviruses are *zoonoses,* diseases that can be transmitted from animals to humans. Strains found primarily in Asia and Europe affect the kidneys and may cause severe circulatory problems, but less than 10 percent of the people infected die. The strain in the Four Corners outbreak, however, was different. Later named the Sin Nombre virus, it caused a much deadlier illness: hantavirus pulmonary syndrome (HPS). Affecting the heart and lungs, HPS has a mortality rate of 50 percent. Between 1993 and 1995, it claimed the lives of more than 45 people in the southwestern United States.

Identifying the pathogen was only the first step in addressing the Four Corners outbreak. Next, researchers had to figure out how the disease spread. All previous cases of hantavirus were spread by rodents, so researchers began trapping and examining as many rodent species as possible in the Four Corners area. On June 14, 1993, the CDC identified the deer mouse, found throughout North America, as the primary carrier. Other rodents have also been found to carry viruses that cause hantavirus pulmonary syndrome: the cotton rat, ranging from the southeastern United States to South America; the rice rat, ranging from the southeastern United States to Central America; and the white-footed mouse, found throughout much of the United States and Mexico.

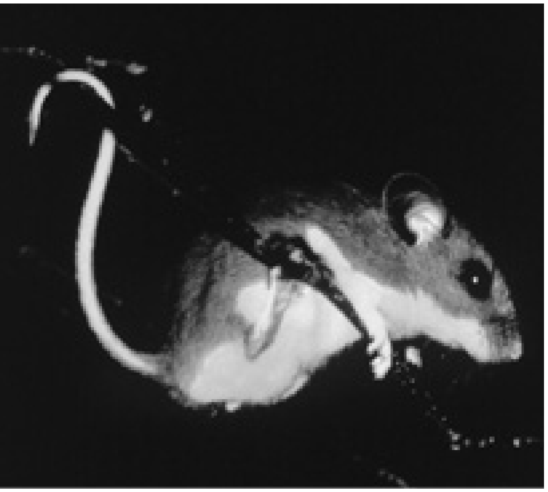
Mice infected with hantavirus can transmit the disease to humans through bites that break the skin, but this is fairly rare. The virus usually spreads through "aerosolization"—a process through which infected mice shed the virus through their saliva, droppings, and urine, and humans inadvertently inhale the particles if they are stirred up.

Although roughly 30 percent of the deer mice tested in the Four Corners region investigation were carrying the Sin Nombre virus, they weren't sick or dying. A virus does itself no favors by killing its host. "Smart" viruses coexist peacefully with their hosts, thereby prolonging their own lives, and the Sin Nombre virus may have coevolved with its rodent hosts for more than 20 million years. If humans were suddenly contracting the virus, their contact with the carrier rodents must have increased. Why?

"That's what the field of epidemiology is all about," said Gregory Glass, associate professor at the Johns Hopkins Bloomberg School of Public Health. "We try to understand the factors that alter the risk people have for disease."

Glass has used satellite data to map animal populations since the 1970s. He realized that if he could map the distribution of animals, he could also map the diseases


UTAH
COLORADO
ARIZONA
NEW MEXICO



Above: The white-footed mouse, found throughout the United States and Mexico, is a carrier of hantavirus pulmonary syndrome. (Image courtesy of NOAA)

they carry. To examine the Four Corners hantavirus outbreak, Glass used Landsat satellite images, archived at the Land Processes DAAC at EROS Data Center. He also collaborated with researchers at the IBM Watson Research Center Public Health Earth Science Information Partner.

Understanding the Four Corners outbreak wasn't a simple matter of knowing where to look; scientists also had to know when to look. "Bob Parmenter, an ecologist at the University of New Mexico, pointed out that mouse populations take some time to get big enough to cause disease in humans," Glass said. "So the time to be looking at the environment wasn't when people got sick, but probably before that."

Glass and fellow investigators started reviewing satellite images from 1992, the year before the outbreak. Early on, researchers hypothesized that the 1991–92 El Niño contributed significantly to the hantavirus outbreak by increasing precipitation. More precipitation meant more vegetation; more vegetation meant more mice. Yet, this hypothesis was based on data from just two study areas: the University of New Mexico's Sevilleta Long-Term Ecological Research Station, and Moab, Utah. Glass set out to test the hypothesis with a case-control study.

"If you know where people were when they got the disease, you can use satellite data to monitor the environmental conditions where the outbreak happened," said Glass. "But there's a problem. You could, for example, conclude that the area where people got sick has lots of trees. Does that mean being around trees helps the disease spread, or does it just mean that people like to have trees around their homes?" He explained that a case-control study is one in which the environment and habits of the people who become ill (cases) are compared to those who did not contract the disease (controls).

Glass and fellow researchers estimated precipitation at 28 case sites and 170 control sites during the springs of 1992 and 1993. They then compared those data to the previous six years' precipitation using rainfall records from 196 weather stations. They also examined Landsat Thematic Mapper satellite imagery collected the year before the outbreak to estimate the hantavirus pulmonary syndrome risk. Glass and his collaborators published the results of their study in *Emerging Infectious Diseases*. What Glass found is that, while there is a relationship between precipitation and hantavirus, it's not as simple as previously thought.

"One of the complicating factors relates to remote sensing. In areas that are semiarid, like the U.S. Southwest, the satellite readings don't correspond well with the actual amount of vegetation. The images show both vegetation and bare soil, and depending on the soil type, you can get false readings," Glass said. "Another complicating factor is the vegetation. I visited the Four Corners region during the next El Niño in 1998 and 1999 and realized that disease risk doesn't depend on the vegetation, per se. Broad categories of vegetation exist for high- and low-risk areas, but it's not a simple matter of saying piñon juniper forest is high risk, or salt bush lowlands is low risk."

A crucial step in solving the puzzle, Glass said, is collecting ground truth data. He began overlaying risk maps from 1992 through 1998 to determine where the high-risk areas persisted, and he visited those sites with CDC researchers to learn more about them. "Mice might be fussier than we thought about where they live. The vegetation might look promising, but maybe the soil's too hard, so the mice can't burrow. Maybe there's not enough moisture in the soil. These are all things we have to figure out, and public health officials need remote sensing scientists to understand the nuances of the imagery."

Another key to understanding hantavirus risk is acquiring more data. "We don't have enough statistical power to say much about precipitation patterns yet," Glass said. "An additional problem is that the data could be contaminated with past outbreaks of the disease. I'm positive there were earlier cases that just weren't recognized." The CDC agrees. Earlier cases of the Sin Nombre virus have been found in stored tissue samples taken from people who died of unknown lung diseases before the 1993 outbreak. Now, the earliest known case of the Sin Nombre virus has been confirmed in a 38-year-old Utah resident who died in 1959.

Do public health officials pay too much attention to illnesses like hantavirus pulmonary syndrome? "We don't have that many infectious diseases in the United States, so even 30 or 40 people dying from something is pretty frightening," Glass said. "You could compare the Four Corners outbreak to the recent anthrax outbreak. Nobody knew where it was coming from or how many people would be affected. With hantavirus, we didn't even know what it was or how it spread. So the problem isn't that you've got huge numbers of deaths, it's that you have a lot of people who don't know whether or not they've been exposed."

Beyond protecting Americans, monitoring conditions in the United States can alleviate suffering elsewhere. "Diseases like malaria, schistosomiasis, and dengue fever affect hundreds of thousands, even millions of people. In many cases, animals provide a reservoir for germs, or spread them among humans, and those animals are influenced by the environment. Using satellite data the way we have for hantavirus gives us a good evaluation of the data's use. Does having an image every 16 days at 30-meter resolution tell us enough to make some predictions? If it does, we can start using the data; if it doesn't, we have better ideas for how to design the next sensor."

One conclusion Glass reached from his research on zoonotic diseases is that outbreaks are more easily tied to environmental conditions when the carriers are arthropods. "The dynamics of arthropod populations, such as mosquitoes, are tightly linked to temperature and precipitation patterns. Vertebrates are generally bigger, they can move around more, and they can control their own body temperature. So while vertebrates certainly respond to the environment, it isn't clear just how they respond. That makes predicting hantavirus a little tougher."

Predicting hantavirus outbreaks accurately is what Glass eventually hopes to do. "You could just be extra cautious and predict a lot of outbreaks, but you can cause almost as much concern by over-predicting as by under-predicting. Businesses that depend on tourists, hikers, backpackers, and campers really feel the economic crunch when an outbreak is predicted.

"Being prepared for an outbreak helps mitigate the huge economic and emotional losses," Glass concluded. "Epidemiology has been a good detective tool, but it hasn't turned into a predictive science. Remote sensing and ground truthing can improve predictions. Once we understand the link between environment and disease, we ought to be able to forecast disease at least as well as we forecast the weather."

Links:

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http://www.esipfed.org

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Gregory Glass is a professor in the W. Harry Feinstone Department of Molecular Microbiology and Immunology at the Johns Hopkins Bloomberg School of Public Health. His research focuses on the transmission of zoonotic diseases, including field and laboratory studies of animal reservoirs, and epidemiologic studies of affected human populations. As part of this research, Glass and his collaborators have developed a geographic information system to better understand environmental conditions that accompany disease risks. He is a recipient of the Honors Fellow Award from Johns Hopkins University and has served as a review panel member for the U.S. Agency for International Development and the National Institutes of Health. Glass earned his PhD in systematics/ecology from the University of Kansas in 1983.

Tais that Bind

> *"Groups within a society distinguish themselves—rulers from subjects, educated from illiterate, rich from poor—through differences in pronunciation and word usage. At the point of origin, these language divides have simply been at work longer and proliferate over time."*

Socioeconomic Data and Applications Center

Land Processes DAAC

by Rachel Hauser

Right: Tai Lue farmers construct a traditional diversion dam in Sipsongpanna, Yunnan Province, Muang Long. (Image courtesy of John Hartmann)

COMMON SENSE MIGHT SUGGEST THAT the farther a migrating people travel from their homeland, the more their language will change over time. But by tracing the origins and migration routes of the Tai—an East and Southeast Asian ethnic group whose modern-day descendents include many Thai (or Siamese) of modern Thailand—linguists discovered recently that just the opposite is true. Migrating populations tend to cling to historical language patterns acquired from their homelands. Interestingly, linguists find the greatest changes in languages usually occur at their point of origin.

"We know that English originates from England, and in the British Isles you may hear hundreds of dialects—some incomprehensible to American listeners," said John Hartmann, a Thai language professor at Northern Illinois University (NIU). "However, in parts of Appalachia you might hear forms of the English language that date back to Shakespearean times spoken by descendents of original English settlers. At the point of origin, England in this example, pronunciations get 'worn down,' to use a geologic term."

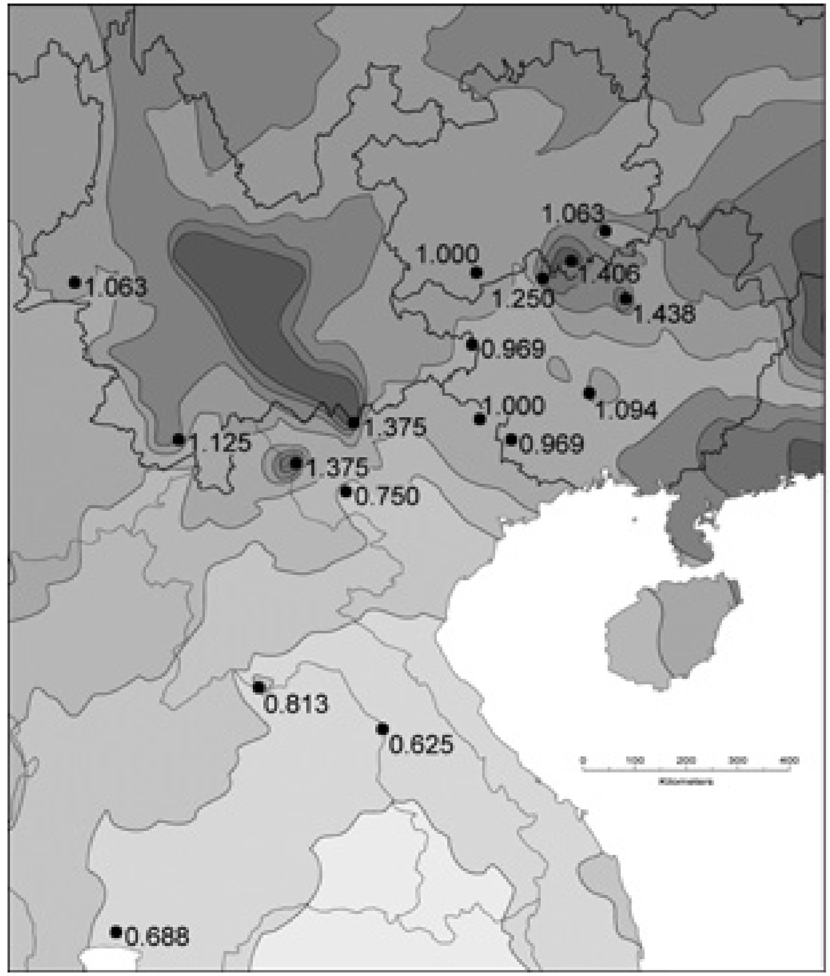
"A lay person might describe this as the 'Away Theory.' The farther a group moves away from its homeland, the more likely the language will preserve older forms," explained Vinya Sysamouth, a graduate student at the University of Wisconsin–Madison who conducted fieldwork with Hartmann and a team of Americans studying Chinese linguistics in China.

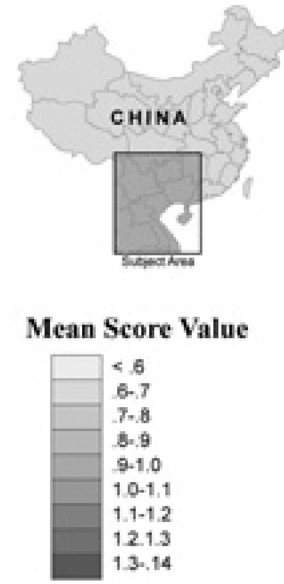
Over centuries, changes in language occur due to pressures within the language's sound and semantics system as well as influences from speakers of adjacent languages, according to Hartmann.

"Groups within a society distinguish themselves—rulers from subjects, educated from illiterate, rich from poor—through differences in pronunciation and word usage. At the point of origin, these language divides have simply been at work longer and proliferate over time," he said.

Richard O'Connor, an anthropology professor at the University of the South in Sewanee, Tennessee, studied two of Southeast Asia's neighboring cultural groups, the Tai and Mon-Khmer. O'Connor hypothesized that the development of wet-rice agriculture and the resulting complex political and social structure required to sustain the irrigation system ultimately resulted in Tai dominance over the Mon-Khmer.

In Southeast Asia, a dependable rice crop produces more calories per acre than any other grain and can support rapid population growth and expansion. Tai irrigation methods ensured reliable rice production and, ultimately, a well-fed population. For the Tai irrigation system to work, the minimal political unit was village-sized, requiring a complex division of labor to ensure system functionality. Alternatively, the Mon-Khmer opted for a less complex system—each family labored independently to grow and harvest rice crops and relied on the elements for adequate rainfall.





The map at left shows the mean scores for the current pronunciation of 21 words related to rice culture, 1 being the closest to the proto-Tai pronunciation, and 3 being the most different. (Image courtesy of Wei Luo)

Tai agricultural success resulted in growing population numbers, causing groups of Tai to migrate from their region of origin to other, geographically similar areas favoring wet-rice agriculture.

Expanding on O'Connor's research and focusing on Tai ethnic groups, Hartmann hoped to determine the Tai people's location of origin and track their movements from southern China into mainland Southeast Asia. By combining the Theory of Linguistic Origins and Spread and Geographic Information System (GIS) technology with population and elevation data, available from

NASA's Socioeconomic Data and Applications Center (SEDAC) and Land Processes (LP) DAACs, Hartmann and colleagues set out to trace Tai migration patterns.

"The Tai, a cultural group that includes the Thai of northern Thailand, the Shan of Burma, and various groups in Vietnam and southern China, used mountain streams and diversionary dams and canals to irrigate rice crops. Because of their irrigation success, the Tai had rice surpluses, which attracted other people to help sustain their system," Hartmann said.

According to Hartmann, some contention exists as to the original location of the Tai. "Many believed the Tai originated in Yunnan Province or the middle Yangtze River region, but based on our research, we believe they originated in the Guangxi-Guizhou region of China," he said.

Funded by a Luce Foundation award, Hartmann and Jerold Edmondson, linguistics professor at University of Texas–Arlington and a veteran Tai dialect researcher, began their work in the summer of 1999. Hartmann invited Professor Li Jinfang from China's Central University of Nationalities to Illinois to collaborate in the research. Hartmann also enrolled in a GIS class taught by Wei Luo, an NIU geography professor who helped him realize the potential utility of GIS in tracing changing linguistic and water resource patterns and in mapping regional Tai minorities.

Hartmann and colleagues first investigated the origins and spread of the Tai through the prism of irrigated rice agriculture and engineering.

"We created a list of about 400 words, beginning exclusively with rice agriculture-related words like 'dike' and 'dam.' Other words of interest to us included those describing aquatic life, such as fish species or frogs, the rice plant's anatomy, and any tools associated with rice agriculture," Hartmann said.

"Focusing on 21 words, we examined pronunciation differences at varying locations. We used the SEDAC's China Dimensions data, which provided us with background on regional land use and environmental and socioeconomic information. These data allowed us to identify the names and x- and y-coordinates for each of the linguistic sites Dr. Hartmann selected and studied," said Luo.

Sysamouth traveled to China with Hartmann and Edmondson to help interview rice farmers. After making audio recordings, the researchers classified and ranked varying pronunciations to identify differences in the dialects.

"We used a scale of 1 to 3," said Sysamouth. "Words with the greatest similarity to the prototype form were assigned a score of 1, while the most significantly changed pronunciations were assigned a score of 3."

The researchers also examined the relationship between Tai settlement patterns and the natural environment and water resource availability. They knew Tai people tended to settle in lowland areas near water in order to grow rice.

"The ideal landscape for wet-rice agriculture is low elevation with little slope. Using digital elevation data from the LP DAAC and population data from SEDAC, we plotted county population against each county's mean elevation and land surface slope, finding high concentrations of Tai-speaking ethnic groups in places with both low elevation and slope," Luo said.

Next, by averaging scores for the set of 21 words at each assigned location, Sysamouth and Luo created a contour map of pronunciation changes. The resulting map displays an overall pattern of change and illustrates Tai migration routes relative to where the language originated.

"The map reveals two high-value regions, one at the southeastern Yunnan-Vietnam border and the other at the Guangxi-Guizhou border," Luo said. "The primary candidate of origin lies in the border region of Guangxi and Guizhou, and we believe the general direction of population migration is from the Guangxi-Guizhou border southwestward toward Vietnam and Thailand."

"Prior to our study, no one had given precise geographic locations that identified various language dialects spoken in particular areas. We ended up looking at about 12 locations in Guangxi and Guizhou to identify regional dialects," Hartmann said.

By combining historical records with comparative linguistics, based on the degree and direction of pronunciation change, Hartmann and his colleagues found that proto-Tai likely originated in the Guangxi and Guizhou provinces, which border northern Vietnam. Notably, many Tai groups still dominate this region today.

Demonstrating language patterns, the study offers a rich history of politics and human geography. Over time, the pronunciation of words changes, resulting in shifts and extensions of meaning that have both social and political implications.

An example is the Tai word *muang*, which Hartmann says originally meant "rice-growing basin." It later evolved to indicate a political principality or kingdom. Today, it means "country"—as in *Muang Thai*, or Thailand.

"By its very complexity, the Tai's irrigation system re quired a cooperative political system that brings new peo ple into the system," Hartmann said. "So, it has always been possible to become Tai. It's an acquired set of fea tures—you grow irrigated rice, live along riverbanks, and have a cooperative type of social organization.

"The genius of the Tai was to combine skilled rice growing with astute political skills, through which they succeeded in populating much of Southeast Asia," said Hartmann.

Links:

China Dimensions.
http://sedac.ciesin.columbia.edu/china

Global Digital Elevation Map.
http://edcdaac.usgs.gov/gtopo30/gtopo30.html

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John Hartmann is a professor in the Department of Foreign Languages and Literature at Northern Illinois University. He holds a bachelor's degree in English and a master's degree in linguistics from the University of Michigan. Prior to beginning his graduate studies, he served as a Peace Corps volunteer in Central Thailand and also worked briefly as an interpreter-escort for the U.S. State Department. Hartmann's research includes regular travel to Thailand and other areas in Southeast Asia and China to conduct fieldwork in Tai language communities.

Wei Luo is an assistant professor in the Department of Geography at Northern Illinois University. His research interests include physical geography, hydrology, and computer simulation of geomorphic and hydrologic processes. Much of his work involves applying Geographic Information Systems (GIS) to a variety of topics, including health care and linguistic geography. Luo earned a PhD at Washington University, St. Louis.

"Nobody has ever collected data from high altitudes in a hurricane. Now we have a data set that is very rich, because we have eight vertical profiles through the center of this strong storm, which represents a complete snapshot of the inside of the hurricane."

Dropping in on a Hurricane

Global Hydrology Resource Center

by Laurie J. Schmidt

FOR YEARS, SCIENTISTS HAVE STRUGGLED to understand the inner workings of hurricanes, in short, because they had no way to get a complete picture of the storm from the top down.

Now, by dropping small sensors into hurricanes from above, scientists are acquiring data at high altitudes that will help them better understand the structure and dynamics of hurricanes.

"Historically, getting measurements of the temperature and wind structure in the upper levels of a hurricane has been difficult, if not impossible," said Gerald Heymsfield, Research Meteorologist at NASA's Goddard Space Flight Center. "There's been a lot of speculation about what's going on up at those high levels, but nobody has been able to take the measurements."

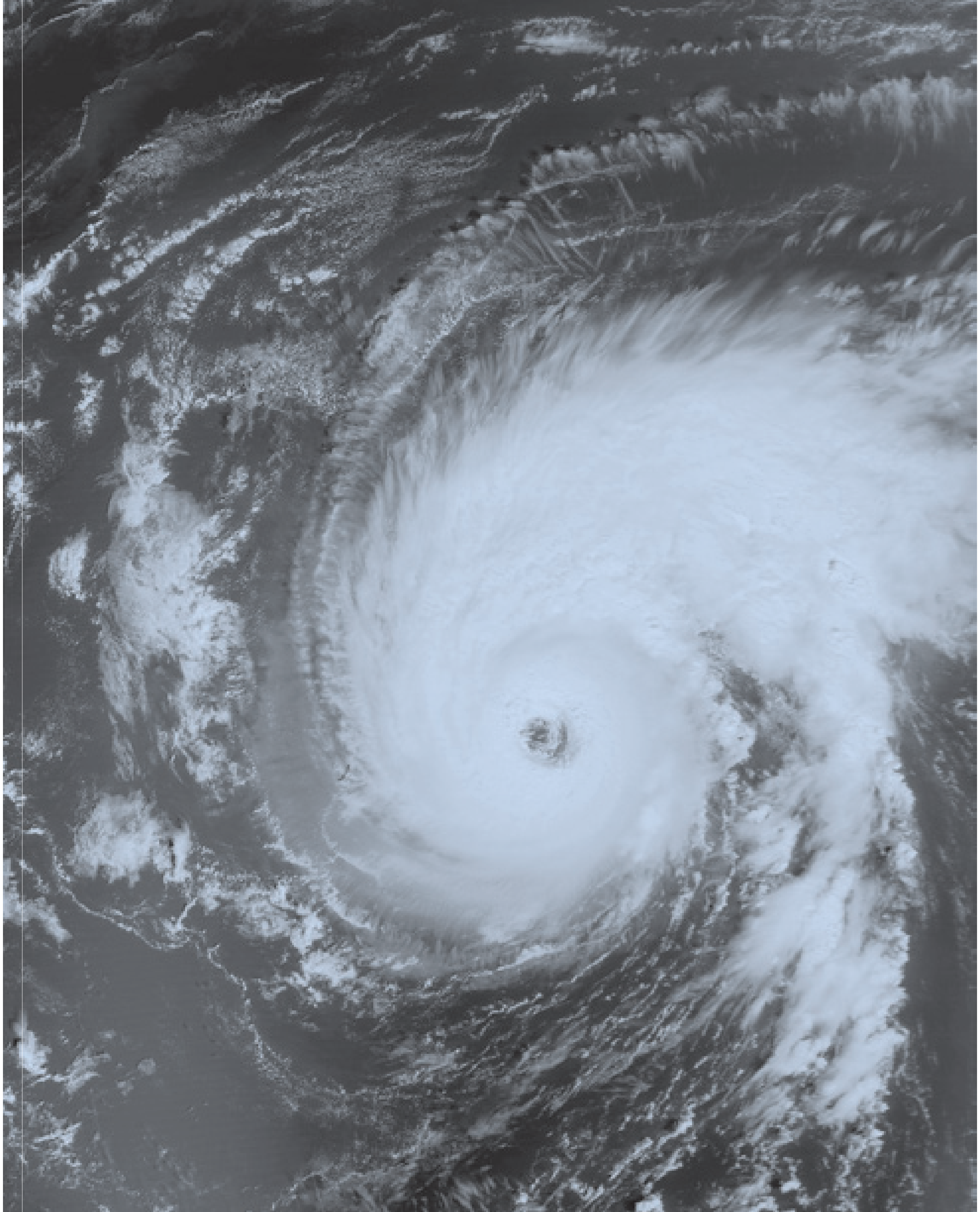
Researchers also need to know what occurs in real time inside a hurricane, according to Jeff Halverson, assistant professor of geography at the University of Maryland, Baltimore County and research scientist at NASA's Goddard Space Flight Center. "Models that make predictions about hurricanes need real-time observations on which to base a forecast," said Halverson. "We have to understand the physics better, and then put that information into the forecast models."

Halverson and Heymsfield are participants in a series of hurricane field research investigations, initiated by NASA's Earth Science Enterprise, called the Convection and Moisture Experiment (CAMEX). The first two missions, conducted in 1993 and 1995, focused on atmospheric and precipitation processes. In 2000, CAMEX-3 turned its attention to the hurricane intensification process and captured an unprecedented look at Hurricane Bonnie's eyewall—the zone surrounding the eye where surface winds reach their highest speed.

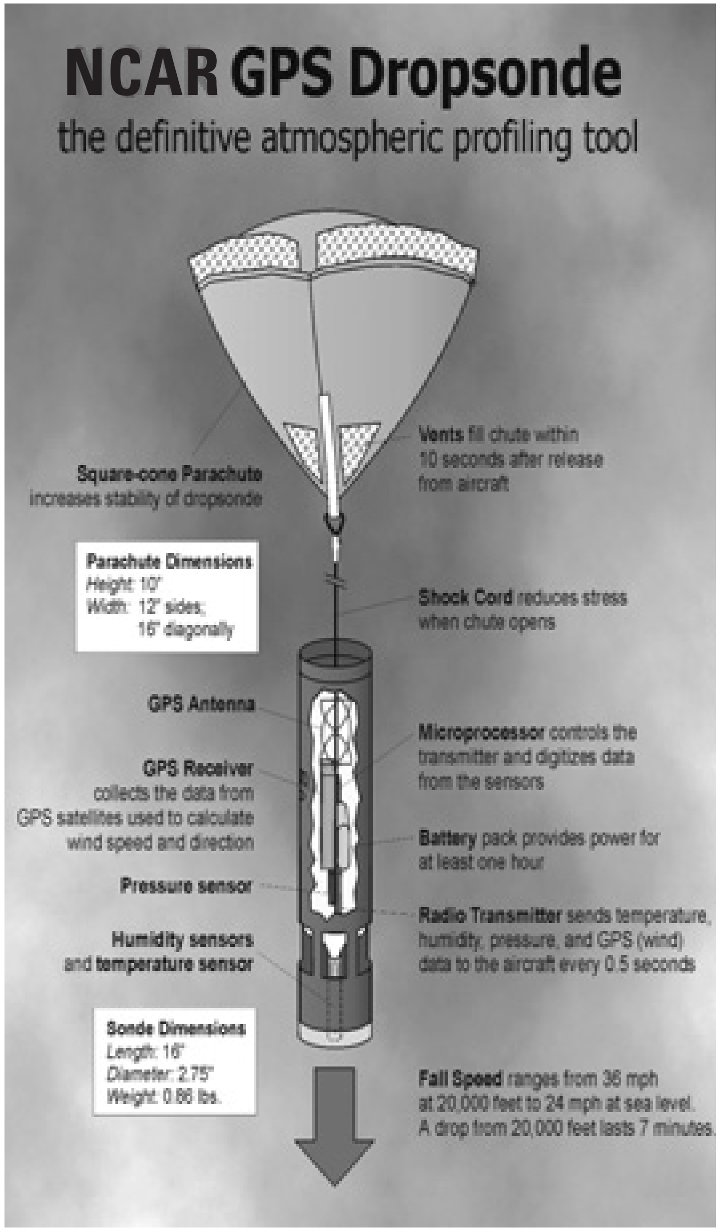
CAMEX-4, conducted in collaboration with the National Oceanic and Atmospheric Administration (NOAA) Hurricane Research Division and the United States Weather Research Program (USWRP) and sponsored by NASA's Atmospheric Dynamics and Remote Sensing Program, took place during the 2001 hurricane season. Based at the Naval Air Station in Jacksonville, Florida, the CAMEX-4 team embarked on a campaign to study hurricane development, tracking, and landfall impacts. The researchers hoped to gather valuable hurricane data by venturing into a hurricane at high altitudes, but there was just one problem: a shortage of hurricanes in the Atlantic.

While the previous few seasons in the Atlantic had produced numerous hurricanes, several of which made landfall, only a few storms occurred in 2001. These were short-lived, and only one made landfall. "It was just one of those dead seasons," said Halverson. "Then Hurricane Erin came along, and we were like a bunch of little kids dying to get our hands on it because we'd been kicking a can around doing nothing."

With Hurricane Erin, the CAMEX-4 team finally hit pay dirt. On September 8, 2001, Erin, which was churning towards the island of Bermuda, was upgraded from a tropical storm to hurricane status. On September 10, the National Weather Service classified Erin as a Category 3



Left: MODIS captured this image of Hurricane Erin east of Bermuda on September 9, 2001. (Image courtesy of NASA)



Right: This schematic of the NCAR/Vaisala GPS (Global Positioning System) dropsonde shows its internal components. The instrument is ejected from a tube in the underside of weather research aircraft and falls freely through the atmosphere. During its descent it radios back information on the structure of temperature, moisture, pressure, and winds. (Image courtesy of CAMEX-4)

hurricane, a storm accompanied by winds of up to 130 miles (210 kilometers) per hour.

That same morning, the research team, equipped with aircraft from both NASA and NOAA, immediately geared up to fly into the region around Erin's eye. "NASA has a unique suite of high-altitude aircraft that can get to those upper levels of the hurricane," said Halverson. "For years, NOAA has been flying planes into hurricanes, but they can't get much above 18,000 feet, and that's just a small piece of what the whole storm represents." NASA's ER-2, however, is a modified U-2 that can fly at 70,000–75,000 feet (21,000–23,000 meters). "This is practically outer space. The pilot is actually required to wear a spacesuit," Halverson said.

Key to the mission was a cylindrical instrument called a dropsonde, which weighs less than one pound and measures about 16 inches in length. "This technology has been around for awhile, and it involves launching robot sensors, or dropsondes, from aircraft. These sensors fall to the Earth via parachutes, taking measurements of temperature, pressure, winds, and humidity every half second," said Halverson. During their descent, the dropsondes transmit the data to the aircraft where they are recorded for later analysis.

Although dropsondes were deployed during previous CAMEX missions, CAMEX-4 introduced a new dimension to the experiment: for the first time, dropsondes were launched from the ER-2 aircraft at an altitude of 65,000 feet (20,000 meters).

During the flight mission over Erin, Halverson was on a NOAA DC-8, situated 30,000 feet (9,100 meters) below the ER-2, telling its pilot where to release the dropsondes. "We had three different layers of aircraft flying through this storm and dropping these little instrument packages from different altitudes, and we managed to get eight of them placed very nicely," Halverson said.

"These storms can change their structure in a matter of minutes. We're up there in the thick of things where we can see how the storm structure is unfolding and how it's changing as we fly through it. You can't make those observations sitting on the ground relying on a weather satellite."

Another boon for CAMEX-4 was that, for the first time, the entire dropsonde process was automated. "Basically, the pilot pushed a button, and when the light turned green, the dropsondes were released. In prior years, you had to have an operator sitting in front of the onboard computer telling it to pick up the dropsondes, put them in the launch tube, and open up the tube to release them," said Halverson.

Although the release process was fully automated, the timing sometimes got tricky, according to Richard Wohlman, a dropsonde system scientist on the CAMEX-4 mission. "It takes about 20 minutes for the dropsonde to fall to the ocean's surface. Because of our flying patterns and locations, sometimes we only had six minutes between drop points," said Wohlman, also a meteorologist at NASA's Global Hydrology and Resource Center. "One of our receivers became inoperative, so we had to be really quick on the preflight and launch procedure so that we wouldn't miss a drop point. There were a couple of times when it got pretty hectic, but we got the job done."

CAMEX-4 accomplished what no previous hurricane field studies have achieved, according to Halverson. "Nobody has ever collected data from high altitudes in a hurricane. Now we have a data set that is very rich, because we have eight vertical profiles through the center of this strong storm, which represents a complete snapshot of the inside of the hurricane," he said. These new data, according to Halverson, not only promise to help researchers understand the inner workings of a hurricane at high altitudes, but they will also improve future hurricane forecasting.

Halverson and his colleagues expect improved hurricane forecasting will offset some of the costs of hurricanes, which cause hundreds of fatalities and billions of dollars in property damage worldwide each year. "The often-repeated statistic is that every mile of U.S. coastline that's placed under a hurricane warning costs about $1 million in evacuation expenses," said Wohlman. "If making forecasts more accurate and timely allows us to cut down that warning time by even 10 miles—that saves a cool $10 million. Not a bad return on the investment, I'd say."

Links:

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"Seeking a Better Understanding of Hurricanes: NASA Marshall's Role in the CAMEX Hurricane Study." August 2001.

Jeff Halverson is assistant research professor of geography at the University of Maryland, Baltimore County, and research scientist at NASA's Goddard Space Flight Center. He studies the dynamics of severe storms, including hurricanes and thunderstorms, and also serves as Education and Outreach Scientist for NASA's Tropical Rainfall Measurement Mission (TRMM) satellite. Halverson earned a PhD in environmental sciences from the University of Virginia.

Senior research meteorologist at NASA Goddard Space Flight Center's Mesoscale Atmospheric Processes division, **Gerald Heymsfield** holds a master's degree in geophysical sciences from the University of Chicago and a PhD in meteorology from the University of Oklahoma. Heymsfield's current research interests include radar meteorology, remote sensing of precipitation, observations of mesoscale convective systems, instrument development, and the study of severe storms.

Teaching Old Data New Tricks

"The SCP project is a prime example of an application of the NASA/NOAA Pathfinder Program. We have a serendipitous application of data that were really designed to study something else."

Physical Oceanography DAAC

by Robin Welsh

In 1978, NASA launched a new radar remote sensing instrument, called a scatterometer, on the Seasat satellite. The instrument ceased working after only three months due to a power source failure in the satellite, but 20 years later, data from that first scatterometer and its descendants have opened up new possibilities for scientists who study climate change.

A scatterometer sends a pulse of microwave energy to the Earth's surface and then interprets the resulting echo, or backscatter. Since each material on Earth reflects, or scatters, energy in a different way, scientists use the backscatter from the scatterometer energy pulse to identify and study surface features, such as forests, snow and ice cover, icebergs, clouds, and oceans.

Originally designed to measure ocean winds, scatterometers detect wind speed and direction by analyzing the backscatter from the small wind-induced ripples on the ocean surface. However, researchers discovered that the data could provide important information on a variety of other surfaces, such as forests and ice, which became the basis for global climate change study applications. David Long, professor in the Electrical and Computer Engineering Department at Brigham Young University, and several of his graduate students are applying scatterometer data to a variety of environmental problems, ranging from deforestation to global warming to iceberg tracking.

"The scatterometer data are clearly useful for climate studies, especially in the polar regions," said Long. "The idea that these data are only useful for ocean winds is outdated."

The Scatterometer Climate Record Pathfinder (SCP) project, sponsored by NASA as part of the broader NOAA/NASA Pathfinder Program, is a collaborative effort between investigators at Brigham Young University, the Jet Propulsion Laboratory, the European Space Agency, and the National Ice Center (NIC). The SCP project's main goals are to find new ways to use the ocean scatterometer data to study climate, and to make the data more widely available to researchers.

Scatterometer data have proven useful in global climate studies largely due to the length of the data record. The data cover more than 20 years intermittently, providing scientists with a wealth of information. In a 1999 study, Long and his colleague, Mark Drinkwater, used the 1978 Seasat data as a baseline to track the changes in the Greenland ice sheet from 1978 to the present. The results showed a retreating ice sheet melt line and a warming trend in Greenland.

The scatterometer data also show striking changes in Antarctica, but the evidence for warming in that region is not as clear. Icebergs have been breaking off the main Antarctic ice sheets in higher numbers over the last two years, which many people interpret as a sign of global warming. But the long-term evidence provided by the scatterometer data seems to show something different.

"While there has been a substantial increase in the number of icebergs reported for the last two years, this is primarily related to some large calving events on the Ross and Ronne Ice Shelves," said Long. Aside from those events, the actual number of very large icebergs has not changed much in the last 20 years.

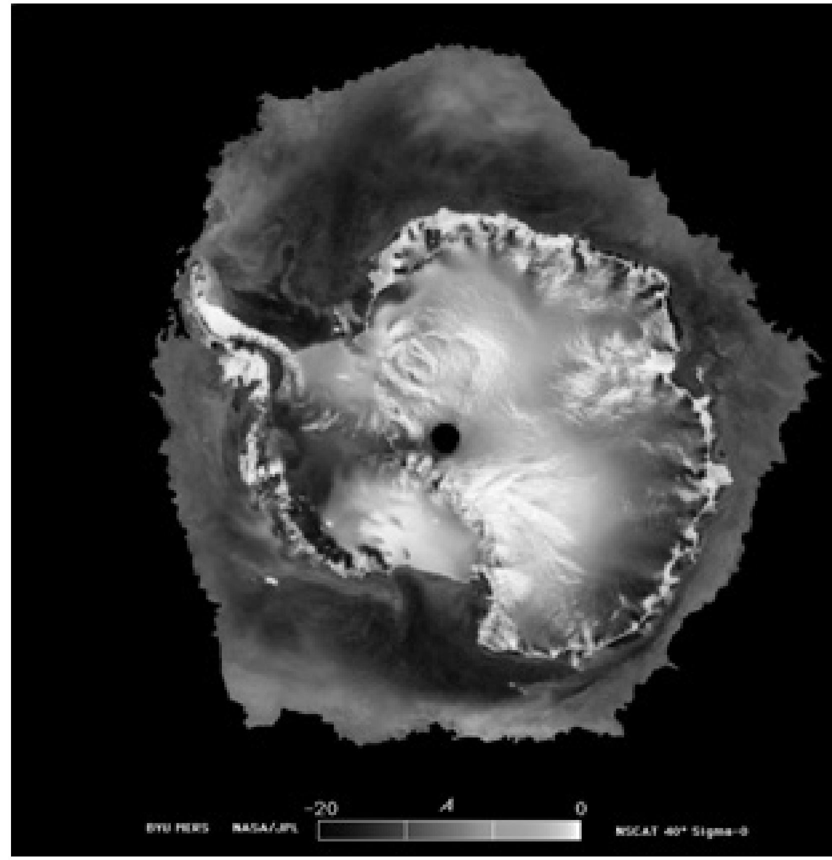
Historical shipping data from the last 100 years show that 50 or 60 years ago, similar large calvings occurred in the Ross and Ronne Ice Shelves. The evidence seems to suggest that the large Antarctic ice shelves are actually returning to previously mapped extents, and so far, they are not shrinking beyond historical minimums.

"A lot of what we're seeing now, in terms of increased iceberg count, stems from improved technology at the National Ice Center and a greater interest in Antarctic processes, rather than any real physical change. Our retrospective analysis of scatterometer data confirms this," said Long. "The scatterometer data show that the changes going on in Greenland and Antarctica are consistent with what other investigators are finding."

Sea ice extent and iceberg tracking are two other areas where the SCP data have proven useful. Project researchers have developed techniques and methods to interpret scatterometer data so that the National Weather Service, National Oceanic and Atmospheric Administration, and the National Ice Center can use it in "real time" for ship routing and weather forecasting. "The SCP data are actually providing about half of the iceberg tracks that are being used by the NIC," said Long.

Scatterometer data have coarser spatial resolution than Synthetic Aperture Radar (SAR) imagery, but much better coverage over time. Researchers get daily near-global coverage with the scatterometer data, making it easier to see changes that occur over short periods of time.

The January 2002 issue of *National Geographic* contained a composite image map of Antarctica based on satellite data. The central continent image required one month's worth of RADARSAT SAR data to make a full coverage, high-resolution map of the whole continent; whereas the sea ice portion of the map required only one



Above: This NASA Scatterometer (NSCAT) image, constructed from six days of scatterometer data in September 1996, shows Antarctica and the surrounding sea ice. Antarctica is covered with a thick ice sheet, which appears very bright in the image due to snow crust and refrozen ice in the snow cover. The black circle in the center of the image is where no data were collected. The dark band around the continent is sea-ice pack surrounding Antarctica. (Image copyright NASA Scatterometer Climate Record Pathfinder at Brigham Young University) day's worth of scatterometer data from the SCP project. Although the resolution was lower with the scatterometer data, the image was clear, was generated more quickly, and covered a broader range. Since hours can make all the difference in discerning melting events, the scatterometer data proved more useful in this case.

Comparing data from different scatterometers presents some challenges. Because each generation and type of scatterometer uses different angles and resolution, researchers at Brigham Young University's Microwave Earth Remote Sensing Laboratory developed the Scatterometer Image Reconstruction (SIR) algorithm to merge all the data onto a common grid. The SIR algorithm also combines data from multi-orbit passes to achieve the best possible resolution and image coverage. "The SIR algorithm makes the data more useful. It has its limitations, but it's well-suited for many applications because it makes images that general investigators, not just scatterometer experts, can use," Long said.

Researchers using the SCP data continue to look for new ways to use the data and to maintain the inflow of data. "We're looking at new funding opportunities to keep this activity going and ways to keep scatterometer missions flying so we can continue the long-term climate studies that we've started."

"The SCP project is a prime example of an application of the NASA/NOAA Pathfinder Program. We have a serendipitous application of data that were really designed to study something else. The project has given us the opportunity to develop and process all the data sets and make them available to a wide variety of investigators at a very low cost to the Pathfinder Program," said Long.

Links:

NASA Scatterometer Climate Record Pathfinder at Brigham Young University.
http://www.scp.byu.edu

NASA Scatterometer Climate Record Pathfinder at the Physical Oceanography DAAC.
http://podaac.jpl.nasa.gov/scp

References:

Drinkwater, M. R., and C. C. Lin. 2000. Introduction to the Special Section on Emerging Scatterometer Applications. *IEEE Transactions on Geoscience and Remote Sensing* 38:1763-1764.

Long, D. G., and M. R. Drinkwater. Cryosphere Applications of NSCAT Data. 1999. *IEEE Transactions on Geoscience and Remote Sensing* 37:1671-1684.

Long, D. G., M. R. Drinkwater, B. Holt, S. Saatchi, and C. Bertoia. 2001. Global Ice and Land Climate Studies Using Scatterometer Image Data. **http://www.agu.org/eos_elec/010126e.html** *EOS Transaction,* AGU 82(43):503.

David G. Long is a professor in the Electrical and Computer Engineering Department at Brigham Young University (BYU), where he teaches upper division and graduate courses in communications, microwave remote sensing, radar, and signal processing. He also serves as director of the BYU Center for Remote Sensing and is a member of the NASA Scatterometer (NSCAT) and SeaWinds science teams. Long earned a PhD in electrical engineering from the University of Southern California.

Scientist for a Day

> *"Having the satellite pictures online with students' observations showed teachers and parents how exciting the science really is and, more importantly, how satellite data contribute to global climate change studies."*

National Snow and Ice Data Center DAAC

by Jason Wolfe

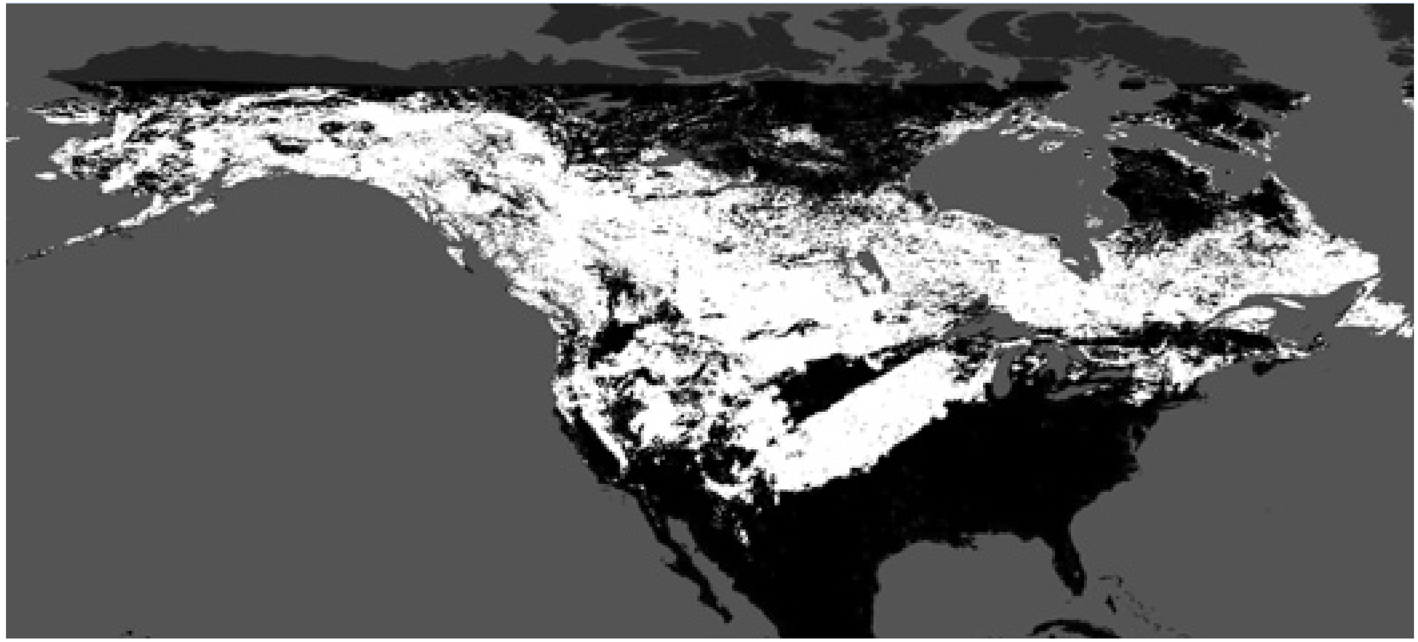
Left: A researcher takes snow measurements in the Rocky Mountains of northern Colorado. (Image courtesy of NASA's Cold Land Processes Experiment)

IMAGINE TAKING SNOW MEASUREMENTS and recording cloud observations for NASA researchers. Imagine a scientist using your data in an important scientific study related to global climate change. Sound like a difficult job? How about for a sixth grader?

Given the chance, most children would jump at the prospect of becoming scientists for a day. This opportunity came to over 1,750 students in the upper midwestern U.S. through a program led by Dr. Kevin Czajkowski, professor of geography at the University of Toledo. Czajkowski and a team of researchers developed an educational outreach program, funded by the NASA New Investigator Program, that enabled teachers and students to collect data for a global change study.

Beginning in summer 2000, the University of Toledo hosted the *Global Change and Remote Sensing Summer Teacher Workshop and Observation Program* for elementary and secondary teachers in Ohio, Michigan, and Pennsylvania. During the seminar, Czajkowski introduced the teachers to climate-related topics, such as solar radiation, weather observing techniques, satellite imagery, and global climate change issues.

Right: This image is a MODIS composite of 8-day snow cover, from January 25, 2002 to February 1, 2002. The white area represents regions with 90 percent or greater snow cover per pixel. Note the large band of snow across the midwestern United States, which occurred around February 1, 2002. This image does not show snow cover in the Arctic. MODIS observed the Arctic at night, so no classification could be determined here. Black represents either night coverage, land, or pixels with less than 90 percent snow cover.



Janet Struble, a science educator and visiting faculty member at the University of Toledo who managed the seminar, helped the teachers develop classroom lesson plans based on Czajkowski's scientific discussions. These lesson plans introduced students to principles of remote sensing and global climate change through hands-on data collection.

According to Struble, many children don't understand the meaning of global climate change. "A common misconception is that everything is heating up, but Dr. Czajkowski pointed out that in some parts of the world the temperature is actually decreasing," she said.

In the first year of the program, Czajkowski, Struble, and Terri Benko, a researcher with the University of Toledo, accompanied a local television meteorologist to schools to discuss the students' role in collecting data for the project. "Our ultimate goal is to collect surface temperature data and compare those data with measurements from local meteorological stations and satellites, which will help us better understand local temperature patterns. To build the foundation for that future study, we needed to first validate the data retrieved from satellites, so we introduced the students to Earth science data—namely, clouds and snow," said Benko.

Czajkowski stressed the important role that ground-based cloud and snow data play in making sure the satellite data are valid. "Some satellite sensors can't detect surface features on the Earth, because of their inability to penetrate cloud cover. Since the Upper Midwest is mostly cloudy in the winter months, we needed snow cover measurements and cloud coverage observations from the students," he said.

Although Czajkowski only needed the percentage of cloud coverage, he asked students to record the types of clouds and their relative height (low, medium, or high) to teach them more about weather-related phenomena.

Students were given a data collection manual with detailed instructions for recording their observations. The first set of observations took place December 4–12, 2000, and the more recent from January 28 to February 8, 2002. Teachers helped the students identify cloud patterns, 24-hour snow depth, and how much water results from melting snow (snow water equivalent). Czajkowski, Struble, and Benko often accompanied the students outside to show them proper data collection techniques. "When there was no snow on the ground, we demonstrated how to measure snow depth using popcorn instead of snow," said Benko.

The program became so popular that the number of participating students increased with each new data collection phase. "Originally we had 25 schools involved, but then it became too many schools to visit after the second year," he said. Now, Czajkowski communicates topics in remote sensing and global climate change to students through a Web-based presentation, and he answers questions via an Internet discussion board.

Students submitted their observations online through a simple Web interface so others could see their results. "When Dr. Czajkowski and I looked at the first batch of student data, we discovered mathematical errors and some excess data. So we created a Web interface that performed calculations from students' data and only allowed them to enter valid data. It was a much more efficient means of compiling data compared to the original paper spreadsheets the students used in 2000," said Benko.

Using latitude and longitude values that students recorded for their school location, Czajkowski compared the students' snow data with satellite-derived snow cover data for the same location. He used Moderate Resolution Imaging Spectroradiometer (MODIS) snow cover data, available from the National Snow and Ice Data Center (NSIDC) in Boulder, Colorado, to create satellite pictures of snow cover over the U.S. Midwest. Czajkowski also posted satellite pictures from the Advanced Very-High-Resolution Radiometer (AVHRR) sensor, also available from NSIDC, on the project's Web site. "We needed to make it visually appealing for the students, so in addition to displaying the snow product, we also showed a visible band of AVHRR data," he said.

Czajkowski unveiled the results of comparing student observations with MODIS satellite pictures in a Webcast to all participating schools on the last day of Earth Week, April 26, 2002. Students will later learn how to measure surface temperature at their schools, and how their observations compare with satellite-derived temperatures. "Data are only collected for two-week periods, so students and teachers won't be able to see if average temperatures in their neighborhoods are changing over time," said Benko. "But they will be able to use their data to study local temperature patterns."

"Having the satellite pictures online with students' observations showed teachers and parents how exciting the science really is, and more importantly, how satellite data contribute to global climate change studies. The students asked us a lot of good questions about snow, clouds, and global climate change—I was astounded by their interest in science," said Benko.

According to Struble, the program appealed to teachers partly because it required only a short time commitment. "Many projects ask teachers to devote more time than they have available, but we only asked for four weeks of manageable data collection," she said. "The teachers also appreciated the interaction. Czajkowski was very accessible, and the students were excited when he visited their school or sent them e-mail messages."

Czajkowski, Struble, and Benko plan to continue the summer workshops for at least five more years. "We want to recruit more teachers for next winter's program and continue the snow and cloud observations. Our goal is to link an educational outreach opportunity to a viable scientific question such as, 'Will global warming affect where I live?' This project teaches the concepts of global climate change to students and teachers by having them collect data and observe weather patterns in their own communities," said Czajkowski.

Link:

"Observing Earth Systems from Space."
http://www.utoledogis.org/education/student_obs/index.html

References:

"Observing Earth Systems from Space."
http://www.utoledogis.org/education/student_obs/index.html
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As assistant professor of geography at the University of Toledo, **Kevin Czajkowski** teaches courses on weather, climate, and remote sensing. His research focuses on thermal remote sensing, land use/land cover change, and furthering the use of remote sensing technology through educational and community outreach. Czajkowski holds a bachelor's degree in meteorology from the State University of New York at Oneonta and a PhD in atmospheric sciences from the University of Michigan.

Tracking Clouds

The MISR cloud data may be able to provide more accurate wind speeds and heights over the Pacific Ocean, increasing the warning time for severe weather events threatening the west coast of North America.

Langley Research Center DAAC

by Robin Welsh

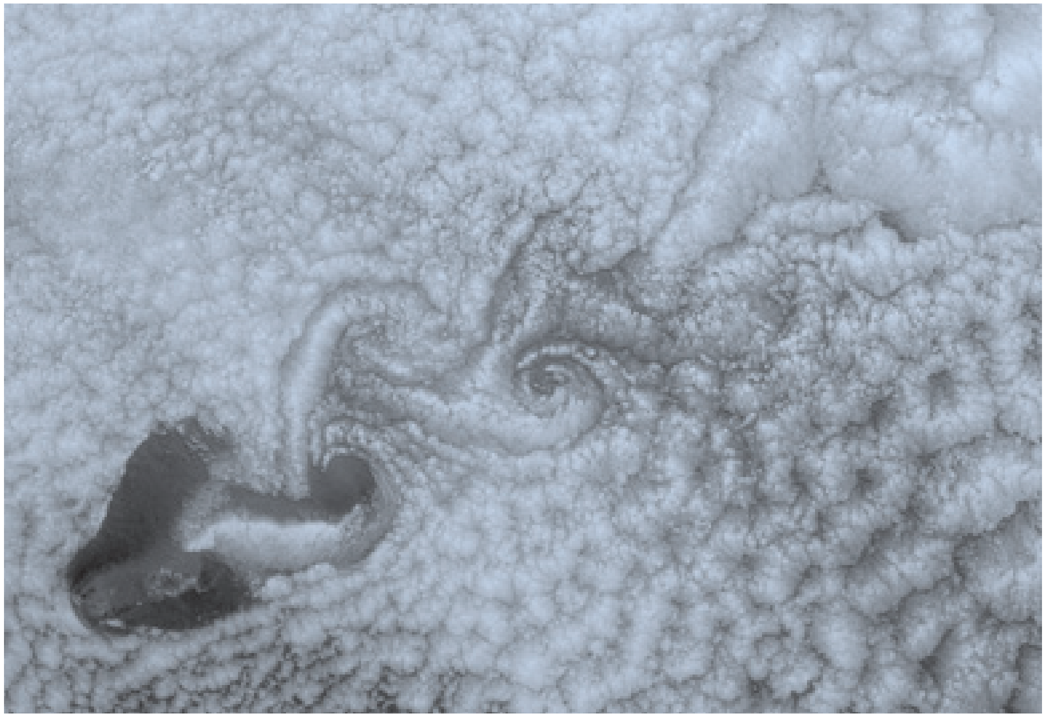
TUNE IN TO THE EVENING WEATHER REPORT on any given day, and you'll no doubt see satellite images of clouds. For years, experts have used cloud observations to predict the weather, from forecasting extreme weather events, such as tornadoes and hurricanes, to simply telling people whether they need to take an umbrella or sunscreen on their afternoon picnic.

Weather experts monitor clouds with the help of satellite data, and they use cloud height and motion data to calculate wind speed and altitude. Although these calculations have proven useful in predicting the path and severity of developing storms, existing satellite instruments are limited in their coverage of vast ocean expanses and higher latitude regions, the common birthplaces of many storms.

Currently, the cloud motion data used to derive wind measurements are observed from geostationary satellites. These instruments circle the Earth at a speed matching the Earth's rotation, which allows them to obtain continuous images of one location on the surface. Consequently, wind data predictions based on cloud motion have been most accurate at latitudes lower than 55 degrees.

Geostationary satellites measure reflected sunlight in only one direction. This means that cloud height calculations require measurements from more than one satellite, or they must be determined indirectly based on assumptions about the relationship between temperature and height. In addition, data collected from geostationary satellites can only classify wind heights as low, middle, and high, rather than at fixed altitudes.

A new instrument and remote sensing technique, however, may improve the accuracy of cloud motion and height data over many areas of the Earth, boosting the accuracy of weather predictions. "We're still testing the new technique for calculating cloud height and motion, but it looks like a very promising addition to future weather forecasting tools," said Roger Davies, a principal scientist at NASA's Jet Propulsion Laboratory and a specialist on clouds and climate modeling.



Left: MISR captured this image of atmospheric vortices near Guadalupe Island on June 11, 2000. (Image courtesy of NASA/GSFC/JPL, MISR Team)

NASA's Multi-angle Imaging SpectroRadiometer (MISR) instrument, launched in 1999 on the Terra satellite, is the first satellite instrument to simultaneously provide directly measured cloud height and motion data from pole to pole.

As the MISR instrument orbits the Earth, it uses cameras fixed at nine different angles to view reflected light and collect global images. The cameras capture images of clouds, airborne particles, and the Earth's surface, collecting information about each point from multiple angles.

"Originally, the cloud motion data from MISR were intended to provide input to cloud height calculations, and to more precisely identify the location of each cloud," said Davies.

Cloud heights are important in modeling cloud properties for long-term climate studies, but they are only useful if accurately related to the exact position of the cloud. Davies and his team developed a pattern recognition algorithm that uses MISR data to recognize the same cloud from different angles. The algorithm then derives the cloud motion and height and uses them to calculate the position of the cloud.

Although the pattern recognition technique was intended as a way to pinpoint the location of clouds, the team discovered that the wind speed results were better than expected—providing wind values accurate to within three meters per second at heights accurate to within 400 meters. "We realized that we were getting extremely accurate cloud motions that could drastically improve weather prediction," said Davies.

Winds crossing the Pacific Ocean are difficult to monitor with current satellite instruments, because there are no landmarks to show the exact location of the clouds. The MISR cloud data may be able to provide more accurate wind speeds and heights over the Pacific Ocean, increasing the warning time for severe weather events threatening the west coast of North America.

"Weather tends to come in from over the ocean, and there's a general shortage of satellite data over oceans, meaning that MISR data promise to improve short-term weather prediction," said Davies. In addition, wind-based storm activity near the poles will also be easier to monitor, since MISR collects data from pole to pole.

Initial validation efforts have proved promising, according to Davies. The team compared data from the National Oceanic and Atmospheric Administration's (NOAA) current geostationary satellites (GOES-W) with the MISR data distributed by the Langley Research Center (LaRC) DAAC. The two matched well enough to verify the accuracy of MISR's preliminary data.

In fact, MISR data proved more accurate than the GOES-W data for the wind heights, especially where more than one layer of clouds existed. "Most of the time we get very good agreement between the two instruments, and when we don't—it's usually because the two satellites are looking at different clouds," said Davies.

In addition to improving short-term weather forecasting, the cloud height and motion data will benefit long-term climate studies. "Clouds are the weakest link in our whole understanding of the climate system, as they affect albedo [the amount of solar radiation reflected into space from Earth's surface, atmosphere, and clouds] and have a stronger greenhouse effect than all the other gases put together, so they're incredibly important," said Davies.

Once Davies and his team fully develop and validate the technique to provide accurate height-resolved cloud motion winds, they expect that wind experts from around the world will continue to explore the best way to apply the MISR technique to real time weather forecasting.

Most likely, they will streamline the instrument and expand its coverage to obtain the most useful wind information, according to Davies. "I can imagine a fleet of small satellites with a simplified version of MISR onboard that would provide us with accurate global wind data and greatly improved weather prediction abilities."

Link:

MISR.
http://www-misr.jpl.nasa.gov

Reference:

Horvath, A. and R. Davies. 2001. Simultaneous Retrieval of Cloud Motion and Height from Polar-orbiter Multiangle Measurements. *Geophysical Research Letters* 28:2915-2918.

Principal scientist at NASA's Jet Propulsion Laboratory, **Roger Davies** has been a member of the MISR Science Team since 1988. His research involves studying cloud-radiation interactions from microphysical to global scales, with a special interest in the effects of cloud heterogeneity. As a former faculty member at University of Arizona, McGill University, and Purdue University, he has taught a wide range of courses on most aspects of atmospheric physics and climate theory. Davies holds a PhD in meteorology from the University of Wisconsin–Madison.

Acknowledgements

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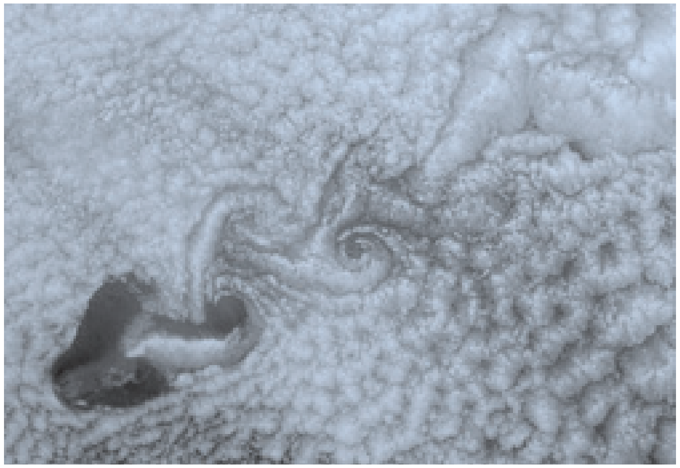
Writing, Editing, and Design

Editor: Laurie J. Schmidt

Writers: Yarrow Axford, Rachel Hauser, Laura Naranjo, Laurie J. Schmidt, Michon Scott, Robin Welsh, Jason Wolfe, and Evelyne Yohe

Interior Design: Polly Christensen, Publications and Creative Services, University of Colorado at Boulder

Cover: Polly Christensen and Nancy Geiger-Wooten



The pattern that appears at the bottom of pages is derived from the atmospheric vortices seen in the above image, captured by the MISR satellite instrument on June 11, 2000. The image demonstrates a turbulent atmospheric flow pattern known as the von Karman vortex street, named after the aerodynamicist who theoretically derived the conditions under which it occurs. The alternating double row of vortices can form in the wake of an obstacle, in this instance the eastern Pacific island of Guadalupe.

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Greenbelt, Maryland
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E-mail: **gsfc@eos.nasa.gov** • Web: **http://daac.gsfc.nasa.gov**

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Huntsville, Alabama
Voice: +1 256-961-7932 • Fax: +1 256-961-7859
E-mail: **ghrc@eos.nasa.gov** • Web: **http://ghrc.msfc.nasa.gov**

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E-mail: **podaac@eos.nasa.gov** • Web: **http://podaac.jpl.nasa.gov**

Population, Sustainability, Geospatial Data, and Multilateral Environmental Agreements
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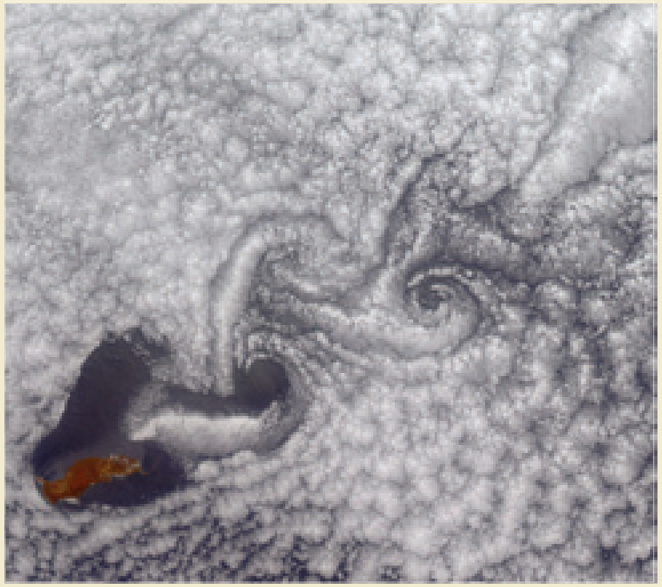
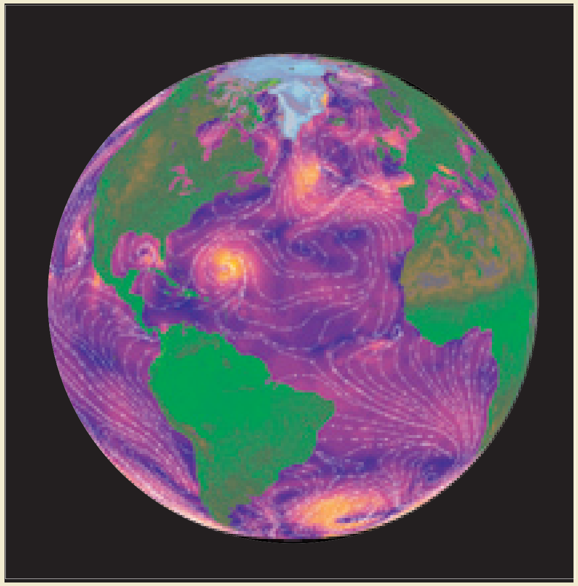
SEDAC User Services
CIESIN at Columbia University
Palisades, New York
Voice: +1 845-365-8920 • Fax: +1 845-365-8922
E-mail: **sedac@eos.nasa.gov**
Web: **http://sedac.ciesin.columbia.edu**





Applications of Earth observing data from NASA's Earth Science Enterprise

DAACAlliance

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