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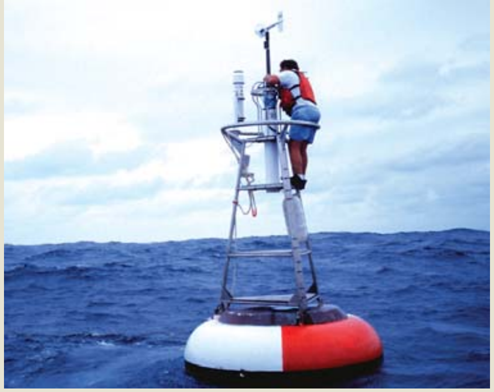

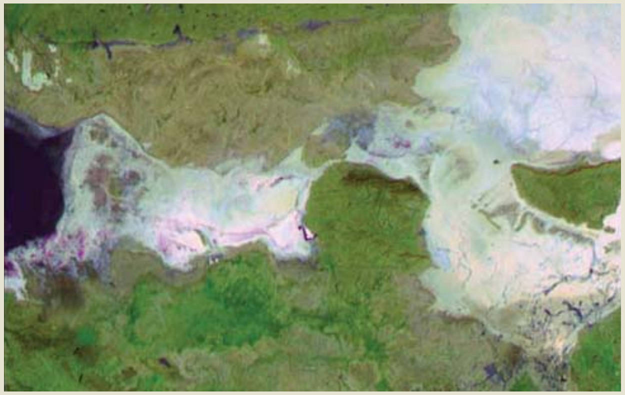

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http://nasadaacs.eos.nasa.gov

Cover Images

FRONT–

Left to right, from top:
1. An uninhabited aerial vehicle (UAV) helps researchers in the Altus Cumulus Electrification Study (ACES) gather weather data safely and also test new aircraft technology. (Image courtesy of NASA/Dryden/Tom Tschida)

2. A worker maintains a Tropical Atmosphere Ocean (TAO) buoy on the equatorial El Niño array in the Pacific Ocean. Although they offer limited coverage, the buoys provide a valuable ongoing record of ocean changes in conjunction with TOPEX/Poseidon and Jason-1 observations. (Image courtesy of the NOAA Photo Library)

3. Structures in the village of Bhuj, India, located 50 miles (80 kilometers) from the epicenter of the 2002 Bhuj earthquake, sustained considerable damage. (Image courtesy of James Mori, Research Center for Earthquake Prediction, Disaster Prevention Institute, Kyoto University)

4. Weathering and erosion processes have left massive sandstone structures standing in Monument Valley, which straddles the Utah-Arizona border in the southwest United States. (Image courtesy of Photospin)

5. This false-color MISR image was acquired after the Bhuj earthquake, on January 31, 2001. The image shows numerous areas where groundwater flowed up to the surface, including within the Rann of Kachchh, as well as near the Indo-Pakistani border. (Image courtesy of NASA/GSFC/LaRC/JPL, MISR Team)

6. A researcher observes the edge of the Greenland Ice Sheet in 2001. (Image courtesy of Ted Scambos, National Snow and Ice Data Center, University of Colorado at Boulder)

7. This false-color SeaWiFS image, acquired on October 6, 2002, shows a phytoplankton bloom off the California coast. (Image courtesy of James Acker, NASA Goddard Space Flight Center).

BACK–

Left to right:
1. During times of severe drought, the Sonoran Desert near Tucson, Arizona, becomes more susceptible to fire danger. (Image courtesy of Laurie J. Schmidt)

2. Nighttime images show where the Earth is the most urbanized, though not necessarily the most populated. Improved understanding of human land use, and incorporation of that information into climate models, can help scientists better predict changes in weather and climate. (Image courtesy of Craig Mayhew and Robert Simmon, NASA GSFC)

3. A line of fractured ice reveals a trace of the Denali Fault, which runs up the side of Alaska's Canwell Glacier. (Image courtesy of the U.S. Geological Survey).

Earth Science Data and Information System (ESDIS) Project
National Aeronautics and Space Administration
Goddard Space Flight Center
Greenbelt, MD 20771

Dear Friends and Colleagues:

I am pleased to present the 2003 Distributed Active Archive Center (DAAC) Alliance Annual. This outstanding ninth edition continues the series of publications describing important science discoveries resulting from analysis of the data managed by the NASA DAACs. The 2003 Annual illustrates the variety of data products and information available from the DAACs.

The year 2003 has been an important one for the DAACs, the operational data centers of the Earth Observing System Data and Information System (EOSDIS). In the past twelve months we have seen the delivery of the first validated science products from the Aqua mission, a major reprocessing of the data from the science instruments on Terra, and the completion of the development of the EOSDIS Core System (ECS). Through the year, the DAACs continued to provide superior service to the nearly two million users who contacted the DAACs looking for data products, data services, or general information.

Thank you for your interest in the EOSDIS DAACs and the scientific achievements being realized from the EOS data. You can find information about the DAACs and the EOSDIS by visiting the DAAC Alliance Web site at: http://nasadaacs.eos.nasa.gov.

Vanessa L. Griffin
Manager
ESDIS Science Operations Office

Acknowledgements

We extend our gratitude to the Earth Science Data and Information System (ESDIS) project for its support of this publication; to the DAAC managers and User Services personnel for their direction and reviews; and to the DAAC scientists who alerted us to the research and investigations that made use of DAAC data in 2003. A special thanks goes to the investigators whose accomplishments we are pleased to highlight here.

This publication was produced at the National Snow and Ice Data Center DAAC under NASA contract No. NAS5-32392.

Distributed Active Archive Center (DAAC) Alliance: Supporting Earth Observing Science 2003 is also available online in PDF format at:
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Researchers working with NASA DAAC Alliance data are invited to contact Laurie Schmidt, editor, at daaceditor@nsidc.org to explore possibilities for developing a future article.

Writing, Editing, and Design

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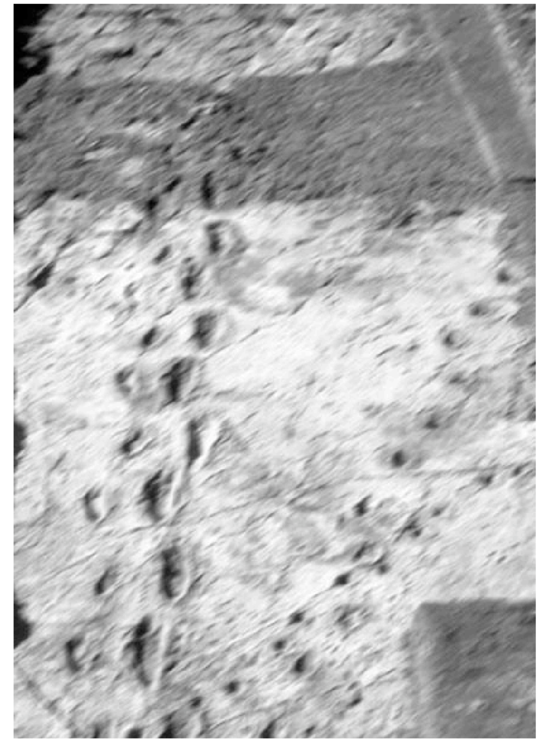
Publication Design: Nancy Geiger Wooten

The design below is based on human footprints located at the Laetoli Trackway within the Ngorongoro Conservation Area in northwestern Tanzania. Laetoli, a short stretch of hominid footprints preserved in volcanic ash now turned to soft stone, was excavated in 1978 and 1979 by Mary Leakey. The trackway holds great significance, settling a long debate over which was first in human evolution – the development of the brain or bipedalism. The prints, 3.6 million years old, precede by nearly one million years the earliest known stone tools and are evidence that walking on two feet came first.



The footprints at the Laetoli Trackway, which date 3.6 million years, are among the earliest traces of human impact on the Earth. By combining population statistics and satellite data archived at the NASA DAACs, scientists have produced two complementary global maps of human influence: The Human Footprint and The Last of the Wild (see The Human Footprint, page 1).

Drawing design by Nancy Geiger Wooten.

Supporting Earth Observing Science 2003

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The Human Footprint

"Preserving places that are already wild is the most practical thing to do. Fewer people, less infrastructure, less human land use, and less power lead to less human conflict."

Socioeconomic Data and Applications Center DAAC

by Michon Scott

While teaching a class in Nairobi in summer 2002, conservationist Eric Sanderson heard a familiar story. The woman who organized the course told him that when she was little, her father would take her to a nearby place to watch elephants and giraffes. Now, the area is a suburban banking center.

"I talk to people from all over the world, and many of them tell the same story," said Sanderson, associate director of the Landscape Ecology and Geographic Analysis Program at the Wildlife Conservation Society. "They say, 'I grew up in this place and had nature all around me, but it's changed now.'"

The people Sanderson talks to are not imagining these changes. In North America, the black-tailed prairie dog occupies as little as 5 percent of its former habitat. In Madagascar, more than 20 lemur species are threatened with extinction, and at least 15 species are already extinct. And on the island of Mauritius in the Indian Ocean, fewer than 50 mature mandrinette hibiscus plants remain in the wild.

These organisms share a common threat: human impact, usually in the form of habitat destruction, eradication efforts, overharvesting, and the introduction of invasive species. Though conservationists have long been concerned about the impact of human activity, a lack of quantifiable data has historically hampered efforts to achieve conservation goals.

"I'm convinced that we're in a weird paradox," said Marc Levy, co-project scientist at the Socioeconomic Data and Applications Center (SEDAC) at Columbia University. "The international community has finally started taking sustainable development seriously, but now ecosystem preservation is fading into the background. While we've had clear, quantitative targets set for poverty reduction, literacy, and health care, biodiversity benchmarks have been very vague."

Now, Sanderson, Levy, and collaborators have taken an important step in resolving that vagueness. They have produced two complementary global maps: The Human Footprint and The Last of the Wild.

Until recently, compiling global maps of human influence simply wasn't possible, but the 1990s brought substantial technological advances. Satellite data facilitated the production of global land use and land cover maps, and geographic information systems allowed researchers to integrate satellite and population data efficiently. Using these technologies, Sanderson and his collaborators chose four types of data to measure human influence: population density, land transformation, human access, and power infrastructure.

Increased human population often leads to greater influence on the environment and sharper declines in species and ecosystems. According to the authors of the human footprint study, however, land transformation probably poses the single greatest threat to biodiversity, resulting in habitat loss and/or fragmentation for wild species. Beyond its effects on the nearby area, it can have global consequences, such as worldwide changes in soils and increased demand for fresh water for irrigation.

The authors also found that the greater the human access through roads, rivers, and coastlines, the greater the likelihood of resource extraction, pollution, and the introduction of invasive species. Both human access and land transformation have been fueled by increased power infrastructure

(access to fossil fuel and electrical power) over the last century. Throughout most of human history, impact on the environment was constrained by raw human and animal muscle power. But today, one person with a bulldozer can match the power of 300 horses.

The researchers measured these four variables using nine data sets, assigning each locality a numerical value between 0 (minimum) and 10 (maximum). Next, they summed the scores for all the data sets. Brownsville, Texas, was the only area to reach the maximum score for human influence on the environment, though most of the world's largest cities fell within the top 10 percent. Sanderson and his collaborators found that 83 percent of Earth's land surface (98 percent where rice, wheat, or maize can be cultivated) is directly influenced by human activity. "But different ecosystems respond to human activity in different ways," said Sanderson. To account for these differences, the scores needed refinement.

Biologists have divided the terrestrial portions of the Earth into biomes, regions characterized by specific climatic conditions and by certain types of life, especially vegetation. For each biome, as defined by the World Wildlife Fund - U.S. Conservation Science Program, Sanderson and his collaborators mapped the original scores to a new scale of 0 to 100. (Because each biome has an independent scale, a score of 50 in a desert might indicate a very different level of human influence than the same score in a grassland environment.) The resulting human footprint is a quantitative measurement of humanity's impact on the Earth's land surfaces.

Completion of the human footprint map marks major progress in conservation efforts. Ruth DeFries, associate professor at the University of Maryland, College Park, said, "Each of the supporting data sets used to map the human footprint represents an

Left: Footprints of the Laetoli trackway in Tanzania show some of the earliest lasting human impact. (Image Copyright © The J. Paul Getty Trust, 1995. All rights reserved.)

enormous investment by scientists in that discipline. By bringing those data sets together, the human footprint gives an interesting overview of the regions on Earth where humans have the greatest and the least presence."

"The main virtue of the human footprint is that it's open to improvement. Other researchers can duplicate our results, or substitute improved data," said Levy. He pointed out another unusual feature. "These maps were created without government funding and have been made available by choice, and using SEDAC to distribute our data has been critical to the project."

Sanderson and his collaborators acknowledge, however, that the map is not a perfect picture. It includes only land surfaces — not oceans, lakes, or rivers — and it excludes Antarctica and many small Pacific islands. The map also uses a coarser scale than most conservation studies, and it contains inaccuracies at the local level. Moreover, focusing on different parameters can yield different conclusions.

Two months after the human footprint was completed, Conservation International released a study concentrating on population density and plant cover without examining human land usage to the same extent as Sanderson and his collaborators. Whereas Sanderson's team found human impact on most of the Earth's land surfaces, the new study suggested that nearly half the land on Earth is still wild. "Different conservation organizations have different ways of looking at the world, and they measure different factors," said Sanderson. "But we all share the same goals of conserving biological diversity and saving wild places and wildlife."

Finding Earth's remaining wildlife, or the last of the wild, is the flip side of the human footprint. Sanderson and his collaborators found minimal human impact in the Arctic tundra, the boreal forests of Canada and Siberia, the deserts of Africa and central Australia, and the Amazon Basin. They also found reduced impact along many national boundaries. "An interesting phenomenon is that countries tend to develop more infrastructure in the middle of their territories than along the borders. Because there's less competition between people and wildlife, those border areas become important for conservation," Sanderson explained. Some countries, such as Mozambique and South Africa, have established transnational peace parks across their shared borders to preserve natural habitat.

To find the best places to preserve wildlife, the researchers searched the human footprint for the top 10 percent of the wildest areas in each biome. From 568 locations, they selected the 10 largest contiguous areas. While some of those areas cover more than 100,000 square kilometers (38,610 square miles), other biomes have no undisturbed wild areas larger than 5 square kilometers (3.1 square miles). (The Wildlife Conservation Society has made the complete list available through its Web site.)

"It's important to conserve these remaining wild places, and not solely because of moral or aesthetic values," said Sanderson. "Preserving places that are already wild is the most practical thing to do. Fewer people, less infrastructure, less human land use, and less power lead to less human conflict."

A recent article in Science provides another compelling argument for preserving wild places. Andrew Balmford of the University of Cambridge and his coauthors cited the often-overlooked economic benefits of healthy ecosystems. They found that in addition to the harvest of wild organisms for food, fuel, fiber, and medicine, people also benefit from ecosystem services like nutrient cycling, soil formation, and flood protection. Although ecosystem services have not historically been priced, the authors estimated that an effective global conservation program would repay its cost a hundredfold.

But is human presence necessarily bad? "People convert land cover for a host of reasons, some of which are very necessary and good for human welfare," said DeFries. "We need to eat, so we have cropland. We need places to live, so we have urbanization. But we also need a way to assess the tradeoff between the obvious benefits and possible negative consequences. Then we'll be able to make informed decisions to both satisfy human needs and maintain the ecosystem services that vegetation provides."

"No matter where you are, there's something in nature that's worth saving," said Kent Redford, director of the Wildlife Conservation Society Institute. "If you live in a city, you can build a 'green' roof so that migratory butterflies have a place to stop. If you live in a suburban setting, you can develop street curbs that allow turtles and amphibians to cross without getting pulled into the drains. If you're in a rural setting, you can try to control urban sprawl and the use of pesticides."

"I think most people feel sad about what's happening to the natural world, and they want to make better choices," said Sanderson. "But I also think a lot of people feel helpless about what to do. That's why conservation organizations exist — to try to offer solutions."

According to Sanderson, it is especially important to conserve wildlife "across the gradient of human influence" not just in wild places, but also in cities. Luckily, he can point to some success stories. "Hawk migrations over New York City had almost come to an end between the 1920s and 1940s. Now that threats from DDT and recreational hunting have been reduced, the birds are returning, and thousands of people come to the city to see them," he said. "It's a magnificent sight. It's amazing."

For more information, visit the following Web sites:

The Human Footprint from the Wildlife Conservation Society
http://wcs.org/humanfootprint/

Last of the Wild from the Center for International Earth Science Information Network
http://www.ciesin.columbia.edu/wild_areas/

References

Balmford, Andrew, Aaron Bruner, Philip Cooper, Robert Costanza, Stephen Farber, Rhys E. Green, Martin Jenkins, Paul Jefferiss, Valma Jessamy, Joah Madden, Kat Munro, Norman Myers, Shahid Naeem, Jouni Paavola, Matthew Rayment, Sergio Rosendo, Joan Roughgarden, Kate Trumper, and R. Kerry Turner. 2002. Economic reasons for conserving wild nature. Science. 297(5583):950-953.
http://www.sciencemag.org/cgi/content/full/297/5583/950

Sanderson E. W., M. Jaiteh, M. A. Levy, K. H. Redford, A. V. Wannebo, and G. Woolmer. 2002. The human footprint and the last of the wild. Bioscience. 52(10):891-904.
http://wcs.org/media/general/human_footprint2.pdf

Related color data image, page 23

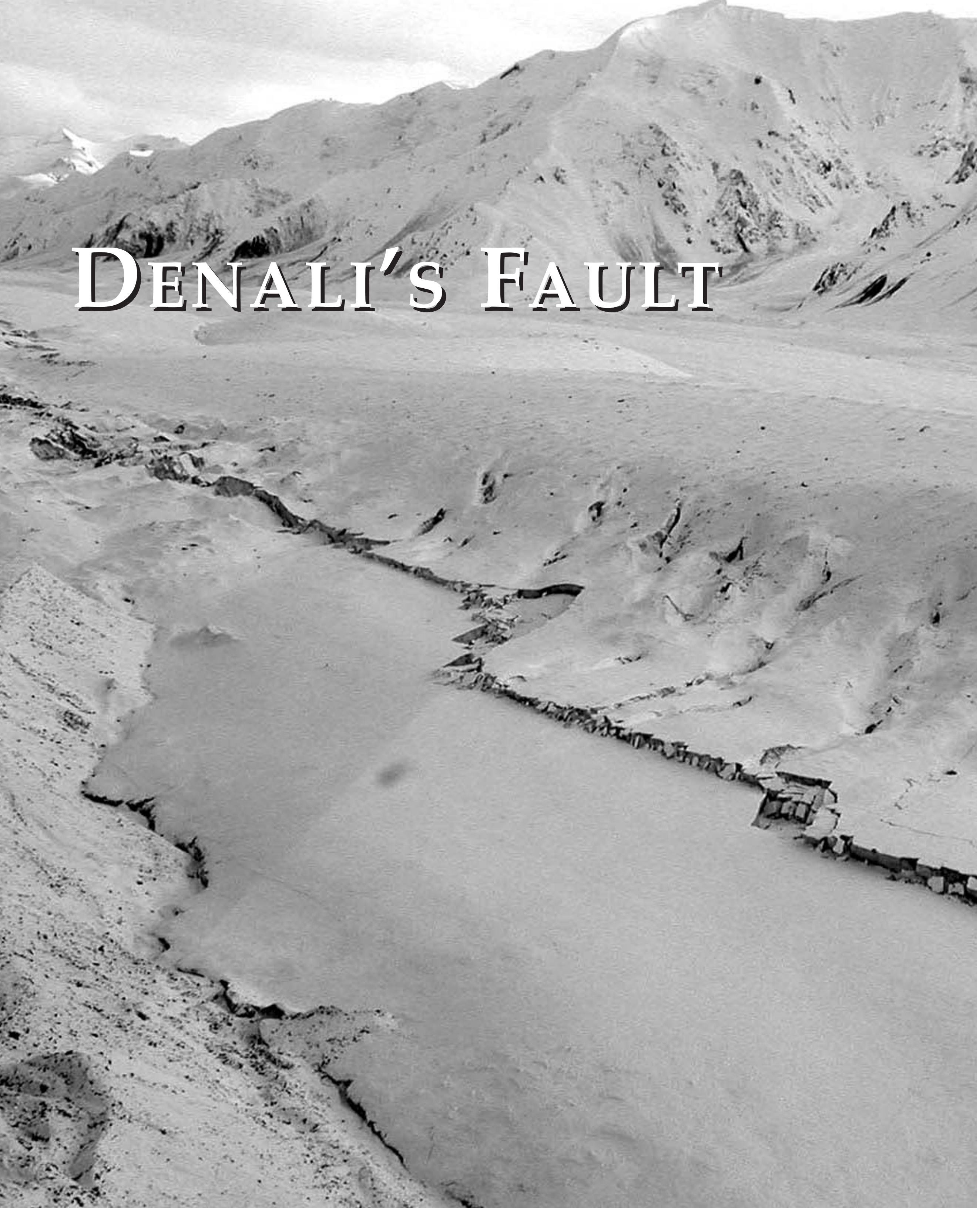
Eric Sanderson is the associate director of the Landscape Ecology and Geographic Analysis Program at the Wildlife Conservation Society. His research focuses on the use of remote sensing to study changes in ecological patterns across time and space. Sanderson is the lead investigator for the Human Footprint and Last of the Wild data sets. He earned a PhD in landscape ecology from the University of California, Davis.

Kent Redford is the director of the Wildlife Conservation Society Institute. Prior to joining the Wildlife Conservation Society, he taught at the University of Florida and worked at the Nature Conservancy. He has worked on issues concerning conservation of neotropical mammals, park- based conservation, resource use by indigenous peoples, and conservation strategies. Redford holds a PhD in ecology from Harvard University.

Ruth DeFries is an associate professor in the Department of Geography, Earth System Science Interdisciplinary Center, at the University of Maryland, College Park. She holds a PhD from the Department of Geography and Environmental Engineering at Johns Hopkins University. Her research interests include relationships between human activity and land surface, and land cover change at regional and global scales.

Marc Levy is the associate director for science applications at Columbia University's Center for International Earth Science Information Network. He is also a project scientist for the Socioeconomic Data and Applications Center. As a member of the U.S. government's Task Force on State Failure, which has studied the relationship between environmental or economic change and political instability, he coauthored the task force's Phase II Findings report. He is also coeditor of Institutions for the Earth and Institutions for Environmental Aid.

Denali's Fault



Interferometry is a good way to locate faults and determine which sections are susceptible to deformation.”

Alaska Satellite Facility DAAC

by Laura Naranjo

DURING THE AFTERNOON OF NOVEMBER 3, 2002, the water in Seattle's Lake Union suddenly began sloshing hard enough to knock house-boats off their moorings. Water in pools, ponds, and bayous as far away as Texas and Louisiana splashed for nearly half an hour. The cause? Alaska's Denali Fault was on the move, jostling the state with a magnitude 7.9 earthquake.

The earthquake began at 1:12 p.m. Alaska local time, and was centered approximately 84 miles (135 kilometers) south of Fairbanks and 176 miles (283 kilometers) north of Anchorage. Shaking at the epicenter lasted approximately 1.5 to 2 minutes, but in Fairbanks, the duration of the earthquake was over 3 minutes.

Originating on the previously unknown Susitna Glacier Fault, the earthquake shot eastward along the well-known Denali Fault at a speed of over 7,000 miles (11,265 kilometers) per hour before branching southeast onto the Totschunda Fault. The resulting surface rupture was approximately 209 miles (336 kilometers) long, and it cut through streams, divided forests, opened chasms in roads, and even generated fault traces visible across several glaciers. Because the earthquake released most of its energy on the sparsely populated eastern end of the fault, Alaska's major cities were spared serious damage.

The November 3 Denali Fault earthquake was preceded by the magnitude 6.7 Nenana Mountain earthquake on October 23. Now considered a foreshock of the larger quake, the October earthquake caused no surface ruptures. Both quakes were centered along the Denali Fault.

Andrew Ford, a researcher at the University of Utah, was studying the fault system in southeast Alaska with colleagues Rick Forster and Ron Bruhn, both professors at the University of Utah. "When the earthquakes occurred, we wanted to see if we could determine how much ground motion there was," said Ford.

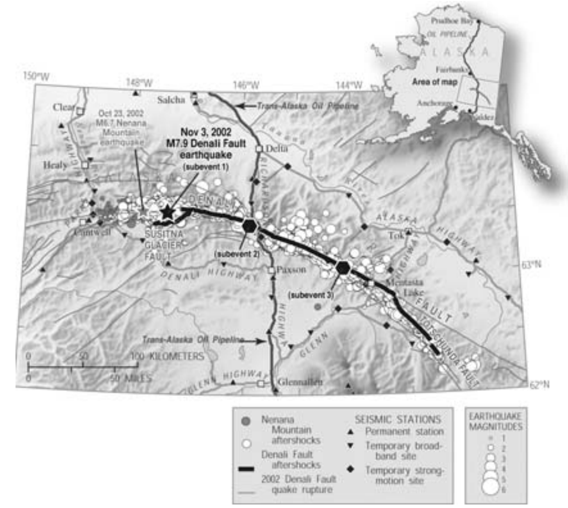
Using a remote sensing technique called InSAR (Interferometric Synthetic Aperture Radar), Ford created a map of surface changes caused by the earthquake. Interferometry involves taking Synthetic Aperture Radar (SAR) satellite images from two different dates and precisely calculating the differences between the two. The resulting image, called an interferogram, shows where deformation occurred on the Earth's surface. "Interferometry is a good way to locate faults and see which sections are susceptible to deformation," said Evelyn Price, a research associate at the University of Texas Institute for Geophysics.

In the past, scientists typically relied on SAR imagery from the European Remote Sensing (ERS) satellites, ERS-1 and ERS-2, to map earthquake deformation. But ERS-1 failed in 2000, and ERS-2 began malfunctioning shortly afterwards. So Ford and his colleagues turned to SAR imagery from RADARSAT-1 (a satellite managed by the Canadian Space Agency), which had never before been applied in earthquake interferometry.

One of the biggest challenges with SAR imagery is the infrequency of satellite overpasses. In that respect, RADARSAT-1 had an advantage over the ERS missions. "RADARSAT-1 repeats its orbit every 24 days, whereas ERS-1 and ERS-2 repeated every 35 days," said Ford. Surface changes occurring between orbits (such as excessive rainfall or snowfall, or changes in vegetation) can cause "noise" in interferograms, making them less accurate. "The less time between repeat orbits, the less chance there is for change on the Earth's surface," said Ford.

After the November 3 earthquake, Ford and his colleagues contacted the Alaska Satellite Facility (ASF) in Fairbanks. "ASF gave us priority. Once the satellite acquired the image we needed, ASF downloaded and formatted it, and it was ready for us within hours," said Ford. Fortunately, ASF had images from October 5 (prior to the foreshock earthquake), October 29 (between the two earthquakes), and November 22 (after the second earthquake) that included the area of both earthquakes' epicenters.

ASF's fortuitous collection of images allowed Ford and



Above: This map of Susitna Glacier and the Denali and Totschunda Faults shows the locations of the October 23, 2002 and November 3, 2002 earthquakes and their aftershocks. (Image courtesy of the U.S. Geological Survey)

Facing page: A line of fractured ice shows a trace of the Denali Fault, which runs up the side of Alaska s Canwell Glacier. (Image courtesy of the U.S. Geological Survey)

Above: This fault scarp is visible near Augustana Creek, Alaska. The surface offset at this location was approximately 16 feet (5 meters). (Image courtesy of the U.S. Geological Survey)

his colleagues to make a series of three interferograms: one for each of the earthquakes, and a cumulative interferogram that includes both earthquakes. "It's the first time this has ever been done in earthquake research. Every pair of SAR images used in the past has straddled both the major foreshocks and the mainshock. Now we can actually separate the two quakes," said Ford.

The ability to generate interferograms for each earthquake allowed Ford to investigate how the foreshock focused tectonic stresses and added strength to the mainshock. Because earthquakes tend to recur along faults, an earthquake that relieves stress on one part of a fault may actually increase stress on other parts of a fault system.

Alaska's network of faults is a result of tectonic activity; the Pacific Plate is actively subducting (sliding under) the North American Plate, and the Denali Fault is located on the boundary between the two plates. Prior to the 2002 earthquakes, the Denali Fault was known to be seismically active, but scientists weren't sure if it was capable of generating a large earthquake.

Because some of the faults in southeast Alaska are heavily glaciated, Ford and his colleagues are also interested in studying the relationship between glaciers and structural geology. Glaciers tend to flow down fault lines, eroding the ground surface and acting as conveyor belts for rock material. They also prevent material from filling in faults, which tends to keep faults active.

In addition, landslides completely covered parts of several Alaskan glaciers after the November 3 Denali Fault earthquake. Landslide material may insulate glacier ice, raising its temperature towards the melting point. The additional weight of rocks and dirt can also cause greater pressure and melting at the base of the glacier, increasing the likelihood that a glacier may surge forward. "We want to know how earthquakes affect the behavior of these glaciers and how the glaciers are moving and responding," said Ford.

Even though the earthquakes occurred in a sparsely populated area, scientists are keeping an eye on the Denali Fault because of its similarities to the San Andreas Fault, located near heavily populated areas in California. According to Ford, "The Denali Fault earthquake was the 'big one' for Alaska." The cracks in the Earth's surface along parts of the fault were as much as 22 feet (6.7 meters), an amount that would have considerably damaged a more heavily populated area, such as California. While the November 3 earthquake in Alaska caused few injuries and no deaths, it did cause numerous landslides and damaged roads and bridges at a cost of at least $25 million.

In addition, both of the Denali Fault earthquakes occurred at a depth in the Earth's crust of 3.1 miles

(5 kilometers) or less, which is considered relatively shallow. "Usually, the earthquakes that are damaging to populations and structures occur close to the surface, so this is significant," said Price. By further studying and understanding the kind of deformation that split open the ground surface in Alaska, scientists hope to glean clues about earthquake damage potential along the San Andreas Fault.

The InSAR maps of surface deformation near the earthquake epicenters that Ford and his colleagues generated agreed with USGS findings, which included aerial and ground surveys of the fault rupture, as well as Global Positioning System (GPS) measurements. Although Alaska's Denali Fault was home to a network of GPS receivers, earthquakes are unpredictable, and no one knows whether the next one will strike in a location with a GPS receiver to measure it. "With InSAR, we can capture the whole picture, no matter where the epicenter of an earthquake is," said Ford. "And you can't measure ground motion on the scale of millimeters over that kind of area unless you use interferometry."

References:

Price, Evelyn J. and David T. Sandwell. 1998. Small-scale deforma tions associated with the 1992 Landers, California, earthquake mapped by synthetic aperture radar interferometry phase gradi ents. Journal of Geophysical Research. 103(B11):27,001-27,016.

USGS Fact Sheet 014-03: Rupture in South-Central Alaska The Denali Fault Earthquake of 2002. Accessed August 10, 2003. http://geopubs.wr.usgs.gov/fact-sheet/fs014-03/

M7.9 Earthquake on November 3, 2002. Accessed June 26, 2003. http://www.aeic.alaska.edu/M7.9_quake_2002/M7.9_quake.html

InSAR concepts. Accessed July 23, 2003. http://www.asf.alaska.edu/apd/software/insar/

Related color data image, page 22

Andrew Ford is a post-doctoral fellow in the University of Utah s Department of Geography. His research focuses on using Interferometric Synthetic Aperture Radar (InSAR) to investigate Antarctic ice streams, paleo ice streams, drumlin topography, ground subsidence, and Alaskan glaciers. Ford holds a MS degree in earth observation science from the University of Leicester and a PhD in remote sensing and glaciology from the University of Southampton.

Evelyn Price is a research associate at the Institute for Geophysics at the University of Texas at Austin. She received a BA degree in geological and geophysical sciences from Princeton University and a PhD in earth sciences from the University of California, San Diego. Her research includes using Interferometric Synthetic Aperture Radar (InSAR) to measure deformation caused by volcanoes and earthquakes in Alaska and earthquake-related deformation in California’s Mojave Desert.

Little Islands, Big Wake

"It's very surprising that an almost invisible geographic feature can have such a profound effect on the ocean-atmosphere system."

Physical Oceanography DAAC

GSFC Earth Sciences DAAC

by Laurie J. Schmidt

On a map of the world, the Hawaiian Islands are barely a speck in the 64 million square miles of the Pacific Ocean. But oceanographers recently discovered that these tiny dots on the map have a surprising effect on ocean currents and circulation patterns over much of the Pacific.

In the Northern Hemisphere, a system of persistent winds blows from northeast to southwest, from North and South America toward Asia, between the equator and 30 degrees north latitude. These northeasterly winds were dubbed the "trade winds" by ancient mariners who used them for trade voyaging. Typically, the trade winds continue on an uninterrupted course across the Pacific -- unless something gets in their way, like an island.

Although many people associate Hawaii with flat, sunny beaches, the elevation of the major Hawaiian Islands generally exceeds 3,200 feet (1,000 meters). Mauna Kea and Mauna Loa on the island of Hawaii (commonly referred to as "the Big Island") both tower nearly 14,000 feet (about 4,300 meters) above sea level. In addition, Mount Haleakala on the island of Maui stands at over 10,000 feet (3,055 meters) high.

Hawaii's high mountain landscape presents a substantial obstacle in the path of the trade winds. The elevated topography blocks the airflow, effectively splitting the trade winds in two. This split causes a zone of weak winds, called a "wind wake," to form on the leeward side (away from the wind) of the islands.

"If there were no mountains on the Hawaiian Islands, then nothing would happen. The trade winds would just blow smoothly across the ocean with no effect," said Shang-Ping Xie, professor and researcher at the University of Hawaii's International Pacific Research Center and Department of Meteorology.

The finding that a small island chain can have such a great impact on the Pacific Ocean is significant to the future of ocean observation, Xie said. "If you look at a large region of the Pacific Ocean, you can barely see the Hawaiian Islands. But if you look at the winds or currents in that region, you can clearly see the influence of the Hawaiian Islands. It's very pronounced."

According to Xie, conventional theories indicate that an island wind wake effect should dissipate within a few hundred kilometers and not be felt in the western Pacific. But Xie and his colleague Timothy Liu, senior research scientist at NASA's Jet Propulsion Laboratory, discovered a very unusual wake west of the Hawaiian Islands - one that extends 3,000 kilometers, which is roughly 10 times longer than any wake observed elsewhere.

"We started seeing a very long tail trailing the Hawaiian Islands for 3,000 kilometers. We'd never seen such a thing before, so that motivated us to dig deeper for an explanation," Xie continued. "Aerodynamic theory tells us that the 'island wake effect' should continue for no more than a few hundred kilometers. No way would you expect to see this effect for 3,000 kilometers."

"This finding presents a completely different view of ocean-atmosphere interactions in the Pacific. It's something that nobody has seen before," said Liu.

Xie, Liu, and colleagues noticed the long wake while analyzing data from NASA's QuikSCAT satellite, which uses microwave radar to measure winds near the ocean surface. They then confirmed their finding with data from the TOPEX/Poseidon and Tropical Rainfall Measuring Mission (TRMM) instruments. QuikSCAT and TOPEX data are available from the Jet Propulsion Laboratory Physical Oceanography Distributed Active Archive Center (PO.DAAC), and TRMM data are archived at the Goddard Space Flight Center Earth Sciences (GES) DAAC.

They also discovered that the wind wake drives an eastward "counter current" that brings warm water 8,000 kilometers from the Asian coast to Hawaii. This warm water drives further changes in wind, allowing the island effect to extend far into the western Pacific.

Left: This picture of the Hawaiian Islands was taken from the Shuttle Discovery in September 1988. Although some volcanic aerosols can be seen blowing downstream from the island of Hawaii (the Big Island), the clouds and surface water patterns in the wake of the other islands show how far downstream the island wakes persist. From the lower right corner in a diagonal directed upward to the north are the islands of Kauai (1), Oahu (2), Molokai (3), Lanai (4), Maui (5), Kahoolawe (6), and Hawaii (7). (Image courtesy of The Gateway to Astronaut Photography of Earth from NASA Johnson Space Center)

Above, left: This tree grows near South Point, the southernmost tip of the island of Hawaii. The trade winds that continually blow across the island cause it to be permanently bent in one direction. (Image courtesy of Laurie J. Schmidt)

Above, right: Mauna Kea, a dormant volcano, looms over the island of Hawaii, the largest member of the Hawaiian Islands. (Image courtesy of Laurie J. Schmidt)

"It's logical to think that water would flow in the same direction that the winds blow," said Liu. "But this current is actually going in the opposite direction - against the trade winds and back towards Hawaii."

"The current may actually extend all the way to the Asian coast, which is about a quarter of the Earth's circumference," added Xie.

According to Liu, the counter current had been observed by oceanographers near the Hawaiian Islands years before the long wake was discovered. "Drifting buoys off the coast of Hawaii routinely measure currents," he said. "So researchers were able to document the existence of a current that goes against the trade winds, but they didn't know exactly what the mechanism was."

One theory, according to Xie, was that the force of the ocean current hitting the islands generated eddies. "It's like the story about the blind man feeling the elephant," said Liu. "When he felt the leg, he thought it was a tree. So Japanese oceanographers would see a little part of the current here, the Hawaiians would see another part there, but they did not have a complete picture of what was happening. Satellite data enabled us for the first time to see the whole process across the Pacific, linking what people know in Asia with what people know in Hawaii."

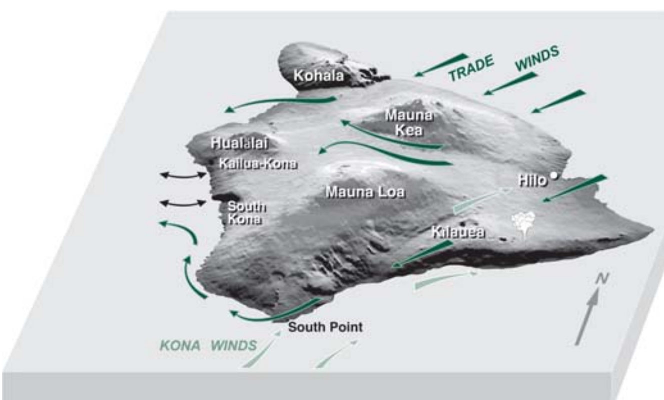
"The fact that separate measurements by three independent satellites come together and fit into a physically consistent picture gives us confidence in our results," Xie and colleagues said in a paper published in an issue of Science.

Xie cited a number of reasons why this phenomenon has only been observed in Hawaii. First, because the ocean reacts slowly to fast-changing winds, the wind system must be steady to exert forcing on the ocean, as is the case with the trade winds. Second, the high mountain topography of Hawaii provides a significant disturbance to the winds. Third, the Hawaiian Islands are large in horizontal scale, extending over four degrees in latitude. "It is this active interaction between wind, ocean current, and temperature that creates this uniquely long wake west of Hawaii," Xie said.

The researchers' discovery of the long wake testifies to the strong interaction between the atmospheres and ocean, which has strong implications for global climate research. "The strength of ocean-atmosphere interaction revealed in the Hawaiian wake helps us assess climate sensitivity, namely how much increase we will observe in the global mean temperature as we increase carbon dioxide levels," said Xie. "It's also important for understanding natural climate variations, like El Niño."

According to Xie, the finding has important implications for models that predict the Earth's climatic future. "There are a lot of uncertainties in existing models," said Xie. "The vast Pacific Ocean has been poorly measured until now because there are only a few ships at sea at any given moment. We need to be able to reproduce this long wake effect in a model, and this can only be done with high-resolution satellite data. The discovery of this far-reaching effect of tiny islands demonstrates the huge potential for observing the oceans from space, and for even more surprising discoveries.

“A lot of people can't even locate Hawaii on a map," Xie concluded. "So, in that sense - it's very surprising that an almost invisible geographic feature can have such a profound effect on the ocean-atmosphere system."



Above: Prevailing trade winds and Kona winds blow in opposite directions around the mountainous island of Hawaii. (Image courtesy of U.S. Geological Survey)

For more information, visit the following Web sites:

Physical Oceanography DAAC
http://podaac.jpl.nasa.gov/
GSFC Earth Sciences DAAC
http://daac.gsfc.nasa.gov/
International Pacific Research Center
http://iprc.soest.hawaii.edu/
QuikSCAT products at PO.DAAC
http://podaac.jpl.nasa.gov/quikscat

References:

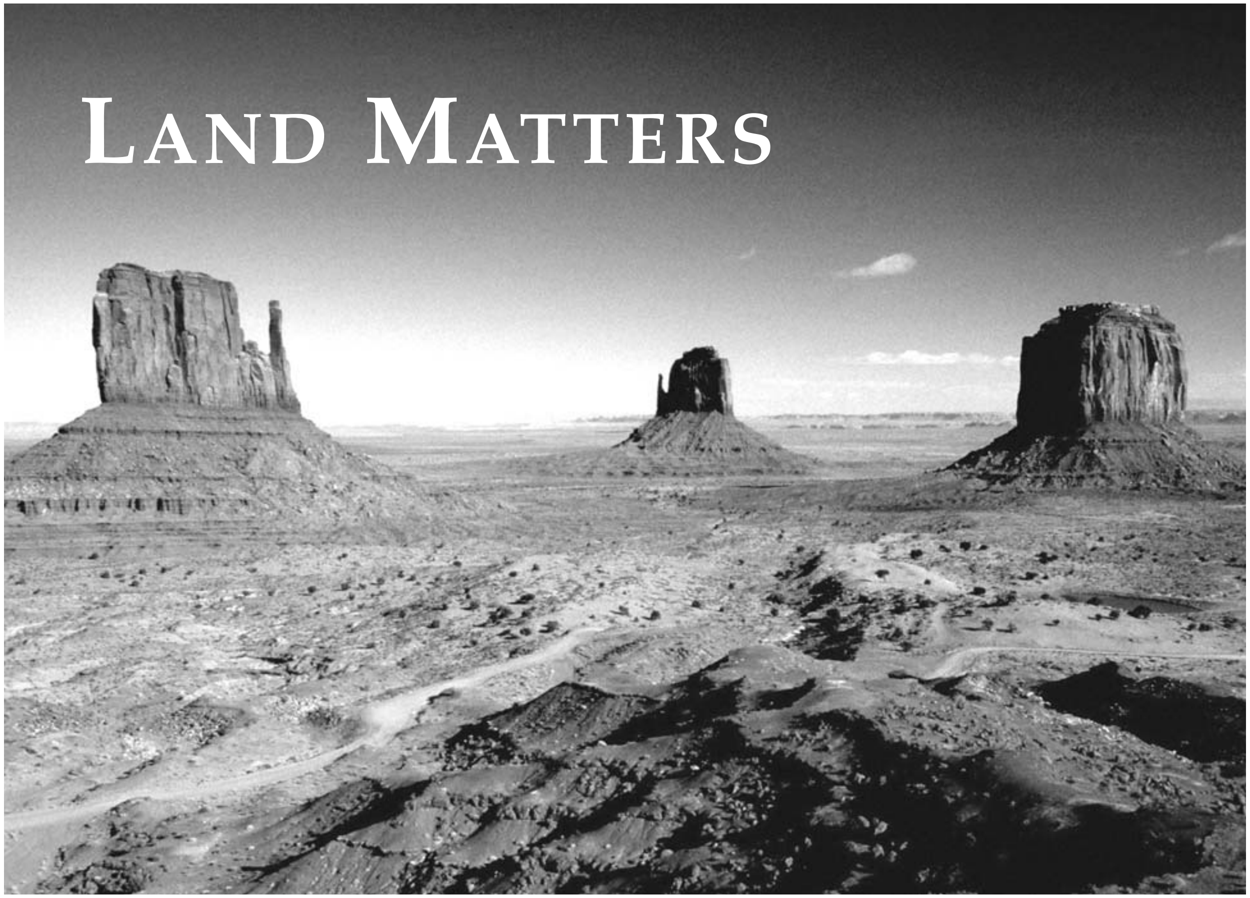
Xie, S.-P., W.T. Liu, Q. Liu, and M. Nonaka. 2001. Far-reaching effects of the Hawaiian Islands on the Pacific Ocean-Atmosphere System. Science. 292(5524):2057-2060.

Related color data image, page 21

Shang-Ping Xie is a professor of meteorology and co-team leader for Indo-Pacific Ocean climate research at the International Pacific Research Center, University of Hawaii. His research focuses on ocean-atmosphere interaction and its role in climate using satellite observations and numerical modeling. Xie received his PhD in geophysics in 1991 from Tohoku University, Japan.

W. Timothy Liu is a principal scientist/senior research scientist at the Jet Propulsion Laboratory (JPL), California Institute of Technology. His research focuses on studies concerning ocean-atmosphere interaction and satellite oceanography. Liu is leader of the Air-sea Interaction and Climate Team and project scientist for the NASA scatterometer missions NSCAT, QuikSCAT, and SeaWinds. He received his PhD in atmospheric sciences from the University of Washington and is a Fellow of the American Meteorological Society.

LAND MATTERS



Distributed Active Archive Center Alliance

by Michon Scott

> *"Slowly but surely, the International Satellite Land Surface Climatology Project (ISLSCP) has helped climate modelers realize the importance of accurate data for land components. That was not the case 10 years ago, but now it's widely accepted."*

STORM-RELATED LOSSES FROM THE 1982-83 EL NIÑO cost the state of California an estimated $2.2 billion. Fifteen years later, damages from the 1997-98 El Niño cost California only half that amount. Differences in storm intensity and duration accounted for some of the reduced costs, but other factors were also at work.

In anticipation of the 1997-98 El Niño, the U.S. Federal Emergency Management Agency spent approximately $165 million to prepare for storms and heavy rain in California. Local governments distributed sandbags to residents for flood protection, established volunteer programs to remove debris from storm drains, monitored high flood risk areas, and provided special training to damage-control teams.

All of this preparation was possible because the 1997-98 El Niño had been forecast six months in advance.

"The ability to predict El Niño events has improved enormously over the past five to 10 years," said Pavel Kabat, professor in climate hydrology at Wageningen University in the Netherlands. Kabat, who is the science chair for the International Satellite Land Surface Climatology Project (ISLSCP), thinks an important reason for the improved predictions is the incorporation of information that, until recently, had been largely ignored.

"Ten to 15 years ago, the climate modeling community was working with global models that used only ocean and atmosphere data," Kabat said. "At that time, the community believed the climate system was driven by just those two components. Five to seven years ago, some of the largest climate centers began incorporating vegetation data into their models, but they were assuming only one vegetation type per continent. All of Europe, for example, was classified as having one vegetation type. Slowly but surely, ISLSCP has helped climate modelers recognize the importance of accurate data for land components. That was not the case 10 years ago, but now it's widely accepted."

Established in 1983 under the United Nations' Environment Programme, ISLSCP promotes the use of satellites to develop data sets of land surface parameters for use in climate models. Forrest Hall, senior research scientist at the University of Maryland Joint Center for Earth Systems Technology, is the principal investigator in this project. "One element of ISLSCP involves very large-scale field experiments to develop and test our methods for understanding the Earth's ecosystems and how they interact with the atmosphere to influence climate. Another important aspect is taking measurements in the field to validate satellite data," he said.

The First ISLSCP Field Experiment took place on the Konza Prairie in Kansas between 1987 and 1989 and provided satellite-derived data on land-surface states and processes. Building on that work, the Boreal Ecosystems-Atmosphere Study examined the Canadian boreal forest from 1994 to 1996.

ISLSCP has progressed in stages, consisting of three different initiatives. In 1995, Initiative I published CD-ROMs of global land cover, soil, hydrometeorology, and radiation data. "Climate modelers typically use a latitude/longitude grid, and the ISLSCP data are all in a consistent grid format," said Richard Armstrong, an ISLSCP researcher and senior research scientist at the National Snow and Ice Data Center, one of NASA's Distributed Active Archive Centers (DAACs). The Initiative I data sets cover a two-year period, 1987 and 1988, but the longer the time span, the greater the benefit to the models. "It's good to look at data covering at least 10 to 20 years," said Armstrong.

Due for release in 2003, Initiative II has expanded coverage, with data spanning at least 10 years (1986 to 1995) and even longer for selected data sets. Initiative II also improved on the spatial and temporal resolutions of Initiative I and used updated algorithms.

"Initiative III will pick up where Initiative II left off," Hall said. "First, we'll extend it in time through 2007. Second, we'll add new data sets that have just recently become available as a result of new satellites or new analysis techniques. Finally, we may go back and reprocess some of the Initiative II data sets with newer algorithms."

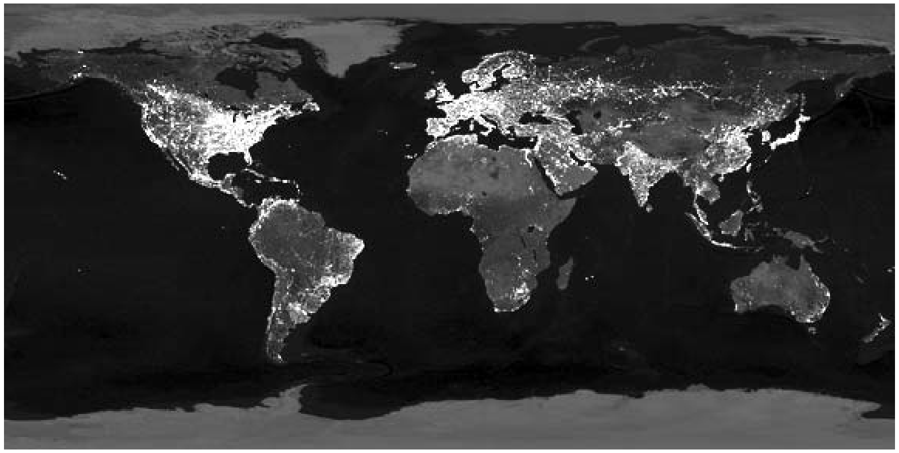
Continual improvements to data sets and algorithms may sound excessive, but the satellite record spans only 30 years, and scientists are just beginning to understand all the factors that affect global climate change. "We often don't have much luck predicting the weather five days out," said Armstrong. "Climate modeling and prediction is still a pretty new field."

Kabat recalled an early ISLSCP experiment. "It was a very short time scale, just a couple of weeks. This was partly because of the cost, but also because we hadn't realized by that time how important the living biosphere actually is to climate studies," he said. Researchers and climate modelers have improved their validation efforts over the years by recognizing the need to spend enough time in field validation and by monitoring different sites at different times.

"In the Sahel, the vegetation growth happens within a three- to five-month time period each year, so it doesn't matter if you stay there beyond that because nothing really happens," said Kabat. "But when you're in Europe or the central United States, you really need to spend a whole year monitoring the area. The conditions in the winter, spring, summer, and fall are all different."

Accurate climate models can benefit millions, through better predictions of severe weather events like El Niño to more astute monitoring of scarce resources. "If you look around the world and identify resources that are important for the sustainability of the region, water is always crucial. Yet in some regions, it's more critical than in others," said Kabat. "Some sectors of the society are more dependent on accurate predictions of water resources or precipitation. To plan effectively for a shortage, they would ideally have that information six months to one year ahead."

Facing page: Weathering and erosion processes have left massive sandstone structures standing in Monument Valley, which straddles the Utah-Arizona border in the southwest United States.



Above: Nighttime images show where the Earth is the most urbanized, though not necessarily the most populated. (China and India, for example, have denser populations but fewer city lights than Western Europe.) Increased urbanization, including removal of trees and addition of pavement, can create "heat islands" that affect local weather patterns. Improved understanding of human land use, and incorporation of that information into climate models, can help scientists better predict changes in weather and climate. (Data courtesy of Marc Imhoff, NASA GSFC, and Christopher Elvidge, NOAA NGDC. Image courtesy of Craig Mayhew and Robert Simmon, NASA GSFC.)

An example of how ISLSCP field experiments have improved weather forecasts comes from the ISLSCP field experiment in Kansas. "In the Kansas experiment we learned that operational weather models didn't correctly predict the impact of stored soil moisture on the weather machine. Model forecasts of a 1993 spring flood in Minnesota were off by several hundred miles. In fact, heavy rains inundated Missouri, catching emergency officials off guard and causing hundreds of millions of dollars in damages that might have been prevented by earlier accurate forecasts," said Hall. "ISLSCP data led to corrections in the model with significantly improved operational forecasts, which has potentially huge benefits to aviation and agriculture."

Better climate models may help researchers more accurately predict Earth's long-term changes as well. To understand these changes, ISLSCP activities focus on uncovering the exchange of energy, water, and carbon between Earth's land and atmosphere.

In recent years, the carbon cycle has been the focus of considerable scientific study and debate. Carbon is amazingly diverse. Pure carbon can form something as hard as a diamond or as soft as graphite (pencil lead). Carbon can reside in the tissues of living and dead organisms, in soil, in oceans, and in the atmosphere. Depending on the form it takes and where it resides, it has an enormous impact on Earth's climate. "Humans put about 7 gigatons of fossil fuel into the air each year. About half of the carbon dioxide we put into the atmosphere is re-absorbed by the oceans and the land surface," said Hall. "The northern latitudes have been taking up carbon since the last ice age. An enormous amount of carbon is stored in the soil in the form of peat."

Soils that can absorb carbon act as carbon sinks. "The land surface and the oceans perform a real service for us," Hall said. "They mitigate the effects of fossil fuel emissions and slow climate warming. But we need to know where those sinks are, what's causing them, and how long they may continue to take up carbon dioxide, because some sinks are probably sensitive to climate change. If we begin to dry and warm the climate - and we know this is happening at northern latitudes - we could start warming these large peat bogs and releasing carbon into the atmosphere very rapidly."

Should this happen, reduced ice and snow cover would also play a role in global change. Because it is white, snow reflects sunlight back into Earth's atmosphere. As snow melts, darker soils underneath absorb, rather than reflect, heat from the sun. "Climate is also affected by glacier coverage and freshwater melt that drains into the oceans at northern latitudes. Freshwater melt can affect ocean circulation patterns and, potentially, the Gulf Stream," said Hall.

Beyond the use of fossil fuel, human impact on the environment can be substantial, especially in the form of changes to the land surface. To better understand human factors, ISLSCP includes population data sets.

In addition to helping with long-term predictions of climate change, improved models may help health officials better monitor vector-borne diseases. Vegetation, for example, significantly affects mosquito populations, including bugs carrying harmful diseases. "People have used ISLSCP's land surface records from the Advanced Very High Resolution Radiometer to study regional patterns of tropical diseases and their dependence on climate variation," said Hall.

Scientists aren't the only ones using ISLSCP data sets. "Middle schools, high schools, and colleges have used ISLSCP data," said Hall. "You can make animations with the data sets and look at radiation and meteorological patterns, global vegetation, and precipitation."

The ISLSCP data sets are available from the GSFC Earth Sciences DAAC and incorporate data holdings from a variety of existing data sources. "Users have ordered over 13,000 CD-ROMs and downloaded over 267,000 files from the Web site," said Hall. In November 2001, the Global Energy and Water Cycle Experiment, of which ISLSCP is a part, reported more than 5,000 citations in scientific literature of ISLSCP data or research. Hall explained that the ISLSCP Initiative III is designed to build on this success. "We will be acquiring data sets on fossil fuel utilization, population change and its distribution in time, and agricultural productivity. We will also have all the standard data sets: the climate record, the satellite record of land surface change over a number of years, and surface temperature records."

"ISLSCP is sort of at the beginning of the process of understanding climate," said Kabat. "Our goal is to provide data, often on a daily basis, for the climate modelers to try. We also want to see the benefits of the improved predictions for the communities that are affected: water managers, planners, local governments, and the people who live there."

For more information, visit the following Web sites:

ISLSCP Initiative I
http://daac.gsfc.nasa.gov/CAMPAIGN_DOCS/ISLSCP/islscp_i1.html

ISLSCP Initiative II
http://islscp2.sesda.com/ISLSCP2_1/html_pages/islscp2_home.html

Global Energy and Water Cycle Experiment:
http://www.gewex.org

References

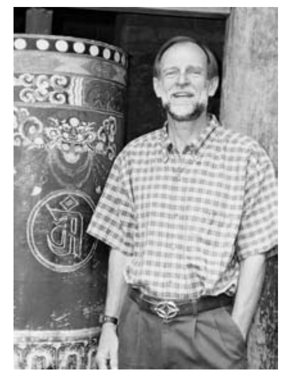
ISLSCP builds on success. GEWEX News. 11(4):3. (PDF file, 1.3 MB, http://www.gewex.org/nov2001.pdf)

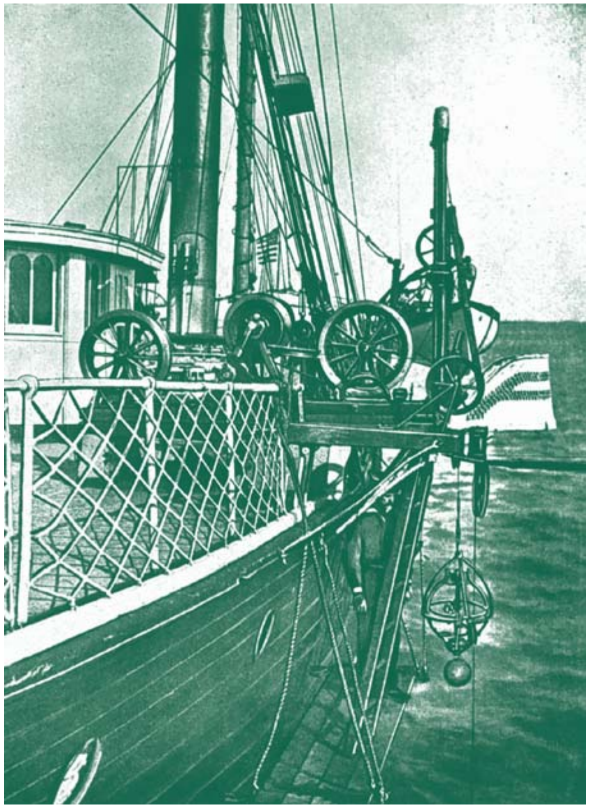
Sellers, P.J., R.E. Dickinson, D. A. Randall, A. K. Betts, F. G. Hall, J. A. Berry, G. J. Collatz, A. S. Denning, H. A. Mooney, C. A. Nobre, N. Sato, C. B. Field, A. Henderson-Sellers. 1997. Modeling the exchanges of energy, water, and carbon between continents and the atmosphere. Science. 275(5299):502-509.

Pavel Kabat is a professor in climate hydrology and chair for the Climate Change and Biosphere Research Programme at Wageningen University in the Netherlands. He is also the science chair for the International Satellite Land Surface Climatology Project and scientific director of the International Secretariat of the Dialogue on Water. He holds PhDs in hydrology and applied mathematics.

Forrest Hall is a retired NASA employee now working as a senior research scientist at the University of Maryland Joint Center for Earth Systems Technology. He is a principal investigator on the International Satellite Land Surface Climatology Project Initiative II. Hall holds a BS degree in mechanical engineering and MS and PhD degrees in physics.

Richard Armstrong is a senior research scientist at the National Snow and Ice Data Center and an adjunct associate professor in the Department of Geography at the University of Colorado, Boulder. His research interests include physical and mechanical properties of snow; passive microwave remote sensing of snow, ice, and frozen ground; and changes in snow cover and glacier mass as indicators of climate change. He has been active in developing data sets to support research and education in snow and ice. Armstrong earned his PhD in physical geography from the University of Colorado, Boulder.





Physical Oceanography DAAC

by Laura Naranjo

"We used to think that when the atmosphere underwent a sudden change, it would take 20 years for the entire Pacific Ocean to respond to a new pattern of ocean circulation. Now we know it only takes about 10 years for this response to occur."

DOUBLE VISION

FOR THE FIRST TIME, SCIENTISTS CAN RELY ON NOT one, but two satellites to monitor ocean surface topography, or sea level. Jason-1 and TOPEX/Poseidon, launched nearly 10 years apart, are now engaged in a tandem mission, creating a spaceborne ocean observatory that provides scientists, climate modelers, and forecasters with nearly global coverage of the world's ocean surface at an unprecedented level of precision.

Achieving this high-quality coverage hasn't been easy. Traditional ocean observation methods such as tide gauges, buoys, profiling floats, and ocean ship crossings offered reliable but sparse coverage. A series of ocean monitoring satellites launched during the 1970s and 1980s made slow progress, some hindered by poor accuracy and short instrument life spans. SEASAT, launched in 1978, failed after only three months in orbit. A subsequent mission, GEOSAT, flown from 1985 to 1990, encouraged the scientific community about the potential of future altimetry missions.

The 1992 launch of TOPEX/Poseidon, as a joint venture between NASA and the Centre National d'Études Spatiales (CNES), the French Space Agency, transformed ocean monitoring by providing a windfall of near-real-time data that exhibited a high level of accuracy. It was also the first of a sequence of missions designed specifically to monitor global ocean surface topography and ocean circulation.

"TOPEX/Poseidon fundamentally changed our understanding of ocean circulation and how we model the ocean for climate prediction," said Lee-Lueng Fu, project scientist for the TOPEX/Poseidon and Jason-1 mission at NASA's Jet Propulsion Laboratory (JPL). The mission enabled researchers to monitor large-scale ocean phenomena such as El Niño, La Niña, and the Pacific Decadal Oscillation, and it opened the door for longer-term forecasting. Although its life expectancy was only three to five years, the TOPEX/Poseidon satellite continues to operate successfully after 11 years in orbit.

Planning for the follow-up mission, Jason-1, began in 1994, and the satellite was launched in December 2001. Although Jason-1 was designed to replace TOPEX/Poseidon, scientists took advantage of TOPEX/Poseidon's unexpected longevity by placing the satellites in a tandem orbit.

During its first six months of flight, the Jason-1 satellite was placed along the same groundtrack as TOPEX/Poseidon, about one minute apart. Because the two satellites observed nearly identical ocean conditions, scientists could then calibrate the new instruments on Jason-1. Once scientists confirmed that Jason-1 was taking measurements with equal or better accuracy than its predecessor, TOPEX/Poseidon was maneuvered into a parallel groundtrack to increase coverage between the two satellites.

The data processing and distribution for both satellite missions are jointly supported by the NASA JPL Physical Oceanography Distributed Active Archive Center (PO.DAAC), and the CNES Archiving, Validation, and Interpretation of Satellite Oceanographic Data (AVISO) service. This support includes the worldwide distribution of data products to researchers and climate modelers.

TOPEX/Poseidon and Jason-1 use radar altimetry to measure the height of the ocean surface relative to the center of the Earth. However, the ocean surface is affected by factors such as ocean currents, winds, tides, gravity, and atmospheric pressure. Data from the two satellites allow scientists to study the dynamics of ocean currents and their response to the forcing by winds and atmospheric pressure. Scientists are also developing new models of ocean tides and the Earth's gravity field based on the satellite's observations.

Ocean surface topography measurements also tell scientists how much heat is stored in the ocean, which can affect sea level. "When temperature rises, water volume expands, so when heat is stored in the ocean, the topography is higher. Measuring the spatial change of the height helps us determine where heat is being stored," said Fu.

Oceans are capable of absorbing and storing large amounts of heat, which is why ocean temperatures don't vary as widely as temperatures on land. This implies that oceans would react slowly to atmospheric changes. But data from TOPEX/Poseidon revealed that the ocean responds to the atmosphere on a much shorter time scale than previously thought. "We used to think that when the atmosphere underwent a sudden change, it would take 20 years for the entire Pacific Ocean to respond to a new pattern of ocean circulation. Now we know it only takes about 10 years for this response to occur," said Fu.

Observing circulation changes in the tropical Pacific Ocean was key to detecting several past El Niño events. The Earth's oceans and atmosphere constantly interact, meaning that changes in ocean heat storage and circulation can affect the atmosphere, and vice versa. For instance, the El Niño of 1997-98 produced anomalies in the Pacific Ocean (such as a build-up of warm water accompanied by a rise in sea level), as well as atmospheric disturbances that affected inland and coastal communities around the world. TOPEX/Poseidon's measurements also revealed acceleration in global sea level rise within the past 10 years, which is about 50 percent faster than the rate of the rest of the 20th century.

Fulfilling scientists' expectations, Jason-1 demonstrates improved accuracy over its predecessor. Whereas TOPEX/Poseidon measures sea surface height accurate to within four centimeters, Jason-1 improved the measurement accuracy to within three centimeters.

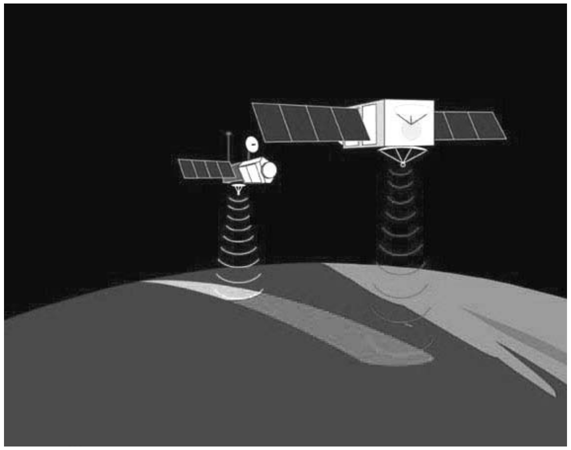
Jason-1's accuracy during the tandem mission has helped scientists monitor ocean circulation in greater detail. For instance, tidal motion near the coasts occurs on a spatial scale too small to be detected by TOPEX/Poseidon. The tandem mission's improved level of accuracy allows for proper removal of this motion, allowing scientists to better detect climate variation near the coasts, Fu said.

Fu also credited the tandem mission with improved observations in the open ocean. Eddies, or rotating swirls of water that carry large amounts of heat, salt, and nutrients, are too small to be resolved by TOPEX/Poseidon, but the tandem mission is capable of measuring these phenomena. Warm water eddies can rise up to 31.5 inches (80 centimeters) higher than surrounding waters, and cold water eddies indicate depressions in the ocean surface, influencing ocean circulation and surface topography.

While scientists have already observed an El Niño and its transition into a La Niña using Jason-1 data, they anticipate more observations of ocean circulation and temperature variations, and increased use in practical applications such as determining coastal environment management practices and forecasting ocean conditions. Currently, both the NASA JPL PO.DAAC and the CNES AVISO service provide satellite altimetry data from TOPEX/Poseidon and Jason-1. Aside from science and research applications, data are being applied in a variety of sectors, including commercial fishing, ship routing, marine wildlife monitoring, ocean debris tracking, and offshore industries.

Above: A worker maintains a Tropical Atmosphere Ocean (TAO) buoy on the equatorial El Ni o array in the Pacific Ocean. Developed under the auspices of the Tropical Ocean Global Atmosphere (TOGA) Program, these buoys measure ocean temperature at varying depths and give forewarning of El Ni o or La Ni a events. Although they offer limited coverage, the buoys provide a valuable ongoing record of ocean changes in conjunction with TOPEX/Poseidon and Jason-1 observations. (Image courtesy of the NOAA Photo Library)

Facing page: Prior to satellite technology, scientists relied on tools such as sounding instruments to study oceans. Invented in the late 19th century, the Sigsbee Sounding Machine was the first efficient piano wire sounding instrument. The basic design of ocean sounding instruments remained the same for the next 50 years. (Image courtesy of the NOAA Photo Library)



Above: This artist's rendering shows the Jason-1 and TOPEX/Poseidon instruments working in tandem. (Image courtesy of the NASA Jet Propulsion Laboratory)

However, Fu stressed that the mission's long-term goal is to continue the time series of ocean observations. "The revolutionary aspect of Jason-1 is that for the first time we can detect ocean changes on the order of decades rather than years, something that has not been achieved by TOPEX/Poseidon alone," said Fu. "Extending the time series will be key to understanding global warming and climate change."

For more information, visit the following Web sites:

Jason-1
http://podaac.jpl.nasa.gov/jason/

Ocean Surface Topography from Space
http://topex-www.jpl.nasa.gov/

Aviso, Observing the Ocean from Space
http://www.aviso.oceanobs.com/

Physical Oceanography DAAC
http://podaac.jpl.nasa.gov/

References

Jason-1 Mission. Accessed June 5, 2003. http://www.aviso.oceanobs.com/html/missions/jason/welcome_uk.html

Ocean Surface Topography From Space: Science. Accessed May 19, 2003. http://topex-www.jpl.nasa.gov/science/science.html

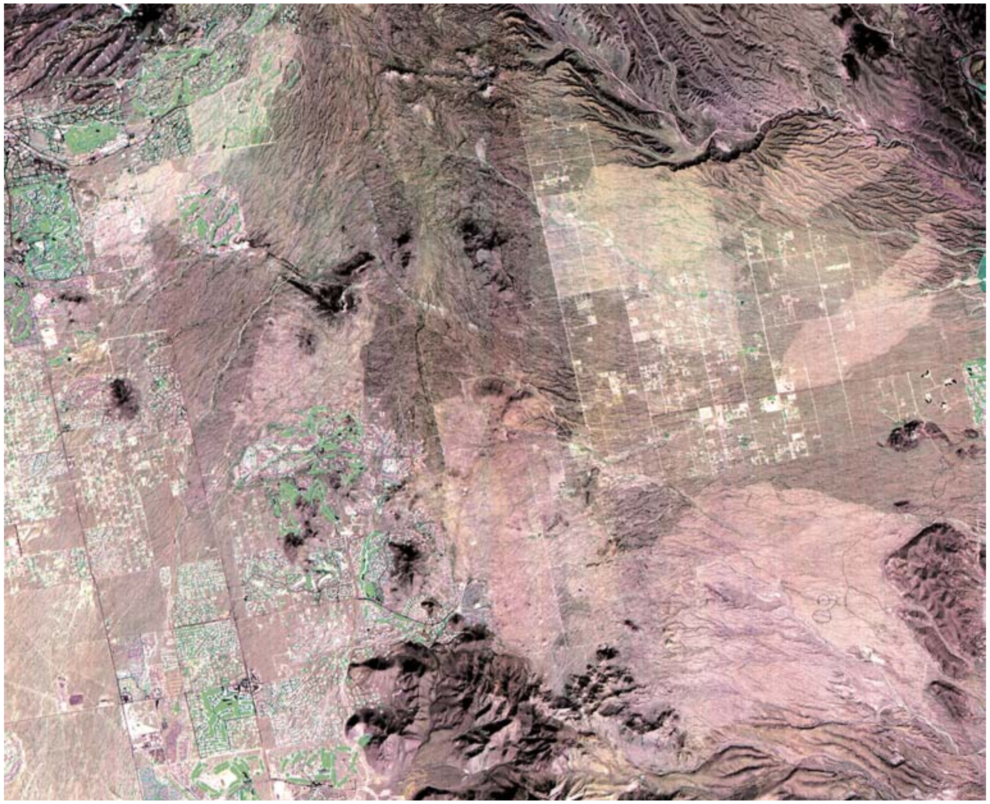
Douglas, Bruce, C., and W. Richard Peltier. 2002. The Puzzle of Global Sea-Level Rise. Physics Today. 55(3):35.

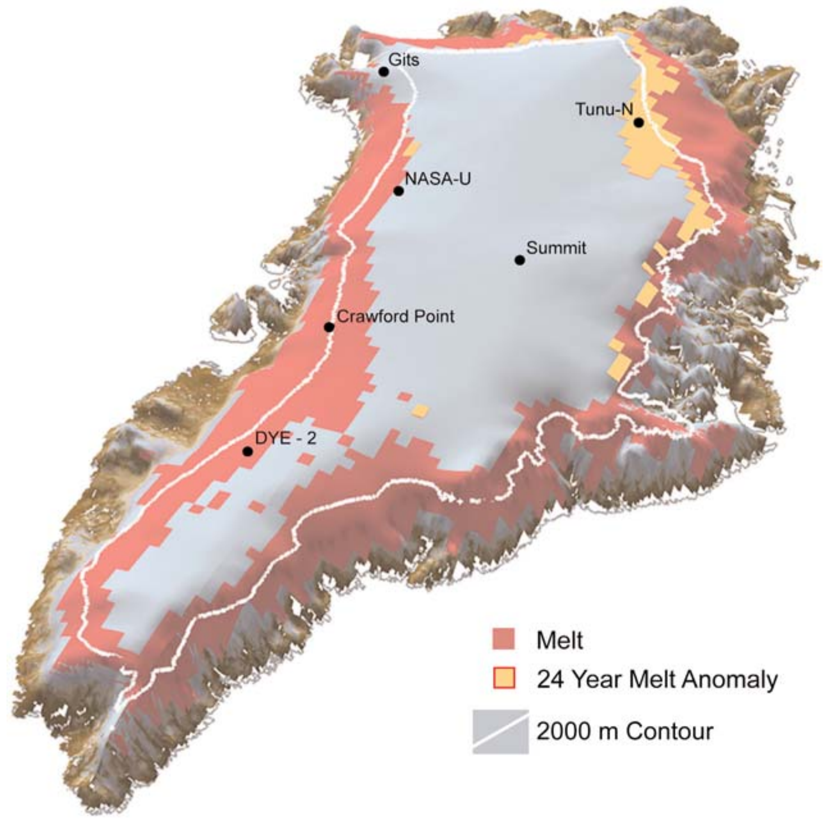
Wunsch, C., and Detlef Stammer. 1998. Satellite Altimetry, the Marine Geoid, and the Oceanic General Circulation. Annual Review of Earth and Planetary Sciences. 26:219-53.

Related color data image, page 22

Lee-Lueng Fu is a senior research scientist at the Jet Propulsion Laboratory, California Institute of Technology, and NASA project scientist for the joint U.S./French TOPEX/Poseidon and Jason-1 missions. He is also head of the Ocean Science Research Element of the Division of Earth and Space Sciences of JPL. Fu received a BS degree in physics from National Taiwan University and a PhD in oceanography from Massachusetts Institute of Technology and Woods Hole Oceanographic Institution.

Supplemental Data Image Section



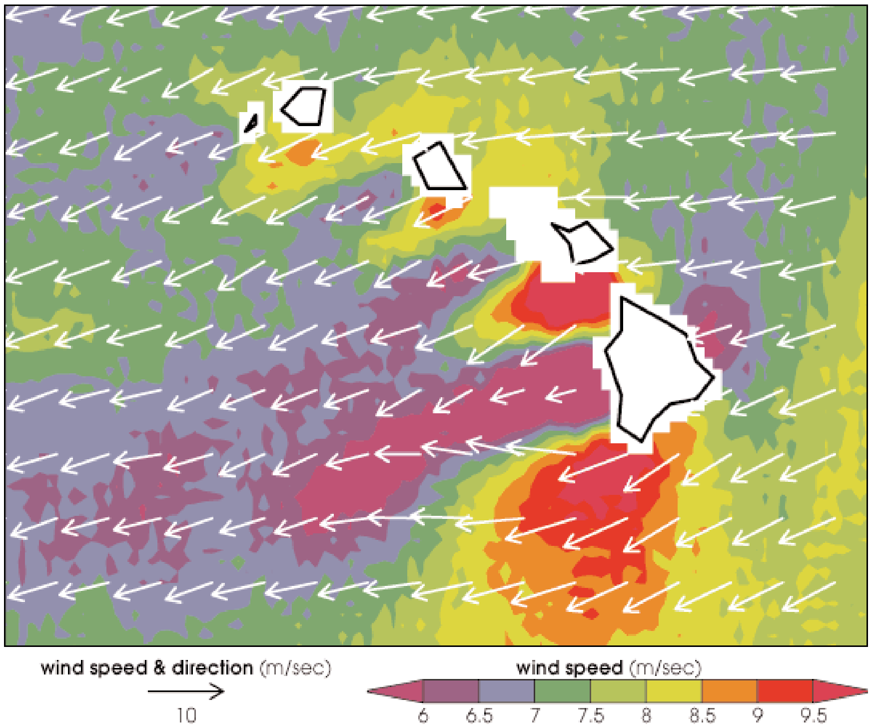


Left: This image, acquired on September 19, 2000, is a false-color composite of ASTER bands 2, 3, 1 in red, green, and blue, respectively. The image shows detectable fire scars (lighter areas) in Arizona s northeast Phoenix valley. Each of these scars were the product of either human or naturally-caused brush fires over the past 50 years, with the most recent and largest being the Rio Fire in 1995. (Image courtesy of NASA)

(See *Flame and Flood*, page 38)

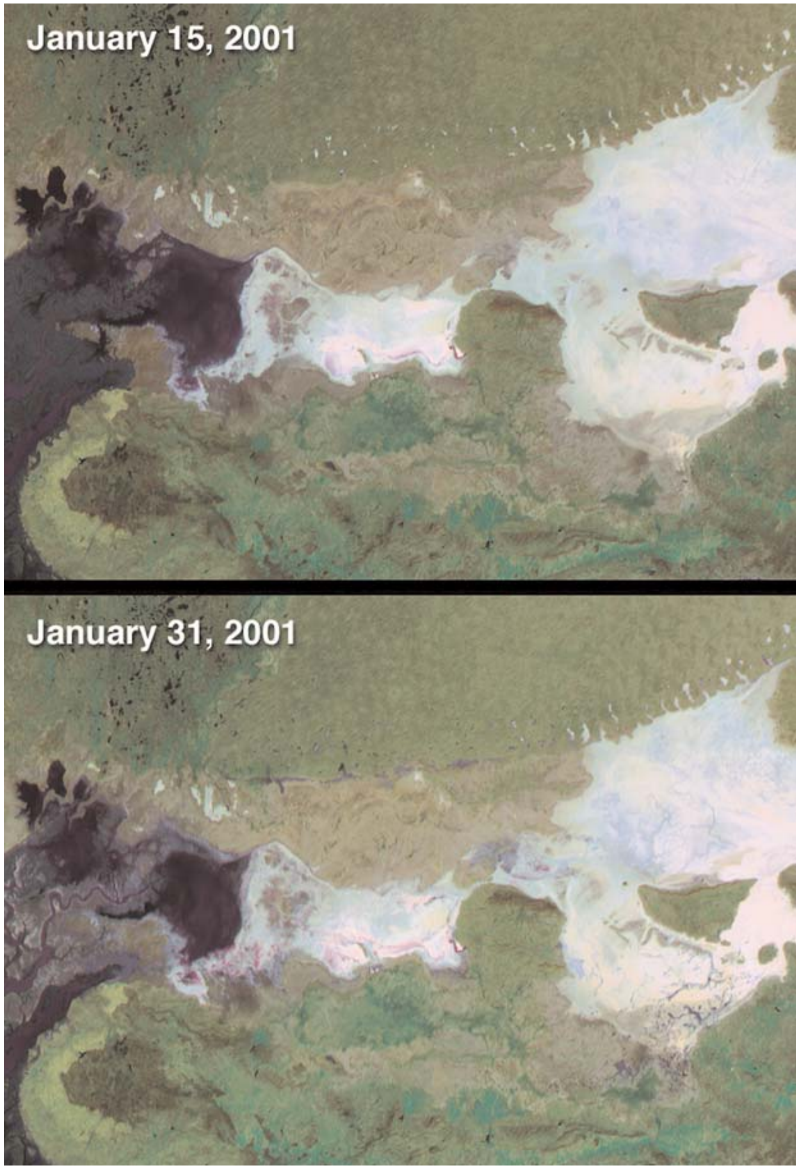
Right: This 3-D computer graphic of the Greenland Ice Sheet shows the 2002 melt extent (pink and yellow areas). In 2002, the melt started unusually early and progressed higher up the ice sheet than at any time in the past 24 years (yellow area). Surface melting extended up to 6,560 feet (2,000 meters) in elevation in the northeast portion of Greenland, where temperatures normally are too cold for melting to occur. In addition, the total melt area covered 265,000 square miles (686,350 square kilometers), representing a 16 percent increase above the maximum melt area measured in the previous 24 years. (Image courtesy of Konrad Steffen and Russell Huff, CIRES, University of Colorado at Boulder)

(See *Vanishing Ice*, page 34)



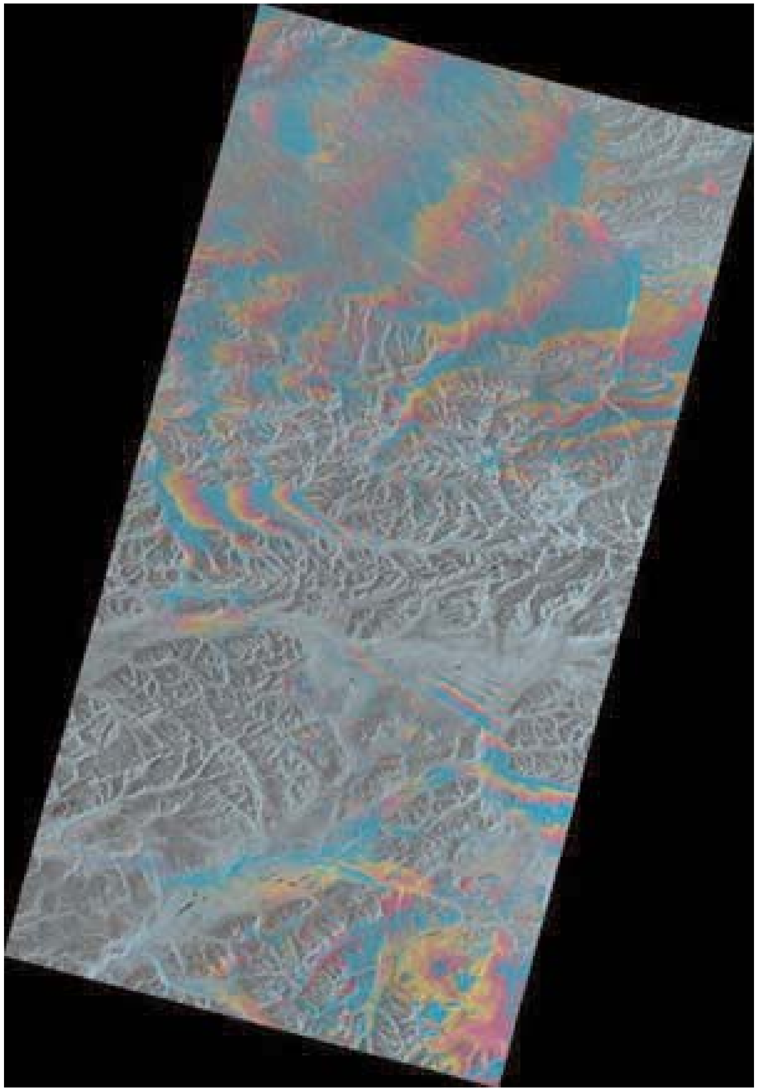
Left: The SeaWinds sensor on the QuikSCAT satellite captured this image of the Hawaiian wake in August 1999. Trade winds blow from east to west (right to left in the image), intensifying between the islands and weakening in the islands wakes (colors in image indicate intensifying winds). (Image courtesy of Shang-Ping Xie, University of Hawaii International Pacific Research Center and Meteorology Department, and Timothy Liu, NASA Jet Propulsion Laboratory)

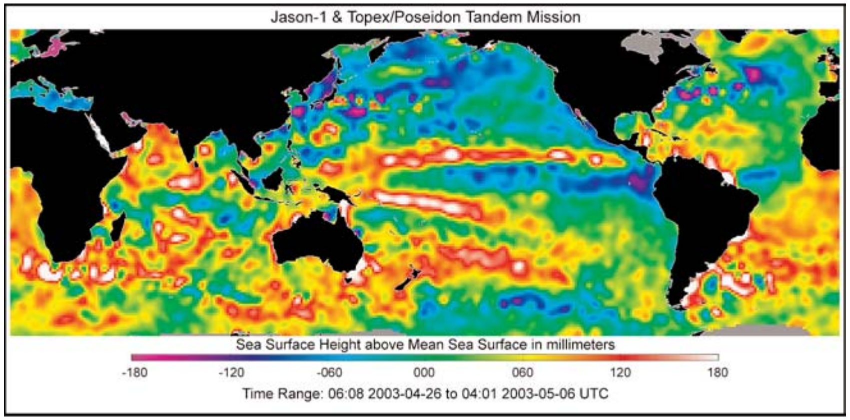
(See *Little Islands, Big Wake*, page 9)

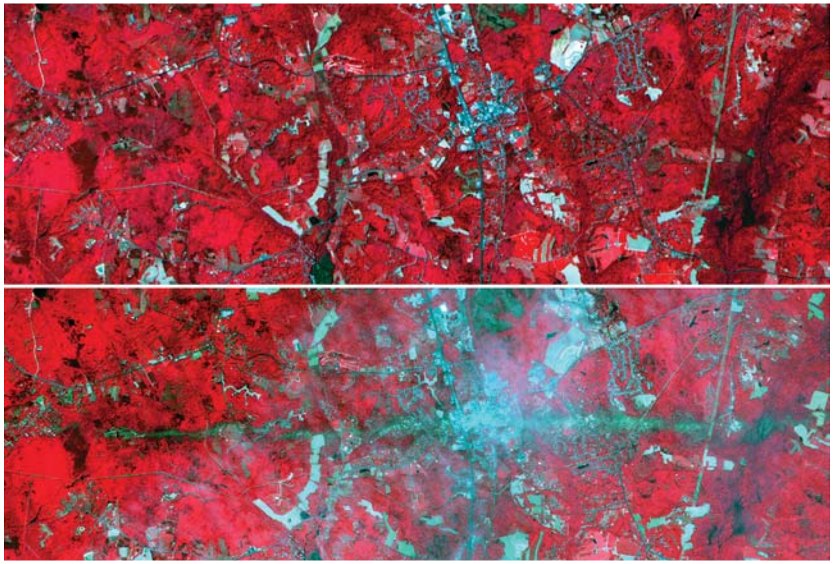


Right: These two false-color MISR images were acquired before and after the Bhuj earthquake, on January 15 and 31, 2001, respectively. The earthquake epicenter was located about 50 miles (80 kilometers) east of the city of Bhuj, situated in the lower part of the images. The later image depicts numerous areas where groundwater flowed up to the surface, including within the Rann of Kachchh and near the Indo-Pakistani border. These regions of earthquake-associated surface water are apparent up to 124 miles (200 kilometers) from the earthquake s epicenter (surface water appears in shades of blue and purple). (Images courtesy NASA/GSFC/LaRC/JPL, MISR Team)

(See *Squeezing Water from Rock,* page 27)







Left: This Synthetic Aperture Radar (SAR) interferogram includes the epicenters of the October 23, 2002, and November 3, 2002 Denali Fault earthquakes, which are located at the extreme western end of the fault rupture. RADARSAT-1 images used are from October 16 and November 9, 2002, and cover 100 kilometers by 200 kilometers. Each color cycle (e.g. blue-to-blue) can be regarded as a contour showing approximately three centimeters of ground motion. Note how they appear to radiate like ripples in a pond. The points from which they radiate indicate the epicenters of the earthquakes. (Image courtesy of Andrew Ford, University of Utah. SAR data originally supplied by the Alaska Satellite Facility.)

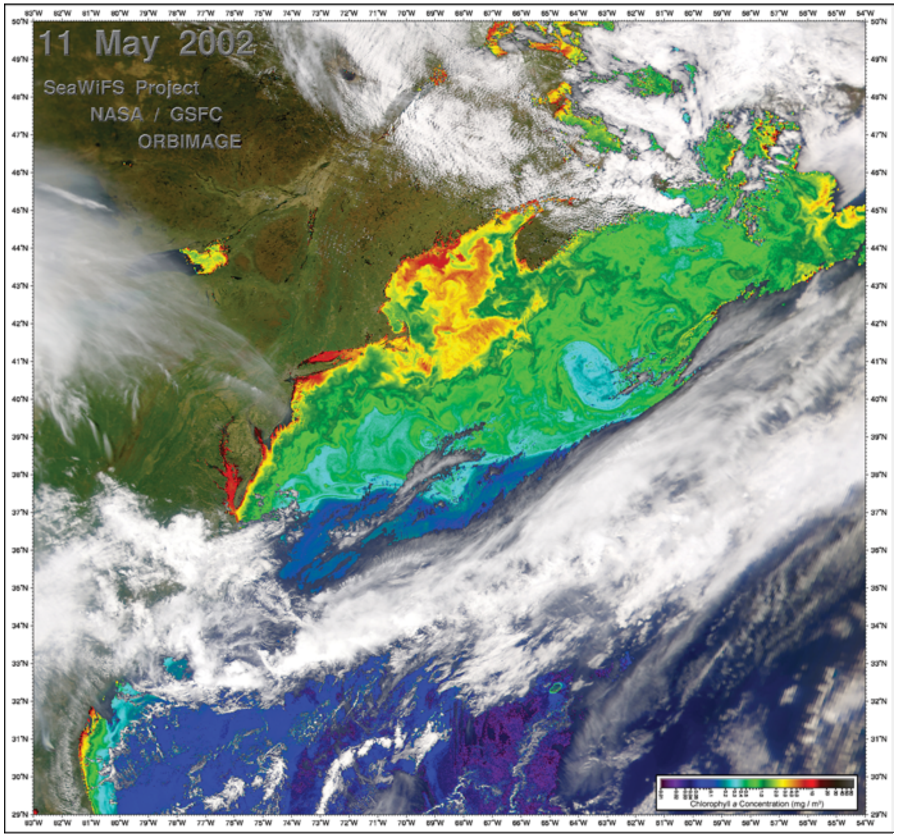
(See *Denali s Fault*, page 5)

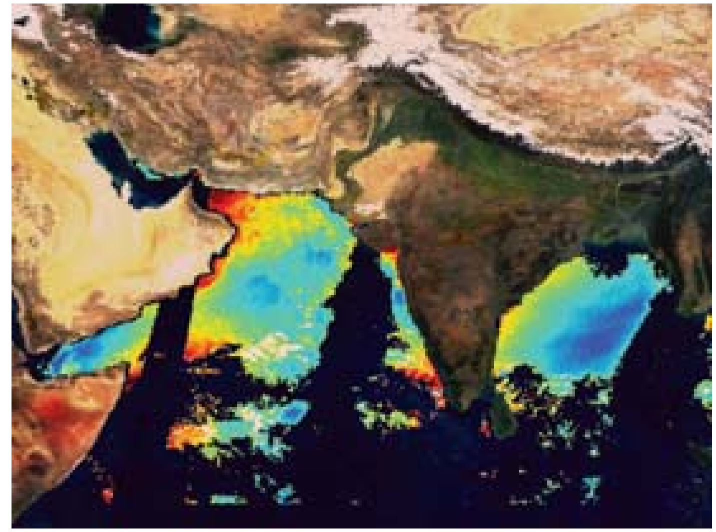
Top, right: This image represents combined data from the Jason-1 and TOPEX/Poseidon tandem mission and shows sea surface height anomaly for the 10-day period of April 26, 2003 through May 6, 2003. Purple and blue represent below normal sea surface height, while green represents average sea surface height. Red and white areas indicate sea surface height that is greater than 4 inches (10 centimeters) above normal. (Image courtesy of the Jet Propulsion Laboratory)

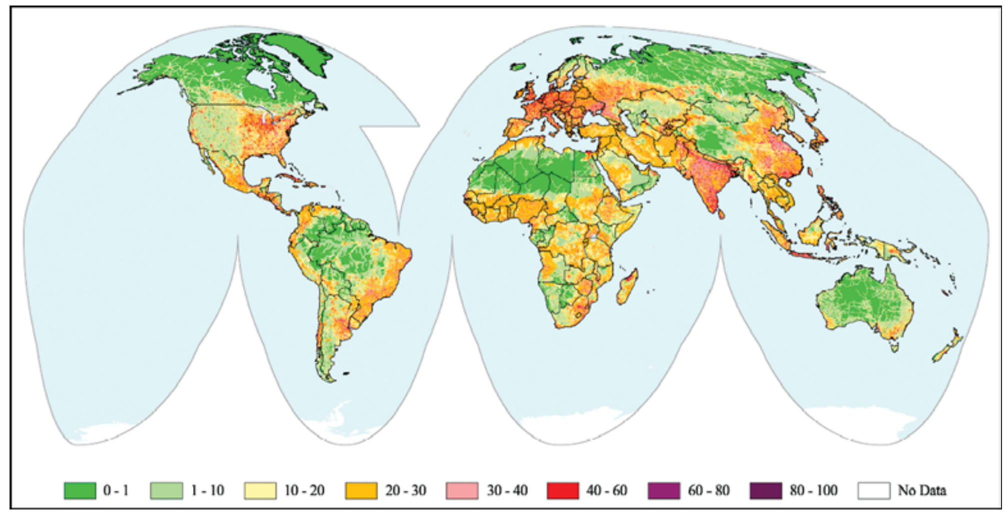
(See *Double Vision*, page 17)

Bottom, right: On April 28, 2002, a tornado carved a path through La Plata, Maryland, killing three people and injuring more than 100. These images show a 6 x 17.8 kilometer area centered on the town of La Plata. The top image was acquired on May 12, 2001, and the bottom on May 3, 2002. Vegetation appears in red, and bare fields and urban areas appear in blue-green. The dark turquoise swath across the middle of the bottom image is the track of the tornado, where vegetation was ripped up and removed.

(See *Lightning Spies*, page 31)







Left: On May 11, 2002, clear skies revealed the highly productive waters in the North Atlantic Ocean off eastern North America. This image was produced using data acquired by the Sea-viewing Wide Field-of-view Sensor (SeaWiFS), flying aboard the OrbView-2 satellite. In this view, the waters over Georges Bank and the Gulf of Maine exhibit the high chlorophyll concentrations that mark thriving phytoplankton populations. To the south, chlorophyll concentrations decrease rapidly across the northern boundary of the Gulf Stream. (Image courtesy of the SeaWiFS project, NASA GSFC, and ORBIMAGE)

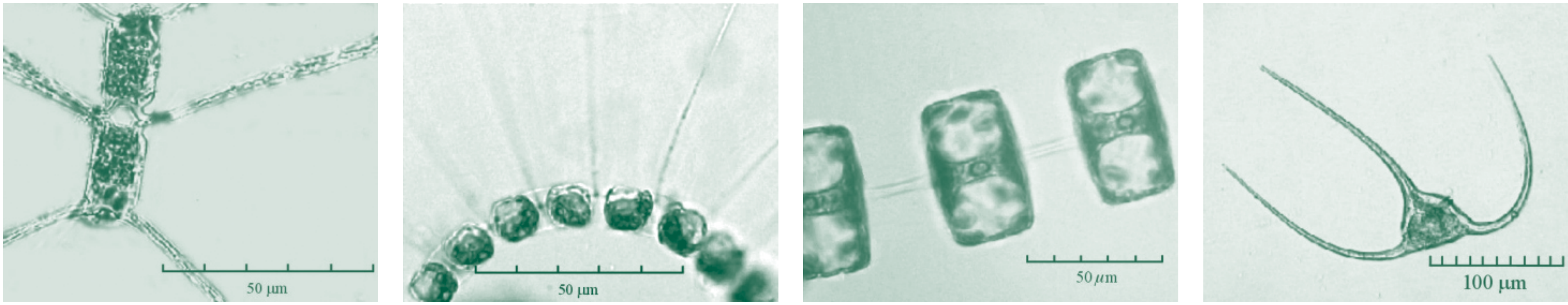
(See *The Incredible Glowing Algae*, page 24)

Top, right: MODIS provides the unprecedented ability to measure chlorophyll fluorescence, which gives insight into the health of phytoplankton in the ocean. When phytoplankton are under stress, they no longer photosynthesize and begin to emit absorbed sunlight as fluorescence. This image taken over the Arabian Sea shows levels of fluorescence (red indicates high values). (Image courtesy of Scientific Visualization Studio, NASA Goddard Space Flight Center)

(See *The Incredible Glowing Algae*, page 24)

Lower, right: The Human Footprint is a quantitative analysis of human influence across the globe. In this map, human impact is rated on a scale of 0 (minimum) to 100 (maximum) for each terrestrial biome. A score of 1 indicates the least human influence in the given biome. However, because each biome has its own independent scale, a score of 1 in a tropical rainforest might reflect a different level of human activity than in a broadleaf forest. (Image courtesy of Sanderson et al.)

(See *The Human Footprint*, page 1)



THE INCREDIBLE GLOWING ALGAE

EACH YEAR, THE NORTH ATLANTIC OCEAN announces springtime by producing "blooms" large enough to be seen from space. These explosive increases in microscopic marine algae, called phytoplankton, appear as sudden bright blossoms in satellite imagery. Phytoplankton blooms occur in all the Earth's oceans when nutrient and sunlight conditions are right.

Although scientists have been able to view these blooms through satellite data for the past 25 years, they could not get much detail about phytoplankton health. The latest development in oceanographic remote sensing, however, enables researchers to detect the glow, or phytoplankton fluorescence, from chlorophyll.

"I think the most exciting advance in remote sensing is fluorescence from space," said Mark Abbott, professor and dean in the College of Oceanic and Atmospheric Sciences at Oregon State University. "This is the first time we've been able to measure physiological changes in phytoplankton communities rather than just population increases."

Like other plants, phytoplankton use photosynthesis to grow. During photosynthesis, the green pigment chlorophyll absorbs light, which allows plants to produce organic carbon (carbohydrates) from carbon dioxide and water. The amount of organic carbon plants produce is called primary productivity.

Ocean remote sensing instruments measure primary productivity by determining the amount of light absorbed by phytoplankton chlorophyll. Sunlight enters ocean water, bounces around on particles, phytoplankton, and water molecules, then bounces back up toward space. The instruments detect variations in the intensity of light, called ocean color, at the ocean surface.

The first remote sensing instrument designed to survey ocean color, the Coastal Zone Color Scanner (CZCS), operated from 1978 to 1986. The Sea-viewing Wide Field of View Sensor (SeaWiFS) was launched in 1997 and is still operational. These instruments measure light absorption at particular wavelengths (bands).

Specific bands on each sensor detect chlorophyll absorption. As the concentration of chlorophyll

"This is the first time we've been able to measure physiological changes in phytoplankton communities rather than just population increases."

GSFC Earth Sciences DAAC

by Amy Casey

Top: Different phytoplankton species take diverse forms. (Images courtesy of NOAA) increases, satellite images show the ocean surface changing from blue to shades of green. To illustrate these changes, most ocean color imagery uses a color palette ranging from purple to orange or red as chlorophyll concentration increases.

One of the initial challenges in ocean color remote sensing was determining the difference between phytoplankton chlorophyll and dissolved organic matter, called gelbstoff. A high concentration of gelbstoff affects how much sunlight penetrates the water, which impacts the growth of phytoplankton populations, and can present a false signal in the satellite's color measurements of chlorophyll.

"If you've ever raked leaves and put them in a bucket of water, you see the water turn yellow over time - the yellow color is gelbstoff," said Ken Carder, professor of ocean optics at the University of South Florida.

Carder has developed an algorithm, called chlor-a 3, that distinguishes between gelbstoff and chlorophyll by measuring the chlorophyll a molecules. "CZCS didn't have the ability to separate gelbstoff from phytoplankton. High concentrations of gelbstoff looked just like chlorophyll," Carder said. "So CZCS and SeaWiFS historically overestimated the amount of chlorophyll, and chlor-a 3 now adjusts for that."

Using data from the chlorophyll bands on CZCS and SeaWiFS, researchers could track the size and movement of phytoplankton populations, but they could not determine phytoplankton health or efficiency. What scientists needed was fluorescence data, which is now available from the Moderate Resolution Imaging Spectroradiometer (MODIS), launched in 1999.

Carder and Abbott are both members of the MODIS Ocean Science Team, based at the Goddard Space Flight Center (GSFC) in Greenbelt, Maryland. The GSFC Earth Sciences (GES) DAAC archives and distributes oceanographic data from CZCS, SeaWiFS, and MODIS. Along with other team members, Carder and Abbott are working on new models of primary productivity using MODIS fluorescence data. Monitoring fluorescence can help scientists describe the physiological state of phytoplankton, determine the cause of population decreases, and make accurate estimates of primary productivity on a global scale.

Abbott explained, "Phytoplankton can do three things with absorbed light: use it to conduct photosynthesis, turn it into heat, or emit light (glow) in the red portion of the spectrum called fluorescence. The relative balance of these processes tells us about the health of the phytoplankton. Relatively low fluorescence indicates a healthy area."

When phytoplankton cells absorb light efficiently for photosynthesis, they have less light energy available for fluorescence. Therefore, researchers can evaluate phytoplankton health by looking at fluorescence levels.

Different species of phytoplankton fluoresce at different rates, called fluorescence quantum yield. Phytoplankton use light differently as the amount of sunlight changes from sunrise to sunset and from sunny days to cloudy days. "As phytoplankton age or the availability of nutrients decreases, they become less healthy and the amount of fluorescence may increase," Abbott noted.

While ocean color remote sensing instruments can detect blooms and track their progress, fluorescence data provide more specific information about how phytoplankton use light. This information could lead to more accurate models of primary productivity and give scientists a better idea of how ecosystem changes affect algal populations.

"MODIS is the first satellite sensor to measure chlorophyll fluorescence from space," said Abbott. "Fluorescence is an indicator of phytoplankton health, and we'll be able to use that to improve estimates of phytoplankton productivity - and to understand how the ecosystem is responding to changes in its physical environment."

For more information, visit the following Web sites:
GSFC Earth Sciences DAAC
http://daac.gsfc.nasa.gov/
MODIS Web
http://modis.gsfc.nasa.gov/
SeaWiFS Project
http://seawifs.gsfc.nasa.gov/SEAWIFS.html

References:

College of Oceanic and Atmospheric Sciences at Oregon State University. Accessed July 7, 2003. http://www.oce.orst.edu/

College of Marine Science at the University of South Florida. Accessed July 25, 2003. http://www.marine.usf.edu/phy/

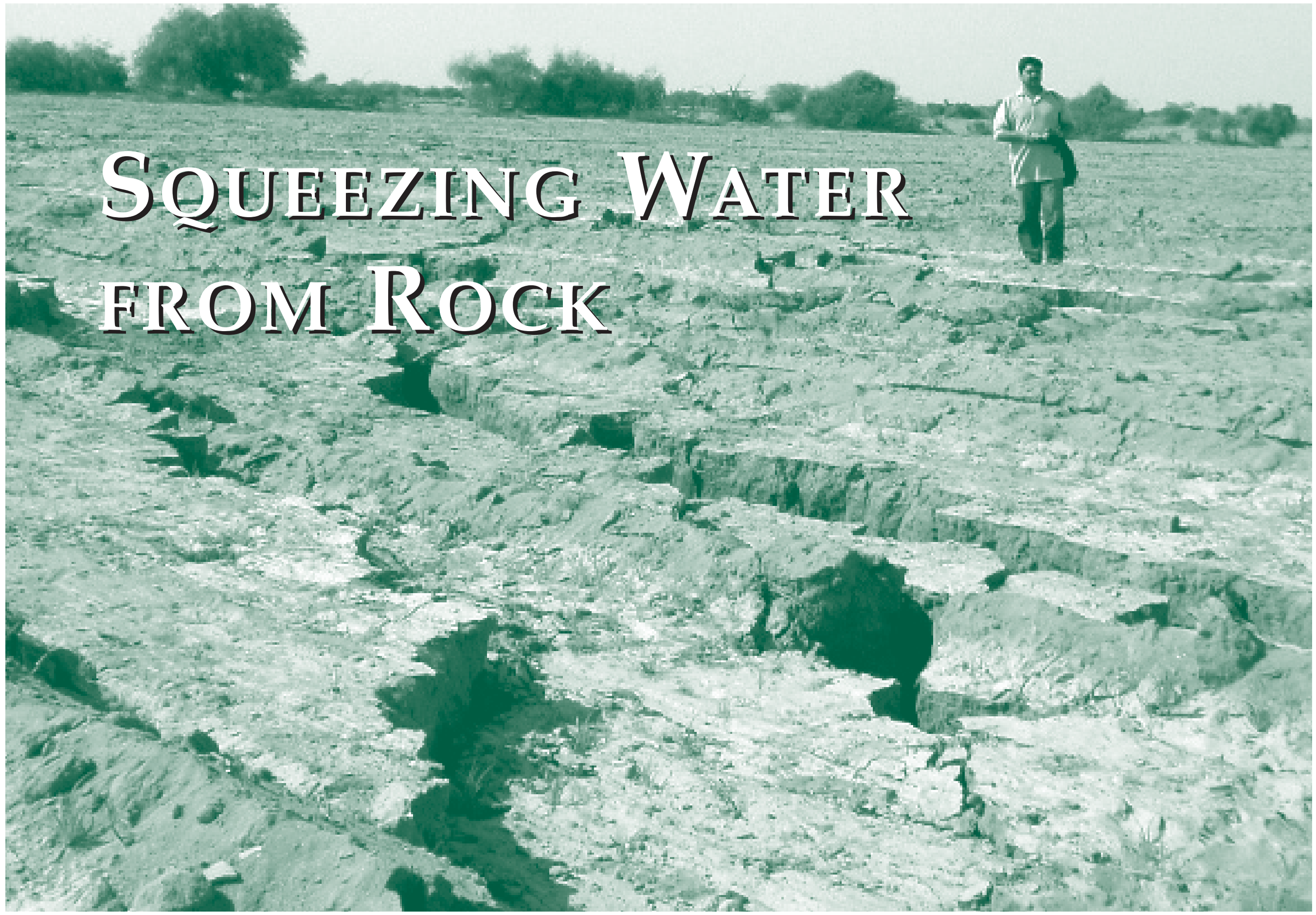
Related color data image, page 23

Mark Abbott is dean of the College of Oceanic and Atmospheric Sciences at Oregon State University. He received his undergraduate degree in conservation of natural resources from the University of California, Berkeley, and his PhD in ecology from the University of California, Davis. Abbott is a member of the MODIS Science Team and is chair of the Committee on Earth Studies for the National Academy of Sciences and the U.S. Joint Global Ocean Flux Study.

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.

"Interpreting historic and prehistoric earthquake events involves a lot of uncertainty, due to the lack of data. We often don't know precisely where the earthquakes occurred or how big they were."

Squeezing Water from Rock



Atmospheric Sciences Data Center DAAC

by Laurie J. Schmidt

Right: These cracks in the ground surface north of Chobari, India, were caused by liquefaction induced during the 2001 Bhuj earthquake. (Image courtesy of James Mori, Research Center for Earthquake Prediction, Disaster Prevention Institute, Kyoto University)

On December 16, 1811, an earthquake estimated at magnitude 7.0 to 8.0 on the Richter scale rocked the frontier town of New Madrid, Missouri, in the central United States. It was the first of three powerful earthquakes that would shake the central Mississippi River Valley that winter. Damages were reported as far away as Charleston, South Carolina, and Washington, D.C. According to the U.S. Geological Survey, the New Madrid events were the most powerful earthquakes in recorded U.S. history.

Survivors of the New Madrid earthquakes reported not only intense ground shaking and land movement, as would be expected during an earthquake, but also an unfamiliar phenomenon: water and sand spouting up through fissures, or cracks, in the Earth's surface. In a letter published in Lorenzo Dow's Journal, New Madrid resident Eliza Bryan wrote in 1816:

> *. . . the surface of hundreds of acres was, from time to time, covered over in various depths by the sand which issued from the fissures, which were made in great numbers all over this country, some of which closed up immediately after they had vomited forth their sand and water . . .*

Modern earthquake researchers refer to this expulsion of water and sand from the ground as earthquake dewatering, which results from liquefaction. Liquefaction occurs when an earthquake vigorously shakes and compacts water-saturated sediments. As the compaction process displaces the water between the sediment pores, water and sand shoot upward and out of the ground.

"Imagine a cube full of sand and water. If you press it in from both sides (compressing and releasing it, then compressing it again), you build up what's called pore-water pressure," said Martitia Tuttle, geologist and consultant for the U.S. Geological Survey. "It's like shaking a soda can – when the pressure builds up and you release it, the fluid comes shooting to the surface." These fountains of water can sometimes shoot as high as 30 feet into the air, according to Tuttle.

Tuttle is part of a team that has been studying the New Madrid earthquakes in an effort to interpret them in the geologic record. "Interpreting historic and prehistoric earthquake events involves a lot of uncertainty, due to the lack of data," Tuttle said. "There were no instruments back then, so we often don't know precisely where the earthquakes occurred or how big they were." What researchers needed was a modern-day event in a similar environment with which to compare the New Madrid earthquakes.

On January 26, 2001, a magnitude 7.7 earthquake in the village of Bhuj, located in the Kachchh region of northwestern India, provided scientists with just that analogue. Considered one of the two most damaging earthquakes in India's recorded history, the Bhuj earthquake killed about 20,000 people and caused an estimated $3.3 billion in damages.

According to Tuttle and co-authors of a paper recently published in *Eos*, local residents and survey teams working in the area after the earthquake reported fountains of water and sediments surging from the ground during and immediately following the Bhuj earthquake. The water flow was significant enough to reactivate streams in previously dry river channels. "When the Bhuj earthquake happened, it was an opportunity to look at an earthquake that was very similar to the New Madrid events – it was of a similar magnitude, and it occurred within a plate interior, rather than at a plate boundary," said Tuttle. The New Madrid and Kachchh regions are both located more than 185 miles (300 kilometers) from active plate boundaries.

"Before the Bhuj earthquake, there was a lot of debate in the seismological community about the magnitude of the New Madrid earthquakes, but based on the intensity of the Bhuj, most scientists now agree that New Madrid was probably larger than 7.5 magnitude," said Tuttle. "The Bhuj earthquake is a modern event that helps us understand the historic and prehistoric earthquake record."

But despite the unique study opportunity presented by the Bhuj earthquake, the area presented the researchers with some grave challenges. First, the Kachchh region of India is remote and difficult to reach. Second, it shares a politically sensitive border with Pakistan. These factors prevented research teams from conducting field studies to verify liquefaction effects or the presence of water.

Bernard Pinty, research scientist at the Institute for Environment and Sustainability in the Joint Research Centre of the European Commission in Ispra, Italy, and colleagues found that water expelled during the earthquake could be detected in imagery from NASA's Multi-angle Imaging SpectroRadiometer (MISR) satellite sensor.

The MISR instrument, which flies aboard NASA's Terra satellite, views the sunlit face of the Earth at nine widely spaced angles simultaneously. As it passes over the Earth, its nine cameras successively view each piece of the planet's surface at a spatial resolution of 300 yards (275 meters).

The change in reflection at different angles provides a

Richter Magnitude	Earthquake Effects
Less than 3.5	Recorded but generally not felt
3.5 - 5.4	Often felt but rarely causes damage
Less than 6.0	Slight damage at most to well-constructed buildings; over small regions, can cause major damage to poorly constructed buildings
6.1 - 6.9	Can be destructive in populated regions up to 100 kilometers across
7.0 - 7.9	Major earthquake that can cause serious damage over areas larger than 100 kilometers across
8 or more	Great earthquake that can cause serious damage over areas several hundred kilometers across

Earthquake severity table adapted from "What is Richter Magnitude?"
http://seismo.unr.edu/ftp/pub/louie/class/100/magnitude.html

Above: Structures in the village of Bhuj, India, located 50 miles (80 kilometers) from the earthquake epicenter, sustained considerable damage. (Image courtesy of James Mori, Research Center for Earthquake Prediction, Disaster Prevention Institute, Kyoto University)

means for distinguishing different types of land surface covers. Since bright soils in India's Rann of Kachchh (also known as the Rann of Kutch) reflect most of the sun's near-infrared radiation, and water bodies absorb near-infrared radiation, MISR is able to detect the contrast and indicate where dewatering occurred.

According to Pinty, these features made MISR an ideal tool for studying liquefaction in the Bhuj earthquake. "MISR's multi-angle capability was instrumental in exposing the presence of free water close to the Pakistani border, a region where it is difficult, if not impossible, to take ground measurements," he said.

Most other satellite instruments only look straight down or towards the edge of the Earth. "It would take several more passes for another sensor to capture the entire region that the MISR imagery covers," said Tuttle. "The MISR images enabled us to see a large area both during and immediately after the earthquake, and we could see that dewatering was occurring over a huge region."

Scientists now know that the New Madrid earthquakes were not geologic flukes; similar events have occurred repeatedly in the geologic past. In fact, the central Mississippi Valley experiences more earthquakes than any other region in the United States east of the Rocky Mountains.

The New Madrid Seismic Zone, which includes parts of Tennessee, Kentucky, Missouri, Arkansas, Illinois, Indiana, and Mississippi, harbors a large liquefaction field. Scientists estimate the probability of a magnitude 6.0 to 7.0 earthquake occurring in the New Madrid Seismic Zone within the next 50 years at higher than 90 percent, according to the U.S. Geological Survey. But a similar event would have much more serious consequences today.

In 1811-1812, the central Mississippi Valley was a remote frontier. Today, the region is home to millions of people and includes the metropolitan cities of St. Louis, Missouri, and Memphis, Tennessee. In addition, most buildings in the region were not built to withstand earthquake shaking, as they often are in California and Japan.

Buildings and engineered structures are at much higher risk in areas where liquefaction occurs, due to increased ground motion. "The liquefaction process is extremely damaging to all sorts of engineered structures; it has caused major destruction in both Anchorage and San Francisco," said Pinty.

"The ground failure that resulted from liquefaction during the New Madrid earthquakes was severe. We're talking about vertical displacement of 3 to 6 feet (1 to 2 meters), and lateral displacement of about 32 feet (10 meters)," said Tuttle. "A recurrence of that type of event would have severe consequences for engineered structures."

According to Tuttle, in 1988 a magnitude 6.0 earthquake in Quebec, Canada, produced liquefaction. "Basements cracked, septic fields were devastated, and people described water and sand shooting out of their toilets and into their bathtubs," she said. "And that was just a moderate-sized earthquake, not a big one."

MISR imagery, which is archived at the Langley Atmospheric Sciences Data Center DAAC, promises to be a boon to earthquake researchers seeking to minimize hazard risks. "The interesting thing is that this project started as an 'after hours' sort of activity," said Pinty. "But it soon acquired its own momentum, giving us results that are of significant relevance to earthquake study applications. Our findings revealed that MISR can detect water and moist conditions on terrestrial surfaces, even under unfavorable spectral conditions."

"If we study modern earthquakes that produce liquefaction, we can better interpret the geologic record of liquefaction during past events. This helps us anticipate what is likely to happen in the future so that we can make informed decisions about reducing and mitigating hazards," said Tuttle.

"It's one of those things where people tend to think – if it hasn't happened during my lifetime, then it probably won't happen again," Tuttle continued. "But the liquefaction field in the New Madrid Seismic Zone is very large. So we look for liquefaction features, because we know that if we find them we're talking about a huge earthquake that could have a significant impact on society.

For more information, visit the following Web sites:

Langley Atmospheric Sciences Data Center DAAC
http://eosweb.larc.nasa.gov/

References

Bryan, E. 1849. New Madrid, Territory of Missouri, March 22, 1816. In *Lorenzo Dow's Journal*. Published by Joshua Martin: 344-346. Quoted by The Virtual Times, The New Madrid Earthquake http://hsv.com/genlintr/newmadrd/. Accessed June 5, 2003.

Pinty, B. et al. 2003. Observing earthquake-related dewatering using MISR/Terra satellite data. *Eos, Transactions, American Geophysical Union*. 84(5):37-48.

Tuttle, M.P. 2001. The use of liquefaction features in paleoseismolo gy: Lessons learned in the New Madrid seismic zone, central United States. *Journal of Seismology*. 5:361-380.

Tuttle, M.P., J. Hengesh, K.B. Tucker, W. Lettis, S.L. Deaton, and J.D. Frost. 2002. Observations and comparisons of liquefaction features and related effects induced by the Bhuj earthquake. *Earthquake Spectra*. 18(Supp. A):79-100.

Related color data image, page 21

Martitia Tuttle is a consulting geologist for the U.S. Geological Survey and an adjunct faculty member in the Department of Geological Sciences at the University of Memphis and in the Department of Applied Science at the University of Arkansas. Her research interests include paleoseismicity and earthquake hazards in the central and eastern United States and the Caribbean, liquefaction and ground failure triggered by modern and historic earthquakes, and applications of remote sensing in paleoseismology and ground failure studies. Tuttle earned a PhD in geology from the University of Maryland.

Bernard Pinty is a research scientist at the Institute for Environment and Sustainability in Ispra, Italy. He served as Deputy Director of the Laboratoire d'Etudes et de Recherches en Teledetection Spatiale (LERTS) in Toulouse, France from 1990 to 1992 and was appointed professor of physics at the Universite Blaise Pascal in 1993. Pinty is a member of the MERIS Scientific Advisory Group of the European Space Agency, and a member of the MISR Science Team. His research interests include the theory of radiation transfer in plant canopies and the development of tools to quantitatively interpret satellite remote sensing data in the optical spectral domain. Pinty received his Maitrise de Chimie and DEA degrees in atmospheric sciences from the Universite Blaise Pascal in Clermont-Ferrand, France.

Lightning Spies

"Lightning measurements alone don't tell you everything you need to know about thunderstorms, but if you can relate lightning to the severity of the storm, then you have something forecasters can use."

Global Hydrology Resource Center

by Michon Scott

In late April 2002, a cold front pushed eastward across the midwestern United States. Ahead of the cold front, a powerful thunderstorm formed over Maryland, spawning what was perhaps the state's worst tornado. With winds estimated at over 260 miles per hour, the tornado touched down and traveled a path of destruction for 24 miles (39 kilometers), claiming several lives and injuring more than 100 people. The thunderstorm associated with this tornado persisted from the Appalachian Mountains to the Atlantic Ocean, causing an estimated $120 million in damages.

Tornadoes are just one consequence of thunderstorms. Lightning strikes, flash floods, and downdrafts from collapsing storms all threaten lives and property. One of the best defenses against thunderstorm hazards is effective prediction. Predicting storms accurately, however, requires a thorough understanding of electrical storm life cycles.

In 1997, NASA launched the Lightning Imaging Sensor (LIS) aboard the Tropical Rainfall Measuring Mission (TRMM) satellite. The LIS detects and maps the distribution and variability of cloud-to-cloud, intracloud, and cloud-to-ground lightning. "Lightning measurements alone don't tell you everything you need to know about thunderstorms, but if you can relate lightning to the severity of the storm, then you have something forecasters can use," said Richard Blakeslee, senior research scientist at NASA's Marshall Space Flight Center. "To complicate matters, the instruments in space can only 'see' lightning signals above a certain strength; below that, the pulses are too small to detect. So how much lightning are we missing?" Hoping to answer this and other questions, Blakeslee organized the ALTUS Cumulus Electrification Study (ACES).

With a primary goal of validating LIS data, the ACES project examined thunderstorms in the Florida Everglades region over a four-week period in August 2002. Key to the study was the ALTUS II, an uninhabited aerial vehicle capable of flying at high altitudes for long durations. Especially useful to ACES was ALTUS II's ability to fly at relatively slow speeds, between 70 and 100 knots, or approximately 70 miles (113 kilometers) per hour. "The aircraft's slow speed was important because we desired a plane that could observe a thunderstorm continuously," said Blakeslee. The most common thunderstorms consist of multiple storm cells (air masses fed by warm, moist rising air). At its peak, a storm cell receives warm air and produces rain or hail. When the supply of upward-moving warm air stops, the storm cell collapses, and the resulting downdrafts feed new storm cells that repeat the process. While a thunderstorm might persist for hours, individual storm cells generally last from only 10 to 30 minutes. "A high-speed plane flies over a storm in about 2 minutes then takes up to 15 minutes to turn around and come back, giving you 2-minute observations separated by 15-minute gaps. And 15 minutes later, you're looking at a different storm cell," said Blakeslee. "But ALTUS II could make tight turns, still within measurement range of about 5 kilometers, and come back over the storm repeatedly. Since the plane stayed within measurement range, we didn't miss any of the storm's evolution."

Observing a storm's development can help forecasters better monitor thunderstorms' rapidly changing behavior. Despite the rain or hail they may produce at their peaks, collapsing storm cells sometimes pose the greatest danger. Mature storms produce downdrafts, and while some downdrafts are nothing more than gentle breezes, others are hazardous. "If there's a rotation in the storm, a strong downdraft can foster the development of a tornado. Sometimes the cold air in a storm cell descends at a high velocity and spreads out at the ground in what's called a microburst. If a plane flies into a microburst and the pilot reacts incorrectly, he can lose control of the plane. Once microbursts hit the ground, they can be almost as severe as tornadoes, producing straight-line winds that blow roofs off buildings," Blakeslee said.

Another aim of the ACES study was to determine how lightning rates might help predict thunderstorm hazards. "We often see lightning jumps, where the lightning rate increases dramatically then suddenly decreases, and these jumps often precede severe weather on the ground. If the lightning measurements can be combined with other measurements, like radar, then we might be able to anticipate which storms will rapidly intensify and need to be watched very closely," said Blakeslee.

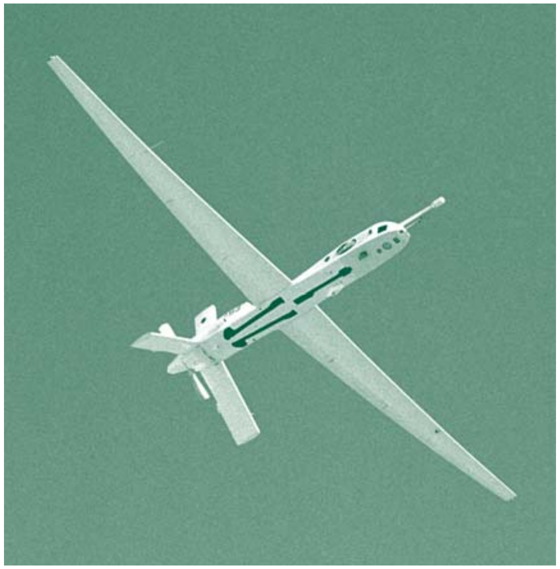
During the ACES experiment, the aircraft carried electrical, magnetic, and optical sensors to measure lightning activity and the electrical environment around thunderstorms. "The ALTUS II was a very effective platform," said Bill Farrell, Blakeslee's co-investigator at NASA's Goddard Space Flight Center. "Prior to the mission we were concerned the ALTUS would make so much electromagnetic noise that it would interfere with our observations, but it was really quiet. We could detect storms with our instrumentation long before the aircraft reached them."

An overriding concern throughout the ACES experiment was safety. "In most airplanes, the pilot is assumed to have 'see and avoid' capability to keep from colliding with other planes," Blakeslee said. Uninhabited aerial vehicles are equipped only with cameras, whose images must be interpreted by someone at a remote location. For this reason, the ACES experiment's flight area included only the sparsely populated Florida Everglades and nearby ocean, and the ALTUS II was flown above 40,000 feet to keep it separated from commercial aircraft. "Our plane was flown remotely by a pilot in the control center who could respond to the camera's images and aircraft flight data. So it could also be called a remotely piloted vehicle, but we still had to be extra cautious." Throughout the experiment, the researchers took care to fly the plane over and near thunderstorms, but never into them.

In addition to the practical concern of improving severe storm predictions, the ACES study looked at the global electric circuit and the Sun-Earth connection.

Bounded by the Earth's surface at the bottom and the ionosphere at the top, the global electric circuit surrounds the Earth in an electric field of up to 100 volts per meter. Scientists have long known that thunderstorms feed this circuit, but the details are still poorly understood. Farrell said, "When a thunderstorm is not discharging lightning, it behaves like a battery; when it is discharging lightning, it behaves like a radio antenna. Previous global electric circuit models usually considered only the battery mode, but we've found that for short periods of time - anywhere from once per second to once per minute - the radiated power actually exceeds the battery-like power. So we're trying to figure out how this affects the global electric circuit."

Equally interesting to Farrell is the link between the



Above: The Altus II uninhabited aerial vehicle, built by General Atomics Aeronautical Systems, Inc., was chosen for its slow flight speed of 70 to 100 knots (80 to 115 mph), long endurance, and high-altitude capability (up to 65,000 feet). (Image courtesy of NASA/Dryden/Tom Tschida)

Sun and the Earth. "When a solar event hits the Earth's magnetic field, energy is deposited in Earth's ionosphere. But how does this energy ultimately reach low altitudes? If we can understand thunderstorms and radiation going upwards and out, then by reversibility we might have a better understanding of how things from outside get in."

According to Farrell, part of the Sun-Earth link might take the form of sprites. Sprites are brief flashes of light, sometimes red or blue, that appear directly above thunderstorms and may extend all the way up to the ionosphere. "Sprites represent a connection between the ionosphere and the Earth's surface, or at least to the level where thunderstorms occur. It's almost like the missing link in the Sun-Earth connection," said Farrell. Sensors in the ACES experiment have enabled the researchers to look for signatures of upward currents and possible effects in the middle atmosphere in daylight. Farrell explained that this study is ongoing.

"In this experiment, we were able to detect storms as soon as they formed and immediately fly the aircraft to them," Blakeslee said. "Then we could correlate measurements to look at the cause and effect between the storm's electrical processes and its overall development." Blakeslee and Farrell are pleased at how the ACES project has demonstrated the utility of uninhabited aerial vehicles in research. Farrell hopes that these planes will be able to fly over places where humans can't safely travel, including extremely dense forest and volcanic plumes.

Blakeslee and Farrell plan to present their findings at the International Conference on Atmospheric Electricity in Versailles, France in June 2003, and data sets resulting from the study are archived at the Global Hydrology Resource Center. "The ACES project has been a cornucopia of new data," said Farrell. "We have over 4,300 lightning-trigger events to review, and we've already found some surprising results in the first few."

For more information, visit the following Web sites:

Altus Cumulus Electrification Study, Global Hydrology Resource Center
http://ghrc.msfc.nasa.gov/

References

ACES Description Document (adapted from papers given at the AIAA First Technical Conference and Workshop on Unmanned Aerospace Vehicles, Systems, Technologies, and Operations, May 20-23, 2002, Portsmouth, VA; and the Technical Applications and Analysis Center UAV Conference, October 28-30, 2002, Santa Fe, NM).

ACES Executive Summary and Science Plan (PDF file, 3.8 MB). Accessed April 30, 2003.
http://aces.msfc.nasa.gov/docs/Sections_1-2.PDF

Related color data image, page 22

Richard Blakeslee is a senior atmospheric scientist at the NASA Marshall Space Flight Center's Global Hydrology and Climate Center in Huntsville, Alabama. His primary research interests include satellite-based lightning measurements, thunderstorm and atmospheric electricity research, global electric circuit studies, and lightning instrumentation. In his role as lead validation scientist for the team, Blakeslee has served as the principal investigator in a number of aircraft and ground-based thunderstorm and lightning field studies. Blakeslee received a BS degree in physics from Miami University (Ohio) and a MS and PhD in atmospheric physics from the University of Arizona.

Bill Farrell is a scientist at NASA's Goddard Space Flight Center. His research interests include atmospheric electricity, magnetospheric plasma processes, heliospheric radiation processes, and extrasolar planets. Farrell is a scientific co-investigator on the GGS/WIND and CASSINI Saturn missions, and he has published over 55 articles in the fields of space science, atmospheric science, and radio instrumentation. He earned a PhD in physics from the University of Iowa.

VANISHING ICE

"By the end of the 2002 season, the total area of surface melt on the Greenland Ice Sheet had broken all known records, and sea ice levels in the Arctic were the lowest in decades."

National Snow and Ice Data Center DAAC

by Evelyne Yohe

KONRAD STEFFEN ARRIVED ON THE GREENLAND ICE Sheet for the 2002 summer fieldwork season and immediately observed that something significant was happening in the Arctic. Pools of water already spotted the ice surface, and melting was occurring where it never had before. "That year the melt was so early and so intense — it really jumped out at me. I'd never seen the seasonal melt occur that high on the ice sheet before, and it had never started so early in the spring," said Steffen, principal scientist and associate director of the Cooperative Institute for Research in Environmental Sciences (CIRES) at the University of Colorado.

By the end of the 2002 season, the total area of surface melt on the Greenland Ice Sheet had broken all known records. That same summer, Mark Serreze and his colleagues at the National Snow and Ice Data Center in Boulder, Colorado, began noticing unusually low levels of sea ice in the Arctic, based on remote sensing data. "I was really surprised by the change," Serreze said. "By the end of the summer, sea ice levels in the Arctic were the lowest in decades and possibly the lowest in several centuries."

Seasonal melt areas on the Greenland Ice Sheet are generally located along the edges of the ice sheet at its lowest points. In 2002, however, the melt started unusually early and progressed higher up the ice sheet than at any time in the past 24 years. Surface melting extended up to 6,560 feet (2,000 meters) in elevation in the northeast portion of the island, where temperatures normally are too cold for melting to occur. In addition, the total melt area covered 265,000 square miles (686,350 square kilometers), representing a 16 percent increase above the maximum melt area measured in the past 24 years.

Serreze's team coincidentally discovered that in September 2002, Arctic sea ice extent was approximately 400,000 square miles (1.04 million square kilometers) less than the long-term average of 2.4 million square miles

(6.2 million square kilometers), and that much of the remaining sea ice was unusually thin and spread out. To determine whether their independent findings were related, the research teams measured the sea ice extent and ice sheet melt using passive microwave data from satellites, including data from the NIMBUS-7 Scanning Multichannel Microwave Radiometer (SMMR) (1978-1987) and its successor, the DMSP Special Sensor Microwave/Imager (SSM/I) (1987-present).

Passive microwave sensors provide data that are processed into brightness temperatures. Brightness temperatures are both a measure of the physical temperature within the snow and a gauge of emissivity, or the ability of water or ice/snow to emit radiation at the microwave frequencies (frequencies in the centimeter wavelength range). Dry snow emits much less radiation than wet snow, which behaves almost like a perfect emitter (blackbody), giving off a wide range of frequencies of radiation. Therefore, dry snow and ice have lower brightness temperatures than wet snow surfaces.

The brightness temperature of seawater (ice-free ocean) is much lower than that of ice/snow or melting ice/snow. By calculating daily brightness temperatures (from the daily pass of the satellite over the Arctic), scientists can determine the extent of sea ice in the Arctic and the extent of melt on the Greenland Ice Sheet. Because the microwave instrument can "see through" clouds and darkness, ice extent can be monitored year-round, even during storms and winter darkness.

To validate, or confirm, their calculations of ice extent, the sea ice team used images from the Moderate Resolution Imaging Spectroradiometer (MODIS). The Greenland team validated its findings with climatological data from 20 automatic weather stations distributed over the entire ice sheet. The passive microwave data and the MODIS images are archived at the National Snow and Ice Data Center, one of NASA's Distributed Active Archive Centers.

The Greenland team has access to year-round passive microwave data from the last 24 years for their study area, a significant observation period. During that period, Steffen documented an overall trend of increasing melt area in Greenland, taking into account years with a great deal of melt, like 2002, and years with less-than-average melt, like 1992 when the Mt. Pinatubo eruption sent aerosols into the atmosphere, which reflected solar radiation and resulted in cooler temperatures and less melt.

Steffen and Serreze believe the accelerated melt in 2002 may be linked to shifts in Northern Hemisphere atmospheric circulation patterns. Air circulation is driven by pressure differences, and in 2002 unusual stationary low-pressure areas occurred in the Arctic. A relatively stationary low-pressure cyclone over the Atlantic Ocean northeast of Greenland moved air from the North Atlantic onto the ice sheet, which is rare. While it is normal for cyclones to form over the North Atlantic, they usually are quite dynamic and are not "locked" in one place, as occurred during the summer of 2002.

The low sea ice levels in 2002 seem to be part of a general downward trend in Arctic sea ice over the past 24 years, which appears to be driven by a combination of higher temperatures and altered wind fields that tend to break up the ice cover. A key feature of 2002 was the persistent stormy conditions in summer, with low sea level pressure over the central Arctic Ocean from June through August. Temperatures were also unusually high from January through August. "I've never seen this situation occur before," said Serreze.

The unusual late winter warmth and the increased ice melt seen in the Arctic in recent years appear to be signs of a positive trend in the Arctic Oscillation (AO). The AO, which is very similar the North Atlantic Oscillation, is a large-scale atmospheric circulation phenomenon — a cyclic shifting of atmospheric mass between the Arctic and the mid-latitudes. When the AO is in a positive state, as has generally been the case for the last two decades, atmospheric pressures are low over the Arctic Ocean, winds are usually stronger than normal, and the wind transports warm air into the Arctic. Serreze explained, "Researchers at the University of Washington have shown that variations in atmospheric circulation seem to play a strong role in creating regional differences in sea ice thickness that precondition the ice for extensive summer melt and breakup. However, the stormy conditions we saw in summer 2002 don't really fit the AO framework, so we're still not sure why the summer was so stormy."

Steffen added, "It's not by chance that we had the minimum sea ice distribution and the maximum melt that year; having so little sea ice affected the local climate around Greenland quite substantially. Because the sun wasn't reflecting off the sea ice, the air close to the ocean surface was warmed, and certainly the ocean water was much warmer. This has a very strong effect on cyclones."

But were the 2002 ice minimums an indication of continual warming in the Arctic, or was 2002 just another peak in a long-term Arctic climate cycle?

Warming trends have been observed over Greenland in the past, but the warming has progressed at a much slower rate. In the early 1930s, average temperatures over Greenland were as warm as those observed recently, but it took about 30 years of gradual warming to reach those levels. That warming trend could have been part of a natural, long-term cycle in the Arctic. But today, the Arctic is warming much faster, reaching current warm temperatures in less than a decade. And the warming is starting earlier in the year, with the greatest warming generally occurring in the spring and late winter.

If the warming is part of a continuing trend, higher Arctic temperatures and less ice may have long-term effects on both sea level and navigable waters in the Arctic. Steffen, Serreze, and colleagues estimate that a warmer climate over Greenland might lead to an increase in the rate of sea-level rise. Increased melt on the Greenland Ice Sheet sends more meltwater into the surrounding ocean. It also increases the rate of ice flow off Greenland, because the meltwater penetrates the ice sheet and forms a thin film between the ice and bedrock, which causes the glaciers to slide off the continent faster.

A trend in lower concentrations of Arctic sea ice may mean that historically unnavigable areas of the Arctic may open, such as the famed Northwest Passage. If current warming continues and results in lower ice concentrations, the Northwest Passage could become accessible to ice-strengthened ships, opening the area not just as a trade route, but also as a means to economically exploit the far north. This could have profound economic implications in addition to sociological implications for Arctic peoples such as the Inuit, who depend on the ice cover for travel and hunting.

Some researchers, however, believe that recent Arctic warming is only a recurring peak in a long-term Arctic climate cycle. A group of Alaskan researchers recently published their assessment of Russian long-term observations of air temperature from coastal stations, and sea-ice extent and fast-ice thickness from Arctic seas. They found a great deal of variability in Arctic temperatures, with cyclic fluctuations on a timescale of 60 to 80 years. A climate cycle of this length might mean that the Arctic will cool again soon, rather than continue warming.

Given these findings and the world's interest in global climate change, long-term observations are essential to understanding Arctic climate change. "Climatologists generally need a 30-year mean (or average) to be able to talk about trends in climate variability. With the availability of data from satellites that have been in orbit for 24 years, scientists now have close to that 30-year standard, which is unique," said Steffen.

"The real question is, is this recent trend unusual?" said Serreze. Both teams will rely on the orbiting "eyes" of satellites to observe Arctic ice conditions

Above: A researcher observes the edge of the Greenland Ice Sheet in 2001. (Image courtesy of Ted Scambos, National Snow and Ice Data Center, University of Colorado at Boulder) over the next few years as they attempt to determine whether these changes are part of a long-term climate cycle or whether the Arctic is experiencing an ongoing warming trend.

For more information, visit the following Web sites:

Greenland Maximum Melt Extent
http://cires.colorado.edu/steffen/melt/index.html

Arctic Sea Ice Shrinking, Greenland Ice Sheet Melting, According to Study
http://nsidc.org/news/press/20021207_seaice.html

National Snow and Ice Data Center DAAC
http://nsidc.org/daac/

References

Abdalati, W. and K. Steffen. 2001. Greenland Ice Sheet melt extent: 1979-1999, *Journal of Geophysical Research*. 106:33,983 - 33,989.

Polyakov, I.V., G.V. Alekseev, R.V. Bekryaev, U. Bhatt, R.L. Colony, M.A. Johnson, V.P. Karklin, A.P. Makshtas, D. Walsh, and A.V. Yulin. 2002. Observationally based assessment of polar amplifi cation of global warming. *Geophysical Research Letters*. 29(10):1029.

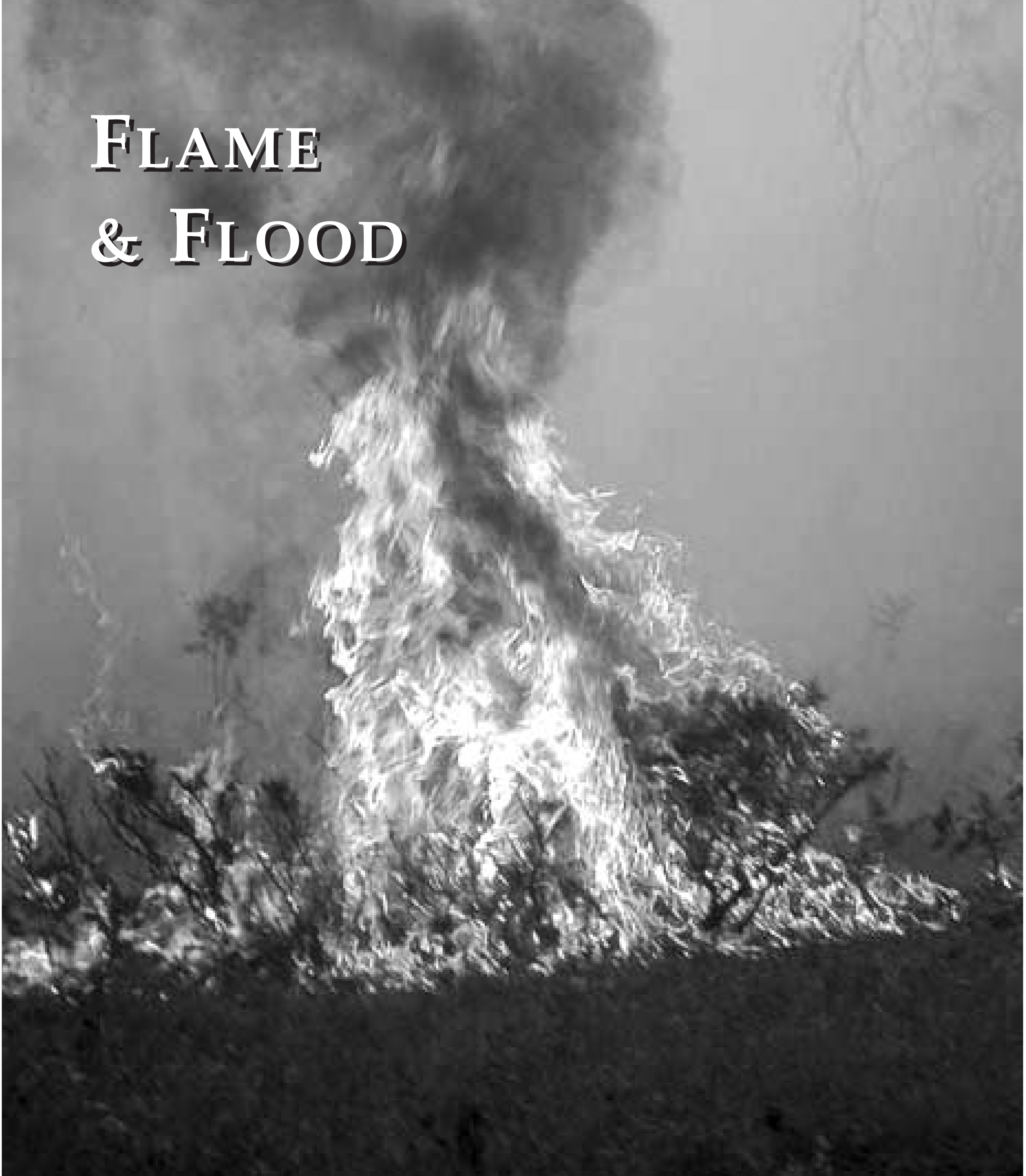
Serreze, M.C., J.A. Maslanik, T.A. Scambos, F. Fetterer, J. Stroeve, K. Knowles, C. Fowler, S. Drobot, R.G. Barry, and T.M. Haran. 2002. A record minimum Arctic sea ice extent and area in 2002. *Geophysical Research Letters*. 30(3):1110.

Related color data image, page 20

Mark C. Serreze is a research scientist at the Cooperative Institute for Environmental Sciences (CIRES) at the University of Colorado, Boulder. His varied research interests in the Arctic include atmosphere-sea ice interactions, hydro-climatology, and synoptic climatology. In recent years, Serreze has been especially active in addressing issues of Arctic climate change. He serves on the Science Steering Committee for the multi-agency Study of Environmental ARctic CHange (SEARCH), and he is a member of the National Science Foundation s Arctic Climate System Study (ACSYS) Committee. Serreze holds a PhD in geography from the University of Colorado.

Konrad Steffen is a professor of geography at the University of Colorado, Boulder, and associate director of the Cooperative Institute for Research in Environmental Sciences (CIRES). His research interests relate to the application of remotely sensed data in climate research. Steffen has worked in polar regions for over 20 years, organizing several field expeditions in the Arctic and high altitude regions to measure surface energy fluxes, which are important for the understanding of our present climate. He holds a PhD from the Swiss Federal Institute of Technology in Z rich.

FLAME & FLOOD



"People often forget about the constant fire danger in desert areas until it actually happens."

Land Processes DAAC

by Amy Casey

Above: To study differences in vegetation between burned and unburned areas, researchers use weather balloons that carry a remotely controlled digital camera. (Image courtesy of Michael Ramsey, University of Pittsburgh)

Facing page: The same scenic terrain that attracts homeowners is also often prone to brush fires.

THE FASTEST-GROWING CITIES IN THE WORLD ARE often located in the warmest, sunniest climates. Phoenix, Arizona, which sprawls over a 2,000-square-mile (5,180-square-kilometer) area in the southwestern United States, provides warm weather and a cosmopolitan lifestyle that attracts retirees and young families alike.

In the past 10 years, the city's population has increased over 30 percent to 1.3 million in 2000, according to the Greater Phoenix Convention and Visitors Bureau. With rapid growth comes a demand for new housing, which motivates builders to spread farther into the surrounding Sonoran desert.

Michael Ramsey, assistant professor at the University of Pittsburgh and director of the Image Visualization and Infrared Spectroscopy (IVIS) Laboratory, is concerned that the same scenic terrain that attracts homeowners is also prone to brush fires and flooding. "People often forget about the constant fire danger in desert areas until it actually happens. The Rio fire in July, 1995, which burned more than 22.4 square miles (58 square kilometers), was close to a large housing development. Fire danger suddenly became a very big deal," said Ramsey.

In the desert, fires can move fast; constant winds funnel through shallow dry creek beds to keep parched vegetation burning. A hot fire can make soil "hydrophobic," meaning that water runs off instead of soaking into the ground. Increased runoff after a subsequent rainstorm can cause sudden or "flash" floods that erode surface soil.

In recent years, severe drought has escalated the fire danger in the southwest.

Arizona's 2000 wildfire season was the worst in 50 years, burning more than 3.5 million acres and over 800 structures. The damage done by fires that summer prompted Ramsey to propose a study using past fires to predict future fire and flood hazards.

Ramsey uses data collected by the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) instrument on NASA's Terra satellite. Using ASTER imagery, he looks for fire scars, which he defines as "large tracts of land with highly burned vegetation or no vegetation cover at all."

Since certain desert vegetation can grow back quickly after a fire, it is difficult to tell from a ground perspective where past fires have occurred. ASTER is particularly useful for this study, because it generates 15- to 90-meter resolution infrared (IR) images that can reveal differences in soil temperature due to slightly lower amounts of vegetation in the once-burned areas. These images show the scars left by fires that occurred up to 50 years ago — patterns that may help scientists predict the likelihood of fires in similar areas.

ASTER captures images in several wavelengths: visible near-infrared (VNIR), short-wave infrared (SWIR), and thermal infrared. "We focus on the visible (shorter) wavelength, because it has the highest spatial resolution. But we can also detect different ages of fire scars using different wavelength regions. The longer wavelengths, such as thermal IR, are more sensitive to vegetation," said Ramsey.

While ASTER's high-resolution images aid in identifying fire scar locations, the study requires information about plant growth and erosion that ASTER cannot provide. "Even with ASTER's high resolution, the changes in stream channels are too subtle to detect," said Ramsey. So he and his colleagues, Ramon Arrowsmith, associate professor at Arizona State University, and Tamara Misner, a graduate student at the University of Pittsburgh, trek to the desert to gather more detailed information.

In one phase of the study, the team collects sediment that washes down gullies during rainstorms, which may help them understand how fires affect rainfall runoff. Misner collects samples in both burned and unburned areas using specially designed metal containers called sediment traps. The sediment traps are buried in drainage areas, with the opening at ground level to collect sediment that washes down during rainstorms. "After a big storm event, we go out and collect sediment," Misner said. "We dry and weigh it and then compare the samples to look for a relationship between the burned landscape and increased erosion."

In another phase of the study, Arrowsmith and Ramsey team up for aerial photography using either a kite or weather balloon that carries a remotely controlled digital camera. A long tether attaches the balloon to a heavy-duty kite reel, which straps around the waist of the person controlling it. "It's fun, but I've actually been dragged across the ground a couple of times," Ramsey said, laughing. "The wind blowing the kite can put a lot of force on you."

One person controls the balloon and the other person tries to keep up with the floating balloon to control the camera. According to Ramsey, this arrangement makes for occasional communication problems, resulting in unexpectedly close images. "Last time we were out there, the balloon popped, and my colleague couldn't hear me because he was down in a gully. I just kept snapping pictures during the balloon's entire descent. The final image is from about two inches above a bush before the balloon crashed."

The combination of aerial photography and ASTER VNIR data shows differences in vegetation between burned and unburned areas. It also illustrates fire scar recovery. In the spring after a fire event, seasonal grasses bloom, hiding the fire scar from the casual observer. But over several years, aerial photographs taken in the same area show larger plant growth, such as trees and saguaro cacti.

Ramsey's goal is to create a software application that recognizes fire scar patterns, which will help planners predict areas of high fire risk. He hopes to use the software to educate city planners and developers about the potential for natural hazards.

"To get people to stand up and take notice is a difficult thing. You can't ring all the alarm bells and say, 'Danger, danger, danger!' but you can present them with the facts," Ramsey said.

Ramsey acknowledged that the results of the study will not stop development, but they could encourage better planning. "City planners might consider putting in more buffers, such as placing houses further from creek beds and installing more fire hydrants," he said.

Ramsey is also involved in NASA's Urban Environmental Modeling Project, which uses ASTER data to study 100 of the world's fastest-growing cities, including Phoenix. "A logical extension of fire scar pattern recognition is to apply it to other project cities located in similar climates. In Sydney, Australia, huge fires broke out during the summers of 2001 and 2002 right at the edge of the city. Although that area is more humid than most arid regions and has different vegetation types, we can apply what we've learned in Phoenix," he said.

Ramsey hopes the results of his study will also be helpful in predicting hazards around sprawling cities in different climate zones. "Large, urban areas are growing fast and are subject to a lot of potential hazards, whether it be drought or major ocean impact hazards on the coast," he said. "We're focused on these sprawling cities because the rapid growth is encroaching on environments that weren't populated before. That's the driving force behind our work."

Above: During times of severe drought, the Sonoran Desert near Tucson, Arizona, becomes more susceptible to fire danger. (Image courtesy of Laurie J. Schmidt)

For more information, visit the following Web sites:

Image Visualization and Infrared Spectroscopy (IVIS) Laboratory
http://ivis.eps.pitt.edu/

Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER)
http://asterweb.jpl.nasa.gov/

References

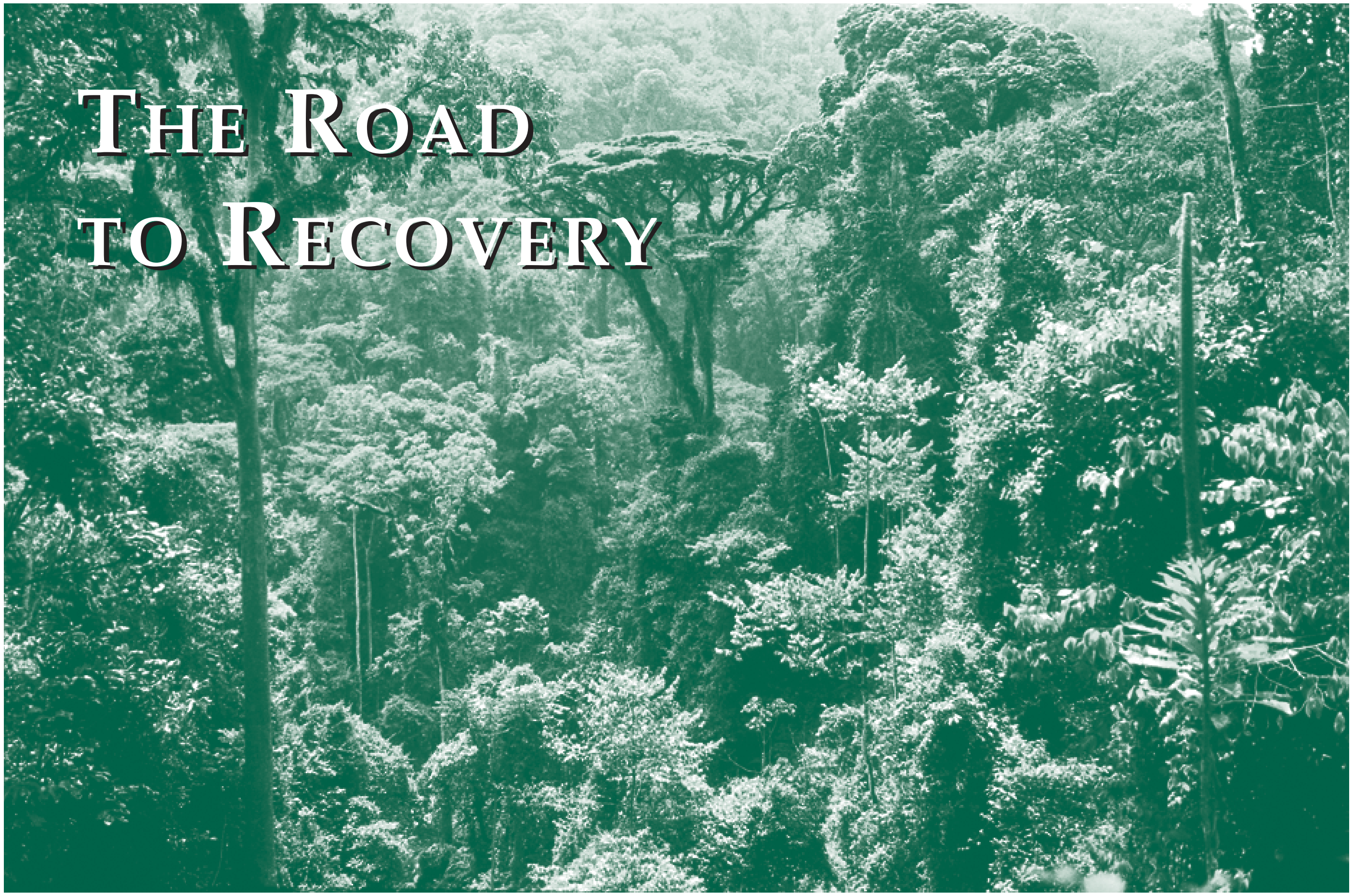
Multi-Spectral Remote Sensing of Brush Fire Scars in Arid Urban Regions: Analysis of Future Fire and Flooding Hazards. Mike Ramsey, Ramon Arrowsmith. Accessed February 28, 2003. http://activetectonics.la.asu.edu/Fires_and_Floods/

Ramsey, M.S., and J.R. Arrowsmith. 2001. New images of fire scars may help to mitigate future natural hazards. EOS, Trans. Amer. Geophys. Union, 82(36):393-398, September 4, 2001.

Related color data image, page 20

Michael Ramsey is an assistant professor in the Department of Geology and Planetary Science at the University of Pittsburgh, and an associate science team member for NASA s Advanced Spaceborne Thermal Emission and Reflectance Radiometer (ASTER) instrument. In 2000, Ramsey formed the Image Visualization and Infrared Spectroscopy (IVIS) Laboratory, which stores imagery for the ASTER program. Ramsey s varied research interests include remote sensing of active volcanoes, urban environmental science, and natural hazards of brush fires and urban flooding. He holds a PhD in geology from Arizona State University.

The Road to Recovery



"If the forest is not too heavily disturbed during the logging, rates of regrowth and carbon accumulation can be quite rapid following a clearing."

Oak Ridge National Laboratory DAAC

by Jason Wolfe

According to a recent report in *Science*, the Amazon rainforest has lost nearly two million acres to logging each year since 1996. This alarming loss of trees in the world's largest rainforest could increase the amount of atmospheric carbon dioxide by roughly 200 tons each year, raising the threat of global warming. But a recent study in the Amazon rainforest shows that some types of logging may not negatively impact the carbon cycle as originally thought.

Michael Goulden, an associate professor in the Department of Earth Systems Science at the University of California at Irvine, found that six to eight months after a 1,700-acre (700-hectare) forest plot was logged in Tapajos National Forest, Brazil, fast-growing trees repopulated the forest, and photosynthesis levels returned to normal. His study suggests that logging selective areas is a way to use the forest efficiently without disrupting the carbon cycle.

According to Goulden, the forests develop a natural tendency to withstand minor tree cutting and soil disturbance. "The forest is adapted to deal with these activities. But we were still surprised at how quickly it recovered," said Goulden.

Goulden participates in the Large-Scale Biosphere-Atmosphere Experiment (LBA) in Amazonia, an inter-

Facing page and above: The Amazon region contains about 40 percent of the world's remaining tropical forest. (Facing page image courtesy of Oxfam's Cool Planet)

national research project led by Brazil's Ministry of Science and Technology. Goulden works specifically with LBA-Ecology (LBA-ECO), a NASA-funded component of LBA, to understand how land use change in the Amazon affects the carbon cycle, nutrients, and movement of trace gases in the Amazon tropical forest. These factors work together to maintain a healthy ecosystem.

The Amazon region contains about 40 percent of the world's remaining tropical forest, and its large diversity of plants and animals makes it a prime target for preservation efforts. "Tropical forests have incredible biodiversity. If you look at a hectare of tropical forest, you may see hundreds of different species of trees, compared with a pine forest in the western United States, which may only contain about 10 or 20 species," said Goulden.

Because the Amazon is rich with trees, it contains a massive stock of carbon, the building block of life. Carbon is essential for ecosystem development and plays a lead role in regional and global climate. Logging leaves behind dead plant material, or slash, which decomposes and provides a food source for invertebrates. Respiration and microbial activity within the slash eventually releases carbon dioxide into the atmosphere, increasing atmospheric carbon dioxide levels. At the same time, organic carbon within the soil column is depleted. Scientists study the carbon cycle by looking at the "net carbon exchange" between the biosphere and the atmosphere, which is the difference between carbon that the ecosystem removes from the atmosphere for photosynthesis and carbon that it releases to the atmosphere by respiration and decomposition.

Goulden wanted to know how selective logging would affect net carbon exchange. Selective logging is a low-impact activity that involves cutting only two to four trees per acre (five to ten trees per hectare) of forest. It is meant to minimize disturbance of the forest ecosystem. "Selective logging creates a mosaic in the forest with patches of trees interspersed with small gaps from logging," said Goulden.

Goulden measured carbon dioxide exchange and evaporation in Tapajos National Forest, Brazil, using 200-foot (61-meter), NASA-constructed observation towers that rise high above the forest canopy. In addition to being part of LBA, the towers contribute data to FLUXNET, a global network of research sites that measure regional carbon, energy, and water vapor exchange between terrestrial vegetation and the atmosphere. FLUXNET is managed by the Oak Ridge National Laboratory (ORNL) Distributed Active Archive Center (DAAC). According to Robert Cook, a scientist at the ORNL DAAC, there are currently 215 towers worldwide, some in the Amazon. "Data from these LBA towers will be added to data from other networks of towers around the world. The FLUXNET collection aids research on the global carbon cycle and also contributes to validating Moderate Resolution Imaging Spectroradiometer (MODIS) photosynthesis products," said Cook.

The observation tower that Goulden used in his research has several instruments that measure wind direction and carbon dioxide levels in gusts of air. On a sunny day when photosynthesis conditions in the forest are optimal, updrafts of air contain less carbon dioxide than downdrafts. That difference in carbon dioxide indicates how much carbon is taken up by the forest during photosynthesis.

Goulden observed carbon dioxide exchange in a 1.5-square-mile (4-square-kilometer) plot of healthy forest near Santarem, Brazil, starting in July 2000. In September 2001, logging contractors selectively logged 1,700 acres (700 hectares) of the forest. Goulden compared carbon dioxide exchange after the logging to prior levels. He expected that logging would reduce photosynthesis in the forest because many of the leaves were removed. He also expected to see more carbon lost to the atmosphere, since logging creates dead material that is transported to the atmosphere. But what Goulden found surprised him. For the first six to eight months after logging, the forest did lose carbon to the atmosphere, but it then recovered to the point where photosynthesis levels were back to normal. Even more surprising was that fast-growing, young trees with short life spans, such as balsa, quickly colonized the gaps created by logging. "I wouldn't say the forest is back to what it was before, but with respect to photosynthesis, I would say it has recovered," said Goulden.

But was this fast recovery a pure coincidence, or was it typical of forest behavior?

Alan Townsend, assistant professor with the Department of Environmental, Population, and Organismic Biology at the University of Colorado, has also studied the effect of logging on carbon exchange in the Amazon. He was not surprised by Goulden's findings. "If the forest is not too heavily disturbed during the logging, rates of regrowth and carbon accumulation can be quite rapid following a clearing," he said.

Both scientists agree that the method by which the forest is logged affects the status of the carbon balance, and that recovery rates are dependent on the intensity of the disturbance. So the more the soil is disturbed from logging, the slower the recovery will be.

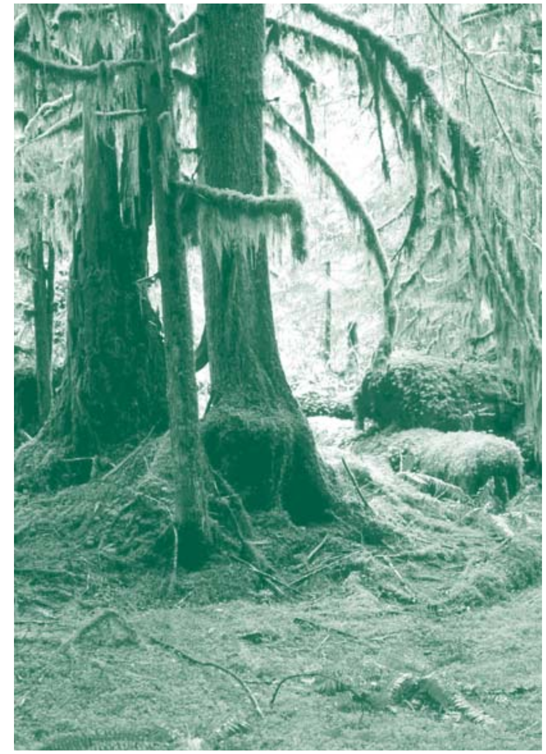
Townsend cautions, however, that while it is exciting to see photosynthesis levels recover quickly after selective logging, the long-term implications of any forest disturbance must be considered. "The overall integrity and structure of a forest that has been selectively logged will be nothing like that of a healthy, non-disturbed forest for a very long time, especially with repeated disturbances," said Townsend.

Townsend cited research by Daniel Nepstad, a scientist with the Woods Hole Research Center, who studies the relationship between selective logging and fire potential in forests. According to Nepstad, any type of logging, including selective logging, can change the small-scale climate of the forest such that the ground dries out and the chance for fire increases. In areas where forests were cleared for pasture, Nepstad observed several fires that started from the heat of the logging equipment. "Does that mean that every logged place is going to burn? No. But logging increases that chance, so it is worth looking at the pros and cons of selective logging," said Townsend.

Still, Goulden believes his findings may help answer general questions about carbon dioxide, such as its sources, movement, and whether or not tropical logging increases atmospheric carbon dioxide. But he believes the more practical implications of his results relate to land management. "There is a wide range of opinions on logging in tropical forests: some people believe the forests should be left alone, and others want to cut down the forests and convert them to pastures," he said. "There are also people who say that if we don't do something economically useful with these forests, we will lose them.

"I think our findings indicate that selective logging is not necessarily a bad thing. It's not as if the logging was so aggressive that the forest couldn't recover, for example, if 10 or 20 percent of the wood were to be removed," said Goulden.

Goulden will continue to collect data from the observation towers for at least the next two years. Data collected from LBA-ECO research in the Amazon will be sent to the ORNL DAAC when the data are finalized. The same data will also be archived at the Brazil Center for Weather Prediction and Climate Studies in Sao Paulo. "The research is in full swing right now, and we are really beginning to synthesize the data," said Michael Keller, project scientist for LBA-ECO. "We clearly have a better appreciation for things we didn't know about when we started."



Above: Land use changes can have a significant impact on the health of a tropical rainforest.

For more information, visit the following Web sites:

LBA Project from ORNL DAAC
http://www.daac.ornl.gov/LBA/misc_amazon.html

LBA-ECO
http://www.lbaeco.org/lbaeco/

References

Hauser, R. 2001. A view from above. Distributed Active Archive Centers: Supporting Earth Observing Science 1999/2000. Boulder, CO: National Snow and Ice Data Center. http://earthobservatory.nasa.gov/Study/Fluxnet/

Laurance, William F., Mark A. Cochrane, Scott Bergen, Philip M. Fearnside, Patricia Delam nica, Christopher Barber, Sammya D'Angelo, Tito Fernandes. 2001. The future of the Brazilian Amazon. Science. 291(5503):438. http://www.sciencemag.org/cgi/content/full/291/5503/438950 (Registration or subscription may be required for access.)

LBA-ECO. Accessed September 30, 2002. http://www.lbaeco.org/lbaeco/

Measuring the effects of logging on the CO2 and energy exchange of a primary forest in Tapajos National Forest. Accessed September 30, 2002. http://ess1.ps.uci.edu/~goulden/Tropicallogging.html

Downie, A. Roads to ruin for Amazon. The San Francisco Chronicle. 20 January 2001.

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

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