



Sensing Our Planet



Sensing Our Planet

NASA Earth Science Research Features **2008**

National Aeronautics and Space Administration

NASA Earth Observing System Data and Information System (EOSDIS) Data Centers

Front cover images

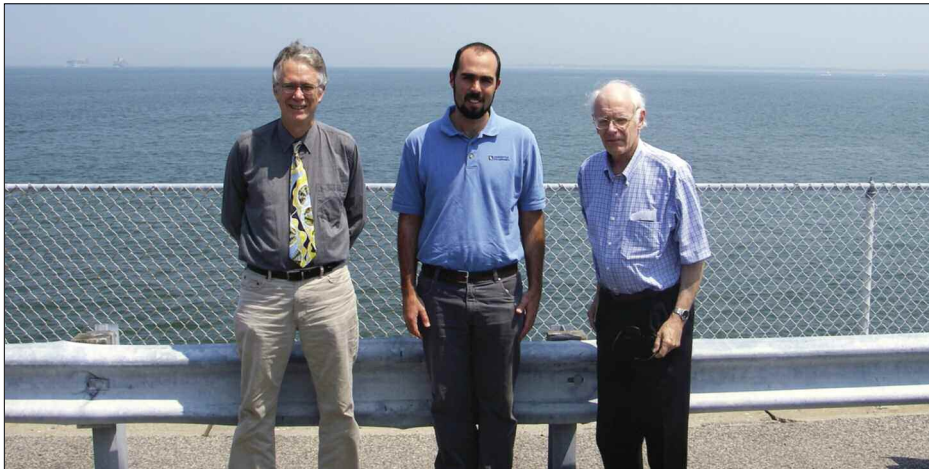
Top row, left to right:

Crew members recover a buoy which broke loose in the Gulf Stream. The instrument shown along the shiprails was later destroyed in a storm. See the related article, “Where oceans meet atmosphere,” on page 44. (Courtesy T. Joyce)

Haze from smoke and dust aerosols can interfere with ultraviolet radiation reaching the Earth, an effect that may be increasingly important as global temperatures rise. See the related article, “Aerosols over Australia,” on page 32. (Courtesy C. Calvin, University Corporation for Atmospheric Research)

The glasswing butterfly feeds on the nectar of flowers in Nicaragua’s rainforests. Deforestation destroys habitat critical to the glasswing and many other insect and animal species. See the related article, “Scorecard on the environment,” on page 28. (Courtesy B. Garland)

Arctic sea ice provides critical habitat for polar bears. Researchers are increasingly concerned that negative trends in summer sea ice extent may affect polar bear reproduction and species survival. See the related article, “Younger sea ice and scarcer polar bears,” on page 24. (Courtesy Photos.com)



Scientists Willett Kempton, Felipe Pimenta, and Richard Garvine (left to right) worked together on the research featured in “The power of a Brazilian wind.” Richard Garvine was a pioneer and international authority in the field of coastal physical oceanography. He was also dedicated to the study of renewable energy solutions and to the mentoring of young oceanographers. Garvine passed away last December. (Courtesy F. Pimenta)

Bottom row, left to right:

Offshore wind turbines take advantage of predictable winds to produce carbon-free energy; potential sites are often close to electricity-hungry population centers. See the related article, “The power of a Brazilian wind,” on page 6. (Courtesy A. Upton, npower renewables)

Satellites can detect water-level changes in forested swamps, like this bald cypress forest in Louisiana. Swamp water levels are important to ecosystem health. See the related article, “Sensing the swamp beneath the trees,” on page 16. (Courtesy E. Leger)

A researcher checks the calibration of a ground-mounted Global Positioning System (GPS) station on Mount St. Helens. GPS receivers and satellites can precisely capture movements in the Earth’s crust, giving scientists a picture of processes concealed deep in the ground during earthquakes and volcanic eruptions. See the related article, “Earth’s crust in action,” on page 10. (Courtesy M. Lisowski)

Back cover images

Left to right:

Lake Taihu in China is normally tranquil and picturesque; recently, massive algal blooms have spoiled its potability. Researchers hope to use remote sensing to help local officials manage the lake’s health. See the related article, “Cleaner water from space,” on page 40. (Courtesy S. J. Photography)

The 2005 Kashmir earthquake badly damaged the town of Balakot in northwestern Pakistan. Debris littered walkways and roads, making relief access difficult. See the related article, “When the Earth moved Kashmir,” on page 2. (Photograph by Lieutenant Colonel W. Thompson, courtesy U.S. Department of Defense)

A shroud of smog hangs over Houston in this November 2006 photograph. Although air pollution tends to be more common during hot summer months, air quality can be poor at any time of the year. See the related article, “Regional pollution goes local,” on page 20. (Courtesy I. Bettinger)

Apple blossoms and other blooms may be increasingly susceptible to late spring freezes that can damage or destroy entire crops. See the related article, “Freezing in a warming world,” on page 36. (Courtesy Photos.com)



The design featured in this issue represents waves. Several articles for 2008 reveal the sometimes unexpected connections between water and all of Earth’s life. See “Sensing the swamp beneath the trees” on page 16; “Younger sea ice and scarcer polar bears” on page 24; “Cleaner water from space” on page 40; and “Where oceans meet atmosphere” on page 44.

About the EOSDIS data centers

The articles in this issue arose from research that used data from NASA Earth Observing System Data and Information System (EOSDIS) data centers. The data centers, coordinated by NASA's Earth Science Data and Information Project (ESDIS), offer thousands of Earth system science data products and associated services to a wide community of users. ESDIS develops and operates the science systems of EOSDIS, including processing, archiving, and distribution of data from Earth science satellites and related data. These data enable the study of Earth from space to advance scientific understanding and meet societal needs.

For more information about the EOSDIS data centers, visit the NASA Earth Science Data and Information Project Web site (<http://esdis.eosdis.nasa.gov>).

Acknowledgements

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Publication notes

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For additional print copies of this publication, please e-mail nasadaacs@eos.nasa.gov.

Researchers working with EOSDIS data are invited to e-mail the editors at eosdiseditor@nsidc.org with ideas for future articles.

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Global Positioning System (GPS) stations like the one above receive satellite signals to precisely capture movements in the Earth's crust. See the related story, "Earth's crust in action," on page 10. (Courtesy M. Lisowski)



Printed with vegetable-based inks at a facility certified by the Forest Stewardship Council; uses 100% recycled chlorine-free paper that is manufactured in the U.S.A. with electricity offset by renewable energy certificates.

About this issue

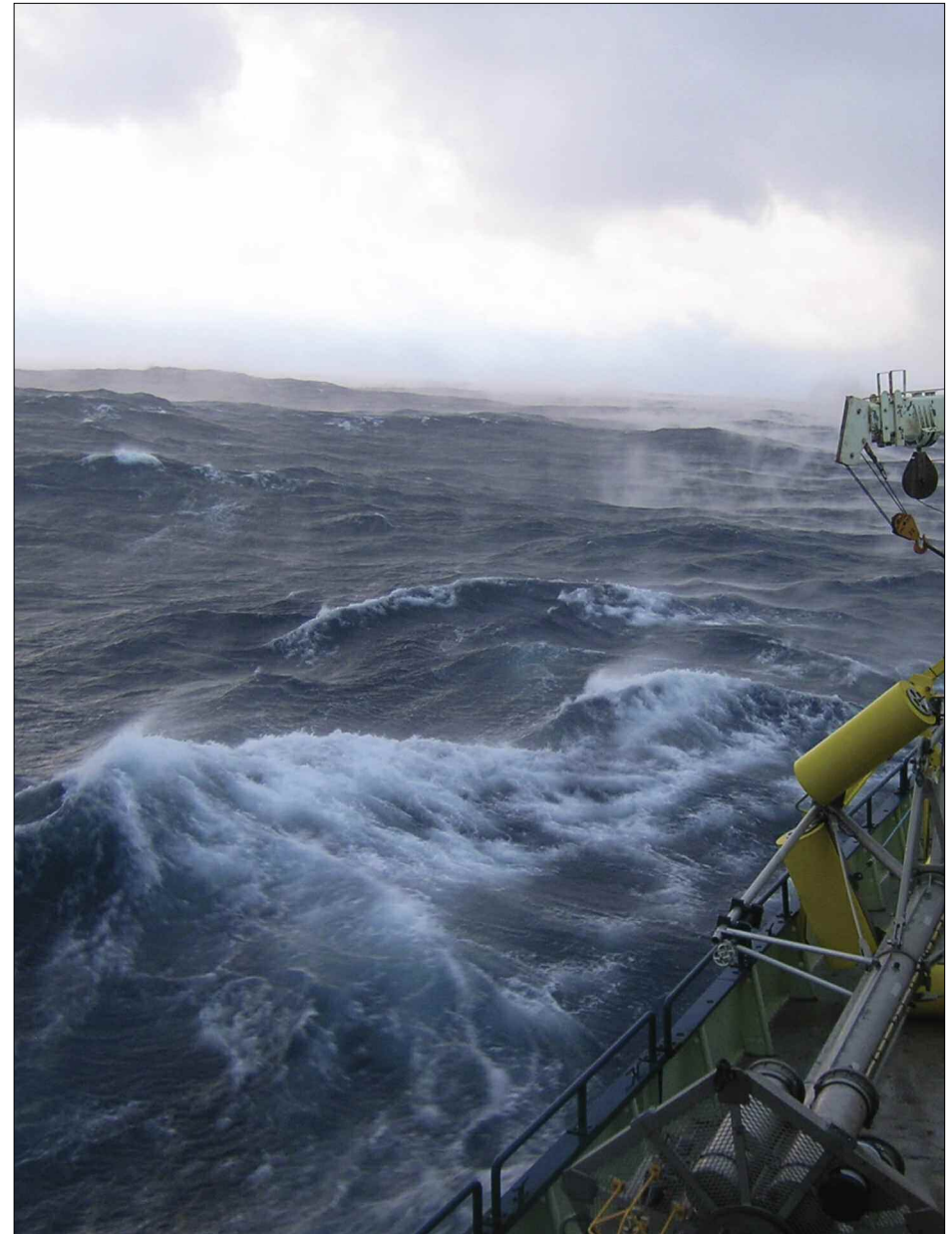
Seen from space, Earth appears fragile and blue with water. Water runs through all life on our planet, in one way or another. Water also runs through the pages of this issue of *Sensing Our Planet*.

The researchers we spoke with study water in multiple forms: liquid and frozen, saltwater and fresh, local and global. They ask questions that acquaint us with water in the most mundane and the most unusual of Earth's corners. Is swamp water really useless? Are the ocean's global circulation patterns truly so inscrutable? Scientists also ask questions that connect Earth's water with the health of people and planet, animals and plants. Scientists wonder if we can see a drinking-water resource become unhealthy from space. They study whether winds over the oceans might someday provide us with clean energy while preserving Earth's health. Polar bears are strained as their summer homes on sea ice in the Arctic continue to shrink. Plant experts know that freezing water means freezing plant tissues; will plant survival strategies be tested as our warming Earth disrupts historical climate patterns?

Our home planet freely provides the materials for life, including water, but we sometimes find it challenging to live safely and wisely on the Earth. Articles in this issue explore new ways researchers use satellites to study earthquakes and volcanoes and help relief workers pinpoint aid after a disaster. Scientists collect data to show nations how they score on their environmental choices. Experts use satellites so cities can sort out their pollution from that of their neighbors. And satellites may even be able to measure the risk of sunburn.

The Earth never stands still. Understanding our planet's dynamics drives the curiosity of scientists. We hope you sense that curiosity as you read about their efforts to better understand our planet home.

—The Editors



Water forms the basis for many of the research projects highlighted in this year's issue of *Sensing Our Planet*. The photograph above shows sea smoke off the side of an ocean-going vessel during a research project featured in "Where oceans meet atmosphere" on page 44. (Courtesy T. Joyce)

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NASA Earth Science Research Features **2008**



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When the Earth moved Kashmir



“I call it the flash-to-bang. From the first event to the first relief there, you want to minimize the time in between.”

Wiley Thompson
Oregon State University

by Laura Naranjo

Nestled in the Himalaya Mountains, Kashmir inhabits a crossroads between the Middle East and Asia. Kashmir’s valleys and snow-clad peaks have historically hosted divergent cultures and housed scholarly learning centers. Its natural resources and complex heritage have attracted tourists and border disputes; the region is administered by the neighboring countries of Pakistan and India.

Kashmir also inhabits another crossroads: It lies atop a web of active faults with underground dynamics that rival the complexities above ground. On October 8, 2005, one of the faults gave way, resulting in a magnitude 7.6 earthquake. In a matter of seconds, the rugged terrain that lures travelers became a disaster zone that soon would host relief workers providing food and shelter, military rescue operations airlifting supplies, and scientists seeking to understand how the earthquake happened.



The 2005 Kashmir earthquake badly damaged the town of Balakot in northwestern Pakistan. Debris littered walkways and roads, making relief access difficult. (Photograph by Lieutenant Colonel W. Thompson, courtesy U.S. Department of Defense)

After a major earthquake, scientists have traditionally relied on ground surveys to understand the damage. But satellite imagery is producing increasingly accurate ways to spot exposed faults and map deformation caused by earthquakes, especially in remote areas like Kashmir. What scientists learn by studying earthquake geology and post-earthquake deformation can advance what we know about earthquake dynamics and provide valuable information to relief organizations.

Anatomy of an earthquake

Kashmir sits atop the boundary of two colliding tectonic plates: the small Indian plate that underlies most of India and Pakistan, including much of Kashmir; and the vast Eurasian plate that underlies Europe, China, Russia, and much of the Middle East. Jean-Philippe Avouac, a geologist and professor at the California Institute of Technology, studies Asian earthquakes and tectonics. Avouac said, “Northern India is being thrust under the Himalaya, and the mountains are being pushed up by this motion. It’s a small increment of deformation, which over millions of years has built the Himalaya range.” This slow-motion collision created one of the planet’s most active earthquake hotspots; as the plates collide, stress builds up in the fault zones where the plates meet.

Sudden and rapid releases of seismic stress can cause large earthquakes. And sometimes, an abrupt movement along a shallow fault can rupture the surface, as happened during the 2005 Kashmir earthquake. This surface rupture extended for seventy-five kilometers (forty-seven miles) and was a first among earthquakes in the Himalaya seismic zone. Robert Yeats, a geologist at Oregon State University, traveled to Pakistan after the Kashmir

earthquake and witnessed the damage caused by the rupture firsthand. Yeats said, “In the known historic and recent records, not one of the earthquakes in the Himalaya has ever produced a surface rupture, not in Nepal, or India, or anywhere. This rupture was the first one.”

The Kashmir earthquake killed nearly 75,000 people, injured more than 100,000 people, and destroyed 3 million homes. Two towns that straddled the newly exposed fault suffered the most damage: Muzaffarabad and Balakot. In addition, the earthquake generated massive landslides that buried entire towns. Yeats said, “The upper side of the fault had a lot of landslides. Tens of thousands of people died because of landslides.”

Mapping deformation

Yeats, an earthquake expert, has a long history of working in Pakistan. After the 2005 Kashmir earthquake, he joined a team of researchers who were the first to map the fault line on the ground. The team returned to the area several times to walk the fault and record the resulting earthquake deformation. “In that kind of terrain, seventy-five kilometers [forty-seven miles] takes a long time to cover,” Yeats said. This traditional method of ground surveying can be difficult after an earthquake because the land surface has changed. Mapping ruptures typically means finding features that used to be continuous before the earthquake, like a road or fence. But in parts of Kashmir, few of these man-made features exist, meaning that the survey team had to find natural features that had been disrupted by the fault, like small crests or river gullies.

Because of the difficulties of ground surveying, researchers like Avouac are investigating how



The 2005 Kashmir earthquake displaced more than three million people, primarily affecting residents in the Kashmir region. Over time, the collision between the Indian and Eurasian plates formed the Himalaya Mountains, and has made the region seismically active and susceptible to earthquakes. (Courtesy L. Naranjo, based on United Nations map)

satellite imagery can aid ground surveys and rescue work by generating more immediate maps of earthquake deformation. In theory, observing earthquake deformation should be as simple as comparing two optical satellite images that show the land surface before and after the earthquake. However, correlating three-dimensional images is technically very difficult. Avouac said, “There are distortions in the images because of the topography and geometry of the terrain, the angle at which the satellite instrument is viewing the Earth’s surface, and the satellite’s motion.” When correlating the two images, all of these distortions produced visual offsets in the resulting image that the earthquake did not cause.

Avouac's team discovered that accurately correlating the images was not a simple process. To remove the distortions, the team needed to match geographic coordinates between the images and the ground; calculate the satellite's position and motion; drape the images onto the corresponding portion of the Earth's surface; and then compare differences between the two images. Avouac and his team refined these steps until they created a reliable technique that would accurately show the earthquake deformation without the visual distortions.

The team applied this technique using imagery of the Kashmir area from the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) aboard the NASA Terra satellite. Although Avouac has a variety of image sources to choose from, he frequently relies on ASTER images from the NASA Land Processes Distributed Active Archive Center (LP DAAC).

He said, "I've switched to using ASTER because the community of users is much larger and because of the lower cost."

Avouac chose an image taken before the earthquake and compared it to a post-earthquake image captured on October 27, 2005. The results were successful, and correlated very well with the surface rupture measured by Yeats' team. Avouac said, "We confirmed that our technique can provide information that may be very difficult to measure in the field but is critical for modeling earthquakes."

Remote answers to relief

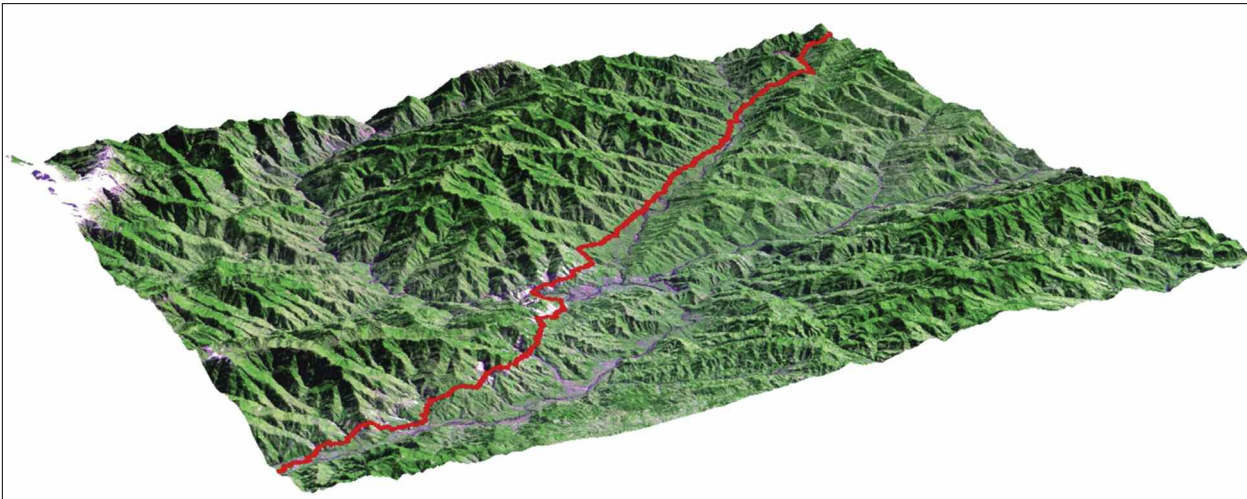
Earthquake-stricken areas are notoriously difficult for relief workers to access because communication networks and infrastructure are damaged. Avouac hopes that the technique he and his colleagues developed can be used to hasten aid to future earthquake victims. He said, "Our technique

provides detailed information that could be used by rescue teams to estimate whether a major town has been badly shaken or not."

Wiley Thompson, a lieutenant colonel in the United States Army serving in Afghanistan when the quake occurred, assisted with the disaster relief efforts. Thompson said, "As a disaster response coordinator, my goal was to get relief—the right kind of relief—to the people who needed it the most at that moment."

Having access to remote sensing and field studies can help relief workers zoom in on a crisis area. Thompson said, "You need to know where to go, so you don't spend time going to places that weren't the worst hit. I call it the flash-to-bang. From the first event to the first relief there, you want to minimize the time in between." Researchers often try to deliver maps and data as soon after an earthquake as possible, but because many relief efforts evolve into long-term projects, new information can be helpful at any stage. New maps, for instance, may reveal damaged towns that were initially missed, but where relief is still badly needed. Thompson said, "Just because you don't have definitive information right after an earthquake doesn't mean it's not going to do you some good later."

Recovering from the October 2005 Kashmir earthquake will likely take several more years, putting Kashmir once again at a crossroads, this time between the old and the new. Governments are razing old concrete block buildings and replacing them with modern structures designed to better withstand earthquakes. Relief organizations are helping relocate residents of towns destroyed by the earthquake to newly erected



A three-dimensional view, looking to the southeast, shows the fault that ruptured during the 2005 Kashmir earthquake. Scientists determined the deformation caused by the earthquake by correlating Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) images taken before and after the earthquake. (Image by J. Giberson, courtesy Tectonics Observatory, Caltech)

town sites. And scientists and researchers continue to focus on Kashmir and other earthquake-prone areas, mapping ancient geological faults and identifying new ways to examine an earthquake's aftermath.

Avouac said, "By studying these ruptures, we can learn more about the characteristics of future earthquakes, like what kind of ground motion we can expect." Understanding how past earthquakes happened and how much damage they caused can help scientists estimate future seismic hazards and pinpoint areas with a high earthquake risk. They hope that this knowledge will eventually protect people living in areas with earthquakes.

To access this article online, please visit http://nasadaacs.eos.nasa.gov/articles/2008/2008_earthquakes.html.



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- Parsons, T., R. S. Yeats, Y. Yagi, and A. Hussain. 2006. Static stress change from the 8 October, 2005 $M = 7.6$ Kashmir earthquake. *Geophysical Research Letters* 33, L06304, doi:10.1029/2005GL025429.

For more information

NASA Land Processes DAAC
<http://lpdaac.usgs.gov>
 Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER)
<http://asterweb.jpl.nasa.gov>

About the remote sensing data used

Satellite	Terra
Sensor	Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER)
Data set used	ASTER L1A Reconstructed Unprocessed Instrument Data
Resolution	15 meter (VNIR), 30 meter (SWIR), 90 meter (TIR)
Parameter	Land surface
Data center	NASA Land Processes DAAC

About the scientists



Jean-Philippe Avouac is the director of the Caltech Tectonics Observatory and a geologist and professor at the California Institute of Technology. He studies and models earthquakes and tectonics, focusing on the Himalaya region, China, Taiwan, and Sumatra. Avouac is currently developing new approaches to studying earthquakes by combining field observations, satellite imagery, and models. The National Science Foundation funded his research. (Photograph courtesy J.-P. Avouac)



Wiley C. Thompson is a lieutenant colonel in the United States Army and a professor of geography at West Point. He served in Afghanistan in 2005 and helped provide disaster relief after the 2005 Kashmir earthquake. The Department of Defense funded his 2005 earthquake relief work. (Photograph courtesy W. C. Thompson)



Robert S. Yeats is a geologist and professor emeritus at Oregon State University. He has studied earthquake hazards worldwide and has been working to understand active faults and earthquakes in Pakistan since 1978. Yeats was a member of the team that discovered the surface rupture accompanying the 2005 Kashmir earthquake. His research was funded by Earth Consultants International, an environmental consulting firm in which he is partner and senior consultant. (Photograph courtesy R. S. Yeats)

Co-Registration of Optically Sensed Images and Correlation (COSI-Corr)
http://www.tectonics.caltech.edu/slip_history/spot_coseis/index.html
 Jean-Philippe Avouac
<http://www.gps.caltech.edu/~avouac>

Wiley C. Thompson
<http://www.dean.usma.edu/departments/geo/Faculty&Staff/bio-Thompson.htm>
 Robert S. Yeats
<http://www.geo.oregonstate.edu/people/faculty/yeatsr.htm>

The power of a Brazilian wind



“Think of it like petroleum or coal: you need a resource assessment so that you have a sense of how much resource is located where, and how you’ll need to extract it. That’s what we need to do with offshore wind.”

Willett Kempton
University of Delaware

by Stephanie Renfrow

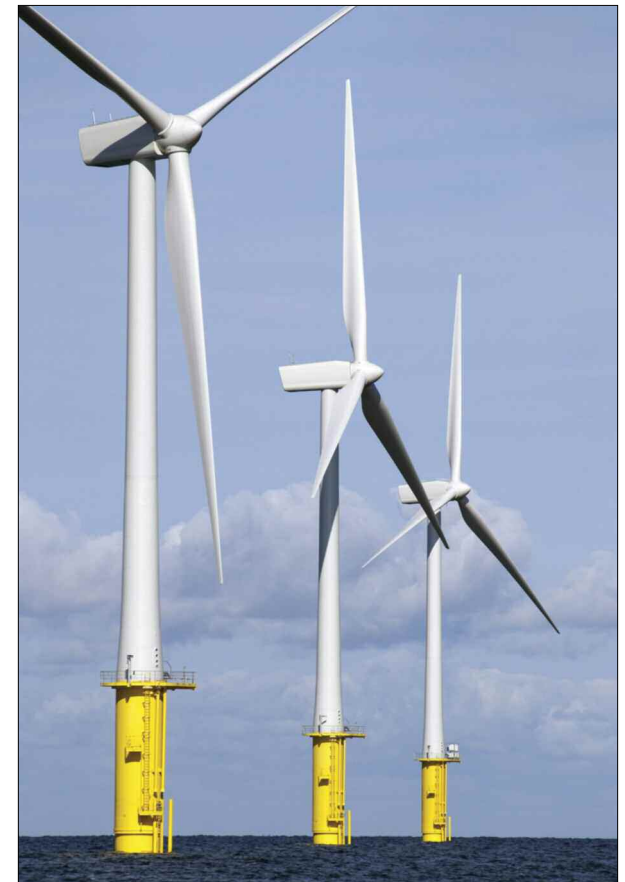
People often picture wind turbines rooted in waving fields of golden grass, but wind turbines can also stand among the waves of coastal waters. Offshore wind offers more than just clean and economical energy; winds over the ocean can often be faster and fluctuate less than land-based winds, leading to higher and more sustained output. Offshore wind sites tend to be naturally close to the large coastal population centers that need their power, and they do not have to compete for valuable land. Willett Kempton, a professor at the University of Delaware, said, “Offshore wind power is particularly attractive because the resource is large and current technology is ready for implementation now.”

So if wind energy can provide the world with clean power, why are turbines not up and spinning along every coastline? Developers need solid assessments of coastal wind energy potential before they consider a new wind project, information not easily available using traditional ground-based tools. In an effort to help assess wind energy potential, Kempton and his colleagues are using an unexpected tool: satellite data. Their latest project focuses on the undulating coastline of Brazil.

Location, location

Whether along the coast of northern Europe, the United States, or Brazil, cost-effective wind turbine sites have a few specific requirements. First, wind speeds must fall within a defined zone. Kempton said, “The ideal wind-speed zone has winds that are high enough to produce

energy but without strong storms that pose a threat to the installation.” Second, offshore turbine foundations must be on relatively shallow coastal shelves; the deepest installed turbine is currently rated for 50 meters (164 feet) in depth. Finally, the site must be able to accommodate the whirling blades of enough turbines to be



Offshore wind turbines take advantage of predictable winds to produce carbon-free energy; potential sites are often close to electricity-hungry population centers. (Courtesy A. Upton, npower renewables)

cost-effective. Kempton said, “The idea is to fan them out and make sure they are spaced apart appropriately for effective energy production.”

While the wind industry and turbine manufacturers are concerned with all of these details, scientists are, too. “Coastal zone assessment is the piece that scientists, like our team, can provide,” Kempton said. “Think of it like petroleum or coal: you need a resource assessment so that you have a sense of how much resource is located where, and how you’ll need to extract it. That’s what we need to do with offshore wind.”

One of the most recent and promising wind assessment studies that Kempton and his colleagues Richard Garvine and Felipe Pimenta developed was to determine wind energy potential off the coast of southeastern Brazil. Pimenta, a native of Brazil, said, “My goal is to search for renewable energy solutions that can help diversify the Brazilian electric grid.”

Assessing a Brazilian wind

Most of Brazil’s electricity comes from hydroelectric dams, with a sizable portion from traditional fossil-based resources and only a small percentage coming from renewable resources like wind. Now Brazil wants to increase its share of renewable energy. Pimenta said, “A new government program, ProInfra, seeks to increase the use of new renewables to 10 percent of our annual electricity consumption. Our study is important because it is the first to evaluate Brazil’s offshore wind potential.”

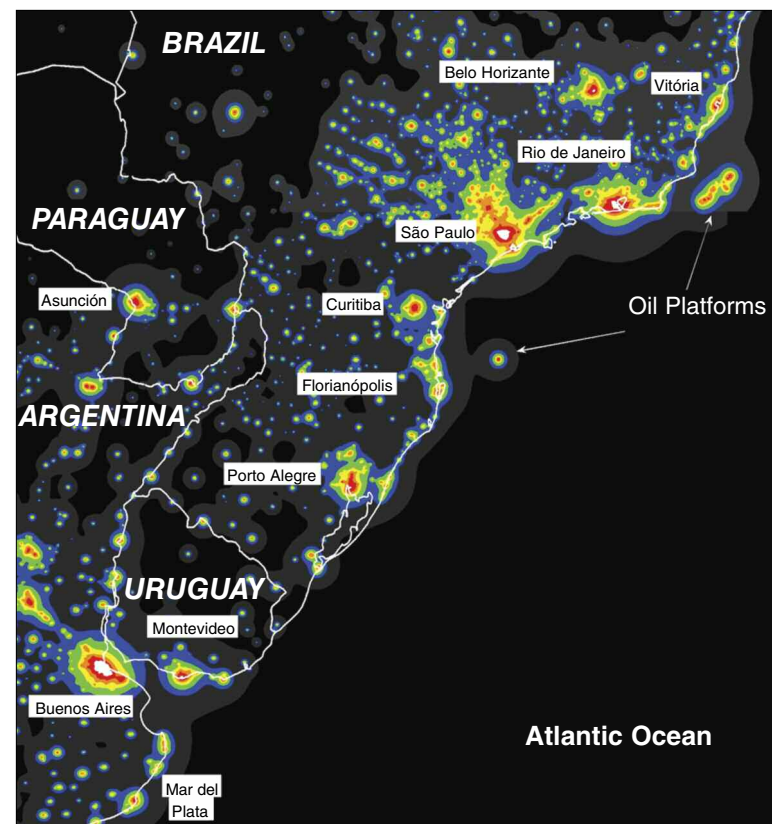
With its bustling, coast-hugging population centers like São Paulo and Rio de Janeiro, offshore wind is a promising fit for Brazil. “Brazil has

a long coastline and vast continental shelves, and it seems to have even more wind resources than we might have expected,” Pimenta said.

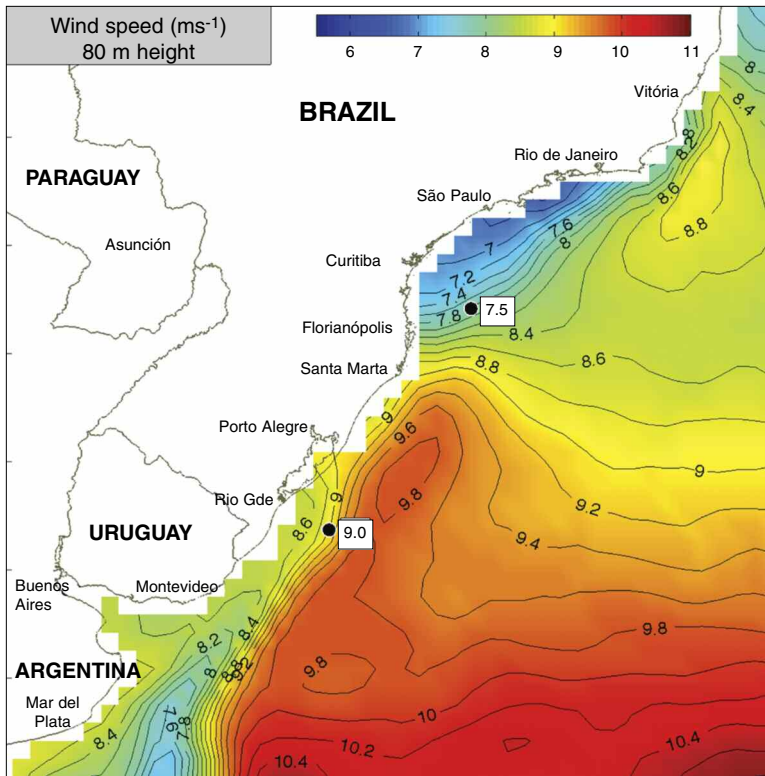
Typically, wind energy assessments begin by analyzing data from continuously operating meteorological stations on buoys that float offshore near the potential site. These stations measure wind speed up to twenty meters (sixty-six feet) above the sea surface. From these measurements, scientists extrapolate the wind speed at the turbine’s hub height, approximately 80 meters (262 feet), to get an idea of the wind available to turn a turbine’s blades. Researchers also use station data to analyze wind speed fluctuations from one minute to the next. However, meteorological data from buoys and fixed platforms can be hard to get. Kempton said, “Many countries simply lack historical meteorological buoy information over the ocean.” The chosen study area turned out to be a good example of the sparseness of meteorological station data. Kempton said, “For the entire study area, we only had two offshore buoys available.”

Given the dearth of wind speed data from meteorological stations, the team needed a different source. “In a new offshore wind power seminar we teach at the University of Delaware, student Oleksiy Kalynychenko suggested using NASA QuikSCAT data. Felipe decided to try it,” Kempton said. “To our knowledge, this study is the first to use QuikSCAT to assess wind power

resources over a large ocean area.” The SeaWinds instrument, on board the QuikSCAT satellite, provides scatterometer data that is hosted by the NASA Physical Oceanography Distributed Active Archive Center (PO.DAAC). The instrument measures ocean roughness and relates it to wind speed at the ocean surface. “QuikSCAT has exceptional global geographic coverage at a very reasonable spatial resolution, from just over twelve to fifty kilometers [seven to thirty-one miles],” Kempton said. “The satellite data filled in the gaps in the vast areas around the two buoys.”



Bright colors indicate population centers in this nighttime image of the offshore study area, along 900 kilometers (559 miles) of Brazil’s coast. Two oil platforms were the only ground-based sources of surface wind speed data. (From F. Pimenta, courtesy Elsevier *Renewable Energy*)



Wind speeds at a height of 80 meters (262 feet), or approximately the hub height of a turbine, indicate a viable wind resource in the study area. If the area were fully developed for offshore wind, it could supply more than Brazil’s current electricity needs. Image is compiled from satellite, buoy, and bathymetric data. (From F. Pimenta, courtesy Elsevier *Renewable Energy*)

Before settling on QuikSCAT, the scientists first wanted to confirm that the satellite data correlated well to existing buoy data. “We crosschecked meteorological data from several places against QuikSCAT to ensure that we could use the satellite data for assessing the Brazilian power resource,” said Kempton. By combining the meteorological and QuikSCAT data, the team could also address a limitation of the satellite data. Wind speeds can fluctuate from minute to minute and from hour to hour, so unless data are taken continuously—as meteorological stations are able

to do—those fluctuations will not be captured. Kempton said, “When the satellite passes over the study region, that’s when you get the data, once or maybe twice per day. The buoys are running continuously, but in only a few places. The two together provide both spatial and temporal coverage.” One of the two buoys within the study area was particularly helpful for this purpose because it took measurements during the same months that QuikSCAT passed overhead. “We could confirm that the satellite data was within acceptable margins of error for a first-cut evaluation of power resources,” he said. “QuikSCAT can indeed provide practical measures of wind power, especially when looking for monthly or yearly estimates.”

Where the wind blows

Having cross-referenced the buoy and satellite data, the scientists’ next step was to explore the “footing” on which turbines could stand in the study area. “Felipe got bathymetric information by digitizing Brazilian Navy nautical charts,” Kempton said. “This helped us estimate the shelf areas that are within the practical limits of exploration, in terms of depth.”

Kempton and his team now had the information needed to assess the practical wind-turbine-worthy wind resource: the wind speed at hub height over a large area from the satellite data; an idea of the fluctuations of wind speed based on the hour and season from both buoy and satellite data; and the depth of the continental shelf, where the turbines would be planted, from the bathymetric data.

Using all of this information, Kempton, Garvine, and Pimenta calculated the potential power production for two different wind turbine models. Kempton said, “The total average electricity use of Brazil is near 100 gigawatts, and the offshore wind resource of this one section of coast, to only 50 meters [164 feet] of water, is 102 gigawatts.” That means that if the study area were fully developed as a wind energy project, it could supply enough electricity for the entire country’s electricity needs.

“However,” Kempton said, “there would certainly be areas that would be excluded from development, and we didn’t attempt to consider those in our calculation. According to previous studies, exclusions for shipping lanes, marine conservation sites, and commercial fishing, could reduce the site’s capacity by 10 to 46 percent.” Even with such areas excluded from development, an offshore wind project in the study region could still meet ProInfra’s efforts to increase Brazil’s renewable energy output.

Kempton feels optimistic about the future of the team’s work. He said, “The work on the Brazilian wind assessment was the first step in a larger picture. We hope to make a database of wind assessments available for various coastal areas, with wind resource, energy demand, potential electrical output and revenue, and so on. We think this would help the wind industry decide whether or not a site is feasible economically and help with government planning.”

Pimenta agreed, adding, “I want to return to Brazil and continue this work. There are still many tools, including satellite data, left for us to explore as we look at wind energy. I hope our

work will help other large countries estimate their wind resources, too.” A better understanding of global offshore wind potential could help many countries reduce their portion of humanity’s carbon output.

The main message, from Kempton’s perspective, is one of hope. “In the end,” he said, “people really understand the results of this type of research. They say things like, ‘Wow, this makes me very optimistic. I thought climate change was all doom and gloom. But we can actually do something to turn it around.’ And, given the technologies already available today, offshore wind is one of the best options out there.”

To access this article online, please visit http://nasadaacs.eos.nasa.gov/articles/2008/2008_wind.html.



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For more information

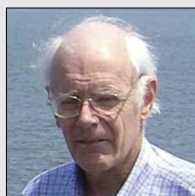
NASA Physical Oceanography DAAC
<http://podaac.jpl.nasa.gov>
 NASA QuikSCAT satellite
<http://winds.jpl.nasa.gov/missions/quikscat/index.cfm>

About the remote sensing data used

Satellite	QuikSCAT
Sensor	SeaWinds scatterometer
Data set used	Level 2B Ocean Wind Vectors in 25 km Swath Grid and 12.5 km Swath Grid
Resolution	12.5 and 25 kilometer
Parameter	Wind vectors
Data center	NASA Physical Oceanography DAAC

The table above lists the public NASA archive for these remote sensing data sets. The authors also used reprocessed fifty-kilometer, medium-range weather forecast data from the European Centre for Medium-Range Weather Forecasts.

About the scientists



Richard Garvine was an award-winning physics professor at the University of Delaware; he passed away in December 2007. He was Felipe Pimenta’s PhD advisor, working closely with both Willett Kempton and Pimenta. Garvine’s central contribution to this collaboration was in fluid dynamics and the use of surface wind speed data to estimate wind speed at turbine hub height. His funding for this project came from Sea Grant. (Photograph courtesy F. Pimenta)



Willett Kempton is an associate professor in the College of Marine and Earth Studies at the University of Delaware. His research interests include offshore wind, vehicle-to-grid power, lay environmental beliefs and values, and energy and transportation policy. His funding for this project came primarily from Sea Grant. (Photograph courtesy F. Pimenta)



Felipe Pimenta is pursuing his doctoral degree in the Physical Oceanography program at the College of Marine and Earth Sciences at the University of Delaware. His work on Brazilian offshore wind energy potential grew from a course taught by several professors, including Garvine and Kempton. Funding for his education and this project came from the Ministry of Education of Brazil. (Photograph courtesy F. Pimenta)

Centre ERS d’Archivage et de Traitement [French ERS Processing and Archiving Facility] (CERSAT)
<http://www.ifremer.fr/cersat/en/welcome.htm>

Willett Kempton, University of Delaware,
 College of Marine and Earth Studies
<http://www.ocean.udel.edu/people/willett>

Earth's crust in action



“It would be like taking a picture of a vacant lot, then a picture of the finished house. It doesn't tell you how the house got there.”

Kristine Larson
University of Colorado at Boulder

by Jane Beitler

Standing on the Earth, we sense it as solid. But beneath us, the abutting plates of Earth's crust jockey for position; lava squeezes to the surface through rock fissures from molten layers below. Stresses build slowly, silently. Then the destructive shaking of an earthquake or a violent volcanic eruption reminds us that the crust is not static.

People naturally prefer the Earth's crust to hold still. But some years ago, Kristine Larson, a professor of aerospace engineering, was becoming slightly impatient: she had measurement problems to solve, and needed higher-resolution data on crustal movements. “If the ground is only moving a centimeter per year, you spend a lot of time waiting around to see things,” she said. Larson had been studying plate tectonics, the processes that form and deform the Earth's crust.



In this photograph, lava partially fills the Pu'u Ō'ō crater of Kilauea Volcano on the island of Hawaii. Kilauea is one of the world's most active volcanoes, erupting almost continuously since 1983. (Courtesy J. Kauahikaua, Hawaii Volcano Observatory)

Her work involved measuring movements with Global Positioning System (GPS) receivers, much like the portable versions known for helping wanderers find their way, but mounted firmly to the ground. She thought that by seeking out more dynamic cases to study, she could figure out how to get very precise GPS measurements, minute to minute. This method, called high-rate GPS, is like a time-lapse camera giving scientists a detailed playback of how the crust shakes, shifts, and bulges when plates rupture and lava surges.

Fixing GPS on the problem

The Earth's crust is like cracked pottery. Pressure in layers below causes these shards to shift at the fracture. Subterranean forces associated with volcanoes can also cause a once-familiar mountaintop to bulge as lava tries to push to the surface. For some time, scientists studying these processes found GPS data to be uniquely helpful. Soon after its introduction for navigation and satellite tracking, GPS was quickly adapted to track the Earth's crust. NASA helped mount GPS receivers near fault zones and near active volcanoes, where the caldera spews hot ash and lava bombs. Larson said, "You don't want to send people out to make those measurements."

Larson, at the University of Colorado at Boulder, specializes in this research-quality GPS, which has a much higher precision than consumer GPS. "You don't need to know where your car is to a centimeter," she said. But scientists do want to know about even tiny movements or bulges in Earth's crust, especially while an earthquake is in progress, or just before and during a volcanic eruption. Without this information, Larson said, "It would be like taking a picture of a vacant lot,



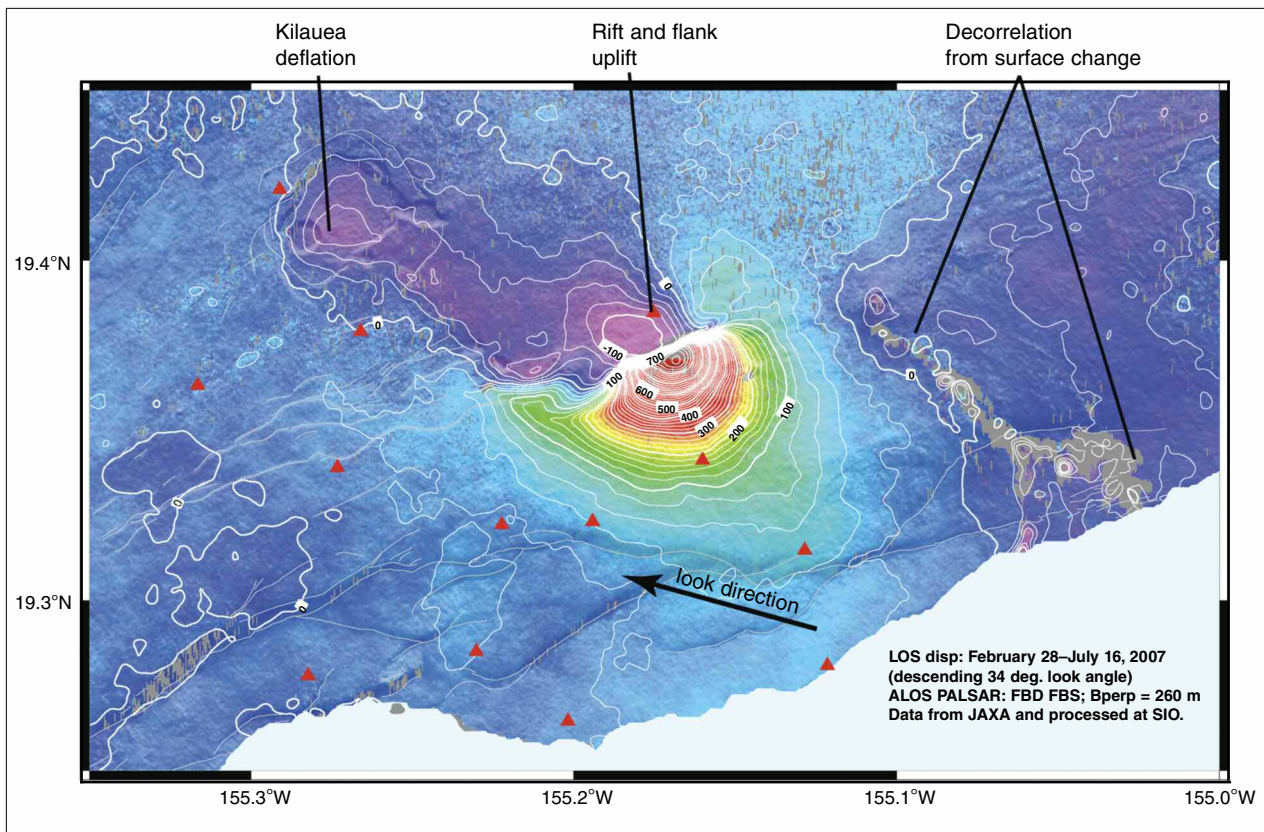
A researcher checks the calibration of a ground-mounted Global Positioning System (GPS) station on Mount St. Helens. GPS receivers and satellites can precisely capture movements in the Earth's crust, giving scientists a picture of processes concealed deep in the ground during earthquakes and volcanic eruptions. (Courtesy M. Lisowski)

then a picture of the finished house. It doesn't tell you how the house got there."

For years, researchers could not get these very precise GPS position measurements more than once a day. GPS depends on a constellation of twenty-four satellites orbiting the Earth. A GPS receiver picks up their time- and position-stamped signals, and compares data from at least four satellites to compute its own latitude and longitude. But as the satellite signals travel through the atmosphere and are reflected near

the GPS receiver, small delays occur, causing "noise" in the data. So data were averaged over a day to smooth out the signal.

Larson thought that she could solve this problem, but she needed data, ideally from something that was moving more often. She became curious about the movements of underground lava. Larson said, "You can look at the gases coming out of the caldera and the lava flowing on the surface. But how do you know where the lava is moving around



This image of the dike intrusion at Kilauea Volcano on June 17, 2007, was constructed from L-band Synthetic Aperture Radar, with help from high-rate Global Positioning System (GPS) data. GPS stations, marked with red triangles, provided extremely precise measurements of ground displacement. Green, yellow, and red areas show elevation contours; pink indicates ground deformation. (Courtesy D. Sandwell, Scripps Institution of Oceanography)

underneath the earth? How does the lava move around before an eruption?”

Larson started experimenting with data that were already being collected from GPS receivers and stored by the NASA Crustal Dynamics Data Information System (CDDIS). She said, “I was able to use the data for an entirely different purpose than originally intended, because NASA had the foresight to archive it.” Aided by advances in computing and data storage, which helped her work with the large volume of data

from frequent measurements, Larson proposed and tested new data-filtering strategies for the GPS-Inferred Positioning System (GIPSY) software, developed by NASA’s Jet Propulsion Laboratory. She was able to separate the data trends from the noise to get more frequent measurements without losing the precision.

A volcano at work

On sabbatical in 1997, Larson traveled to Hawaii’s Kilauea Volcano Observatory to try her solution firsthand on an active volcano, and there

worked with Michael Lisowski, a research scientist at the United States Geological Survey (USGS). Researchers watch Kilauea intently for warning signs of a major eruption that could trigger earthquakes, landslides, or a tsunami.

Lisowski studies how the ground deforms around a volcano, a sign of unrest and potential trouble. He said, “As the magma nears the surface, it hits the brittle rock, and then you see what’s going on, as the ground deforms. Deformation measurements help us tell how much material is moving through the crust.” Scientists call this a dike intrusion: magma rises into a fracture in the rock, or forces its way through the rock to create a new crack. As the intrusion and fracturing continues, the volcano widens internally to make room for the magma, causing the surface to deform.

The research team upgraded the existing network of twenty-two GPS receivers to obtain position estimates every fifteen minutes, computed in near-real time. During the study, magma moved under Kilauea’s Pu’u ‘Ō’ō vent, and the ground deformed thirty-six centimeters (fourteen inches). The study proved the role of high-rate GPS. Lisowski said, “GPS is easy to deploy and is a more stable measurement over a long time period than other instruments, such as seismometers, tiltmeters, and strainmeters.” So scientists would later reach for high-rate GPS during a dike intrusion; meanwhile, Larson wanted to see what else high-rate GPS could reveal.

A dike intrusion can announce itself with the many small earthquakes caused by the fracturing rock. This connection helped lead Larson to the idea for applying high-rate GPS data to earthquakes. She said, “A seismologist explained

to me that if you put a seismometer in the middle of an earthquake, especially a big earthquake, it is too sensitive. He thought, wouldn't it be great if high-rate GPS could work during an earthquake?" Lisowski said, "Early on there were proposals for high-rate earthquake data, such as dragging a GPS receiver behind a truck to measure road lines." Road line shifts are a clue to earthquake damage (see "When the Earth moved Kashmir," in this issue, for more on post-earthquake assessment). Larson started work on capturing actual seismic activity with high-rate GPS.

Catching an earthquake

By fall 2002, Larson thought she knew how to capture the shaking during an earthquake. Ready for data, and impatient for an actual earthquake, she planned a static test in a nearby parking lot. Then a magnitude 7.9 earthquake occurred along the Denali Fault in Alaska, and she quickly shifted gears. Larson said, "I trolled on the Web to see if there were any GPS receivers near the Alaska earthquake, and I found one about 100 kilometers (62 miles) away in Fairbanks, and some in British Columbia." Her search led her to Joan Gomberg, a USGS scientist who studies earthquakes.

Gomberg was also watching the Denali earthquake. She studies earthquake triggering: seismic waves traveling beneath the earth that can set off other earthquakes. Gomberg said, "If you're a fault sitting there, patiently waiting in the Earth, and a big seismic wave comes and shakes you, then sometimes that will cause you to fail and produce an earthquake. It's a trigger." But conventional seismic instruments are not designed to measure these very big waves.

Gomberg said, "Because of the mechanics of a seismometer, if you design it to record only the biggest earthquakes, you won't see anything little, and vice versa. GPS doesn't go off scale."

The largest waves of the Denali earthquake lasted only about two minutes. Larson helped

Gomberg extract from GPS data the signal of the waves emanating from Denali. Gomberg said, "Denali produced extraordinarily large waves because it is a very long and skinny fault, and it's all within the crust. And the fault broke from one end to the other." The rupture continued for 336 kilometers (209 miles) from



This rupture of the Tok Cutoff Highway in Alaska resulted from a magnitude 7.9 earthquake along the Denali Fault in 2002. The earthquake disrupted roadways and triggered thousands of landslides, but because of the sparsely populated terrain, no one died. (Courtesy Alaska Department of Transportation and Public Facilities)

northwest to southeast, pointing in the direction of the western United States. Gombert said, “An earthquake is like a crack that grows. If the crack grows in one direction, it focuses all the energy in that direction. This focusing effect was really profound in the Denali earthquake, because it was so long, and started at one end and went in one direction. To understand

this triggering process, we want to know, how big were the waves?”

Larson’s high-rate GPS data answered that question. Gombert said, “The earthquake saturated most of the other instruments; they went off scale. With the high-rate GPS data, you could see as the waves passed by various sites: the

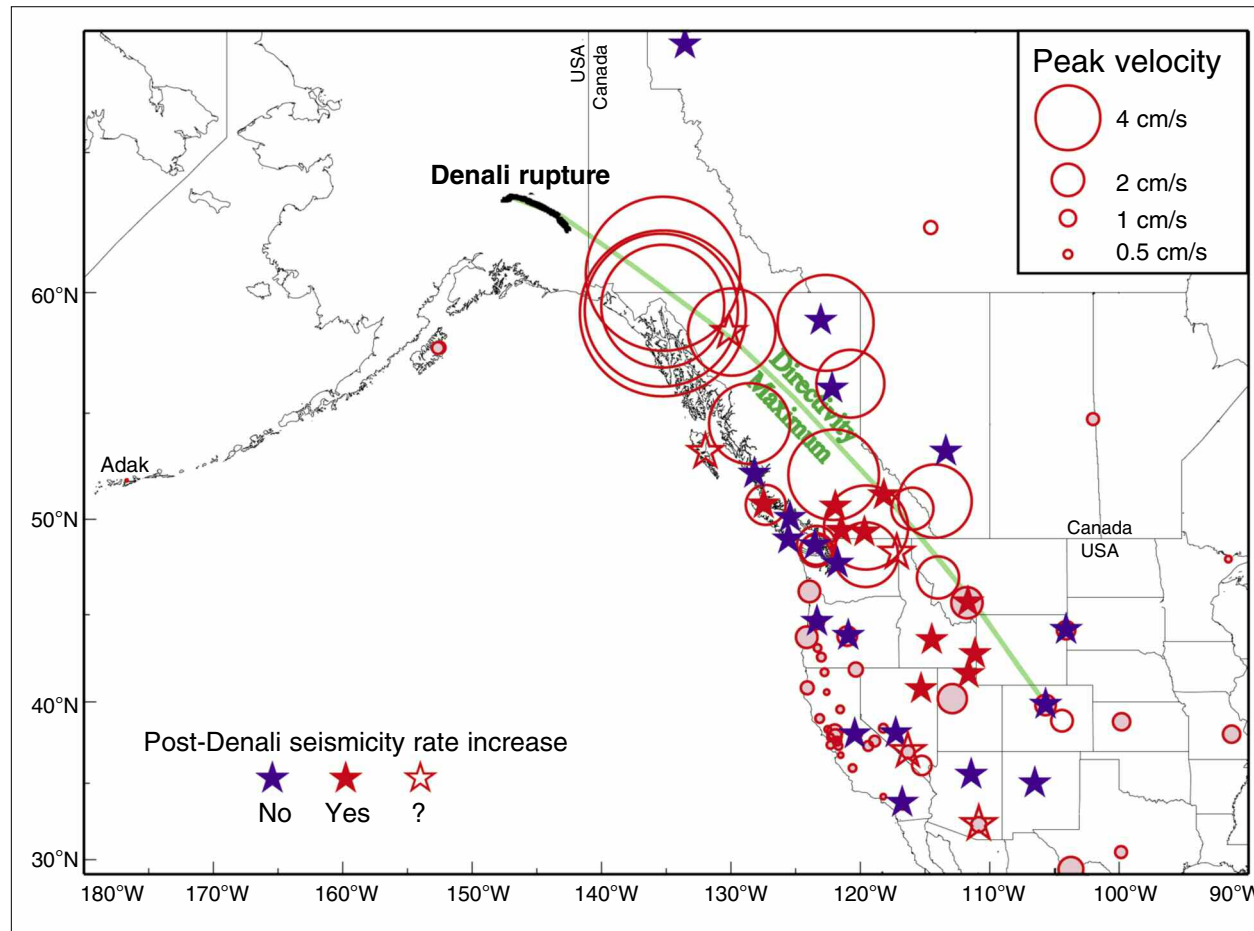
earthquakes started going bing bing bing bing all the way down western Canada and the United States for thousands of kilometers.”

Reuse, recycle

High-rate GPS opened new avenues for studying earthquakes and volcanoes. From the Denali study, Gombert said, “We learned the power of this focusing effect. We knew that the waves were phenomenally big due to the way the fault broke, but without GPS, we would never have known how big.” Gombert thinks these data could lead to greater insights about the processes that cause earthquakes. She said, “Since seismic waves can travel so far, it raises the possibility that you can connect all earthquakes together.”

More recently, high-rate GPS confirmed its place in the volcano study toolbox. Back in Hawaii, when Kilauea’s Pu’u ‘Ō’ō again stirred in June 2007, researchers quickly deployed temporary GPS arrays, and called on Larson for high-rate GPS data. With an unprecedented combination of satellite and ground data, they saw a frame-by-frame story of a three-phase dike intrusion, accompanied by a slow earthquake that continued over two days, ending in a small eruption. Lisowski said, “GPS has become the major tool for tracking slow deformation, down to minutes. We can now build models that account for the movement of magma and the growth of a dike. These are exciting times, when we can make advances in the understanding of volcanic processes.”

Larson likes that GPS is a widespread technology, keeping costs as low as a few thousand dollars per installation. Larson said, “I know a scientist who uses gravity data. His joke is, ‘If only someone



This map of the west coast of North America shows seismic measurements recorded by Global Positioning System (GPS) instruments, related to the 2002 Denali earthquake, indicated with a thick black line. The green line marks where seismic waves from Denali triggered increased seismic activity in the direction of the rupture. Solid red stars mark areas with increased seismic activity resulting from Denali’s seismic waves. GPS stations are marked with open red circles; the size of the circle is in proportion to seismic velocity. Shaded circles indicate traditionally instrumented seismic stations. (Courtesy J. Gombert)

could tell where their car was by putting one of my \$350,000 gravity meters on the hood. Then maybe someone else would buy them.” The economy of scale of GPS, and the ability to reuse data collected for other research, help Larson keep moving on to try it on other elusive geophysical measurements.

To access this article online, please visit http://nasadaacs.eos.nasa.gov/articles/2008/2008_gps.html.



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- U.S. Geological Survey. Rupture in South-Central Alaska—The Denali Fault earthquake of 2002.
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About the remote sensing data used

Satellite	Global Positioning System (GPS)
Sensor	GPS Receivers
Data set used	GPS Data Archive
Resolution	1 second
Parameters	Latitude and longitude
Data center	NASA Crustal Dynamics Data Information System

About the scientists



Joan Gomberg is a research geophysicist at the United States Geological Survey (USGS) at the University of Washington. She specializes in earthquake hazard assessment, earthquake interactions, wave propagation, and source scaling. The National Science Foundation (NSF) and the USGS supported her research. (Photograph courtesy J. Gomberg)



Kristine M. Larson is Professor of Aerospace Engineering Sciences at the University of Colorado at Boulder. She focuses on high-precision GPS techniques to address a range of geophysical issues: measuring and interpreting crustal deformation, measuring soil moisture, and engineering development. NSF, NASA, and the University of Colorado at Boulder supported her research. (Photograph courtesy K. Larson)



Michael Lisowski is a research geophysicist at the USGS Cascades Volcano Observatory in Vancouver, Washington, where he specializes in monitoring crustal deformation. Previously, he was at the Hawaiian Volcano Observatory, where he revitalized the program by establishing continuously measuring GPS, strain, and electronic tilt networks on Kilauea and Mauna Loa volcanoes and by displaying the data in near-real time. The USGS and NSF supported his research. (Photograph courtesy M. Lisowski)

U.S. Geological Survey. Using the Global Positioning System (GPS) to measure volcano deformation.
<http://volcanoes.usgs.gov/activity/methods/deformation/index.php>

Sensing the swamp beneath the trees



“We are talking about trying to use highly specialized tools . . . to piece together how water is flowing through these wetland environments. That is exciting scientific work.”

Doug Alsdorf
University of Ohio

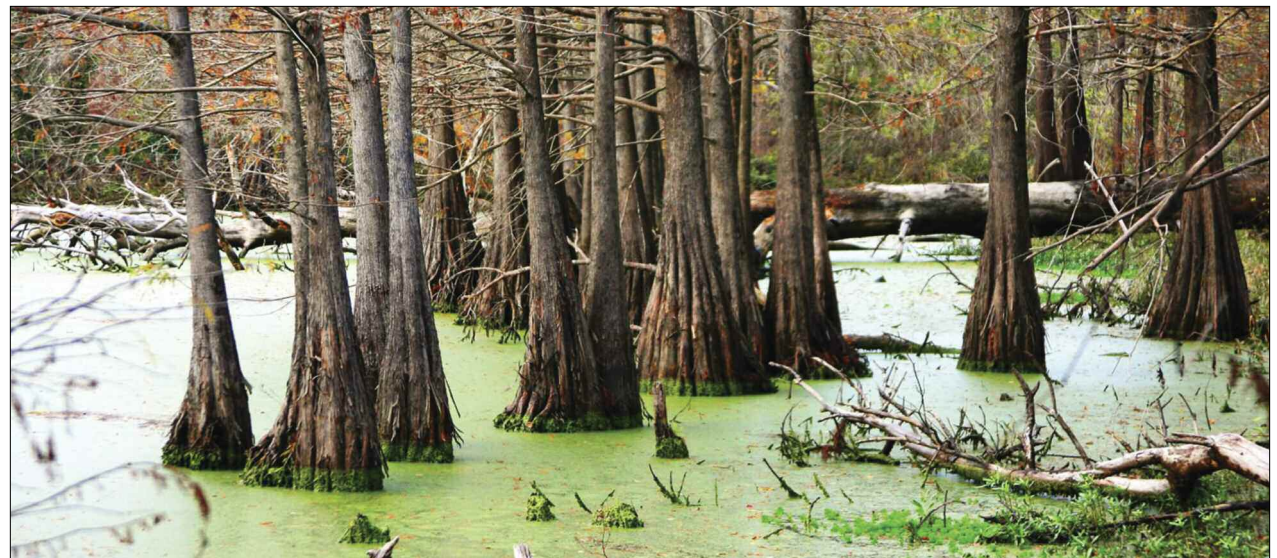
by Natasha Vizcarra

In the mid-1950s, two geologists surveyed the terminus of the majestic Mississippi River, the seemingly endless stretch of interconnected swamps, bayous, and muddy land that comprises southeastern Louisiana. In their report to the United States Army Corps of Engineers, Charles Kolb and Jack Van Lopik described the delta as “a land between Earth and sea—belonging to neither and alternately claimed by both.”

Five decades later, southeastern Louisiana remains in this timeless tug of war between land and water. Residents continue to bury their dead above ground and safe from the shallow water table. In New Orleans, twenty pumping stations

drain the land of 85 billion liters (22.5 billion gallons) of water each day. However, the massive artificial levees built to protect communities from seasonal flooding have instead caused the land to be more vulnerable to water. Scientists say the 560 kilometers (350 miles) of levees prevent the river from replenishing the delta with new sediment, causing parts of the land to sink further below sea level. This, and the increase in flooding, have left communities extremely vulnerable to damage from hurricanes, such as Hurricane Katrina in 2005.

Zhong Lu, a physical scientist at the Earth Resources Observation and Science Data Center in Sioux Falls, South Dakota, was drawn to the delta’s unique, if complex, geological processes.



Satellites can detect water-level changes in forested swamps like this bald cypress forest in Louisiana. Swamp water levels are important to ecosystem health. (Courtesy E. Leger)

Lu was interested in land subsidence, or the sinking of the Earth's surface in response to geologic or human-induced causes. Lu said, "I wanted to make a map of how land was sinking in and around the New Orleans area using remote sensing. Instead, I saw interesting signals from the delta's swamps and marshes." Lu suspected he had found a more efficient way to detect water-level changes, a process that is crucial to flood hazard modeling and wetland management in the delta.

Watching the delta sink

Lu was a volcano man; his expertise was volcano deformation mapping and monitoring using satellite imagery. More importantly, Lu specialized in a remote sensing technique highly favored in geologic and geophysical research. Satellite-based Synthetic Aperture Radar (SAR) rapidly shoots beams of radar waves towards the Earth and records them after they bounce back off the Earth's surface. Image maps are made from these signals, and experts combine two such maps of the same area, taken at different times. The resulting image, called an interferogram or InSAR, uses color to show how parts of a land surface—around a volcano, for example—have moved. "This is why the technique is primarily associated with the study of volcanoes, earthquakes, and land subsidence," Lu said.

However, it was not difficult for Lu to shift from volcanoes to looking at the delta's sinking land, and then to studying its swamps and marshes. "I am very interested in exploring the use of InSAR on broad geophysical, geological, as well as hydrological problems," he said. "If we can demonstrate that the technique can measure water-level changes, it would be a great discovery. It could improve accuracy in flood hazard modeling and assessment."

Stephen Faulkner, an ecologist at the National Wetlands Research Center in Lafayette, Louisiana, said that monitoring water levels is crucial not only in flood hazard modeling but also in wetland ecology and management. Scientists need long-term records of water levels to understand how swamp forests can regenerate under changing conditions. Faulkner said, "Coastal Louisiana has changed a lot over the last hundred years. There has been a lot of subsidence and coastal land loss, and the hydrology has changed across entire landscapes, resulting in longer and deeper flooding. When the water is too deep for too long, even flood-tolerant trees like bald cypress and water tupelo cannot regenerate." Some forested wetlands turn into areas with smaller or no vegetation or are converted to permanent open water. This is a concern because logging of bald cypress and water tupelo forests in the deep water areas will accelerate the loss of these forests and the ecosystem services they provide.

On a larger scale, scientists say the entire delta will continue to sink at a rate of 5 to 10 millimeters (0.19 to 0.39 inches) and lose 6,500 hectares (16,000 acres) of wetlands each year. But accurate and long-term water-level measurements can help experts identify areas suitable for either artificial or natural regeneration and protect some wetland areas from complete loss.

Under the canopy

Scientists have used in situ gauge measurements in wetlands to assess flood hazards and record water-level changes. Lu said, "But this method is cost prohibitive. Insufficient measurements cause significant errors in hydrologic simulations. Satellite sensors can be a cost-effective tool to monitor water-level changes. Satellites take



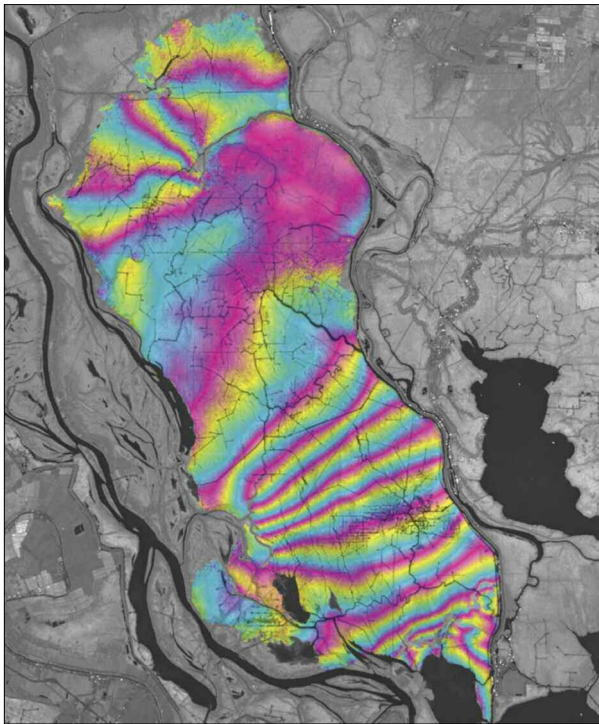
Louisiana's interconnected swamps and bayous provide habitat for a variety of wildlife, such as this great blue heron. (Courtesy E. Anestad)

measurements more frequently and cover a wider area."

Lu wanted to know if the InSAR remote sensing method for studying land deformation could detect water-level changes in wetlands. He focused his study on southeastern Louisiana, an area that encompasses almost 40 percent of the coastal wetlands of the lower forty-eight United States. Wetlands are transitional areas that are sandwiched between permanently flooded deepwater environments and well-drained uplands. They buffer the land from storms and floods. In Louisiana, wetlands include swamps, mangroves, marshes, and bogs, all fed with fresh water and sediment from the Mississippi River and salt water from the Gulf of Mexico. Muskrats, otters, minks, and alligators inhabit these soggy wetlands. Crawfish burrow in the mud, and bald cypress and water tupelo trees form green canopies over the remaining swamp forests. Could radar waves even penetrate a swamp forest canopy enough to get bounced off water and back to the satellite? Would the technique work, considering the large variety of vegetation that the radar waves had to penetrate to get bounced off of water?

Penetrating a swamp forest

Lu recalled that Doug Alsdorf, a hydrology expert and professor at the School of Earth Sciences at Ohio State University, demonstrated in 2000 that radar waves could bounce off water underneath the thick and tall forest canopy of the Amazon River in South America. Alsdorf had used L-band radar signals with a wavelength of 24 centimeters (9.4 inches). Lu had been using C-band signals with an even shorter wavelength when he accidentally picked up interesting signals from the delta's swamp forest. "I asked myself, can SAR C-band images be used to monitor water-level changes?" Lu said.



This InSAR image captures the dynamic water-level changes over the Atchafalaya Basin in southeastern Louisiana from May 22 to June 15, 2003. Scientists use the color bands to detect water-level changes through time. (Courtesy Z. Lu, O.-I. Kwoun)

First, Lu needed to find out if C-band radar waves could penetrate the vegetation and if their backscattering behaviors would characterize vegetation in the study area. To do this, Lu and his colleague Oh-Ig Kwoun consulted maps and determined that southeastern Louisiana had six major classes of vegetative cover: bottomland forests, swamp forests, freshwater marshes, intermediate marshes, brackish marshes, and saline marshes. They then compared these classes to data from Synthetic Aperture Radar (SAR) sensors on the RADARSAT-1 satellite, distributed by the NASA Alaska Satellite Facility Distributed Active Archive Center (ASF DAAC), and from the European Remote Sensing (ERS) satellites ERS-1 and ERS-2. "The data showed that SAR signals can be used to classify existing vegetation over wetlands," Lu said. "Multiyear and season-averaged observations would provide more robust results."

With an idea of how C-band radar behaves over different kinds of wetland vegetation, Lu and Kwoun generated interferograms. They found that a specific C-band wavelength of 5.66 centimeters (2.2 inches) was suitable for producing InSAR images from the moderately dense tree canopies and other vegetation in Southeastern Louisiana. Lu said, "The images had an unprecedented degree of vertical accuracy. InSAR can indeed be used to estimate water-level changes. But there are limitations, so we have more questions to explore."

Tools for precision

One of these limitations is that the technique requires the presence of vegetation in the water to allow radar pulses to be bounced back to the sensor. So during intense flooding where the water is higher than the vegetation, InSAR is useless. Another limitation is that water-level changes

differ from point to point. In an ideal situation, water flows placidly over a symmetrical, smooth surface devoid of obstruction. But southeastern Louisiana's wetlands have barriers, such as levees. Measurements from gauge stations are still required to calibrate SAR measurements.

Alsdorf, whose work on L-band radar encouraged Lu to pursue his own research questions regarding InSAR and wetlands, said that scientists have a long way to go in finding out how much water exists at any one place at any point in time. Alsdorf said, "In the world of surface water hydrology, we have sparse measurements and knowledge of how much water is on the planet at any one place or time. But the exciting thing about Lu's work is that in certain cases like the Louisiana swamp forest, C-band will penetrate a particular forest canopy. We are talking about trying to use highly specialized tools—the C-band satellite for one location, the L-band satellite for another location—to piece together how water is flowing through these wetland environments. That is exciting scientific work."

To preserve and protect

As Lu resolves the limitations of the technique, more scientists are recognizing possibilities for using InSAR in understanding the delta's hydrology. In Louisiana, Faulkner is compiling in situ measurements from the Atchafalaya Basin to confirm SAR data. A science working group has recognized the importance of remotely sensed data in studying the delta's changing hydrology. In their report to the Governor, the Coastal Wetland Forest Conservation and Use Science Working Group said, "Adding remotely sensed data . . . should be aggressively pursued.

Such data are critical to wisely manage and care for the coastal forest wetland system of Louisiana.”

Lu plans to improve his methods by using other remote sensing data, such as data from the NASA Ice, Cloud, and Elevation Satellite (ICESat), to refine estimates on absolute water changes. He may also use data from a radar altimeter to provide temporal and spatial variations of water-level height. Lu said, “I have been using InSAR for ten years to study volcanoes and earthquakes. But personally, I feel that I learned more when I looked at this question.” Lu is not leaving his field of specialty, but he is hopeful that his discovery will help in the preservation of the delta’s wetlands and in the protection of communities that have chosen to make southeastern Louisiana their home.

To access this article online, please visit
http://nasadaacs.eos.nasa.gov/articles/2008/2008_wetlands.html.



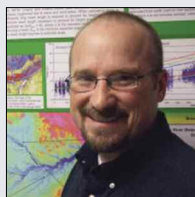
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About the remote sensing data used

Satellite	RADARSAT-1
Sensor	Synthetic Aperture Radar (SAR)
Data set used	C band
Resolution	10 to 100 meter
Parameter	Water level
Data center	NASA Alaska Satellite Facility DAAC

About the scientists



Doug Alsdorf is an assistant professor at the School of Earth Sciences at Ohio State University (OSU). He conducts research in hydrology, tropical wetlands, and geophysics. He also leads the United States segment of the upcoming NASA Surface Water Ocean Topography mission. OSU and NASA funded his research. (Photograph courtesy T. C. Brown)



Stephen P. Faulkner is a research ecologist at the United States Geological Survey (USGS) National Wetlands Research Center. His research interests center on biogeochemical processes in wetland ecosystems, their responses to disturbance, and the associated linkages to wetland restoration, ecosystem services, and global climate change. The USGS and the United States Department of Agriculture funded his research. (Photograph courtesy S. P. Faulkner)



Zhong Lu is a physical scientist at the USGS Earth Resources Observation and Science Center and Cascades Volcano Observatory. His research focuses on technique developments of Synthetic Aperture Radar (SAR), InSAR, persistent scatterer InSAR processing, and applications of InSAR. USGS, NASA, the European Space Agency, Japan Aerospace Exploration Agency, and the German Space Agency funded his research. (Photograph courtesy J. Lu)

For more information

NASA Alaska Satellite Facility Distributed Active Archive Center: SAR Data Center
<http://www.asf.alaska.edu/sardatacenter>
NASA Surface Water Working Group
<http://www.geology.ohio-state.edu/swwg>

USGS National Wetlands Research Center
<http://www.nwrc.usgs.gov>
About Zhong Lu
<http://volcanoes.usgs.gov/insar/zhong.html>

Regional pollution goes local



“We wanted to show the impact that satellites can have on studying air quality in the lowest portion of the atmosphere.”

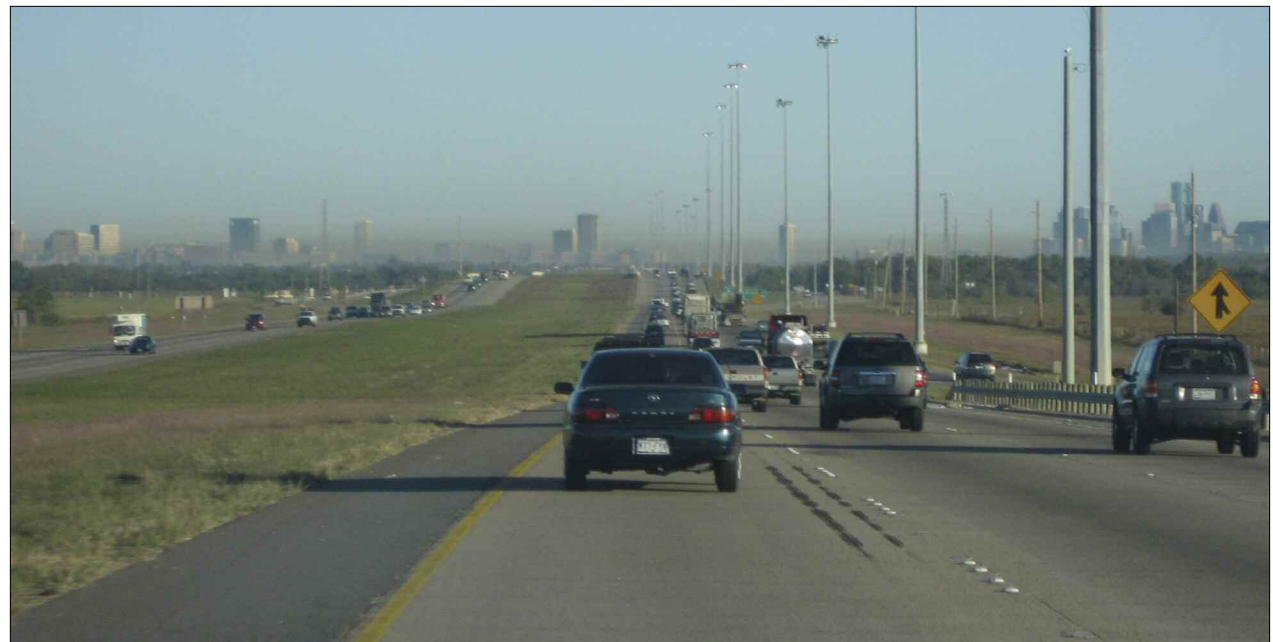
Wallace McMillan
University of Maryland

by Laura Naranjo

Houston has some of the most polluted air in the United States. The city and the ship channel that leads south to the Gulf of Mexico bustle with industrial activity, producing an unintended byproduct that affects the entire southeastern portion of Texas: air pollution. Currently, Houston and several other urban areas in southeastern Texas do not meet air quality standards established by the United States Environmental Protection Agency (EPA). The state of Texas has conducted several field studies, which revealed the largest pollution sources in the congested southeastern part of the state.

However, officials found that efforts to reduce pollution produced in their cities have not consistently improved air quality.

To determine why some cities still fail to meet EPA air quality standards, experts needed more information about how regional and even national pollution might be circulating into Texas. The most recent study, conducted in 2005 and 2006, collected data over the eastern half of the state and included remote sensing data from the Atmospheric Infrared Sounder (AIRS) instrument, flown on the NASA Aqua satellite. Wallace McMillan, an AIRS science team member, said, “We wanted to show the impact



A shroud of smog hangs over Houston in this November 2006 photograph. Although air pollution tends to be more common during hot summer months, air quality can be poor at any time of the year. (Courtesy I. Bettinger)

that satellites can have on studying air quality in the lowest portion of the atmosphere.” By incorporating satellite data, scientists could observe not only how pollution circulated within the state, but also whether some of the pollution measured in Texas originated farther afield.

Local versus regional

Vehicles, manufacturing plants, and coal-burning facilities emit chemicals that cause air pollution. Some of these chemicals, when combined with sunlight and high temperatures, react in the atmosphere to form ozone, the primary ingredient in urban air pollution. Experts focus on ozone because it is an indicator of overall air quality. Too much ozone can make breathing difficult, aggravate asthma, and cause lung damage. Consequently, the EPA regulates ozone levels, requiring cities to measure ambient levels hourly, averaged over each eight-hour period daily.

The EPA ozone standard is 80 parts per billion (ppb), but because of how measurements are calculated, cities do not violate the standard until ozone levels exceed 84.5 ppb. An extended record of violations can have severe consequences. Mark Estes, a senior air quality scientist with the Texas Commission on Environmental Quality, studies Houston’s air pollution. Estes said, “If the EPA deems that you are not making enough progress, their ultimate penalty is to withdraw your highway funding. That really gets people’s attention.”

Officials are discovering that air pollution is not just a local problem, however. Regional and continental air circulation patterns frequently carry pollution from one area to another. But whether pollution is from a local factory or from another state, cities are expected to meet EPA



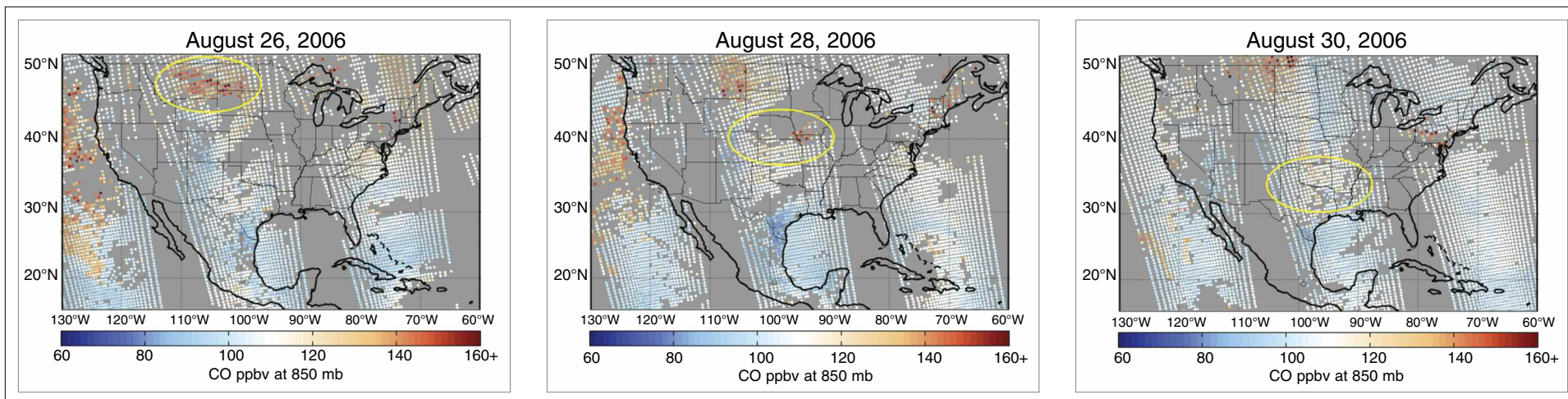
This photograph, taken at dawn in August 2006, shows an oil refinery in Corpus Christi, Texas. Emissions from the petrochemical and shipping industries that operate along the coast often affect air quality in southeastern Texas. (Courtesy C. Young)

standards. “If your city has, for example, sixty or sixty-five ppb of ozone blowing in from somewhere else, then the city doesn’t have to produce very much to exceed the standard,” Estes said. “The higher the ambient ozone levels are, the more difficult it is to attain the standard.” The EPA does not allow cities to subtract drifting pollution from their measured ozone levels, meaning that a city like Houston must lower local emissions even further to accommodate pollution that drifts in.

To measure how much pollution was drifting into eastern and southeastern Texas, the state organized the Texas Air Quality Study II (TexAQS II), a collaboration between NASA, the State of Texas, the National Oceanic and Atmospheric Administration (NOAA), and other federal partners. TexAQS II was an eighteen-month study completed in 2006, during which researchers

collected data from ground instruments, aircraft, ships, and satellite data. Remote sensing was particularly important for the intensive field study portion, conducted between August and October, which was strategically timed to capture Houston’s worst air quality days.

McMillan helped provide satellite data during the field study. McMillan said, “We provided AIRS data in as close to near-real time as possible to assist in flight planning for fleets of aircraft making in situ air measurements of air quality around Houston.” AIRS data revealed where high levels of carbon monoxide and other pollutants occurred in the atmosphere over southeastern Texas, determining exactly where the aircraft should fly each day. McMillan retrieved the AIRS data from the NASA Goddard Earth Sciences Data and Information Services Center (GES DISC) and the NOAA



During the summer of 2006, large wildfires burned in Montana and Idaho, and the resulting smoke drifted more than 2,090 kilometers (1,300 miles) to Texas on August 26, 28, and 30. These maps show carbon monoxide from the fires at approximately 1.5 kilometers (0.93 miles) in altitude. Red and brown dots indicate the highest amounts of carbon monoxide, and the yellow ovals show the smoke drifting south. Even though the carbon monoxide had diluted by the time it reached southeastern Texas, it still contributed to poor air quality in Houston on September 1 and 2. (Courtesy W. McMillan, from Aqua AIRS)

National Environmental Satellite, Data, and Information Service (NESDIS). “The people at GES DISC were very helpful, and the data center was instrumental in providing the data,” he said.

Discovering the pollution plume

Even as McMillan and his team provided daily satellite data to guide aircraft flights within the state, remote sensing also permitted the investigators to view larger drift patterns. Estes said, “A satellite can observe large-scale movements of air much better than one or two airplanes or a bunch of ground stations can. Satellite data can often reveal a causal link if you can track the pollutant plume from its origin all the way to the city of interest, kind of a source-receptor relationship.” During the field study, air quality experts discovered where some of Houston’s pollution was coming from.

Scientists had already used satellite data to track air pollution from China wafting to North America, and had followed smoke from Brazilian forest fires streaming across the tropics. But AIRS data revealed that the pollution drifting into Houston came from less exotic sources. McMillan said, “One of the biggest impacts that we saw was actually smoke from extensive forest fires in Montana and Idaho. During late August, air pollution from the fires was transported right down across the Great Plains into Texas.” The wildfire smoke, generated between August 26 and 30, drifted 2,090 kilometers (1,300 miles) before blowing into Houston in early September. At the same time, air pollution from the Midwest also drifted into southeastern Texas. Consequently, on September 1, ozone levels in Houston reached 129 ppb. “It was one of the worst ozone events in Houston during the summer of 2006,” McMillan said. “Houston’s poor

air wasn’t caused by the drifting pollution, but it was influenced by it.”

Observing how and when pollution was transported into the state helped air quality experts understand the role drifting pollution played in compounding Houston’s already poor air quality. During certain summer days, when Houston’s ambient ozone levels were already high, enough pollution drifted in to produce unacceptable ozone levels. The study helped define an additional challenge for the state: because cities in Texas have no control over pollution generated elsewhere, they must make up for that by more strictly regulating what they can control—their own emissions.

Mitigating the drift

Estes and other air quality officials rely on data from studies like TexAQS II to formulate state air quality programs. They enter the findings

into computer-modeled emission scenarios, extrapolate current emissions into the future, and estimate where the state could reduce emissions. For instance, what if industrial plants emitted fewer pollutants, or what if vehicles passed tighter emissions standards? Estes said, “You can run different scenarios and discover the consequences of various emission reductions.” The state then negotiates with local governments and industries to decrease emissions. The resulting package of reductions, explaining how the state will mitigate air quality problems, goes to the EPA.

The field portion of the TexAQS II study confirmed that pollutants from one source might affect a community thousands of miles away. The study also proved that effectively tracking long-distance pollution drift requires broader coverage, so cities like Houston are beginning to incorporate remote sensing into their air quality management. Estes said, “To get data over large areas, you often have to rely on satellite data. If you have good satellite data, you can fill in the blanks between your monitoring stations.” It is an ongoing challenge, but every new source of information supplies experts with one more way to refine pollution models and negotiate emission reductions.

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About the remote sensing data used

Satellite	Aqua
Sensor	Atmospheric Infrared Sounder (AIRS)
Data set used	Level 1B AIRS Infrared Geolocated Radiances
Resolution	13.5 kilometer
Parameter	Carbon monoxide
Data center	NASA Goddard Earth Sciences Data and Information Services Center

About the scientists

Mark Estes is a senior air quality scientist at the Texas Commission on Environmental Quality. He served as primary technical contact for the Texas Air Quality Study II, and his interests include analysis of photochemical grid modeling, biogenic emissions modeling, applied research planning for air quality, and analysis of monitoring data. His work supports air quality planning for the State of Texas.



Wallace McMillan is an associate professor at the University of Maryland, Baltimore County, and is affiliated with the Joint Center for Earth Systems Technology. His group’s research focuses on ground-, air-, and space-based remote sensing of atmospheric pollution for local and regional air quality studies; monitoring changes in emission sources, particularly forest fires; and assessing the impacts of long-range transport. NASA funded his Texas air quality research. (Photograph courtesy W. McMillan)

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For more information

NASA Goddard Earth Sciences Data and Information Services Center (GES DISC)
<http://disc.gsfc.nasa.gov>

Atmospheric Infrared Sounder (AIRS)
<http://www-air.jpl.nasa.gov>

Texas Air Quality Field Study II (TexAQS II)
<http://www.tceq.state.tx.us/nav/eq/texaqsII.html>

Texas Commission on Environmental Quality (TCEQ)
<http://www.tceq.state.tx.us>

Wallace McMillan
<http://physics.umbc.edu/~mcmillan>

Younger sea ice and scarcer polar bears



“The perennial ice is the mainstay of the Arctic ice cover.”

Joey Comiso

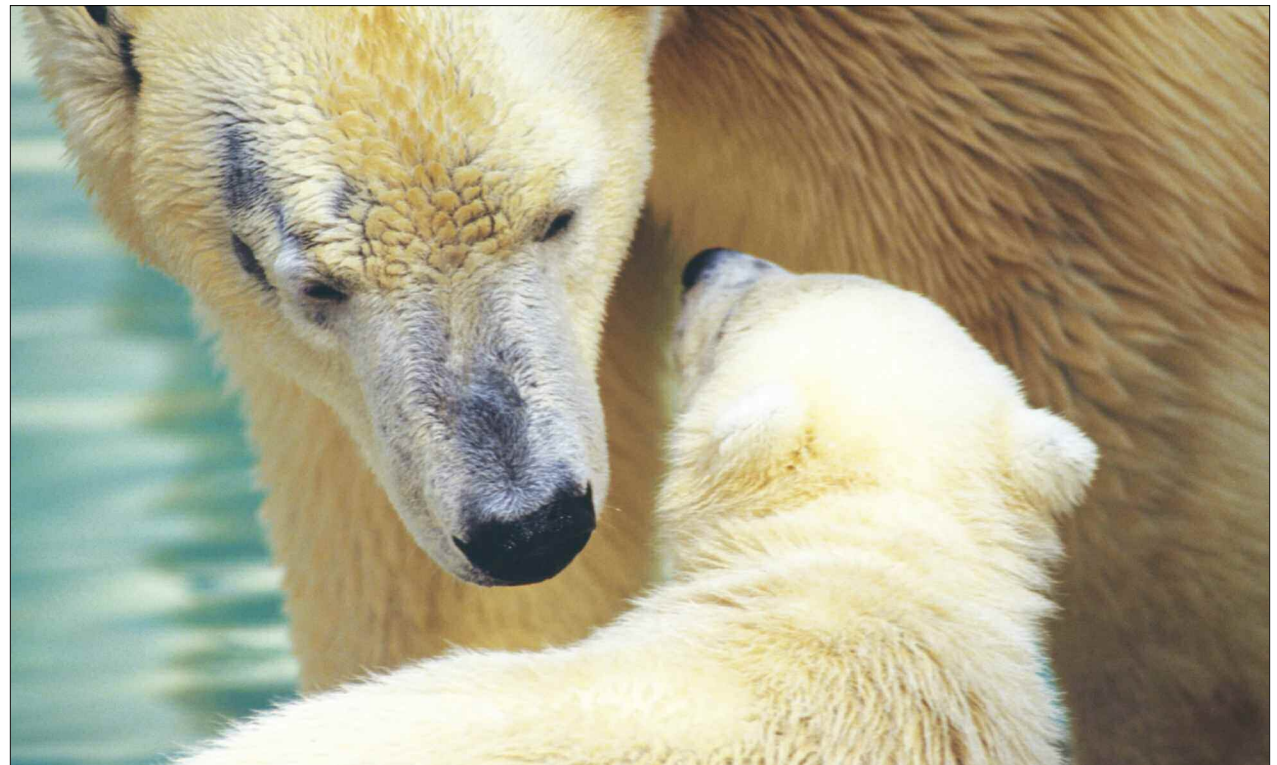
NASA Goddard Space Flight Center

by Jane Beitler

In late summer of 2005, sea ice covering Arctic waters shrank to the lowest extent ever measured in nearly thirty years of satellite records. This record low was quickly shattered in 2007, and nearly again in 2008; yet these lows were only the exclamation points in decades of decline, a trend that scientists say is increasingly unlikely to slow or reverse. The changes that cascade from dwindling Arctic sea ice affect polar bears, whose lives are closely tied to

seasonal ice cycles. George Durner, a research zoologist said, “Polar bears evolved to take advantage of an empty niche on the surface of the sea ice, which is key to their survival.”

The 2005 record low spurred the United States Department of the Interior to ask for scientific projections of polar bear survival and population trends into the 21st century. The news was not good: if sea ice declines at the rate that scientific models predict, only one-third of the world’s polar bears will survive by the end of the 21st century.



Arctic sea ice provides critical habitat for polar bears. Researchers are increasingly concerned that negative trends in summer sea ice extent may affect polar bear reproduction and species survival. (Courtesy Photos.com)

Durner, who helped develop the polar bear outlook, relies on data about sea ice changes from researchers like Joey Comiso, a sea ice specialist at NASA Goddard Space Flight Center. Comiso has studied sea ice using satellite data for years, but recently he began to focus on changes in perennial ice, the older, thicker ice that persists through the summer melt season. The data lead Comiso and Durner to think that both summer sea ice and bears may be at risk of vanishing much sooner than anyone thought.

The cycle of ice and bears

Durner, a longtime polar bear researcher at the United States Geological Survey (USGS) Alaska Science Center, knows what sea ice and its cycles mean to bears. He said, “In the eye of the polar bear, not all sea ice is equal. Bears seem to prefer sea ice that’s relatively extensive, as a platform for hunting and for safety from ocean storms.” Bears take refuge in the drifts next to pressure ridges of sea ice piled up by wind and ocean currents. From autumn until spring, bears in the Beaufort Sea find the best sea ice conditions in the area between shore-fast sea ice and the active sea ice pack.

In summer, sea ice melts first along the heat-absorbing Alaskan coastline. Durner said, “Polar bears find cracks in the ice pack that are narrowly open or thinly frozen over, for hunting seals.” Most bears in the Beaufort and Chukchi Seas stay on the main pack to hunt, as it recedes miles from shore. Durner said, “Bears distribute themselves along the ice edges, where they have better access to seals.” Outside of the main ice pack, isolated ice floes break into smaller floes or large patches of unconsolidated ice. Bears that are isolated from the main pack or land use these floes like a series of floating islands for hunting or resting. Eventually the floes become too small

for a bear, which may have to swim to the main ice pack or to land.

In fall, ice and bears return nearer to shore. “As autumn progresses, temperatures cool, and ice begins to form again. Bears follow that leading edge of ice south, eventually occupying the shallow waters of the continental shelf, where the seal population is highest,” Durner said. Then polar bears build fat stores necessary for winter survival, and pregnant females in particular fatten in early autumn to fuel their long winter fast and the nursing of their cubs. Later in autumn, they look for winter birthing dens near the coast or on stable ice pack, near good hunting habitat. Long swims between sea ice and shore deplete their body stores, affecting their reproductive success.

How fast and how much change?

The receding summer sea ice edge means bears are placed further from this productive seal habitat. Durner said, “Right now in September, the edge of the main pack in the Beaufort Sea is more than 400 miles north of Alaska. Many polar bears are in deep water areas where few seals are available, or bears are on melting floes surrounded by miles of open ocean. What does it mean for polar bears that have to summer for a long time in the deep water? How do they fare compared to bears that summer on land, and what are the energetic costs to bears forced to swim long distances?”

For pregnant females in the southern Beaufort Sea, the receding ice edge has lengthened their travel between ice pack and dens by six to eight kilometers (four to five miles) each year since 1979. As sea ice recedes even faster, by 2060 the distance may reach 1,500 kilometers (932 miles), increasing the time for bears to reach their dens by nearly a month. Durner and colleagues looked

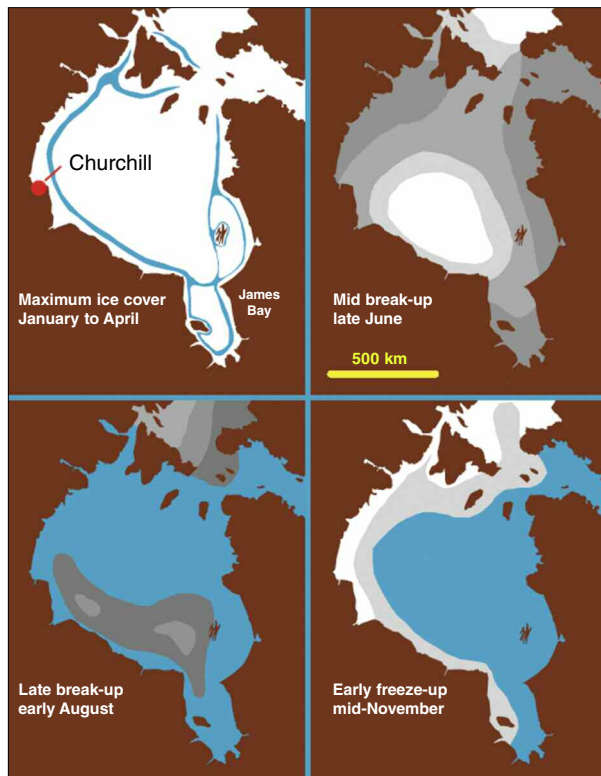
at relationships between sea ice conditions, polar bear body condition, and population patterns. For future sea ice projections, they turned to scientific climate models.

The climate models used several data sources, including sea ice trends from the satellite record. For years, Comiso and other sea ice researchers had watched summer’s low mark sink lower, in a slow but steady trend. Data from three satellite sensors provide year-to-year comparisons of sea ice conditions: the Scanning Multichannel Microwave Radiometer (SMMR), the Special Sensor Microwave/Imager (SSM/I), and the Advanced Microwave Scanning Radiometer for Earth Observing System (AMSR-E), all archived at the National Snow and Ice Data Center Distributed Active Archive Center (NSIDC DAAC). From 1978 to 2007, the annual sea ice cover declined by 3 to 4 percent each decade; but after 1996, the decline accelerated. “All of a sudden, the decline changed to 10 percent per decade,” Comiso said. Researchers knew that the loss of sea ice, which insulates the ocean and reflects solar radiation, would create conditions that allow it to melt even faster.

The models used this increased rate of decline for their ice projections, which the researchers in turn used in their polar bear studies. But as they completed their studies in 2007, the polar bear researchers heard news that added even more gloom to the population projections. Sea ice researchers reported that Arctic ice was declining even faster than the models had estimated. If sea ice was declining faster, it might accelerate the decline of polar bear populations even more. What was speeding up the decline of sea ice? Comiso thought that one of the factors the models were not accounting for was the increasing loss of older, thicker sea ice.

Younger and thinner

As summer turns into fall, the Arctic begins to cool. During the onset of the long dark winter, virtually all of the Arctic Ocean refreezes, but Comiso knew it was not that simple. He said, “I started looking at other types of ice that people normally ignore. The old ice that was normally able to survive summer months, year in and year out, is disappearing.” This perennial ice was declining by 12 percent per decade.



Sea ice is a key habitat for polar bears. These four diagrams show the seasonal patterns of sea ice concentration in Hudson Bay, on the northern Canadian coast. White areas contain nearly solid sea ice; grays indicate lower concentrations of ice; blue indicates open water. (Courtesy G. Durner)

Comiso examined the perennial ice, which has survived two to seven summer melts. “The perennial ice is the mainstay of the Arctic ice cover. It’s the base from which the seasonal ice builds up during the end of summer,” Comiso said. As it ages, it becomes thicker, two to four meters (seven to thirteen feet) on average. When fall and winter set in, even more ice builds up on this surviving ice layer.

The thick ice is better able to endure through summer than the thinner ice. But because so much ice has melted in recent summers, Arctic sea ice now consists increasingly of thinner, first-year ice, averaging around a meter (three feet) thick. On average, perennial ice appears to be getting younger, and therefore thinner. “If you have a thinner ice cover, then it is more vulnerable to totally melting during the summer,” Comiso said. Sea ice models lacked data on trends in older ice.

To help distinguish ice age in satellite data, researchers started with knowledge about older ice handed down from native Arctic people. For ages, Inuit have used older ice as a source of drinking water: they knew that after a few years, sea ice loses its saltiness. Freezing, thawing, and refreezing over several years causes salty brine to drain out of sea ice. So scientists found that ice that has survived at least one melt season had unique characteristics that made it transparent to radiation. Air pockets and other inconsistencies within this ice also scatter much of the radiation before it reaches the satellite sensor. Comiso used this information to classify the ice by age, which gave him information about variability and trends in the age of the ice cover. Now he could better understand the rapid decline in perennial ice.

Comiso refined the algorithms for obtaining ice age, using AMSR-E data as the baseline, since it

has higher resolution and a wider swath than the other sensors. He was able to look closely at the long time series of sea ice growth and melt, resolving ice classes by analyzing and comparing data from the instrument’s multiple frequencies. AMSR-E also provides more data around the geographic North Pole, which is typically covered by perennial sea ice.

The AMSR-E data, together with the historical SMMR and SSM/I data, helped Comiso confirm the faster retreat of the old ice. Although all types of ice are declining, including both seasonal ice and ice that is two or more years old, the oldest ice was declining the fastest. He said, “Compared to total ice extent and perennial ice extent, the trend for sea ice that is at least three years old is even steeper. This ice type is declining by 14 percent per decade.”

The balance of the ice

Comiso thinks that the accelerating loss of older ice suggests that the perennial ice pack will eventually disappear. The function of perennial ice in the Arctic can be compared to a thick block of ice in a picnic cooler, which will stay frozen longer than small ice cubes that have many exposed surfaces. In a similar way, the greater mass of thicker, older sea ice resists melting. Starting each summer with an increasingly thinner, first-year ice cover, the Arctic Ocean could be ice free in summer much sooner than anyone ever thought possible.

Without summer sea ice for hunting, polar bears will struggle to survive, if they do at all. For now, despite the challenges, bear populations are holding up in some areas. Durner said, “We haven’t measured a decline in the Beaufort Sea population, as researchers have observed in

western Hudson Bay in Canada. But in the Beaufort Sea, we see a relationship between poorer body condition and low sea ice years, and lower survival following a year of reduced sea ice. These are the same conditions researchers observed just before the Western Hudson Bay population declined.”

Durner will go out on the ice next summer to see firsthand how the bears are faring. Then before the long, dark Arctic winter, he will return to land and use satellite data for a closer look at the cycle of sea ice in each bear habitat area. He said, “Having consistent passive microwave data since the 1970s has been so critical to our research over the past several years. If we didn’t have that data available, I don’t know where we would be.”

To access this article online, please visit http://nasadaacs.eos.nasa.gov/articles/2008/2008_seaice.html.



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About the remote sensing data used

Satellite	NASA Aqua	Nimbus-7, Defense Meteorological Satellite Program (DMSP)
Sensor	Advanced Microwave Scanning Radiometer for Earth Observing System (AMSR-E)	Scanning Multichannel Microwave Radiometer (SMMR), Special Sensor Microwave/Imager (SSM/I)
Data sets used	AMSR-E/Aqua Daily L3 12.5 km Brightness Temperature, Sea Ice Concentration, & Snow Depth Polar Grids	Bootstrap Sea Ice Concentration from Nimbus-7 SMMR and DMSP SSM/I
Resolution	12.5 kilometer	25 kilometer
Parameters	Brightness temperatures, sea ice concentration, snow cover over sea ice	Brightness temperatures, ice extent, sea ice concentration
Data center	NASA National Snow and Ice Data Center DAAC	NASA National Snow and Ice Data Center DAAC

About the scientists

Josefino “Joey” Comiso is a senior research scientist in the Cryospheric Sciences Branch at NASA Goddard Space Flight Center. His research interests include climate change studies in the polar regions as inferred from historical satellite data with emphasis on passive microwave and infrared techniques. He has developed numerous algorithms and data sets related to sea ice extent, concentration, surface temperature, albedo, and clouds, and analyzed sea ice data for trends. NASA supported his research.



George Durner is a research zoologist at the United States Geological Survey (USGS) Alaska Science Center. He specializes in studies of spatial patterns of polar bears relative to reproductive status, habitat, and prey distribution, including mapping polar bear dens and using remote sensing to locate dens. The USGS supported his research. (Photograph courtesy G. Durner)

For more information

NASA National Snow and Ice Data Center DAAC
<http://nsidc.org>
 NASA Goddard Space Flight Center Cryospheric Sciences Branch: Josefino Comiso
http://neptune.gsfc.nasa.gov/csb/personnel/index.php?page=profile&pers_id=4

Alaska Science Center: George Durner
<http://alaska.usgs.gov/staff/staffbio.php?employeeid=137>
 Polar Bear Research at the Alaska Science Center
http://alaska.usgs.gov/science/biology/polar_bears

Scorecard on the environment



“A lot of the things that matter most are hard to measure—things like halting deforestation, conserving freshwater quality, or preserving biodiversity.”

Marc Levy

NASA Socioeconomic Data and Applications Center

by Laura Naranjo

Daniela Rivera and her colleagues are planting seeds of success in Nicaragua’s forests: millions of tree seeds. Rivera, vice-chair of a tree nursery, worked with six other nurseries during 2007 to plant more than 1.4 million trees. Each tiny sapling will ultimately supply forestry projects and plantations. Together, nurseries like Rivera’s are growing an industry that provides much-needed

jobs and a steady income for rural residents. In addition, Rivera and her colleagues are following environmental best practices that will help sustain, rather than exploit, forests in Nicaragua.

Policy makers are discovering that protecting and maintaining their nation’s environment can benefit economic development, and a growing global movement is encouraging countries to treat



The glasswing butterfly feeds on the nectar of flowers that grow in Nicaragua’s rainforests. Deforestation destroys habitat critical to the glasswing and many other insect and animal species. (Courtesy B. Garland)

natural resources as investments, similar to basic societal infrastructure. Marc Levy, a project scientist for the NASA Socioeconomic Data and Applications Center (SEDAC), said, “In the same way that a country would spend money every year to maintain its trains and roads, countries are starting to think of their water, forest, and soil resources as if they were capital assets. If they run them down, they’re going to pay a price.”

Nicaragua’s government now supports and encourages the tree nurseries, and this effort is just one example of how countries are investing in their environment. However, many governments like to see data before they decide where to invest. Policy makers need to know which resources are being successfully managed and which may need more protection. Some factors, such as air quality, are easy to monitor and regulate. But factors such as habitat degradation and ecosystem health are hard to track; without data, officials cannot easily remedy problems. “A lot of the things that matter most are hard to measure—things like halting deforestation, conserving freshwater quality, or preserving biodiversity,” Levy said. “It turns out that it’s very difficult to get data that lets you measure and compare environmental resources in a rigorous way.”

Measuring up

To overcome the difficulty of gathering environmental data, Levy and his colleagues at SEDAC partnered with the Yale Center for Environmental Law and Policy to locate data that were comparable worldwide. However, many governments lacked the resources or desire to measure environmental factors. “I think there’s kind of a chicken-and-egg problem going on,” Levy said. “Because many governments aren’t

getting good measurements, they don’t set clear goals. And then, the fact that many countries don’t have goals undermines the incentives to measure these environmental factors.”

Consequently, to fill gaps in the data, Levy and his colleagues frequently had to consult specialists in different areas, such as marine fisheries, sustainable agriculture, water resources, and biodiversity conservation. The researchers also collaborated with various international agencies that gathered environmental information, such as the World Health Organization, the United Nations, and The Nature Conservancy.

Levy and his colleagues used the data to compile a pilot report in 2000, which ranked countries according to their environmental performance. As more data became available over time, the researchers refined subsequent reports to better match policy categories that many countries had established. They also revised the reports to define specific outcomes for governments to aim for. “It makes sense to start setting some targets and measuring progress,” Levy said. “These things can be tracked, if people put resources into gathering the data.”

For the most recent report, the *2008 Environmental Performance Index (EPI)*, the researchers tried to be as inclusive as possible, although there were some gaps. They could find sufficient comparable data for only 149 countries, leaving out more than 80. They also lacked data on some important indicators, such as wetlands loss and waste management. However, they added a number of new and improved indicators, including the measure of burned land area based on 1-kilometer- (0.6-mile-) resolution remote sensing data.

Rank	Country	Score
1	Switzerland	95.5
2	Sweden	93.1
3	Norway	93.1
4	Finland	91.4
5	Costa Rica	90.5
6	Austria	89.4
7	New Zealand	88.9
8	Latvia	88.8
9	Colombia	88.3
10	France	87.8
11	Iceland	87.6
12	Canada	86.6
13	Germany	86.3
14	United Kingdom	86.3
15	Slovenia	86.3
16	Lithuania	86.2
17	Slovakia	86.0
18	Portugal	85.8
19	Estonia	85.2
20	Croatia	84.6
21	Japan	84.5
22	Ecuador	84.4
23	Hungary	84.2
24	Italy	84.2
25	Denmark	84.0

The 2008 *Environmental Performance Index (EPI)* ranked 149 nations according to 25 indicators. For a full listing, see <http://sedac.ciesin.columbia.edu/es/epi>. (Courtesy 2008 EPI)

The 2008 EPI ranks countries based on two objectives. “Environmental health” assesses environmental conditions that directly affect human health: air quality, sanitation, and safe drinking water. “Ecosystem vitality” measures how well a country protects its natural resources and maintains healthy ecosystems. The objectives are broken down into twenty-five indicators, or specific outcomes, that policy makers can track over time. “These indicators represent realistic targets against which governments can compare themselves and measure their progress,” Levy said.

While most industrialized nations scored well in environmental health, some developing nations still struggle to provide basic infrastructure for human welfare. For instance, the United States scored 98.5 in environmental health; Nicaragua scored 72.9. But the scores also penalized unsustainable activity that destroys natural resources or generates unclean air. The United

States continues to emit the most carbon dioxide per person, which factored into its ecosystem vitality score of only 63.5, falling below Nicaragua’s score of 74.0.

Healthy ecosystems, healthy people

The EPI did not look at human health and environmental quality in isolation. The index also assessed how human activity affected ecosystems by including indicators such as fishing intensity, or the amount of irrigation stress caused by farming. Alex de Sherbinin, a deputy manager at SEDAC, said, “For instance, if you’re not over-using water resources, you have more water for diluting waste streams that might go into waterways, which means you’re more likely to have functioning aquatic ecosystems. And you have more water for domestic consumption.”

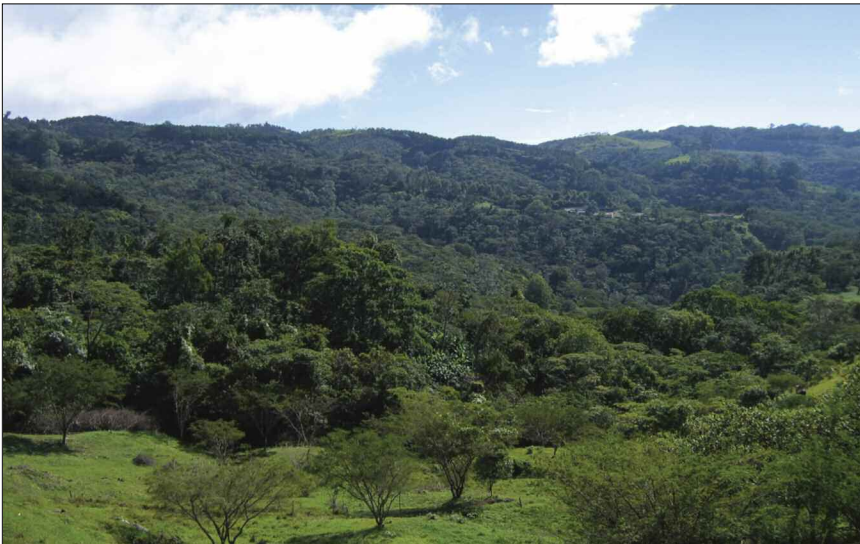
More governments and funding agencies recognize the connections between ecosystems and human health, and they are beginning to formulate policies that incorporate environmental protections. One program, the Millennium Challenge Corporation (MCC), is a United States government foreign aid program that uses a variety of criteria to screen nations before distributing funds. Levy said, “Congress mandated that MCC include natural resource sustainability indicators as part of their screening process.” However, MCC officials were not able to gather sufficient environmental data, so they now rely on Levy and his colleagues for help. The researchers

culled a subset of the EPI data to form the Natural Resource Management Index (NRMI). MCC officials can use this subset to assess whether candidate countries are doing enough to protect their ecosystems and maintain sanitation, safe drinking water, and low child mortality rates. “MCC has provided a pretty clear financial incentive to the developing countries that compete for those funds,” Levy said.

Even after countries receive funding, the MCC continues to evaluate their environmental performance using the NRMI, encouraging projects that foster environmental sustainability. In Nicaragua, for example, the effects of clearing land for agriculture become apparent each year during the hurricane season. During a hurricane’s heavy rain, deforested hillsides are more susceptible to landslides than are naturally forested hills. The MCC is encouraging reforestation in Nicaragua by funding tree nurseries like Rivera’s.

Raising awareness

The EPI provides another incentive by harnessing the power of competition. In addition to ranking countries overall, the index ranks countries within their geographical peer group. These peer groupings permit countries to compare themselves to neighboring nations that face similar issues or geographical challenges. De Sherbinin said, “If a country sees other countries in their geographic region performing better, then it gives them less grounds to dismiss the whole effort. They can see practices in other countries that might yield positive results in their own.” For instance, in addition to promoting reforestation, Nicaragua’s government is trying to emulate Costa Rica’s successful ecotourism industry. Properly planned ecotourism helps preserve biodiversity while creating jobs and generating money to improve urban and rural infrastructure.



Selva Negra, an organic farm and ecotourist destination in northern Nicaragua, produces shade-grown coffee using environmentally sustainable methods that help preserve native habitats. (Courtesy B. Garland)

But even within similar geographical groupings, each nation still faces different challenges. Policy makers require more than a static snapshot, so the EPI researchers created an interactive online version of the index. Policy makers can see exactly where they have been successful, or even adjust the weight of certain indicators to reflect particular values. Levy said, “If you’re the World Wildlife Fund, you might increase the weight for ecosystem vitality. Or, if you’re the World Health Organization, you might increase the weight for environmental health indicators.” Government workers can see how their country ranking might change if they improved certain indicators, allowing them to choose which areas are most practical for them to address first.

Because few global standards exist for maintaining environmental health or ecosystem vitality, the goal of the EPI is primarily to raise consciousness and encourage sustainable environmental development. Several countries, such as South Korea and Mexico, have evaluated the EPI to see how it might help them formulate policies that would protect natural resources without hindering economic development. “One of the reasons we produced the EPI was to create a framework for how countries could improve. Luckily, the situation is getting a bit better over time,” Levy said. The EPI is giving governments data that may help improve environmental conditions in their countries, while encouraging policy makers to invest in livelihoods that foster and preserve local natural resources.

To access this article online, please visit http://nasadaacs.eos.nasa.gov/articles/2008/2008_epi.html.



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NASA Socioeconomic Data and Applications Center <http://sedac.ciesin.columbia.edu>

2008 Environmental Performance Index (EPI) <http://sedac.ciesin.columbia.edu/es/epi>

Millennium Challenge Corporation (MCC) <http://www.mcc.gov/index.php>

World Data Center for Human Interactions in the Environment map gallery http://sedac.ciesin.columbia.edu/wdc/map_gallery.jsp

About the data used

Data set used	2008 Environmental Performance Index (EPI)
Parameter	Environmental indicators
Data center	NASA Socioeconomic Data and Applications Center

About the scientists



Marc Levy is deputy director of the Center for International Earth Science Information Network (CIESIN), and is lead project scientist of the Socioeconomic Data and Applications Center (SEDAC). He studies the human dimensions of global change and has served on a number of global environmental assessments. The Samuel Family Foundation, the Coca Cola Foundation, and the Betsy and Jesse Fink Foundation funded his work on the Environmental Performance Index (EPI). (Photograph courtesy CIESIN)



Alex de Sherbinin is deputy manager for SEDAC and is a senior research associate for CIESIN. His geography research focuses on the human aspects of environmental change at local, national, and global scales. The Samuel Family Foundation, the Coca Cola Foundation, and the Betsy and Jesse Fink Foundation funded his work on the EPI. (Photograph courtesy CIESIN)

Aerosols over Australia



“Atmospheric studies show that aerosols have a very big effect on the climate, but that effect is not well understood.”

Olga Kalashnikova
NASA Jet Propulsion Laboratory

by Katherine Leitzell

Beachgoers in Darwin, Australia, have given up their bikinis and bare chests. Instead, they shield their skin from the blistering sun with long-sleeved shirts and hide their faces under floppy hats. Ultraviolet (UV) radiation in Australia is so intense that on a sunny day, a fair-skinned person can get a sunburn in less than fifteen minutes.

Australia’s unusually harsh sunshine results mainly from its location in the Southern Hemisphere. The elliptical orbit of the Earth places the Southern Hemisphere closer to the sun during its summer months than the Northern Hemisphere during its summer. This means that the summer sun in Australia is 7 to 10 percent stronger than similar latitudes in the Northern Hemisphere. Air currents high in the atmosphere sometimes bring ozone-depleted air from Antarctica’s ozone hole to Australia, letting even more UV through. And Australia’s sunny weather and relatively pollution-free air provide little additional protection from harmful UV rays.

With the highest skin cancer rates in the world, Australians have reason to pay attention to the factors that modulate UV light, such as cloud cover, ozone, and aerosols. Australians have already experienced an increase in sun intensity from ozone depletion, resulting from human-generated emissions of chlorofluorocarbons. Scientists are concerned that climate change could have further effects on UV radiation levels by changing the amounts of aerosols suspended in the atmosphere. Dust, smoke, pollution, and

other small particles can scatter solar radiation back into space, decreasing the sun’s intensity. But in certain situations, they can also increase UV levels. Aerosols absorb solar and thermal radiation, contributing to warmer temperatures and climate change. Scientists are not sure which of these processes wins, because they know little about how UV and aerosols interact. To sort this out, a group of scientists from Australia and the United States decided to study how aerosols affect UV radiation.



Haze from smoke and dust aerosols can interfere with ultraviolet radiation reaching Earth, an effect that may be increasingly important as global temperatures rise. (Courtesy C. Calvin, University Corporation for Atmospheric Research)

Aerosol interactions

Frank Mills, a research scientist at the Australian National University, moved to Australia from California five years ago with the goal of exploring the relationship between climate change, aerosols, and UV radiation. Other researchers have suggested that climate change may lead to warmer, dryer weather that could increase smoke and dust aerosols. Mills wondered how changing aerosol levels would affect UV rays and whether aerosol type would make a difference.

An atmospheric physicist, Mills saw the lack of information on the interactions between aerosols and UV as a snarl of connections waiting to be untangled. “Climate change is likely to induce changes in cloud cover, aerosol abundance, and wind patterns, and these changes could have effects on surface UV levels,” Mills said. “But there hasn’t been any research as to whether that’s true or not.”

Mills decided to start with a basic question: how do different aerosol types affect UV radiation? From his previous work, Mills knew that a variety of data on aerosols was available. But finding accurate UV data would be more difficult. “At the time that I came to Australia, the UV data that existed were of sporadic quality and limited geographic range,” Mills said. Then in 2004, the Australian Bureau of Meteorology set up full-spectrum UV monitoring stations at Darwin, on Australia’s northern coast, and Alice Springs, a desert town 1,500 kilometers (932 miles) south of Darwin.

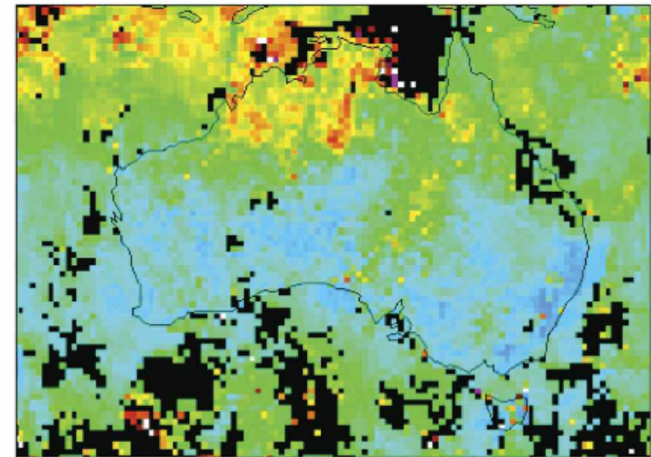
With the UV data gap filled, Mills needed a dust and smoke expert. He recruited research scientist Olga Kalashnikova from the NASA Jet

Propulsion Laboratory in Pasadena, California. Kalashnikova had helped develop a way to separate dust from other aerosol types using the Multi-Angle Imaging Spectroradiometer (MISR) instrument on the NASA Terra satellite. The idea of connecting aerosol properties with variations in UV radiation intrigued her, because she wanted to know how aerosols could affect climate. But knowing that aerosols come in many shapes and sizes, Kalashnikova also knew that different aerosol types have very different effects on sunlight. Understanding those wavelength-dependent differences was crucial for studying climate change.

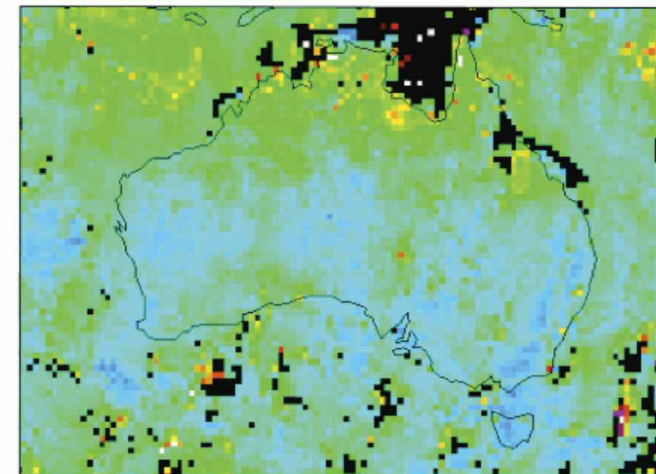
Effects on UV light

Previous studies had shown that some aerosols, such as the pollutants that linger over big cities, reduce the UV reaching the ground, absorbing it or scattering it back into space. But aerosols include a diverse collection of materials, including a variety of airborne particles from the gases and particulate matter in pollution to natural dusts and smoke from wildfires. Each of those particles has different properties. So Mills and Kalashnikova planned to explore how different aerosol types affect solar radiation, using MISR aerosol data from the NASA Langley Research Center Atmospheric Science Data Center (LaRC ASDC), together with the Australian UV measurements.

Aerosol optical depth, November 2004



Aerosol optical depth, December 2004



Australia’s low levels of aerosols primarily come from controlled fires in the north and occasional dust storms in central and southern Australia. The burning season usually peaks in November; December represents the beginning of the rainy season. These images show aerosol optical depth (AOD) in November and December 2004; orange and red indicate higher AOD, while blue and green indicate lower levels. (Courtesy O. Kalashnikova, from Terra MISR)

Serendipitously, the two sites the Australian Bureau of Meteorology chose for their measurements were home to completely different aerosol conditions. Darwin, on Australia's northern coast, is occasionally blanketed in smoke from nearby wildfires. Alice Springs experiences periodic dust storms, which turn the sky a hazy orange. The different aerosol conditions provided a natural laboratory in which to compare the UV effects of dust and smoke.

The aerosol conditions at Darwin and Alice Springs were also well suited to satellite study, since MISR could differentiate between dust and non-dust aerosols. Kalashnikova said, "Unlike other satellites, MISR can see the way light scatters from many different angles." This unique capability meant that MISR could measure not only aerosol depth, but also determine what type of aerosol was present from the particle shape. Most aerosol particles, including smoke, are spherical. But mineral dusts, essentially minuscule pieces of rock, have an irregular shape. By examining the way that an aerosol layer scatters multiple beams of light, Kalashnikova used the MISR sensors to determine whether those layers are made up of chunky, irregular dust particles, or

smooth, spherical smoke. And this allowed her to compare how each aerosol type affected sunlight.

Smoke in the skies

Mills and Kalashnikova first examined smoke effects on UV. They identified wildfires using thermal anomaly data from the NASA Moderate Resolution Imaging Spectroradiometer (MODIS), and identified the smokiest days using MODIS aerosol optical depth measurements. Then they compared UV measurements from the clearest and haziest days in Darwin over the yearlong study period, finding that dense smoke coverage reduced the amount of UV light reaching the ground by as much as 50 percent.

However, the effect depended on wavelength. The UV radiation that reaches the Earth contains wavelengths just shorter than the visible spectrum of light, and is classified into UV-A and UV-B. Lower-energy UV-A has a longer wavelength, while higher-energy UV-B has a shorter wavelength. In Darwin, smoke aerosols reduced UV-B radiation as much as 40 to 50 percent on the smokiest days. The same amount of smoke reduced UV-A only 20 to 25 percent. While the team had expected that UV-A effects would

be smaller, they were surprised at the magnitude of the difference.

Kalashnikova said, "It's very important to know how different wavelengths are affected." UV-B light is responsible for sunburns and is linked to the development of certain skin cancers. Longer wavelength UV-A penetrates further into the skin and can damage collagen, connective tissue that provides skin with structure and elasticity.

Next, Mills and Kalashnikova hoped to compare their smoke results to dust events over the Australian desert. However, in Alice Springs, the team encountered a problem. "We couldn't find any good dust events," Kalashnikova said. Using MISR, Kalashnikova had searched for plumes of aerosols that had dust-like scattering properties, but even with a year of data to draw from, they found only a few days showing moderate dust storms over Alice Springs.

"A big part of Australia is covered by desert," Kalashnikova said. "In theory you would expect a lot of dust there." But even though the deserts around Alice Springs spewed up the occasional dust storm, very little dust reached their

About the remote sensing data used			
Satellite	Terra	Terra and Aqua	Terra and Aqua
Sensor	Multi-Angle Imaging Spectroradiometer (MISR)	Moderate Resolution Imaging Spectroradiometer (MODIS)	MODIS
Data sets used	Monthly Average AOD (558 nm green band) and Angstrom parameter (446-867 nm)	Level 2 fire products (fire mask)	Level 2 aerosol (AOD)
Resolution	380 kilometer	1 kilometer	1 kilometer
Parameters	Aerosols	Thermal anomalies/fire products	Aerosol optical depth
Data center	NASA Langley Research Center Atmospheric Science Data Center	NASA Land Processes DAAC	NASA Level 1 Atmosphere Archive and Distribution System

study site. “In our study, not much dust was transported outside of smaller dusty regions,” Kalashnikova said.

The dearth of dust storms proved a setback in comparing the two aerosol types, but Kalashnikova said that it was a fascinating finding in itself. “It’s interesting because Australia was thought to produce a lot of dust,” she said. However, the study showed that, unlike Africa, where huge desert storms regularly send plumes of mineral dust thousands of miles across the Atlantic Ocean, Australian dust storms may often be confined to smaller areas.

Even without major dust events to draw from, the Alice Springs data suggested that dust aerosols were not as opaque to UV as smoke was. Kalashnikova said she hopes to repeat the experiment in a dustier location.

A global interest

Australia’s unusually strong sunlight has created a national interest in exploring the factors that affect UV radiation. Mills said, “Interest on UV radiation levels within Australia is driven primarily by health concerns.”

But while Australian health officials worry that climate change might increase UV radiation and skin cancer risk, scientists note that the same factors that could lead to changes in UV may also affect the climate. Increased aerosols may contribute to a feedback cycle that increases warming, or they might lead to a negative feedback cycle that dampens warming. Such changes could have broad implications for people and the environment. However, before scientists can incorporate those factors into climate models, they need to understand how aerosols interact with the environment.

Scientists must understand not just aerosol amount, but also aerosol type and how aerosols affect different wavelengths of light. Kalashnikova said, “We need to understand every part of the spectrum, from UV to infrared. Atmospheric studies show that aerosols have a very big effect on the climate, but that effect is not well understood.”

Although it is well accepted that aerosols have an overall cooling effect on the environment, climate scientists still do not understand how changes in total aerosol amount and properties affect the climate on local and global scales. Observing the interplay between UV radiation and aerosols may help scientists tease out the connections and better understand one aspect of the tangled interactions that link climate, dust, smoke, and UV.

To access this article online, please visit http://nasadaacs.eos.nasa.gov/articles/2008/2008_aerosols.html.



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<http://eosweb.larc.nasa.gov>
- Moderate Resolution Imaging Spectroradiometer (MODIS)
<http://modis.gsfc.nasa.gov>
- MODIS Rapid Response System
<http://rapidfire.sci.gsfc.nasa.gov>
- Multi-Angle Imaging Spectroradiometer (MISR)
<http://www-misr.jpl.nasa.gov>

About the scientists



Olga Kalashnikova is a research scientist at the NASA Jet Propulsion Laboratory in Pasadena, California. She uses remote sensing to study aerosol properties and is also interested in the effects of aerosols on the climate and environment. The NASA New Investigator Program in Earth Science supported her work on this study. (Photograph courtesy O. Kalashnikova)



Frank Mills is a fellow at the Australian National University (ANU), with dual appointments in the Research School of Physical Sciences and Engineering and the Fenner School of Environment and Society. His research interests include climate change, ultraviolet radiation, and atmospheric physics. Mills received funding from the Ian Potter Foundation, the International Society of Biometeorology, and the Australian Research Council. (Photograph courtesy ANU)

Freezing in a warming world



“If we artificially change the climate conditions so past experiences don’t apply anymore, then plants have trouble.”

Lianhong Gu

Oak Ridge National Laboratory

by Stephanie Renfrow

In March 2007, the eastern United States enjoyed soaring temperatures and an early spring. Plant ecologist and Oak Ridge, Tennessee, resident Lianhong Gu was among those who noted both the warmth and the plants bursting into growth. He said, “I was enjoying the green outside my office window and watching the plants in my garden at home to see when the buds broke.” For over a week, temperatures in parts of the eastern United States rose as much as 15 degrees Celsius (27 degrees Fahrenheit) above normal, a sharp spike in thirty years of temperature records.

Despite his appreciation for the early arrival of spring, Gu saw a potential downside. “Plant ecologists know that if temperatures in the early spring are high, then plants may start premature development,” he said. “That means tender tissues and organs may be exposed to subsequent frosts, potentially affecting productivity for the whole year.” And, scientists like Gu believe that the cycle of early spring warming, premature plant growth, damage from freezes, and subsequent decline will increase with the unpredictable temperature fluctuations expected as climate change takes hold.



Apple blossoms and other blooms may be increasingly susceptible to late spring freezes that can damage or destroy entire crops. (Courtesy Photos.com)

In early April, as Gu watched the evening news, he heard the forecaster describe a cold arm of Arctic air throwing itself over the eastern United States. A cycle of extremes was about to unfold in real time. He said, “I knew the vegetation and crops were going to suffer greatly.” Gu, a scientist at the Oak Ridge National Laboratory (ORNL) contacted friends and colleagues so that they could help document the freeze with ground observations. “We kept driving around eastern Tennessee and northern Georgia, photographing damaged trees and crops everywhere,” he said. Gu next marshaled a range of data from NASA satellites and ground networks to study the Easter Freeze of 2007, as it came to be called. The efforts of Gu and his colleagues will help make clear the challenges that plants and people face as we adapt to the stresses of a warming world.

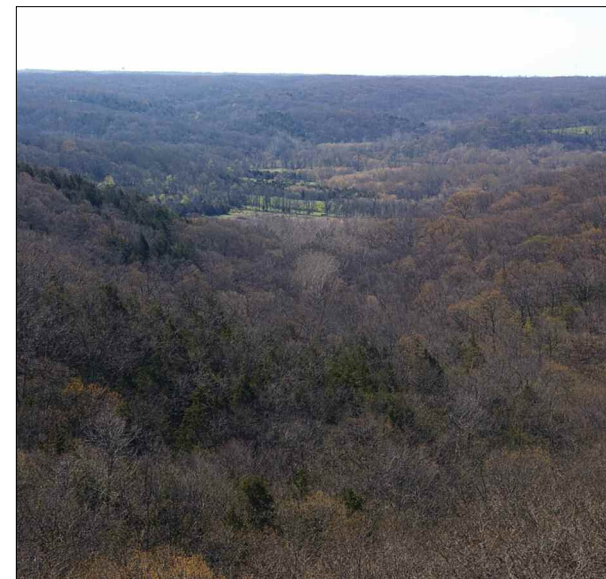
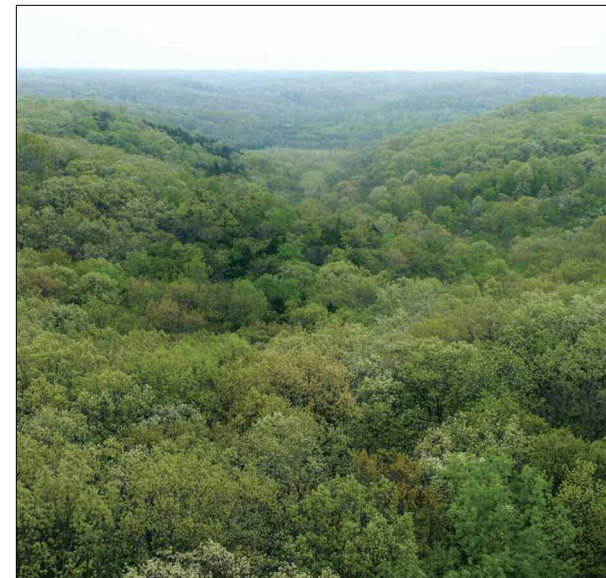
The Easter Freeze of 2007

According to a United States Department of Agriculture (USDA) report, 2007 experienced the second-warmest March on record for the entire United States. Plants broke their winter dormancy and geared up for the growing season much earlier than normal. For example, the USDA found that in Tennessee, 62 percent of the apple trees were in bloom or in even later stages of growth in March, compared to an average of 42 percent at the same time during the last five years.

Then the temperature dropped. In early April, the Arctic air that had gripped Alaska in its third-coldest March on record swept down over the central and eastern United States. Temperatures in some locations plummeted into the teens overnight. Gu said, “The freeze came and the plants drooped miserably—we saw tremendous damage all over the region.”

The USDA reported that four to five nights of sub-freezing temperatures broke 1,237 daily minimum temperature records and tied another 321 records, causing \$2 billion in crop damage. Gu compared the date of the freeze to the long-term record of last frost dates, using temperature data obtained from the National Climatic Data Center in Asheville, North Carolina, and from two ground-based flux tower observational sites, one in Tennessee and one in Missouri. The flux towers are part of the AmeriFlux regional network and the global FLUXNET network of tower-mounted sensors. FLUXNET is a key activity of the NASA ORNL Distributed Active Archive Data Center (DAAC). Gu found that over the past three to five decades, the date of the last frost normally arrived between day 80 and 120 at the Tennessee site and somewhat later at the Missouri site. He said, “The April 2007 frost arrived around day 95. At first glance, it might seem that the freeze, although record-breaking in terms of temperature, was not that unusual in its timing. Why was the freeze so devastating?”

The data confirmed a twist that farmers and gardeners have long known intuitively. The data from Gu and his collaborators documented that the late record-breaking freeze was actually not to blame for the withered plants. “If the temperature is low, new leaves and flowers won’t form and the plants will be okay if a freeze comes. But if the temperature is high and plants have already started the growing process, then a freeze will cause extensive damage,” Gu said. So the Easter Freeze of 2007 was, in a way, innocent; more at fault was the preceding period of early warm temperatures that coaxed the plants out of dormancy and into harm’s way. “Timing is very important for plants as they break dormancy,” Gu said. “And while



In early April 2007, a late spring freeze caught plants by surprise, severely damaging canopies like this one in Missouri. The image on top shows the forest in 2006, a normal year; on the bottom, an image from the same period in 2007 shows the frost-blackened canopy. Scientists learned that it was not the timing of the frost that caused the region-wide plant damage. (From L. Gu et al., courtesy *BioScience*)

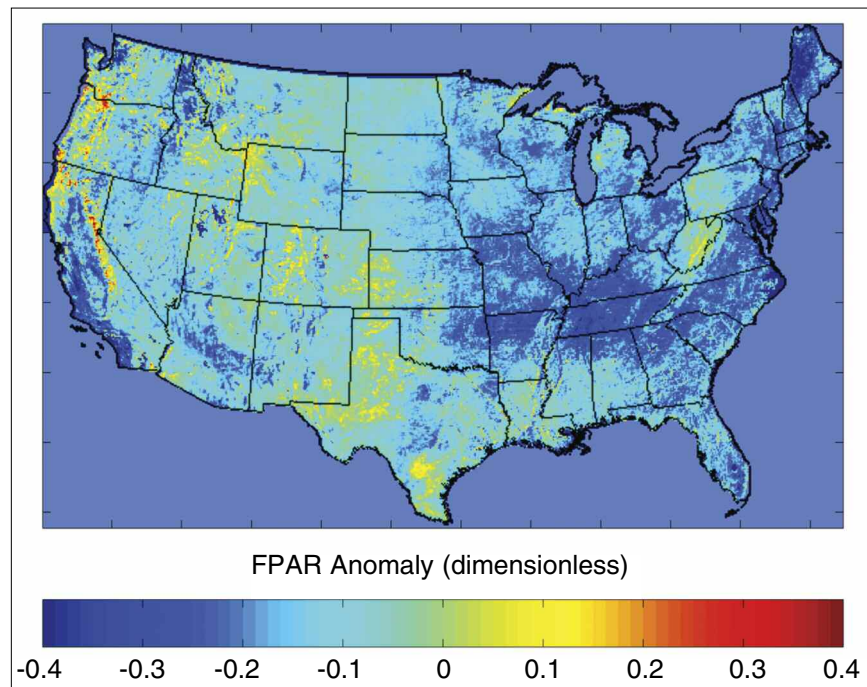
unusual warm-cold patterns like these have always occurred occasionally, global warming may make them more frequent and more severe—and that could be stressful for plants.”

Seeing devastation in the leaves

To measure the degree of ongoing disruption to plants, Gu also used remote sensing data from the Moderate Resolution Imaging Spectroradiometer (MODIS) instrument, onboard the NASA Terra and Aqua satellites. Gu and his collaborators relied on the MODIS Fraction of Photosynthetically Active Radiation Absorbed by Vegetation (FPAR) product, archived at the Land Processes DAAC, to show them where plant photosynthesis declined after

the freeze. “After the April freeze, the green was gone and growth had fallen far behind that of an average year,” Gu said.

The flux tower data also included information on the exchange, or transpiration, of water vapor between the vegetation at the two sites and the atmosphere above them. “Because the freeze damaged leaves, the transpiration stream was stopped,” Gu said. “You’re not just talking about growth stopping as a response to freezing temperatures, but because of physical and physiological damage.” In other words, the data were not simply indicating that the plants had shut down for a while to wait out the cold; it meant that the plants were physically damaged and could not grow.



Following the Easter Freeze of 2007, satellite imagery revealed that plant health declined significantly. Here, the dark blue band across much of the eastern United States reveals anomalously low photosynthetic activity for April 7 to 14 compared to the 2001 to 2006 average. (From L. Gu et al., courtesy *BioScience*, from Terra and Aqua MODIS)

The damage caused by the early growth and late freeze turns around the key point of plant dormancy ending, and growth beginning—the crucial time of transition that spring represents in making or breaking a plant’s survival. “Timing is very important to whether plants make it or die,” Gu said. “Any environmental factor that affects the timing of plant growth can have serious consequences for plant productivity for the long term.” Plants need to experience a set period of temperatures below a certain threshold to enter and maintain dormancy, and a set period of rising temperatures to break dormancy and begin growing. “It’s almost like double insurance,”

Gu said. “Plants are smart. Their reactions have been established based on past climate conditions. That’s why this topic is interesting in terms of climate change. If we artificially change the climate conditions so past experiences don’t apply anymore, then plants have trouble.”

Piling stress on plants

One of the noteworthy findings that Gu and his collaborators unearthed during their work on the Easter Freeze of 2007 was that some plants did fare better than others during the flip-flopping temperature pattern. “Some plants were damaged, and others were okay,” Gu said. “So why was there such a difference? It appears that native species were able to survive even the harsh conditions of spring 2007, but introduced species suffered much more.”

Gu believes that the native species are hardier because, over the ages, they have been exposed to the extremes of their particular locales more frequently. Although the conditions of 2007 broke records, past experience would have helped inform native plants in timing their break from dormancy. Conditions weeded out plants that did not time their growth well, while those with better timing survived and multiplied. But with climate change taking hold, extreme temperature patterns may become more common; even past experience will not be enough to protect plants. “With warming of the climate, the warm-cold sequence might increase in frequency, and that would be stressful on plants, even on native species,” Gu said.

Plants have solid strategies for dealing with stresses like temperature fluctuations, but these strategies cost energy. “To tolerate stressful conditions, plants have to use energy. They have to transform some of the carbon and nutrient reserves in their bodies to increase certain chemicals that allow them to resist

the stressful condition and to replace damaged tissues and organs,” Gu said. “But if they are not healthy, they won’t have enough of these reserves. If a plant is already in bad shape because of freezing conditions or other stresses, it will have trouble surviving the next stress, whether it’s drought or heat or flood.” So in a warming world, the stresses on plants could pile up, leading to long-term damage. Eventually, the damage could impinge on some plant species’ ability to survive in affected regions.

“Sometimes people think that we can take advantage of climate change—the increased length of the growing season, more mild temperatures,” Gu said. “They think we can plant new crops that would normally only grow further south. But there’s a risk there. Because as the 2007 freeze shows, in a warming climate the risk of severe freeze damage may actually be greater—and hit introduced species even harder.”

Gu and his colleagues hope to better understand that risk by studying the long-term effects of the Easter Freeze of 2007. Central to their work is the need for continued data streaming from FLUXNET and other long-term data sets. “The frequency of extreme events may not be high, but once they occur, they are more damaging in the long term. And you can’t plan for them. Freezing, heat, drought—these events aren’t predictable,” Gu said. “We need steady long-term observations and then when an extreme event occurs, we have the data to study it, anticipate the consequences, and plan for the future.”

To access this article online, please visit http://nasadaacs.eos.nasa.gov/articles/2008/2008_warming.html.



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For more information

- NASA Oak Ridge National Laboratory DAAC
<http://daac.ornl.gov>
- NASA Land Processes DAAC
<http://lpdaac.usgs.gov>
- FLUXNET
<http://www.fluxnet.ornl.gov>

About the remote sensing data used

Satellite	Terra and Aqua	
Sensor	Micrometeorological sensor data from AmeriFlux and FLUXNET	Moderate Resolution Imaging Spectroradiometer (MODIS)
Data sets used	Walker Branch and Missouri Ozark flux tower sites	1 kilometer Fraction of Photosynthetically Active Radiation Absorbed by Vegetation (FPAR)
Resolution	8 kilometer	
Parameters	Temperature, water vapor, sensible heat, radiation flux for Normalized Difference Vegetation Index (NDVI)	FPAR
Data center	NASA Oak Ridge National Laboratory DAAC	NASA Land Processes DAAC

The table above lists the public NASA archive for these remote sensing data sets. Gu and his co-authors used reprocessed versions of FPAR data from the NASA Ames Research Center Terrestrial Observation and Prediction System (TOPS).

About the scientist



Lianhong Gu is a plant ecologist at Oak Ridge National Laboratory in Tennessee. His research interests include the influences of phenology on carbon, water, and energy exchanges; the modeling of phenology; and using remote sensing to study terrestrial ecosystem productivity. Funding for his research on the Easter Freeze of 2007 came from the United States Department of Energy. (Courtesy L. Gu)

Cleaner water from space



“We will know what’s happening, and when it’s happening, and can give timely information to local governments for water quality.”

Menghua Wang,
Center for Satellite Applications
and Research

by Jane Beitler

Travelers from around the world pause at China’s Lake Taihu. Tranquility normally prevails along the sculpted limestone cliffs and undulating green hills ringing its placid waters west of Shanghai. But in spring 2007, this picture of Chinese beauty grew ugly when a massive blue-green algal outbreak thickly slimed the lake’s surface.

Chinese officials declared the outbreak a major health emergency. The algae, called cyanobacteria, threw off foul odors as well as toxins that can damage human health. Two million nearby residents who drink Lake Taihu’s water scrambled to buy bottled water for several weeks. Agricultural

runoff and wastewater discharge had overloaded the lake waters with nitrogen; in spring, algae grew explosively in the warm, fertile waters. The most severe of several recent outbreaks, the incident spotlighted the need to better manage Lake Taihu’s water quality.

Far away in Maryland, the news of the bloom in China gave oceanographer Menghua Wang an idea. Wang, who specializes in remote sensing of oceans, thought his idea could some day help people who depend on lakes for drinking water. He said, “Water quality is a very big issue affecting people’s daily lives.” Wang, with help from postdoctoral research associate Wei Shi, had just tested a new method for satellite observations of



Lake Taihu in China is normally tranquil and picturesque; recently, massive algal blooms have spoiled its potability. Researchers hope to use remote sensing to help local officials manage the lake’s health. (Courtesy S. J. Photography)

stirred-up coastal waters. He was fairly sure he could use it to capture a time series of Lake Taihu's algal bloom. Such space observations of lake conditions could help resource managers prevent and intervene in water quality problems like the Lake Taihu bloom.

Detecting the marine food chain

Wang's plan involved satellite sensors designed to detect phytoplankton, microscopic plants that are the building blocks of the marine food chain, near the ocean surface. A single alga or phytoplankton plant is too small to be seen with the human eye, but like pixels in a photograph, masses of them compose a visible image.

Flying 438 miles (705 kilometers) over the Earth, the NASA Sea-Viewing Wide Field-of-View Sensor (SeaWiFS) and Moderate Resolution Imaging Spectroradiometer (MODIS) measure subtle gradations in visible and near-infrared light reflected up from the oceans, including the signature of green chlorophyll that indicates the presence of phytoplankton. The resulting data, called ocean color, map the abundance and distribution of phytoplankton, giving researchers information about climate conditions that favor this organism, as well as overall ocean health.

In a similar way, the sensors could detect algae that normally exist in a healthy freshwater ecosystem. Unbalanced conditions like those at Lake Taihu can trigger runaway growth, upsetting water quality for both people and fish. Long before detecting an actual massive algal bloom, sensors might spot changes in water clarity, an early clue to problems. Steven Greb, a research hydrologist at the Wisconsin Department of Natural Resources, said, "The usual way to measure clarity is to drive to each lake, put a boat in, and lower a Secchi disk on a line." A Secchi disk, designed for water clarity

measurements, is a white disk with a pattern painted on it. As the disk descends, the depth at which the pattern disappears is a measure of the water's transparency.

The technique can be labor intensive and expensive on a large scale. Greb said, "These measurements need to be repeated for several years running to identify changes and trends. We have more than 15,000 lakes in Wisconsin, so it can get expensive. But satellite measurements cost only a few cents per lake."

Greb can use data from another satellite, Landsat, to help assess water quality. But because of its orbit, MODIS can offer more. Greb said, "Landsat passes over any area only every sixteen days. In the Midwest, we have a lot of clouds in the summertime, so there's good chance we'll have cloud cover that sixteenth day that Landsat passes over. Then it's thirty-two days between data, and we don't get a good image that summer. MODIS is going around every day, so the chances are much better of capturing a cloud-free day." While MODIS has the advantage of a more frequent orbit, its resolution is not as fine, so it would be most useful for larger freshwater lakes like Taihu.

Separating air and water

Wang, at the Center for Satellite Applications and Research at the National Environmental Satellite, Data, and Information Service, knew that MODIS and SeaWiFS could obtain high-quality data over the open ocean, but coastlines and inland waters were still a muddle. Wang said, "These areas are very turbid; a lot of sediment causes a problem for remote sensing."

MODIS and SeaWiFS measure solar radiation that is reflected back by both the water and the



A blue-green algal bloom on Lake Taihu, China, recently threatened drinking water supplies. Researchers are studying new methods to detect water quality issues from space. (Courtesy W. Wurtzbaugh)

atmosphere in the near-infrared band. Clear ocean water absorbs almost all of the near-infrared radiation, so the signal of the ocean is quite distinct from the signal of the atmosphere, which reflects much more near-infrared radiation. But sediments in the stirred-up shallower conditions common near coasts and inland also reflect a lot of radiation in the near-infrared band, making it hard to distinguish water from atmosphere.

Wang also knew that MODIS had at least one thing that SeaWiFS did not: a shortwave infrared (SWIR) band, in addition to a near-infrared band. He had recently used this band to refine MODIS ocean color data, sifting out noise in the data from dust and water vapor encountered during radiation's trip up from the ground. Wang said, "Because the signal must travel so high, most of it is from the atmosphere, not from the ocean. The ocean signal is 5 to 10 percent of the data."

Wang thought that SWIR would also be more sensitive to the difference between atmosphere and turbid water, so he proposed to overlay SWIR band data on the near-infrared band data. In 2006, he tried the method along a consistently turbid section of China's eastern coast, near

Hangzhou Bay and the Yangtze River estuary, and the ocean to the north of the Yangtze River mouth. Using the new algorithm and MODIS data from 2003, Wang found that he could closely match ground observations from 2003 field campaigns in the area.

A fast-moving bloom

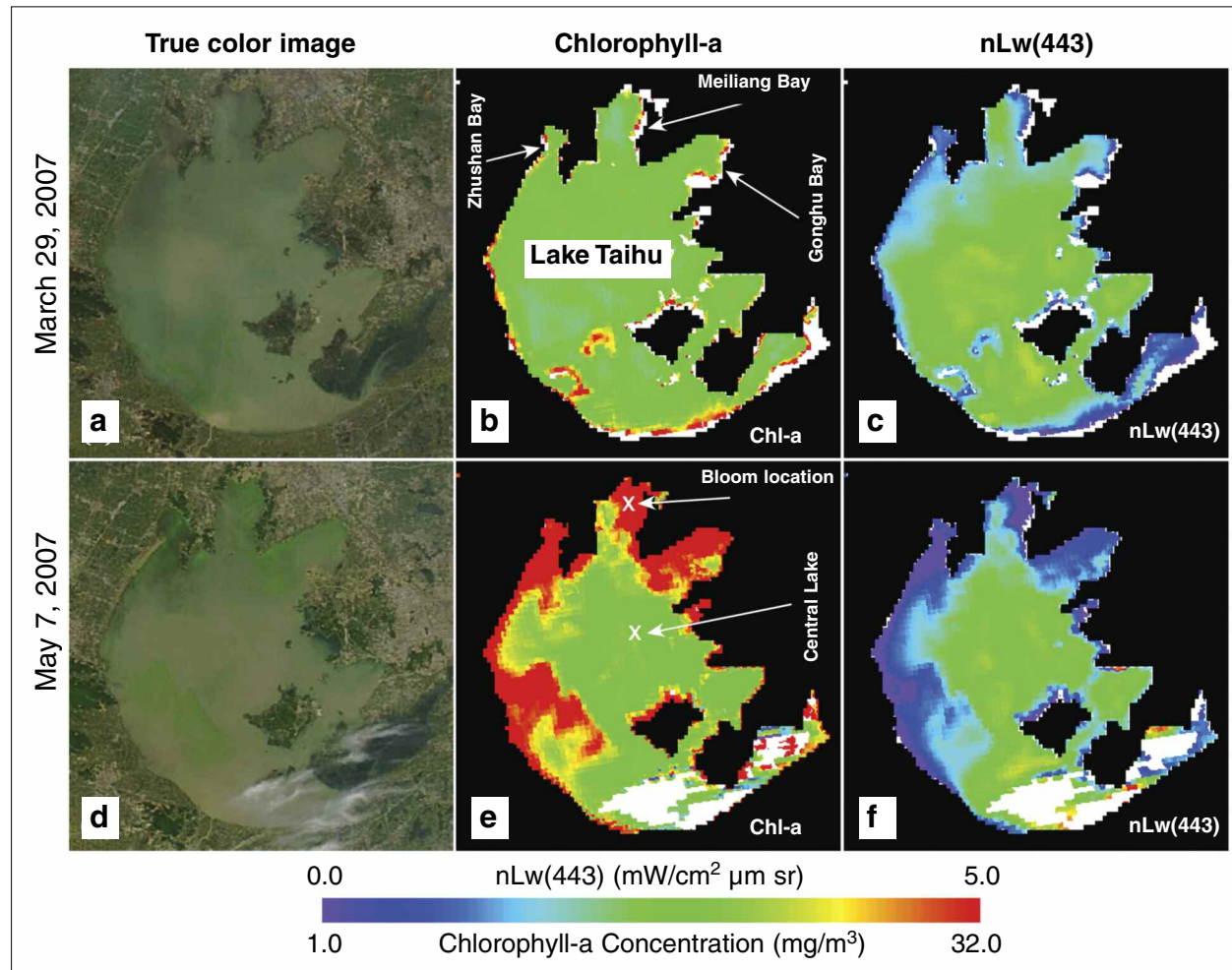
Encouraged by his success with measurements in turbid coastal waters in 2006, Wang saw the 2007 bloom at Lake Taihu as a chance to prove the method in turbid fresh waters. Wang obtained archived MODIS data for March through May 2007 for the Lake Taihu area from NASA's Level 1 Atmosphere Archive and Distribution System Web site. MODIS data were ideal for capturing the fast-spreading bloom, providing time-continuous coverage at a high resolution of up to 0.25 kilometers (0.15 miles).

The new algorithm worked. Wang said, "We looked at the MODIS data and sure enough, we could pick up the signal of where the bloom was happening." Applying the SWIR method, Wang studied Meiliang Bay, one of the main water sources for Wuxi, a city on the Lake Taihu shore. A series of MODIS images on cloud-free days captured the algal bloom as it started the first week of April, peaked around May 7, and then tapered off in early June.

Wang sees a key role for near-real-time space observations of lake water in the Taihu area and in other regions trying to manage increasingly pressured water resources. Wang said, "An image series like this will be very useful for local officials in the management of water quality. We will know what's happening, and when it's happening, and can give timely information to local governments for water quality."

Satellites for drinking water?

After the bloom, cleanup crews removed 6,000 tons of blue algae and 1 million cubic meters (1.3 million cubic yards) of silt from the lake, and after some weeks, restored its potability for local residents. The cleanup



Before-and-after satellite images captured a fast-moving algal bloom at Lake Taihu, China. Images (a) and (d) are true-color, similar to what the human eye would see. Images (b) and (e), processed with the shortwave infrared (SWIR) method, show the dramatic change in levels of chlorophyll (yellow and red), indicating the presence of algae. Images (c) and (f) compare the radiation before and after the bloom in the blue range to help accurately detect chlorophyll. (Courtesy M. Wang, from Aqua MODIS)

resolved only the latest crisis. Agriculture, city sewage, and manufacturing in the area continue to increase, overloading the lake with nutrients. Local officials must work to lower emissions and better treat sewage, while also finding substitutes for nitrogen and phosphorus-rich fertilizers, pesticides, and detergents. Continuous observations from space could help gauge the success of such measures, and in the shorter term enable officials to warn residents well before an algal bloom fouls their drinking water.

While the quarter-kilometer (0.2-mile) view of MODIS may be too coarse to capture data on smaller lakes in his region, Greb thinks that work like Wang's underscores the possibilities for future sensors. Greb said, "Many of us in the water quality community want a sensor on the next generation of Earth observing satellites that is tuned for measuring inland and coastal water quality." Banding with like-minded researchers as members of the international Group on Earth Observations (GEO), Wang and Greb helped craft a series of recommendations to this end.

Wang continues his work with existing satellite data, refining and testing the SWIR algorithm. He is inspired by the possibility of making a difference to people who depend on freshwater lakes like Taihu. He said, "I would like to see if someone can use this method for monitoring, or apply it to other regions. We need to learn if this is a useful tool to do not only science, but also to have an effect on people's daily lives."

To access this article online, please visit http://nasadaacs.eos.nasa.gov/articles/2008/2008_algae.html.



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- Wang, M., and W. Shi. 2008. Satellite-observed algae blooms in China's Lake Taihu. *Eos, Transactions, American Geophysical Union* 89: 22, 201-202.

For more information

NASA Level 1 Atmosphere Archive and Distribution System
<http://laadsweb.nascom.nasa.gov>
 Center for Satellite Applications and Research
<http://www.star.nesdis.noaa.gov/star>
 Group on Earth Observations
<http://www.earthobservations.org>
 Wisconsin Department of Natural Resources
<http://www.dnr.state.wi.us>

About the remote sensing data used

Satellite	Aqua
Sensor	Moderate Resolution Imaging Spectroradiometer (MODIS)
Data sets used	MYD02QKM—Level 1B Calibrated Radiances—250 km MYD02HKM—Level 1B Calibrated Radiances—500 km
Resolution	0.25 kilometer and 0.5 kilometer
Parameter	Radiances
Data center	NASA Level 1 Atmosphere Archive and Distribution System

About the scientists



Steven Greb is a research hydrologist for the Wisconsin Department of Natural Resources. His interests include new technologies for surface water monitoring and modeling, use of remote sensing tools for water quality measurements, and the influence of process hydrology mechanisms on water quality. He also is the point of contact for the Group on Earth Observations water quality work task. (Photograph courtesy S. Greb)

Menghua Wang is an oceanographer at the Center for Satellite Applications and Research at the National Environmental Satellite, Data, and Information Service in Camp Springs, Maryland. His research interests include radiative transfer modeling; ocean color remote sensing; ocean and aerosol optical and microphysical properties; and development of techniques. NASA and the National Oceanic and Atmospheric Administration supported his Lake Taihu study.

Where oceans meet atmosphere



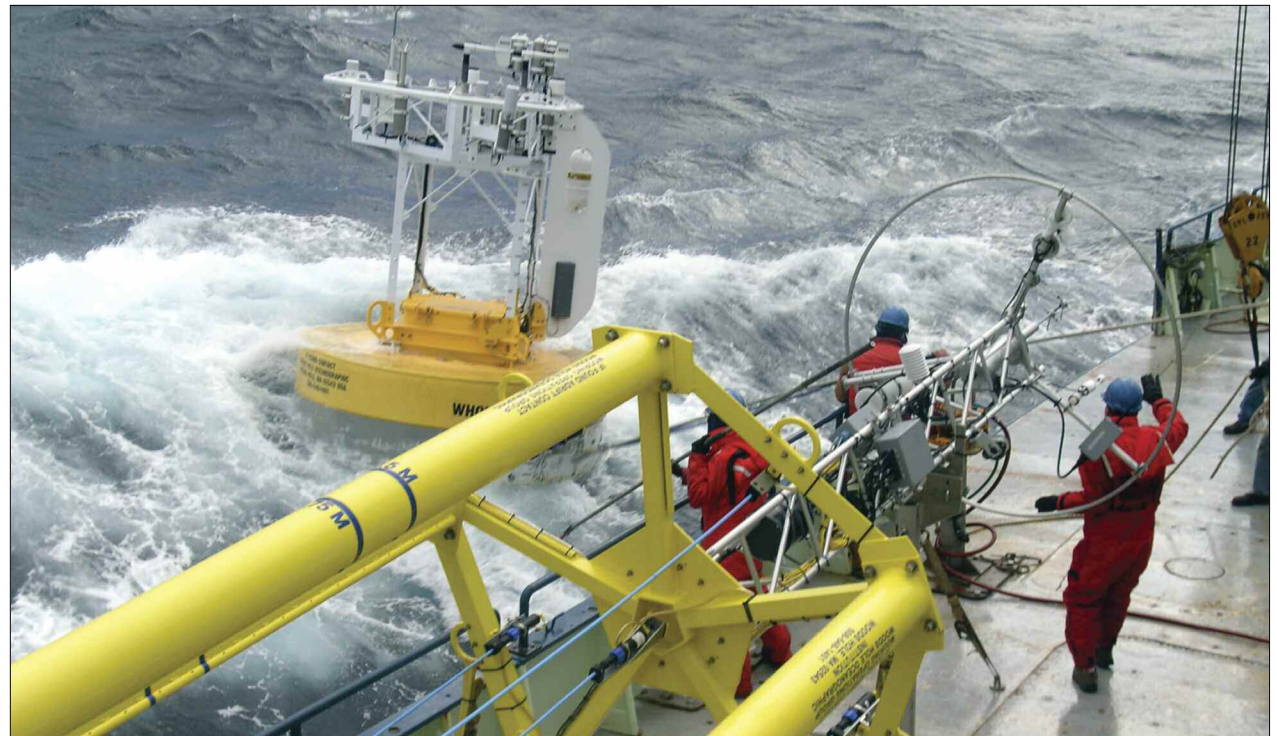
“Ocean-going scientists don’t want to go out without their satellite maps—it would be like taking a cross-country tour without your road atlas or GPS.”

Kathie Kelly
University of Washington

by Stephanie Renfrow

On February 24, 2007, a storm hit the *Research Vessel Knorr* 1,200 kilometers (650 nautical miles) off the coast of Bermuda. Below decks, the crew listened as the fifty-foot waves and hurricane-force winds slammed into the ship. On the deck, strapped down with fourteen cargo straps, a fifty-foot-long instrument lay awash. Oceanographers aboard the ship had been using the instrument, called a spar buoy, to take measurements in the storm-pounded Northern Atlantic.

Terry Joyce, an oceanographer with the Woods Hole Oceanographic Institution, was aboard the ship during the cruise. He said, “During the night, as we limped toward Bermuda, we took a big wave over the bow and had water up on the bridge. The wave destroyed the spar buoy, which we’d gone to such effort to recover just the day before so it wouldn’t get damaged at sea.” The wave snapped seven of the cargo straps and swept parts of the buoy overboard; heavy battery cases rolled around on deck threatening to short out and spark a fire. The crew spent much of



Crew members recover a buoy which broke loose in the Gulf Stream. The instrument shown along the shiprails was later destroyed in a storm. (Courtesy T. Joyce)

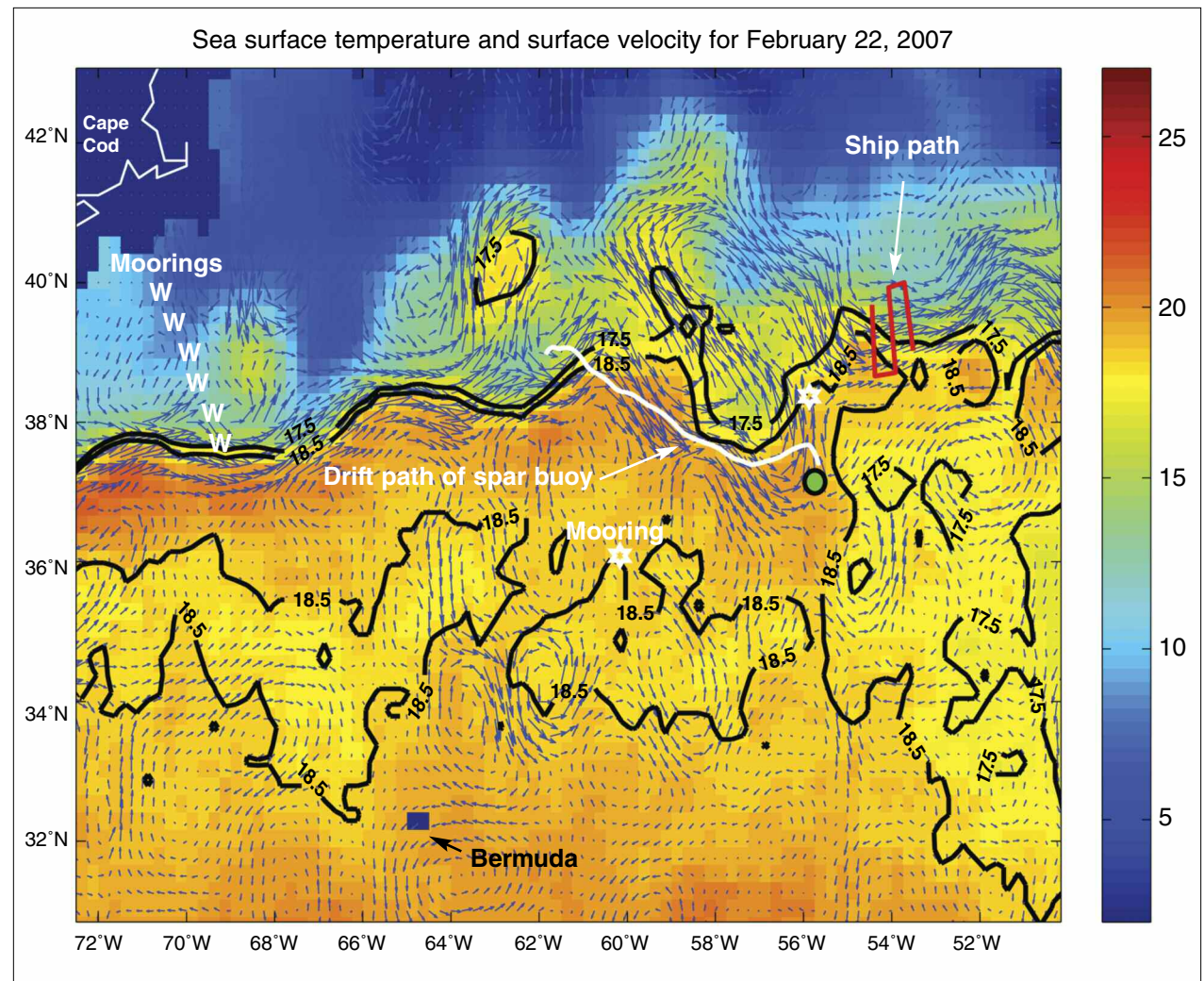
the night working to secure the mess while the storm continued to toss the ship. “When we got to Bermuda, we realized that there was no way to bring the Humpty Dumpty buoy back to life,” he said. “We knew we’d have to write it off and continue the cruise without it.”

So why would Joyce join other oceanographers and crew members aboard a ship purposefully bound for the Gulf Stream, an ocean current associated with dangerous winter storms? Joyce was part of a three-year, multi-institutional effort that included fifteen Principal Investigators, five research cruises, and both satellite and in situ data. The goal: to improve our understanding of Earth’s climate by studying the interaction between our planet’s ocean currents below and its atmosphere above.

Tracking a layer of slow-changing water

Before the storm destroyed the spar buoy, it was one of several key research tools for the crew aboard the *R/V Knorr*. Its downward end could probe into the ocean waters for conductivity, temperature, depth measurements, and surface wave height and direction; its skyward end could provide meteorological information like temperature, humidity, winds, and radiation. Joyce said, “It was like spawning a second vessel that stayed in just the right spot, drifting with the flow, while the ship went off and took additional measurements. It was a fantastic device for measuring air-sea exchange.”

Joyce and the other scientists aboard the *R/V Knorr* were interested in air-sea exchange because that interaction helps drive global climate. To get measurements of the heat handoff between oceans and atmosphere, the science team wanted to be sure that they deployed the spar buoy, as well as dozens of other instruments, where a



This image shows conditions during a cruise north of Bermuda in late February 2007. Blue arrows show surface currents; color bands indicate sea surface temperatures; black contours reveal eighteen-degree water forming at the ocean's surface. (Image courtesy T. Joyce, from TOPEX/Jason-1 and Aqua AMSR-E)

specific layer of ocean water in the Gulf Stream was actively forming. This layer, loosely referred to as subtropical mode water, forms during the winter when the waters of the Gulf Stream flow to thirty degrees North Latitude and hand heat off to the atmosphere. The mode water is a large mass—sometimes 500 to 800 meters (1,640 to

2,625 feet) thick—that is consistently 18 degrees Celsius (64 degrees Fahrenheit). University of Washington oceanographer Kathie Kelly said, “The mode water is so thick, and is such a heat reservoir, that it takes years and years to change it.” Kelly continued, “Mode water is considered the long-term memory of the climate system.”

The layer of water is so very deep, it's almost impossible for the atmosphere to warm it and almost impossible to cool it. So it stabilizes the climate system and provides a long-term signal for climate." Joyce agreed, saying, "The connection between the Gulf Stream, mode water formation, and winter storms is fundamental to the way climate on Earth works—but that connection isn't really very well understood. That's what we're hoping to learn by studying mode water." But to study the thick layer of water, the ship's crew first had to find it.

Satellite data comes onboard

How did the crew aboard the *R/V Knorr* know exactly where to find the elusive mode water to deploy their instruments? Suzanne Dickinson, Kelly's colleague and fellow oceanographer, worked closely with the crew while she stayed warm and dry on land. She said, "During the cruises, I uploaded daily satellite maps, based on sea surface temperature, to the ship." Sea surface temperatures helped the shipboard scientists find the eighteen-degree water because it forms when

the atmosphere strips off the overlying warmer water through heat exchange, allowing the cooler water to appear at the surface. The satellite data they used came from the Advanced Microwave Scanning Radiometer for Earth Observing System (AMSR-E), which flies on the NASA Aqua satellite. AMSR-E is a passive microwave instrument, so it was able to see through the winter clouds and provide data even during the all-too-frequent winter storms.

Dickinson retrieved the sea surface temperature data through a NASA project called "Distributed Information Services: Climate/Ocean Products and Visualization for Earth Research," or DISCOVER. The goal of DISCOVER is to provide accurate long-term climate records and near-real-time ocean data products for scientists. Frank Wentz of Remote Sensing Systems, Inc., leads the DISCOVER team; the NASA Global Hydrology Resource Center (GHRC) hosts the data for distribution in easy-to-use formats.

Joyce said, "The remote sensing information was invaluable. We'd wait for it daily and download it

around two in the afternoon. We were working twelve-hour shifts day and night on the ship, so we tried to have a clear plan before we turned it over to the next shift." By studying the broad coverage of the satellite maps, the crew was able to sail the ship to areas where mode water was forming to deploy their instruments.

Dickinson said, "In addition to the sea surface temperature data, we also sent QuikSCAT wind data, which helped the crew see what weather was coming, and altimeter data, which helped indicate currents."

Gathering three types of data from various sources for five cruises spanning three years was not a simple task. Dickinson said, "Near-real-time data streaming doesn't just happen all the time. Sometimes I'd look for the data and it wasn't there—and I'd have to work with the DISCOVER team to figure out the problem and how to fix it." Kelly added, "And the thing about cruises is that it's not okay if they miss a couple of days of data. The DISCOVER team and Suzanne were

About the remote sensing data used			
Satellite	QuikSCAT	TOPEX/Poseidon/Jason-1	Aqua
Sensor	SeaWinds scatterometer	Nadir-pointing radar altimeter	Advanced Microwave Scanning Radiometer for Earth Observing System (AMSR-E)
Data sets used	QuikSCAT near-real-time ocean wind vectors	Sea surface height	Sea surface temperatures
Resolution	25 kilometer	0.0001° in latitude and 0.05° in longitude	25 kilometer
Parameters	Wind vectors	Sea surface height	Sea surface temperature
Data center	NASA Physical Oceanography DAAC	NASA Physical Oceanography DAAC	NASA National Snow and Ice Data Center DAAC

The table above lists the public NASA archive for these remote sensing data sets. Dickinson used reprocessed versions: QuikSCAT, by NOAA/National Environmental Satellite Data and Information Service; Poseidon-2, by the Colorado Center for Astrodynamics Research; AMSR-E, by Remote Sensing Systems, Inc.

tag-teaming every day to make sure the crew had a map each afternoon. Ocean-going scientists don't want to go out without their satellite maps—it would be like taking a cross-country tour without your road atlas or GPS.”

Understanding the ocean's memory

Joyce, Kelly, Dickinson, and the other scientists involved in the study, called the Climate Variability and Predictability Mode Water Dynamics Experiment (CLIMODE), hope that the years of work, the many stormy wintertime cruises, and the unique combination of satellite and shipboard data will ultimately improve our understanding of both mode water and climate on Earth.

Because of the ocean's predilection for slow change, understanding the current state of mode water and how it may influence future climate are uppermost in the minds of oceanographers. Some oceanographers who study Greenland ice cores as a paleological record of climate have suggested that if global warming continues, we could see changes in ocean circulation that could cause abrupt or extreme changes in climate.

Joyce said, “But before we can understand how heat transport is going to evolve in a warming world, we have to understand how the basic system works: If you had more heat transported by the Gulf Stream, would that make it more stormy? Or would it change where the storms happen? And if you perturb the system, how would it react? Right now, we don't know. But that's what we're hoping to learn.”

To access this article online, please visit http://nasadaacs.eos.nasa.gov/articles/2008/2008_oceans.html.



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- Woods Hole Oceanographic Institute. The hunt for 18° water. <http://www.whoi.edu/oceanus/viewArticle.do?id=11274>

For more information

- NASA Global Hydrology Resource Center
<http://ghrc.nsstc.nasa.gov>
- NASA DISCOVER
<http://www.discover-earth.org> and
<http://discover.itsc.uah.edu>
- Climate Variability and Predictability (CLIVAR) Mode Water Dynamic Experiment (CLIMODE)
<http://www.climode.org>
- University of Washington Applied Physics Laboratory
<http://www.apl.washington.edu>
- Woods Hole Oceanographic Institution
<http://www.whoi.edu>

About the scientists



Suzanne Dickinson is an oceanographer at the Applied Physics Laboratory at the University of Washington. She specializes in processing and analyzing satellite observations to better understand ocean-atmosphere coupling, oceanic heat transport, and other dynamic ocean processes. She uses wind vectors, sea surface temperature, and sea surface height data. NASA and the National Science Foundation (NSF) funded her research. (Photograph courtesy S. Dickinson)



Terry Joyce is an oceanographer at the Woods Hole Oceanographic Institution in Woods Hole, Massachusetts. He specializes in studying oceanic fronts and mixing phenomena, dynamics of warm-core Gulf Stream rings, shipboard acoustic profiling of ocean currents, hydrographic sampling, oceanic subduction, physics of hydrothermally forced circulation, and decadal climate variability. NSF funded his research. (Photograph courtesy T. Kleindienst)



Kathie Kelly is an oceanographer at the Applied Physics Laboratory at the University of Washington. Her focus is applying large data sets, particularly from satellite sensors, to problems of climate, atmosphere-ocean interaction, and ocean circulation. Kelly has been a member of the science teams for the NASA Scatterometer and TOPEX/Poseidon and has served on NASA science advisory committees. NASA and NSF funded her research. (Photograph courtesy K. Kelly)



About the NASA Earth Observing System Data Centers

Alaska Satellite Facility Distributed Active Archive Center (DAAC)

Synthetic Aperture Radar, Sea Ice, Polar Processes, Geophysics
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<http://www.asf.alaska.edu>

Crustal Dynamics Data Information System

Space Geodesy
NASA Goddard Space Flight Center
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+1 301-614-6542
Carey.Noll@nasa.gov
<http://cddis.gsfc.nasa.gov>

Global Hydrology Resource Center

Hydrologic Cycle, Severe Weather Interactions, Lightning, Atmospheric Convection
NASA Marshall Space Flight Center
Huntsville, Alabama
+1 256-961-7932
ghrc@eos.nasa.gov
<http://ghrc.nsstc.nasa.gov>

Goddard Earth Sciences Data and Information Services Center

Global Precipitation, Solar Irradiance, Atmospheric Composition, Atmospheric Dynamics, Global Modeling
NASA Goddard Space Flight Center
Greenbelt, Maryland
+1 301-614-5224
help-disc@listserv.gsfc.nasa.gov
<http://disc.gsfc.nasa.gov>

Land Processes DAAC

Surface Reflectance, Land Cover, Vegetation Indices
United States Geological Survey Earth Resources Observation and Science (EROS) Center
Sioux Falls, South Dakota
+1 605-594-6116, +1 866-573-3222
LPDAAC@eos.nasa.gov
<http://lpdaac.usgs.gov>

Level 1 Atmosphere Archive and Distribution System (MODAPS)

Radiance, Atmosphere
NASA Goddard Space Flight Center
Greenbelt, Maryland
+1 866-506-6347
modapsuso@saicmodis.com
<http://laadsweb.nascom.nasa.gov>

NASA Langley Research Center Atmospheric Science Data Center

Radiation Budget, Clouds, Aerosols, Tropospheric Chemistry
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<http://eosweb.larc.nasa.gov>

National Snow and Ice Data Center DAAC

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Oak Ridge National Laboratory DAAC

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Ocean Biology Processing Group

Ocean Biology, Ocean Color, Biogeochemistry, Sea Surface Temperature
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Physical Oceanography DAAC

Sea Surface Temperature, Ocean Winds, Circulation and Currents, Topography and Gravity
NASA Jet Propulsion Laboratory
Pasadena, California
podaac@podaac.jpl.nasa.gov
<http://podaac.jpl.nasa.gov>

Socioeconomic Data and Applications Center

Human Interactions, Land Use, Environmental Sustainability, Geospatial Data, Multilateral Environmental Agreements
CIESIN, Earth Institute at Columbia University
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NASA's view from space reveals our dynamic planet
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