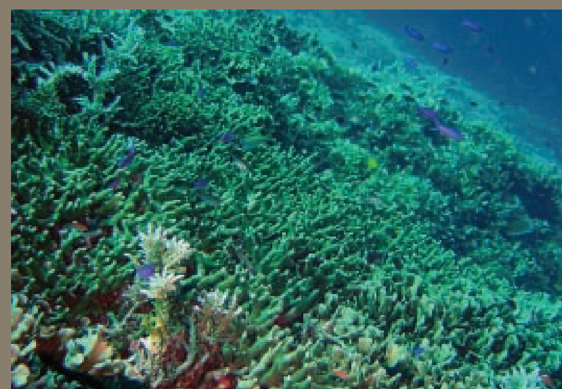
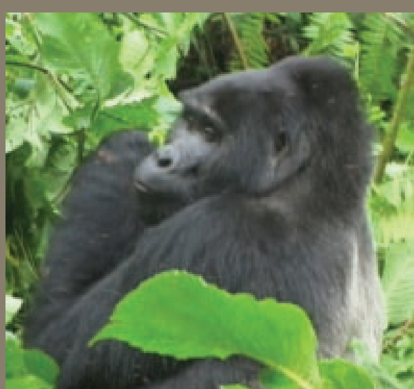
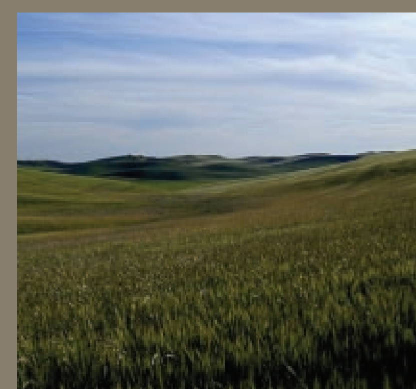
National Aeronautics and Space Administration

NASA: Supporting Earth System Science 2006



NASA: Supporting Earth System Science 2006

Applications of Earth System Science Data from the NASA Science Mission Directorate

National Aeronautics and Space Administration
www.nasa.gov

NASA Distributed Active Archive Centers
http://nasadaacs.eos.nasa.gov

Front cover images

Top row, left to right:

Hurricane Katrina's eyewall swirls on August 28, 2005, a day before the powerful storm slammed into the United States Gulf Coast. See the related story, "Data more powerful than hurricanes," on page 14. (Photograph by Lieutenant Mike Silah/courtesy NOAA)

A diversity of colorful fish and marine species live in the clear waters near this healthy reef. See the related story, "Cattle, crops, and coral: Flood plumes and the Great Barrier Reef," on page 2. (Courtesy Emre Turak/Australian Institute of Marine Science)

Polar bears and other Arctic animals need sea ice for hunting, birthing, raising their young, and survival. See the related story, "Arctic sea ice on the wane: Now what?" on page 34. (© Greenpeace/Beltra)

Bottom row, left to right:

Great Apes, like this silver-back gorilla in Uganda's Bwindi forest, are struggling to survive in the diminishing forests of Central Africa. See the related story, "Mapping the changing forests of Africa," on page 24. (Courtesy Andy Plumptre)

In 2001, an earthquake-induced landslide in a neighborhood near Santa Tecla, El Salvador, buried numerous homes under tons of earth. See the related story, "Gridding the risks of natural disasters," on page 46. (Photograph by Edwin L. Harp/courtesy USGS)

In this photograph, New York City is awash in pollution. Exposure to high levels of air pollutants can inflame lung tissue and aggravate asthma, increase susceptibility to respiratory illnesses, and cause other problems for human health. See the related story, "On the trail of global pollution drift," on page 8. (Courtesy Photos.com)

By combining Moderate Resolution Imaging Spectroradiometer (MODIS) technology with meteorological data to forecast vegetation health, land managers can implement more efficient rangeland management strategies in regions such as this one, near the Charles M. Russel Wildlife Refuge in Central Montana. See the related story, "Predicting productivity: Managing land from space," on page 20. (Courtesy Matthew Reeves)

Back cover images

Left to right:

Scientists and citizen volunteers are observing first bloom and first leaf dates of lilacs to gather data on the timing of spring. These observations, connected with satellite data on plant activity, will help researchers monitor climate and its effects on the biosphere. See the related story, "Seeing climate through the lives of plants," on page 42. (Courtesy Mark D. Schwartz)

Lightning illuminates a funnel cloud forming during a storm near Huntsville, Alabama, in April 2006. Alabama's turbulent weather gives scientists frequent opportunities to study lightning and storm development. See the related story, "Cloud to cloud: Forecasting storm severity with lightning," on page 30. (© Wes Thomas Photography)

The Sea-Viewing Wide Field-of-View Sensor (SeaWiFS) captured this image of the Great Lakes on December 5, 2000, revealing a phenomenon known as the Great Lake effect, in which cool, dry air flowing over the lakes picks up heat and moisture, condensing to form clouds. See the related story, "Monitoring Great Lakes ice from space," on page 52. (Courtesy SeaWiFS Project, NASA/GSFC and ORBIMAGE)

Scientist Nadine Laporte teaches a quick geography lesson to children in Uganda. Laporte visited Uganda during the course of her research on African biomass, which will benefit everyone from gorilla conservationists to forest managers. See the related story, "Mapping the changing forests of Africa," on page 24. (Courtesy Nadine Laporte)

Acknowledgements

We extend our gratitude to the Earth Science Data and Information System (ESDIS) project for its support of this publication; to the Distributed Active Archive Center (DAAC) managers and User Services personnel for their direction and reviews; and to the DAAC scientists who alerted us to the research and investigations that made use of DAAC data in 2006. A special thanks goes to the investigators whose accomplishments we are pleased to highlight here.

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Supporting Earth System Science 2006 articles and additional images are available online at the NASA Earth System Science Data and Services Web site (http://nasadaacs.eos.nasa.gov/articles/index.html). A PDF of the full publication is also available on the site.

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

Researchers working with NASA DAAC data are invited to contact the editor of this publication at daaceditor@nsidc.org to explore possibilities for developing a future article.

Writing, editing, and design

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Publication Design: Laura Naranjo

The design featured at the end of the articles throughout this edition shows a stylized satellite view of a hurricane. After the devastating 2005 hurricane season in the United States, scientists are seeking new ways to monitor hurricanes and their impact. To read about some of the ways scientists are using NASA DAAC data to study hurricanes, see "Data more powerful than hurricanes" on page 14.

National Aeronautics and Space Administration

Dear Friends and Colleagues:

The NASA Earth Observing System Data and Information System (EOSDIS) generates more than 2,800 Earth system science data products and provides associated services to researchers involved in interdisciplinary studies. EOSDIS distributes NASA Earth science data to a broad user community, enabling research, applications, education, and policy analysis. In fiscal year 2006, we provided information and data to more than 3.2 million distinct users. Since 1994, EOSDIS has been archiving and distributing data from the Earth Observing System (EOS) program and from NASA observation programs before EOS began.

At the heart of the system are geographically distributed data centers. Each data center serves one or more specific Earth science disciplines and provides its science, government, industry, education, and policymaker communities with data information, data services, and tools unique to its particular science discipline.

In this publication, you will find articles about applications and uses for EOS data that speak to our partnerships and to NASA goals. These articles describe research using data from multiple sensors and across data centers. We focus on the meaning of scientific results within a global perspective for Earth and its inhabitants—both now and in the long term. We hope these articles will acquaint you with the wealth of resources available through the EOSDIS.

Jeanne Behnke
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NASA: Supporting Earth System Science 2006

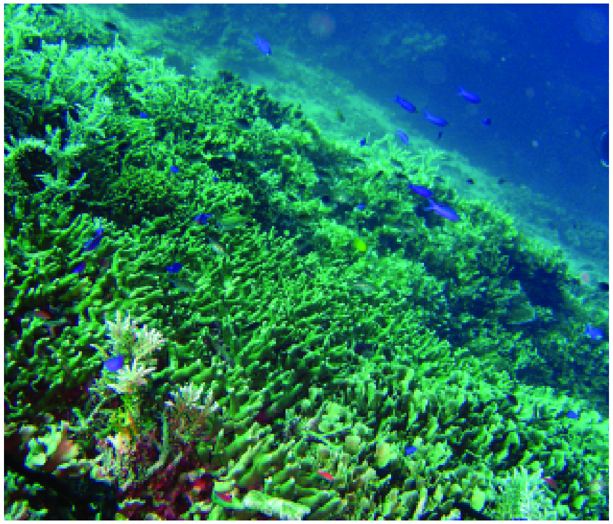
Cattle, crops, and coral: Flood plumes and the Great Barrier Reef

"Nutrients like nitrate. . .can travel much further than we would have thought, for hundreds of kilometers up the coast and across the reef under plume conditions. They present a risk to the offshore reef that we wouldn't have guessed at a couple of years ago."

Jon Brodie
Australian Centre for Tropical Freshwater Research at James Cook University

by Stephanie Renfrow

Most of the time, Australia's Fitzroy River does not really exist. For years at a time, the river is only a dry streambed. Upriver, cattle wander about the surrounding rangeland, plucking at tufts of brown grass and kicking up dust. Downriver, farmers irrigate, fertilize, and tend their cotton and other crops. Every five or ten years, the rains come. In a single day, water can pour down the river at a rate of 1.5 cubic kilometers (0.4 cubic miles) per second from a river catchment the size of the state of Illinois. The Fitzroy's waters flush sediment, fertilizers, pesticides, herbicides, and other civilization-borne



A diversity of colorful fish and marine species live in the clear waters near this healthy reef. (Courtesy Emre Turak/Australian Institute of Marine Science)

This MODIS image from July 19, 2006, shows muddy water from the rangeland-dominated Fitzroy River catchment entering the waters near the Great Barrier Reef, seen in turquoise off the East Coast of Australia. Information about flood plumes helps coastal managers understand which areas of the reef the floods affect, as well as how far into the reef the sediment- and nutrient-laden waters spread. White indicates cloud cover. (Courtesy Arnold Dekker/CSIRO)

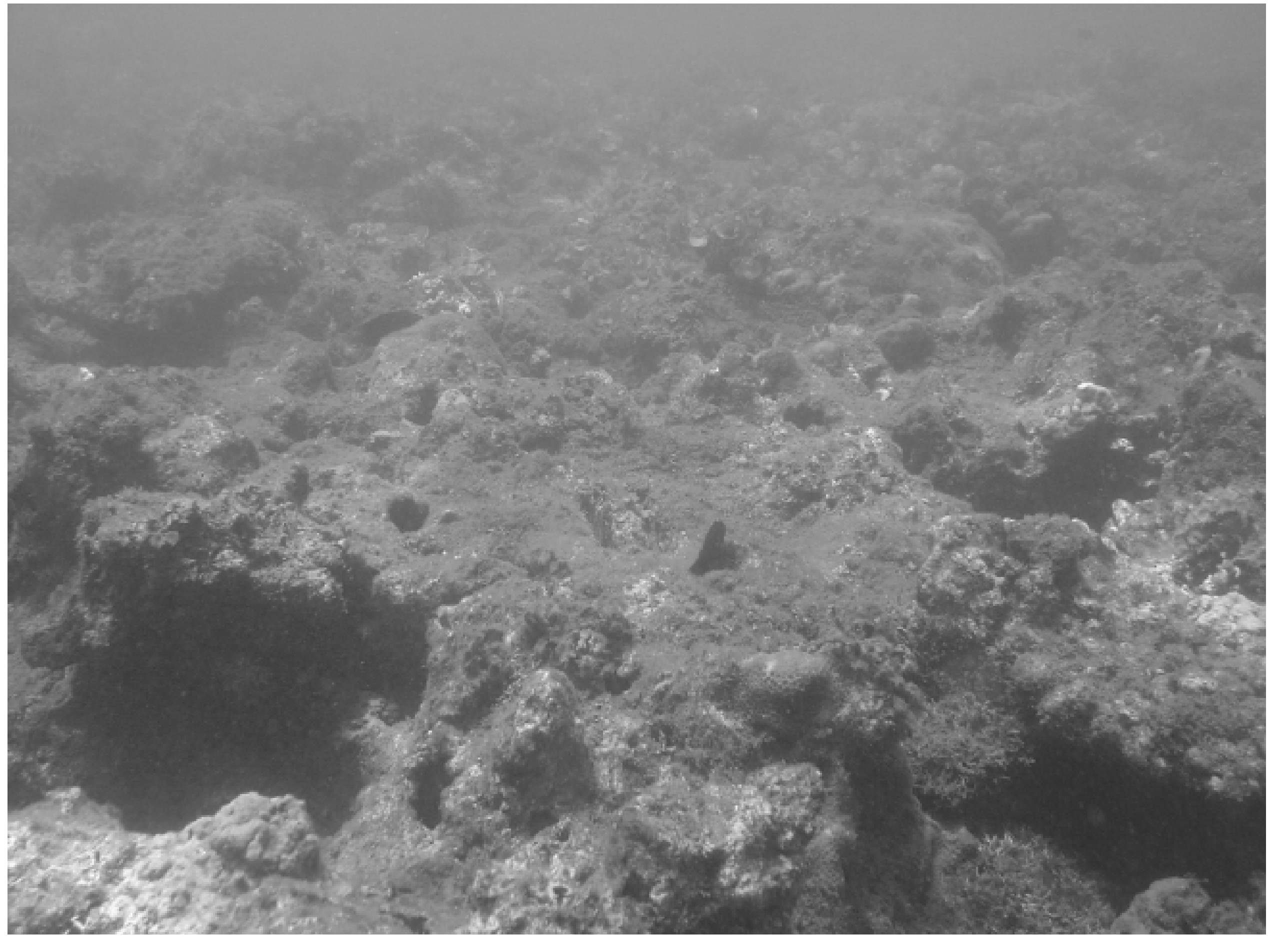
runoff hundreds of miles into the water off the coast of Australia. At the end of the runoff plume, waiting for the sediment and nutrients to settle, are the prismatic corals of the Great Barrier Reef. The Great Barrier Reef is the world's largest marine ecosystem and an economic bedrock for Eastern Australia. When the Fitzroy's runoff arrives at the coast, where exactly does it go, what does it do to the Great Barrier Reef, and what can be done about it?

Tracking the runoff

Arnold Dekker is a scientist with the Commonwealth Scientific and Industrial Research Organisation (CSIRO). Dekker is collaborating with researchers from the Australian Institute for Marine Science and James Cook University to study river runoff into the Great Barrier Reef Lagoon, the body of water between the coast and the Great Barrier Reef. Dekker said, "We can see huge sediment plumes at the mouth of the rivers as the water sweeps sediment into the Great Barrier Reef Lagoon after extreme rain events. We wondered: Can we track plumes of water? Can we trace the influence of land runoff?" The questions have not been easy to answer.

"Australia is a data-poor environment. It's a huge continent—the coastline along the Great Barrier Reef, alone, is thousands of kilometers long," Dekker said. "We know very little about how the rivers and coasts and oceans actually interact." Besides the immense length of the coast that bounds the Great Barrier Reef, an additional challenge is that flood events are infrequent and ephemeral. "Field measurement programs are weather-dependent and crews can only go out about once a month; they can't really establish long-term patterns very well," Dekker said. "But satellite imagery can give a much more holistic view of the materials that the river is transporting and where they are going, as well as nutrients that may cause algal overgrowth." Plus, satellites can capture information about flood plumes through actual images from space, which would be difficult or impossible to accomplish using traditional observation techniques.

Scientist Jon Brodie, of the Australian Centre for Tropical Freshwater Research (ACTFR) at James Cook University, agreed. "I've been trying to track flood plumes for twenty years, and now we finally have enough satellites up there that we have daily overpasses. Even in cloudy weather, we can get images every day," he said.



Sediment and algal overgrowth have overtaken this once-healthy reef. (Courtesy Emre Turak/Australian Institute of Marine Science)

"For example, after years of effort, last year we got clear images of Pioneer and O'Connell river flood plumes—every day for ten days."

Dekker is primarily using ocean color data, archived at the NASA Goddard Space Flight Center Earth Sciences Data and Information Services Center (GES DISC), from the Moderate Resolution Imaging Spectroradiometer (MODIS) instrument on the NASA satellites Aqua and Terra. Dekker uses the ocean color data to track differences in the color of the coastal water following flood events. Coastal waters are notoriously difficult to work with, and Dekker's team had to develop algorithms, or complex processing equations, to better make use of the data. "Unlike in clear ocean water, coastal optics are dominated by more than just green chlorophyll. There's also colored dissolved organic matter—the stuff called tannins that colors water pea soup green, yellow, brown, or orange," Dekker said. "Plus, you have suspended matter, re-suspended matter, bottom visibility—and ships, tides, and cyclones churning it all up."

Dekker and his team are applying the new algorithms in three areas of study: using MODIS data archives to determine long-term trends in nutrient increases and algal blooms along the entire Eastern Australian coast; providing near-real-time images to coastal managers; and performing focused research on specific coastal regions and systems.

Determining long-term trends in water quality will require Dekker to go back into the MODIS data archives to reconstruct and quantify amounts of sediments and chlorophyll. Chlorophyll, while not a direct measure of nutrients, often indicates the presence of nutrients. Dekker said, "Chlorophyll and other algal pigments, colored dissolved organic matter, and suspended matter all color the water and combine to give a pretty strong argument for nutrient enrichment."

Understanding such trends as river outflow, algal blooms, and eutrophication—or increasing levels of nutrients and minerals that stimulate plant growth—is important for monitoring Australia's coastal waters. Andy Steven, a former Environmental Protection Agency catchment scientist who currently works at CSIRO, said, "Remote sensing allows us to cover vast areas of the reef with frequent and consistent data. This allows us to set a line in the sand based on some measure of water quality, and then collect data to compare how we are doing." Coastal managers can then monitor ongoing water quality to determine whether things are improving, getting worse, or staying the same. "The only way that we can be responsible stewards of a great ecological asset like the Great Barrier Reef is to have adequate monitoring programs telling us the true status of the system," Steven said. "And the only cost-effective and reliable tool that we can see is remote sensing."

However, effective use of remote sensing will not only start with scientists. Steven said, "Getting the trust of coastal managers is one of the broad goals that we'll need to crack in the next four to five years." One way that Dekker hopes to raise their trust in remote sensing is to provide near-real-time satellite images that will help managers make decisions based on current, reliable information. Dekker said, "We'll probably provide the images through a Web-based system so that they can see what's going on in their system, in their estuary, or along their coast." The key, Dekker said, is to meet the real needs of the managers on the ground. "They've got so little information on what's going on; a series of images would give them the insight they need into where material is going," Dekker said. "The next stage of that project could be a harmful algal bloom warning system."

Steven explained that the algal bloom warning system would probably be based on a blend of different types of information, such as chlorophyll, suspended sediment, and wind data that would create flags in the data under certain circumstances. "Then you might send a message to the relevant coastal managers that they need to be aware of a developing situation," Steven said. "Together with information on local conditions, the managers could make proactive decisions based on real-time data." For example, if coastal managers received a forecast that conditions could lead to a potential harmful algal bloom, they could issue a warning that the water may be unsafe for swimming.

Perhaps the project that has yielded the most results, so far, is Dekker's focused research on the interaction between the Fitzroy River and the waters of the Great Barrier Reef Lagoon. Dekker said, "We've got all these models that show what the Fitzroy waters do. For example, we have a hydrodynamic model that shows beautiful animated loops of how the waters go in and out of the estuary with the tides, altering the distribution of suspended materials. But we're noticing that, while sometimes the MODIS data shows similar patterns of suspended sediment, chlorophyll, and algae, at other times it's showing different patterns. The MODIS data is beginning to drive the field of modeling, in turn helping us understand how estuaries and the Fitzroy outflow interacts with the Great Barrier Reef."

By studying and analyzing four years of MODIS data for the Fitzroy River, Dekker also discovered an important piece of information concerning the direction and distance of river outflow. "Most of the material goes to the east, straight out from the river, with some transport along the coast to the north and even less to the south," he said. This information has helped coastal managers understand which areas of the Great Barrier Reef the Fitzroy River floods affect, as well as how far into the reef the nutrient-laden waters spread. Steven said, "The Fitzroy is usually quite dry. So when the river flows, it really flows. And it has a significant and acute impact; it can virtually reset the whole ecosystem." In 1991, the Fitzroy River flooded spectacularly. "We recorded changes in suspended sediment and salinity up to Heron Island, which is about 120 kilometers (75 miles) off the coast," Steven said. "MODIS provides a great opportunity to capture what's going on there and how far it is going. If we can measure total suspended solids, we know how far they're spreading and what the likely area of risk is for the reef."

Downriver realities

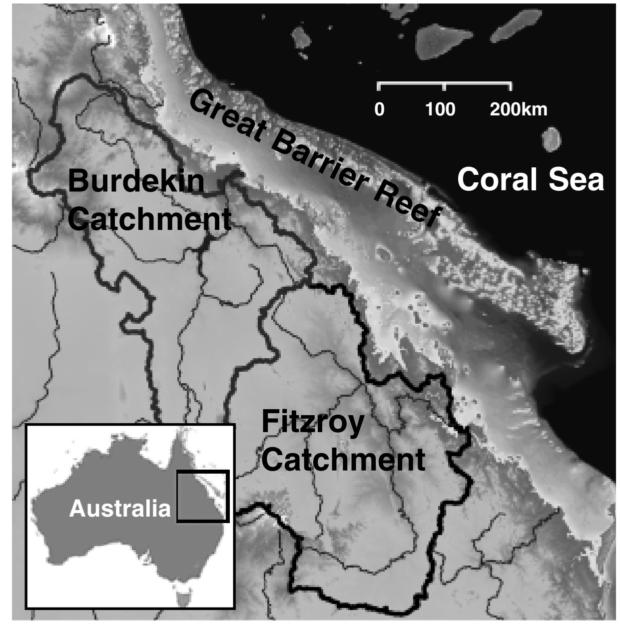
The Great Barrier Reef consists of three layers of reef: the inner reef, closest to the coast; the mid-reefs; and the outer reef, which is the furthest out to sea. Dekker said, "The inner reefs have always had to deal with more runoff from the land. So it's possible that the reefs closer to shore are more adapted to having increased suspended sediment and chlorophyll."

Brodie agreed, adding, "The suspended sediments don't travel very far; they stay near the coast. But nutrients like nitrate are not immediately taken up biologically and can travel much further than we would have thought, for hundreds of kilometers up the coast and across the reef under plume conditions. They present a risk to the offshore reef that we wouldn't have guessed at a couple of years ago."

What risks does runoff pose to the coral reefs? Reef-building corals are small animals living in reefs that they build through their secretions. However, corals respond to the world around them almost like plants because they have a symbiotic relationship with zooxanthellae, a type of algae that gives the transparent corals their vibrant colors. Zooxanthellae live in the coral's tissues and use light for photosynthesis; they assist corals with nutrient production and the calcification needed to build the protective reef. In return, corals provide the algae with carbon dioxide and protection from predators. The corals gain nutrients day and night, using photosynthesis during the day and living off other reef animals at night.

However, this tightly managed nutrient budget is susceptible to change, especially changes in temperature, light, salinity, or nutrient levels. Land runoff may affect all of these measurements, but is especially likely to change light and nutrient levels by adding nutrients that spur algal growth, and increasing turbidity. Dekker said, "A fear is that the resilience of the corals on the Great Barrier Reef decreases with increasing nutrients and suspended sediment. There is more smothering, less light availability, and you're upsetting some of the delicate balances in the reef." A recent study published in *Ecology Letters* indicates that algae release sugars that spur the growth of bacteria; the bacteria cut off oxygen to the corals, suffocating them and leading to further mortality. Turbidity, while perhaps not as directly linked to mortality as overabundant algae, can reduce the amount of light that gets to the corals, affecting photosynthesis.

The world's reefs face multiple pressures, in addition to land runoff. Brodie said, "When you have pressures like crown-of-thorn starfish outbreaks, cyclones, bleaching, climate change, sea water temperature rise, over fishing—the reason that our reefs look like they do is a complicated story." Piecing apart the various pressures and their impacts on the reefs is difficult, but the importance of clear, clean water should not be underestimated. "In good water quality conditions, the reefs can recover quite well from acute events," Brodie said. "But when you have other pressures plus poor water quality, the reefs don't recover."



The enormous catchments of the Burdekin and Fitzroy Rivers empty into the Great Barrier Reef Lagoon, affecting the health of Australia's world-famous reef. (Courtesy Peter Briggs/CSIRO; inset locator map © Commonwealth of Australia, Geoscience Australia, 2005)

Upriver solutions

The plumes of runoff that Dekker helps track using MODIS are a good way to assess water quality on the Great Barrier Reef. However, water quality on the reef depends on conditions far inland, where the water begins flowing towards the coast. Brodie said, "If you want to do something about conditions at the mouth of the river, then there's no point doing anything on the Great Barrier Reef. You have to do it hundreds of kilometers upriver."

The two greatest inputs of sediment and nutrients into the Fitzroy River are cattle ranches and farms. "We have a whole raft of pollutants coming out of the catchment, including sediment and dissolved nutrients and herbicides," Brodie said. "Much of our work is aimed at disentangling those pollutants, identifying which industries are producing which ones and in what quantities. So we do a lot of monitoring to determine source areas."

Cattle grazing is a large source of sediment into the Fitzroy. Dekker said, "There's increasing evidence that in the past 200 years, since European settlement and changes in land use, there has been a significant increase in suspended sediment and nutrient input." As the cattle graze, they break down the riparian areas along the riverbanks, sending soil into the streambed to be carried away during the next flood. Unmanaged cattle will also spread out over the land, increasing erosion by stirring up the soil and grazing on the groundcover. Brodie said, "We believe sedimentary export has increased five or six times over natural erosion because of cattle grazing."

Several government programs, under the Department of Primary Industries and Fisheries, seek to help land managers and cattle ranchers connect. "We're using the Southern Oscillation Index, a measure of air pressure, to predict what the weather is going to be like next wet season. The idea is for ranchers to manage the cattle in advance. If it's going to be a bad drought year, you could sell off your cattle now," Brodie explained. "But if it's going to be a good year with lots of grass, then you might build your cattle numbers up a bit. That allows us to retain better pasture cover."

Another program subsidizes fencing so that farmers can confine cattle to specific areas of rangeland and move the animals from paddock to paddock. Controlling the cattle allows the vegetation to recover, protects riparian areas, and holds down erosion.

Nutrient input from farming also concerns scientists. Fertilizers contain large amounts of nitrate, which can leach into groundwater and river systems. Brodie indicated that nitrate discharge from rivers has increased ten to twenty times over natural amounts.

However, controlling nutrient input from farming is a bit more challenging than preventing overgrazing, Brodie said. "We have 7,000 individual sugar cane farmers and we can't monitor everywhere," he said. "We do have some simple monitoring that they can do themselves—thirty-cent test strips that measure nitrate flowing out of the fields." However, the most important aspect of farm runoff management is to influence the way farmers use fertilizer, before it gets into the water. "We can replant vegetation and artificial wetlands," he said, "but the best solution to fertilization loss is on the farm itself, rather than trying to trap it once it gets off. That, and choosing the right amount of fertilizer for the crop."

The challenge of improving water quality coming out of ranches and cropland goes beyond monitoring and subsidizing improvements. "Another problem is political expectations," Brodie said. "Government officials are spending millions on these water quality issues, and they want to see results immediately. But you can't plant seedlings along the river one year and expect them to be doing anything the next year. It takes ten years for them to grow big enough to trap sediment and nutrients."

Plus, the river's natural variability, flooding one year and then not flowing again for several years, makes getting statistically valid data a long-term project. "Picking a human signal out of that huge natural variability is very difficult," Brodie said.

Convincing government officials that land management efforts are making progress, even though the numbers are not final, is also an ongoing challenge. "What they have to take as evidence is on the ground: that we have an extra ten farms using the grazing land management package or that we've built all this fencing to manage the cattle," Brodie said. "And those improvements will produce—believe us, trust us—a change in the river."

And the scientists believe and trust that a change in the upper reaches of the Fitzroy River will trickle down to the Great Barrier Reef Lagoon, helping keep the water clear and clean for the health and survival of the corals of the Great Barrier Reef. With a healthy reef come billions of dollars of economic benefit for Australia, potential new medicines from coral substances, and the immeasurable beauty of a complex ecosystem thriving in the waters that have been its home for eighteen million years.

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For more information

NASA Goddard Space Flight Center Earth Sciences Data and Information Services Center (GES DISC)
http://daac.gsfc.nasa.gov/

Commonwealth Scientific and Industrial Research Organisation
http://www.csiro.au/

Australian Centre for Tropical Freshwater Research at James Cook University
http://www.actfr.jcu.edu.au/

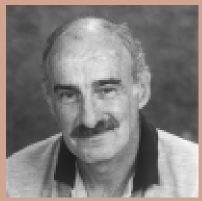
NASA Aqua satellite
http://aqua.nasa.gov/

Great Barrier Reef Marine Park Authority
http://www.gbrmpa.gov.au/

About the remote sensing data used

Satellites	Aqua and Terra
Sensor	Moderate Resolution Imaging Spectroradiometer (MODIS)
Data set used	Ocean Color
Resolution	1 kilometer
Tile size	Regional extract from granules
Parameter	Total suspended matter concentration in ocean Chlorophyll-a concentration, semi-analytic ("chlor a 3") Gelbstoff absorption coefficient at 400 nanometers
Data center	NASA Goddard Space Flight Center Earth Sciences Data and Information Services Center (GES DISC)
Science funding	Commonwealth Scientific and Industrial Research Organisation Cooperative Research Centre for the Reef

About the scientists



Jon Brodie is a principal research officer with the Australian Centre for Tropical Freshwater Research (ACTFR) at James Cook University in Townsville, Australia. Brodie researches the sources of pollutants in catchments; transport of pollutants to the marine environment; the dispersal of land-based pollutants in coastal and marine environments; and the effects of terrestrial pollutants on marine ecosystems. (Courtesy ACTFR)

Arnold Dekker is a senior scientist at the Commonwealth Scientific Industrial Research Organisation (CSIRO) and an associate professor at the University of Queensland, Australia. He specializes in the use of remote sensing for understanding inland and coastal waters. He is especially interested in the link between coastal and reef water quality and land management practices. (Courtesy Heinze Buettikofer/CSIRO)

Andy Steven is a scientist at CSIRO and an associate professor at Griffith University in Australia. He has more than twenty years of experience in aquatic environment research and management throughout temperate and tropical Australia, Asia-Pacific, and the Middle East. He has worked on issues as diverse as fisheries, marine pest management, and water quality in catchments, estuaries, and coral reefs. (Courtesy Heinze Buettikofer/CSIRO)

On the trail of global pollution drift

"We'd seen elevated levels of ozone over the northern midlatitudes before. But with TES data, for the first time we have a way to separate and identify the anthropogenic contributions."

Daniel Jacob
Harvard University

by Laura Naranjo

On any given day in the United States, an American might wear a shirt sewn in Morocco, drive a car manufactured in Japan, or eat an apple grown in Chile. The global economy thrives on the constant exchange between countries. As more nations become industrialized, however, they are creating an unintended new export: air pollution. For years, scientists have observed belts of air pollution traveling on wind currents, following weather patterns, and crossing oceans and continents. However, determining where air pollution originated is not as easy as reading a clothing tag or a fruit label.

High levels of air pollution affect millions of people each year. Excessive amounts of ozone and carbon monoxide can cause respiratory problems, and ozone can aggravate asthma and lead to the premature aging of lung tissue. Other components of air pollution can cause eye irritation, skin rashes, headaches, and sore throats. Bad air days in Los Angeles and Houston, while occurring less frequently, still lead to increased hospital admissions. And poor air quality in large Asian cities often forces residents to remain indoors, affecting their health and disrupting their ability to travel, work, and attend school. To monitor and improve air quality, organizations such as the United States Environmental Protection Agency (EPA) need to know where that pollution is coming from.

Daniel Jacob, an atmospheric scientist and professor at Harvard University, studies atmospheric chemistry, air quality, and pollution drift. Although he has used a variety of instruments and sensors in his research to accurately study where pollution originates and where it drifts, he needed a global data set that could expose both natural and anthropogenic sources of common air pollutants.

Jacob began analyzing data from a new satellite mission, the Tropospheric Emission Spectrometer (TES) instrument, launched aboard NASA's Aura satellite in July 2004. "We'd seen elevated levels of ozone over the northern midlatitudes before. But with TES data, for the first time we have a way to separate and identify the anthropogenic contributions," Jacob said. By investigating the relationship between ozone and carbon monoxide, Jacob discovered that not only could TES data detect pollution drift patterns, but it could also reveal ozone sources.

The needle tips of this white pine have turned pale, revealing burns caused by ozone. Overexposure to ozone not only causes discoloration; it can also reduce tree growth. Ozone diminishes a plant's ability to produce and store food, making it vulnerable to disease, pests, and inclement weather. (Photograph by Andrew J. Boone/courtesy www.forestryimages.org)

Identifying the sources of drifting air pollution can be difficult, because most pollutants are emitted by both natural and human sources. For instance, nitrogen oxides, which contribute to ozone development, are produced by lightning strikes, and wildfires emit carbon monoxide. Both pollutants are also generated by anthropogenic sources such as automobile exhaust and industrial emissions.

And while ozone in the upper atmosphere, called the stratosphere, helps protect the planet by absorbing solar radiation, ozone in the atmosphere closest to Earth's surface, called the troposphere, is a pollutant and can be harmful to people and plant life. Ground-level ozone, the primary component of smog, forms when high temperatures induce chemical reactions between various air pollutants that human activities often generate.

The Northern Hemisphere pollution belt

Jacob and his colleagues studied the pollution belt that develops each summer across the Northern Hemisphere midlatitudes between the Arctic Circle and the Tropic of Cancer, an area that includes most of the United States and Canada, northern Mexico, North Africa, Europe, Russia, and China. The scientists noticed a correlation between different atmospheric chemicals. "In addition to measuring ozone with TES data, we're observing carbon monoxide, which allows us to 'tag' the ozone," Jacob said. "If the elevated ozone comes with elevated carbon monoxide, it's coming from pollution."

In the Northern Hemisphere, motor vehicle and industrial emissions are the most common sources of atmospheric carbon monoxide. By associating elevated levels of ozone with increased amounts of carbon monoxide, Jacob could locate anthropogenic pollution sources in North America, Asia, and Europe.

Jacob's findings corresponded with results from the Goddard Earth Observing System Chem (GEOS-Chem) model, which simulates the chemical composition of the atmosphere using meteorological data from the NASA Global Modeling and Assimilation Office. "This northern midlatitude pollution belt appears to be very consistent between the model results and the TES observations,"

About the remote sensing data used

Satellite	Aura
Sensor	Tropospheric Emission Spectrometer (TES)
Data set used	TES Level 2 Global Survey Standard Products
Parameters	Ozone, carbon monoxide
Data development	Jet Propulsion Laboratory
Data center	NASA Langley Atmospheric Sciences Data Center (LaRC) DAAC
Science funding	NASA

The photograph above shows air pollution in New York City. Exposure to high levels of air pollutants can inflame lung tissue and aggravate asthma, increase susceptibility to respiratory illnesses, and cause other problems for human health. (Courtesy Photos.com) he said. "That gives us confidence in the predictions that we can make for intercontinental transport of ozone pollution."

Air pollution observations are important for air quality agencies that are trying to measure how much pollution is drifting into their countries. "Using the GEOS-Chem model, we've been giving numbers to the EPA, but until we received the TES data, we weren't able to provide a check on those numbers," Jacob said.

Pollution and air quality

To help regulate air quality, the EPA estimates "background levels" for pollutants like ozone and carbon monoxide. These levels reflect the amount of pollution that would exist in the atmosphere naturally, without human contribution, and provide the basis against which scientists can measure anthropogenic levels of these pollutants in the air.

But if a country is trying to reduce air pollution, what happens when pollution from another country drifts in? "Ozone has a pretty long lifetime in the atmosphere, so it gets transported by weather systems," Jacob said.

Nature's contribution

by Jane Beitler

Around the world, ash and thick smoke from wildfires can choke the surrounding skies. While this visible, murky mess seems to disappear with distance from the fires, polluting gases and small particles not visible to the human eye drift upward and are carried away by global air currents. Can large wildfires contribute to smog problems in distant places? Gabriele Pfister, a researcher at the National Center for Atmospheric Research in Boulder, Colorado, is part of a team that confirmed wildfire-generated pollution can indeed be an intrepid—if unwelcome—global tourist.

The 2004 Alaskan wildfire season was the worst on record, largely because of unusually warm and dry weather. Throughout central Alaska and Canada's Yukon Territory, more than eleven million acres burned, or an area equivalent to the states of New Hampshire and Massachusetts together. During this wildfire season, Pfister took part in an international study of pollutant drift, the International Consortium for Atmospheric Research on Transport and Transformation (ICARTT).

The researchers noticed that concurrent with the fires, numerous observing systems detected increases in pollutants from North America all the way to Europe. This extreme fire season posed an opportunity for researchers. "We wanted to study wildfires in boreal areas," Pfister said. "The contribution of boreal forest fires to pollution is not yet well understood. Do they produce significant amounts of tropospheric ozone?"

Identifying fire-generated pollutants

As forests burn, and their underlying, thick peat layer of partially decayed plant matter also burns, they emit highly visible pollution in the form of smoke, soot, and ash. But the fires also generate other harmful pollution. "Fires can affect air quality," Pfister said. "Species emitted by the fires—pollutants such as carbon monoxide, nitrogen oxides, and volatile organic compounds—might cause a significant increase in ozone levels, even far downwind from the fires." Unlike ozone in the stratosphere, which protects us from ultraviolet radiation, high levels of ozone in the troposphere, closer to ground level, can injure or destroy living tissue.

Imagine the challenge of tracking a carbon monoxide molecule as it travels thousands of miles around the Earth, several miles above the surface, drifting and mixing with carbon monoxide from other sources. To track the Alaska and Yukon fire pollutants, Pfister's team designed a unique combination of established methods, including remote-sensing data from satellite instruments, and data modeling. The team needed a way to distinguish fire-generated carbon monoxide from other sources of the gas.

Combining several remote-sensing and modeling approaches produced a sharper picture of the pollution from the fires. "The first step is to know how much carbon monoxide is emitted from the fires," explained Pfister. The team determined a first estimate of fire location and emissions using fire area and vegetation data from the Moderate Resolution Imaging Spectroradiometer (MODIS), a remote sensing instrument on NASA's Earth Observing System Aqua and Terra satellites. Actual measurements of carbon monoxide were obtained from Terra's Measurements of Pollution in the Troposphere (MOPITT), data distributed by the NASA Langley Atmospheric Science Data Center Distributed Active Archive Center (LaRC DAAC). The MOPITT data have been key to helping researchers better understand pollution

Observations of the Northern Hemisphere pollution belt show that pollution drifts from Asian sources to western North America, and from eastern North American sources to Europe.

In the United States, timing makes a difference, said Jennifer Logan, a senior research fellow at Harvard University and one of Jacob's colleagues. "The effect of Asian emissions is largest in springtime, because that's when the transport most effectively brings Asian emissions to the West Coast of the U.S.," she said. However, this does not usually impact air quality, because ozone levels in the United States are actually higher in summer, when sizzling temperatures fuel the chemical reactions in the atmosphere that create ozone. "Also, quite a lot of these Asian emissions are drifting so high in the troposphere that they're not in the air that we're breathing," she said.

Logan added that the amount of pollution drifting from Asia to the United States is also relatively small. While Asian air pollution does affect the northwestern United States, it only accounts for a few parts per billion of ozone,

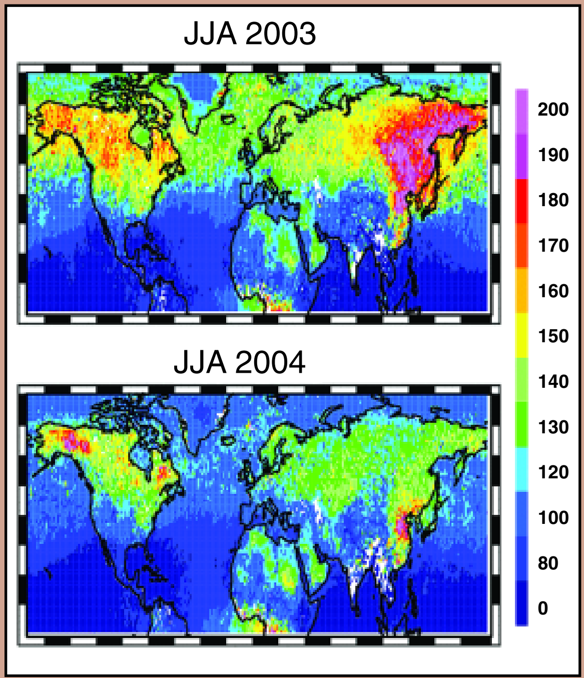
in the Earth's atmosphere system, including pollutant transport. Using an atmospheric chemical transport model named the Model for Ozone and Related Chemical Tracers (MOZART), the researchers calculated the transport of the emissions to tie in with the MOPITT observations.

Measuring the impacts of the fires

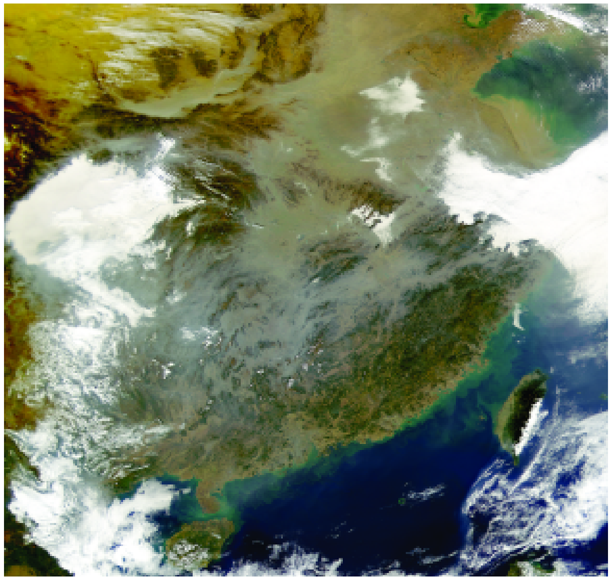
Using the emissions and transport estimates, together with actual pollution data, the team was able to calculate the amount of Alaskan wildfire pollution and how it affected large parts of the Northern Hemisphere. "We were surprised to learn the magnitude of the fires and their impact," Pfister said. From June through August, the fires produced approximately thirty teragrams of carbon monoxide, roughly equal to all the human-generated carbon monoxide for the entire continental United States during the same period. Their study estimated ground-level ozone increased by up to twenty-five percent in the northern continental United States, and by up to ten percent in Europe.

Pfister believes that continuing studies of boreal forest fires are needed to answer many remaining questions. One task, for example, is to refine estimates of peat burning. "At northern latitudes, fire emissions might include a large contribution from peat fires," Pfister said. "Many fire models do not yet include peat burning, but burning peat and burning forest emit different pollutants and, as a result, produce ozone differently."

Pfister hopes that her work will contribute to a better understanding of air pollution sources. "It's important to know what wildfires contribute to pollution, so that we can accurately measure the impacts of nature and of human activity on air quality," Pfister said. "Plus, human-induced climate change might cause an increase in intensity and frequency of wildfires, as other studies have indicated." The fire season of 2004 made a significant contribution to pollution levels during certain time periods. But humans far outweigh nature as a polluter, because our contributions do not come from isolated events. "It's important that people don't dismiss the significance of human activity," Pfister said, "because our contribution to pollution is year round."



The images above show examples of the Northern Hemispheric Measurements of Pollution in the Troposphere (MOPITT) carbon retrievals, indicating carbon monoxide levels in the atmosphere. "JJA" stands for June, July, August. The summer 2003 image includes the large fires in Siberia; warm colors show how the fires increased carbon levels over North America. The summer 2004 image shows the strong signal from the Alaska/Canada fires. (Courtesy Gabriele Pfister/NCAR)



An opaque layer of polluted air covers much of southeastern China, obscuring parts of the landscape. Increasing use of heating fuels like wood and coal contributes to this haze. The image, captured on January 2, 2000, is from the NASA Sea-Viewing Wide Field-of-View Sensor (SeaWiFS). (Courtesy SeaWiFs Project, NASA/Goddard Space Flight Center, and ORBIMAGE)

Logan said. Considering that the EPA estimates the background level for ozone at forty parts per billion, this means that drifting pollution is not usually the culprit when U.S. cities violate air quality standards.

Even if only occurring in small amounts or at certain times of the year, drifting pollution has the potential to affect people all over the globe. “One thing that people don’t like to talk about so much is how much ozone we’re sending to Europe,” Logan said. “But the Europeans care about that just like we care about how much Asia is sending to us.”

Pollution in the Southern Hemisphere

In the Southern Hemisphere, air pollution stems from a different source. “One of the things we see with TES data in the tropics is that ozone is formed by biomass burning,” Logan said. “We can see the seasonal evolution of ozone development that seems to parallel the seasonal evolution of biomass burning.” Biomass burning produces carbon monoxide and nitrogen oxides, two pollutants that lead to ozone formation.

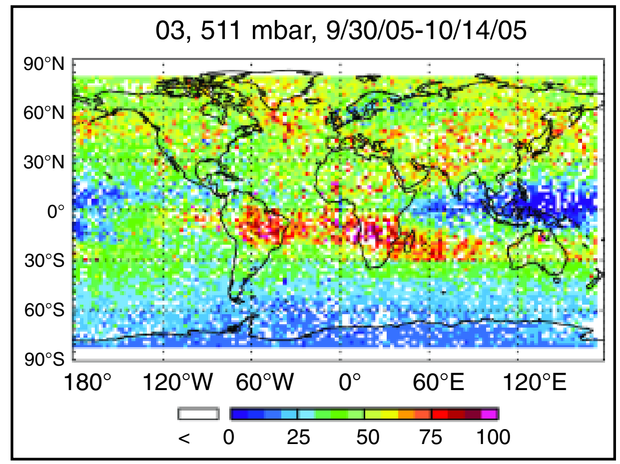
From July through October is the Southern Hemisphere’s dry spring season. Farmers across tropical regions burn savanna and forest to clear land and revitalize the soil. The carbon monoxide these fires generate correlates with the increased ozone levels that Logan sees in satellite measurements. “Readings are higher over South America, the south Atlantic, and Africa than they are over the remote Pacific,” she said. “That’s a planetary-scale feature that we see quite clearly in the TES data. It’s great to have a global data set that shows this for the first time.”

Piecing together a dynamic picture

And although the first data results from TES are now available from the NASA Langley Atmospheric Science Data Center Distributed Active Archive Center (LaRC DAAC), TES science team members like Jacob and Logan are still validating the instrument’s measurements by comparing them to model results, field data, and atmospheric readings from other sources. This process confirms the accuracy of the data and helps researchers improve the data quality.

Because TES is a relatively new instrument, science and validation teams are still conducting extensive campaigns.

One of the validation campaigns, the Intercontinental Chemical Transport Experiment (INTEX), is also looking specifically at air pollution drifting into and out of the United States. As industrialization and automobile use increases in developing regions like Asia, researchers want to identify how drifting air pollution will impact U.S. air quality, as well as identify more accurately where U.S. pollution is ending up.



Tropospheric Emission Spectrometer (TES) data reveal the seasonal progression of elevated ozone in the southern hemisphere. High ozone levels, indicated with warm colors, are prominent over Brazil and southern Africa, where farmers frequently burn fields to rejuvenate the soil before the summer growing season. Retrieved ozone mixing ratio is in parts per billion (ppb) at 511 millibars, for the first two weeks of October 2005. White indicates no data, and any values greater than 100 ppb are shown as 100 ppb. (Courtesy Jennifer Logan)

TES data are providing more information about pollution sources, but atmospheric chemistry is dynamic, and scientists are still piecing together what they discover. And although air quality in the United States has improved over the past twenty years, scientists and monitoring agencies are still investigating the global nature of atmospheric transport.

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For more information

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

Tropospheric Emission Spectrometer (TES)
http://tes.jpl.nasa.gov/

Goddard Earth Observing System Model (GEOS-Chem)
http://www-as.harvard.edu/chemistry/trop/geos/index.html

Measurements of Pollution in the Troposphere (MOPITT)
http://terra.nasa.gov/About/MOPITT/about_mopitt.html

About the remote sensing data used

Satellite	Terra
Sensor	Measurements of Pollution in the Troposphere (MOPITT)
Data set used	MOPITT Level 2 V3
Resolution	22 square kilometers
Tile size	North America
Parameter	Carbon monoxide
Data center	NASA Langley Atmospheric Science Data Center (LaRC) DAAC
Science funding	NASA

About the scientists

Daniel Jacob is Vasco McCoy Family Professor of Atmospheric Chemistry and Environmental Engineering at Harvard University. Jacob leads the Atmospheric Chemistry Modeling Group at Harvard with Jennifer Logan, researching atmospheric chemistry and human impacts on the atmosphere. He studies tropospheric ozone and atmospheric aerosols, and is a member of the Tropospheric Emission Spectrometer (TES) science team.

Jennifer Logan is a senior research fellow at Harvard University. She is a member of the TES science team. Her research interests include tropospheric ozone, carbon monoxide, ozone trends, and the effects of boreal fires on global air quality.

Gabriele Pfister is a project scientist at the National Center for Atmospheric Research (NCAR), in Boulder, Colorado. In her research, she combines observations with chemistry-transport modeling to gain a better understanding of the contribution of different pollution sources on the composition of our atmosphere.

Data more powerful than hurricanes

"Emergency managers need close-up, detailed statistics about the people in each neighborhood so that they can make the best plans at each stage of their disaster work."

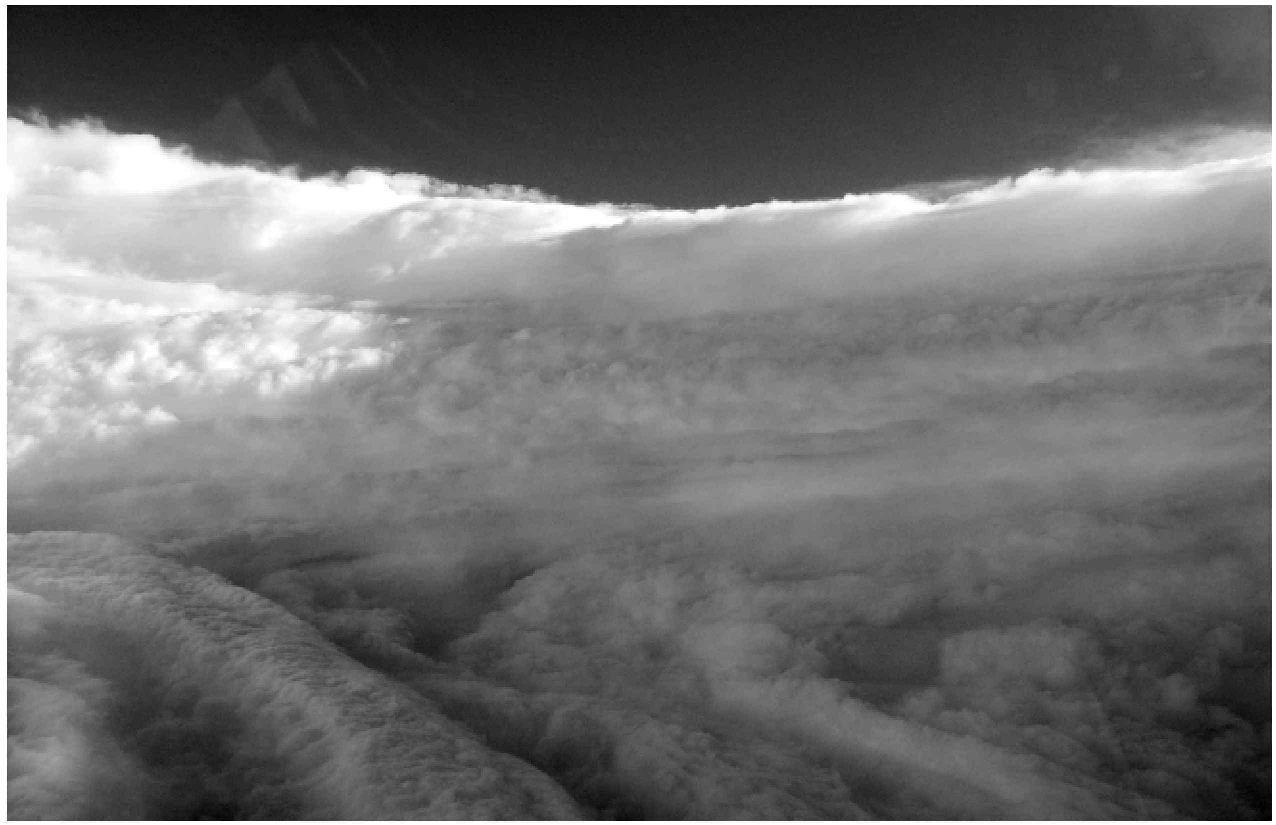
Lynn Seirup
Socioeconomic Data
and Applications Center

by Jane Beitler

On the evening news, a graphic tells us that a new hurricane is forming: a little spiral cloud grows over a distant ocean. As days go by, it swells and wobbles towards land. At a distance, inlanders witness its landfall and aftermath. Meanwhile, coastal dwellers have time to get out of the way.

Science has not eliminated hurricanes, but scientific advances in the last fifty years have helped people survive them. Consider the story of the Category Four hurricane that struck Galveston in September 1900, still regarded as the deadliest hurricane in United States history.

Galveston meteorologist Isaac Cline could not have predicted the hurricane's path or fury in time to evacuate the city. From the rooftop of the Galveston weather bureau, Cline observed high tides and large swells first, then rapidly dropping barometric pressure just hours before landfall. The storm then certain, he waded



Hurricane Katrina's eyewall swirls in a photograph by a National Oceanic and Atmospheric Administration (NOAA) P-3 hurricane hunter pilot on August 28, 2005, a day before the powerful storm slammed into the United States Gulf Coast. (Photograph by Lieutenant Mike Silah/courtesy NOAA) home through waist-deep water. During the hurricane, Cline's house collapsed, and Cline and his two surviving children drifted on wreckage for three hours until the storm subsided. Fifty people took refuge in his house; only eighteen survived. The unnamed hurricane killed 6,000 of the city's 37,000 residents and flooded the entire city 7 feet deep.

Sadly, while life on the coast is safer now, Hurricane Katrina revealed how much must still be done to prevent suffering and death. Key questions need still sharper answers: Where is the storm going to hit? How strong is it? Who is in its path? What can be done to save lives? Researchers are looking more deeply into remote sensing and population data for these answers.

Forecasting hurricanes

Hurricane forecasters today are unlikely to be found monitoring conditions from the roof, as Cline had to do. Well-equipped storm centers digest data from spaceborne sensors, ocean buoys, and storm-chasing aircraft, enabling forecasters to see and understand storms still many days away. Methods continue to improve: three-day storm-track predictions are now as accurate as the two-day forecast was twenty years ago. But forecasters want to make similar progress in storm-intensity forecasts.

What do we gain from more accurate storm-intensity forecasts? At all points, more certainty supports better decisions. Uncertainty can stall people as they weigh storm risks against the physical hardships and costs of evacuation. A study of North Carolina coastal residents who were affected by Hurricane Bonnie in 1998 confirmed that most based their decision to evacuate on the forecasted severity of the storm. Despite mandatory evacuation orders, only one of every four residents and vacationers evacuated.

Particularly, forecasters want more data about wind intensity, a strong indicator of storm intensity and threat that has improved more slowly than storm-track forecasts. The best data about wind intensity for developing storms comes from sensors on ocean buoys and from storm-chasing aircraft that fly through the hurricane eyewall, where the most intense conditions occur. These measurements are then relayed to hurricane centers and used in storm forecast models.

But buoys and aircraft have limitations. Frank Monaldo, a researcher at Johns Hopkins University's Applied Physics Laboratory (APL), explained, "Aircraft measure wind speeds at altitude, not down on the ocean surface. And at higher wind intensities, you can't rely on the measurements from buoys. The buoy flops up and down and is shielded from the winds by waves, so you can't believe its data."

Monaldo and APL colleague Donald Thompson see promise in a new remote-sensing method for monitoring hurricane winds. Thompson said, "Weather satellites can show the familiar spiraling cloud-cover patterns that you see on television. But those dramatic cloud-top images aren't the whole story." Monaldo added, "If you had high-resolution wind data, you could look at the structure of the winds, and better understand the storm dynamics." Some remote-sensing instruments can measure winds, but do not provide enough detail for hurricane tracking. So Monaldo and Thompson, teaming with other scientists and the National Oceanic and Atmospheric Administration (NOAA), have been studying Synthetic Aperture Radar (SAR) data, which has a resolution as fine as 100 meters (328 feet). SAR is better known for detecting sea ice, forest cover, and coastal erosion. The research team developed a method to retrieve wind speed from SAR data, using data from Canada's RADARSAT-1 instrument. The data are archived at the NASA Alaska Satellite Facility DAAC (ASF DAAC) and distributed to U.S. researchers through a special agreement between the United States and Canada.

Detecting hurricane winds

SAR microwave radar pulses can "see" the ocean surface day or night, in clear or cloudy conditions. SAR uses a special technique to synthesize a long antenna, providing much finer detail than normally possible from an instrument compact enough to ride on a satellite. Using this higher resolution, SAR can detect relatively small surface features. The highest-resolution images have been able to detect ships and their wakes, as well as surface waves, which are telltales of wind.

"The physics underlying the measurement of marine wind speed from space can be observed by a casual walk to a pond or lake," Monaldo said. "When no wind is present, the surface of the water is smooth, almost glass-like. As the wind begins to blow, surface waves begin to develop and the surface roughens. As the wind blows more strongly, the amplitude of the waves increases, roughening the surface still more."

Waves generated by winds have a high radar cross section, seen as bright areas in SAR images, because more of the radar signal is being bounced back. By studying SAR data on waves off the Alaskan coast and comparing the data to surface wind measurements, the researchers tuned their methods for detecting the wind signatures. Moving on to hurricane-force winds, the team then studied SAR images from Hurricane Ivan near Jamaica in September 2004, comparing the results to actual wind measurements from the storm, and to winds forecast by hurricane models. The SAR data agreed with the surface and model data for wind speeds up to approximately 120 knots (138 miles per hour).

About the remote sensing data used

Satellite	RADARSAT-1
Sensor	Synthetic Aperture Radar (SAR)
Data set used	RADARSAT Standard SAR
Resolution	100 meters
Tile size	100 square kilometers
Parameter	Wind speed
Data center	NASA Alaska Satellite Facility (ASF) DAAC
Science funding	United States Office of Naval Research

More work is needed to refine this method, called the SAR inversion process, to accurately estimate the higher winds associated with hurricanes. Unlike a boat that leaves only a wake behind it, the circulating nature of a hurricane generates waves in all directions from its spiraling winds. Thus, the sea surface is much more "confused" in hurricane conditions than it is when the wind is blowing in a constant direction. Under such conditions, the wind direction becomes more difficult to extract from the SAR data. Thompson said, "Under hurricane conditions, the ocean surface is roughened not only by the local wind field, but also by long waves that were previously generated by the hurricane and that have traveled along to its current position. So the surface roughness depends not only on the local wind at that moment, but also on how strong the hurricane's winds were on its way there."

Another task is to make the wind data suitable for operational forecasting, which requires frequent updates. The team continues to seek ways to streamline data processing and thus be able to provide quicker snapshots of winds. "Because of the fine resolution of SAR, the data volume is quite large, so we can't process it instantly as it comes off of the instrument," Thompson said. "But at least for the Alaskan coastal winds project, we have it down to an hour from receiving the raw telemetry from the satellite, to posting wind data on the Web. We're currently working with the Center for Southeastern Tropical Advanced Remote Sensing (CSTARS) at the University of Miami to achieve a similar turnaround time for the SAR imagery that we expect to collect at CSTARS during the 2006 hurricane season." With continued research and refinement, the team hopes that SAR hurricane wind sensing will become a valuable part of the hurricane forecaster's toolkit in the near future.

About the census data used

Data set used	U.S. Census Grids
Resolution	250 square meters (metropolitan area data) 1 square kilometer (country/state data)
Parameters	Individuals: age distribution, race, ethnicity, income, poverty, educational level, and immigrant status Households: household size, one-person households, female-headed households with children under 18, and linguistically isolated households Housing units: occupancy, seasonal usage, occupied housing units without a vehicle, and year of construction
Data center	NASA Socioeconomic Data and Applications Center (SEDAC)
Science funding	NASA

Preparing populations

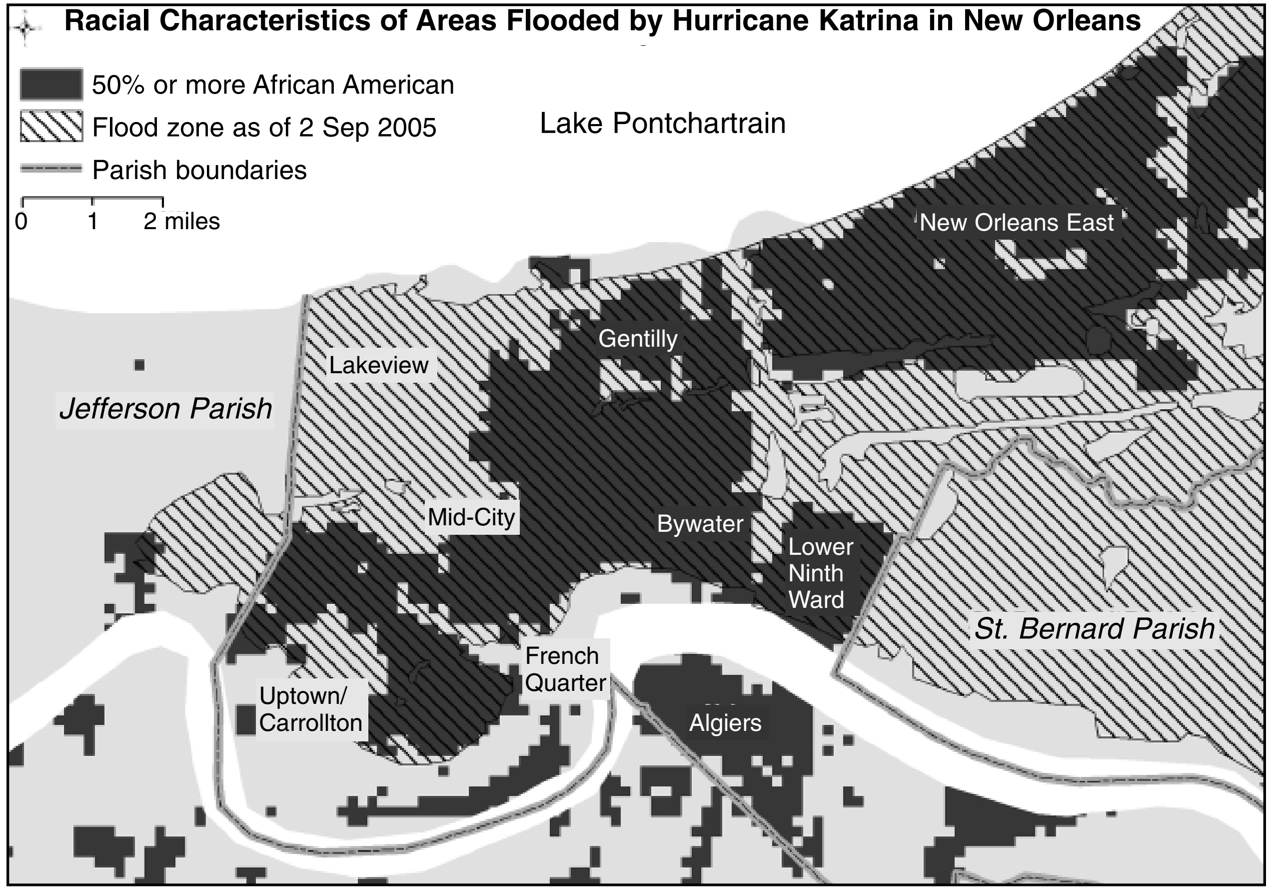
Accurate and early hurricane forecasting translates into time for the communities in a storm's path: time to make appropriate preparations, such as stockpiling resources, securing structures, moving boats, and recommending evacuation. Such efforts call on a complex set of knowledge, resources, tools, and strategies.

Even had people in 1900 Galveston known what they faced, the town lacked the means to get people out of the way of a storm. Few people had telephones; storm warnings spread by word of mouth. Cars were rare, and roads unpaved. People took shelter the best they could, and those in the cheapest or most ramshackle structures suffered most. The city was completely unprepared. Afterwards, survivor John Bladgen wrote, "The more fortunate are doing all they can to aid the sufferers but it is impossible to care for all. There is not room in the buildings standing to shelter them all and hundreds pass the night on the street. . . . The City is under military rule and the streets are patrolled by armed guards." No one had planned a response to a disaster of this magnitude.

Emergency management has since become a discipline, and experts seek to learn from past tragedies and anticipate the worst that might occur. Technology has brought helpful communication tools and transport. Still, emergency managers cannot take their success for granted. Hurricane Katrina dramatically illustrated the limits of evacuation orders and the continued reality of people failing to evacuate. Emergency managers have come to a greater understanding of the human and social issues that put people at risk.

Well before Hurricane Katrina devastated the Gulf Coast in August 2005, researchers from the NASA Socioeconomic Data and Applications Center (SEDAC), located at the Center for International Earth Science Information Network (CIESIN) at Columbia University, were working to make demographic information from the United States Census more useful and accessible to local emergency managers. Demographic data can reveal the "social vulnerability" of populations to a disaster. CIESIN researcher Lynn Seirup said, "How a disaster impacts a household can result from a complex set of circumstances, such as age, location, and economic factors. Census data gives us very specific information on who lives in an affected area and their needs before, during, and following a disaster."

Seirup, who worked in the New York City Office of Emergency Management before joining CIESIN, said, "Vulnerable populations are disadvantaged in each stage of the emergency



This map of New Orleans shows flooding and racial demographics in September 2005 following Hurricane Katrina. African Americans were 67 percent of the total population of New Orleans, but 75 percent of the population in the flooded areas. This map was compiled using SEDAC demographic data from *U.S. Census Grids, 2000*, and flooding data from the Dartmouth Flood Observatory. (Courtesy Lynn Seirup/CIESIN)

management cycle—mitigation, preparation, response, and recovery—lacking some combination of time, money, health, knowledge, social capital, and political clout. Emergency managers need close-up, detailed statistics about the people in each neighborhood so that they can make the best plans at each stage of their disaster work."

The research team identified sixteen variables in the census data that may characterize vulnerable populations, their problems, and their needs. "The elderly may be reluctant to leave their homes unattended, or may fear sleeping in a large public shelter," Seirup said. "Knowing that you have populations with these concerns helps you address those concerns when you educate people about what to do."

United States Census data are freely available, but because of their format, the data can be difficult to integrate and compare with other data. SEDAC Project Scientist Deborah Balk said, "Social science data never come on a grid. Social scientists don't think in grids—they think in communities. Policy makers are at a county or state level, not at a grid or pixel level. But if you want to compare census data to geographic elevation, to see how many people are at risk from floods, for example, you need complementary data formats."

Gridded data have been evenly distributed, using uniform assumptions, across a grid of a defined geographical size. Gridding the data allows it to be easily overlaid on a map, and for additional variables to be overlaid as well, to create a more complete picture of the factors that might affect the area being studied. People with less computing power and expertise can analyze gridded data more quickly, over a much larger area, and in more detail.

Using census data

This specific, uniform data about population characteristics supplements the local knowledge of emergency planners. Seirup said, "The local fire and police departments know who lives in their neighborhoods." The challenge is turning this qualitative knowledge into data for planning at a community level. "When I was an emergency manager in New York City, I knew that in one neighborhood that would be flooded by a Category One storm, 50 percent of the households had no one over age thirteen who spoke English," Seirup said. "But not every city has someone who would be able to work with raw census data, or the tools to do so."

Balk and Seirup first converted the census data to a grid, then further refined the data to match the needs of emergency managers. For most areas of the United States and Puerto Rico, a grid square of one kilometer (six-tenths of a mile) is sufficient. For the 50 urban areas of more than one million people, the team increased the resolution of the data down to a 250-meter grid square (820 feet). This finer resolution gives planners and responders much better data in cities with densely populated areas.

Hurricane Katrina's inundation of New Orleans offered a sad case study for social vulnerability. News coverage suggested that elderly and African American populations had suffered the most. Balk and Seirup applied the gridded census data to see if it could provide detailed information in the affected areas. Addressing questions such as "Who lived in the flooded areas?" and "Who was most likely to die?" Balk and Seirup analyzed the gridded census data. Integrating a map of the New Orleans area with the gridded census data and satellite imagery showing flooded areas, they found that in fact African Americans had been disproportionately affected, since more African Americans lived in the flooded parts of the city.

The researchers then obtained preliminary death statistics from Orleans Parish, the 180-square-mile parish that constitutes the city of New Orleans. Orleans Parish was 80 percent flooded after Katrina, and at least 555 people died there. The researchers were able to analyze the gridded census data and death statistics together; preliminary findings revealed disturbing facts. While only 12 percent of the parish population were age 65 or older, 67 percent of those who died were over 65. African Americans in Orleans Parish in every age group under age 65 also died at a higher rate; in all, they represented 77 percent of the under-65 population, but 82 percent of the deaths.

Saving lives

Balk and Seirup hope that in the future, the availability of gridded demographic data will help save lives, rather than confirm losses. Emergency planners could use demographic data to inform and tailor their plans for the unique needs of each area. The researchers also want to make census data more accessible and even easier to use. "We hope to develop a Web-based application so that people can view the data they need online, instead of needing to download files and work with them on their computers," Seirup said.

The researchers also plan to examine more case studies as new census data are released. "In the past, census data have been released every ten years," Seirup said. "Old data may not reflect the current population." Starting in 2005, the Census Bureau will release data more often, and will issue special releases for New Orleans. "The demographics in New Orleans are changing rapidly as a result of the storm and displacement of the population. It's even more important to have this detailed information on who's now living in the New Orleans area," Seirup said.

At CIESIN, researchers have also analyzed low-elevation coastal zones and population, using gridded census data from low-lying regions in countries such as Indonesia, Vietnam, and India, as well as the United States. Balk said, "A significant percentage of the U.S. population lives near the coast." Approximately 2.4 percent of the U.S. total population, and 6.3 percent of the U.S. urban population, live at below

10 meters elevation (32 feet), an elevation prone to flooding from both tropical storm surge and rising river delta waters from heavy rainfalls upstream. The analyses have drawn attention to risks in low-lying areas that have been poorly understood. The researchers are repeating the analyses by state, including the additional census variables that indicate social vulnerability.

We can be certain that hurricanes will continue to occur, although no one can predict exactly when and where the next major hurricane will make landfall in a highly populated and socially vulnerable area. After the next major hurricane, forecasters and planners hope to look back on Hurricane Katrina, much as we now look back on the 1900 Galveston hurricane, and see that new understandings of storm intensity and human issues have indeed saved people's lives.

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http://fermi.jhuapl.edu/en_sar.html

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

U.S. Census Grids
http://beta.sedac.ciesin.columbia.edu/usgrid/

Center for Southeastern Tropical Advanced Remote Sensing
http://cstars.rsmas.miami.edu/

About the scientists

Deborah Balk is an associate professor with the Baruch School of Public Affairs and acting associate director of the Institute for Demographic Research at the City University of New York. She also collaborates on integration and analysis of remote sensing and population data with the NASA Socioeconomic Data and Applications Center (SEDAC), where she served as lead project scientist until October 2006.

Frank Monaldo is a principal staff physicist at the Johns Hopkins University Applied Physics Laboratory and acting supervisor of the Ocean Remote Sensing Group. Monaldo has published on the use of radar altimetry, synthetic aperture radar (SAR) imagery, and optical image processing to measure geophysical properties. More recently, he developed a system for converting SAR imagery into real-time estimates of wind speed and has evaluated WindSat estimates of ocean surface wind vectors.

Lynn Seirup is a staff associate at the Center for International Earth Science Information Network (CIESIN). She has developed *U.S. Census Grids, 2000*, a raster data set of demographic and socioeconomic variables derived from census data. Before joining CIESIN, she worked for the New York City Office of Emergency Management, where she developed a Web-based application to provide emergency planners and first responders with demographic and socioeconomic data.

Donald Thompson supervises the Theory and Modeling Section of the Ocean Remote Sensing Group at The Johns Hopkins University (JHU) Applied Physics Laboratory. He is currently investigator on NOAA-sponsored grants for ocean remote sensing and high-resolution wind mapping using SAR. Thompson teaches for the Whiting School of Engineering at JHU and is adjunct professor with the Rosenstiel School for Marine and Atmospheric Sciences of the University of Miami.

Predicting productivity: Managing land from space

Soon, it may be possible for land managers to keep watch over remote acreage with the click of a mouse.

by Lindsay Husted

In the Northern Great Plains, open prairies extend, unbroken, to the horizon. Amid the rolling hills and endless skies, proximity is an illusion. A team of researchers, making their way through the 800,000 hectares (2 million acres) of the Little Missouri National Grassland of North Dakota, spent countless hours clipping, separating, drying, and weighing various plains grasses during the spring and summer seasons of 2001 and 2002. The goal of this tedious undertaking was to test a new way to manage enormous pieces of land like the National Grasslands. The researchers used these ground observations to corroborate data received from a satellite sensor.

One of the investigators, Matthew Reeves of the LANDFIRE Program at the Rocky Mountain Research Station Fire Sciences Laboratory in Missoula, Montana, focused his PhD research on management applications derived from satellite technology. "There's a large interest and a big push, nowadays, to get satellite technology distilled into a format that a more general audience can use for answering strategic questions." Reeves aims to wrap this

Using remote sensing data, scientists can now help predict harvest yields from wheat fields, such as this one in North Dakota. (Courtesy Matthew Reeves) high-end technology into a comprehensible data package that land managers can apply to overseeing rangelands.

Knowing how the land is responding to pressures is key to maintaining its health and longevity. For example, if cattle herds eat all of the vegetation, the rangeland, which supplies important habitat for many species of plants and animals, will be depleted and the animals living there will eventually go hungry. In such a case, land managers seek to move the cattle before the land becomes barren; restoring it to a fertile state can take decades. Researchers have turned to Moderate Resolution Imaging Spectroradiometer (MODIS) satellite data, archived at the NASA Land Processes Distributed Active Archive Center (LP DAAC), in hopes that it will provide large-scale land managers with a tool to help them keep the plains healthy and robust.

Soon, it may be possible for land managers to keep watch over remote acreage with the click of a mouse. From the vantage of an office, decision makers could open up a satellite image on a computer screen and find out that an isolated pasture shows signs of greening up or dying off. Analyzing the health of large landscapes can help gauge the human impact on an area and the demand for resources. By monitoring fluctuations in the vitality of rangelands, decision makers can design cohesive management strategies and modify grazing pressures accordingly. For the Bureau of Land Management and other agencies that are responsible for monitoring huge districts, using satellites to supervise large tracts of land alleviates demand for operating money and employee time.

Predicting productivity

Using a new data processing scheme, which includes MODIS satellite data and meteorological inputs, Reeves intends to predict potential future conditions instead of simply interpreting current conditions. Knowing the types of weather events that a land area endures enables investigators to forecast how vegetation will respond. Without the supplementary meteorological data, Reeves could only look at the satellite imagery and determine whether or not the land cover was green and healthy on the day the image was captured. He could not predict its vigor two weeks into the future by looking at surface reflectance data from MODIS alone.

By combining Moderate Resolution Imaging Spectroradiometer (MODIS) technology with meteorological data to forecast vegetation health, land managers can implement more efficient rangeland management strategies in regions such as this one, near the Charles M. Russel Wildlife Refuge in Central Montana. (Courtesy Matthew Reeves)

Researchers can now apply a specific mathematical equation, known as the MOD17 algorithm, to deduce a measure of vegetation health from a satellite image. Steve Running, of the Numerical Terradynamics Simulation Group (NTSG) at the University of Montana, said, "It's meant to be a simplified carbon balance for a terrestrial ecosystem, where you are using the satellite to quantify the vegetation cover and light absorption." The carbon balance accounts for the carbon dioxide that plants absorb from the atmosphere and use for respiration. Through the process of photosynthesis, plants transform carbon into sugar, which feeds them and helps them grow. Researchers can determine the amount of sunlight and rainfall an area receives to predict vegetation growth. Applied to what is known about the life cycle of different plant species, information from MOD17 presents managers with the capability to forecast the health of a landscape.

Because the MOD17 equation uses both the MODIS satellite data and separate meteorology data from the Global Modeling and Assimilation Office (GMAO) at NASA's Goddard Space Flight Center, the algorithm has unprecedented applications. GMAO data include air temperature measurements, which can indicate that vegetation's photosynthetic activity has ceased because of below-freezing temperatures. The data also include vapor pressure measurements, essentially the amount of pressure that water molecules exert within a given volume of air.

The combination of temperature and vapor pressure provide key information on humidity and water balance. Water balance provides a comparison of the amount of water supplied by precipitation, released into the atmosphere through evaporation and respiration, and stored within the soil.

Farming applications

To monitor vegetation vitality, investigators typically use a direct measure of the amount of solar energy absorbed by a plant's leaves. Researchers derive this measure from a remote sensing product called the normalized difference vegetation index (NDVI), which can indicate when the vegetation cover is dying or when the ground appears greenest, for instance. Using these measurements to construct a crop prediction model is practical only when on-the-ground conditions, such as season and region, are the same as the conditions assumed in the model. Land-cover researchers can now use the weekly vegetation measurements of MOD17 to avoid having to go back and formulate relationships between remote sensing data and observed vegetation.

About the remote sensing data used

Satellites	Terra/Aqua
Sensor	Moderate Resolution Imaging Spectroradiometer (MODIS)
Data set used	MOD13Q1
Resolution	250 meters
Tile size	Regional
Parameter	Biomass
Data center	NASA Land Processes (LP) DAAC
Science funding	NASA

Many crops, such as wheat, are sensitive to meteorological conditions that NDVI computations do not include, especially at crucial stages in the growth cycle. NDVI may indicate a significant amount of above-ground plant material, but it may not always be an accurate measure. For example, if a wheat crop suffers a drought during flowering, the crop yield could be lower than expected because the lack of water reduces a plant's fertility. NDVI, by itself, only allows for analysis of crop yield after the harvest has already taken place. Offering an eight-day, global composite data product, along with meteorological data, gives the MOD17 algorithm an advantage over the traditional NDVI method.

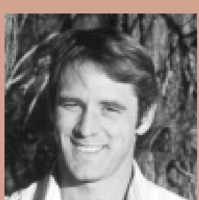
Accurate information about crop progress and production is essential to government planners in establishing market prices and preparing for emergency food reserves. The techniques also have the capability to provide statewide crop yield predictions, information that can prepare a state for the economic setbacks caused by drought. When Reeves applied the MOD17 equation to the readily available MODIS photosynthesis data, he was able to make accurate statewide wheat yield predictions in Montana.

The future of MOD17

Reeves hopes to extend his PhD research to the operations and maintenance side of the LANDFIRE program at Rocky Mountain Research Station, which is aimed at assessing fire potential and supporting landscape fire management planning. "I am planning to once again go to the MODIS data set, take advantage of its fantastic temporal resolution, and use it to update LANDFIRE fuel products," Reeves said. Using this type of technology to quantify the material that fuels wild fires presents another example of the extensive applications for MODIS.

After many tiresome days of working in the hot and humid fields of the Little Missouri National Grassland, cutting and sorting plant clippings, Reeves is confident in the satellite technology he toiled to validate with ground-based data. "MODIS is the most professional suite of products ever produced at this level," Reeves said. In the bright future of MOD17,

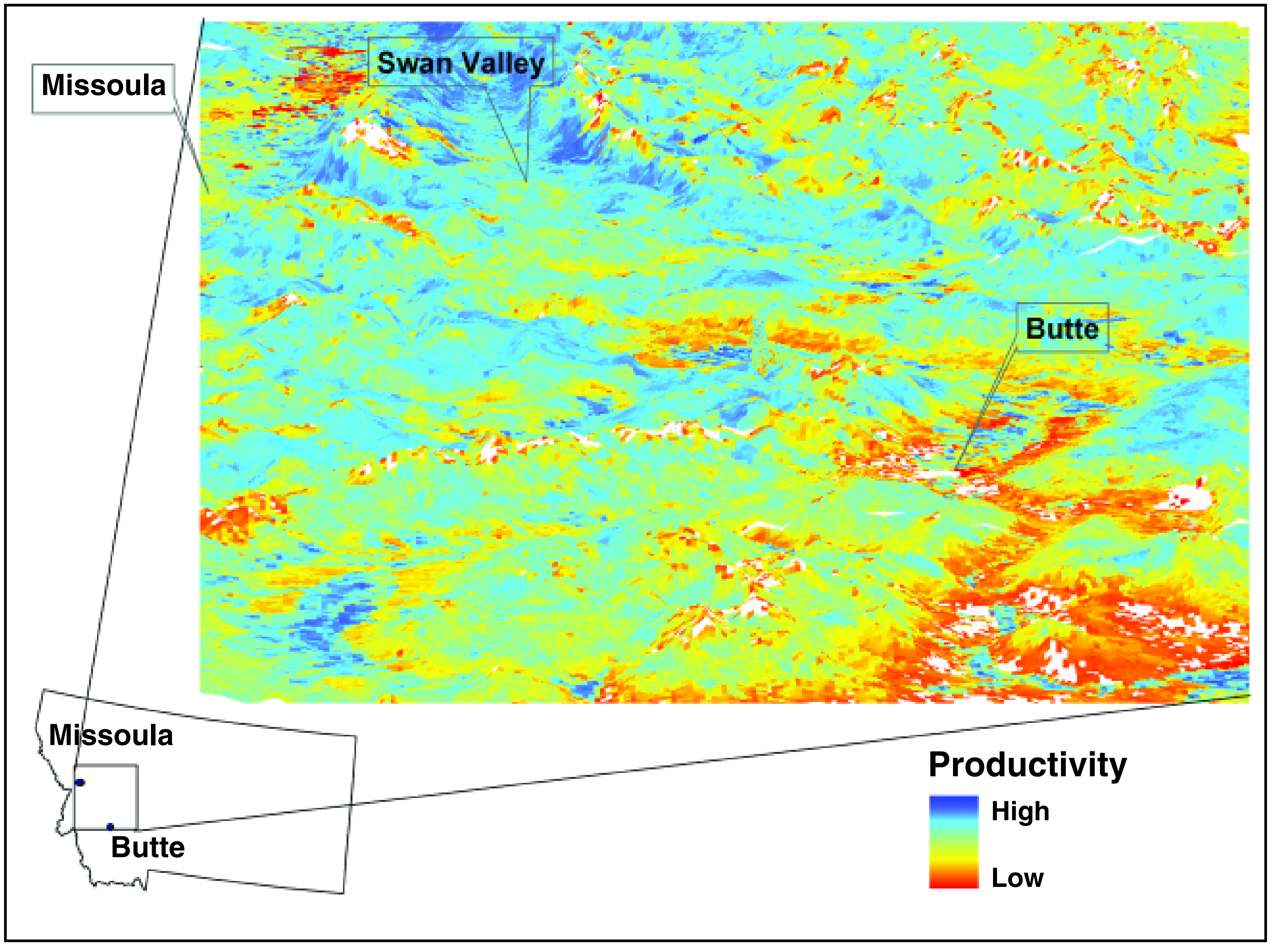
About the scientists



Matthew Reeves leads the fuels team and is a Geographic Information Systems (GIS) specialist for the LANDFIRE program. He received his PhD from the University of Montana, where he developed satellite-based assessments of rangeland productivity and agricultural yield for Montana and North Dakota. (Courtesy Matthew Reeves)

Steven Running is a terrestrial ecologist and professor at the University of Montana, Missoula. He is interested in the development of global and regional ecosystem biogeochemical models through integrating remote sensing, climatology, and terrestrial ecology. Running is a NASA Earth Observing System (EOS) Moderate Resolution Imaging Spectroradiometer (MODIS) team member; he focuses on the EOS global terrestrial net primary production and evaporative index data sets. (Courtesy Steven Running) a single land manager will be capable of monitoring mile upon mile of these rural tracts more efficiently than a handful of overseers could previously.

The next big step in the research is to give this technology a try. Running hopes to have a small group in Idaho test the package for actual application. He thinks managers will save time and money through the use of MODIS technology. "If a range manager can pop online to view a satellite image while in their office and find ou t that fifty miles away, a high-elevation pasture is now greened up and ready for grazing," Running said, "that may be the only way to get that information—other than by driving fifty miles up some dirt road and taking a look in person."



Investigators can view Moderate Resolution Imaging Spectroradiometer (MODIS) productivity data, as shown in this area of western Montana, to determine which areas of a landscape are healthy and green. Here, MODIS data are "draped" over topographic data to help land managers better monitor remote lands. (Courtesy Matthew Reeves)

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http://edcdaac.usgs.gov/main.asp

Numerical Terradynamics Simulation Group at University of Montana
http://www.ntsg.umt.edu/

Mapping the changing forests of Africa

"Once the forest is gone, starvation and increased poverty follow."

Nadine Laporte
Woods Hole Research Center

by Stephanie Renfrow

In the Central African Bwindi forest in Uganda, a gorilla sits on the forest floor nursing her young. A few miles away, a subsistence farmer burns a patch of forest in preparation for a crop that will feed his family. And as the smoke from the burning forest floats into the sky, carbon dioxide (CO_2) drifts into the Earth's atmosphere.

The gorilla, the farmer, and the burning forest's emissions are interconnected by a single phenomenon: a change in the way people use land. More than 900 million people live in Africa, and many of them rely on traditional slash-and-burn agriculture to survive lives of profound poverty. Slash-and-burn fires in developing countries contribute a significant amount of CO_2 to the atmosphere; up to a third of all global CO_2 emissions comes from land-use changes, including agricultural fires. Carbon dioxide is one of the greenhouse gases that is causing our planet's average surface temperatures to rise.

But land-use change does more than just add to our world's growing burden of CO_2. Land-use change also affects and threatens entire ecosystems and the plants and animals within them. In the case of the Central African forests, land-use change has contributed to pushing three species of Great Ape to the edge of extinction. Sadly, the very people who burn the forests to survive can deepen their own plight if they run out of the vital fuel and resources the forests provide. Land-use change and its global and local effects are interrelated from the point of view of Nadine Laporte, a scientist at the Woods Hole Research Center in Woods Hole, Massachusetts. Laporte is the director of the Africa Program, which studies African land-use planning and forest management. For Laporte, finding a way to address rising CO_2 and dwindling Great Apes populations, as well as helping to improve forest management, are central to her day-to-day work.

A biomass map of Africa

In the spring of 2005, Laporte accepted an invitation to visit Uganda's National Forest Authority. While there, she learned that the Ugandans were trying to use maps of the forest's biomass—trees, plants, and other living matter—to help them manage the land use of their forests. "By law, the government of Uganda must come up with an estimate of the forest biomass every five years," Laporte said. On-the-ground field surveys are expensive

Great Apes, like this silver-back gorilla in Uganda's Bwindi forest, are struggling to survive in the diminishing forests of Central Africa. (Courtesy Andy Plumptre) and time-consuming, so the Ugandans had turned to satellite imagery, also called remote sensing data, as a logical solution for creating a map. "But the last time they produced a map," Laporte said, "they used high-resolution satellite imagery and it took them almost ten years to produce." Laporte thought she knew why.

The satellite imagery the Ugandans used is called Satellite Pour l'Observation de la Terra (SPOT) data. The SPOT sensor collects data at a resolution of two-and-a-half to twenty meters, and its image footprint covers areas measuring sixty kilometers by eighty kilometers (thirty-seven miles by fifty miles). "It's like covering the whole country with hundreds of little tiles that you have to put together," Laporte said. "It's very time consuming to do that, especially with limited resources."

Laporte knew of another option: data from the Moderate Resolution Imaging Spectroradiometer (MODIS) sensor, flying aboard NASA's Terra satellite. MODIS data are distributed by the NASA Land Processes Distributed Active Archive Center (LP DAAC) at the United States Geological Survey's Earth Resources Observation and Science (EROS) Data Center in Sioux Falls, South Dakota. The data have a lower resolution than SPOT data; the specific data set that Laporte used has a resolution of one kilometer (six tenths of a mile). However, MODIS data are organized in large tiles that cover entire regions, so MODIS data were a more manageable choice for the project. The Ugandans welcomed Laporte's help and expertise. Laporte said, "For all of Uganda, we only had to process two giant tiles from MODIS instead of hundreds of tiny tiles from SPOT."

Nadine Laporte teaches a quick geography lesson to children in Uganda while she waits for a tire on her vehicle to be repaired. (Courtesy Nadine Laporte)

Laporte realized that the biomass map that the Ugandan government needed for forest management was actually one piece of a much larger puzzle. "The same remote sensing data sets can have different applications according to the question you want to answer," she said. She decided to propose an expanded version of the Ugandan biomass-mapping project to NASA through its Land-Cover Land-Use Change and Biodiversity and Ecological Forecasting programs. Laporte knew that the biomass project would be more useful if it extended to all of Africa rather than just focusing on Uganda. She also recognized that the biomass map of Africa could be used to seamlessly address multiple needs at the same time: quantifying CO_2 emissions, helping conserve the Great Apes, and improving forest management.

Quantifying carbon dioxide emissions

When a farmer burns a patch of forest, carbon stored in the trees and forest biomass returns to

Scientist Nadine Laporte sits with Mbaka Pygmy women in Northern Congo. Pygmies, who survive primarily through traditional hunting and gathering, often serve as guides for forest research and conservation expeditions. (Courtesy Nadine Laporte, Tiffany Lin/WHRC)

the atmosphere as CO_2; this exchange of carbon between the Earth and the atmosphere is called the carbon cycle. By changing its land use, the forest patch goes from being a "carbon sink," which stores carbon, to being a "carbon source," which gives off CO_2.

Different countries produce different amounts of CO_2, depending on various factors, including the amount of forest that is burned within their borders. However, the amount of carbon released into the atmosphere also varies depending on the type of forest burned. Evaluating the forest types of Central Africa is one of the main goals of the Africa biomass map project.

Alessandro Baccini, a remote-sensing scientist at Boston University who is collaborating with Laporte on the biomass map, explained the reason that different forests store differing amounts of carbon. "If you log a young forest, the amount of carbon released may not be very big," he said. "But if you log a mature forest, the amount of carbon released is probably much higher because the trees are taller and have a larger diameter." So, if scientists assume one average biomass amount for an entire country or region, their carbon estimates probably will not be accurate.

Laporte said, "That is why it's important to know the type of forest. Using MODIS imagery, we can determine the biomass of particular forests; then we know how much CO_2 is released when those forests are burned." However, to effectively use satellite imagery to estimate the biomass that a forest represents, scientists first need some sample field data to check against. Baccini said, "We need to know how much biomass we have on the ground in a particular spot. Then, using this field data, we can calibrate the relationship between actual biomass and the remote-sensing data."

Richard "Skee" Houghton, a carbon modeler at the Woods Hole Research Center and collaborator on the project, agreed. "We're going to try to link the land-use change finely enough in space, at a specific location, to attach a biomass to it. That's what makes this map so much more difficult to produce, and it ought to be that much more accurate, too."

Once Laporte and Baccini have produced the biomass map and checked its accuracy, Houghton will use the information to model, or predict, the sources and sinks of carbon in Africa's forests. "The model is based on the processes of disturbance and recovery," Houghton said. "It tells us that if you cut down a particular area of rainforest, here's how much carbon was held in the rainforest, here's how much carbon would be held in a field of shifting cultivation, and here's how much carbon was released to the atmosphere when the forest was cleared." The model will be comprehensive enough to account for different land-use changes, including whether the forest is cut down for building materials, burned and farmed, or even replanted.

Using the completed model, Laporte will begin the analysis in earnest. "Starting with Central Africa, we'll be able to break down the contribution of CO_2 by region and country." This information will help scientists understand the sources and sinks of carbon, as well as the role

About the remote sensing data used

Satellite	Terra
Sensor	Moderate Resolution Imaging Spectroradiometer (MODIS)
Data set used	Nadir Bidirectional Reflectance Distribution Function (BRDF)-Adjusted Reflectance (NBAR)
Resolution	1 kilometer
Tile size	Regional
Parameter	Biomass
Data center	NASA Land Processes (LP) DAAC
Science funding	NASA

of land management in controlling carbon emissions from land-use change.

Helping conserve the Great Apes

People are not the only ones affected by land-use change in Africa. Three of the four species of Great Apes—gorillas, chimpanzees, and bonobos—dwell in the forests of Central Africa and rely on the forests for their survival. They are under grave pressure because their habitat is diminishing as increasing numbers of people burn or cut down the forests. Laporte said, “In Uganda, only two small pockets of mountain gorilla habitat remain in vast areas converted for agriculture.” According to House testimony from Marshall Jones, Deputy Director of the United States Fish and Wildlife Service, gorilla, chimpanzee, and bonobo populations have been reduced by half since 1983.

Central African Great Apes live in forests and occasionally in bordering woodland or savanna areas. Their main staples are forest plants and fruit. Gorillas are the largest of the Great Apes; males may be 180 kilograms (400 pounds) and almost 2 meters (6 feet) tall when standing upright. Maintaining this large bulk requires extensive vegetation in which to forage. Chimpanzees and bonobos, although much smaller than gorillas, also require substantial and largely undisturbed tracts of forest for their survival. However, their forest habitat is rapidly vanishing, which is isolating populations and reducing their ability to survive.

The biomass map of Africa will be of great benefit to conservationists who are working to save the Great Apes from extinction. The Integrated Forest Monitoring System for Central Africa (INFORMS) project, which Laporte created in 2000, established the use of remote sensing to monitor Great Apes habitat change. Laporte said, “The Africa biomass map project could be seen as a natural continuation of INFORMS, but more oriented towards better information on the stock and volume of biomass throughout Africa.”

Subsistence agriculture in a tropical forest in Mozambique sends plumes of smoke and carbon dioxide into the atmosphere. (Courtesy Frank Merry)

The application of the biomass map to Great Apes conservation is clear. “The Great Apes are found in high biomass forests. Forests that have been degraded have lower biomass and are less likely to be good habitat for these animals,” Laporte said. “Using the biomass map of Africa, we can predict potential habitat or prime habitat for them.”

The biomass map will also help conservationists pool their efforts to save the remaining habitat that is most suitable for the diminishing populations of Great Apes. “The biomass map can be used as a layer of information as people who are monitoring the apes decide which areas of forest to focus on for protection,” she said.

Improving forest management

Conservation of the forest for the benefit of Great Apes is closely tied to forest management. Forest managers must balance the needs of other species with those of our own. This means monitoring deforestation, carefully planning reforestation, and providing incentives for wise use of the forests.

Millions of people rely on Central African forests to survive lives of extreme poverty. Each year, individual farmers burn significant areas of forest to plant food crops for their families. In subsequent years, subsistence farmers may allow land cleared previously to regrow into savannas, woodlands, and forest. However, overall, more forest is being destroyed than is being created.

The biomass map of Africa that Laporte and her team are working to produce will be valuable to forest managers in African countries, including Uganda. "Most of Uganda has been converted to agriculture, and they don't have much forest left," Laporte said. "Most of the logs that they use are imported from outside the country." In a country with few and dwindling forest resources, forest managers want accurate, current information that will help them determine how to manage the forest and where to focus planting efforts. Government officials could also use the information to determine where to provide social assistance or incentives for sustainable use of the forest.

The biomass map of Africa has already pinpointed some interesting information for forest managers. "We've been catching areas that used to be savannas with few trees and which are now like woodlands, with higher biomass," Laporte said. "We think that might be associated with regrowth." Comparing future versions of the map would help forest managers monitor the success of forest conservation and forest restoration projects.

About the scientists

Alessandro Baccini is a research associate in the Geography Department at Boston University. He uses remote sensing to map and estimate forest biomass and carbon in Central Africa, North America, and Eastern Europe. He is also working to quantify the impact of land-cover and land-use change on the regional carbon cycle in the Black Sea region. He is a member of the Moderate Resolution Imaging Spectroradiometer (MODIS) Global Land Cover Team. (Courtesy Alessandro Baccini)

Richard Houghton is an ecologist at the Woods Hole Research Center. He is interested in the role that terrestrial ecosystems play in climate change and the global carbon cycle. He coordinates the Center's efforts to understand the role of biotic systems in global warming and climate change. Houghton was an assistant scientist at the Ecosystems Center of the Marine Biological Laboratory and a research associate at Brookhaven National Laboratory. (Courtesy Gabriel Amadeus Cooney)

Nadine Laporte is a biologist at the Woods Hole Research Center. Her research focuses on the applications of satellite imagery to tropical forest ecosystems, including vegetation mapping, land-use change, and deforestation causes and consequences. She has worked with in-country scientists, foresters, and international conservation organizations to develop integrated forest monitoring systems and promote forest conservation in Central Africa. (Courtesy Gabriel Amadeus Cooney)

The possibilities for applying the biomass maps to future forest management efforts are extensive. "One future direction for the work is that I would like to develop the link between biomass and poverty," Laporte said. "If we find low biomass in an area that we would predict should have high biomass, we can predict fuel wood scarcity. And the poorer you are, the more you depend on natural resources like forests for land, food, and fuel." The indication of a high-risk, high-poverty area could help identify places that need rapid, focused attention by forest managers, national governments, and international aid groups.

"Once the forest is gone," Laporte said, "starvation and increased poverty follow."

Mapping Africa into the future

Given the urgency for forest managers and conservationists, the more frequently Laporte's team can update the biomass map, the more relevant and helpful it will be.

"In June, I'll be in Uganda to do some validation work on the map," Laporte said. "We're hoping that maybe in a year or so, we'll be able to produce these biomass maps on a routine basis for the Uganda National Forest Authority." The current version of the biomass map took the team six months to produce, with calibration and polishing still left to do; they hope to finish the map sometime this year. Laporte hopes her team will eventually be able to provide maps annually to conservationists and forest managers.

Once the team has used the polished map and deforestation rates to develop the carbon model, the focus will be on understanding specific areas of the carbon story. "We hope to get a better estimate of CO_2, establish an annual rate of deforestation, and calculate how much CO_2 is going into the atmosphere," Laporte said. "We'd even like to predict CO_2 on an annual basis."

These details will be of interest as scientists compare carbon sources and sinks within and among regions and continents to better understand global warming. Plus, Baccini said, "If the technique works well in Africa, maybe we will expand it and have something more extended to cover other continents."

A better understanding of carbon's sources and sinks could also be useful as governments attempt to sort out policies to curb global carbon emissions. Houghton said, "In a world of carbon credits, you can imagine that countries will get credits or debits for sources and sinks of carbon that result directly from their land management practices." Being able to quantify a nation's carbon cycle would be an important part of that system.

Whether it's a government official, an international conservationist, or a forest manager, Laporte said, "I want to identify what the needs are—what people need so they can do a better job. And after we produce a finished product, then we will know that it has filled a real need." The MODIS biomass map of Africa is already on its way to addressing not just one need, but three: improving our understanding of the carbon cycle, adding to the knowledge-base of Great Apes conservationists, and providing a tool to help forest managers use their nations' resources wisely.

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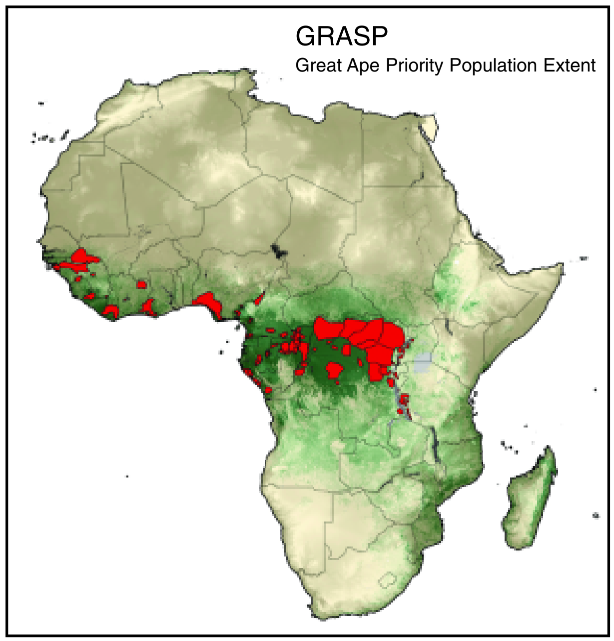


The Great Apes are scattered over an increasingly fragmented forest landscape. The United Nations Great Ape Survival Project (GRASP) is now using satellite imagery and field surveys to identify priority populations, indicated in red, to guide conservation actions. Green indicates forest density. (Courtesy Nadine Laporte, Greg Fiske/WHRC)

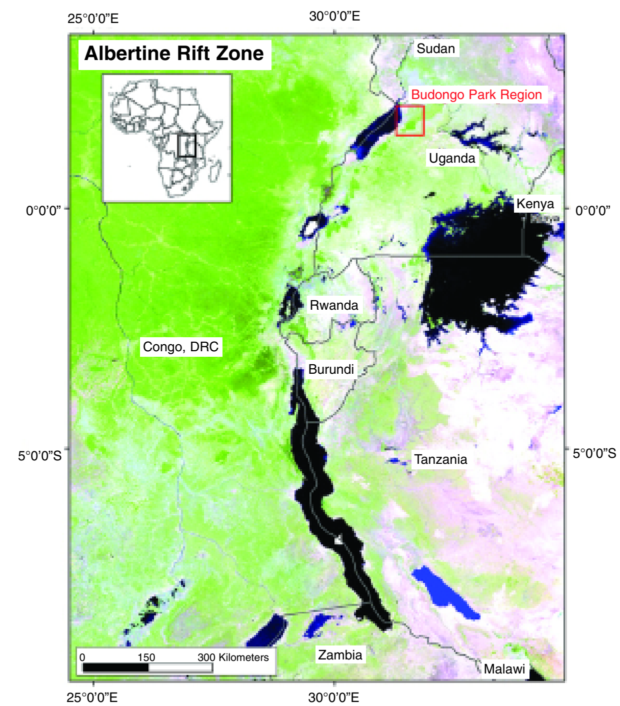
For more information

NASA Land Processes DAAC
http://edcdaac.usgs.gov/main.asp

NASA Terra satellite
http://terra.nasa.gov/About/

SPOT image
http://www.spotimage.fr/html/_.php

Woods Hole Research Center's Africa Program
http://www.whrc.org/africa/index.htm



This map shows a detail of the Moderate Resolution Imaging Spectroradiometer (MODIS) data set that Laporte's team used to map biomass in Central Africa's Albertine Rift Zone. The dark green indicates higher biomass, light green indicates lower biomass, and lavender indicates savannas. The red rectangle highlights the Budongo Forest Reserve in southwest Uganda, where many of the surviving Great Apes are protected. (Courtesy Nadine Laporte, Alessandro Baccini)

Cloud to cloud: Forecasting storm severity with lightning

"When forecasters are not quite sure about the severity of a storm, lightning data may tilt the balance one way or the other."

Richard Blakeslee
Global Hydrology and Climate Center

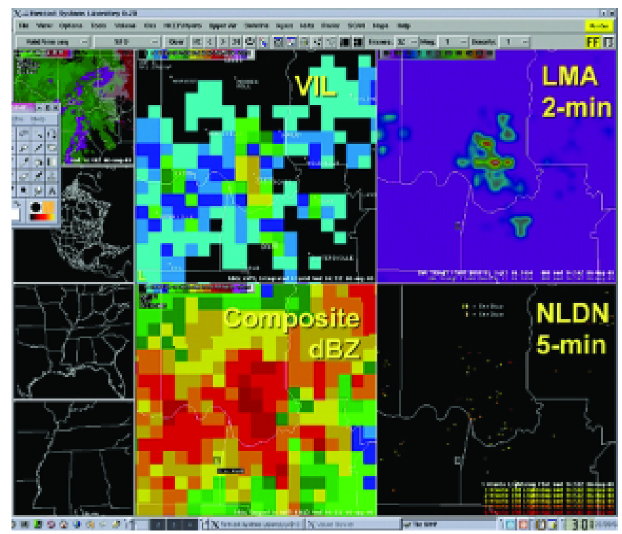
by Laura Naranjo

Summertime in northern Alabama means sunny family picnics and lazy afternoons by the pool. But clear skies often rapidly fill with storm clouds that produce tornadoes, hail, and lightning. While the sudden eruption of severe weather may thrill a storm chaser, it can make a forecaster cringe. Weather conditions can worsen rapidly, sometimes giving forecasters little time to assess a situation and even less time to issue a warning. Forecasters must monitor a variety of constantly changing factors affecting storm formation, but researchers have discovered that observing one of the components of severe weather, lightning, can reveal clues about an impending storm's severity.

Mapping the frequency of lightning

Richard Blakeslee has studied the relationship between lightning and storm development for more than twenty-five years. As a senior research scientist at the Global Hydrology and Climate Center (GHCC) in Huntsville, Alabama, Blakeslee has relied on a variety of methods to research lightning, and has helped develop satellite sensors to monitor lightning on a global scale. But to better understand how lightning can help make storm forecasting more accurate, he also conducts research in his own neighborhood, incorporating data from the North Alabama Lightning Mapping Array (LMA), a set of sensors that began operating in 2001.

"The Lightning Mapping Array maps out lightning discharges within the clouds, providing a three-dimensional map of the lightning as it develops," Blakeslee said. The network consists of eleven receivers that capture detailed lightning observations. The LMA was initially deployed to validate the Lightning Imaging Sensor aboard the Tropical Rainforest Measuring Mission (TRMM) satellite, but LMA data are also proving useful to regional forecasters on the ground. Every two minutes, data from this network are forwarded to the National Weather Service office in Huntsville responsible for forecasting in eleven northern Alabama counties



Weather forecasters rely on the Advanced Weather Interactive Processing System (AWIPS) display. This AWIPS includes Lightning Mapping Array (LMA) data (upper right corner) as a single gridded graphic showing lightning flash density. The display also shows National Lightning Data Network (NLDN) data, vertically integrated liquid (VIL) measurements, and radar reflectivity composites. (Courtesy SPoRT) and three southern Tennessee counties. The data are also provided to nearby forecast offices in Nashville, Tennessee; Birmingham, Alabama; and Jackson, Mississippi.

Using the new LMA data, Blakeslee and his colleagues studied two thunderstorms that occurred over northern Alabama in 2002, and discovered that lightning activity increased dramatically just before the storms intensified and became severe. The researchers also incorporated cloud-to-ground lightning data from the National Lightning Detection Network (NLDN). NLDN data are acquired by the Global Hydrology Resource Center (GHRC) from Vaisala, Incorporated, and made available to approved NASA Earth Observing System (EOS) and TRMM investigators. This combination of data allowed the team to observe the total lightning flash rate, including cloud-to-ground, intracloud, and cloud-to-cloud lightning.

By looking at the flash rate maps, the researchers discovered a pattern: an increase in total lightning activity followed by a dramatic decline often indicated the development of strong storms. This pattern of lightning activity often even preceded the occurrence of cloud-to-ground lightning strikes by several minutes—information forecasters could use to issue earlier warnings to communities and airports in a storm's path.

From data to forecasts

One of the challenges, however, was making the lightning maps accessible to forecasters. "Forecasters do not actually look at the data that the researchers look at. We had to get the data into a format that forecasters could understand," Blakeslee said. Weather service forecasters rely on the Advanced Weather Interactive Processing System (AWIPS), an interactive computer system that integrates meteorological, satellite, radar, and other data, often all in one display screen. "When the weather gets severe, forecasters are glued to their AWIPS displays. If the lightning data are not available there, they're not going to be used," Blakeslee said.

Lightning illuminates a funnel cloud forming during a storm near Huntsville, Alabama, in April 2006. Alabama's turbulent weather gives scientists frequent opportunities to study lightning and storm development. (© Wes Thomas Photography)

To develop a solution, the lightning team collaborated with Chris Darden, science operations officer at the Huntsville National Weather Service office, which is co-located with GHCC. Darden was familiar with northern Alabama's unruly weather and understood the need for data that forecasters could use quickly and easily. Darden said, "The goal of the weather service is the protection of life and property, and that ties right back into the warning aspects for severe thunderstorms and tornadoes."

In addition, scientists at the Short-Term Prediction Research and Transition (SPoRT) Center, which is co-located with GHCC and the Huntsville National Weather Service Office, partnered in the project. Researchers at SPoRT focus on improving short-term weather forecasts by integrating NASA Earth science data. Darden said, "I worked with the SPoRT researchers and developers to look at the technology and data sets that they had available, and how the National Weather Service might use them operationally."

Together, they designed products from LMA data that could be used in the AWIPS displays. Although forecasters often prefer a single gridded graphic of lightning density that conveys a lot of information, they can choose other ways to view the lightning data. "We can view the summary by itself or overlay it directly onto our radar or satellite data. Or, we can look at individual levels, ranging from ground level to 17 kilometers (10.5 miles) above the surface," Darden said. Each of these levels is like looking at a "slice" of a storm. This allows forecasters to see lightning density at different altitudes and help them assess a storm's development. "We

On November 24, 2001, a series of tornadoes swept across Alabama, striking a mobile home community near New Hope. One tornado damaged twenty-one homes, completely destroyed eight, and overturned vehicles. The tornado path was 4.18 kilometers (2.6 miles) long, and as wide as 275 meters (900 feet). While damaging, this tornado caused no fatalities or injuries. Several residents of the damaged mobile home community heard the National Weather Service Tornado Warning on television and were able to take cover in underground storm shelters. (Courtesy Birmingham National Weather Service)

now utilize the LMA maps a lot when developing our early warning decisions," Darden said.

The lightning maps are also useful for weather prediction because their coverage overlaps that of radar and other data sources that forecasters rely on. Storms do not always develop neatly within the circular sweep of radar beams. Blakeslee said, "Where a storm is located relative to the radar system may make it difficult for the forecasters to know exactly what's going on, meaning that they miss some of the details. But the lightning data can help compensate for some of that."

Predicting severity, protecting lives

Even with the most advanced equipment and data, however, summertime weather often poses special problems for forecasters. Not only are more people likely to be outdoors and vulnerable to severe weather, but short-lived storms, called pulse storms, are more common. Pulse storms are small, isolated storms that last less than thirty minutes. Darden said, "Pulse storms can develop and diminish quite rapidly. They evolve so quickly that it's difficult to provide much warning or lead time." Although pulse storms pose the greatest danger to aircraft, they can also produce hail, heavy rainfall, and weak tornadoes, endangering people and property on the ground. "On a particular day, forecasters may have to track twenty or thirty storms, but only one or two of them will produce severe weather," Darden said. Forecasters need an indicator to tell them which storms might become dangerous.

Lightning may be one of those indicators. Blakeslee said, "When forecasters are not quite sure about the severity of a storm, lightning data may tilt the balance one way or the other. Lightning can be that confirming bit of observation that indicates we definitely need to issue a warning."

By taking advantage of the advance notice provided by the LMA lightning maps, forecasters have been able to more accurately predict the onset of severe weather. Darden said, "We can correlate flash rates directly to the strength of a building thunderstorm. In certain cases, we've issued a warning for a storm after seeing a surge in lightning rates." The additional few moments of warning may be especially useful when dangerous weather erupts over populated areas. Blakeslee said, "A tornado warning delivered five or ten minutes early might really make a difference in whether a person is able to get to shelter."

LMA data have also revealed some unexpected characteristics of electrical charges during storms. The data can sometimes indicate lightning in areas where forecasters would not normally expect it to be. "The data are showing occasional cloud-to-ground lightning strikes trailing a system, miles from the front, and well away from the really severe weather activity," Blakeslee said. When forecasters spot this additional lightning hazard, they can now alert people who may otherwise feel safe resuming outdoor activities after the worst part of a storm has passed.

The Huntsville weather forecast office also uses lightning maps to help issue weather warnings for the local airports and to develop aviation and terminal forecasts. "These kinds of systems are only now being explored in terms of how they can help with forecasting ramp and ground operations. I think we're going to see more of that kind of activity in the future," Blakeslee said. One such network is the DC Metro LMA in Washington, D.C., which began operating during the summer of 2006. Washington, D.C., is home to three major international airports, making this a high-profile project for studying lightning and aviation. Lightning and severe weather frequently affect flight schedules, so forecasters are interested in using lightning data to improve airport forecasts, particularly when potentially severe weather begins to develop. Air traffic controllers can use the advance warning to halt departures and detour incoming flights, keeping passengers and crew out of dangerous weather. And advance warning can give ramp workers and other airline ground staff additional time to get to shelter.

Learning from lightning

In addition to northern Alabama and Washington, D.C., lightning mapping networks are operating in Texas, Oklahoma, Florida, and New Mexico. While scientists are still probing the many aspects of lightning, they have gleaned valuable information from studying LMA data. Blakeslee said, "We've learned a lot through the years about how storms generate electricity and how they operate."

Researchers like Blakeslee and Darden will continue to analyze data from a variety of sources, such as the LMA networks and satellite sensors. Whether they learn more about specific storms or about broader aspects of electrical discharges in the atmosphere, each new bit of knowledge about meteorological processes brings forecasters a step closer to more accurate weather predictions and more timely forecasts. And this knowledge might help forecasters and Alabama residents, alike, plan ahead for wayward summertime weather.

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For more information

NASA Global Hydrology and Climate Center
http://www.ghcc.msfc.nasa.gov/
NASA Global Hydrology Resource Center
http://ghrc.msfc.nasa.gov/
North Alabama Lightning Mapping Array
http://www.ghcc.msfc.nasa.gov/sport/sport_lightning.html
Short-term Prediction Research and Transition Center (SPoRT)
http://www.ghcc.msfc.nasa.gov/sport/

About the data used

Networks	National Lightning Detection Network (NLDN), operated by Vaisala, Incorporated	3-D Lightning Mapping Array (LMA)
Sensors	U.S. NLDN consists of more than 100 remote, ground-based Vaisala IMPACT ESP Lightning Sensors	10 Very High Frequency (VHF) lightning mapping detectors
Data sets used	GAI Lightning Ground Strikes	North Alabama LMA
Spatial coverage	Continental United States	11 counties in northern Alabama and 3 counties in southern Tennessee
Parameter	Lightning	Lightning
Data Center	NASA Global Hydrology Resource Center (GHRC)	GHRC
Science funding	NASA	NASA

About the scientists

Richard Blakeslee is a senior research scientist at the Global Hydrology and Climate Center, based at the National Space Science and Technology Center in Huntsville, Alabama. His research interests include lightning, thunderstorms, and hurricanes, and the use of ground-based, aerial, and satellite-borne weather instruments. He serves as the lead validation scientist for the Lightning Imaging Sensor (LIS) on the Tropical Rainfall Measuring Mission (TRMM) satellite. (Courtesy NASA)

Chris Darden is the science operations officer at the National Weather Service's Weather Forecast Office in Huntsville, Alabama. He earned a BS in meteorology, and spent several years as an intern and general forecaster for the National Weather Service. He is currently a graduate student at the University of Alabama.

Arctic sea ice on the wane: Now what?

"When I say the Arctic has reached a tipping point, it's not like the ball just fell off the desk, one day."

Ron Lindsay
University of Washington
Applied Physics Laboratory

by Stephanie Renfrow

Drowning polar bears, seals under stress, changing global weather patterns, and blue icebergs steadily dripping water: these are the images that accompany discussions of disappearing Arctic sea ice. But does the dwindling icecap of the north signal real change for the Arctic and for the planet? For as long as human beings have taken notice, millions of square miles of Arctic sea ice have covered a roughly predictable area. While melting back during the summer and growing during the winter, the sea ice has kept the Arctic cool and may have helped stabilize Earth's weather patterns for the past eight thousand years.

However, sea ice growth and melt are no longer in the same balance, and the ice is disappearing. Scientists from all over the world are keeping watch: measuring Arctic sea ice decline, studying what that decline will mean for life on Earth, and ascertaining the future of sea ice.

Polar bears and other Arctic animals need sea ice for hunting, birthing, raising their young, and survival. (© Greenpeace/Beltra)

A record disappearance

Arctic sea ice is simply frozen sea water atop the Arctic Ocean. But sea ice is far away from almost everyone and everything on Earth. So why does it matter? Walt Meier is one of a team of scientists at the National Snow and Ice Data Center (NSIDC) that monitors Arctic sea ice year round. Meier said, "Sea ice has a high albedo, meaning it reflects a lot of sunlight. Sea ice absorbs less solar energy than the darker ocean water, beneath, and that keeps the Arctic cool." If you think of the planet as a house, the poles play the role of the whole-house air conditioner, supplying cool air masses to lower latitudes. Meier said, "Contrasting temperatures set up circulations in the atmosphere and oceans that lead to weather patterns around the globe."

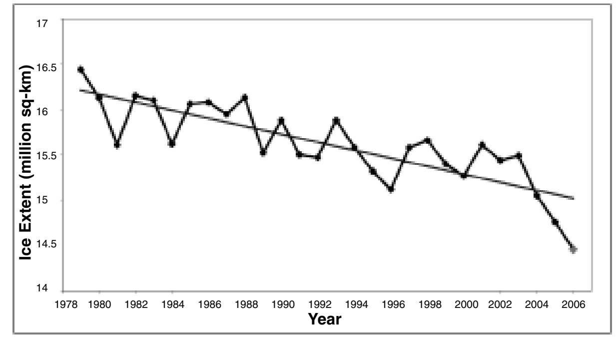
Given the importance of Arctic sea ice to global climate, accurately measuring the ice is crucial to understanding if its once-predictable patterns are changing. However, according to Meier, taking measurements in the frigid, isolated, and expansive geography of the Arctic was difficult until the dawn of the satellite era. "Ships can take observations, which can help tell us about ice formation, but few icebreakers can push all the way through the ice to the North Pole, so they have to skim around the edges of the ice," Meier said. "Plus, single ship transects don't give a good regional picture of ice conditions." In the 1950s, the United States government began compiling ship and airplane observations into sea ice charts, with inconsistent results.

In 1978, after deploying experimental satellites in the 1960s and early 1970s, NASA launched the Nimbus-7 satellite carrying the Scanning Multichannel Microwave Radiometer (SMMR). Sea ice records from this sensor are now managed at the NASA Distributed Active Archive Center (DAAC) at NSIDC. SMMR afforded a bird's-eye view of nearly the entire Arctic region, recording consistent year-round sea ice concentration data in all weather conditions every other day. Following SMMR, a series of satellites have circled the poles; their sensors have created a long record of sea ice conditions. "Sea ice has one of the longest satellite records of any environmental aspect on Earth," Meier said.

What kind of sea ice data do satellites collect? Some satellite sensors measure the albedo, or the fraction of solar energy reflected from ocean waters and sea ice. Passive microwave sensors, like SMMR, measure the microwave energy emitted by ocean waters and sea ice, called brightness temperatures. The contrast in brightness temperatures between surfaces allows scientists to distinguish the sea ice from the water. From there, researchers can determine sea ice extent, or the area of ocean covered by at least 15 percent sea ice. "Currently, extent is the longest-running and most accurate measure of sea ice that we can get with satellites," Meier said.

The long record of sea ice indicates that the Arctic sea ice never melts completely, but fluctuates with the seasons. Sea ice extent increases during the cold, dark winter, and it decreases during the warmer, brighter Arctic summer. But now, sea ice extent measurements are breaking the patterns that satellites have recorded since 1978. "Sea ice is disappearing," Meier said. "Every summer since 2002 has brought record or near-record lows. This is the first time we've seen such continuously low sea ice extent in the satellite record."

Winter Maximum Sea Ice Extent



Arctic sea ice melts back during summer and grows or "recovers" during winter. The winter maximum extent is usually reached in March. March 2006 mean sea ice extent, indicated by the last dot at the far right, was 300,000 square kilometers (115,860 square miles) less than the 2005 record, and 1.2 million square kilometers (463,000 square miles) below the 1979 to 2000 mean. (Courtesy NSIDC)

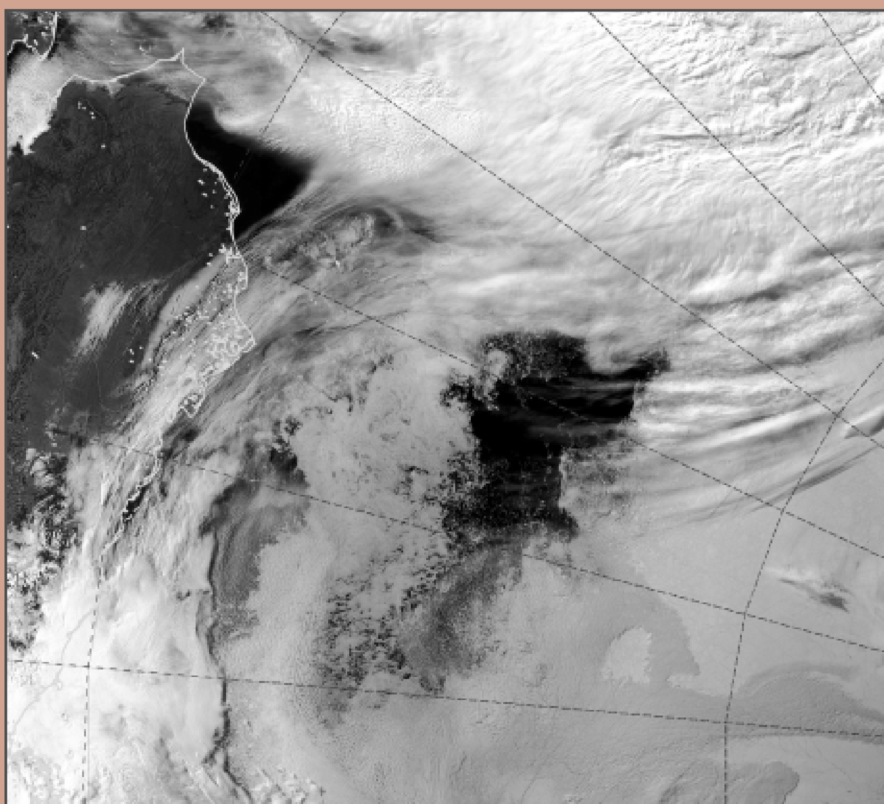
Data from the Special Sensor Microwave Imager (SSM/I) and Advanced Microwave Scanning Radiometer–EOS (AMSR-E), also managed at NSIDC, are especially important for Meier's sea ice research. Based on sea ice concentration data from these instruments, Meier has calculated that Arctic sea ice would typically cover approximately seven million square kilometers (2.7 million square miles) at the end of the summer melt season; now, that number is down to six million square kilometers (2.3 million square miles). "That's a loss of sea ice extent the size of the state of Alaska in only twenty-eight years," Meier said.

Following the summer low, scientists would expect the sea ice to bounce back to normal during the following winter. However, winter refreezing patterns are also changing. "In the past, less ice in the summer would mean more of the ocean would be exposed to the air once winter came, and the ice would grow rapidly and recover to normal pretty quickly," Meier said. "Sea ice at the end of the winter was always really stable, around fifteen-and-a-half million square kilometers [six million square miles], give or take a few hundred thousand." But now, the ice is not recovering to normal winter levels. "Winter air temperatures are higher, the ocean is warmer, and that is delaying the onset of refreezing in the fall," Meier said. In March of 2005, the sea ice area bottomed at a record wintertime low of only 14.5 million square kilometers (5.6 million square miles). "This is well outside what we've seen in the past."

Sea ice in context

Is this striking downward trend in sea ice merely a blip in the natural long-term "ups and downs" of sea ice? Scientist Ron Lindsay, of the University of Washington Applied Physics Laboratory, wondered this, too. He said, "In the 1990s, we thought it was all driven by a pressure fluctuation between the Arctic and the lower latitudes, called the Arctic Oscillation which seemed to explain much of the interannual variability of the ice." But in 1996, the Arctic Oscillation cycled from a strong positive phase, which normally brings warmer temperatures and pushes ice out of the Arctic Ocean, to its negative phase, which normally brings cooler temperatures and keeps ice sequestered in the Arctic. But despite the change, the sea ice kept declining.

The significance of the disappearing sea ice, within the context of the Earth's complex climate system, is still unfolding. Yet Meier and Lindsay agree that the sustained downward trend in sea ice is compelling evidence



September 2006 sea ice

Following the record low Arctic sea ice minimum of 2005, scientists at NSIDC watched the 2006 melt season closely using satellite data.

The final numbers, which NSIDC announced on October 3, 2006, indicated that the melting season came to a close on September 14 with 5.7 million square kilometers (2.2 million square miles) of sea ice coverage. This was the fourth lowest single-day extent of the twenty-nine-year satellite record. The average sea ice extent for the entire month of September was 5.9 million square kilometers (2.3 million square miles), the second lowest September extent on record, missing the 2005 record by 340,000 square kilometers (131,000 square miles).

Including 2006, September sea ice is declining at a rate of approximately 8.6 percent per decade, or 60,421 square kilometers (23,328 square miles) per year. The NSIDC science team reported that at this rate, the Arctic Ocean will have no ice in September by the year 2060. NSIDC scientist Mark

An unusual area of open water surrounded by persistent ice, captured in this MODIS image in mid-September, appeared during the melt season. The feature, called a polynya, is the dark area of open water surrounded by sea ice. To the left is the coastline of Alaska; out of the field of view to the right is the North Pole. (Courtesy NSIDC) of a changing system. Meier said, "Things like the Arctic Oscillation, the Pacific Decadal Oscillation, El Niño, the Southern Oscillation—all of these fluctuations make for a complex system. But the trend of the sea ice decline is so strong that we don't believe it's a product of natural variability. We just don't doubt its significance."

Lindsay put the trend's significance this way: "Our hypothesis is that we've reached the tipping point." In climate science, reaching a tipping point means that a stable climate system has changed direction. A tipping point can happen when a positive feedback takes hold, meaning that a small change in one direction leads to yet further change in the same direction. Lindsay's example of a positive feedback is a ball rolling down a sloping plank, gathering momentum as it travels down the incline. "For sea ice," Lindsay said, "the positive feedback is that increased summer melt means decreased winter growth and then even more melting the next summer, and so on."

Reaching a tipping point can also mean that one climate regime has shifted to another, and that switching back would take a major change. This recalls the image of the ball rolling down the incline. While it might be possible to reverse the direction of the rolling ball and push it back up the plank, it would probably be quite difficult to do. In the case of the sea ice, reverting to conditions that favor normal levels of summertime sea ice would require an enormous export of heat out of the system.

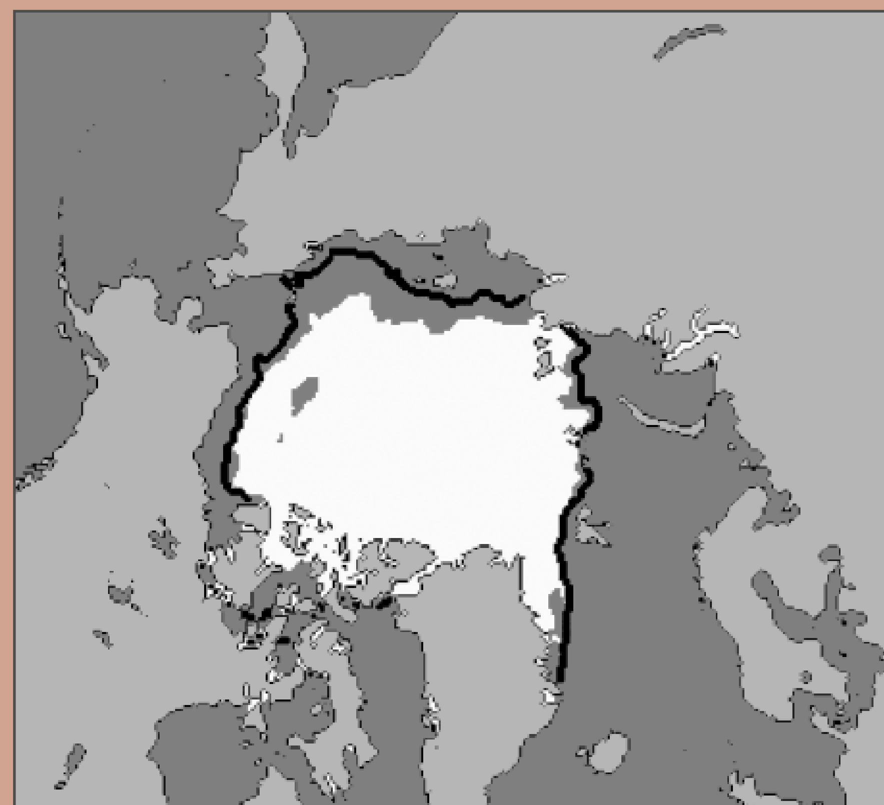
Scientists have wondered if natural forces could reverse the positive feedback of melting sea ice before we reach an ice-free summer ocean in the Arctic. Working with satellite data, as well as ice charts and other observational data, Lindsay

Serreze said, "The reduction in summer sea ice is a bad omen for animals like the polar bear, which need sea ice for their survival."

The science team noted that high temperatures throughout the year set the ice up for huge losses by the end of the melt season, but cooler temperatures in August prevented 2006 from setting a new record.

The 2006 season was also marked by an unusual new feature in the ice. A polynya the size of the state of Indiana formed in the Beaufort Sea, north of Alaska. Serreze said, "Given its large size, the polynya no doubt contributed to this year's low sea ice extent numbers." Scientists plan to use satellite data to formally study the polynya and better understand its unprecedented formation in the Beaufort Sea.

"I'm not terribly optimistic about the future of the ice," Serreze said. "Although it would come as no surprise to see some recovery of the sea ice in the next few years—such fluctuations are part of natural variability—the long-term trend seems increasingly clear. As greenhouse gases continue to rise, the Arctic will continue to lose its ice. You can't argue with the physics."



This image shows the average sea ice extent for the month of September 2006; the black line indicates the average September sea ice extent from 1979 to 2000. 2006 had the second-lowest average September sea ice extent on record. (Courtesy NSIDC Sea Ice Index)

A lead, or fracture, has opened in the sea ice near Arctic explorer Lonnie Dupre. He and fellow explorer Eric Larsen trekked to the North Pole in summer of 2006 to bring attention to the plight of animals like the polar bear, which need sea ice to survive. (© OWE/Greenpeace)

has plumbed the possibilities using climate models. "Perhaps a cooling period could reverse the situation," Lindsay said. "But with global warming, temperatures are only bound to rise." And even a relatively powerful cycle, like the Arctic Oscillation in its negative phase, would not be enough to reverse the trend. "Without cooling, none of these climate regimes would matter," Lindsay said.

With little chance of a natural change sparking an increase in sea ice growth, a popular question in the news media has been, "When will we have an ice-free Arctic?" Lindsay, however, does not see that as the central concern. "When we talk about an ice-free Arctic, where the bulk of the basin is ice-free, that's not really as important as measuring and understanding the gradual decline," he said. "Even when we still have 10 to 20 percent of today's summer ice, that will already be a cause for big changes in the circulation and ecology of the oceans." In other words, we will not have to wait for an ice-free Arctic to witness dramatic changes.

Lindsay wants to focus his upcoming research on the "why?" behind the sea ice decline. He said, "Why isn't the ice regrowing more in the winter? What is the fate of that additional heat coming into the system during the summer? Why have we reached a tipping point, in the first place?" These questions are important to understanding both what is happening now, and what will happen in the future.

"When I say the Arctic has reached a tipping point, it's not like the ball just fell off the desk, one day," Lindsay said. "The ball simply started rolling down a ramp. It's the beginning of a process, not a sudden accomplishment." Monitoring that metaphorical ball as it rolls down the ramp is an important way for scientists to understand the changes to come.

Understanding sea ice change

As Arctic sea ice disappears, scientists seek to improve their measurements and analyses so that they can better understand future change. Ron Kwok is one of a team of scientists at NASA's Jet Propulsion Laboratory who are focusing their efforts on sea ice thickness, rather than extent. Kwok said, "The holy grail of Arctic sea ice is thickness. If you don't know how thick the ice is, you don't know much about the volume of the ice. We know the sea ice is disappearing. But, the question we want to understand is how fast it is being depleted by volume." Thickness and volume are crucial to understanding the future of sea ice because if the ice is thinning, it will melt more quickly than thick ice would. Understanding thickness is key to understanding how quickly we are approaching a nearly ice-free summertime Arctic.

Because of the limitations of field observations, Kwok believes that satellite sensors provide the best vantage for measuring sea ice thickness. "It's difficult to come up with answers based on field data," Kwok said. "Satellites really are the best way to provide a large-scale view of the ice." Satellite sensors measuring sea ice thickness rely on two measurements: simple records of elevation between one surface and another; and differences in reflectance between various surfaces, with ice being highly reflective, snow less so, and water the least reflective. Kwok is using reflectance and elevation profiles from the Geoscience Laser Altimeter System (GLAS) sensor on the NASA Ice, Cloud, and Land Elevation Satellite (ICESat), data archived at NSIDC. To actually see images of where sea ice has moved or broken apart, he is also using Synthetic Aperture Radar data from Canada's RADARSAT satellite, archived at the Alaska Satellite Facility DAAC.

Analyzing and comparing the reflectance, elevation, and visual imagery from the two satellites, Kwok can more easily determine and confirm

About the remote sensing data used

Satellites	Nimbus-7/Defense Meteorological Satellite Program (DMSP)	Aqua	Ice, Cloud, and land Elevation Satellite	RADARSAT
Sensors	Scanning Multichannel Microwave Radiometer (SMMR)/Special Sensor Microwave/Imager (SSM/I)	Advanced Microwave Scanning Radiometer–Earth Observing System (AMSR-E)	Geoscience Laser Altimeter System (GLAS)	Synthetic Aperture Radar (SAR)
Data sets used	Sea Ice Concentrations from Nimbus-7 SMMR and DMSP SSM/I Passive Microwave Data	AMSR-E/Aqua Daily L3 12.5 km Tb, Sea Ice Conc., & Snow Depth Polar Grids	GLAS/ICESat L2 Sea Ice Altimetry Data	RADARSAT Standard SAR
Resolution	25 kilometers	12.5 kilometers	60 meters	100 to 500 meters
Parameters	Brightness temperature	Brightness temperature, sea ice concentrations, snow depth over sea ice	Elevation, reflectance	Backscatter
Data Centers	NASA National Snow and Ice Data Center (NSIDC)	NSIDC	NSIDC	NASA Alaska Satellite Facility
Science funding	NASA United States Navy's Office of Naval Research			

the thickness of sea ice. "For example, let's say ICESat flew over a lead, or fracture in the ice. The data would indicate a dip in elevation and a change in reflectance between the sea ice and the open water, while the RADARSAT imagery would confirm visually that a lead had opened," Kwok said "The combination of the two data sources is the best way, because the imagery helps us make sense of the elevation profiles and also confirms that we're actually seeing what we think we're seeing."

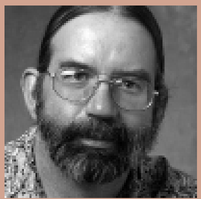
With the existence of the lead confirmed, Kwok's team could more confidently use the reflectance and elevation data in calculating the freeboard, or the amount of ice above the waterline. The freeboard calculation would then provide the information necessary to calculate the total thickness of the sea ice. However, because the result from one calculation feeds into the next calculation, the possibility for magnification of error is large. Kwok and his team want to reduce this possibility for error. "Right now, we're trying to interpret the results of our work," Kwok said. "We need to understand the limitations of using ICESat data this way, and define how confident we are in the results. ICESat provides the best information available to help U.S. scientists determine sea ice thickness. So this data is truly compelling."

About the scientists

Ron Kwok is a research scientist and leader of the Polar Remote Sensing Group at the Jet Propulsion Laboratory in Pasadena, California. His interests include polar heat exchange, sea ice mass balance, and the surface forcing and response of the polar oceans. His recent focus is on understanding ice production in Southern Ocean polynyas, quantifying circumpolar Arctic sea ice flux, and applying ICESat data to Arctic research.

Ron Lindsay is a research meteorologist at the University of Washington Applied Physics Laboratory in Seattle, Washington. Lindsay's research interests are in Arctic climate, climate change, sea ice deformation, sea ice modeling, and remote sensing. He works with colleagues at the Polar Science Center to incorporate satellite data assimilation methods in a coupled ice-ocean model and to analyze the thermodynamic and dynamic characteristics of recent sea ice thinning. (Courtesy APL)

Walt Meier is a scientist at the National Snow and Ice Data Center (NSIDC) at the University of Colorado at Boulder. Meier is the project manager for the SSM/I sea ice products archived at NSIDC and a science liaison for the AMSR-E sea ice products. His current research interests involve understanding changing sea ice conditions in the Arctic and improving sea ice climate records. He obtained MS and PhD degrees from the University of Colorado in 1992 and 1998 respectively.



Mark Serreze is an Arctic climatologist at NSIDC at the University of Colorado at Boulder. His current research focuses on declining sea ice, the Arctic's large-scale heat and freshwater budgets, and the role of Greenland in heat and moisture transports. He and NSIDC Director Roger Barry recently published *The Arctic Climate System*, a comprehensive and accessible overview of Arctic climate. (Courtesy NSIDC)

Because thinner ice means a faster decline in sea ice extent, the question of sea ice thickness is also an important piece of Lindsay's ongoing big-picture work on Arctic climate. Lindsay said, "We believe that Kwok's sea ice thickness data could be an important piece of information for our work with large-scale climate models." These models will focus on the possible future of the Arctic sea ice, especially the changes it will undergo from the ongoing influx of heat, and the global influences it will have once it reaches a new stabilized state or "point of no return."

Even if we are only at the beginning of the metaphorical ball rolling down the incline, sea ice scientists are watching that ball carefully. "An Earth without Arctic sea ice in even part of the year," Meier said, "will be a dramatically different planet."

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For more information

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

Jet Propulsion Laboratory
http://www.jpl.nasa.gov/

University of Washington Applied Physics Laboratory
http://www.apl.washington.edu/

Scanning Multichannel Microwave Radiometer (SMMR)
http://nsidc.org/data/docs/daac/smmr_instrument.gd.html

Special Sensor Microwave Imager (SSM/I)
http://www.ncdc.noaa.gov/oa/satellite/ssmi/ssmiproducts.html

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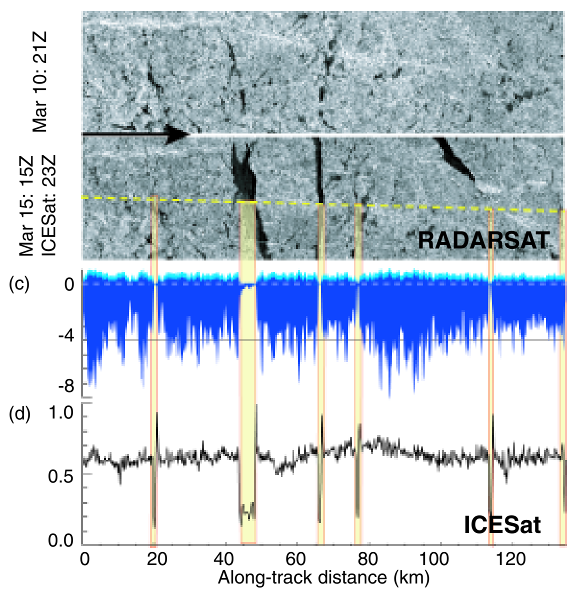
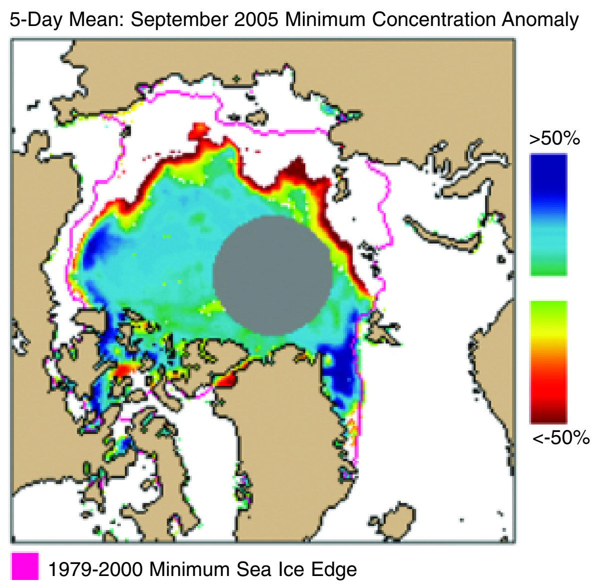
http://icesat.gsfc.nasa.gov/

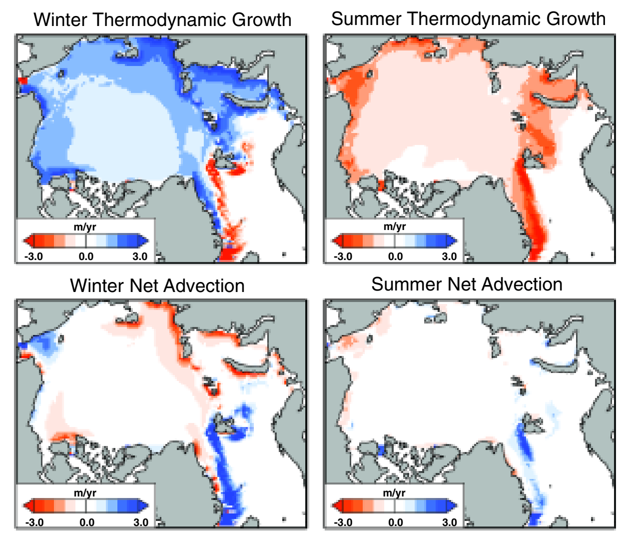
Advanced Microwave Scanning Radiometer–Earth Observing System (AMSR-E)
http://www.ghcc.msfc.nasa.gov/AMSR/



A combination of data from two different satellites provides the information needed to calculate sea ice thickness. The image at the top shows an area of sea ice north of Ellesmere Island. Leads, or fractures in the ice, are darker gray. The black graph at the bottom of the image (d) shows elevation data; yellow bars show correspondence between leads and elevation data. In between, dark blue indicates sea ice thickness, with snow on top of the ice in light blue (c). (Courtesy Ron Kwok)



September 2005 broke the record for low summer sea ice extent, the measure of area containing at least 15 percent ice. The ice extent is shown by the edge of the colored region. The long-term average minimum extent contour (1979 to 2000) is in magenta. The grey circle indicates the area where the satellite does not take data. Data are from the Special Sensor Microwave/Imager (SSM/I). (Courtesy NSIDC)



Where and how Arctic sea ice builds up and thickens is influenced by two processes: melting/growing, and horizontal transport of the ice, or advection. These maps show model simulations of the mean thickness changes from these processes in winter (October to April) and summer (May to September) for 1948 to 2003, with red showing negative growth/advection, and blue showing positive growth/advection. (Courtesy Ron Lindsay)

Seeing climate through the lives of plants

"These data will allow us to monitor changes in climate and at the same time understand more about the dynamics of the plant and animal communities."

Mark D. Schwartz
University of Wisconsin-Milwaukee

by Jane Beitler

On a May morning, a gray-haired woman counts the opened blooms on the bud clusters of a lilac branch that is just starting to release its sweet fragrance. She then goes into her house to access an Internet site, where she logs today as the "first bloom" date of her lilac plant. She is helping researchers understand global climate.

Citizen scientists like this woman are forming an eventual network of thousands who will volunteer to make careful and specific local observations of plants and animals. Plant budding and blooming are one aspect of phenology, the study of periodic plant and animal life cycle events that are influenced by environmental changes. In particular, researchers are examining seasonal variations in temperature and precipitation that are driven by weather and climate. Measured as a few degrees of temperature, climate change may seem abstract. Yet these changes can be expressed vividly in the lives of plants and animals.

A long series of data on the timing of phenological events, gathered by observers blanketing a continent, can help scientists monitor climate change and its effects on Earth's life. Toward this goal, a team of researchers, including Bradley Reed at the United States Geological Survey (USGS) in Arizona, and Mark D. Schwartz at the University of Wisconsin-Milwaukee, are growing the USA National Phenology Network (NPN). These researchers are working to join a network of ground observations with satellite-based remote sensing data to create a "wall-to-wall" phenological record of climate in the United States.

Spring's onset from ground and space

"Plant phenology can help us understand global change questions," said Reed, who along with Schwartz is a member of the NPN implementation team. "With global warming, it appears that growing seasons are getting longer. Spring is coming sooner, and fall is beginning later. We've been studying remote sensing data for some time to get an objective answer to those questions," Reed said.

Schwartz and two colleagues studied the onset of spring using observational data on Northern Hemisphere temperatures from 1955 to 2002. Compiling temperature patterns relative to plant

Scientists and citizen volunteers are observing first bloom and first leaf dates of lilacs and other plants to gather data on the timing of spring. These observations, connected with satellite data on plant activity, will help researchers monitor climate and its effects on the biosphere. (Courtesy Mark D. Schwartz) development, they calculated dates of first bloom, first leaf, last freeze, first freeze, freeze period, chill dates, and average annual temperature. They concluded that biological spring is indeed arriving earlier in the Northern Hemisphere, coming an average of 1.2 days earlier each decade.

Schwartz said, "Our premise is that phenological response in the spring is a proxy for what's going on with climate. An early warm spring, for example, will impact soil moisture later on, and set off a chain of connections." The effects of a warmer climate are stronger in spring and winter; examining average temperatures for spring and winter alone may reveal sharper variations than the average temperatures for a whole year. Plant activity helps bring these variances to light.

Remote-sensing instruments, such as the Moderate Resolution Imaging Spectrometer (MODIS), can detect events related to the onset of spring. MODIS detects spring leaf-out, for example, by sensing changes in the amount of energy reflected back from earth. Leaves, because of their chlorophyll and other pigments and special structure, reflect more energy in certain wavelengths than bare ground, bare trees, or dormant grasses. MODIS detects these wavelengths; by comparing reflectance measurements over time, researchers can measure what they call the "leaf area index." MODIS data, distributed on a global scale by the NASA Land Processes Distributed Active Archive Center (LP DAAC), can also estimate the timing of other events tied to seasonal cycles. These indicators include green up and maturity in spring and summer; in fall and winter, MODIS detects senescence, or vegetation decline resulting in fall color change, and dormancy.

But other indicators are best studied on the ground. Schwartz said, "MODIS can detect leaf out, but it's harder to see subtle events like bud break in the satellite data." Reed agreed, saying, "We could tell there was a lot more information in the satellite data than we knew how to extract. The data from the ground network will help us sort this out."

People have long recognized the timing of plant, insect, and animal life-cycle events as markers of spring. To better record and understand climate, researchers systematically study the timing of these events. The Milbert's Tortoiseshell butterfly (*Nymphalis milberti*) is a harbinger of spring in many northern areas of North America, often emerging in March. (Courtesy Photos.com)

Emphasizing the value of both field and space observations, Schwartz said, "We're not trying to replace remote sensing with the phenological network, but make it more flexible. A lot of my work in the past concentrated on going out in the field and recording phenology by examining individual plants. We want to know what's going on over the whole continent. Having observations on a few trees from an area is not a fair way to compare to a 250-meter MODIS pixel. Instead of looking at a couple of trees, we are now collecting spatially concentrated phenological measurements from hundreds of trees that are more comparable to satellite pixels."

Scaling up the view to a continent is far from simple. Reed said, "Ground observations of phenology are critical for validation of the satellite data. Remotely-sensed phenology is very difficult to validate because of the need for constant observations, which are costly over large areas. The idea is to create an organized network by engaging a large number of different observational communities, and to increase the density of observations."

Effects of climate on life

Long-term, continental-scale phenological records will help researchers measure the impacts of climate change that may not be easily reversible, even if temperatures returned to historical ranges. Schwartz said, "If you think about how surface weather data has been collected by volunteer observers over the last century, and how much better we understand weather phenomena as a result, we need the same sort of dense, ongoing observations of biology. These data will allow us to monitor changes in climate and at the same time understand more about the dynamics of the plant and animal communities."

To illustrate how changes in timing of seasons affect plant reproduction, take the example of a peach tree that is well-adapted to Georgia. Plant it in a northern state, and it continues to leaf out and grow, but seldom produces peaches. Spring's warmth stimulates bloom too early, and then the normal, late spring frosts of the cooler climate nip the developing fruit. Natural variability can also disrupt plant life cycles from year to year. In southwestern Michigan's fruit belt, the influence of nearby Lake Michigan moderates a more slowly warming spring that usually protects fruit crops. But now and then, grape and cherry growers lose their crops to early warm spells or unseasonable frosts.

Even after intense cold, heat, flood, or drought, life will eventually rebound, within normal ranges of climate variability. But persistent change, even if small, can have permanent, rippling effects on an entire ecosystem. "Changes in the onset of spring can disrupt the established synchronization between plants, insects, and birds," Schwartz said. "Insects are adapted to hatch in sync with the life cycles of plants that provide their food supplies, and in turn, insects are food for birds and mammals. And with climate changes, conditions may become more favorable to invasive plants, which then move in more readily and compete with native species. Then native species, and the insects and birds that depend on them, can decline or disappear."

Understanding these dynamics requires distinguishing natural and local variability from more extensive and persistent climate change. "A phenology network will help us understand variability on a fine scale," Schwartz said. Remote sensing of plant phenology depends on interactions between vegetation, regional climate, soil, and microclimate, and all of these factors can vary across a study area. So researchers must be able to distinguish smaller-scale variability from larger-scale changes. "The ground data will help us understand spatial variability that results from differences in the responses of species and from differences in micro-environments," Schwartz said.

To get this simultaneously broad continental view and at the same time, local ground understanding of plant phenology, researchers face the task of relating satellite pixels to thousands of individual ground sites. To help scale this task down, the NASA Oak Ridge National Laboratory Distributed Active Archive Center (ORNL DAAC) offers the MODIS subsetter, a tool that helps field study researchers work with MODIS vegetation data.

"The subsetted MODIS data helps us with the scale issues involved in a large study area," Schwartz said. "We need frequent data to track phenological events in spring, and over a wide area." Frequent, large volumes of data can be difficult and expensive to work with because of computing requirements and format. The MODIS subsetter allows researchers to pick out the MODIS data pixels that correspond exactly to field sites, and receive the data in either plain (ASCII) or geographically-coded (GeoTIFF) format. The ease of access, smaller data volume, and simple file format make large-scale studies such as a continent-wide ground phenology network more manageable and affordable.

About the remote sensing data used

Satellites	Terra/Aqua
Sensor	Moderate Resolution Imaging Spectroradiometer (MODIS)
Data sets used	Leaf Area Index (MOD15A2) Vegetation Indices (MOD13) Land Cover Dynamics (MOD12Q2)
Resolution	250 meters, 500 meters, and 1 kilometer
Parameters	Leaf Area Index (LAI) Fraction of Photosynthetically Active Radiation absorbed by vegetation (FPAR) Normalized difference vegetation index (NDVI) Enhanced vegetation index (EVI) Greenness (increase, maximum, decrease, minimum)
Data centers	NASA Oak Ridge National Laboratory (ORNL) DAAC for Biogeochemical Dynamics NASA Land Processes (LP) DAAC
Science funding	National Science Foundation United States Geological Survey

Implementing the network

The idea of a "citizen scientist" network is not new. In the United States, Thomas Jefferson began recruiting volunteer weather observers in 1776. Today, under the direction of the National Weather Service, more than ten thousand volunteers record local temperature and precipitation data. "We are hoping to enlist some of those volunteer weather observers and so make use of a network that already exists," Schwartz said.

The implementation team chose lilacs as key phenology indicators for the NPN. "We based our approach on the experience of agricultural experiment stations of the 1950s and 1960s," Schwartz said. "They chose lilacs, because of their hardiness, broad distribution range, and distinct phenology. And people like receiving lilacs." Volunteers receive lilac plants cloned from cuttings, ensuring that they are genetically identical and will respond the same way to the environment. Lilacs will not grow everywhere, though, so observers may also select other indicator plants, or a plant from a list of natives. The volunteers choose a sunny location and nurture their lilac for one to two years before reporting first leaf and first bloom observations. The team hopes to develop a network of two thousand or more sites across the United States.

In the future, the volunteers may also record animal observations and signs of fall. Schwartz said, "Autumn phenological events have been poorly explored. The kinds of events that occur in autumn, related to first freeze or leaf drop, are often not as sharp." Researchers have been noticing changes in fall, and want to study more closely what they signal. Reed said, "For example, our colleagues in agriculture noticed that temperatures are remaining warmer longer than in the past, after winter wheat has germinated. Winter wheat germinates in late fall and remains dormant until spring. If its growing season is extended in autumn, it becomes more susceptible to pests, affecting yields."

Today, the USA National Phenology Network is growing, thanks to the committed efforts of many researchers who look forward to some day tapping this network for their research. "The development of NPN is totally grass-roots," Reed said. "It's a multidisciplinary science effort, with researchers around the country all working for the same goal. The network will have many applications: knowing how to time agricultural activities, for example, or studying the human health effects of longer allergy seasons."

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NASA Oak Ridge National Laboratory DAAC
http://www.daac.ornl.gov/

NASA Land Processes DAAC
http://lpdaac.usgs.gov/

About the scientists

Bradley Reed is a research geographer for the United States Geological Survey in Flagstaff, Arizona. His research focuses on techniques for deriving phenological measures from time-series satellite data, including data from the Advanced Very High Resolution Radiometer (AVHRR) and the Moderate Resolution Spectroradiometer (MODIS) instruments. (Courtesy Bradley Reed)

Mark D. Schwartz is a climatologist and professor of geography at the University of Wisconsin-Milwaukee. His research focuses on plant phenology and lower atmosphere interactions during the onset of spring in mid latitudes, detecting climatic change, and assessing vegetation condition with remote sensing imagery. Schwartz is working to develop a National Phenology Network, which will help assess the long-term impacts of climate change on the biosphere. (Courtesy Mark D. Schwartz)

Gridding the risks of natural disasters

"For the World Bank, this is the really critical tool for making decisions on development priorities."

Margaret Arnold
World Bank Hazard Risk Management Team

by Laura Naranjo

When buying a new house, most people probably would not choose to live in an earthquake-prone, routinely flooded area subject to landslides and cyclones. Yet in places around the world, such as the Philippines and parts of Central America, nearly everyone considers such an area their home. To help predict, mitigate, and plan for disasters, scientists have developed a global analysis of where natural disasters occur, quantifying their human and financial impacts and identifying areas around the world with the highest natural disaster risk.

Scientist Maxx Dilley took part in a mission to develop a global picture of natural disaster risk. Dilley said, "We wanted to produce an analysis of the places in the world where disasters were most likely to occur, as well as why disasters were more likely in those places." Dilley, who now specializes in disaster and risk assessment as a policy advisor with the United Nations

After the 2004 Southeast Asia tsunami, aid organizations provided clothing to help disaster victims like these children in Sri Lanka. Disaster recovery involves not only rebuilding, but finding ways to provide essential resources to the population until roads and distribution facilities are restored. The Hotspots report indicates that the nation of Sri Lanka is at extremely high risk for floods and flood-related mortalities. (Photograph by Dr. Graeme Peel/courtesy AusAID)

Development Program (UNDP) Disaster Prevention Unit, was then on a team at Columbia University, led by Robert Chen, Manager of the Socioeconomic Data and Applications Center (SEDAC), and Art Lerner-Lam, Director of the Center for Hazards and Risk Research, that collaborated with The World Bank and the ProVention Consortium on this goal. The resulting report, *Natural Disaster Hotspots: A Global Risk Analysis*, and the accompanying data set, synthesized historical data on six major natural hazards—cyclones, drought, earthquakes, floods, landslides, and volcanoes—as well as population, economic, and hazard-related mortality information. The "Hotspots" report provides the first integrated global picture of natural hazards and their impacts around the world.

The team combined population data, provided by SEDAC, with gross domestic product (GDP) and other socioeconomic data to provide the global basis for quantifying risk. Because these data were gridded, Dilley and his colleagues could break down risk by grid cells, enabling them to analyze risk at subnational and regional levels. After masking out sparsely populated cells, they could focus on areas where natural disasters would have the greatest impact. Their analysis rated each of the remaining grid cells according to historical losses incurred from each of the six hazards, and then classified each cell's level of risk. For instance, a cell with high population that has been exposed to no hazards is rated as relatively low risk, but a cell with high concentrations of population or GDP that has been exposed to multiple hazards is rated as a hotspot.

The 2001 El Salvador earthquake-induced landslide, located in a neighborhood near Santa Tecla, El Salvador, buried numerous homes under tons of earth. The Hotspots report identified El Salvador as being at high risk for landslides, earthquakes, floods, and cyclones. (Photograph by Edwin L. Harp/courtesy USGS)

Analyzing disaster risk in terms of grid cells also allowed their study to transcend geopolitical borders. "We get a finer sense of the risk by looking at these relatively small grid cells than we do when we're dealing with countries as the unit of analysis," said Dilley. "We start seeing regions of risk that are dictated by fault lines and tectonic plate boundaries and climatic systems that span across national boundaries."

Defining vulnerability

Natural Disaster Hotspots: A Global Risk Analysis is not just a compilation of new and existing data, statistics, and maps. Scientists needed to look beyond statistics to understand what makes certain communities and regions more vulnerable to natural disasters. "We faced a major challenge in how to introduce the concept of vulnerability, which is a very important element of disaster risk," Dilley said. Vulnerability assesses how a particular disaster affects a specific area, and it is a complicated combination of risk factors that accounts not just for the type and severity of disaster, but also for geography, social dynamics, land-use practices, economics, and infrastructure.

"The basic equation for identifying vulnerability is so simple, but also very subtle and very powerful," Dilley said. "If you have a collection of anything—people, buildings, or any kind of infrastructure—and a natural disaster occurs, like an earthquake, it's not only the earthquake that destroys or damages things. It's also the internal characteristics of those things, themselves, that determine the losses."

An earthquake, for instance, may not damage steel-reinforced buildings on shock absorbers, but might completely destroy unreinforced masonry buildings. "We can't treat a cell in Kathmandu the same as a cell in San Francisco when we're calculating risks, because the building stock and many other things are so different. That's where the concept of vulnerability became necessary in order to come up with the results," Dilley said. While both areas are earthquake-prone, Kathmandu's masonry buildings are more vulnerable than the better-engineered buildings in San Francisco.

Governments, aid organizations, and funding agencies are increasingly focused on quantifying vulnerability because it can help them identify in advance which areas are at higher risk than others. Margaret Arnold, the senior program officer on The World Bank's Hazard Risk Management Team, is not only one of the co-authors of the Hotspots report, but is also helping incorporate the results into various country development plans.

"We've taken the lists of the top twenty or so hotspots, and then compared it to our pipeline of Country Assistance Strategies," she said. Developed jointly by the individual government and The World Bank, a Country Assistance Strategy (CAS) lays out the priorities for socioeconomic development and poverty reduction over a certain period and determines the types of projects that The World Bank funds. "Essentially, if a certain topic isn't a priority in the CAS, then it may not appear in the portfolio of projects that happen on the ground," Arnold said.

Results from the Hotspots report are increasingly incorporated into CAS documents that are up for renewal, facilitating the integration of disaster risk considerations into development investments. "Our aim is to have both World Bank staff and our clients—our borrowing country governments—have a more proactive and preventive approach to disaster, so that we're not always just reacting and rebuilding," Arnold said.

For example, some countries, such as Bangladesh, may acknowledge high flood risk in their CAS, but not include projects designed to mitigate that risk. The Hotspots report provides The World Bank with hard evidence of a country's risk factors, making it easier to demonstrate that a particular country needs to reduce its vulnerability. "When you show countries a science-based approach, it helps convince them to invest in reducing their risk," said Arnold. "It's an awareness-raising tool. Once countries become aware of the impacts that disaster can have on long-term socioeconomic growth, they can make disaster-risk reduction a development priority."

The Independent Evaluation Group (IEG) at The World Bank recently recognized the value of this approach, and used the Hotspots analysis extensively in a major review of The World Bank's record of natural disaster-related assistance. The IEG also gave the Hotspots team a "Good Practice" award for showing "demonstrated impact/results." World Bank President Paul Wolfowitz gave the award to members of the team in a ceremony in Washington, D.C., in May 2006.

In his role at the United Nations Development Program Disaster Prevention Unit, Dilley is also relying on the Hotspots report results to aid disaster-prone countries. "We help countries identify the risk factors that lead to recurring disasters and then work to establish programs that reduce and transfer those risks," he said. "Now that we have information about which countries are at risk, we have a motivation to try to do something about it."

Reducing and transferring risk

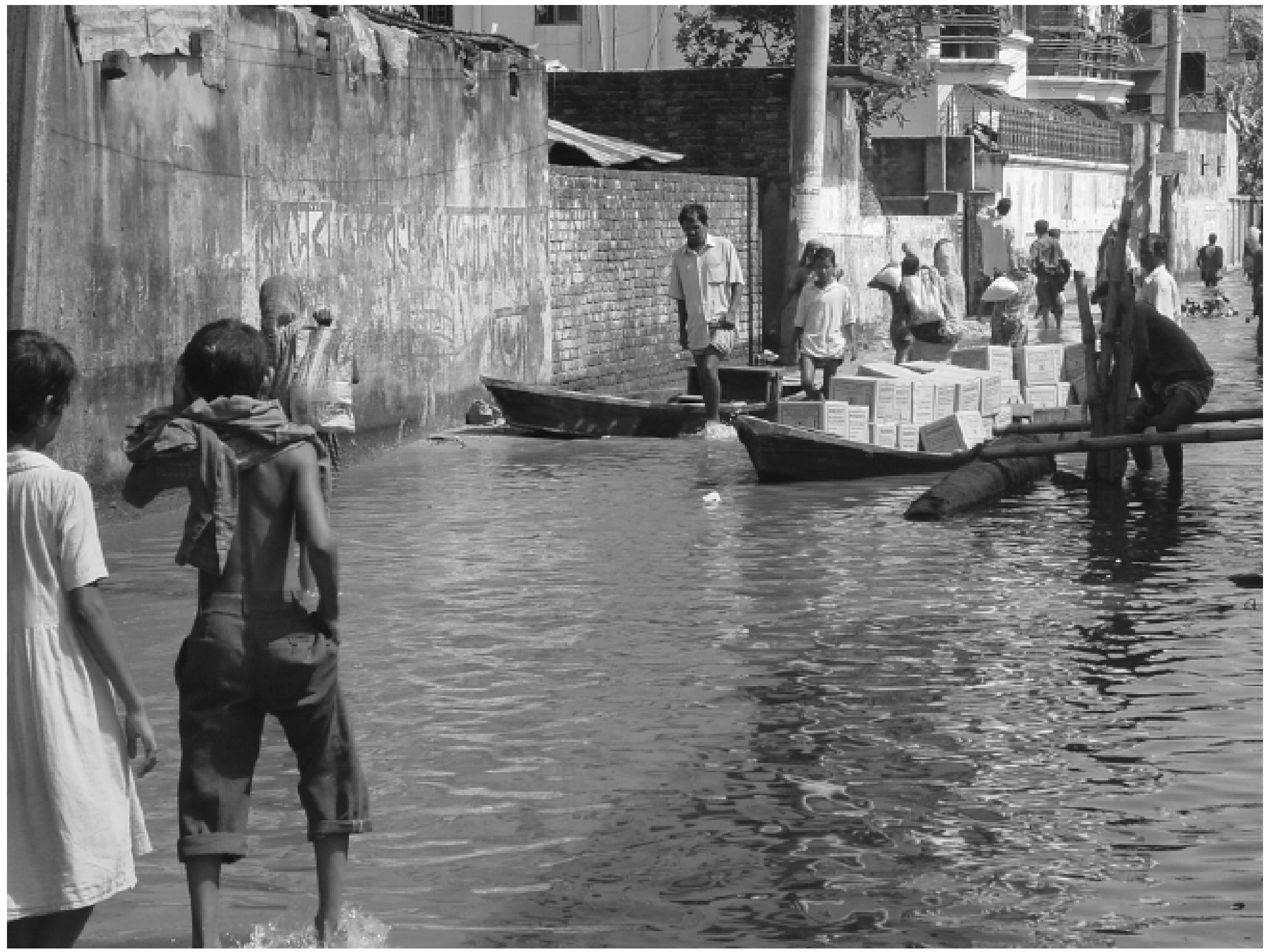
Risk transfer is one strategy that countries can use to limit their natural disaster liability. Risk transfer works like car insurance. After a car accident, the car owner is not burdened with the entire expense of replacing the car, because the insurance company pays for a portion of the loss. Similarly, a pilot program in Ethiopia lets farmers obtain a form of weather insurance. "Farmers can buy something like a lottery ticket prior to the season, and if the rainfall is below a certain threshold, they get paid back a certain amount when they cash that ticket in," Dilley said. "Rather than the people who are at risk suffering all the losses when a disaster occurs, they can transfer some of that risk away to somebody else."

Insurance helps transfer the risk to a larger, often global, market, which can absorb small losses more easily than individual farmers can. In addition, when drought does occur, farmers with insurance can rely on timely payouts that would prevent them from having to sell their assets. This immediate post-disaster assistance would leave them with more resources with which to begin the next planting season.

Dilley added that risk transfer becomes more viable when countries reduce their risk. "But

About the data used

Data set used	Gridded Population of the World
Resolution	2.5 arc-minutes
Maps	Regional
Parameter	Population
Data Center	NASA Socioeconomic Data and Applications Center (SEDAC)
Science funding	ProVention Consortium with support from The World Bank, UK Department for International Development (DfID), and Norwegian Ministry of Foreign Affairs



Boats transport World Food Programme high-energy biscuits to flood victims in Bangladesh. Organizations distributing disaster aid often grapple with destroyed roads, buildings, and basic communication channels. The World Bank's Country Assistance Strategies can help regions plan according to their disaster risk factors, and encourage countries to invest in infrastructure that will withstand commonly occurring natural disasters. (Courtesy World Food Programme)

This maize, severely stunted by drought in Southern Province, Zambia, should be the height of the farmer's shoulders. The farmer indicated that he would not harvest any maize from this field. Subsidized drought insurance would help protect farmers during years with low precipitation. (Photograph by F. Sands/courtesy USAID)

that depends on the hazard and on what kind of activity or infrastructure exists," he said. "Reducing risk associated with earthquakes is very different from reducing risk associated with drought." For example, reducing risk in countries like drought-stricken Ethiopia is extremely difficult. Even in a good year, Ethiopian farmers may make only a small profit, and then rainfall over the following years may be so low that they lose what little they had. "The risks of farming there are so high, and the upside so low; there's almost nothing to be gained. In these kinds of places, we need to come up with measures to reduce their risk, and as a complement to that, institute some kind of insurance for when they do lose their crops," Dilley said.

Because many of the people most frequently affected by natural disasters are poor, organizations must not only develop innovative insurance programs, but work to reduce premium costs as well. To help finance the weather insurance program in Ethiopia, the World Food Programme sought donors to help subsidize the premiums and make insurance more accessible to poor farmers.

Another risk reduction strategy is to replace buildings and homes with structures designed to withstand the natural hazards that the area is historically known to experience. "Very often, the period immediately after a disaster is your best window of opportunity for doing something about the next disaster," Dilley said. Being aware of the hazard risk helps inform which building codes need to be improved and which construction methods will help prevent similar structural failure when a similar disaster happens in the future.

Dynamic analysis and local perspective

While *Natural Disaster Hotspots: A Global Risk Analysis* is already a valuable tool for increasing awareness about disaster risks, Dilley and Arnold believe that this is just the beginning. Arnold said, "For The World Bank, this is the really critical tool for making decisions on development priorities. It has been useful so far, and we want to continue to develop it and make it an even more useful tool."

The original hotspots data are now available through SEDAC, and selected data sets are being put online through interactive mapping servers. But the team is also planning to make current data more easily accessible. "Right now, the Hotspots report is a static look at the vulnerability picture," Arnold said. "We'd like to create a dynamic picture, because things like demographic changes, climate change, and environmental degradation will change that picture over time." A dynamic analysis incorporating these changes may help reveal future hotspots or changes in disaster-related impacts. In 2006, the team also published *Natural Disaster Hotspots Case Studies*, which addresses specific hazards and specific locations.

Dilley indicated that in a few years, the team plans to release a new analysis that will incorporate updated information and provide more national-level detail. Although a global perspective is insightful, much of the disaster aid is distributed on a national basis, making it important to understand specific needs within individual countries. "We want to get a more detailed view about what the national and subnational vulnerabilities and risks are and why," Dilley said. "We'll try to work with governments and universities to obtain local risk information. We are also working closely with SEDAC to incorporate some of their new data on population, urban areas, poverty, and infrastructure."

Arnold added that the subnational data is important when rebuilding infrastructure. "For example, it's one thing to say that Indonesia is very vulnerable to natural disasters. But Indonesia is a huge country and we need to be able to drill down and decide where to put hospitals and determine what construction standards we need to use," Arnold said.

Dilley and Arnold plan to continue building on the Hotspots work for more dynamic risk mapping and locally defined strategies. But they both believe that the global perspective presented in their work so far is a big step forward. The Hotspots report provided an unprecedented look at not only the distribution of certain hazards, but at the magnitude of their impacts. “I knew that floods and droughts were major hazards, but I didn’t realize how flood-prone a lot of Asia really is,” Dilley said. “I was also surprised by the geographic extent of some of the flooding. The report gave me a fresh look at things. I’m still looking at the Hotspot report maps. And I’m still learning from them.”

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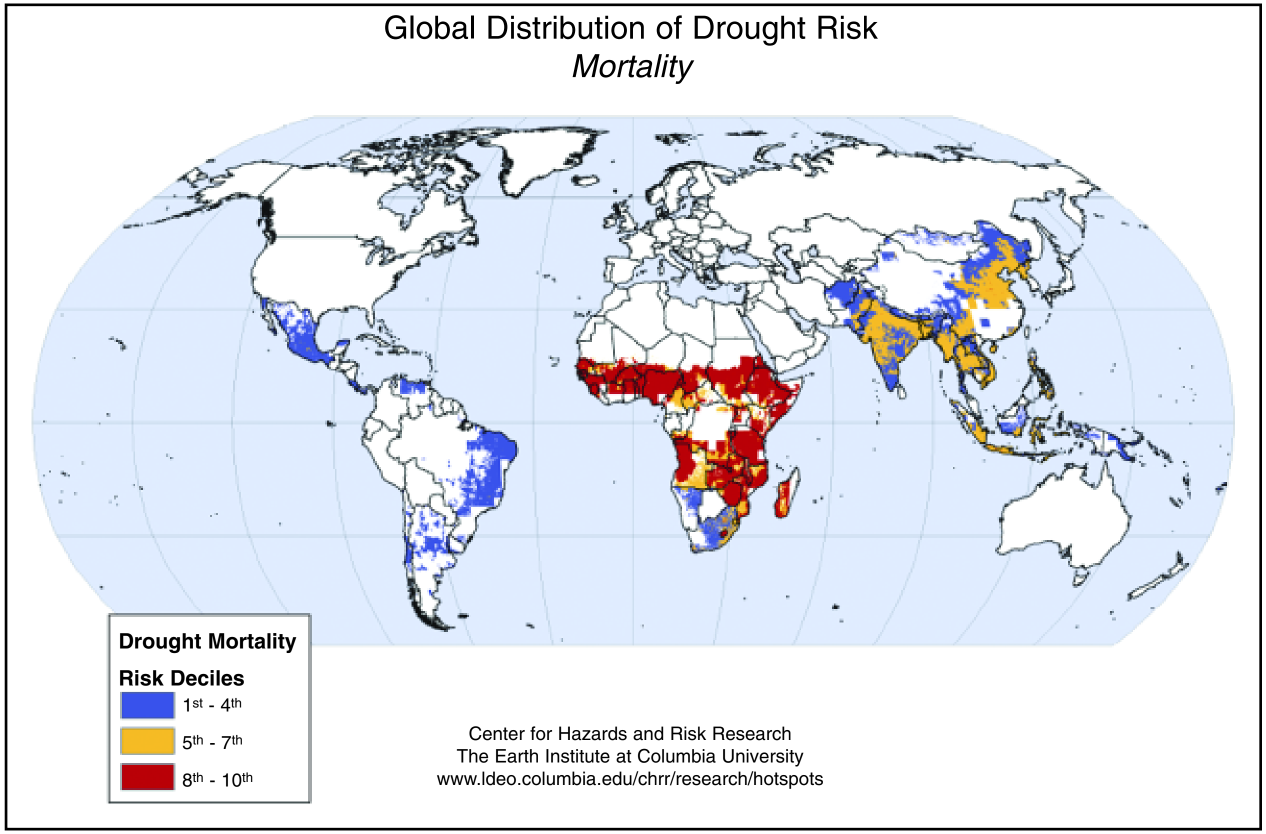
For more information

NASA Socioeconomic Data and Applications Center (SEDAC)
http://sedac.ciesin.columbia.edu/

Center for Hazards and Risk Research at Columbia University
http://www.ldeo.columbia.edu/chrr/index.html

The World Bank
http://www.worldbank.org/

United Nations Development Programme Disaster Reduction Unit
http://www.undp.org/bcpr/disred/



This map, produced as part of *Natural Disaster Hotspots: A Global Risk Analysis*, shows the global human mortality risk from drought. Areas in blue have the lowest risk, while those in red have the highest risk; white areas indicate regions where there is little or no risk. (© 2005, The World Bank and Columbia University, *Natural Disaster Hotspots: A Global Risk Analysis*, Figure 6.2a)

About the scientists

Margaret Arnold is the senior program officer on the Urban Unit Hazard Risk Management Team at The World Bank. She focuses on project management, providing technical assistance to disaster-related operations, developing policy and training, and assisting the Bank in integrating disaster risk management into its development efforts.

Maxx Dilley is a policy advisor at the United Nations Development Programme Disaster Reduction Unit. He specializes in disaster and risk assessment, climate risk management, and food security, and has designed and managed disaster mitigation programs in Africa, Latin America and Asia. Dilley has a PhD in geography from Pennsylvania State University.

Monitoring Great Lakes ice from space

"Although it's seasonal—we don't have second-year ice or multiyear ice—the ice cover on the Great Lakes can be very dynamic."

George Leshkevich
National Oceanic and Atmospheric Administration CoastWatch Program

by Michon Scott

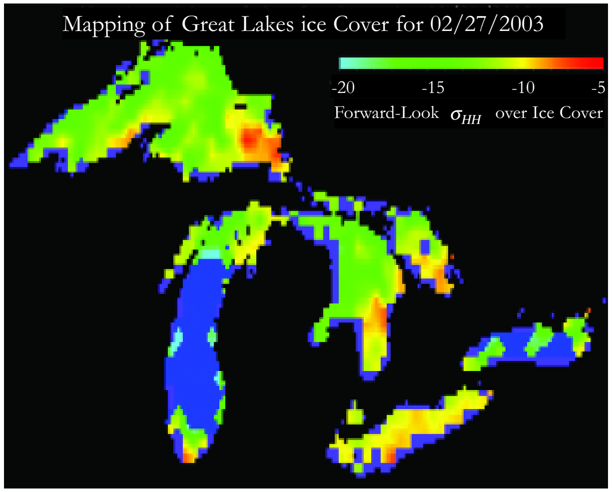
People who live on the islands that dot Lake Erie, one of Michigan's Great Lakes, have a tradition of visiting each other by driving across the frozen lake's surface in the wintertime. The islanders do not use regular vehicles, however. They drive cars without doors and roofs, so if the vehicles fall through the ice, the passengers can escape. A few weak spots in the ice are well known because they persist in the same area from year to year, but the overall behavior of ice on the Great Lakes is dynamic and hard to predict.

Understanding Great Lakes ice means enduring some tough conditions. A Web page encouraging tourism to Lake Superior observes that, in the wintertime, lakeshore temperatures rarely fall below negative thirty-five degrees Celsius (negative thirty degrees Fahrenheit). "When you're trying to collect data, you certainly appreciate why there's so little data available about ice during the winter," George Leshkevich said.

Leshkevich is a research physical scientist and the Great Lakes Node Manager for the National Oceanic and Atmospheric Administration's CoastWatch Program, and he has studied the Great Lakes since 1973. From time to time, he has become painfully familiar with the Great Lakes' sub-zero temperatures. He and colleague Son Nghiem, principal engineer at the California Institute of Technology at NASA's Jet Propulsion Laboratory, have traveled across Lake Superior, studying the ice at close range. One thing they have learned about the Great Lakes in the wintertime is that the wind only intensifies the cold. Yet the same wind that makes personal inspection so uncomfortable may hold the key to answering their questions about Great Lakes ice: how much ice will form, how thick it will be, and where it will drift.

Problems with brash ice

Collectively, the Great Lakes cover approximately 244,060 square kilometers (94,230 square miles), and have become a hub of economic activity. In 2000 and 2001, the population for the Great Lakes Basin, including both Canadian and United States residents, was estimated at thirty-four million people. The lakes provide a means of moving iron ore, coal, and grain; and



This prototype of the Quick Scatterometer (QuikSCAT) ice-cover product for the Great Lakes shows that on February 27, 2003, ice covered most of Lakes Superior, Huron, and Erie for the first time in almost a decade. Red and green indicate ice cover, with red corresponding to thick brash ice. Blue indicates open water and violet indicates unclassified areas. (Courtesy Leshkevich and Nghiem) they provide fish, hydropower, and drinking water. Human uses aside, these giant bodies of water affect regional weather. Leshkevich explains that ice cover on the lakes not only affects regional weather, but also hinders the movement of goods and passengers.

Not every kind of ship can pass through every kind of ice cover. For example, especially thick or ridged ice can normally only be crossed with an icebreaker, a ship with a reinforced bow specifically designed to break ice. "The U.S. Coast Guard services the Great Lakes with ice-breaking activities. They want to know where the ice is and what type of ice they have to deal with," Leshkevich said. Providing the answer is not necessarily simple. On a large body of water subject to freezing temperatures, there will be ice somewher.e. But knowing exactly where, when, and how this ice will form and move is hardly straightforward. "Although it's seasonal—we don't have second-year ice or multiyear ice—the ice cover on the Great Lakes can be very dynamic," he said.

Nghiem said, "Winds can push the ice together and create a kind of ice called brash ice." Formed by broken ice, often with protruding edges, this kind of ice can accumulate until it is several meters thick, posing a serious challenge for ships trying to pass through it.

Leshkevich said, "Even the U.S. Coast Guard Cutter Mackinaw, which is an Arctic-class ice-breaker, can have trouble in brash ice. Some-times it has to back up and ram several times to get through that ice. So if you're talking about a lake freighter that doesn't have those capabilities, the ice can present real problems."

Shipping in the region would be far less complicated if ships could maneuver around such ice, or know when to call on icebreaking ships for assis-tance. By being able to forecast the location and thickness of Great Lakes ice cover, Leshkevich and Nghiem can help both the businesses using the lakes and the icebreakers servicing the lakes.

The Sea-Viewing Wide Field-of-View Sensor (SeaWiFS) captured this image of the Great Lakes on December 5, 2000. This image shows the Great Lake effect, in which cool, dry air flowing over the lakes picks up heat and moisture, condensing to form clouds, which can cause lake-effect snow. (Courtesy SeaWiFS Project, NASA/GSFC and ORBIMAGE)

Compared to trekking out onto the ice, taking a picture of the ice cover would be easier. Although any kind of aerial view of the region might seem beneficial, not all views are equal. Aerial photographs or satellite images that show the same things that human eyes see, namely what is revealed by light in the visible spectrum, may not be the best choice because clouds can get in the way. Nghiem said, "Cloud cover is persistent over the Great Lakes, especially during the wintertime. When the ice starts to break up, a lot of vapor comes off the lake." This vapor forms clouds that make imaging the lake ice dif-ficult. Moreover, he added, "At night, it's very hard for the satellites to 'see.'" Satellites that rely on visible light can only acquire images during the daytime.

Fortunately, satellite sensors can detect several different kinds of light, including wavelengths invisible to human eyes. Defined as accurate and stable radars, scatterometer sensors operate in the microwave portion of the spectrum. "The advantage of scatterometry is that it can 'see' through clouds, and it can cover the Great Lakes area once or twice a day, depending on the orbit of the satellite," Nghiem said. Unlike some satellites with nighttime passes that do not yield usable data, scatterometers can collect data at night. Even better, they can "see" wind.

The Moderate Resolution Imaging Spectroradiometer (MODIS) captured this image of Lake Huron, Lake Erie, and Lake Ontario (clockwise from upper left) on January 27, 2003. Dark indicates open water; light indicates snow and clouds. Extent of ice coverage was fairly normal during winter 2003, but researchers found that it was thinner than usual. (Courtesy MODIS Rapid Response Team, NASA/GSFC)

Detecting wind with SeaWinds

During World War II, something known at the time as "sea clutter" interfered with radar measurements over the ocean. Only in the 1960s did scientists realize that winds caused this noise in their radar measurements, and that radar could be used to measure wind speed and direction. The Skylab missions of 1973 and 1974 included a newly built scatterometer designed to collect those measurements. In the years that followed, NASA introduced new scatterometers.

Operated by NASA's Jet Propulsion Laboratory, the SeaWinds scatterometer flies on the NASA Quick Scatterometer (QuikSCAT) mission. The sensor measures wind speed and direction over Earth's ice-free water surfaces; these data are archived at the NASA Physical Oceanography Distributed Active Archive Center (PO.DAAC). The SeaWinds sensor works by transmitting a microwave signal toward the water's surface and measuring the strength of the returned signal. Because winds influence waves, winds roughen the water's surface. A smooth water surface returns a weak signal, but a rough surface returns a strong signal as the waves scatter more energy back toward the sensor. The SeaWinds sensor also uses a spinning antenna, enabling the measurement of wind direction.

One advantage that SeaWinds has over some other sensors is that it sends and receives data in different polarizations. Polarization is defined as the spatial orientation of electromagnetic waves, and when the spatial orientation is not random, it polarized. Leshkevich said, "Sometimes wind waves—waves caused by wind speed and direction—can duplicate the signal of certain ice types. So if you look at the data, you're not sure if you're looking at an ice type or if it's waves caused by wind." This problem occurs when satellite sensors operate at one wavelength and in one polarization. Because SeaWinds sends and receives signals in different polarizations, it better distinguishes between rough waves and certain kinds of ice. This is important for the mapping project because it shows the difference between the ice itself and the wind that moves it around. By distinguishing between these two data signals, while also incorporating them into the same product, Leshkevich and Nghiem hope to show exactly how the wind is likely to move the ice.

Acquiring field data on the lakes

To further discern the difference between rough waves and ice detected by scatterometers, Leshkevich and Nghiem have taken a closer look at the Great Lakes. In a recent field experiment, Nghiem built a radar that they mounted on a Coast Guard icebreaker. They matched the radar's backscatter readings with the physical characteristics of the ice, collecting all the measurements for comparison with calibrated satellite measurements. Nghiem said, "It's like a library or dictionary so we know what kind of ice would have what kind of radar signature."

While looking closely at the ice, Nghiem and Leshkevich noticed something else. "What we've noticed on Lake Superior during March is that 1997 was probably the last year where you had extensive ice cover of good quality. By 'good quality,' I mean the ice is not noticeably decaying, the ice is thick, the ice covers more of the lake," Nghiem said. "It seems that since 1998, we've had below-normal ice cover, with the exception of 2003."

Leshkevich agreed. "As we went across Lake Superior on the Mackinaw in mid-March 2003, the ice just seemed to be more in a state of decay. Even though the coverage was more extensive that winter, the ice cover wasn't the

About the remote sensing data used

Satellite	QuikSCAT
Sensor	SeaWinds
Data set used	Backscatter
Resolution	12.5 kilometers
Parameter	Lake vector wind
Data center	NASA Physical Oceanography (PO.DAAC)
Science funding	National Oceanic and Atmospheric Administration

same quality. It had water on it and holes in it that were probably caused by water drainage through the ice. It wasn't as thick and much of it was in a state of decay."

Are they seeing a trend? They think it is too soon to tell. Nghiem said, "People should not come to a conclusion too quickly to say the Great Lakes won't be covered by ice anymore. The past decade is a short time period compared to the climate record."

Future plans

Nghiem and Leshkevich plan to continue to develop and refine products to map ice cover on the Great Lakes. "The limitation of scatterometer data is the resolution," Nghiem said. "The lower-resolution scatterometer data is twenty-five kilometers, which has a limited application to the Great Lakes. But we do have higher-resolution data that we call 'slice data.' It can give you about twelve-kilometer resolution." Nghiem and Leshkevich use SeaWinds data in conjunction with Synthetic Aperture Radar (SAR) data to "see" through clouds and monitor the Great Lakes ice cover. The SAR data has higher spatial resolution, but the scatterometer data has much better temporal resolution, with two overpasses a day.

Nghiem and Leshkevich hope to develop a process that automatically maps Great Lakes ice cover in real time. Leshkevich said, "This project is ongoing and we still haven't finished it, but we're a good ways along in development, and we just need to do a little more testing." As for results achieved so far, they can point to prototype maps on the NOAA Great Lakes CoastWatch Web site. These maps show Great Lakes ice cover and wind fields derived from QuikSCAT/SeaWinds data. With this information, forecasters may be able to predict where wind might move the ice cover or open leads, or fractures, in the ice.

Leshkevich and Nghiem have considered developing a composite product to show ice cover, open water, and wind direction, or wind vector. "That would give users a sense of not only where the ice cover is and what type it may be, but also, based on the wind vectors, which direction the ice is likely to move," Leshkevich said. That information would help inform the Coast Guard and companies and commuters who use the Great Lakes during the winter, aiding them in safe winter navigation and more cost-effective ice breaking.

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National Oceanic and Atmospheric Administration CoastWatch ice cover maps
http://coastwatch.glerl.noaa.gov/overview/cw-overview.html

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

About the scientists

George Leshkevich is a research physical scientist and Great Lakes Node Manager for the National Oceanic and Atmospheric Administration (NOAA) CoastWatch Program at the Great Lakes Environmental Research Laboratory. His remote sensing research uses optical and radar satellite sensors, as well as field experimentation. His research has involved the analysis of Great Lakes parameters and features, including ice cover, classification and mapping, and ocean color applications.

Son V. Nghiem is a principal engineer at the Jet Propulsion Laboratory at the California Institute of Technology. His research covers active and passive remote sensing, field experimentation, electromagnetic wave theory and applications, and scattering and emission modeling. He received the 1999 Lew Allen Award for Excellence for his research in Earth science remote sensing and the 2006 NASA Exceptional Achievement Medal for developing scientific applications for scatterometry.

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