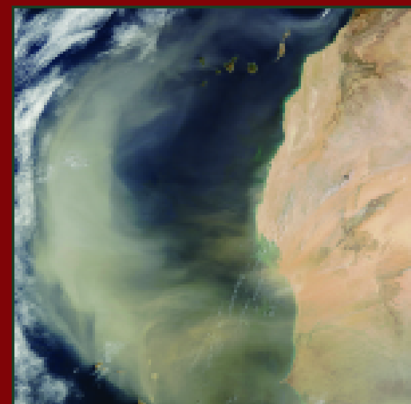
National Aeronautics and Space Administration

Sensing Our Planet







NASA Earth Science Research Features 2007

Sensing Our Planet

NASA Earth Science Research Features *2007*

National Aeronautics and Space Administration
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NASA Earth Observing System Data and Information System (EOSDIS) Data Centers

Front cover images

Top row, left to right:

Debris from the February 17, 2006, landslide that buried Guinsaugon shows the effect of tectonic weakening. The landslide occurred along a fault line, where tectonic movement grinds and crushes the rock. This ground-up rock and soil on the mountainside had become more prone to landslides, especially after several days of rain. See the related story, "Connecting rainfall and landslides," on page 22. (Courtesy Stephen Evans)

Without the buffer of the Larsen B ice shelf, several glaciers now feed directly into the embayment left behind after the shelf collapsed in 2002. From left to right are the Melville, Mapple, and Crane Glaciers; Jorum Glacier is in the foreground. See the related story, "After the Larsen B," on page 32. (Courtesy Ted Scambos)

The MODIS instrument, aboard NASA's Terra and Aqua satellites, captured this image of a Saharan Air Layer outbreak moving off of Africa into the North Atlantic on March 2, 2003. See the related story, "Saharan dust versus Atlantic hurricanes," on page 8. (Courtesy NASA MODIS Rapid Response Team)

People have long depended on groundwater for drinking water, farming, and commercial uses. When groundwater dries up, so can the communities that depend on it. Windmills scattered across the Great Plains mark where people have brought groundwater to the surface. See the related story, "Getting at groundwater with gravity," on page 46. (Courtesy Photos.com)

Bottom row, left to right:

This photograph of the Hall of Supreme Harmony in Beijing's Forbidden City was taken on a relatively clear day, but air pollution often obscures much of Beijing's famous architecture. See the related story, "Pollution trials for the Beijing Olympics," on page 14. (Courtesy Photos.com)

Human beings rely on our planet's net primary production for survival. Plants provide food and fiber, as well as support the animals we use for food and clothing. See the related story, "Can Earth's plants keep up with us?" on page 28. (Courtesy Gillian Bolsover)

Apprentice Stephane Ciron works on a family-owned farm near his village of Uxeau. Farms in the study region have expanded their operations, leading to opportunities for youth from nearby towns. See the related story, "Burgundy through space and time," on page 2. (Courtesy Gillian Bolsover)

Back cover images

Left to right:

The twin World Trade Center Towers stand over New York City prior to their collapse on September 11, 2001. The collapse sent a noxious plume of smoke drifting over the city, and health officials were challenged to monitor its drift and possible impacts on health. See the related story, "Following the World Trade Center plume," on page 38. (Courtesy Photos.com)

This FLUXNET tower is one of many worldwide that scientists have erected to constantly monitor landscape health and productivity. They hope to better understand the energy exchanges that are essential to the lifecycles of vegetation. See the related story, "Grasping the subtle needs of vegetation," on page 42. (Courtesy FLUXNET)

Invasive tamarisk trees like this one continue to gain footholds in the West, changing habitats and pushing out native species. Without intervention, they could be cropping up soon in surprising places, such as the Midwest. See the related story, "Pinpointing an invasive plant's next move," on page 18. (Courtesy Jeffrey T. Morisette)

Susan Kool monitors data from the Lidar Atmospheric Sensing Experiment (LASE) instrument on board a NASA DC-8 aircraft flying through a Saharan dust storm over the Atlantic. Researchers hope to use these data to track interactions between the dust and tropical storms and to better understand Atlantic hurricane development. See the related story, "Saharan dust versus Atlantic hurricanes," on page 8. (Courtesy NAMMA team)

About the EOSDIS data centers

The articles in this issue arose from research performed using data from NASA's Earth Observing System Data and Information System (EOSDIS) data centers. The Earth Observing System (EOS) comprises a series of satellites, a science component, and the EOSDIS data system. The data centers distribute more than 2,400 Earth system science data products and associated services for interdisciplinary studies. The centers process, archive, document, and distribute data from NASA's past and current Earth system science research satellites and field programs. Each center serves one or more specific Earth science disciplines and provides its user community with data products, data information, services, and tools unique to its particular discipline.

For more information about the EOSDIS data centers, visit the NASA Earth System Science Data and Services Web site (http://nasadaacs.eos.nasa.gov/).

Acknowledgements

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We thank the Earth Science Data and Information System (ESDIS) project for its financial support of the publication; to the Earth Observing System Data and Information System (EOSDIS) data center managers and User Services personnel, for their direction and reviews; and to the NASA scientists who alerted us to the research and investigations that made use of EOSDIS data in 2007. We especially thank our featured investigators for their time and assistance.

Writing, editing, and design

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Writers: Jane Beitler, Gloria Hicks, Lindsay Husted, Laura Naranjo, and Stephanie Renfrow
Publication Design: Laura Naranjo

The design featured in this issue represents the leaf of a plant. Several articles for 2007 shed light on ways the seemingly mundane lives of plants are the base of sustenance, Earth's ecosystems, and our material comforts. To read about some of the ways scientists are using NASA Earth system science data to study vegetation, see "Pinpointing an invasive plant's next move" on page 18, "Can Earth's plants keep up with us?" on page 28, and "Grasping the subtle needs of vegetation" on page 42.

Publication notes

Articles and additional images from *Sensing Our Planet: NASA Earth Science Research Features 2007* 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 e-mail nasadaacs@eos.nasa.gov.

Researchers working with EOSDIS data are invited to e-mail the editors at daaceditor@nsidc.org to explore possibilities for developing a future article.

About this issue

This issue of *Sensing Our Planet: NASA Earth Science Research Features* (formerly *NASA: Supporting Earth System Science*) focuses on some of the unexpected ways that scientists use remote sensing data to study the Earth. Our lead story, and the inspiration behind this year's color palette, captures this concept perfectly. In "Burgundy through space and time," we tell the story of anthropologists and archaeologists who found that satellite data provided the ideal framework for a long-term research perspective on life in Burgundy, France.

As this year's variety of topics indicates, researchers across scientific disciplines appreciate the global reach and tireless observations that satellites provide. More and more experts are creatively using remote sensing data in their research fields. These innovative approaches unfold in articles about the World Trade Center collapse and implications for air quality, "what-if" musings about human consumption patterns, and the mysterious presence of water hidden beneath the Earth's surface.

Scientific research is often tied to understanding how Earth's many related systems interact, and how these natural processes affect our lives and our use of the Earth's resources. Satellites give us new insights that can help us plot our next move against pollutants, unstable hillsides, and invasive plants. Although perhaps less surprising, the scientific uses of remote sensing to study far-flung Antarctic ice shelves and the birth of Atlantic hurricanes are no less important. Remote sensing provides scientists with the opportunity to approach the world's natural systems with fresh eyes and new thinking. In the words of NASA scientist Marc Imhoff, "Our ability to assess our environment and our situation should give us a sense of empowerment."

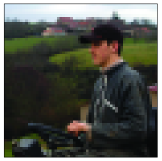
The Earth never stands still. Understanding our planet's dynamics drives the curiosity of scientists. We hope you sense that curiosity as you read about their efforts to learn more about our home planet.

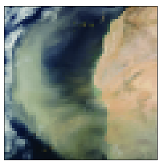
—The Editors

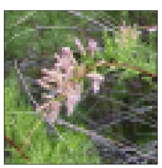
A farmer in Burgundy, France, tends his sheep on a farm that has survived for generations. Our lead story tells how satellite data have helped provide scientists with new perspectives on the centuries-long interaction between people and their environment. (Courtesy Gillian Bolsover)

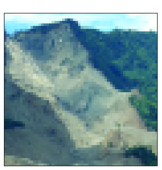
Sensing Our Planet

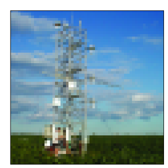
NASA Earth Science Research Features *2007*

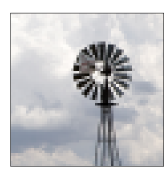












Burgundy through space and time

"This region is a laboratory of antiquity."

Carole Crumley
University of North Carolina at Chapel Hill

by Stephanie Renfrow

A few years ago, a man moved back to his family farm in Burgundy, France. Among other updates to the centuries-old farmhouse, he wanted to install a water heater in an old closet. However, the closet turned out to have a false bottom. In the darkness below, the man discovered yellowed paperwork: records of the farm's history going back to the 1500s, mysteriously placed there for safekeeping generations before.

The discovery of documents and objects from generations past makes for fascinating stories. However, these family records can also help scientists and researchers piece together an entire region's history, one bit of information at a time.

Carole Crumley, a professor of anthropology and ecology at the University of North Carolina at Chapel Hill, likes to tell the story of this man's hidden family archive as a way of introducing a research project that she has been working on in Burgundy for more than two decades. The project relies on dozens of researchers using every tool in their toolbox: historic family records like those hidden in the farmhouse closet; oral histories from current residents; analysis of the structure of Medieval outbuildings; pollen in sediment cores from farm ponds; analysis of river channels; linguistic studies of Latin place names; and even satellite remote sensing data. Each of these individual resources provides one thread in a larger story that, taken together, weaves a broad and deep narrative of the region's development and helps scientists understand the interaction of land and people through time.

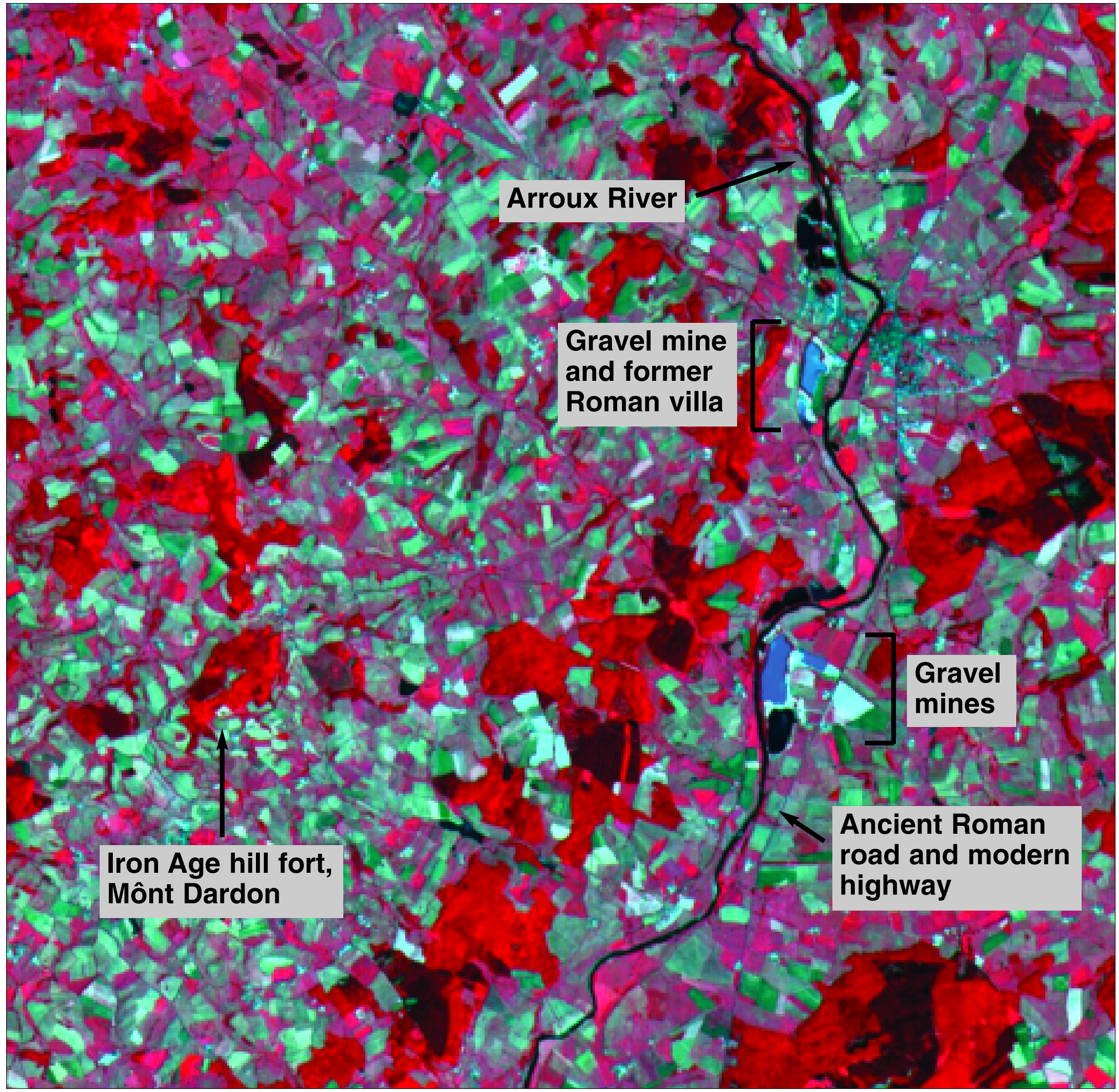
The Burgundy region drew Crumley's interest for a long-term study because hundreds of

Successful farms in the Burgundy region have lasted through the generations; according to archaeologist Carole Crumley, species diversity and varied farmland are key factors. (Courtesy Gillian Bolsover) cultures—from Iron Age settlers to Romans to commoners of the Middle Ages—have inhabited the region for centuries. Crumley said, "This region is a laboratory of antiquity. It has been occupied for more than 200,000 years." In looking at the ongoing interaction between the land and the people who have lived in the region, Crumley realized that she would have to focus not just on the archaeology, but on each culture's use of the surrounding resources. "We simply couldn't talk about the people without talking about the environment around them," she said.

Weaving the narrative

At the same time that the Burgundy project began, a new technology fired the minds of scientists: satellite remote sensing allowed researchers to see our planet from a new vantage above Earth. However, most of the scientists involved in early remote sensing work were in Earth science, not anthropology. Scott Madry, a self-described technologist, studied with Crumley at the start of the long-term Burgundy work. Madry was fascinated by the possibility of using geoinformatics —a combination of remote sensing data, ground observations encoded to geological coordinates, and Geographic Information System (GIS) data—to study how people and the environment have interacted in Burgundy through the centuries. He said, "I wanted to figure out how we could apply new geo-informatics technologies, like remote sensing, to solve some of the problems of organizing long-term research like our Burgundy project."

Now, some twenty-five years later, Madry can still remember the exact date of the first satellite



This Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) image from NASA's Terra satellite shows the focal point of the long-term Burgundy research study: the Arroux River valley of Burgundy, France. A gravel mine destroyed the site of a Roman villa before archaeologists could excavate; an ancient Roman road, now pressed into service as a modern highway, parallels the river; and a small speck of white reveals the Iron Age hill fort of Mônt Dardon. The study area is patchworked with small fields and pasturelands, indicated in greens; forest areas are indicated in red. (Image courtesy Scott Madry) remote sensing data set that he used. "It was the March 22, 1973, Multispectral Scanner data from NASA," he said. "I remember thinking, 'Wow! I can get an exact number of hectares of forest, just like that!' Traditional methods can take months."

Beginning with that first data set, and continuing to incorporate remote sensing and other geoinformatics data as it becomes available, Madry has compiled a detailed database of the Burgundy study area. He has used data from European and United States sensors, including the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER), distributed by the Land Processes Distributed Active Archive Center, and RADARSAT-1 data supported by the Alaska Satellite Facility Distributed Active Archive Center. "Each data set fills an important gap," he said. "For example, the RADARSAT-1 data filled in an important gap in information about vegetation cover in the late 1990s, when we were seeing a lot of land-use changes in our study area." Because he uses so many types of data, one of his students told Madry, "You're like a vacuum cleaner; any data that gets near you is in danger."

Lucien Dauvergne and his wife, Rose, have chickens, rabbits, and a vegetable garden behind their house in Vendenesse sur Arroux, Burgundy. Family-grown food helps communities survive in times of change, according to Crumley's research. (Courtesy Gillian Bolsover)

But how does the birds-eye view of geoinformatics intersect with the on-the-ground realm of anthropology? "Everything we're doing relates to space and time, whether it's carbon dating or an archaeological object at the centimeter scale," Madry said. "The database provides spatial and temporal data, putting the rest of the research into a scaleable, concrete context." By providing a common context for their interaction, the database allows the many specialists involved in the Burgundy project to build on each other's work. "Each specialty brings a piece of the whole to the bigger story," Madry said. "And that helps us understand the complexities of the changes in Burgundy through time."

Crumley said, "I think Scott Madry has something like 130 layers of different types of information in the database, at this point." The layers include information taken from historical maps, church ledgers, tax and legal records, oral histories, sediment research, and geological studies—all woven together within the loom of the remote sensing and other geoinformatics data. The database has allowed researchers to organize and overlay all of these disparate pieces of information about the Burgundy study area, helping the group to see patterns and commonalities across cultures and time. "We couldn't do this kind of long-term anthropological work without it—the geoinformatics piece has been our anchor," Crumley said.

Climate change and history

Tackling big questions that span broad periods of time and that cause profound societal changes is one of the goals of the long-term Burgundy research project. One idea that Crumley has focused on, recently, is the idea that species diversity and a varied landscape have increased the long-term survival of farms in the Burgundy study area. Crumley said, "In the 1980s, we started to see patterns in the data that suggested that France had undergone periods when the agricultural system collapsed. We looked at the Burgundy study region to determine why that occurred. Species diversity and landscape variability played a central role."

Crumley believes that successful survival stems from flexibility in the face of change. "If the chickens didn't do well, perhaps the rabbits did okay; or if flooding ruined crops in one area of the farm, perhaps a higher area stayed dry," Crumley said. "Farmers and their communities are able to survive change better if they have a redundant and diverse system of crops and a variety of microclimates to farm." To take a well-known example from history, the 1845 potato fungus that hit Ireland occurred at a time when English landowners appropriated the region's wheat. Millions of peasants were forced to rely on a single variety of potatoes as their sole food source. Without species diversity, millions of Irish starved as the potato blight took hold.

The question of diversity and adaptability also has interesting implications for today's society. Aided by remote sensing data, anthropologists have noted that Burgundy forests are increasingly made up of a single species of conifer.

Roman roads, now pressed into modern service, wind through the Burgundy landscape. A succession of cultures have inhabited the study region for centuries. (Courtesy Gillian Bolsover)

They also observe that the number of farms has decreased by 50 percent, while doubling in size in the last fifty years. Crumley's research indicates that many of these changes are inadvertently caused by new European Union (EU) regulations that encourage high production and provide subsidies when certain conditions are met. "The EU regulations have a one-size-fits-all approach, rather than taking into account the different conditions on the ground and the standard practice in different regions," Crumley said. Sometimes, regulations and farm subsidies that are intended to encourage efficiency or increase food production have unanticipated consequences. "For example, the removal of Burgundy's hedgerows to increase room for more cattle actually turns out to be bad for cows," she said. "In the textbook climate-change-caused heat wave that hit Europe in 2003, most of the cattle that died were lost to heat stroke. They died because they couldn't find shade."

For Crumley, this chain of events has some eerie parallels with events in Roman times. "During the early Roman empire, Burgundy was a breadbasket for the many hungry mouths in Rome. But Romans not only brought their crops north with them; they also brought mono cropping and slave labor for big farms," Crumley said. In other words, the Romans reduced diversity and moved away from flexible family-run farms, making them vulnerable to environmental changes like drought or pestilence. "Starting in around 200 AD, the weather worsened," Crumley said. "Crops declined, malnourishment led to plagues, and the population of Europe decreased by half. Disastrous circumstances tend to cascade. The combination of a reckless land-use policy, social changes, and a changing climate pushed Europe into the Dark Ages."

Long term and into the future

Crumley and Madry both intend to continue contributing to the long-term Burgundy research project, as well as encourage new researchers to use and add to the database. Crumley is focusing her efforts on writing a book about the Burgundy study region, as well as continuing to study the effects of EU regulation on family farms in the study area. She is also working with various International Geosphere-Biosphere Programme committees that study the history of human beings and the Earth system, with the goal of improving our planet's and humanity's future.

Madry plans to keep current on the latest satellite data and find ways to strengthen the temporal and spatial content in the database. He said, "Recently, I've been looking at incorporating additional historical cartographic products. I'd like to try to work backwards in time from the remote sensing and GIS data." Adding data from old maps could clarify the picture leading up to the satellite era and strengthen the older spatial and temporal data. The central challenge for Madry lies in stitching together such disparate data into the existing foundation of the database. "How

Apprentice Stephane Ciron works on a family-owned farm near his village of Uxeau. Farms in the study region have expanded their operations, leading to opportunities for youth from nearby towns. (Courtesy Gillian Bolsover)

reliable are the scales on these old maps? How can they be integrated into our existing geographic material? These are the questions I'll be tackling."

The long-term database—a tapestry of histories and knowledge—will continue to grow and stretch as new researchers join the project and new remote sensing technologies strengthen the existing foundation. "If we can understand one place over a long period of time from many perspectives, then we can integrate this information and, in the end, help the next generation of researchers to understand complex issues like global warming and land-use change," Madry said. "I'd never thought of it this way, before, but I guess the database is really a data archive."

Crumley agreed. "And when you go into archives, you never know what you're going to come across," she said. "Except that you'll find things that electrify."

To access this article online, please visit http://nasadaacs.eos.nasa.gov/articles/2007/2007_burgundy.html.

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For more information

NASA Alaska Satellite Facility DAAC
http://www.asf.alaska.edu/

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

GIS and Remote Sensing for Archaeology: Burgundy, France
http://www.informatics.org/france/france.html

Online tour of Mont Beuvray/Bibracte in Burgundy
http://www.informatics.org/bibracte/ipixmain.html

Triquete: The interdisciplinary study of resilient landscapes
http://www.triquete.org/

University of North Carolina at Chapel Hill
http://www.unc.edu/

About the scientists

Carole Crumley is a professor of anthropology and ecology at the University of North Carolina at Chapel Hill (UNC-CH). Her primary research focus is the long-term interaction between people and the environment in a study site in Burgundy, France. Her funding for the Burgundy research has come from the National Science Foundation, the National Endowment for the Humanities, the National Geographic Society, and UNC-CH.

Scott Madry is a research associate professor of anthropology at UNC-CH and is founder and president of Informatics International, Inc. He specializes in applying geoinformatics technologies to environmental, historical, and archaeological research. Madry's Burgundy funding comes from personal resources, as well as the National Geographic Society, the Council on International Exchange of Scholars, Rutgers University, The Institute for Technology Development Space Remote Sensing Center, and UNC-CH.

About the remote sensing data used

Satellite	Terra	RADARSAT-1	Earth Resources Technology Satellite-A
Sensor	Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER)	Synthetic Aperture Radar (SAR)	Multispectral Scanner
Data sets used	Multispectral Visible and Near Infrared (VNIR), Shortwave Infrared (SWIR), and Thermal Infrared (TIR) bands	C band	Multispectral Scanner bands, visible and infrared
Resolution	15, 30, and 90 meters	10 and 30 meters	80 meters
Parameter	Vegetation and land use/land cover	Vegetation and land use/land cover	Vegetation and land use/land cover
Data center	NASA Land Processes DAAC	NASA Alaska Satellite Facility DAAC Canada Centre for Remote Sensing	Originally acquired by NASA; now managed by United States Geological Survey

Saharan dust versus Atlantic hurricanes

"We think that dust aerosols can affect tropical disturbances, sometimes even kill those disturbances."

Syed Ismail
NASA Langley Research Center

by Jane Beitler

On a typically hot and humid August day, researcher Jason Dunion saw something unusual in the sky over Miami. Dunion said, "It was really humid. It felt like a wet towel outside. But just above us, at 5,000 feet, it was super, super dry. No clouds were forming." Dunion photographed a layer of dry, dusty air over Miami that had journeyed from the Saharan Desert in northern Africa, some four thousand miles across the Atlantic. Researchers think these dry, dusty air layers from Africa may be a key to understanding why Atlantic atmospheric disturbances, called tropical waves, sometimes intensify into hurricanes, and sometimes fizzle.

Dunion is one of many researchers who want a clearer picture of the genesis and growth of Atlantic tropical storms and hurricanes. Computer storm modeler Cerese Albers, at Florida State University, wants to understand why storms intensify. She said, "We are looking for warning signs about which waves have the potential to form serious storms.

NASA and the National Oceanic and Atmospheric Administration (NOAA) teamed up to track the dusty Saharan Air Layer across the Atlantic during the 2006 hurricane season. In this photo, Saharan dust gives the sky an orange glow during a late afternoon sunset in the eastern Caribbean. Small cumulus clouds poke through the tops of the dust layer. A NASA DC-8 aircraft flown out of Cape Verde, Africa, started tracking this dust on September 13, 2006; on September 18, a NOAA P-3 Orion aircraft picked up its trail and captured this photo. (Courtesy Jason Dunion)

If we could understand the lifecycle of the disturbance waves, models could better simulate a storm's potential for intensity and growth over the following few days." This knowledge could mean better and faster warnings to coastal residents.

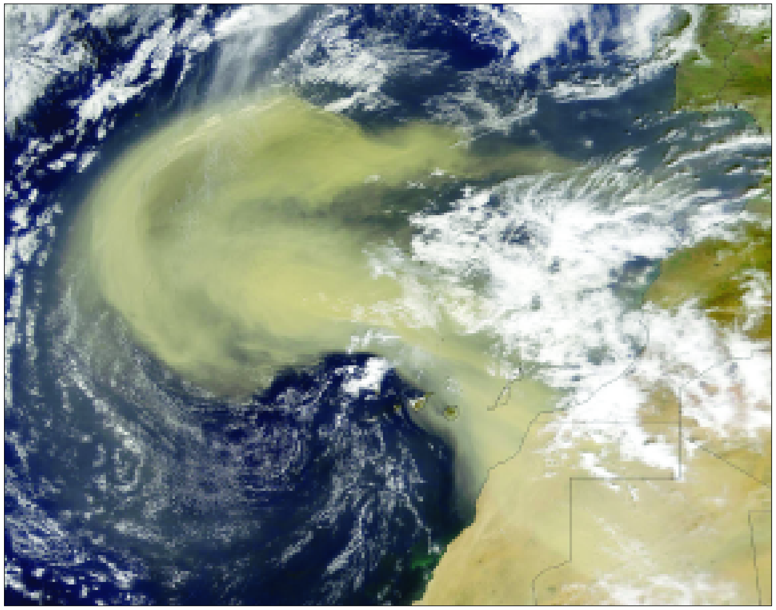
Life cycle of a hurricane

Scientists have long understood that convective waves of westward-traveling atmospheric disturbances from the north African coast can be the beginnings of tropical storms and hurricanes. Dunion said, "In the Atlantic, more than half of tropical storms and weak hurricanes, and 85 percent of major hurricanes—categories three, four, and five—come from Africa." Scientists also know that a number of factors, including sea-surface temperatures, unstable atmosphere, and high water-vapor levels, can cause the waves to intensify and form storms.

Albers and Dunion are among more than one hundred researchers who participated in the NASA African Monsoon Multidisciplinary Analyses (NAMMA) campaign, a joint effort between NASA and the National Oceanic and Atmospheric Administration (NOAA), during the Atlantic hurricane season of 2006. Syed Ismail, a scientist at NASA Langley Research Center, said, "The objective of NAMMA was to see what role the Saharan dust aerosols play in the development of tropical disturbances, which could eventually become hurricanes in the Atlantic. The disturbances propagate from the coast of north Africa, and they get energized in the warm Atlantic climate. And then they sometimes develop into hurricanes." The researchers suspected that Saharan dust storms sometimes prevent disturbance waves from intensifying into tropical storms and then hurricanes. That Saharan dust keenly interests Dunion, a research meteorologist from the NOAA Hurricane Research Division in Miami. He said, "The Saharan Air Layer is essentially a huge dust storm that can be the size of the continental United States. Every three to five days during the summertime, these storms roll off of the African coast." As the dust storms move off northern Africa, convective waves develop farther to the south, pulling moisture up into the atmosphere.

"We think a dust storm has three main components that can suppress a hurricane," Dunion continued. "One, it's got super-dry air. Hurricanes don't like dry air in the middle parts of the atmosphere, and that's exactly what the Saharan Air Layer has. A Saharan dust storm also has a very strong surge of air embedded within it, called the midlevel easterly jet, that can rip a storm apart that's trying to develop. We call that vertical wind shear. And then the third piece is all this dust."

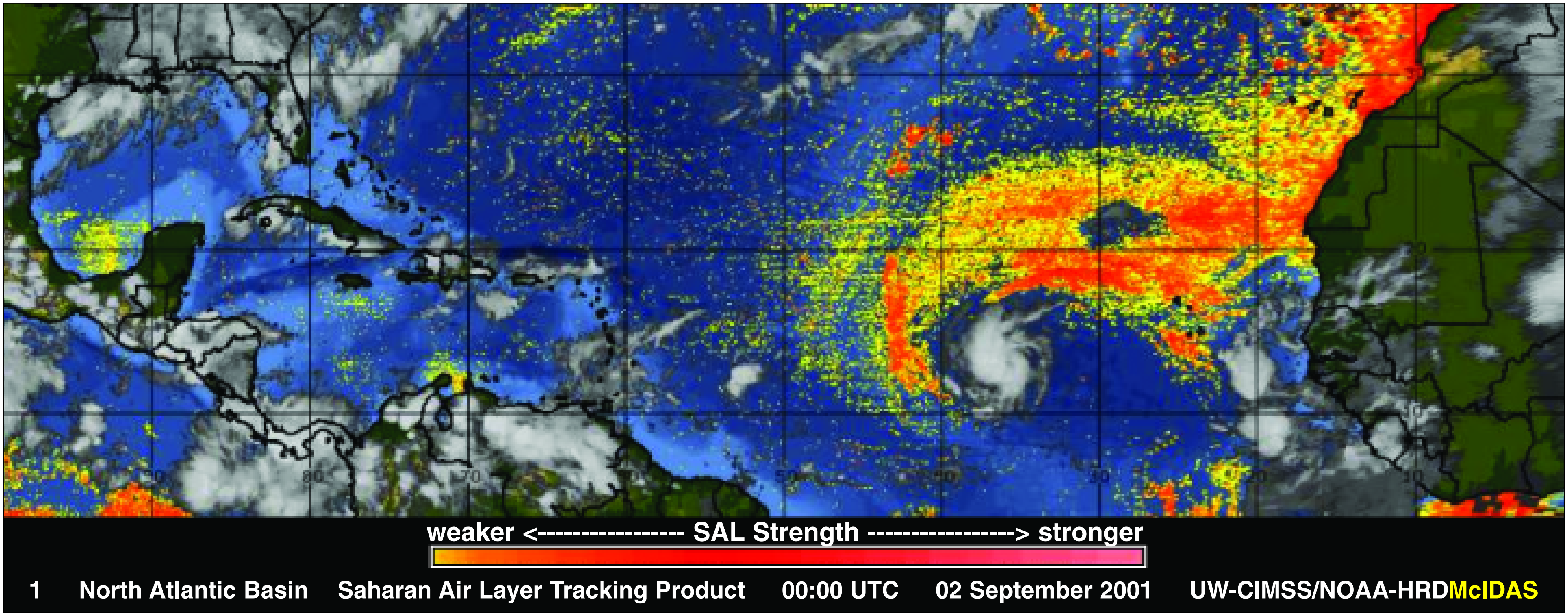
Researchers think the dust itself suppresses cloud formation, playing a role in preventing tropical waves from becoming more intense. Ismail said, "We think that dust aerosols can affect tropical disturbances, sometimes even kill those disturbances. Dust inhibits convection, the process of moisture rising to the higher levels of the atmosphere, and then precipitating as rain. So these Saharan dust layers seem to have a blanketing influence on the development of convection."



This NASA satellite image shows a dust storm, hundreds of thousands of square miles in size, moving from the Saharan Air Layer over Africa into the eastern Atlantic Ocean. The image was captured by the Sea-Viewing Wide Field-of-View Sensor (SeaWiFS) instrument on February 26, 2000. (Courtesy SeaWiFS/Ocean Color Team)

Measuring Saharan dust

The NAMMA team planned to gather information that they lacked on the desert dust and tropical wave interactions. Tropical researcher Robert Ross, also at Florida State University, said, "When one of these waves moves out over the ocean, you have very little data unless you have a special experiment like NAMMA. You see the wave when it passes Dakar as it leaves west Africa, you get a few measurements as it passes over the Cape Verde islands, and then there's a complete data void until you get to the Lesser Antilles. That's one reason we've never been able to understand what's going on with these waves between Africa and the Caribbean."



Tropical Depression Erin interacts with the Saharan Air Layer (SAL) in the North Atlantic on September 2, 2001. This special infrared imagery from the National Oceanic and Atmospheric Administration's Geostationary Operational Environmental Satellites shows dry, dusty air (yellow to red shading) from the SAL wrapping into the storm's circulation. Erin struggled across the Atlantic for the next several days as it became embedded in the SAL, but rapidly intensified into a major hurricane when it separated from the SAL on September 8. (Courtesy Jason Dunion)

Researchers have sought several solutions to this lack of data. They hope someday to use satellite data to continuously track the Saharan Air Layer's dry air and suspended dust over the Atlantic, but current satellites that possess that technology pass over any given location only occasionally, so they may miss the interaction between the dust storms and developing tropical cyclones. A new aerosol-detecting satellite just launched in April 2006, NASA's Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO), promises to supply the needed data. Researchers are still calibrating CALIPSO by comparing the satellite data to ground and aircraft-based measurements.

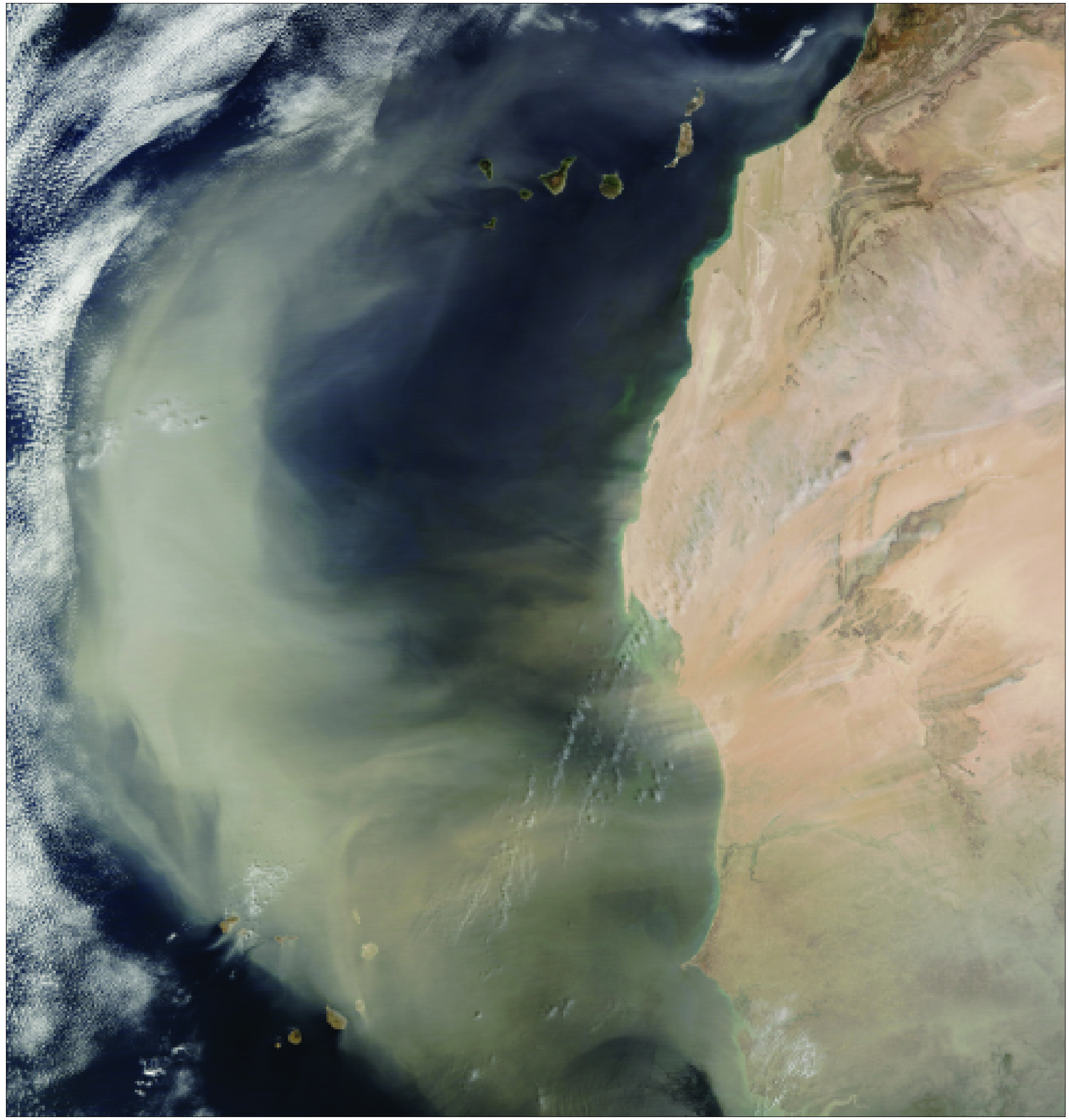
Dunion said, "We were trying to use satellite data to watch how a tropical wave might get embedded in one of these Saharan dust storms. It can really get beat up, it can really get suppressed." Aircraft measurements helped the researchers understand what the new satellite was saying. "We've been flying the NOAA P-3 and G-IV Hurricane Hunter aircraft out of Barbados to look at these interactions, and now that we have these new satellite eyes to track the dust storms, we can use that information to better target our aircraft flight tracks," Dunion said. Hurricane Hunters fly into storms over the western Atlantic to drop instruments, called Global Positioning System (GPS) dropsondes, through the air layers, then relay meteorological measurements and storm positions to forecasters and researchers. To get the complete picture of storm development, they needed similar data from the eastern Atlantic.

To fill the data void over the eastern Atlantic, researchers turned to the Lidar Atmospheric Sensing Experiment (LASE) instrument. LASE, a relatively new instrument developed by NASA, senses aerosols and water vapor using lasers and can be flown on a DC-8 aircraft right into a study area. NASA planned to fly the instrument from Africa into developing dust storms and tropical disturbances during the 2006 hurricane season, while the NOAA team would pick up the storm over the central and western Atlantic. Dunion said, "NASA was flying their DC-8 with LASE out of Cape Verde while we flew the NOAA P-3 and G-IV Hurricane Hunter planes out of Barbados. They would start tracking a dust storm way out east, then a couple of days later we would pick it up as it came into range of Barbados."

LASE also provided an essential piece of data that the Hurricane Hunters could not. Dunion said, "While the GPS dropsonde can measure all sorts of things—pressure, temperature, humidity, wind—it can't measure dust. So that's a piece of the puzzle we can't quite get. The LASE is a great tool to fill that gap. It can measure the super dry air in the Saharan Air Layer, and also look at where dust is situated in the vertical profile. It fills in some of the blanks that we haven't been able to address with our flights over the last couple of years."

The 2006 Atlantic hurricane season

In August 2006, as the hurricane season began, researchers assembled in Cape Verde, Africa, to monitor conditions. As a wave began to develop, the team flew the DC-8 and its LASE instrument into it to capture data. Ismail and the data team retrieved the aerosol and water vapor data from LASE and made it available to researchers on the NAMMA team via the NASA Global Hydrology Research Center, which manages and disseminates the data collected for NAMMA.



The Moderate Resolution Imaging Spectroradiometer (MODIS) instrument, aboard NASA's Terra and Aqua satellites, captured this image of a Saharan Air Layer outbreak moving off of Africa into the North Atlantic on March 2, 2003. (Courtesy NASA MODIS Rapid Response Team)

By scrambling when conditions were right, the NAMMA team successfully captured 2006 storm data with LASE. Ross said, “Seven atmospheric waves moved from Africa out into the Atlantic during the NAMMA experiment. Four ultimately developed into named systems over the Atlantic, three into hurricanes, and one into a tropical storm. The other three did not develop into storms.”

Data from all the cases proved valuable. Dunion said, “We’re learning that when these systems run into the Saharan Air Layer, they consistently struggle, especially if they’re small in size. And positioning and timing is everything.” One wave that NAMMA flew into later became Tropical Storm Debby, in August 2006. “That system came off of Africa and curled up into the Saharan Air Layer and got completely embedded inside of it,” Dunion said. “It was starved for moisture, and there were strong winds that helped to bring that dry air in closer to the storm. We learned that systems that are fairly small, like Debby, are vulnerable if they get embedded inside of the Saharan Air Layer.”

But a larger, differently positioned storm proved less vulnerable. Dunion said, “We followed a system a month later that became category three Hurricane Helene, a much bigger system. It moved along the southern edge of the Saharan Air Layer, so it was tapping into moist tropical air down to the south, but north of it there was dry air lapping into it. That storm seemed to be fighting the effects of the dry air, mid-level easterly jet, and dust.”

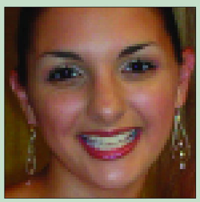
The NAMMA data also suggested why the 2006 Atlantic hurricane season was below-average for the Atlantic, with only two storms making landfall in the United States, both as weaker tropical storms. Ross said, “We think that the 2006 hurricane season in the Atlantic might have been less active because the dry Saharan Air Layer seemed to be unusually strong coming across the Atlantic. Because it persisted in such a strong state as it crossed the ocean, the Saharan dry air and dust may have defeated more disturbance waves from developing into stronger storms.”

Intense studies of intensity

Much is at stake if researchers can solve the puzzle of Atlantic storm-to-hurricane intensification. Dunion said, “Over the last several decades, we’ve made steady improvement in hurricane track forecasts, but improvements in intensity forecasts have been much slower, almost flat. We need to take every little step we can to try to get the intensity trend moving more like the track trend.” For coastal residents and emergency managers, intensity forecasts can be the difference between deciding to make minor storm preparations or to evacuate. More accurate storm intensity forecasts save money, time, and lives for coastal communities.

The NAMMA team continues to sift through the LASE data and the vast array of other observations taken during the campaign,

About the scientists



Cerese Albers is a graduate student at Florida State University. She participated as a student forecaster in both the NASA Tropical Cloud Systems and Processes Mission in 2005, and the NASA African Monsoon Multidisciplinary Analyses Mission in 2006. Her research interests include utilizing observations made during field experiments to validate mesoscale model intensity prediction.

Jason Dunion is a meteorologist at the National Oceanic and Atmospheric Administration’s Hurricane Research Division in Miami, Florida. He specializes in satellite remote sensing of hurricanes and has led the development of several new satellite products for monitoring tropical cyclones and Saharan dust storms.

Syed Ismail is a senior research scientist in the Science Directorate at NASA Langley Research Center. His work focuses on research and development leading to future space-based laser remote sensors and airborne lidars for the characterization of atmospheric composition and processes. Since 1981, he has led the development, testing, and operation of lidar systems.

Robert Ross is a senior research scientist at Florida State University. His research has included evaluation of the skill of numerical prediction models; studies in climate forecasting for several regions of the world; and research into the structure, dynamics, and forecasting of African easterly waves.

hoping for more insights on Atlantic hurricane development. The researchers see the campaign as a unique event that was a long time coming. Dunion said, "Ten years ago we didn't have a way to track these dust layers. We've accidentally flown through and over the tops of the Saharan Air Layer in the past without even knowing it. NAMMA used cutting-edge instruments and technology, and those field experiments help us make these little leaps forward. The idea is to keep that ball rolling."

To access this article online, please visit http://nasadaacs.eos.nasa.gov/articles/2007/2007_hurricanes.html.

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NASA Global Hydrology Resource Center
http://ghrc.msfc.nasa.gov/

Lidar Atmospheric Sensing Experiment (LASE)
http://cloud1.arc.nasa.gov/solve/payload/dc8/lase.html

NASA African Monsoon Multidisciplinary Analyses (NAMMA)
http://namma.nsstc.nasa.gov/

Saharan Air Layer Background
http://cimss.ssec.wisc.edu/tropic/real-time/wavetrak/sal-background.html

Susan Kool monitors data from the Lidar Atmospheric Sensing Experiment (LASE) instrument on board a NASA DC-8 aircraft flying through a Saharan dust storm over the Atlantic. Researchers hope to use these data to track interactions between the dust and tropical storms and to better understand Atlantic hurricane development. (Courtesy NAMMA team)

About the remote sensing data used

Sensor	Lidar Atmospheric Sensing Experiment (LASE)
Data sets used	NASA African Monsoon Multidisciplinary Analyses (NAMMA) Lidar Atmospheric Sensing Experiment (LASE): DC-8 Relative Aerosol Scattering DC-8 Water Vapor Mixing Ratio (Nadir)
Resolution	DC-8 Relative Aerosol Scattering Vertical: 30 meters Horizontal: Data reporting interval is 6 seconds (1.4 kilometers) with horizontal averaging of 3 seconds (0.7 kilometers) DC-8 Water Vapor Mixing Ratio (Nadir) Vertical: 330 meters with a reporting interval of 30 meters Horizontal: 2 minutes (~28 kilometers) with a sub-sampling (reporting) interval of 6 seconds (1.4 kilometers)
Parameter	Aerosol scattering Water vapor mixing ratio
Data center	NASA Global Hydrology Resource Center

Pollution trials for the Beijing Olympics

"I thought, 'Aha! Wouldn't it be neat if we could take advantage of this natural experiment to improve our ability to detect pollution and see if the restrictions had an impact?'"

Michael McElroy
Harvard School of Engineering and Applied Science

by Stephanie Renfrow

In the summer of 2008, humanity's fastest, strongest, and most skilled athletes will compete in the Olympic Games in Beijing, China. How will a city that many people associate with traffic-stopping road congestion and health-endangering levels of pollution handle the additional influx of Olympians and their many followers?

In November of 2006, Chinese officials used a smaller-scale gathering, the Summit of the Forum on China-Africa Cooperation, as a sort of dress rehearsal for the Olympics. During six days surrounding the summit, officials increased bus capacity, limited access to certain roads, and banned or restricted the use of government, commercial, and private vehicles. The idea was to make it easier for summit participants to get around Beijing, while also providing a logistical trial run that would benefit athletes and spectators in 2008.

Harvard environmental studies professor Michael McElroy, a participant in a lesser-known conference, the China International Counsel for Cooperation on Environment

Beijing's traffic volume leads to high levels of pollution, as well as difficulty navigating clogged streets. (Courtesy Tym Altman) and Development, also happened to be in Beijing in November 2006. McElroy leads Harvard's China Project, an interdisciplinary program that studies the impact of air pollution on the environment, economy, public health, and law. One morning during his visit, he picked up the *China Daily* newspaper and noticed an article about the traffic restrictions. He said, "I read the article and thought, 'Aha! Wouldn't it be neat if we could take advantage of this natural experiment to improve our ability to detect pollution and see if the restrictions had an impact?'"

Policy inspires research

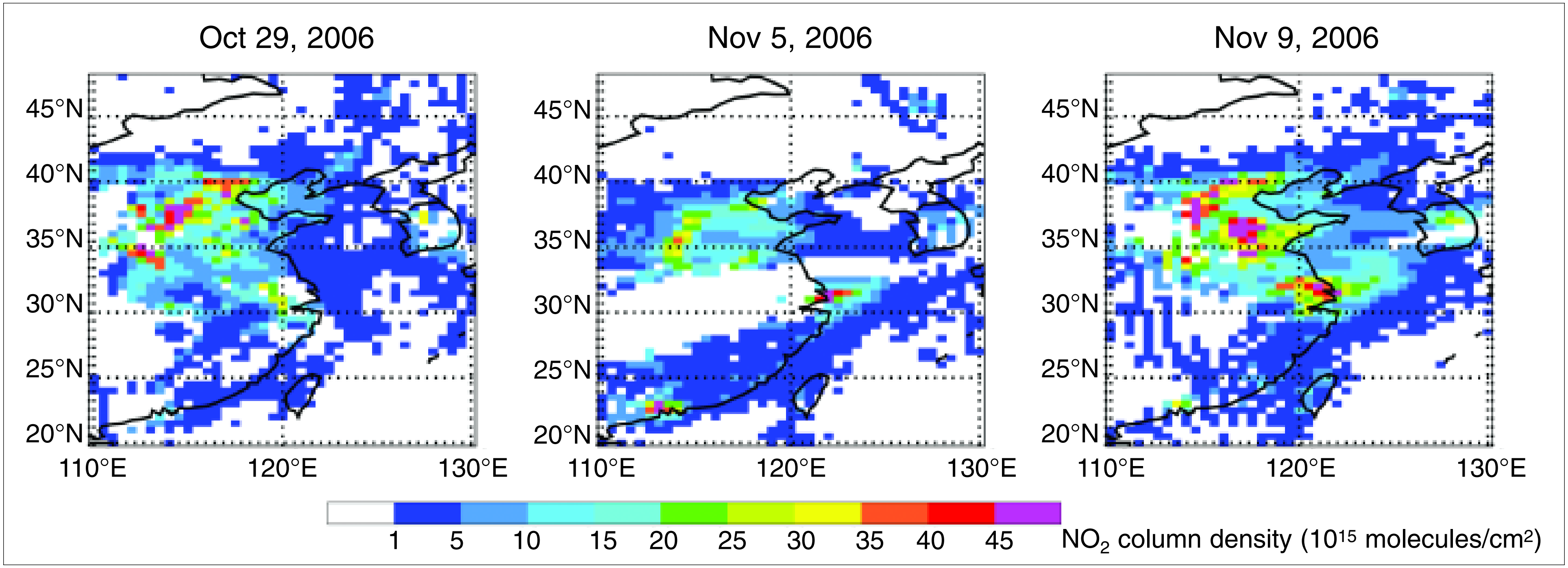
McElroy called upon postdoctoral student Yuxuan Wang, an atmospheric scientist and long-time participant in the China Project, to lead the research study. Wang knew that she would need access to accurate, daily data that offered high-resolution coverage. Based on her experience in using satellite data to understand atmospheric composition, she and her colleagues immediately turned to atmospheric data from the Ozone Monitoring Instrument (OMI). OMI flies on NASA's Aura satellite and is archived at the NASA Goddard Earth Sciences Data and Information Services Center (GES DISC).

Wang said, "OMI is perfect for this type of work. Unlike previous instruments, it sees all parts of the globe daily, which we really needed for a project covering such a short event." Another advantage of OMI is its small footprint, around twenty-four by thirteen kilometers (fifteen by eighteen miles). "The urban center of Beijing, where the traffic restrictions were in place, is about fifty by fifty kilometers [thirty-one miles by thirty-one miles]," Wang said, "so OMI's footprint was perfect."

This photograph of the Hall of Supreme Harmony in Beijing's Forbidden City was taken on a relatively clear day, but air pollution often obscures much of Beijing's famous architecture. (Courtesy Photos.com)

Wang began by downloading near-real-time nitric oxide OMI data, which the Royal Netherlands Meteorological Institute in the Netherlands retrieves from the satellite data. Wang chose nitric oxide to measure pollution levels both because of the availability and quality of the data and because it is a chemical precursor to smog and ozone. After downloading the OMI data, she plotted a time series of nitric oxide measurements taken before, during, and after the summit.

However, before Wang could interpret what she saw, she had to take one more step. "When pollution is emitted from the surface, it moves around in the atmosphere," she said. "For example, you might look at the data and think that emissions were reduced—but maybe conditions that day were windy, blowing the pollution away." So, to get an accurate measure of levels of nitric oxide, Wang first needed to subtract differences caused by natural variation and weather, such as clouds. To do this, she used a chemical transport model called GEOS-CHEM that simulated changes in meteorology, helping her determine their influence on the OMI nitric oxide data.



This series of graphics shows the success of traffic restrictions over Beijing; pinks and reds indicate high levels of nitric oxide before (October 29), during (November 5), and after (November 9) the restrictions were in place. (Courtesy Yuxuan Wang)

In addition to using the GEOS-CHEM model, Wang was also glad to see clear weather in Beijing surrounding the summit. "The days we studied were clear, not very cloudy," she said, "so we had an easier time getting a nice series of day-to-day changes. We got lucky!"

Successful restrictions

With the effects of weather and natural variation removed, Wang could begin to interpret the data. Her findings were clear. "We saw a dramatic change in atmospheric concentrations of nitric oxide during the time of the traffic restrictions," she said. "The traffic restrictions were very effective in cutting down nitric oxide in Beijing's urban area—a 40 percent reduction in emissions."

However, Wang acknowledges that verifying the data has been difficult. "We didn't have access to in situ observations or to official estimates of how much the flow of traffic was actually reduced," she said. McElroy had originally hoped to access data on gasoline sales before, during, and after the summit. These figures would have provided Wang with a way to corroborate the atmospheric data from OMI. McElroy said, "Unfortunately, we couldn't get that data. There was some nervousness about making adverse comments about the environment in the lead-up to the Olympics."

However, although the Chinese were not willing to make gasoline consumption data public, McElroy did get an unofficial confirmation that their measurements were accurate. "A Chinese official did let me know that our estimate was not far from what they had calculated," he said. Wang added, "Plus, Beijing newspapers did report a 30 percent reduction in traffic, which is also similar to what we found."

The future: Olympics and the planet

Despite the lack of in situ data to confirm their findings surrounding the summit traffic restrictions, Wang and McElroy hope to push the research forward during next summer's Olympic Games. Wang said, "We are offering to collaborate with Chinese scientists around the Olympics, and we are hopeful that they will share their data with us." A combination of in situ measurements of pollution, a realistic estimate of traffic flow reductions, and the OMI nitric oxide data could provide a more complete picture concerning how traffic restrictions can address pollution concerns. But why is that complete picture important? McElroy said, "With China's economic growth has come an explosion in coal-burning factories and cars on the road—and a steady deterioration of the atmospheric environment. A lot of people are getting sick, and that costs money in medical care and in missed work."

The idea of pollution hurting people's health is becoming more commonly accepted in China. However, the idea that pollution generated by a healthy economy can actually begin to damage the economy itself is an important concept for McElroy. "If the cost of air pollution is 8 percent of China's Gross Domestic Product, or GDP, and GDP is growing at 10 percent . . . you can do the calculation. The economic growth actually isn't very much, in the end."

Beyond being concerned about Olympic athletes breathing in hazardous levels of pollution, why should people outside of China care about pollution problems on the other side of the world? "Pollution doesn't stay where it is generated; it can drift halfway around the world," McElroy said. "So the Chinese care what we do, and we should care what they do. The globalization of economies is becoming the globalization of environments."

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For more information

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

Harvard Researcher Listings: Michael McElroy
http://harvardscience.harvard.edu/node/2005/

Yuxuan Wang Web site
http://www.people.fas.harvard.edu/~wang3/index.html

About the remote sensing data used

Satellite	Aura
Sensor	Ozone Monitoring Instrument (OMI)
Data set used	Tropospheric nitrous oxide
Resolution	24 by 13 square meters
Parameter	Nitric oxide
Data center	NASA Goddard Earth Sciences Data and Information Services Center (GES DISC)

About the scientists

Michael McElroy is a professor of Environmental Studies at the Harvard School of Engineering and Applied Science in Boston, Massachusetts. He studies changes in atmospheric composition, focusing on the effects of human activity. McElroy leads the interdisciplinary Harvard China Project, which seeks to identify environmentally sensitive paths for China's future development. His funding for the Beijing pollution study came from the National Science Foundation.

Yuxuan Wang is an atmospheric scientist at the Harvard School of Engineering and Applied Science; she works with Michael McElroy on the Harvard China Project. She specializes in using satellite data to study Asian atmospheric pollution. Funding for the Beijing pollution study came from the National Science Foundation.

Pinpointing an invasive plant's next move

"By controlling spread, we can save a lot of time and money."

Jeff Morisette
NASA GSFC

by Jane Beitler

A small tree with needle-like leaves, tiny pink flowers in spring, and a pretty name, tamarisk occupies a million acres in the southwestern United States. Native to Europe and Asia, these small, spreading trees were brought to the United States in the 1800s and prized for their delicate beauty, shade-filtering qualities, and ability to stabilize stream banks. There is no such love anymore for tamarisk in the United States. Now, teams of "tammywackers" spend sweaty, exhausting days trying to eradicate stands of tamarisk, using special jacks to pull these trees up by the roots, or cutting them and painting solutions on the stumps to prevent regrowth. Fighting hundreds of miles of stream bank invasion in Texas, authorities use helicopters to drop herbicides on tamarisk stands along the Pecos River. Despite these measures, the trees continue to spread throughout the southwestern United States, and beyond.

What went wrong? How did this attractive garden specimen become an invasive species, what problems does it cause, and are there better ways to control it? The United States Department of the Interior estimates that invasive plants such as tamarisk cause $20 billion each year in economic damage, and controlling their spread is not cheap either. One group of researchers is developing a new way to outwit invasives like tamarisk. Jeff Morisette, a remote sensing scientist at NASA, said, "We can use remote sensing and models to predict the spread of invasive species. By controlling spread, we can save a lot of time and money."

Morisette is part of an interagency team that developed a tamarisk habitat suitability map for the continental United States. Combining several environmental data layers with the analytical powers of a computer model has enabled them to produce a map that indicates where the next stand of tamarisk might crop up.

Knowing the enemy

Tamarisk (*Tamarix* species) is commonly called saltcedar, so named because it concentrates salts in its leaves. Its leaf litter makes the soil saltier and thus less favorable for other plants. Tenacious and tolerant of poor soils, it spreads aggressively and crowds out native trees, such as cottonwood. "Tamarisk has a deep tap root," Morisette said. "It can outcompete other plants in drought conditions, which is why it's a problem in the Southwest."

Pushing out native species like cottonwood, tamarisk alters bird and insect habitat and so disrupts a long-established local food web. Cottonwood trees have palatable seeds and thick limbs to support large birds like raptors and woodpeckers. But high-density stands of spindly tamarisk offer little structural or microclimatic diversity, and do not harbor the seeds and insects that many birds eat. So the insects and birds that used the cottonwood and other native plants for habitat also decline.

Growing in dense stands, tamarisk changes water flow patterns. Favoring oxbow-shaped bends in watercourses, its stems trap sediments and cause mounding, shallower channels, and increased flooding. Researchers have documented tamarisk spread and river changes along the Brazos River in central Texas over time. From 1941 to 1979, the Brazos became 8 feet shallower and nearly 300 feet narrower. Ranchers and farmers have still more woes. "Tamarisk spreads like grass," Morisette said. "Thick stands make it hard for livestock to get down to the river for water."

As stands increase, local groundwater supplies dwindle. Tamarisk is known for its thirst, drawing up large amounts of water and transpiring it into the air through its leaves. This represents a serious impact on human communities in the arid and drought-prone Southwest, where water is a scarce resource for farm irrigation, hydroelectric power, wildlife and livestock, drinking water, and recreation. In southern California, the Metropolitan Water District alone spends millions of dollars each year finding additional water sources to replace the 260 to 570 million cubic meters (340 to 746 million cubic yards) of water lost annually through tamarisk on the Colorado River banks.

Getting ahead of the spread

Tamarisk, once established, is not easy to get rid of. While many non-native species are slow moving and will stay where humans want them, tamarisk escaped cultivation in the 1880s, spreading aggressively through seeds carried on the wind and by wildlife. It also spreads underground, and can reproduce from buried stems or even pieces of stems. Then, land managers must burn, cut, poison, dig, and pull. These methods are expensive and laborious, with negative impacts on the land and native species.

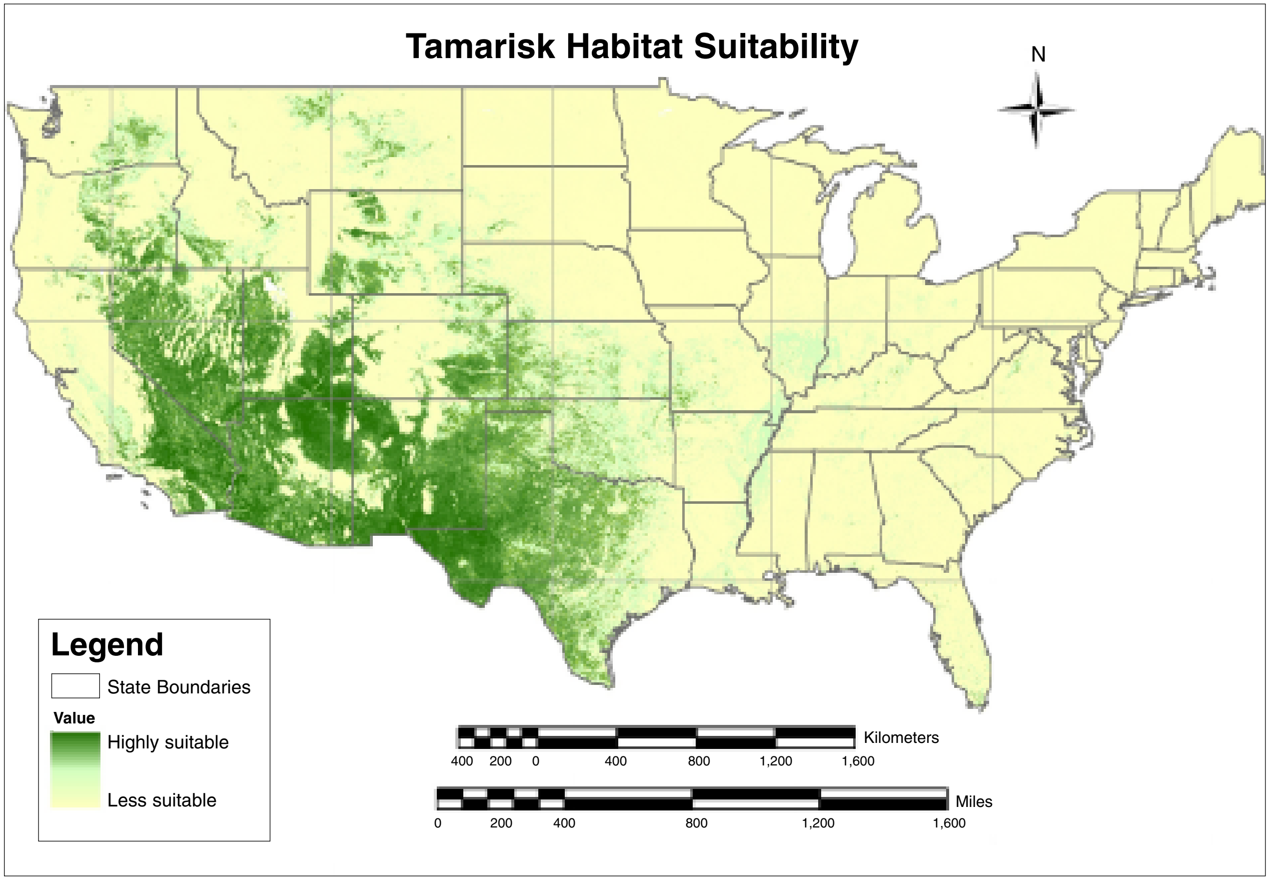
Invasive tamarisk trees like this one continue to gain footholds in the West, changing habitats and pushing out native species. Without intervention, they could be cropping up soon in surprising places, such as the Midwest. (Courtesy Jeffrey T. Morisette)

Kara Paintner, a fire ecologist with the United States National Park Service whose expertise is the recovery of native species after wildfires, explained some of the complexities of managing invasive species. Paintner said, "It's not as simple as just eradicating a species. For example, tamarisk makes the soil more salty, so even after you remove it, the native species have trouble getting re-established. We've learned that after you eradicate one invasive species, a worse one may move in. Sometimes it is best to kill everything and replant. So we've started to pay more attention to what happens after you eradicate an invasive species."

Instead of trying to eliminate large, established stands of an invader, resource managers find it more effective to focus on containment. Paintner said, "The Park Service is focusing more on the edge of a species range. The problem isn't knowing where it is. It's knowing where it isn't." Identifying potential habitat for tamarisk, then watching those areas to prevent tamarisk from becoming established, has become an effective strategy. Yet watching over immense and remote tracts, resource managers cannot continually inspect every riparian area for tamarisk. The maps that Morisette and team are creating can help identify places that tamarisk might grow on a very large scale. While remote sensing has been used to predict invasive plant species before, the novel aspect of this mapping project is its national scale. Tom Stohlgren is a researcher at the United States Geological Survey (USGS) Fort Collins Science Center who works with the National Institute of Invasive Species Science at Fort Collins. He said of the resulting map, "It was like having a weather station every square kilometer, indicating 'Where is the good life for non-native species?'"

Remote sensing of habitat

"A habitat suitability map works for a species like tamarisk that's picky about where it lives," Paintner said. Tamarisk trees need wet soils to survive their first year, like those along a riverbank or where the water table is high, and they need full sun. Tamarisk likes alkaline, fine-textured soils from sea level up to an elevation of about 2,100 meters (6,890 feet). So Morisette and team combined this information with other data to more finely predict where tamarisk would like to grow. The USGS provided geographic layers on soil types and other characteristics, which the researchers then coupled with remote sensing data from the NASA Earth Observing System and climate data. Stohlgren, who works on a project to help collect tamarisk sightings on the ground throughout the United States, supplied additional ground data on tamarisk. The ground observation data identify areas where tamarisk is known to be present, as well as areas where no tamarisk is currently growing.



This map of the continental United States, developed using Terra and Aqua satellite vegetation data from the Moderate Resolution Imaging Spectroradiometer (MODIS) sensor combined with ground observations, indicates areas that are suitable habitat for tamarisk. Highly suitable areas are dark green, with lighter shades of green indicating lesser degrees of suitability. Yellow areas are least suitable. Although tamarisk, usually thought of as a problem specific to the Southwest, has not yet been found in the Midwest, the map indicates suitable habitat as far east as Ohio. (Courtesy Jeffrey T. Morisette)

The remote sensing data, from the Moderate Resolution Imaging Spectroradiometer (MODIS) sensor on NASA's Terra and Aqua satellites and distributed from the NASA Land Processes DAAC, provided two key indicators. MODIS can identify land-cover type, or the kind of vegetation on the ground, by measuring its reflectivity. MODIS measures both the amount of energy and its wavelength across a sensitive spectrum. Different vegetation types—needles, leaves, blades of grass—have different signatures in the data. Tamarisk grows thickly enough to cover soil, and therefore changes the energy reflected from the ground. MODIS can also detect energy changes resulting from a plant's unique lifecycle: dormancy, leaf out, and bloom. "MODIS phenology, or seasonal variation, is helpful for understanding a particular habitat," Morisette said. "We are using the unique temporal signature of tamarisk habitat to understand where it grows and where it might spread." A computer model assimilated the many data about tamarisk and its habitat, sorted out all the factors, and marked areas as "highly suitable" and "less suitable" for tamarisk. And that can tell resource managers where tamarisk could be gaining a foothold.

Morisette thinks that the interagency and national approach to habitat mapping can contribute to thwarting tamarisk's spread. "Because of the spatial extent of the problem, NASA has a lot to contribute—NASA monitors the globe," he said. "Our view extends beyond park boundaries. We can provide insights to agricultural concerns and other agencies facing this problem." Paintner agreed, adding, "A lot depends on the park and the species. The Bureau of Land

Management and Forest Service have big land blocks and experienced staff. The Park Service has a total of ten million acres to watch, made up of many different parks, with staff of varying knowledge. Someone at a small park with five to ten acres and without much knowledge can miss the new thing to watch for." This method may also help alert land managers who are not even thinking about tamarisk; surprisingly, the map showed potential habitat in the Midwest. Morisette said, "We found potential for tamarisk invasion in Ohio." Tamarisk is usually thought of as a scourge of Western states, so the map may help other regions with early detection.

Morisette said, "I'm impressed with the ability of the Parks staff to synthesize so much information about local factors concerning invasive species, anything from seeds in horse feed that wranglers bring in, to air quality concerns that prevent the use of fire to eliminate species. These maps will just add to what is already a dynamic and multifaceted approach to the problem. We are working to figure out how land managers can use this information and integrate it with their decision-making process." Stohlgren has long called for identifying potential habitat as a means of mitigating spread. "Tamarisk is just the poster child of western invaders," he said. "We want to move on to many other species."

To access this article online, please visit http://nasadaacs.eos.nasa.gov/articles/2007/2007_tamarisk.html.

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For more information

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

The National Invasive Species Forecasting System http://www.fort.usgs.gov/resources/spotlight/EcoForecasting/EF_projects.asp

About the remote sensing data used

Satellite	Terra and Aqua
Sensor	Moderate Resolution Imaging Spectroradiometer (MODIS)
Data sets used	Normalized Difference Vegetation Index (NDVI) Enhanced Vegetation Index (EVI)
Resolution	250 meters
Parameter	Land-cover type Greenness (onset, peak)
Data center	NASA Land Processes DAAC

About the scientists

Jeffrey T. Morisette is a remote sensing scientist at NASA Goddard Space Flight Center. His current research focuses on the application of multi-resolution and time series satellite imagery to ecological and climate studies. He is the winner of the 2006 NOAA David John Award for Outstanding Innovative Use of Earth Observation Satellite Data.

Kara Paintner is a fire ecologist and liaison between the Natural Resource Program Center and Fire Management Program Centers of the National Park Service in Fort Collins, Colorado. She has also worked for Oregon State University doing juniper, sagebrush, fire, and climate change research.

Tom Stohlgren is a supervisory research ecologist and Branch Chief with the Fort Collins Science Center of the United States Geological Survey (USGS). He is also the lead scientist for the new National Institute of Invasive Species Science, a USGS-led interagency and non-government consortium improving invasive species early detection, rapid assessment, and forecasting.

Connecting rainfall and landslides

"Developing countries don't often have ground information for rainfall available, so satellite data is the best source."

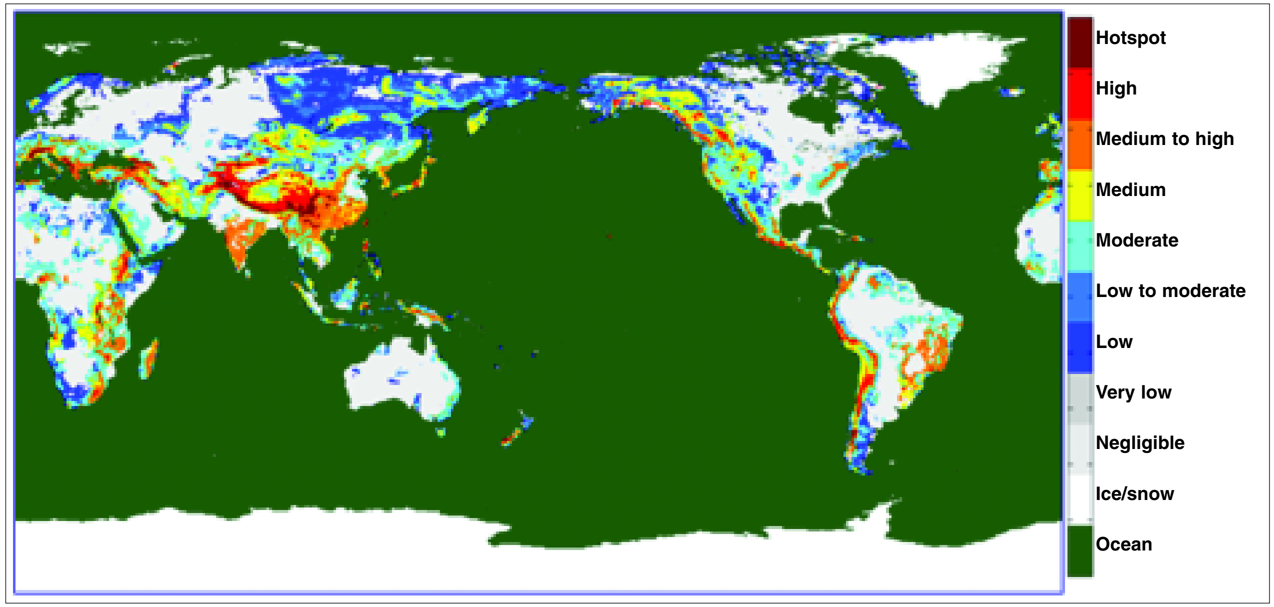
Yang Hong
Goddard Earth Sciences
and Technology Center

By Laura Naranjo

On February 17, 2006, the Philippine village of Guinsaugon disappeared. A massive landslide swallowed more than 350 houses and an elementary school, burying more than 1,100 people. Residents of the village, situated at the foot of a mountain on Leyte Island, had no warning and no time to evacuate. While there was no direct trigger for the Guinsaugon landslide, experts and officials explored several causes, including several days of unusually heavy rainfall that had saturated the mountainside prior to the slide.

While rainfall-induced landslides can happen within minutes, the wet conditions that precede them can take several hours or days to develop. But many countries in high-risk areas lack the resources to maintain the extensive weather

Debris from the February 17, 2006, landslide that buried Guinsaugon shows the effect of tectonic weakening. The landslide occurred along a fault line, where tectonic movement grinds and crushes the rock. This ground-up rock and soil on the mountainside had become more prone to landslides, especially after several days of rain. (Courtesy Stephen Evans) networks required to successfully observe these conditions. Robert Adler, a senior scientist in the NASA Laboratory for Atmospheres at Goddard Space Flight Center, and Yang Hong, a research scientist at Goddard Earth Sciences and Technology Center, approached the problem from space. A reliable satellite-based system would help minimize the challenge of maintaining local systems, especially in regions where heavy rains and flooding often wash away ground-based instruments. Adler and Hong are merging data from an array of satellites to determine whether remote sensing instruments can indicate where rainfall-induced landslides might occur. Adler said, "If we can complete this research and make the results available on the Web, then almost any government or organization in the world can access this information."



This global landslide susceptibility map uses red and orange to indicate hot spots in potential landslide regions. Hotspots often occur in mountainous areas, such as the Himalayas and Andes, and in areas susceptible to heavy monsoon rains, such as southern Asia and parts of South America. (Courtesy Robert Adler and Yang Hong)

Mapping landslide susceptibility

Rainfall is the key factor in Adler and Hong's study, but first the scientists needed to determine which areas were most prone to landslides. The first step was to piece together a global landslide susceptibility map, which would help reveal terrain and ground properties. Hong said, "Rainfall can be a trigger for landslides, but ground conditions are also very important." The researchers needed to account for a range of factors, including terrain, soil type, and land-cover characteristics. However, there was no single source for the data they required. "In order to look at landslide susceptibility, we needed multiple data sources," Hong said.

To compile the map, Adler and Hong used digital elevation models to establish terrain and slope, as well as flow path and direction for rivers and water runoff. Satellite data helped the researchers determine land-cover types, including forests, grasslands, wetlands, deserts, and urban areas. Adler and Hong relied on a soil properties map to distinguish global soil composition and depth.

The map revealed no surprises—the researchers already had a general idea which regions of the world were susceptible to landslides. But the map did provide a solid basis against which to compare rainfall data, and illuminated areas that exhibited the key ingredients for a landslide. "The most important factors are the slope and soil type. Steep slopes and coarse soil types are more susceptible to landslides," Hong said. "And, in terms of land cover, bare soil contributes more to landslides."

Landslides occur everywhere in the world, but the danger of rainfall-induced slides tends to be much greater in tropical mountainous regions like those in the Philippines, Central and South America, and southeastern Asia. Steep terrain, combined with the heavy rains brought by monsoon seasons, hurricanes, and typhoons puts dense populations at risk.

Remotely sensing rainfall

To analyze global rainfall, Adler and Hong required multiple data sources from a variety of satellites. Their primary source of rain data, however, was the NASA Tropical Rainfall Measuring Mission (TRMM), obtained from the NASA Goddard Earth Sciences Data and Information Services Center (GES DISC).

Adler said, "There are two main things that TRMM provides for this multi-satellite analysis. One, it's the calibrator for the information from the other satellites. Two, it's always in the tropics, and gives us very good coverage in a critical area." Launched in 1997, the TRMM satellite was specifically designed to observe tropical rainfall and storm characteristics. TRMM orbits the Earth from west to east along the equator, weaving between 35 degrees north and 35 degrees south. Several of the other satellites from which Adler and Hong collect data are in polar orbits that travel north to south, passing near or over the north and south poles during each orbit and crossing the equator during each pass. "Because the TRMM orbit crosses over the paths of each polar-orbiting satellite, we're able to collect subsets of data from both satellites at the same time," Adler said. "We use TRMM data, which we think is making the best estimate, to calibrate, or adjust the rain estimates from the other satellites." Calibrating the satellites helped correct errors and eliminate inconsistencies, allowing scientists to obtain the most precise rainfall measurements.

To verify the correlation they observed, Adler and Hong identified seventy-four rainfall-induced landslides that occurred between the TRMM launch and 2006, including the Guinsaugon slide. They plugged archived rainfall data into an equation that incorporated rainfall intensity and duration to determine a "threshold" for each of the landslides. Adler and Hong's satellite-deduced results closely matched previous rainfall-gauge-based threshold estimates, confirming that extremely intense rainfall overwhelmed the thresholds for each of the sites and triggered the slides, particularly when the heaviest rain fell in a short duration of less than twelve hours. Their findings demonstrated that a satellite-based approach could successfully indicate potential landslide conditions.

Landslides from ground and space

After the February 17, 2006, landslide that destroyed Guinsaugon, officials scrambled to pinpoint a cause. Landslides can be caused by anything that destabilizes the soil or rock on a slope, such as an earthquake, heavy rainfall, deforestation, or even the vibrations from machinery. But the dense forests on the mountainside above Guinsaugon showed no signs of logging, and recent earthquakes had been too minor to cause such a large landslide. In the end, experts found no definitive trigger, but nearly everyone agreed on a significant contributing factor: heavy rain had drenched the area for days.

Characterizing a landslide

Stephen Evans, a professor of Earth sciences at the University of Waterloo in Canada, has studied landslides around the world, visiting sites and analyzing post-landslide data. In March 2006, he and his team visited Guinsaugon, on Leyte Island in the Philippines. "We gained insight into the mechanism of the failure that we couldn't get without actually being on the ground itself," Evans said. Triggers related to tectonic weakening of the Earth's surface, for instance, are difficult to confirm without fieldwork. The landslide occurred on an active fault line that is creeping at a rate of 2.5 centimeters (1 inch) per year. That may seem slow, but over time the movement grinds and breaks up the rock, affecting the stability of surrounding slopes and making them more prone to landslides. Indeed, Evans' field research and photos confirmed this weakening, showing broken, fragmented, and finely ground landslide debris. "Tectonic weakening was a preconditioning factor making that slope susceptible to catastrophic failure," Evans said.

Evans also used his ground observations to validate what he had observed in remotely sensed data. Before departing for Leyte Island,

This aerial view shows the landslide that destroyed the town of Guinsaugon on February 17, 2006. (Courtesy U.S. Navy by Photographer's Mate 1st Class Michael D. Kennedy)

he and his team obtained satellite data that provided topographic information and optical views of pre- and post-landslide Guinsaugon. In the field, Evans and his team compared the

Experimental development

Adler and Hong's research contributed to the development of the TRMM Real-Time Multi-Satellite Precipitation Analysis (TMPA-RT) product. The TMPA-RT data, currently available online from 2002 through the present, are updated in real time, allowing users to determine if an area is currently receiving particularly intense rainfall or has reached a critical level of accumulation. However, Adler and Hong stress that the product is still experimental. Adler said, "This is a very new approach. We certainly need to do a substantial amount of evaluation to understand the product's potential, and also its limitations."

Even in its experimental status, researchers and agencies are using the TMPA-RT system to assess landslide and flood hazards. For instance, the Mekong River Commission, a partner in the Asia Flood Network, began downloading TMPA-RT data in 2003 to help calculate rainfall totals for the Mekong River basins in Cambodia, Laos, Thailand, and Vietnam. Making the satellite data available helps supplement conventional ground-based rain-gauge networks that do not provide enough coverage. Hong said, "Developing countries don't often have ground information for rainfall available, so satellite data is the only source."

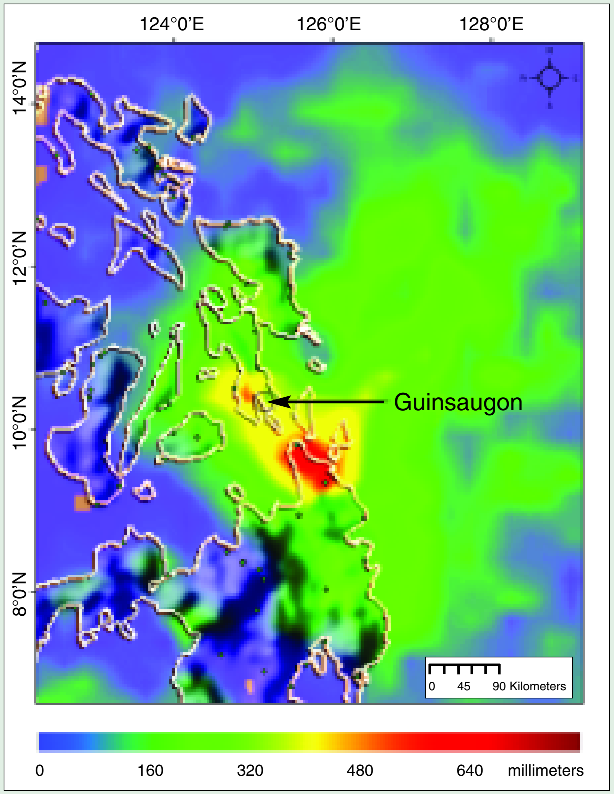
In addition, a research group at Tennessee Technological University is assessing TMPA-RT data to help gauge precipitation and flooding in more than 250 river basins worldwide. Many large river systems cross international borders, meaning that downstream countries often need to negotiate with their upstream neighbors to

data to their measurements of the vertical landslide descent, the horizontal run-out distance, and the landslide volume. "We found the remotely-sensed data to be amazingly accurate," Evans said. "Angles that we measured in the field, from the tip of the debris to the top of the slide, were exactly the same as what we saw in the topographic data."

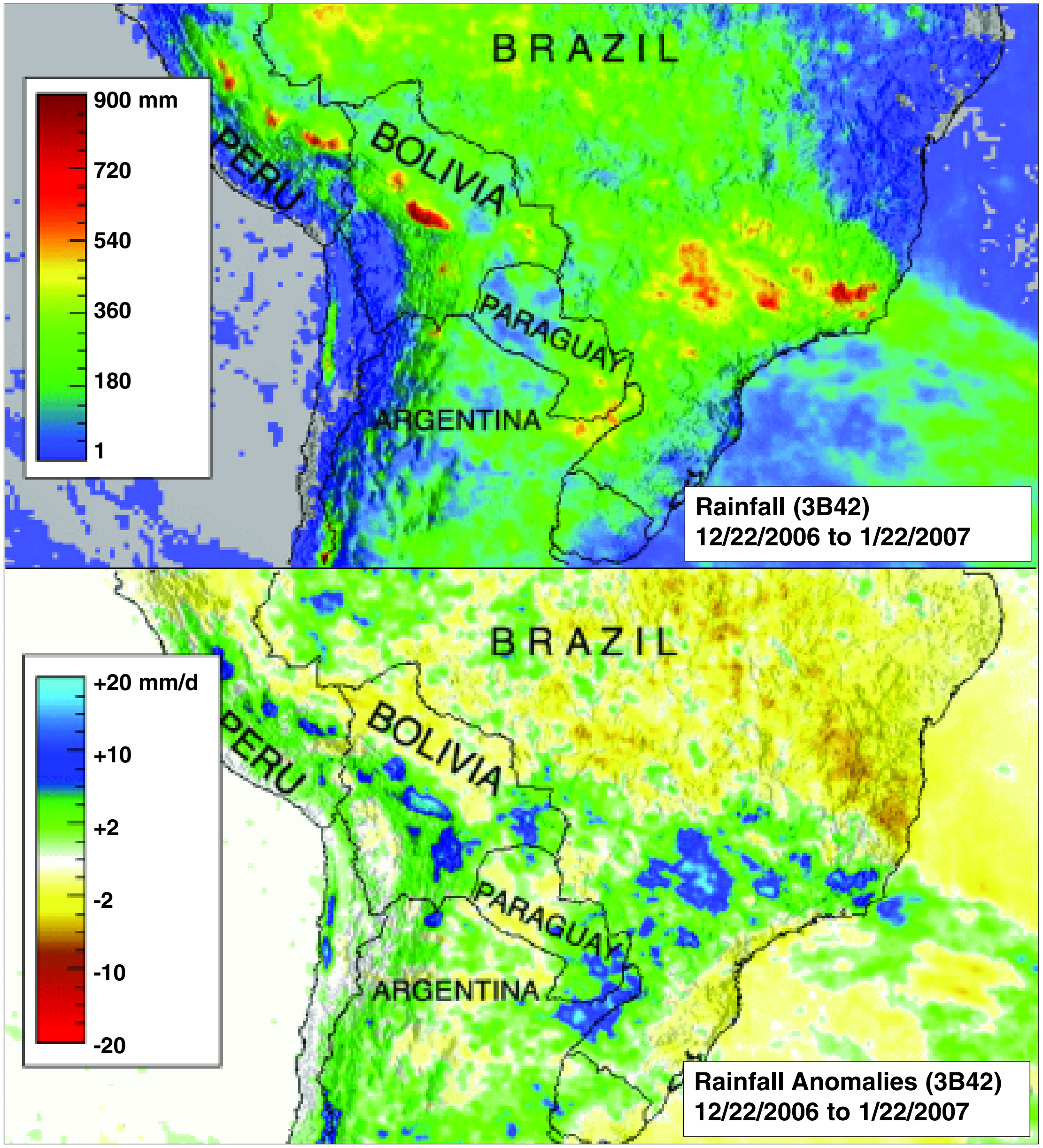
Rainfall as a trigger

To investigate rainfall as a potential trigger, Evans also referred to satellite imagery from TRMM. The TRMM image revealed that, in Guinsaugon, more than sixty-eight centimeters (twenty-seven inches) of rain had fallen between February 4, 2006, and February 17, 2006. "This was excessive rainfall beyond the monthly averages—more than twice as much," Evans said. However, the heaviest rainfall occurred between February 8, 2006, and February 12, 2006, ending four days before the landslide. "The lag time was important, indicating that the rainfall in this situation was a preconditioning factor that led to failure," Evans said. He said that landslides occur all the time and that direct triggers do not always exist; however, the excessive rainfall on Leyte Island definitely was a factor.

"The remote sensing data was amazing for analyzing this landslide," Evans said. "Because of cloud conditions, we couldn't fly over the area, so there would have been no other way of getting this data." This was the first time he had included TRMM data in his research. "It's very exciting to apply TRMM in the landslide hazard research field. I think it could become a major tool for analyzing landslides that occur in the tropical region," Evans said.



Imagery from the Tropical Rainfall Measuring Mission (TRMM) data shows excessive rainfall accumulation between February 4, 2006, and February 17, 2006, in the Central Philippines. Rainfall in Southern Leyte during this time exceeded sixty-eight centimeters (twenty-seven inches), more than twice the normal amount for this time of year. (Courtesy NASA)



Persistent heavy rain during December 2006 and January 2007 triggered flooding and mudslides across South America, killing more than sixty people in Brazil, Bolivia, and Peru. In combination with certain types of terrain, soil conditions, and land cover, heavy rain can make certain regions vulnerable to landslides. These images incorporate data from the Tropical Rainfall Measuring Mission (TRMM) Real-Time Multi-Satellite Precipitation Analysis (TMPA-RT) product. The top image indicates rainfall in millimeters; the bottom image shows which areas received more rainfall than average for this time of year, in millimeters per day. (Courtesy Hal Pierce/SSAI/GSFC)

access critical flood hazard information. Using satellite data can be an easier and more cost-effective method to observe conditions along an entire river basin, proving critical when upstream nations lack adequate information.

Future research

Adler and Hong plan to refine the TMPA-RT system to make it more useful to local governments and organizations on the ground. And for landslide-prone areas like Leyte Island, this research may ultimately save lives. As with many mountainous areas in the tropics, timely landslide hazard assessment may be difficult to accomplish without satellite data. Adler said, "This system will be valuable when national and international organizations have to plan disaster mitigation or relief work. It can give them quantitative information about where exactly the hazard is and which areas are affected. And that's why I think that a lot of people are looking at this information. You don't get it anywhere else."

The online TMPA-RT data provides an easy way for people to download text files or zoom into geographic maps that display three-hour rainfall rates or seven-day accumulations. In addition, Hong is making hourly rainfall data available through Google Earth. Hong said, "We're looking at using this product to predict landslides in an operational way. That's the ultimate goal, and this is our first evaluation of the potential."

To access this article online, please visit http://nasadaacs.eos.nasa.gov/articles/2007/2007_landslides.html.

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For more information

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

Tropical Rainforest Measuring Mission (TRMM)
http://trmm.gsfc.nasa.gov/

Experimental Real-Time TRMM Multi-Satellite Precipitation Analysis (TMPA-RT)
http://lake.nascom.nasa.gov/Giovanni/tovas/realtime.3B42RT.2.shtml

About the remote sensing data used

Satellite	Tropical Rainforest Measuring Mission (TRMM)
Sensor	TRMM Microwave Imager (TMI)
Data set used	Experimental Real-Time TRMM Multi-Satellite Precipitation Analysis (TMPA-RT)
Resolution	0.25 by 0.25 degrees averaged
Parameter	Rainfall
Data center	NASA Goddard Earth Sciences Data and Information Services Center (GES DISC)

Adler and Hong also used NASA Shuttle Radar Topography Mission (SRTM) digital elevation models (DEMs), NASA Moderate Resolution Imaging Spectroradiometer (MODIS) vegetation data, and soil properties from the Digital Soil Map of the World.

About the scientists

Robert Adler is a senior scientist in the NASA Laboratory for Atmospheres at Goddard Space Flight Center and a project scientist for the Tropical Rainfall Measuring Mission (TRMM). Adler's research focuses on analyzing precipitation observations from space on global and regional scales using TRMM and other satellite data. Adler holds a PhD in meteorology from Colorado State University. NASA funded his research.

Stephen Evans is a professor of Earth sciences at the University of Waterloo in Canada. His research focuses on geological engineering; landslides and related processes; and the geotechnical response to climate change. He holds a PhD in engineering geology from the University of Alberta. His fieldwork was supported by the Asia Pacific Initiative Fund of Foreign Affairs Canada.

Yang Hong is a research scientist at the Goddard Earth Sciences and Technology (GEST) Center. His research interests include surface hydrology; remote sensing precipitation; flood forecasting and landslide analysis; and sustainable development. Hong received his PhD in hydrology and water resources from the University of Arizona, Tucson. NASA funded his research.

Can Earth's plants keep up with us?

"Worldwide, we have some very vulnerable populations that could never survive just on the productivity of the land on which they live."

Marc Imhoff
NASA

by Stephanie Renfrow

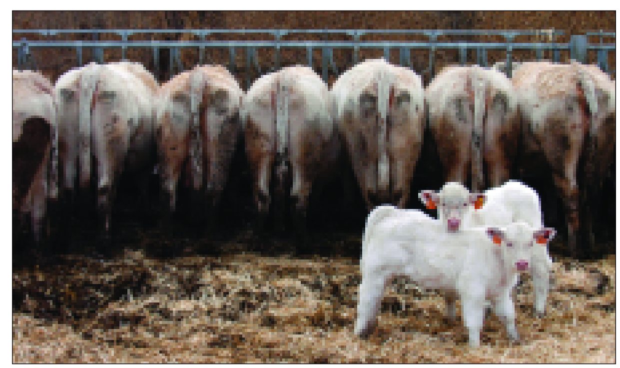
Our lives depend on plants. Plants turn the energy of the sun into our most basic needs: lumber for houses, fuel for cooking, fiber for clothing, feed for livestock, and food for our own growing bodies. But as global population and incomes rise, will plants be able to keep up with the human appetite? And if they cannot, which regions will be short on food and other plant-based resources, and what will that mean for nations as they try to assure food security for their citizens?

Marc Imhoff, a biophysical scientist with NASA, has been exploring these questions with colleagues from the University of Maryland's Earth System Science Interdisciplinary Center, the World Wildlife Fund, and the International Food Policy Research Institute for six years. He said, "Our primary motivation has been to find out where we stand relative to our survival on the planet, and what our needs are compared to the capability of the biosphere to sustain them. In fact, it goes beyond just need; it includes our different lifestyles—our appetites." To build some answers, Imhoff set about measuring global plant productivity, calculating human consumption levels on a cultural level, and then comparing what he learned. His findings remind us that we all rely on the same finite Earth.

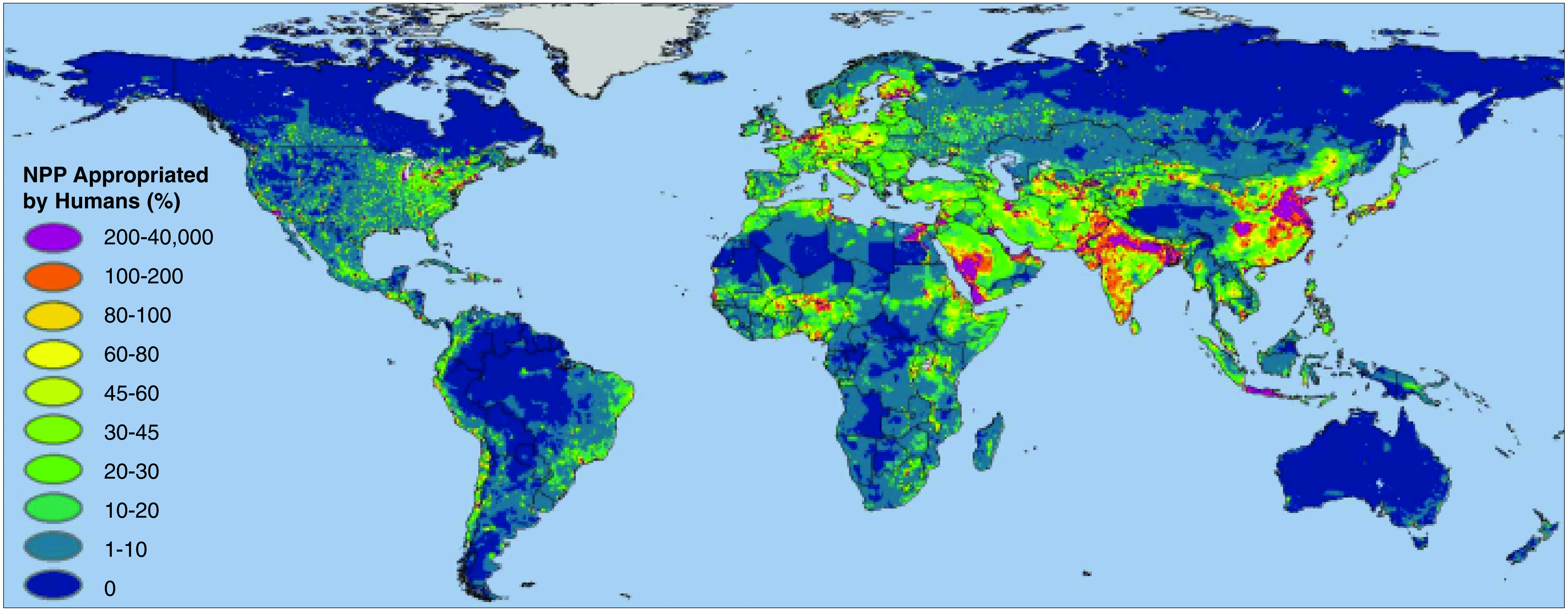
The green supply

Net primary production is a measure of plant productivity, the amount of plant material left over after respiration. Imhoff put it this way: "Net primary production is the plant material that we see above ground, as well as what is below ground, like root systems. All of our food, much of our fiber, and—for many people in developing countries—fuel for cooking, is derived from plant material."

To measure net primary production, Imhoff used Normalized Difference Vegetation Index (NDVI) data, which quantify the presence of healthy vegetation. The data, originally from the Advanced Very High Resolution Radiometer (AVHRR) instrument, were reprocessed under the International Satellite Land-Surface Climatology Project to retrieve NDVI. The data were taken every sixteen days from 1982 to 1998, allowing Imhoff to compute an average maximum NDVI for each month of the year. The monthly NDVI data were input to a biophysical model together



Human beings rely on our planet's net primary production for survival. Plants provide food and fiber, as well as support the animals we use for food and clothing. (Courtesy Gillian Bolsover)



This map shows the net primary production (NPP) supply versus human demand, with demand as a percentage of supply. Red and orange indicate areas where human demand outstrips nature's supply. (Courtesy M. Imhoff, L. Bounoua/GSFC, with collaborators T. Ricketts, C. Loucks, R. Harriss, W. Lawrence)

with temperature, humidity, rainfall, and land-cover type. The model output provided Imhoff and his colleagues with an estimate of the planet's net primary production. Imhoff said, "This information gave us the planetary supply of plant production on land that is available to humans in an average year."

The human appetite

Imhoff's next step was to measure the amount of net primary production that humans use worldwide in an average year, and then tie it to cultural consumption habits. To do that, he turned to statistics from the United Nations Food and Agricultural Organization (FAO) on food and fiber consumption by country, taking the data from 1995 as a typical year that matched the satellite timeline. He said, "We divided the consumption statistics into food, both plant- and animal-derived; and fiber, including wood, wood-based fuel, and paper. Then, we backed out what you would need to see in the field to get those products," he said. "This way, we could double-check what the AVHRR data would have shown in the field with what the consumption statistics indicated was actually used."

Next, Imhoff requested the Gridded Population of the World (GPW) data set, which provides population numbers and density on a regular latitude-longitude grid, from the NASA Socioeconomic Data and Applications Center (SEDAC). "We overlaid the consumption data on the population map and ended up with a gridded surface map showing the amount of net primary production required to support the consumption habits of different human populations all over the world." This map gave Imhoff the information he needed to compare production supply with human demand.

Keeping up with demand

When he compared the global supply of net primary production to the human appetite, Imhoff confirmed some ideas that did not surprise him. "Some things were a no-brainer," he said. "For example, urban populations with a high density consume way more primary production than local ecosystems can produce." One sharp example of this was New York City, which consumed 300 times more primary production than it created. "That says a lot about the dependence of urban areas on our transportation networks and agricultural infrastructure," he said. The ratio of consumption to regional net primary productivity might prove to be a useful indicator of potential trouble spots should natural disasters, economic insecurity, or other problems undermine networks or infrastructure.

Having enough food may seem like a concern only for developing countries, but industrialized countries also have concerns about food security, which is defined simply as always having enough food for an active, healthy life. Developed countries may have dense urban populations, import more food, and be accustomed to high levels of consumption—all of which make these countries susceptible to transitory food supply disruptions. In addition, developed countries may have poor populations that are vulnerable to rising food prices in spite of typical governmental support services. Imhoff said, "Worldwide, we have some very vulnerable populations that could never survive just on the productivity of the land on which they live—with some important implications for national and regional food security."

Closely tied to the question of having enough food for survival is the idea of having enough fuel, clothing, and building materials for survival. The availability of everything from firewood to winter coats begins with plants. Consumption of material goods is an important factor in economic stability and security, as well as in maintaining or improving lifestyle levels. The more a population consumes, the more effort it takes to maintain that standard of consumption. Imhoff found that there were two big factors that lead to high consumption levels. The first is high per-capita consumption rates, as seen in much of the developed world; the second is large populations. Even a low per-capita consumption rate can result in a huge overall level of total consumption if multiplied over a large number of people.

To Imhoff, a more surprising finding was the importance of technology in helping balance the equation between supply and consumption. "We found that using improved technology—especially in harvesting and storage techniques—can actually halve the amount of waste in agricultural production," he said. "Take logging. Without the benefits of improved harvesting technology, you might literally lose a tree for every one that you use."

The interplay between population, consumption rates, affluence, and technology leads to some thought-provoking realizations. "For example, Asia's per-capita consumption is on the rise," he said. "If consumption begins to match Western levels, there will be a significant increase in demand for food and fiber products. If technology improvements do not come with that growth, then you'll see populations that are outstripping their regional food production capacity. They'll be more dependent on resources elsewhere, and will have to compete for them." Although citizens in industrialized countries may not find the rising population in developing nations of immediate concern, poverty has been connected to terrorism, war, underemployment, border pressures, disease, and political unrest.

"It's a question of how much we are willing to pay to keep getting the level of production that we want, and to transport it from one place to another," Imhoff said.

Can we afford it?

Stanley Wood, of the International Food Policy Research Institute (IFPRI), agreed with Imhoff's emphasis on the question of costs. "The bottom line is food availability and food affordability. How stretched will our incomes be to meet our food requirements?" Wood works with a team from the IFPRI that collaborated with Imhoff on the net primary production research and which has joined with him on a new proposal that builds on the initial work.

Imhoff and the IFPRI team hope to improve their understanding of the flow of net primary production between countries. Wood said, "For example, let's say that energy security becomes an increasing concern and the U.S. turns to biofuels. The global price of maize could rise steeply because of competition between maize for food and feed, and maize for biofuels. This would create a double-edged sword for poor countries: the increased prices would generate more income for developing country farmers, but would be bad news for poor consumers."

Widening the global picture is also something that Imhoff hopes to do. "We have begun projecting what would happen to plant production with climate change, and you don't have to look very far to see that the geopolitics of food production could change significantly, with some countries winning and others losing.

Even without climate change, we are already rubbing up against some limits in our planet's ability to supply us," he said.

Both Wood and Imhoff hope their data set on human use of net primary productivity, which is now available through SEDAC, will be useful to policy and decision makers, both in governmental and nongovernmental agencies. "We hope to have more one-on-one conversations with users in the future," Imhoff said. "With the unprecedented population levels that we have, now, surprises can develop very quickly. We need to be ready."

However, even with a growing global population, increasing consumption levels, and other global changes bearing down on us, Imhoff emphasized the positive. "We have the technology to get out ahead of this. The data isn't just showing us the bad news; it is also giving us the power to study the changes ahead and understand them," he said. "We are far from being helpless. Our ability to assess our environment and our situation should give us a sense of empowerment."

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World Watch Institute: Global security http://www.worldwatch.org/taxonomy/term/54/

For more information

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

Human Appropriation of Net Primary Productivity
http://sedac.ciesin.columbia.edu/es/hanpp.html/

International Food Policy Research Institute
http://www.ifpri.org/

About the data used

Satellite	Census data	Polar-Orbiting Operational Environmental Satellite (POES)
Sensor		Advanced Very High Resolution Radiometer (AVHRR)
Data sets used	Gridded Population of the World	International Satellite Land-Surface Climatology Project (ISLSCP) II Global Inventory Modelling and Mapping Studies (GIMMS) Monthly Normalized Difference Vegetation Index (NDVI) 1981–2002
Resolution	2.5 minutes latitude/longitude; 1990–2015, every 5 years	1 kilometer; 16 days
Parameter	Human population density	NDVI
Data center	NASA Socioeconomic Data and Applications Center (SEDAC)	NASA Oak Ridge National Laboratory DAAC

About the scientists

Marc Imhoff is a project scientist in the Biospheric Sciences Branch at the NASA Goddard Space Flight Center. He specializes in applying remote sensing to human population and biodiversity issues, particularly urban sprawl and global biological productivity. Imhoff's primary funding for the net primary productivity work is from NASA.

Stanley Wood is a scientist with the Consultative Group on International Agricultural Research at the International Food Policy Research Institute in Washington, D.C. He and his team specialize in using agricultural research to help eradicate poverty and understand human appropriation of ecosystems. Wood's primary source of funding for his collaboration with Imhoff is NASA.

After the Larsen B

“The glaciers thin, accelerate, and recede, discharging more and more ice into the ocean each year. If you’re a glacier, that’s a pretty bad recipe.”

Neil Glasser
University of Wales, Aberystwyth

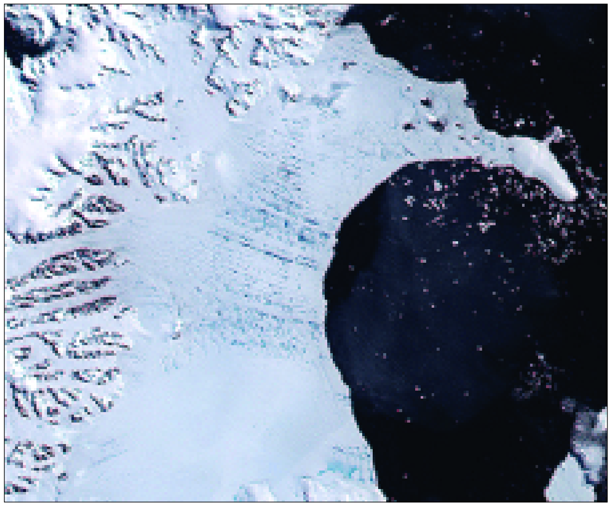
by Laura Naranjo

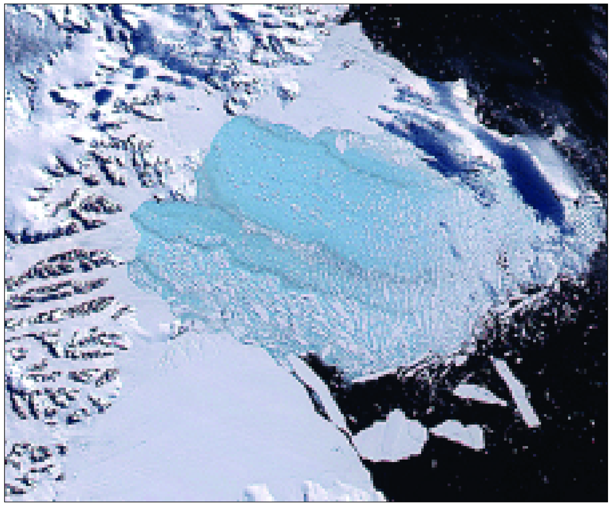
In March 2002, scientists witnessed the largest ice shelf breakup in recent history. Within 35 days, more than 3,250 square kilometers (1,255 square miles) of the Larsen B ice shelf in Antarctica shattered into small icebergs. Researchers were stunned by the rapidity of its collapse, even though they knew the shelf was weakened. For several years prior to the breakup, scientists had been using satellite images and other data to study the shelf. These data revealed a critical combination of factors: rising air temperatures and increased melting on the ice surface. A succession of unusually warm summers had increased the amount of melt water on the surface of the ice, which then wedged open crevasses in the ice, weakening and ultimately breaking up the shelf.

The Larsen B ice is gone forever, but it left behind questions that scientists are now trying to answer in more detail. Ice shelf collapses not only change the shape of Antarctica’s icy fringe: they could soon raise global sea level.

Ice shelves and sea level

The Antarctic Peninsula is a craggy finger of land jutting north from the continent’s





Between January 31 and March 7, 2002, the Larsen B ice shelf shattered, sending 3,250 square kilometers (1,255 square miles) of ice into the ocean. The January 31 image (left) shows the shelf in late austral summer, with dark blue melt ponds dotting its surface. By March 7 (right), the shelf disintegrated, leaving thousands of sliver icebergs and a large area of finely divided bits of ice where the shelf had been. These images were captured by NASA’s Moderate Resolution Imaging Spectroradiometer (MODIS) instrument. (Courtesy NSIDC) mainland toward the tip of South America. Home to some of Antarctica's smaller glaciers and ice shelves, the Peninsula's ice seems insignificant compared to East Antarctica's thick ice blanket and West Antarctica's giant interior ice sheet. But the Peninsula is highly sensitive to warming polar winds, making the region's glaciers and ice shelves a real-time laboratory that is revealing how the rest of Antarctica may respond to climate change.

For years, scientists debated how Antarctica's glaciers might respond to the loss of an ice shelf; understanding glacier behavior is critical for predicting global sea-level rise. An ice shelf itself does not contribute to sea-level rise. Like an ice cube in a glass of water, the floating ice is already displacing its own volume in the ocean. Once an ice shelf collapses, however, scientists theorized that the glaciers that feed into it would no longer be held at bay by the ice shelf's mass. Freed of the barrier, the glaciers would send torrents of ice into the embayment far more rapidly than before the breakup. Some glaciers that flow into the major West Antarctic ice shelves hold so much ice that if they were to slip into the ocean suddenly, they could raise sea level by five to seven meters (sixteen to twenty-three feet), according to NASA. Even a one-meter (three-foot) sea-level rise would inundate shorelines around the world, including heavily populated coastal areas in southeastern Asia, Australia, parts of Europe, and the Atlantic and Gulf coasts of the United States.

Ted Scambos, a glaciologist at the National Snow and Ice Data Center (NSIDC), studied the Larsen B collapse and is using satellite data to observe a small remnant that the shelf left

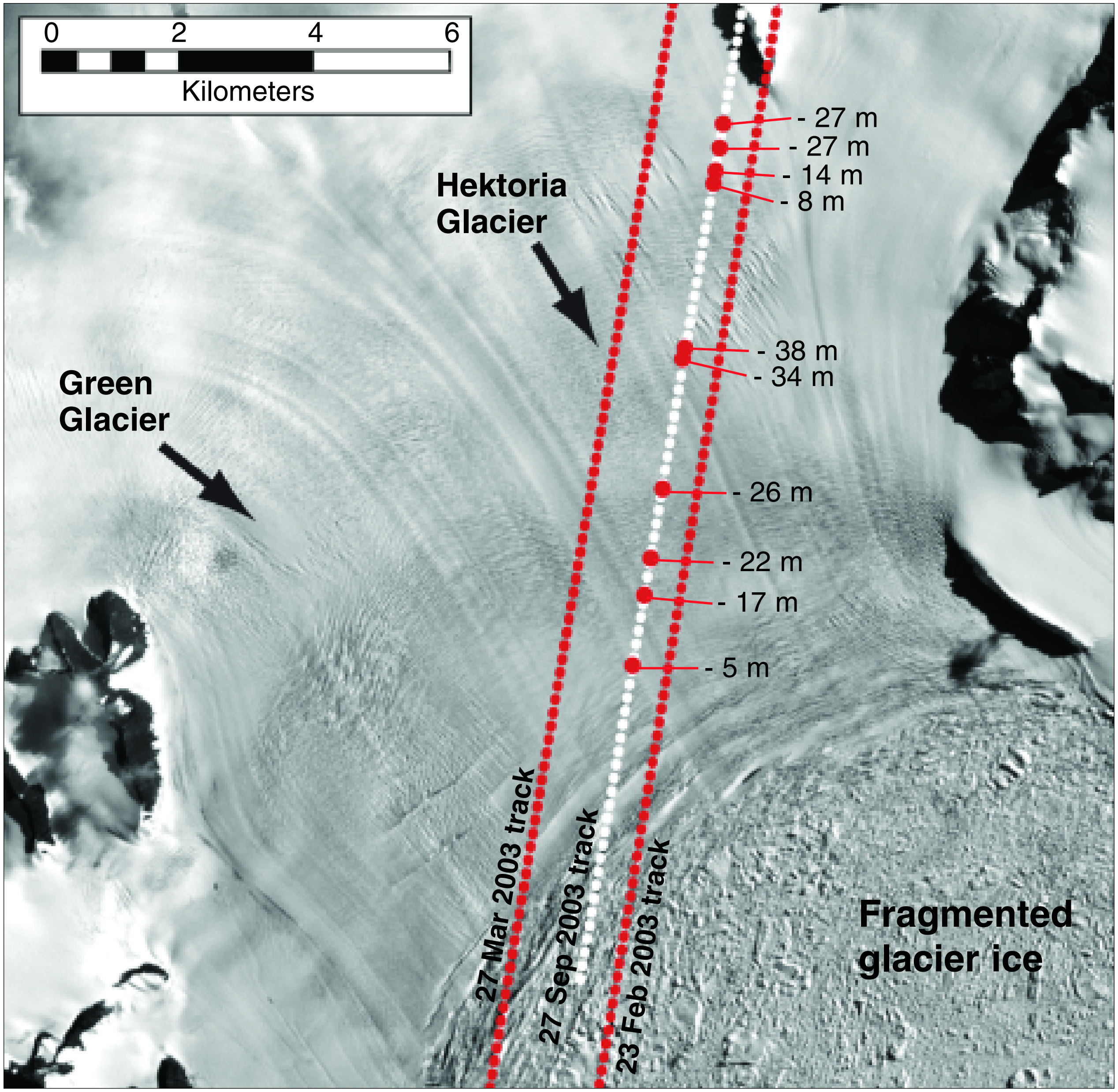
Without the buffer of the Larsen B ice shelf, several glaciers now feed directly into the embayment left behind after the shelf collapsed in 2002. From left to right are the Melville, Mapple, and Crane Glaciers; Jorum Glacier is in the foreground. (Courtesy Ted Scambos)

behind. Scambos said, "The Larsen B remnant is still holding back two large glaciers. While these glaciers aren't large enough to impact sea level, they can give us another chance to watch this experiment play out again and study it in more detail." What he and his colleagues learn may provide clues about the behavior of other ice shelves. "By continuing to watch the Larsen B area, we'll see whether the same kind of pattern is starting to set up on some of the other large ice shelves around Antarctica, like the Fimbul or Ross ice shelves, which hold back some of the really large glaciers," Scambos said.

The sudden breakup of the Larsen B ice shelf has spurred renewed research interest because of the implications for other ice shelves. In particular, scientists are exploring the consequences of ice shelf collapse, their role in ice sheet dynamics, and the potential increase in ice discharge. "Scientists have been taking a new look at the observations," Scambos said, "trying to find what makes the glaciers change."

Accelerating glaciers

Chris Shuman, at the Goddard Earth Sciences and Technology Center, is using satellite observations to examine the behavior of several glaciers that feed into the embayment formed by the Larsen B collapse. Shuman said, "These glaciers have changed markedly, with rapid ice-edge retreat of tens of kilometers [up to



After the 2002 Larsen B ice shelf collapse, glaciers in the embayment emptied directly into the ocean. Without the buffer of an ice shelf, the glacier's flow accelerated, stretching and thinning the ice. This image shows how two of the glaciers thinned between five and thirty-eight meters after the collapse. Dotted red lines and white lines indicate satellite laser tracks that were overlaid on a Landsat image of the area; large red dots indicate locations with surface elevation data. The laser measurements are from the Geoscience Laser Altimeter System (GLAS) aboard the Ice, Cloud, and Land Elevation Satellite (ICESat) mission. (Courtesy NSIDC)

a dozen miles]. The fronts of almost all the glaciers in the area exposed in early 2002 have retreated."

As the retreating glaciers accelerated, their ice stretched and thinned out. Shuman and colleagues tracked this thinning using data archived at the NASA NSIDC DAAC from the NASA Geoscience Laser Altimeter System (GLAS) instrument, flying on the Ice, Cloud, and Land Elevation Satellite (ICESat). ICESat's near-polar orbit repeatedly crosses the Antarctic Peninsula's glaciers and shows how they have thinned over the years since the Larsen B collapse.

To measure this thinning, Shuman mapped the ICESat data onto satellite images of the area's glaciers, captured by the Moderate Resolution Imaging Spectroradiometer (MODIS) on the Terra and Aqua satellites. He discovered that one large glacier, the Crane, thinned from 16 to 150 meters (53 to 492 feet) during the five years following the Larsen B breakup. "The glaciers that are still buttressed by the Larsen B remnant have changed very little, while the ice shelf collapse caused increased glacial ice flow and ice loss on the Crane Glacier," said Shuman. The Crane's ice-edge retreat and dramatic thinning, tens of kilometers (up to a dozen miles) inland, indicates significant change, especially compared to two other glaciers still blocked by the Larsen B remnant.

Even the Larsen B remnant is shrinking. "The Larsen B embayment, especially the remnant, has lost another 1,700 square kilometers [656 square miles] of ice area since 2002, including a large iceberg that calved early in 2006," Shuman said. Under normal conditions, icebergs periodically calve off of the front edge of an ice shelf, helping the shelf maintain equilibrium, but a large iceberg calving from a rapidly receding shelf may indicate instability.

The Larsen B glaciers may be following the same pattern observed in other recent ice shelf collapses. Neil Glasser, at the University of Wales, Aberystwyth, found a way to look back in time to study the behavior of another Antarctic Peninsula glacier, the Rohss Glacier, which fed into the Prince Gustav Ice Shelf prior to its 1995 collapse. He used a combination of archived images from the Landsat satellite missions, available from the United States Geological Survey, and more recent imagery from the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) instrument aboard the NASA Terra satellite, available from the NASA Land Processes Distributed Active Archive Center (LP DAAC).

Glasser mapped the glacier features onto the satellite images to study the glacier's behavior between 2001 and 2006. "In those five years, the Rohss receded about fourteen kilometers [eight miles]," he said. "And that's interesting because that's a long time after the shelf disappeared," Glasser said. He also found that the Rohss glacier appeared to thin as it receded.

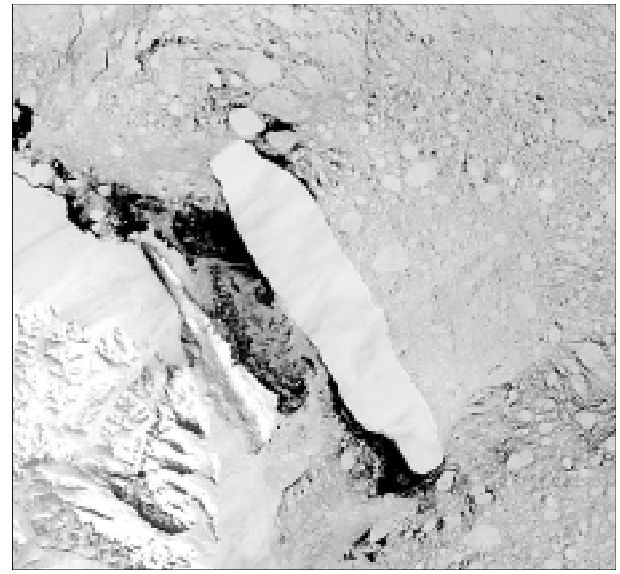
Combined, these findings illuminate how a larger ice shelf collapse may affect global sea level. Scambos said, "In both Greenland and Antarctica we're seeing over and over again that when an ice shelf disintegrates, glaciers behind it accelerate abruptly, and begin to draw down significant volumes of ice and put it into the ocean." The Larsen B shelf was about the size of Connecticut, but Antarctica's largest ice shelves, the Ross and Ronne, are each nearly the size of Spain. If the Ross shelf collapsed, for example, the resulting flow of glacial ice could eventually raise global sea level by up to five meters (sixteen feet).

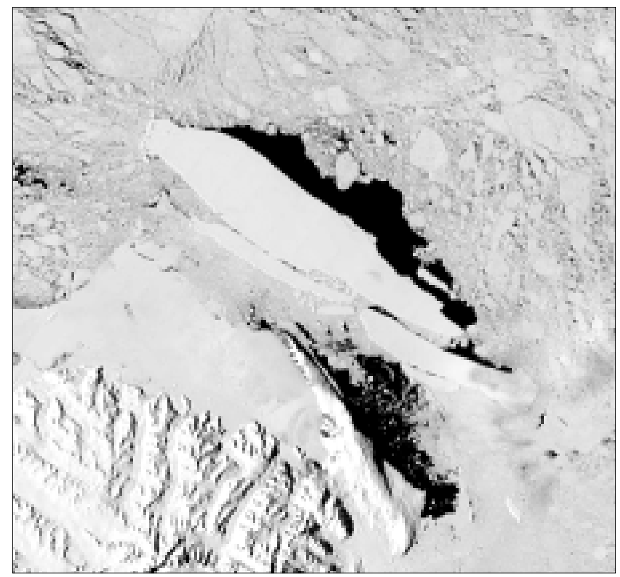
Peril an ocean away

While researchers have since learned more about the role of melt water and the effects of glacier acceleration in ice shelf dynamics, and the potential for global sea level change, the Larsen B collapse spurred researchers to develop additional theories about how and why ice shelves collapse. They learned that surface melting is only part of the story.

Douglas MacAyeal, at the University of Chicago, is pursuing a culprit that may come from halfway around the globe: ocean swells. The swells he studies are not picturesque white-capped ocean waves, but long, low, storm-generated swells that can travel for thousands of miles. MacAyeal said, "You wouldn't see them if you were out on the ocean, because they would have a kilometer [0.62 mile] wavelength. They're very long." The swells also have a low amplitude, or height, of only a few centimeters (less than an inch), making them difficult to detect without sensitive equipment.

MacAyeal and his colleagues discovered the effect of these waves after an iceberg they were studying, named B-15A, abruptly shattered on October 27, 2005. B-15A was a large iceberg, about the size of Luxembourg, which had run aground off of the coast of Antarctica.





The top image shows Iceberg B-15A on October 27, 2005; the bottom image shows the iceberg on November 4, 2005, after breaking into large shards. Researchers believe the iceberg fragmented after low swells generated off Alaska rocked the iceberg against the Antarctic coast. The Moderate Resolution Imaging Spectroradiometer (MODIS) instrument on NASA's Terra and Aqua satellites captured these images. (Courtesy NASA MODIS Rapid Response Project)

It broke up on a calm day with locally mild weather, puzzling observers. MacAyeal and his colleagues retrieved a seismometer that they had previously installed on the iceberg and analyzed the data. They discovered that just before the breakup, the seismometer recorded long, low swells that had rocked the iceberg and pounded it against the coast. MacAyeal traced the swells back to a surprising source—a giant winter storm off the coast of Alaska five thousand kilometers (eight thousand miles) away. Even the surrounding sea ice, which usually absorbs ocean wave energy, had not protected the iceberg. "Sea ice does keep the waves from propagating if the wavelength is short, less than 100 meters [328 feet]. But these waves are so long that they just flex the sea ice," MacAyeal said. This lack of protection could have serious consequences for ice shelves, as well as icebergs.

However, these long, low swells do not act alone. "Melt water tends to fracture the crevasses and produce an ice shelf that's broken up but hasn't fallen apart yet," MacAyeal said. "It's like an old house where the mortar has come out from between the bricks but the bricks are still stacked. If the ice shelf has warmed up and weakened over a long period of time, then the next storm that comes along whacks it. It's the waves that shake the pieces apart." Scambos agreed, saying, "There are a lot of things happening together to cause a catastrophic ice shelf breakup, but these long-wavelength swells may be doing some of the dirty work."

Like Glasser, MacAyeal also plans to look back in time to see if there is a connection between distant storms and previous ice shelf retreats or collapses. For instance, he is investigating the calving of iceberg B-15, the parent iceberg to B-15A. MacAyeal said, "When B-15 broke off the Ross Ice Shelf in 2000, it was thought to have been a time when there were lots of waves being recorded." Storm-generated ocean waves are just one of many environmental triggers behind ice shelf collapse that scientists are trying to understand. And while such triggers may not contribute directly to rising sea levels, they do indicate a larger connection between global weather and the long-term stability of Antarctica's ice masses.

The future of Antarctic ice

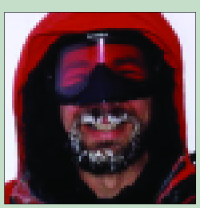
The long-term response of the glaciers behind the Larsen B remnant remains unknown, and continues to be an object of study. Scientists like Scambos, Shuman, Glasser, and MacAyeal are watching the Antarctic Peninsula with keen interest, observing both the post-collapse glaciers and the remaining ice shelves. Glasser said, "So far, the glaciers thin, accelerate, and recede, discharging more and more ice into the ocean each year. If you're a glacier, that's a pretty bad recipe."

About the scientists

Neil Glasser is a glaciologist and professor at the University of Wales, Aberystwyth, in the United Kingdom. He has studied glacial geology and glacial processes in Greenland, Sweden, Norway, Chile, Argentina, and Antarctica. He received a PhD from the University of Edinburgh. His research on Antarctic ice shelves was funded by the Cooperative Institute for Research in Environmental Sciences Visiting Fellows Program and the United States/United Kingdom Fulbright Commission.

Douglas MacAyeal is a researcher and professor at the University of Chicago and holds a PhD from Princeton University. He is currently researching iceberg calving and the break up of ice shelves, and has conducted frequent fieldwork in Antarctica, including ten field seasons on the Ross Ice Shelf and in the Ross Sea. The National Science Foundation funded his research.

Ted Scambos is a glaciologist at the National Snow and Ice Data Center and holds a PhD from the University of Colorado at Boulder. Scambos combines remote sensing data with field observations to better understand the effects of climate change on Earth's cold regions. He has recently focused on the ice shelves and ice sheets of Antarctica and Greenland, which have important implications for sea-level rise. NASA funded his research.



Chris Shuman is a researcher at the University of Maryland's Goddard Earth Science and Technology Center and is an adjunct professor at the University of Maryland. Shuman's work helps bridge the gap between field measurements and satellite data with the goal of understanding the behavior of glacial ice through time. Shuman received a PhD from Pennsylvania State University. NASA funded his research.

Accelerating glacier ice is an unwelcome ingredient in the recipe for global sea-level rise, making it important for scientists to understand the factors behind ice shelf breakup. As long as the massive Antarctic ice sheets remain locked away behind ice shelves, doled out in an occasional iceberg, sea level may remain stable. But if warming and melting trends persist, more ice shelves may begin to show the same signs of weakness observed in the Larsen B ice shelf before it disintegrated. "This problem of sea-level rise is a real one," says Scambos. "It's likely to happen, and the steps could proceed more rapidly than we thought."

To access this article online, please visit http://nasadaacs.eos.nasa.gov/articles/2007/2007_larsen.html.

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National Snow and Ice Data Center Distributed Active Archive Center (NSIDC DAAC)
http://nsidc.org/

Land Processes Distributed Active Archive Center (LP DAAC)
http://lpdaac.usgs.gov/

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

Ice, Cloud, and Land Elevation Satellite (ICESat)
http://icesat.gsfc.nasa.gov/

Landsat
http://landsat.gsfc.nasa.gov/

Moderate Resolution Imaging Spectroradiometer (MODIS)
http://modis.gsfc.nasa.gov/

NASA Earth Observatory: Fragment of its Former Shelf
http://earthobservatory.nasa.gov/Study/LarsenIceShelf/

About the remote sensing data used

Satellite	Terra	Terra and Aqua	Ice, Cloud, and Land Elevation Satellite (ICESat)
Sensor	Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER)	Moderate Resolution Imaging Spectroradiometer (MODIS)	Geoscience Laser Altimeter System (GLAS)
Data sets used	ASTER Expedited L1A Reconstructed Unprocessed Instrument Data	MODIS Mosaic of Antarctica	GLAS/ICESat L2 Antarctic and Greenland Ice Sheet Altimetry Data
Resolution	15, 30, or 90 meters	125 by 125 meters	60-meter spots separated by 172 meters
Parameter	Land ice	Land ice	Elevation
Data center	NASA Land Processes (LP) DAAC	NASA National Snow and Ice Data Center (NSIDC) DAAC	NASA NSIDC DAAC

Following the World Trade Center plume

"Most people were surprised the plume got as high as it actually did."

Ralph Kahn
NASA Jet Propulsion Laboratory

by Lindsay Husted

On September 11, 2001, the collapse of the World Trade Center in New York City sent a pillar of noxious gases and particles high into the atmosphere. People around the world recognize photographs of the towers burning and collapsing as iconic images of that day. Now, some lesser-known images are grabbing the attention of the scientific community because of the questions they help to answer.

Among other questions, the aftermath of the collapse left citizens, policy makers, and scientists alike wondering, "How can we measure the effects of the World Trade Center disaster on people's health and on the environment?" Photographs showed plumes of smoke and debris billowing into New York City streets and into the air. Scientists wanted to assess how and where the miniscule debris particles and invisible toxic gases were dispersed into the atmosphere. One crucial piece of data

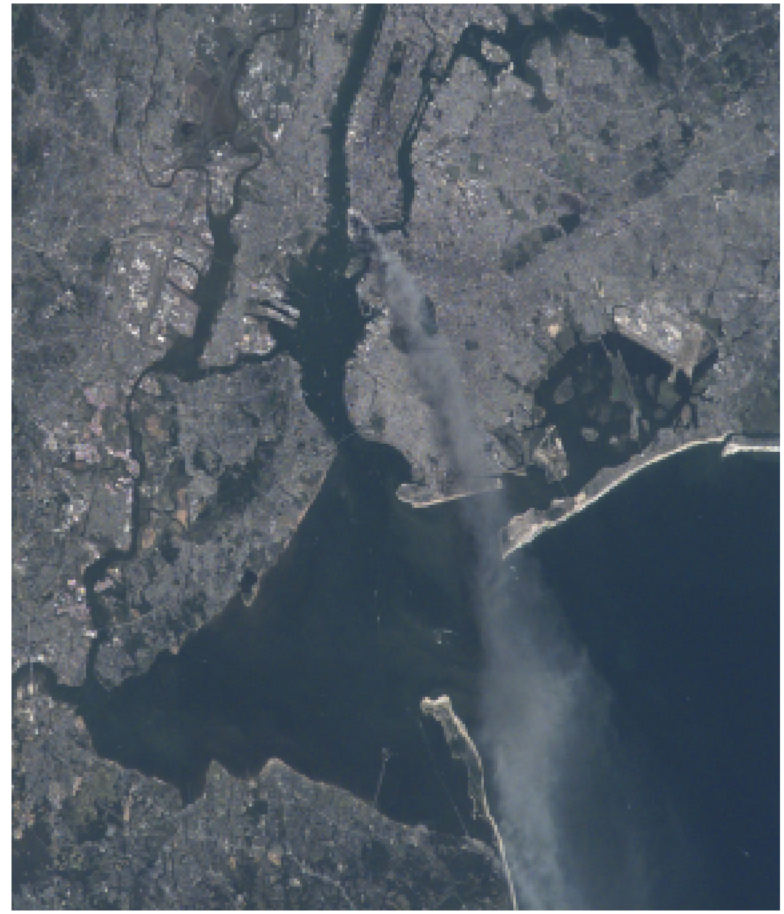
The twin World Trade Center Towers stand over New York City prior to their collapse on September 11, 2001. The collapse sent a noxious plume of smoke drifting over the city, and health officials were challenged to monitor its drift and possible impacts on health. (Courtesy Photos.com) was missing: they needed to know how high the smoke rose up into the atmosphere above the World Trade Center site so that they could determine where it traveled.

Ralph Kahn, a senior research scientist at the Jet Propulsion Laboratory, is Aerosol Scientist for the Multi-Angle Imaging Spectroradiometer (MISR) instrument, which flies on NASA's Terra satellite. He said, "With other available data, there was no information that specifically said how high the plume had reached." On the day of the disaster, power outages spread across New York City; no instruments deployed on the ground could measure plume elevation, and many that collect aerosol samples became so clogged with particles that they no longer functioned. Orbiting satellites, however, remained unharmed, and MISR data proved useful in measuring the height of the smoke plume.

Calculating the height of the plume

To study the potential impacts of the pollutants that dispersed when the World Trade Center collapsed, researchers needed to know when, where, and how many particles entered the atmosphere. The MISR instrument captured images on September 12, 2001, which the researchers retrieved from the NASA Langley Atmospheric Science Data Center Distributed Active Archive Center (LaRC DAAC). These data allowed the scientists to measure the plume of pollutant particles billowing from the buildings.

The researchers used a calculation technique called parallax. Parallax is similar to the way a locust measures distance. By bobbing from side to side, shifting weight on its legs and pivoting its abdomen, a locust is able to decide just how high and far to jump in order to reach its next landing strip. It uses these slight movements to "see" the difference in location of its target from varying points of view—the object's apparent shift against a fixed background. In a similar manner, the MISR instrument captured images of the World Trade Center smoke cloud from multiple angles, all within a few minutes of each other, as the satellite scanned the globe. The scientists could pinpoint the height of the plume by looking down at the scene from slightly different positions in the sky above.



This photograph shows the smoke plume from the World Trade Center collapse drifting over New York City and New Jersey on the morning of September 11, 2001. (Courtesy NASA)

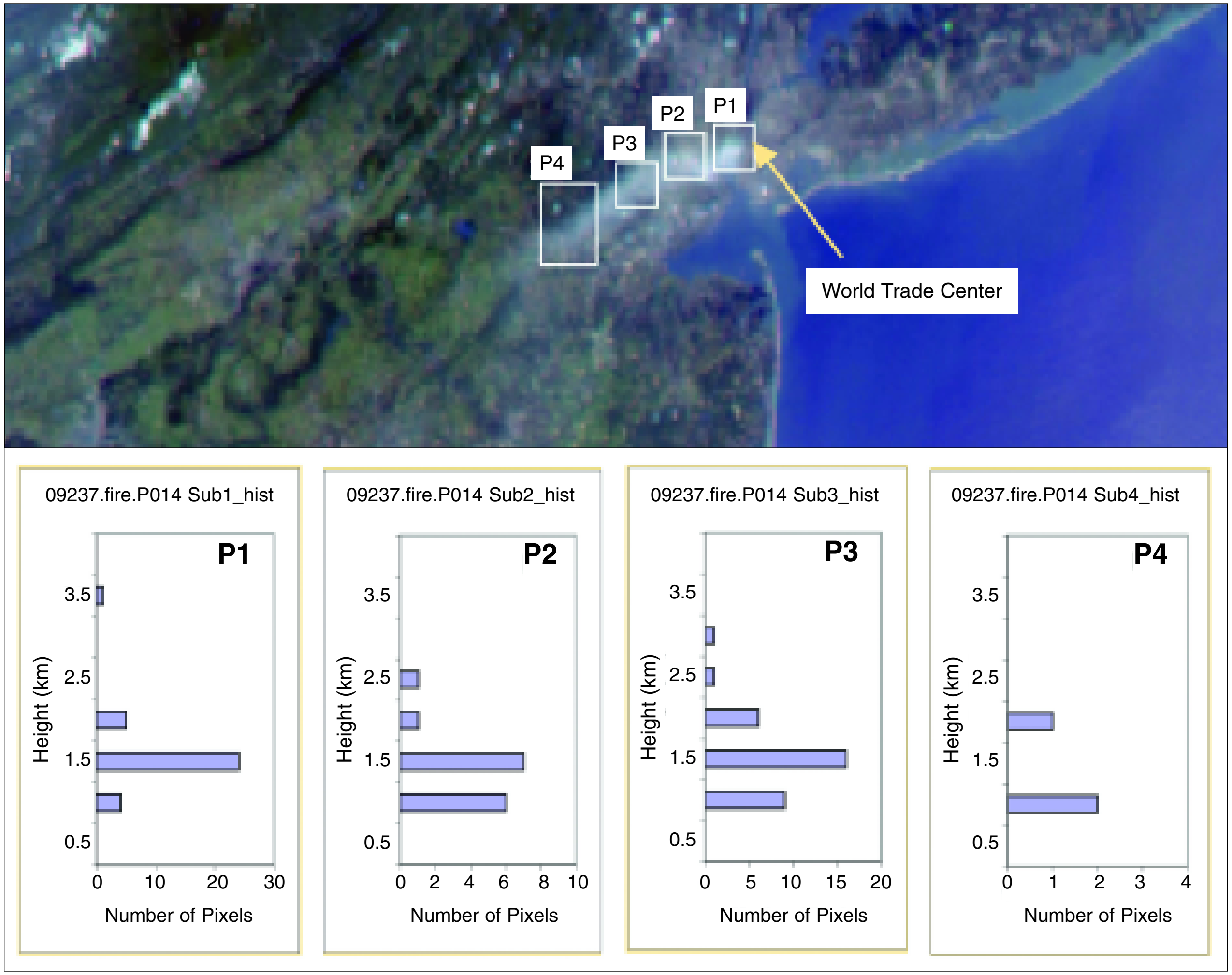
The MISR data enabled Kahn and his colleagues on the MISR team to calculate the maximum height and drift of the smoke plume billowing from the World Trade Center site. With the MISR data, Kahn calculated the height of the plume, composed of sub-visible aerosols, to be 1.25 to 1.5 kilometers (0.78 to 0.93 miles), at four sites, as the smoke drifted 70 kilometers (44 miles) downwind on September 12. Kahn said, "Most people were surprised the plume got as high as it actually did."

Pinpointing the drift

The plume-height information proved crucial to other researchers studying the plume, like scientific modeler Georgiy Stenchikov at the Department of Environmental Science at Rutgers University. Stenchikov wanted to use his fine-scale meteorological and aerosol transport models to calculate where and in what quantity the World Trade Center pollutants drifted over the areas around New York City.

Stenchikov compared his model output to the limited ground-based data available: winds observed at automated meteorological stations in Central Park and at nearby airports, and observations from the rooftops of public school buildings in Queens, Brooklyn, and Manhattan. But the plume in his model did not seem to be in the right place. He thought he needed more information. Kahn said, “Georgiy was modeling the plume and wanted to know what we had to offer with the MISR data that could help refine his model.”

The missing input for Stenchikov’s model was the data on plume height. He needed to pinpoint how high the particles from the conflagration rose, so that he could identify the atmospheric layer they ended up in, and thus determine how far the pollutants traveled. Kahn said, “Wind speed and direction depend on elevation in the atmosphere. So in general, if the aerosol ends up higher in the atmosphere, it is likely to travel a lot farther.” Particles lifted by winds blowing over land initially stay in the layer of the atmosphere closest to the surface of the Earth. However, if particles are lifted by a hot, buoyant source, like a wildfire, volcano, or burning building, the plume can bubble up above the near-surface layer of the atmosphere and reach a higher elevation.



Researchers used this Multi-Angle Imaging Spectroradiometer (MISR) image of the World Trade Center smoke plume, captured at 12:03 p.m. Eastern Daylight Time on September 12, 2001, to measure the plume height and pollutant drift. The data plots corresponding to the image are histograms of height using the 60- and 70-degree forward MISR views with a 250-meter (155-mile) vertical bin size and 1.1-kilometer (0.68-mile) horizontal resolution. The plots show that the plume height was approximately 1.25 kilometers (0.78 miles) when it was closest to the World Trade Center. (Courtesy Ralph Kahn)

Once Stenchikov obtained the correct plume height from MISR, he used it to refine his model and calculate the concentration of aerosols released into the atmosphere. Stenchikov said, “When we put the plume height from MISR into our simulations, we reproduced the position of the plume on September 12 very well.”

Interdisciplinary studies

Stenchikov passed along the aerosol concentration data from his model simulations to investigators from the Environmental and Occupational Health Sciences Institute, who were assessing the human exposure to the pollutants. The ongoing work to understand how pollution is dispersed in the atmosphere and to assess its subsequent impact on the environment involves researchers from many different fields. Kahn said, “We are now in a position to monitor aerosol behavior using satellite data combined with surface data, aircraft data, and models in a way that we have never been able to do before.”

Scientists can now use these same techniques to study other events, like the burning of fossil fuels or the pollution generated from power plants. Stenchikov said, "The combination of satellite observations and modeling is a very fruitful approach, because we cannot believe in the models completely until we validate with observations, and observations do not provide complete information." Researchers can extend these findings to estimate the quantity and drift of pollutants released into the air, and assess the impact of air-quality events on human and environmental health. Ground station data recorded by the Environmental Protection Agency, for instance, can be combined with satellite data to provide information about exposure patterns that can affect people and the environment.

Both Kahn and Stenchikov value the interdisciplinary nature of studies like this. Kahn said, "We have different backgrounds and we come with different expertise, and we're putting our expertise together to get an answer. When we are all done, we have some 'golden days,' as we like to call them—days when all of the data falls into place. Those are the nuggets."

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For more information

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

Multi-Angle Imaging Spectroradiometer (MISR)
http://www-misr.jpl.nasa.gov/

Department of Environmental Science at Rutgers University
http://www.envsci.rutgers.edu/

About the remote sensing data used

Satellite	Terra
Sensor	Multi-Angled Imaging Spectroradiometer (MISR)
Data set used	MISR Level 2 Top of Atmosphere/Cloud Stereo and Aerosol data products from September 12, 2001
Resolution	1.1 kilometers horizontal (stereo height); 17.6 kilometers (aerosol optical depth)
Parameter	Stereo height; aerosol optical depth
Data center	NASA Langley Atmospheric Science Data Center DAAC

About the scientists

Ralph Kahn is a senior research scientist at NASA's Jet Propulsion Laboratory, at the California Institute of Technology. His research interests include the climate and climate history of Mars and Earth. Kahn is currently the aerosol scientist for the Multi-angle Imaging Spectroradiometer (MISR) instrument. NASA provided support for his work on this study.

Georgiy Stenchikov is a professor in the Department of Environmental Science at Rutgers University in New Brunswick, New Jersey. He conducts interdisciplinary studies on climate modeling, atmospheric physics, and environmental sciences. The United States Environmental Protection Agency, the National Institute of Environmental Health Sciences, and the New Jersey Department of Environmental Protection provided support for his work on this study.

Grasping the subtle needs of vegetation

"Rainforests worldwide play a large role in global energy budgets because of their ability to store carbon dioxide, a greenhouse gas."

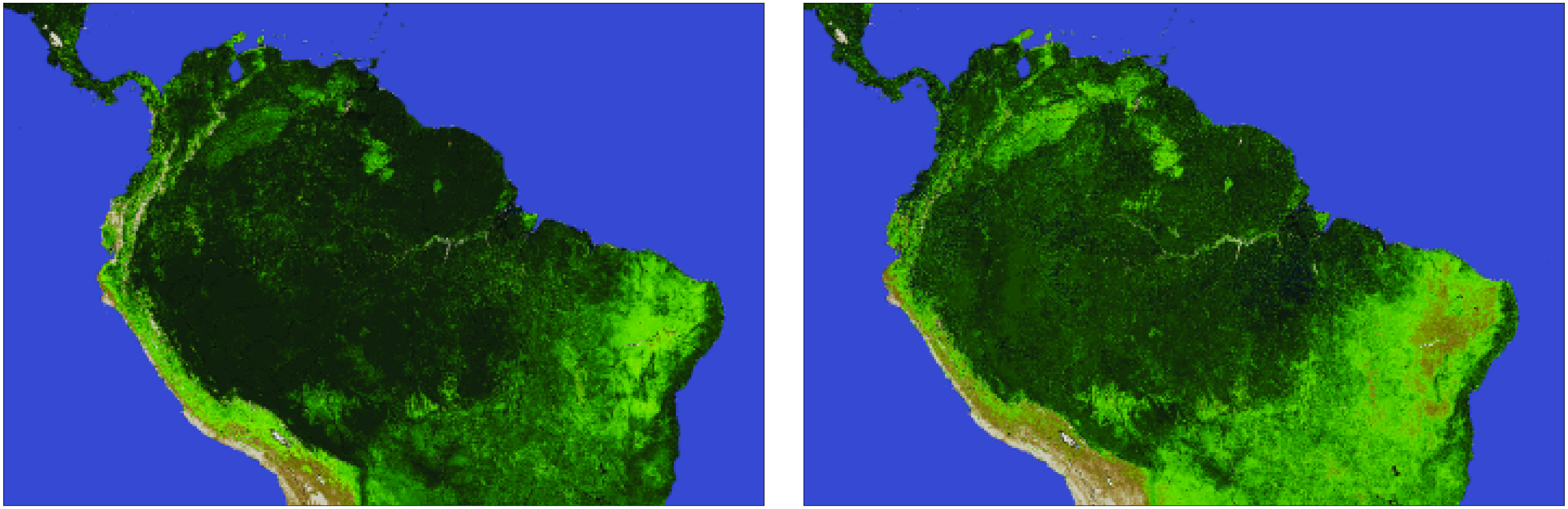
Alfredo Huete
University of Arizona

by Laura Naranjo

During and after World War I, American farmers fanned out across the Great Plains to grow wheat. They plowed up the native grasses, exposing fertile topsoil and straining the sensitive grassland ecosystems. Then, in the early 1930s, Dust Bowl storms ravaged the stripped and drought-weakened Plains. Blizzard-force winds billowed tons of loose soil into the air, forming giant dust clouds that buried entire farms and ultimately blew all the way to the east coast of the United States.

Humans have long relied on crops and vegetation for survival. In more recent human

This FLUXNET tower is one of many worldwide that scientists have erected to constantly monitor landscape health and productivity. They hope to better understand the energy exchanges that are essential to the lifecycles of vegetation. (Courtesy FLUXNET)



These two images reveal different vegetation calculations of the Amazon rainforest in Brazil. Traditional normalized difference vegetation index (NDVI) measurements (left) reach a point of saturation, particularly over densely vegetated regions like the Amazon. This saturation is visible as flat areas of dark green. The Enhanced Vegetation Index (EVI) resolves the saturation and measures more detail and variability (right) in the vegetation, visible as various shades of green. These images were compiled from Moderate Resolution Imaging Spectroradiometer (MODIS) data from September 30 to October 15, 2000. (Courtesy MODIS Land Group/Vegetation Indices)

history, scientists have uncovered the larger role of vegetation in the health of the complete ecosystem of our planet. But understanding the complex needs of an ecosystem requires a lot of information. Farmers and scientists now rely on ground instruments and satellite data to determine what will keep an ecosystem or a cropland healthy. Different ecosystems require varying amounts of sunlight, water, and carbon dioxide. These requirements are characterized by exchanges, or fluxes, between the ecosystem and the atmosphere. If scientists can investigate the relationship between ecosystem health and the fluxes of carbon dioxide, water, and radiation, they can better understand global vegetation cycles and assess human impact in ecosystems around the world.

Manually collecting flux data from each ecosystem is too time-consuming and expensive, so many scientists rely on FLUXNET data, available from the Oak Ridge National Laboratory Distributed Active Archive Center (ORNL DAAC). FLUXNET, a global network of more than 400 micrometeorological tower sites, compiles data and information from ground-based flux towers stationed in a variety of ecosystems around the world. Each tower measures the fluxes of solar radiation (sunlight), water vapor, carbon dioxide, and other trace gases between the atmosphere and the ecosystem. The towers also measure additional ecosystem properties, such as precipitation, air and ground temperatures, vegetation biomass, soil respiration, and soil moisture, which are valuable for studying vegetation cycles.

Characterizing and verifying vegetation

Scientists use the flux data in a variety of ways, including computer models that simulate how weather, climate, and vegetation ecosystems interact. Tim Wilson, a researcher with the National Oceanic and Atmospheric Administration (NOAA), is working with colleagues to create a time series of data that will provide modelers with vegetation characteristics for sites across the United States. Wilson said, “We collected data from eleven flux towers covering grasslands, deciduous forests, evergreen forests, croplands, and desert.” The towers provided a broad cross-section of vegetation types in the United States.

Wilson used data from these eleven towers to calculate the normalized difference vegetation index (NDVI) and Leaf Area Index (LAI), indicators of overall plant health, seasonal growth, and changes in the amount of leaf and vegetation cover in the ecosystem surrounding the tower. "NDVI and LAI data can reveal an ecosystem's role," Wilson said. "If you mischaracterize the vegetation, you mischaracterize the distribution of the energy, water, and carbon budgets."

To confirm his calculations and eliminate faulty data, Wilson needed a second data source. However, he had additional field measurements from only one of the crop sites. So, he and his colleagues compared his NDVI and LAI calculations from flux towers to subsets of data from the Moderate Resolution Imaging Spectroradiometer (MODIS) instrument aboard the NASA Terra and Aqua satellites, also located at the ORNL DAAC. He found that the ground-based and satellite-based measurements agreed. "The overall patterns were consistent and reproduced the seasonal trend: growth in spring and summer, and die-off in fall and winter," Wilson said.

Although there are several remote sensing sources that could have supplied appropriate data, Wilson chose MODIS data because of its ease of use. The ORNL DAAC had created special subsets of MODIS data that correlated specifically to the flux tower locations Wilson was studying. "MODIS data provided the best way to tell that our flux tower measurements made sense," Wilson said.

Revealing a greener Amazon

Other scientists are also applying this combination of ground- and space-based data to verify their observations of vegetation cycles around the globe. Alfredo Huete, at the University of Arizona, used a similar combination to study vegetation in the Amazonian rainforest in South America. Huete said, "Rainforests worldwide play a large role in global energy budgets because of their ability to store carbon dioxide, a greenhouse gas." Like the erosive farm practices on the Great Plains during the early 1900s, human land-use activities, such as clear-cutting and burning of forests, are shrinking the size of many of the world's rainforests and affecting their ability to store carbon. More accurately characterizing rainforest vegetation may help climate modelers understand how much carbon the forests are absorbing, and allow them to better investigate the forest's roles in mitigating climate change.

First, however, Huete and his colleagues needed to solve a problem. Traditional remotely sensed NDVI measurements can reach a point of saturation, beyond which they underestimate the vegetation cover, particularly in densely forested areas like the Amazon. To overcome this limitation, Huete calculated an Enhanced Vegetation Index (EVI) from MODIS land-cover data, which is available from the Land Processes DAAC. The EVI calculations corrected the saturation problem and provided the full canopy conditions in the Amazon.

Instead of going dormant during the dry season, Huete discovered that vegetation in the Amazon responded to the increased amount of sunlight and became 25 percent more green and productive. His finding defied the long-held belief that the Amazon rainforests either decrease in productivity during the dry season, or remain the same year-round. Traditional NDVI and LAI measurements were not sensitive enough to see seasonal changes in the Amazon rainforest canopy, causing scientists to mischaracterize the vegetation cycle for the entire region. Huete said, "Dozens of papers were based on rainforest cycles being flat, with no seasonality, or assumed that rainforest vegetation would green up primarily in response to rainfall." Huete's finding meant that rainforests were very seasonal and that sunlight during the dry season was the main driver.

About the scientists

Alfredo Huete is a professor at the University of Arizona. As a member of the Moderate Resolution Imaging Spectroradiometer (MODIS) science team, he develops, implements, and validates vegetation index products. His research interests include using satellite-based applications to study soil-vegetation-climate interactions, including tropical and arid ecosystems, drought, and land degradation. He holds a PhD from the University of Arizona. NASA funded his research.

Tim Wilson is an Atmospheric Research Scientist at NOAA's Air Resources Laboratory at the Atmospheric Turbulence and Diffusion Division (ATDD) in Oak Ridge, Tennessee. Wilson received his PhD in Soil Science from the University of Wisconsin-Madison. He works principally with surface energy budgets and carbon flux processes using data collected at research towers across the United States as a contribution to NOAA's Climate Program. NASA provided support for his research.

To verify their findings, the researchers used data from flux towers stationed throughout the Amazon. "The flux towers may be the only in situ data source that has continuous time series," Huete said. "We were seeing a pattern that was not seen before in the NDVI data. No one would have accepted the satellite data results if it were not for the independent flux tower data," Huete said. Comparing the two data sources provided confidence that the MODIS EVI data successfully recorded more accurate vegetation conditions.

Future focus

Huete's findings may help scientists better understand the carbon budgets of tropical forests. He is also curious about other rainforests, particularly in Southeast Asia where human activity has had a much larger impact. He is planning to use MODIS EVI calculations to observe how the resulting vegetation is regenerating, and if it is beginning to respond to sunlight during the dry season. "With EVI, we have this enhanced sensitivity, so now we're looking to see what we missed before," Huete said. Understanding the energy cycles of new-growth forests will help scientists understand how much atmospheric carbon new growth is absorbing. Wilson plans to continue studying the eleven selected sites in the United States and comparing them to MODIS data to fully characterize the vegetation at each site. Wilson said, "Our goal is to provide people with additional information about our sites when we give them our flux tower data." By giving users more detailed information about the vegetation conditions present when tower measurements were made, Wilson's study provides data that may improve the accuracy of climate vegetation models.

MODIS data, combined with flux tower data, are giving scientists and modelers instant access to information about Earth's various ecosystems, whether they are rainforests half a world away or croplands next door. And this developing time series of flux records will help scientists understand ecosystem health and provide insight into how Earth's vegetation is faring. "People use these data in climate models so they can see what the vegetation is doing now and understand what the vegetation might do under future conditions," Wilson said. "That's why this information is critical."

To access this article online, please visit http://nasadaacs.eos.nasa.gov/articles/2007/2007_fluxnet.html.

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For more information

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

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

Moderate Resolution Imaging Spectroradiometer (MODIS)
http://modis.gsfc.nasa.gov/

FLUXNET
http://www.fluxnet.ornl.gov/fluxnet/index.cfm

About the data used

Source	Terra and Aqua	Flux towers	Terra and Aqua
Sensor	Moderate Resolution Imaging Spectroradiometer (MODIS)	Radiometer Three-Dimensional Sonic Anemometer Thermometer (SAT) Fast-response infrared gas analyzer	MODIS
Data sets used	MODIS ASCII Subsets	LAI NDVI	MODIS Land Products
Resolution	7 by 7 kilometers		1,200 by 1,200 kilometers
Parameter	Vegetation Indices Leaf Area Index (LAI) Normalized Difference Vegetation Index (NDVI)	Vegetation indices LAI NDVI	Vegetation indices LAI Enhanced Vegetation Index (EVI)
Data center	NASA Oak Ridge National Laboratory (ORNL) DAAC	NASA ORNL DAAC	NASA Land Processes DAAC

Getting at groundwater with gravity

> "Around the world, the availability of groundwater has actually affected the economic success or failure of a region."
>
> Sean Swenson
> National Center for Atmospheric Research

by Gloria Hicks

In southwestern Nebraska, a boom fueled by groundwater is going bust. In the 1970s, new irrigation technology made it possible to grow corn, which is much more lucrative than dryland wheat, in this sandy region. Farmers moved in, drilled wells, and planted new cornfields. But by the late 1970s, groundwater levels had already begun to fall. Thirty years later, towns shrivel as farms decline and families leave for greener pastures.

"Around the world, the availability of groundwater has actually affected the economic success or failure of a region," said Sean Swenson, a researcher in the Advanced Study Program at the National Center for Atmospheric Research (NCAR). "According to the United States Geologic Survey (USGS), 50 percent of people's fresh water comes from the groundwater found in wells. In rural areas, that rises to 90 percent." Whether for personal or commercial use, humans heavily depend upon the availability of groundwater.

With so much depending upon fresh water, local and national officials have long recognized the need for measuring groundwater resources; in some areas, they have established a systematic groundwater observation program. Yet groundwater resources sprawl across huge sections of land, crossing community and political boundaries and making it hard to understand how much water actually flows under any given tract of land. To better understand this essential resource, researchers have developed an innovative model to assess the amount of groundwater available over large areas. This model uses data from instruments on a new pair of satellites that measures changes in the Earth's gravity.

A renewable resource in danger

In May 2006, Colorado State Engineer Hal Simpson ordered the shutdown of 400 wells

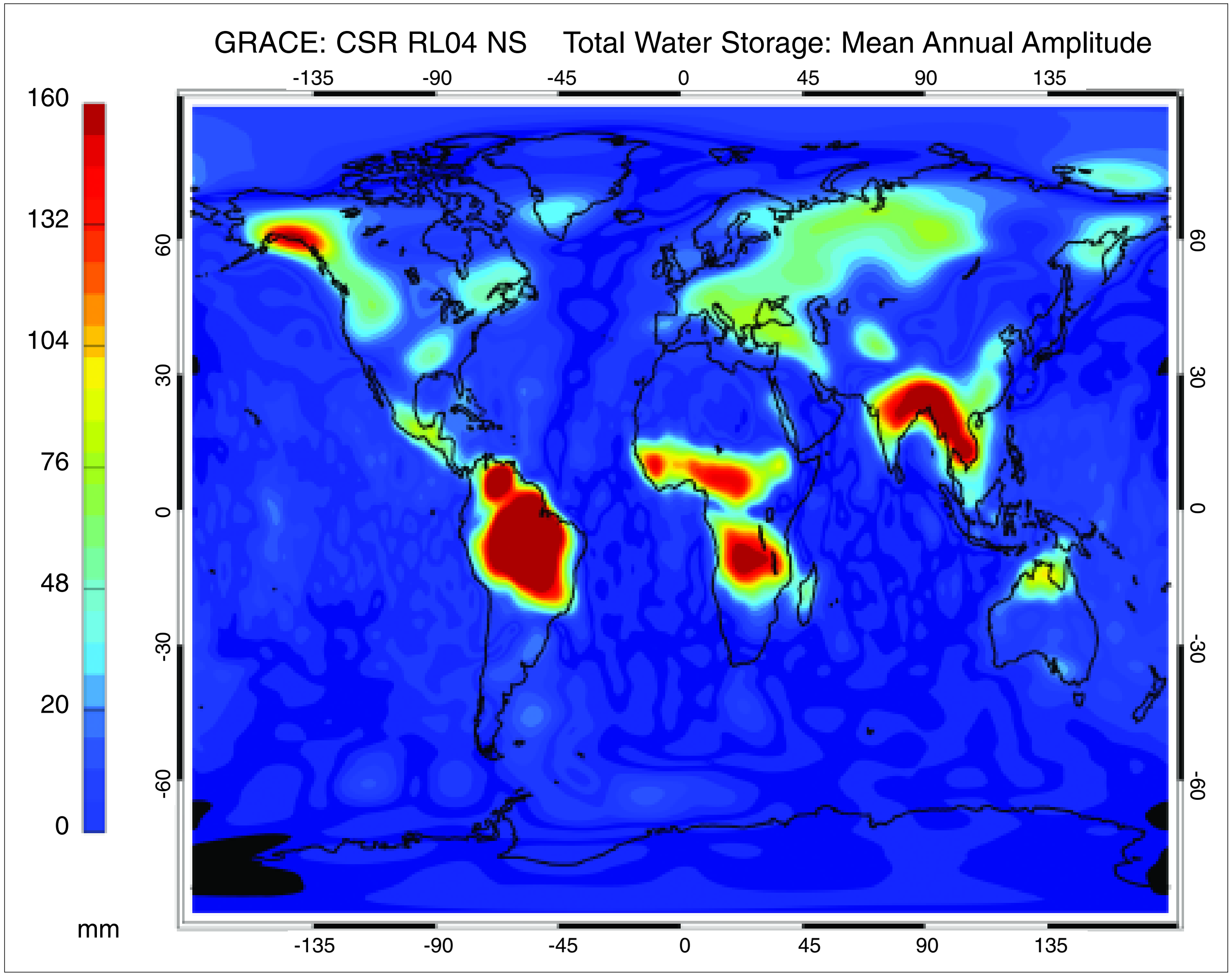
Irrigation allows farmers to grow water-thirsty corn on the relatively arid plains of the western and midwestern United States. But overuse of groundwater supplies can quickly deplete sources like the Ogallala aquifer, which underlies much of the Great Plains. (Courtesy Photos.com) in Platte County, Colorado, to ensure water for contracts downstream. As a result, the Colorado farmers who relied on these wells for their crops were out of business for the year.

"In some places, it's unclear how much groundwater exists, and it's unclear how fast it's going to run out," Swenson said. "You get a certain amount of recharge every year, and if you exceed that, eventually you're going to use up all of your resource. It will be gone."

Despite the estimated 16 million cubic kilometers (3.8 million cubic miles) of groundwater flowing under the Earth's surface, wells and springs often fail to provide enough water when and where it is needed. On a national level, the USGS assesses the nation's water supply, but determining if the regional water supply matches the regional need challenges local, state, and national agencies. Bill Alley, head of the USGS Office of Ground Water, said, "For certain aquifers, we have a pretty good program underway to track what is happening in that system, but there are other regions where we have very little consistent information over a period of time."

Searching for water from space

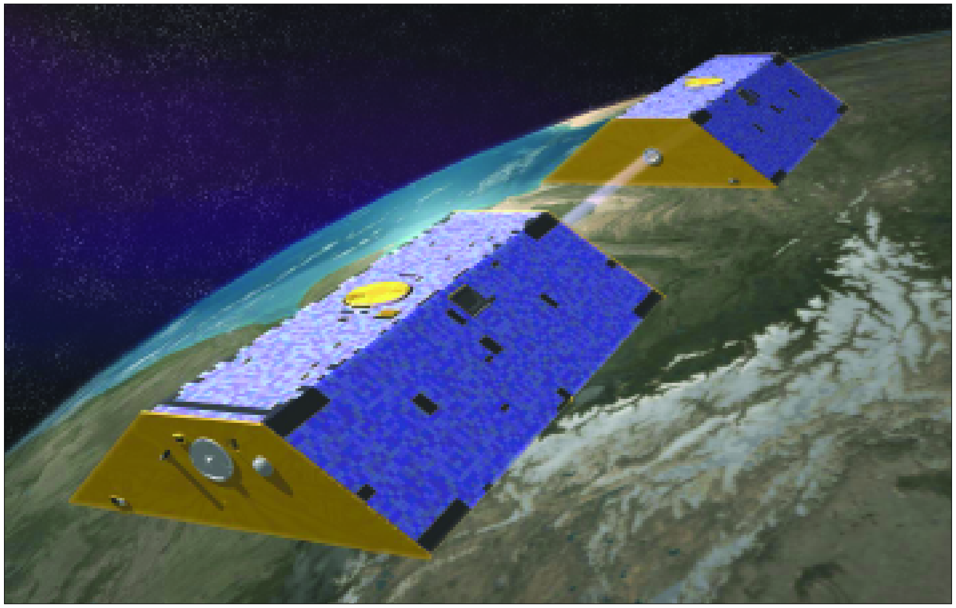
Part of the reason that groundwater monitoring is difficult on a regional scale has to do with measurement methods. Swenson said, "The traditional way to measure groundwater is to dig a well and monitor the water-table level in the well, but a well's water level doesn't translate exactly to groundwater storage. You need to know the properties of the soil subsurface and the aquifer composition to actually determine that." These aspects of the groundwater system help determine



NASA's twin Gravity Recovery and Climate Experiment (GRACE) satellites can detect groundwater by measuring subtle variations in Earth's gravity. This image shows the world's average annual cycle of water storage on land, computed from four years of GRACE gravity data. Colors indicate how much groundwater comes and goes, each year, in various regions; red indicates high levels of annual fluctuation, grading to blue, which represents lower levels of fluctuation. (Courtesy Sean Swenson)

the amount of groundwater that an area will typically store. "Basically, different aquifers store different amounts of water," he said.

Until recently, water resource agencies and scientists used only the data gathered by traditional methods to develop water usage models or to determine actual local usage. But starting in 2002, that changed. NASA and the German Research Institute for Aviation and Space Flight (Deutsche Forschungsanstalt für Luft und Raumfahrt) launched two new satellites, flying on the same track about 220 kilometers (137 miles) apart



As this diagram illustrates, the Gravity Recovery and Climate Experiment (GRACE) mission uses two satellites flying in a tandem orbit. By measuring changes in the distance between the lead satellite and the trailing satellite, scientists can determine changes in the Earth's gravity. (Courtesy NASA/JPL-Caltech)

People have long depended on groundwater for drinking water, farming, and commercial uses. When groundwater dries up, so can the communities that depend on it. Windmills scattered across the Great Plains mark where people have brought groundwater to the surface. (Courtesy Photos.com)

and 500 kilometers (310 miles) above the Earth. This project, called the Gravity Recovery and Climate Experiment (GRACE), measures changes in the Earth's gravity.

But how do gravitational differences tell scientists about the presence of groundwater? If the Earth were a perfectly round sphere, any point on the planet's surface would have the same average gravity field. However, mountains, deep oceanic trenches, and other features cause minute changes in Earth's gravity. Just as these mountains and deep trenches change the Earth's gravity field, so do changes in the amount of groundwater. A satellite's orbit above Earth is partly determined by gravity. So, slight changes in the distance between the twin GRACE satellites as they pass over Earth's features indicate changes in Earth's gravitational field. Scientists can then track differences in the Earth's gravity field from data retrieved from the GRACE satellites, improving their understanding of how water is moving and cycling around the planet.

Scientists like Swenson download and analyze GRACE data from the NASA Physical Oceanography Distributed Active Archive Center (PO.DAAC) to measure groundwater globally over large areas. Swenson calculated the groundwater levels by analyzing the GRACE data and using models to estimate and subtract soil moisture levels. Swenson said, "The GRACE data provide a broad-scale picture of groundwater supplies, which complements local well measurements."

During the last two years, Swenson has repeatedly confirmed that satellites can provide a method to measure groundwater over entire regions. The success of this approach could help speed the development of a national monitoring system. By combining ground and space observations, the USGS and other national agencies can obtain a more comprehensive picture of groundwater availability across the United States. With this larger picture, the USGS, state, and local decision makers could work together to conserve shrinking groundwater. "Ultimately, researchers want to see the data being applied in some way. We want it to be useful to people who make decisions," said Swenson.

National groundwater: the endgame

At the USGS Office of Ground Water, Alley continues to develop an agenda for a national network of systematic monitoring. However, he has found a number of obstacles in the way of a national program. He said, "Installing wells for monitoring is very expensive and existing wells are limited, which makes the development of a good program tough. Satellite monitoring of changes in groundwater storage over large regions is a promising supplement to land-based monitoring methods."

Still another challenge for Alley exists in the very nature of groundwater. "The amount of groundwater in storage fluctuates between recharging and discharging periods. The GRACE data provide a new way to achieve precise estimates of seasonal and interannual variations in groundwater storage over large river basins or aquifers worldwide, estimates that have not been previously available," he said.

Despite the challenges, Alley believes that regional officials and scientific researchers remain tuned in to the need to measure the essential resource that groundwater provides. "We need to understand the impact we're having on groundwater from pumping and land-use activities and how that is playing out over time," Alley said. "With this information, we will be able to better manage the resource."

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

Gravity Recovery and Climate Experiment (GRACE)
http://www.csr.utexas.edu/grace/

National Ground Water Association
http://www.ngwa.org/

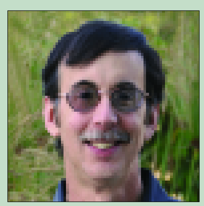
United States Geological Survey
Ground Water Information
http://water.usgs.gov/ogw/

United States Geological Survey
Office of Ground Water
http://water.usgs.gov/ogw/bgas/mission.html

About the remote sensing data used

Satellite	Gravity Recovery and Climate Experiment (GRACE)
Data set used	GRACE L-2 products, version RL03
Resolution	400 kilometers
Parameter	Gravity
Data center	NASA Physical Oceanography DAAC

About the scientists



William M. Alley is a geologist with the United States Geological Survey (USGS) and currently serves as Chief of the USGS Office of Ground Water. Alley works specifically in the field of water resources and has received numerous awards, including the Shoemaker Award for Lifetime Achievement in Communication and the Meritorious Presidential Rank Award in 2006.

Sean Swenson is currently a postdoctoral fellow in the Advanced Study Program at the National Center for Atmospheric Research. His recent research involves validating Gravity Recovery and Climate Experiment data and applying those data to studying water cycles. He received his PhD from the University of Colorado at Boulder.

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