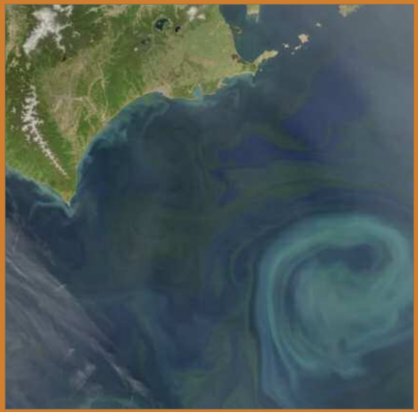
National Aeronautics and Space Administration

Sensing Our Planet



NASA Earth Science Research Features **2010**

Sensing Our Planet

NASA Earth Science Research Features *2010*

National Aeronautics and Space Administration

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

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Front cover images

Top row, left to right:

A workshop participant practices stem diameter measurements, near Concepción, Bolivia. See the related article, "Seeing the forest for the carbon," on page 42. (Courtesy W. Walker)

In this image from the NASA Aqua satellite, a swirling phytoplankton bloom becomes visible from space when warm waters from the Kuroshio Current collide with the frigid waters of the Oyashio Current off the eastern coast of Japan. See the related article, "Probing the Black Current," on page 22. (Courtesy N. Kuring, MODIS Ocean Color Team)

Honeybees are helping remote sensing scientists understand how earlier spring arrival might affect plant-pollinator relationships. See the related article, "Clues in the nectar," on page 34. (Courtesy P. Stein)

The Clouds and the Earth's Radiant Energy System (CERES) Ocean Validation Experiment (COVE) lighthouse site lies fifteen miles east of Chesapeake Bay, in the Atlantic Ocean. Here, instruments help verify satellite measurements taken over the ocean. See the related article, "A speck on the ocean," on page 2. (Courtesy S. Smith, NASA Langley Research Center)

Bottom row, left to right:

Glacial drift during the Pleistocene period deposited sand and silt along the Kobuk Valley in northwestern Alaska, and later strong winds swept the sand into the Great Kobuk Sand Dunes, shown in the photograph. Although slow moving, these dunes are classified as active, with characteristically steep, crisp surface features. See the related article, "Unearthly dunes," on page 6. (Courtesy U.S. National Park Service)

Prayer flags frame Ama Dablam Peak in the Nepalese Himalaya. Understanding what is happening to the glaciers is critical not just for the region's water resources, but also because of the cultural significance of both the mountains and the glaciers. See the related article, "Himalaya's heat pump," on page 10. (Courtesy P. Columba)

This stovepipe tornado formed on May 31, 2010, near the border between Colorado and Oklahoma. Scientists are investigating how soil moisture might influence tornadoes—rotating columns of air that extend from storm clouds down to the ground. See the related article, "The dirt on tornadoes," on page 26. (Courtesy W. Owen)

Back cover images

Top row, left to right:

This photograph looking back at the Earth and moon was taken by the unmanned Galileo spacecraft on its way to Jupiter. Galileo traveled almost three billion miles, a journey that took six years, and then spent almost eight years orbiting Jupiter. Small imprecisions in its launch trajectory could have caused a miss in this long target, so scientists carefully calculated Earth's orientation at the moment of launch. See the related article, "When a day is not a day," on page 14. (Courtesy NASA JPL)

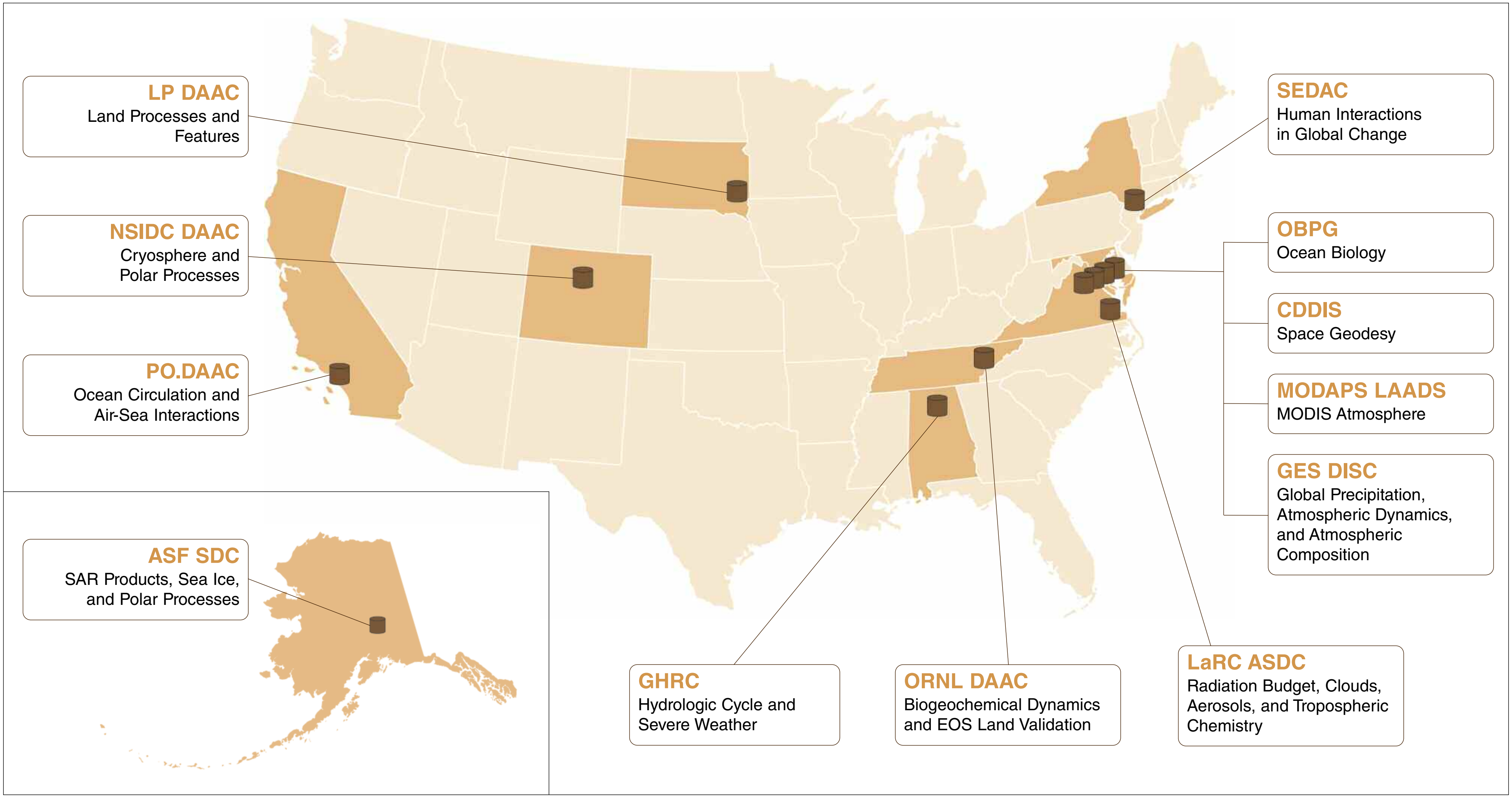
Makeshift shelters dot Haiti after the January 2010 earthquake, as residents struggle to recover from its devastation. See the related article, "On shaky ground," on page 18. (Courtesy United Nations Development Programme)

Bottom row, left to right:

Thunderstorms discharge electricity as both cloud flashes and ground flashes, as shown in this photograph. Each type of lightning may have different effects on air quality and atmospheric electricity. See the related article, "Cosmic charges," on page 38. (Courtesy K. Arnett)

A brownish-white haze hangs low over New York City, as seen in this view from the Brooklyn Bridge. Haze is caused by fine particulate pollution in the air; breathing this polluted air may harm human health in unexpected ways. See the related article, "Heart disease in the air," on page 48. (Courtesy Health Head Images/Unlisted Images, Inc.)

Mnemiopsis leidyi is a species of ctenophore, or comb jelly, that is native to the western Atlantic Ocean, and invasive in many European seas. Ctenophores get their name from the ctenes, or combs, that run down their bodies and help them to swim. In the 1980s, *Mnemiopsis* was introduced in the Black Sea, where it rapidly multiplied and outcompeted other small species. See the related article, "Invasion of the ctenophores," on page 30. (Courtesy E. Ovis)



About the EOSDIS data centers

The articles in this issue arose from research that used data from NASA Earth Observing System Data and Information System (EOSDIS) data centers. The data centers, managed by NASA's Earth Science Data and Information Project (ESDIS), offer more than 4,000 Earth system science data products and associated services to a wide community of users. ESDIS develops and operates EOSDIS, a distributed system of data centers and science investigator processing systems. EOSDIS processes, archives, and distributes data from Earth observing satellites, field campaigns, airborne sensors, and related Earth science data. These data enable the study of Earth from space to advance scientific understanding.

For more information

"About the NASA Earth Observing System Data Centers" (page 52)

NASA Earth System Science Data and Services
http://nasadaacs.eos.nasa.gov

NASA Earth Science Data and Information Project
http://esdis.eosdis.nasa.gov

NASA Earth Science
http://science.nasa.gov

About *Sensing Our Planet*

Each year, *Sensing Our Planet* features intriguing research that highlights how scientists are using Earth science data to learn about our planet. These articles are also a resource for learning about science and about the data, for discovering new and interdisciplinary uses of science data sets, and for locating data and education resources.

Articles and images from *Sensing Our Planet: NASA Earth Science Research Features 2010* 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 eosdis.editor@nsidc.org with ideas for future articles.

The design featured in this issue represents a blooming flower. Several stories for 2010 spotlight small or quiet players in nature that can signal significant changes in Earth's patterns and processes. See "A speck on the ocean" on page 2; "Clues in the nectar" on page 34; and "Seeing the forest for the carbon" on page 42.

Acknowledgements

This publication was produced at the Snow and Ice Distributed Active Archive Center (DAAC), at the National Snow and Ice Data Center, under NASA GSFC contract No. NNG08HZ07C, awarded to the Cooperative Institute for Research in Environmental Sciences at the University of Colorado at Boulder. We thank the EOSDIS data center managers and personnel for their direction and reviews, and the scientists who alerted us to recent research that made use of EOSDIS data.

We especially thank our featured investigators for their time and assistance.

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Sensing Our Planet

NASA Earth Science Research Features *2010*

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A speck on the ocean

> "Clouds are one of our major wildcards for studying climate."
>
> Greg Schuster
> NASA Langley Research Center

by Jane Beitler

Most days, Fred Denn gets in his car and takes the expressway to work, like regular people. Once or twice a month, he instead boards a helicopter to commute east from Virginia's Chesapeake Bay to an eighty-foot square lighthouse platform, more than fifteen miles out to sea.

Normally behind desks and computers processing science data, Denn and colleagues Bryan Fabbri and Bob Arduini pull out their to-do lists and get to work checking, repairing, and calibrating an array of scientific instruments that NASA maintains on the U.S. Coast Guard platform. Denn said, "We're part of a project to measure climate change. Satellites measure the entire Earth and we measure one spot, and compare our measurements to the satellite." Slowly, they are helping to build a long and detailed record that helps researchers understand how Earth's atmosphere and clouds work together to retain

At the CERES Ocean Validation Experiment (COVE) lighthouse site, Bryan Fabbri (left), Fred Denn (middle), and Bob Arduini check on several instruments on top of the lighthouse tower. The instruments help validate satellites that measure clouds and Earth's energy budget. (Courtesy S. Smith, NASA Langley Research Center) and reflect thermal energy, making and changing the globe's climate.

Clouds, clouds, and clouds

Some days, clouds blanket the sky at the site, which is part of the CERES Ocean Validation Experiment (COVE). Those measurement days are important to COVE, because clouds affect the exchange of heat in varied and complex ways. For instance, cloud cover can hold heat in like a blanket at night, or reflect solar energy back to space and keep you cool during the day, depending on the type of cloud. Likewise, the lack of cloud cover on a clear, cool night makes gardeners rush out to cover plants against frost, as heat escapes and the atmosphere cools more intensely than on a cloudy night.

COVE has a small but significant role in the Clouds and the Earth's Radiant Energy System (CERES), a long-running NASA experiment to study Earth's atmospheric heat system. CERES integrates a suite of satellite observations to measure how Earth is holding or radiating heat, what scientists call Earth's energy budget.

Denn said, "You could think of it as a sphere that is outside of the Earth's atmosphere, that encloses the entire Earth system. We're measuring the amount of energy coming in and out of that sphere." If the balance of heat retained or radiated out to space by land, oceans, and atmosphere changes over time, then our planet and its climate will warm or cool.

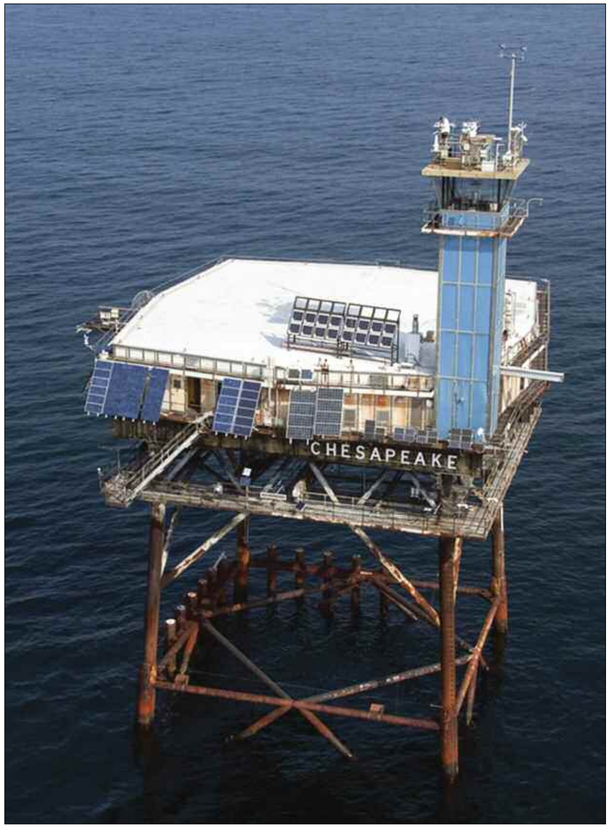
CERES focuses on how Earth's energy balance may be changing over the long term, and investigates what roles clouds play. Researchers learned from previous studies that getting the cloud cover right matters when measuring the movement of radiation, or heat, from ground to sky. Ongoing since 1997, CERES followed on an earlier remote sensing study of Earth's energy balance, the Earth Radiation Budget Experiment (ERBE), which collected data on radiation from 1984 to 2005.

COVE project lead Greg Schuster said, "During ERBE they were trying to figure out if clouds cooled the climate or warmed the climate. You have low clouds that are very bright, so sunlight gets reflected up. Then there are high cirrus clouds that basically block the outgoing longwave radiation, the same way greenhouse gas will block radiation from leaving the planet. You've got two different types of clouds with two different effects, and which one dominates? Back then the conclusion was that the low clouds cool the planet slightly."

But researchers still had many essential questions about clouds and climate, so CERES was specifically designed to detect cloud height, thickness, and amount, along with radiation. "Clouds are one of our major wildcards for studying climate," Schuster said. "What happens if climate warms up? More water evaporates, and makes more clouds. Does it make high clouds, or low clouds?" This raises a scenario for systems feedback: a warming climate could produce high clouds that accelerate warming even more, or low clouds that cool the planet.

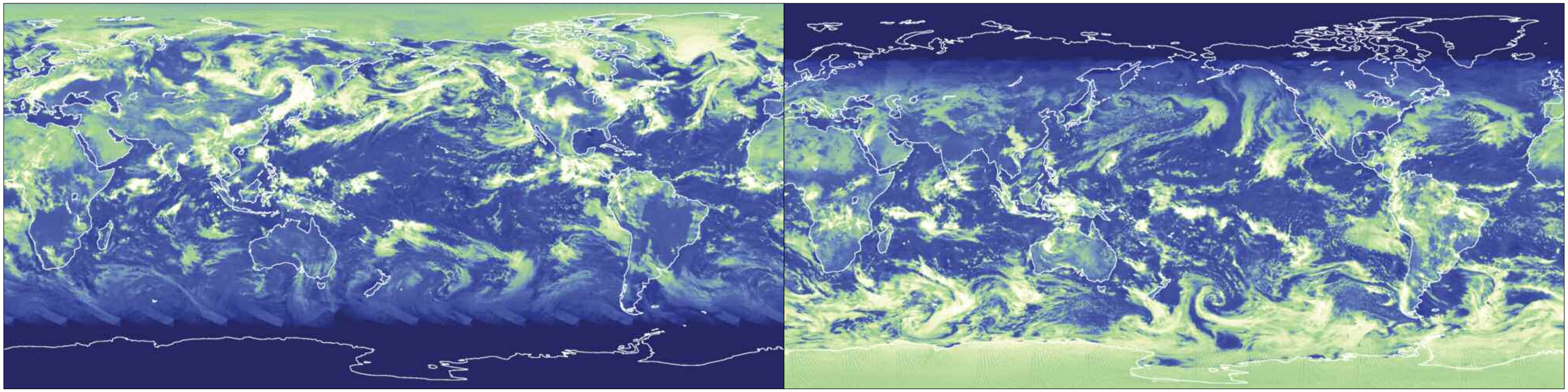
Ocean and atmosphere

The small COVE site helps align the view from the sky with reality on the ground. On a clear day, the COVE team may be able to look up from their man-made deserted island through the upper atmosphere, and see the sun brightly shining overhead. At the same time, satellites orbiting the Earth look down on the lighthouse. Denn said, "When the satellite looks at the lighthouse site, it sees only water." The seeming invisibility of the lighthouse platform to satellites is precisely why the instruments were placed here: this small square is the closest thing to placing instruments on the ocean surface.



The Clouds and the Earth's Radiant Energy System (CERES) Ocean Validation Experiment (COVE) lighthouse site lies fifteen miles east of Chesapeake Bay, in the Atlantic Ocean. Here, instruments help verify satellite measurements taken over the ocean. (Courtesy S. Smith, NASA Langley Research Center)

Comparing ocean surface readings with satellite measurements helps to validate the global data.



These images from NASA's Clouds and the Earth's Radiant Energy System (CERES) sensor on the Terra satellite compare reflected solar radiation from June 20, 2009, the day before the summer solstice (left), and December 22, 2009, the day after the winter solstice (right). At the summer solstice, the North Pole is in constant daylight, while the South Pole is in darkness. At the winter solstice, the opposite is true: the North Pole is in darkness. Dark blue colors in the Arctic regions of the right image show the lack of reflected radiation. Greens, yellows, and whites indicate higher levels of reflected radiation in higher latitudes. (Courtesy NASA/T. Wong and the CERES Science Team at NASA Langley Research Center)

Denn said, "We are data collectors, trying to assess whether or not data actually represent what we are trying to measure." Oceans cover 71 percent of Earth's surface, so accurate measurements over the oceans are a large part of the energy equation. The ocean, however, does not afford many solid surfaces for placing instruments.

Schuster said, "The advantage of the COVE site is that the surface is surrounded by water. In contrast, island sites can have their own local weather. The island will heat up, so clouds will form over the island, and the instruments on the island will look up and see a cloudy day. The satellite will look down at the island and see a tiny speck with a few clouds, and call it a clear day, so it's a mismatch."

Overhead, CERES atmospheric instruments fly in pairs on the NASA Terra and Aqua satellites, with each instrument collecting data on radiation, aerosols, and other atmospheric properties. On the same satellites, imaging instruments such as the Moderate Resolution Imaging Spectroradiometer (MODIS) provide cloud properties by sensing their unique wavelengths. Computer models then gather all these data into a complete profile of the atmosphere's radiative properties and cloud cover for the entire globe. The CERES data are available to researchers via the NASA Langley Research Center Atmospheric Science Data Center (LaRC ASDC).

Schuster said, "We've got satellites that measure the energy budget at the top of the atmosphere, and then ways to infer the energy budget at the surface, so we can capture the radiative properties of entire columns of the atmosphere as the satellites pass over the Earth. The COVE data indicate that we're doing a better job of computing what is at the surface than at other locations."

A long time series

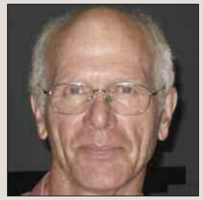
While only a single validation site, COVE plays an important role in the accuracy of these global satellite measurements. Fabbri said, "There's no other validation site like this in the world; to our knowledge, it's the only true water site. When modeling flux from the top of the atmosphere to the surface, COVE data model the best."

So the COVE team maintains its regular flights to the lighthouse site. Fabbri said, "We fix instruments when something breaks, or if we have a new instrument, we test it in the lab first and then deploy it to the lighthouse. We have to maintain power and communication systems. We have solar power, a generator, large batteries, and two wind generators." The lighthouse itself is fully automated and unmanned, so they have to be self-sufficient too. Denn added, "We're off of the grid. It's a self-contained structure. We take our own food and water. If we had to stay for three weeks, we have enough." Happily, they have never been stranded that long. Usually, the helicopter fetches the team back to land and home at the end of the day—except on the occasions they plan to stay overnight, or are marooned by bad weather.

Denn said, "It's great fun working out there, as long as there's a lot to do." And there is still a lot to do to understand clouds and energy, so they hope to continue the trips for years to come. Fabbri said, "We need more measurements that quantify clouds and Earth's energy budget better. That's why multiple satellites have gone up: the longer time series you have, the more information we have on the effects of clouds."

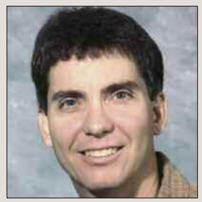
To access this article online, please visit http://nasadaacs.eos.nasa.gov/articles/2010/2010_cove.html.

About the scientists



Fred Denn is a research scientist at Science Systems and Applications, Inc. He has worked on the Clouds and the Earth's Radiant Energy System (CERES) Ocean Validation Experiment (COVE) for the last ten years. He was involved with the initial installation at the COVE site, and numerous instrumentation and infrastructure upgrades. He has also been involved in data analysis and interpretation. NASA supported his research. (Photograph courtesy F. Denn)

Bryan Fabbri is a research scientist at Science Systems and Applications, Inc. and has worked on the Clouds and the Earth's Radiation Experiment (CERES) Ocean Validation Experiment (COVE) since 2000. Fabbri's work focuses on maintaining, troubleshooting and calibrating instrumentation, launching radiosondes for various projects, and data analysis of measurements collected at COVE. NASA supported his research. (Photograph courtesy B. Fabbri)



Greg Schuster is the lead scientist for the Clouds and the Earth's Radiant Energy System Ocean Validation Experiment (COVE) at NASA Langley Research Center. His work has focused on the retrieval of aerosol composition and sensitivity of black carbon retrievals to dust and organic carbon. NASA supported his research. (Photograph courtesy NASA)

About the remote sensing data used

Satellites	Terra and Aqua
Sensor	Clouds and the Earth's Radiant Energy System (CERES) Instrument
Data set	Clouds and Computed Flux Profile Data Sets
Resolution	Globally averaged, gridded regional, zonally averaged
Parameter	Clouds and computed flux profile
Data center	NASA Langley Research Center Atmospheric Science Data Center (LaRC ASDC)

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For more information

NASA Langley Research Center Atmospheric Science Data Center (LaRC ASDC)
http://eosweb.larc.nasa.gov

CERES Ocean Validation Experiment (COVE)
http://cove.larc.nasa.gov

Clouds and the Earth's Radiant Energy System (CERES)
http://ceres.larc.nasa.gov

Unearthly dunes

"For Mars, the real interest in sand dunes is to find out just how alive the planet is."

Donald Hooper
Southwest Research Institute

by Natasha Vizcarra

In 1972, scientists eagerly awaited images from NASA Mariner 9 as it mapped the surface of Mars for the first time. The orbiter sent back thousands of images of craters, canyons, and fields of sand dunes. Succeeding NASA missions took more photos of the Red Planet over the next thirty-five years. But these missions yielded more images of unmoving landscapes. Although fascinating and a source of new research for many scientists, the images of these still landforms disappointed geomorphologists, who study land surfaces and the processes that shape them. "On Mars, we are always looking for signs of active surface processes like erosion, or evidence of wind and water—any sign of something happening on the planet today," geologist Donald Hooper said.

Then in 2008, researchers looked more closely at the images that the Mars Global Surveyor took of the planet's north polar region, and found dunes that shrank or completely disappeared over three Martian years (six Earth years). Curiously, the

Curved barchan dunes and a straight seif dune lie in the north polar region of Mars, where the first significant change to sand dunes was detected in 2008. The study reported that two twenty-meter-wide dome dunes disappeared and a third shrank by 15 percent in three Martian years (six Earth years). (Courtesy NASA/JPL/University of Arizona) surrounding dune field showed no other changes. "Since that discovery, scientists have wanted to know whether the surrounding dunes are also active," Hooper said. With sparse data on Mars, scientists turned to sand dunes on Earth, to gain insight that would help them study and interpret dunes on Mars. They chose a location that is most similar to the north polar dune fields of Mars: the Great Kobuk Sand Dunes in Alaska.

A terrestrial analog

"This dune field is one of the few places on Earth where we can go and study an example of how the dunes probably are on Mars," Hooper said. Scientists think that dune fields on Mars are locked in place somehow by frozen gases. "Because these dunes are indurated or cemented, it slows their migration rate," Hooper said. Hydrogeologist Cynthia Dinwiddie, Hooper's colleague at the Southwest Research Institute (SwRI), made the connection between Martian dunes and the Great Kobuk dunes. Dinwiddie said, "Dune fields in the polar regions of Mars are covered with carbon dioxide and water frost for three quarters of the Martian year. It got me thinking of Kobuk Valley in Alaska, where the dune system is covered with snow for three quarters of the year."

The Great Kobuk Sand Dunes is a butterfly-shaped dune system in northwestern Alaska, about sixty-five kilometers (forty miles) north of the Arctic Circle. Like most high-latitude, cold climate sand dunes, the Great Kobuk dunes move very slowly. Scientists believe that the dunes are slowed by the accumulation of snow and sand, and possibly by permafrost deep under the dune field. Although slow moving, most of the Great Kobuk dunes are classified as active, meaning the dunes still move, evolve, and are shaped by processes like wind and rain.

Reading the landscape

But what could an Alaskan dune field possibly reveal about dunes on another planet thirty-four million miles away? Hooper said, "Geomorphologists can look at the size and shape of dunes and the way they change or stay still, and be able to describe what kind of environment these dunes exist in." A barchan dune, for example, is a crescent-shaped dune with arms or horns that point downwind. It is found in areas where wind flows from only one direction and where there is little or no vegetation. Because there is no vegetation to hold it down, a barchan dune will move across this desert, and it will not need a large supply of sand to invoke its migration. So, just looking at a barchan dune already gives a scientist wind direction, the presence or absence of vegetation, and sand supply—all important hints to the dunes' environment.

"For Mars, the real interest in sand dunes is to find out just how alive the planet is," Hooper said. "We know there's wind on Mars, but we're still trying to identify active surface processes. Being able to detect something like a dune moving, or a landslide on a steep escarpment would give us indicators that the planet is actively changing."

To detect extremely slow sand dune movement on Mars, scientists need an efficient method to analyze thousands of large, high-resolution images. Dinwiddie said, "The resolution of the imagery for Mars is really good right now. Very recently, scientists have spotted movement of sand ripples on Mars. But researchers currently use brute force to identify movement—just looking at an image, then finding the next image of the same feature, and comparing the two."

Glacial drift during the Pleistocene period deposited sand and silt along the Kobuk Valley in northwestern Alaska, and later strong winds swept the sand into the Great Kobuk Sand Dunes, shown in the photograph. Although slow moving, these dunes are classified as active, with characteristically steep, crisp surface features. (Courtesy U.S. National Park Service)

A Kobuk flip book

The team decided to look at all available satellite images of the Great Kobuk dunes. SwRI colleague Marius Necsoiu led the development of a more efficient method to measure subtle changes in sand dunes in Kobuk, with the hope of developing it further for Mars research. He said, "Because the Great Kobuk dunes were covered by snow and ice a good number of months each year, the snow-free images that our team could use were very few. And when you are trying to detect slow changes, you need data that represent a long period of time."

Cynthia Dinwiddie and Donald Hooper perform a reconnaissance survey at a Kavet Creek cut bank in the Great Kobuk Sand Dunes in Alaska. At their immediate right are the water-darkened sands of groundwater seepage. A dune towers over their heads. (Copyright S. Kantner)

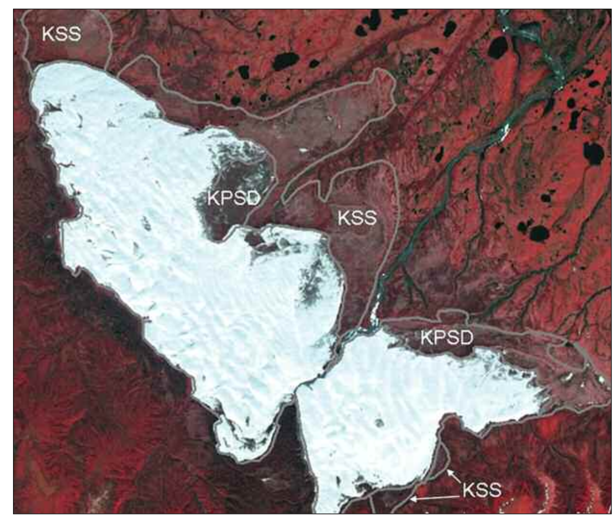
To increase their image selection, the team looked at several sources of data. They started with optical satellite images taken in 2003 by the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) sensor, flying on the NASA Terra satellite and obtained from the NASA Land Processes Distributed Active Archive Center (LP DAAC). "We then combined this with aerial photography taken by the U.S. Air Force and the U.S. Navy, in addition to images taken in 2008 by Spot Image Corporation," Necsoiu said. Combining images taken by different sources and from different viewing angles posed its own challenges. The researchers needed to convert all the images to the same size and orientation to observe changes in the sand dunes. Like a child's flip book that contains a series of pictures that are the same size but vary only gradually from one page to the next, the aerial images of the sand dunes had to be the same size and aligned the same way for the changes to appear accurately.

So Necsoiu and colleague Sebastien Leprince developed a method to co-register or align images at a high resolution, and to detect horizontal movement in the dunes. Dinwiddie said, "Marius came up with a more elegant way to find lateral changes in geomorphology. It has a real advantage over existing methods when you need to detect changes that are subtle, like changes within a year or over a season. It is also something that we hope to automate, so scientists can cover much wider areas of the planet."

Liquid in the sand

The resulting map showed that the Great Kobuk dunes moved at a rate of 1.3 meters (4.3 feet) per year from 2003 to 2008. The researchers were able to plot out the directions these dunes were moving. Dinwiddie and her team also conducted field studies at the Great Kobuk dunes and stumbled on a surprising feature within the dune system. "Using a ground-penetrating radar, we found a groundwater aquifer very near the land surface all throughout the entire active dune system," Dinwiddie said. "It caught us by surprise because we were there in March, after a long period of cold weather. We figured that any water within the dunes would be frozen, like permafrost, but instead we confirmed that the water was liquid by drilling several boreholes."

The scientists think that snow cover and this liquid water within the sand are slowing the movement of the dune field. "Think about how sand castles are constructed with the right amount of sand and water. If you pour dry sand out of a bucket, it flows like a liquid," Dinwiddie said. "Super-wet sand also behaves like a liquid. But moist sand enables you to build sand castles because it behaves like a solid. It will be resistant to wind action, and it's not going to move very



Scientists used aerial and satellite images, such as this 2003 ASTER color composite of the Great Kobuk Sand Dunes area, to track subtle sand dune movements. White indicates the main dune fields; grey outlines mark the stabilized sand sheet (KSS) and partly stabilized dunes (KPSD). (Courtesy Elsevier) fast." Could the slow movement of dunes on Mars also suggest the presence of water?

Hooper said, "Scientists have always been keen on following the water on Mars. We know that there is no surface water, but the thinking is that it may be below the surface. It may be locked into some of these dunes from rainfall from long ago, or from previous moisture patterns or river systems." The team continues to be intrigued by what they are learning from Kobuk. "It's really all about analogies," Hooper said. "Kobuk could tell us what could be happening on Mars."

To access this article online, please visit http://nasadaacs.eos.nasa.gov/articles/2010/2010_dunes.html.

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About the remote sensing data used

Satellite	Terra
Sensor	Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER)
Data set	ASTER L1A Reconstructed Unprocessed Instrument Data
Resolution	15 meter (VNIR)
Parameters	Reflectance, digital elevation
Data center	NASA Land Processes Distributed Active Archive Center (LP DAAC)

About the scientists

Cynthia Dinwiddie is a hydrogeologist at Southwest Research Institute (SwRI). She studies subsurface heterogeneity of terrestrial planetary bodies, and works with field and laboratory instrumentation and geophysical techniques to quantify hydrogeologic property distributions. Her research interests include developing integrated geophysical and remote-sensing site characterization studies. NASA and SwRI funded her research. (Photograph copyright S. Kantner)

Donald Hooper is a geologist at SwRI, where he specializes in geomorphology and volcanology. His research training and expertise includes field and remote sensing studies of deserts and desert landforms, modeling erosion and landscape evolution, volcanic processes and hazards, and planetary geology. SwRI supported his research. (Photograph courtesy D. Bannon/SwRI)

Marius Necsoiu is a remote sensing scientist at SwRI. His research interests include developing collaborative remote sensing and geospatial information solutions to Earth and planetary sciences problems, and climate change, risk assessment, and natural hazards evaluation using remote sensing. SwRI supported his research. (Photograph courtesy SwRI)

For more information

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

NASA Terra Satellite
http://www.nasa.gov/mission_pages/terra

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

Southwest Research Institute (SwRI)
http://www.swri.org

Himalaya's heat pump

"We still don't have a good idea of how much water is actually coming from glaciers, as opposed to coming from ice or snow."

Adina Racoviteanu
University of Colorado

by Laura Naranjo

From the air, the Himalaya Mountains resemble white meringue whipped into sharp peaks that froth from horizon to horizon. Look more closely, and the Himalaya are dotted by thousands of smaller peaks: temples, shrines, pagodas, and monasteries. For in Southeast Asia, water is everything, and these monuments testify how the Himalaya are revered as the birthplace of dozens of major rivers that help to sustain more than three billion people.

At the heart of this birthplace are 15,000 glaciers, frozen reservoirs whose meltwater feeds the rivers that flow through the mountains. In fact, the headwaters for India's holy river, the Ganges, issue from the massive Gangotri Glacier system.

Prayer flags frame Ama Dablam Peak in the Nepalese Himalaya. Understanding what is happening to the glaciers is critical not just for the region's water resources, but also because of the cultural significance of both the mountains and the glaciers. (Courtesy P. Columba)

Scientists and the media have skirmished over reports that the Himalaya's glaciers will melt by 2035; in reality the glaciers are in no danger of disappearing any time soon. But, like many glaciers in the region, the Gangotri overall is receding, leaving scientists to wonder what will happen to Asia's water supply if the glaciers continue to lose ice.

Gleaning data from glaciers

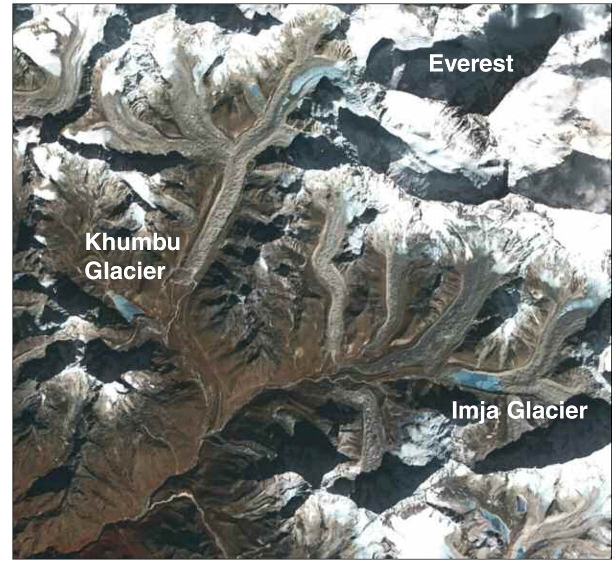
Information about individual glaciers is sparse because, just as snow and ice lay claim to the Himalaya, so do several countries. For instance, the region's longest glacier, the Siachen, winds through disputed territory administered by India but claimed by Pakistan. Boundary squabbles and political unrest compound the jagged, remote geography that makes travel and research in the Himalaya difficult.

One of the scientists investigating glaciers in the Himalaya is Jeffrey Kargel at the University of Arizona. He and his colleagues are looking at glacier shapes and outlines in the Himalaya to determine which glaciers are shrinking, growing, or remaining stable. Glaciers continually adjust their size and flow speed to seek equilibrium with climate, which is always shifting: for a glacier to remain stable, just enough annual snowfall must accumulate at the head of the glacier to balance out the seasonal melting that takes place near the foot of the glacier. Excess snow causes the glacier to grow, and excess melting will cause glacier recession. Scientists can often see these changes reflected in the glacier's extent and shape.

Although topographic maps and aerial images of the Himalaya provide a historical perspective on glacier extent, they often do not reflect recent glacier changes. Kargel and his colleagues needed newer glacier images for comparison. They used images from the Global Land Ice Measurements from Space (GLIMS) project, managed by the NASA National Snow and Ice Data Center Distributed Active Archive Center (NSIDC DAAC). GLIMS offers a global database of both glacier outlines and satellite imagery for studying glaciers.

However, there is a catch to using satellite imagery of the Himalaya glaciers, according to Adina Racoviteanu at the University of Colorado. Racoviteanu said, "The first challenge is choosing adequate images for glacier delineation—there are different factors to consider." It might seem simple to snap an image from space, but glaciers can be tricky to spot during certain times of the year. "Images need to be highly contrasted to detect glacier ice, and they should be acquired at the end of the ablation season, when the snow cover is minimal. Snow on the glacier surface poses challenges in mapping glaciers. Furthermore, in some parts of the Himalayas, monsoon clouds pose challenges for optical sensors because you can't see the glaciers," she said.

Much of the satellite imagery in the GLIMS database comes from the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) sensor, which provides photograph-like images of glaciers. Racoviteanu and Kargel, both members of the GLIMS team, made special requests to the NASA Land Processes Distributed Active Archive Center (LP DAAC), which archives ASTER data, to obtain images over specific glaciers. The researchers received numerous satellite scenes of the Himalaya region acquired between 2001 and 2010. Nearly a thousand of these images were captured during autumn, an ideal time period because it falls after the cloudy summer monsoon season but before winter snows obscure the land surface. In addition, the researchers received 115 ASTER scenes between September and November 2006, when Racoviteanu was collecting field measurements in the region to help validate the satellite-based glacier mapping.



The Imja Glacier, located in the eastern Himalaya, has been retreating. Glacial lakes have been rapidly forming on the surface of the debris-covered glaciers in this region during the last few decades, indicating that the glaciers are out of balance with the environment. (Courtesy NASA, from ASTER data)

By comparing these newer remote-sensing derived glacier outlines with older data sets derived from topographic maps or older imagery, scientists can begin to see how glaciers are changing. Kargel said, "You can take topographic maps produced the old-fashioned way, from say the 1950s or the 1960s, and compare with ASTER topography, and then you may have a baseline of fifty years."

Meltwater from the Gangotri Glacier forms the headwaters for the Bhagirathi River. Sacred ghats, or stairs, like this one in the town of Gangotri, allow pilgrims to bathe in the holy water. Scientists are concerned about the stability of the Gangotri Glacier because the river is an important source of water for India's population. (Courtesy H. Cirici)

Kargel and Racoviteanu are seeing that glaciers are not responding to climate uniformly: Glaciers in certain areas of the Himalaya are behaving differently from glaciers in other parts of the massive range. Some glaciers in the western Himalaya and neighboring Karakoram Range, such as the Baltoro Glacier of Pakistan, are growing. And most of the melting glaciers, such as the Gangotri and Imja, are located in the central and eastern Himalaya. What accounts for the difference between the eastern and western ends of the range?

Atmosphere and ice

The researchers, together with other colleagues, found a clue in the intersection of atmospheric forces swirling above the region. Cold, dry winds blowing south from the Tibetan Plateau clash with moisture-laden monsoon winds swinging north from the Indian Ocean. In the past, this pattern generated enough snow to sustain glaciers across the Himalaya. But combusted carbon and dense air pollution increasingly cloud the skies over Asia, changing precipitation in some areas and increasing melt in others.

Much of this pollution is natural in origin, and includes dust, desert sand, and salt particles. But in South Asia most of the air pollution, particularly black carbon, or soot, is generated by human activity. Kargel said, "In South Asia, brick ovens are a major source of soot. Automobile tires wear down and that puts little rubber particles in the atmosphere. Coal-fired plants produce a lot of soot. And combusting gasoline in automobiles and other engines creates soot."

Soot is a new addition to glaciers already covered with debris. "There's this unsteady, quasi-balance of forces between the building up and the wearing down that produces a huge amount of rock debris. That's mostly what we see from satellites," Kargel said. "But the soot is a very different kind of thing. In terms of particle size, we're talking about microns. Perhaps a thousandth of a millimeter, or ten thousandths of an inch to maybe a thousandth of an inch across." These tiny particles of pollution may be affecting Himalayan glaciers on two fronts: by precipitating directly onto the glacier surfaces and by causing overall atmospheric warming in the region.

If soot falls onto the cold upper reaches where glaciers accumulate ice, the particles may be buried and incorporated into the glacier ice, and have little effect on melting. But if soot falls onto the lower reaches of a glacier or the glacier tongue, particles often remain on the surface. "Instead of having a highly reflective surface, the glacier then has a somewhat less reflective surface," Kargel said. "It absorbs more solar radiation, and there's more melting that can go on."

Soot that remains in the atmosphere also absorbs solar radiation, causing an "elevated heat pump." Kargel and his colleagues, following research conducted by NASA's William Lau and other physicists and climatologists, theorize that this heat pump is blowing large amounts of monsoon moisture farther north than would have been the case otherwise. "This may be a possible cause of additional atmosphere heating beyond that which the greenhouse effect causes, thereby possibly explaining the accelerated melting of glaciers in the eastern Himalaya," he said.

The effects of the elevated heat pump may be changing both regional air temperature and monsoon precipitation patterns over the range. Increased atmospheric heating is causing many glaciers to melt along the southeastern end of the range, where the Gangotri Glacier is located. But the increased moisture caused by the heat pump is being blown to the northwest, where it falls as snow over the high elevations in Pakistan and Afghanistan, possibly aiding the growth of glaciers in that region, such as the Baltoro, according to Kargel.

Whence the water

Just as monsoon rains dominate agricultural life across Southeast Asia, monsoon moisture fuels much of the snow that feeds glaciers in the higher elevations. If the monsoon cycle is changing, or if the elevated heat pump shifts snowfall and precipitation, the results could affect how much fresh water is available for agriculture and drinking. Although much of Southeast Asia and China are wet, humid areas, people in the region do rely at least in part on seasonal glacier melt for water during dry times of the year. Racoviteanu said, "It all comes back to water resources. There's a missing link. We still don't have a good idea of how much water is actually coming from glaciers, as opposed to coming from ice or snow."

Researchers are still trying to assemble a more complete picture of the climate factors affecting the glaciers. Although Kargel and Racoviteanu have begun to investigate some of the large glacier systems, the dearth of information about the thousands of other glaciers makes it difficult to understand the consequences of glacier change—or what role the Himalaya's glaciers play in Asia's water supply. Kargel said, "We don't yet fully understand all of the complexities. Atmospheric soot is a player, but it's not the only major story going on. The biggest story going on is global warming and changing monsoons."

To access this article online, please visit http://nasadaacs.eos.nasa.gov/articles/2010/2010_glaciers.html.

About the remote sensing data used

Satellite	Terra
Sensor	Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER)
Data set	Global Land Ice Measurements from Space (GLIMS) Glacier Database
Resolution	15 meter
Parameter	Glacier extent
Data center	NASA National Snow and Ice Data Center Distributed Active Archive Center (NSIDC DAAC)

ASTER satellite images are available from the NASA Land Processes Distributed Active Archive Center (LP DAAC).

About the scientists

Jeffrey Kargel is a hydrologist and senior associate research scientist at the University of Arizona. He also serves as the coordinator for the Global Land Ice Measurements from Space (GLIMS) project. Kargel became interested in glaciers through his research on the Martian cryosphere and its geologic and climatic history. NASA supported his research. (Photograph courtesy J. Kargel)

Adina Racoviteanu is a graduate student at the University of Colorado, with special expertise in the Himalaya's glaciers. She is also a contributor to the GLIMS project. Racoviteanu studies glaciology; combining GIS, remote sensing and field techniques to monitor glacier mass balance; and glacier changes and their impact on water resources. The National Science Foundation and NASA supported her research. (Photograph courtesy A. Racoviteanu)

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http://nsidc.org

NASA 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

Global Land Ice Measurements from Space (GLIMS)
http://www.glims.org

When a day is not a day

"When you want to directly land a rover on Mars, uncertainties in Earth's rotation can be a problem."

Richard Gross
NASA Jet Propulsion Laboratory

by Jane Beitler

With rigid blade on hard flat ice, a skater moves in curves and circles. Her defiance of straight and solid builds as she stands tall and starts to spin. Not moving a leg muscle, she pulls her arms close, spinning faster and faster until she is almost a blur. Few in the audience may have noted the subtle shift of mass towards her center that created the figure skater's showiest trick.

It is even less likely that the audience realizes that Newton's laws of motion have simply been obeyed. These laws govern any spinning object, such as a planet. Richard Gross at NASA's Jet Propulsion Laboratory said, "Earth is just like that skater. Anything that moves mass closer to the Earth's axis speeds its rotation up, and moving mass away from the axis slows it down." But what on Earth is moving that could affect its spin, and why does Gross study it?

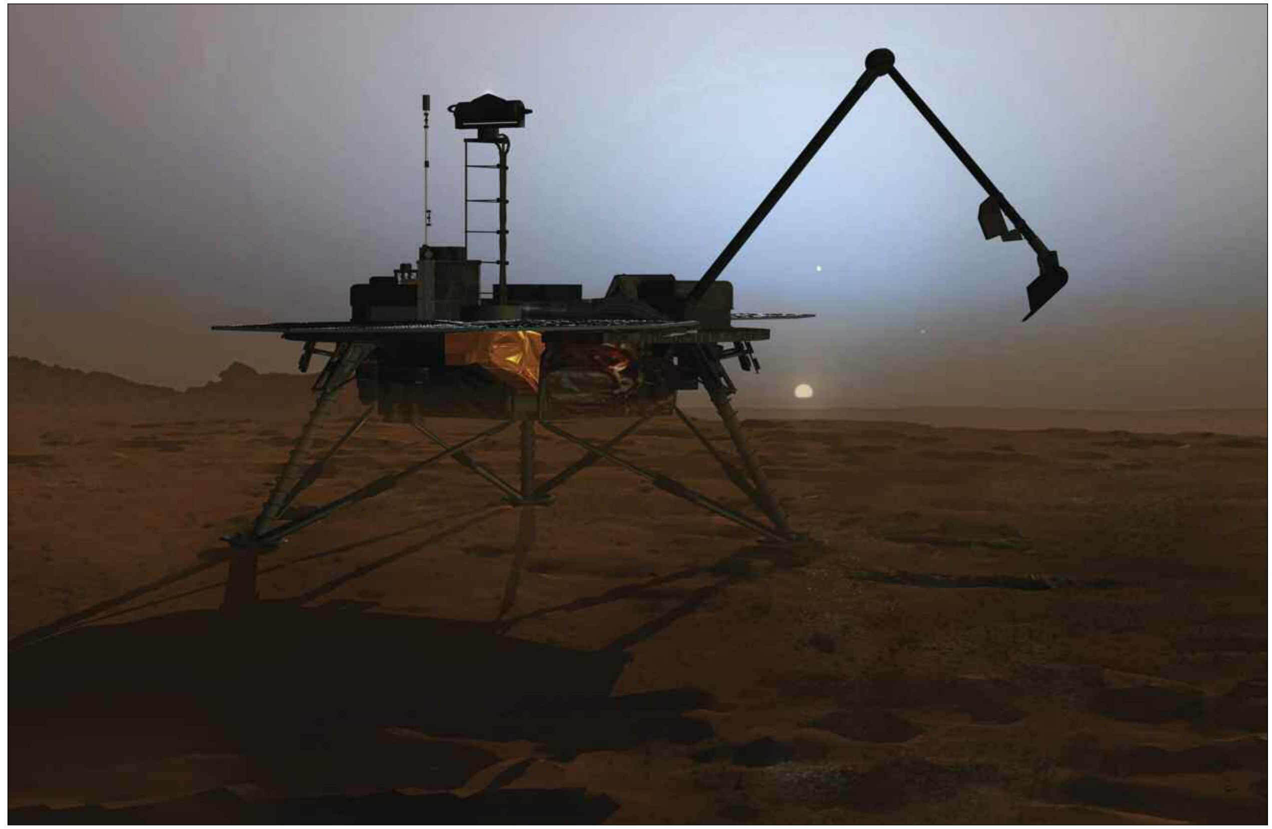
This photograph looking back at the Earth and moon was taken by the unmanned Galileo spacecraft on its way to Jupiter. Galileo traveled almost three billion miles, a journey that took six years, and then spent almost eight years orbiting Jupiter. Small imprecisions in its launch trajectory could have caused a miss in this long target, so scientists carefully calculated Earth's orientation at the moment of launch. (Courtesy NASA JPL)

A less-than-perfect spin balance

The Earth has its own mass-shifting movements. For example, in February 2010, the Nazca tectonic plate in the eastern Pacific Ocean basin moved, causing a destructive 8.8 magnitude earthquake in Chile. But its type—a thrust earthquake—counted most for Earth's rotation. "In a thrust event, one tectonic plate slides under another, and it can move mass up or down," Gross said. When the Nazca Plate pushed under the South American Plate and moved down towards Earth's axis, the laws of physics dictate that Earth's spin sped up.

Likewise, the huge 2004 Sumatran earthquake similarly rearranged the Earth's mass, causing it to spin slightly faster. On the other hand, ice loss on Greenland in recent years may have slowed down the Earth, as meltwater flowed off its massive ice sheet and down into the ocean, moving further away from the Earth's axis.

Such mass shifts and other events change Earth's speed of rotation, and translate into variations as large as a millisecond in length of day, the time it takes Earth to make a complete rotation. These variations create imprecision for navigation systems that depend on Earth's rotation, so Gross looks for ways to measure them, using extremely precise satellite data and special analysis methods. He can detect the effects of ordinary weather patterns. "The biggest causes are changes in the winds, particularly in the jet streams, which can explain 90 percent of length of day changes," Gross said. For example, strong westerly winds can make the atmosphere speed up, and then the solid Earth must slow down its rotation. Changes from tsunamis and earthquakes have so far been too small to measure with current techniques.

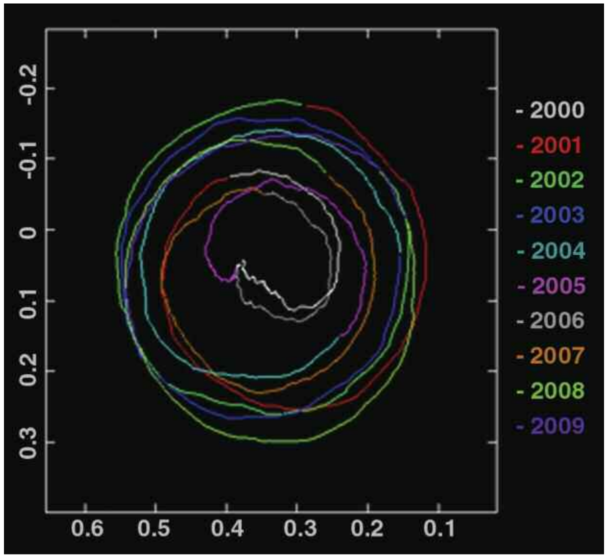


This artist's depiction shows the Mars Rover on the surface of Mars. Because of precise information about Earth's length of day and orientation, NASA was able to directly land the Rover on Mars. (Courtesy NASA Mars Exploration Rover Mission)

Mass-shifting events can also make the Earth wobble. "The Earth rotates around its rotation axis, but its mass is balanced about a different axis, the figure axis. Because these axes are different, the Earth wobbles as it rotates," Gross said. Earth's figure axis is like drawing a line down the center of a pear, but the Earth does not always spin perfectly around that geometric axis. When the oceans rise or fall, or tectonic plates move up or down, the Earth's mass is rearranged, the figure axis changes, and the Earth starts wobbling differently. "It's like the tire on your car; if that tire isn't perfectly balanced, it will vibrate. The mechanic will put weights on the tire to rebalance it around its axis," Gross said. Because the North and South rotation poles mark Earth's axis of rotation, and that axis moves, this wobble is also called polar motion.

Tiny variations, vast spaces

Polar motion and changes in rotation speed complicate the problem of calculating exactly where we are in space and time. A few milliseconds of imprecision in a measure of Earth's orientation become more than a theoretical question when traveling over the vast distances of space.



The spiral lines on this graph track wobbling in Earth's axis of rotation from 2000 to 2009. This wobbling is called polar motion, because it temporarily changes the location of the rotational North and South Poles. (Courtesy USNO)

Everything in space is constantly moving, spinning and orbiting in a complex choreography. Researchers keep track of exactly where the Earth is in this dance, and how it is oriented towards other heavenly bodies. Much as ancient navigators learned to triangulate the stars to find their way over faceless oceans, today's scientists use radio telescopes to peer at very distant quasars as a reference for Earth's orientation, a method called very long baseline interferometry. Gross is especially interested in Earth Orientation Parameters (EOPs), which describe how the Earth is positioned in its rotation at any given point in time, past or future. To know EOP precisely, he must measure polar motion and length of day.

Gross said, "This problem goes back to the 1600s, when astronomers were looking at the position of the moon. As the moon passed in front of the stars, they tried to predict its position based on a uniform rotation of Earth. But they couldn't do it, because Earth is slowing down."

The length of day question became more pressing when humans started launching objects into space. "In the early days of interplanetary spaceflight, navigators assumed that Earth's rotation was constant, but they couldn't fit their tracking measurements with that assumption. When they took into account that the Earth's rotation varies, they got better results," Gross said.

Imagine spinning around in a circle, with a ball in your hand. If you want to hit a target with the ball, you need to predict when you will be facing the target, so that you know when to throw. This is not unlike the problem of launching a spacecraft from the rotating Earth to land on the moon, an average of 239,000 miles away.

Today, precise EOP predictions support longer space journeys and direct landings on Mars, about 34 million miles from Earth at the closest points in the orbits of the two planets around the Sun. Gross said, "When you want to directly land a rover on Mars, uncertainties in Earth's rotation can be a problem. For a precise pinpoint landing, you have to do your best to predict how the Earth will be oriented in the future as the spacecraft approaches Mars. Because of the large distances involved, small millisecond changes in the length of day become kilometer-sized position errors by the time you get to Mars."

Gross's research uses several kinds of data from the archives of the NASA Crustal Dynamics Data Information System (CDDIS), including Global Positioning System (GPS), satellite laser ranging, and very long baseline interferometry. Each of these position-measuring technologies has different coverage and advantages, and by combining and comparing them, Gross can get the most accurate estimates. Using computer models, he can then specify the Earth's orientation at any point in the past or future.

Where on Earth

Here on Earth, tiny spin and wobble variations also have consequences even over just the distance between the poles and the equator. Brian Luzum, at the U.S. Naval Observatory, said, "I'm concerned with very practical matters of Earth orientation, like knowing exactly where we are on the ground or the ocean." An aircraft heading for landing on an aircraft carrier on a foggy night, for example, would like to know very exactly the position of that ship.

Luzum specializes in EOP predictions for navigation and positioning, which depend on GPS systems. GPS receivers triangulate their location from a constellation of satellites orbiting overhead. Luzum said, "A GPS receiver on the ground needs to know how it is oriented to the satellite in space, so it needs these EOPs." The EOPs make the GPS coordinates much more accurate.

"You can essentially turn this into a geometry problem, a large scale surveying problem, one that is constantly changing," Luzum said. "A thousandth of a second difference in rotation speed may seem like a ridiculously small amount of time, but it can translate to about fifty centimeters of distance at Earth's equator. And if you accumulate the length of day variations over a number of days, it can add up to many, many meters. If you can't navigate within a fraction of a kilometer, it is a real problem."

His work depends on Gross's studies of length of day. He said, "Richard takes something complicated and breaks it into less complicated parts. His research tells us how global weather and ocean changes work together." Atmospheric pressure changes and changes in ocean bottom pressure also affect Earth's rotation. "Because people like Richard have figured out these effects, we can use weather forecast data in our EOP predictions," Luzum said.

Gross continues to work on directly measuring the effects of earthquakes, atmosphere, and oceans on length of day, using satellite data, for an even more refined prediction of Earth's rotation. He said, "These changes are so small, most people don't worry about them, but we worry about them."

To access this article online, please visit http://nasadaacs.eos.nasa.gov/articles/2010/2010_gps.html.

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NASA Crustal Dynamics Data Information System (CDDIS)
http://cddis.gsfc.nasa.gov

United States Naval Observatory—Earth Orientation
http://www.usno.navy.mil/USNO/earth-orientation/

About the scientists

Richard Gross is the supervisor of the Geodynamics and Space Geodesy Group at the Jet Propulsion Laboratory in California. His research interests are focused on gaining greater understanding of the mechanisms causing the Earth's rotation, gravity, and shape to change. NASA and the National Geospatial-Intelligence Agency supported his research. (Photograph courtesy JPL)

Brian Luzum heads the Earth Orientation Department at the United States Naval Observatory. He is also the director of the International Earth Rotation and Reference Systems Service (IERS) Rapid Service/Prediction Center; co-director of the Conventions Product Center; and chair of the International Astronomical Union (IAU) Working Group on Numerical Standards for Fundamental Astronomy. The U.S. Navy supported his research. (Photograph courtesy USNO)

About the remote sensing data used

Satellites	Global Positioning System (GPS)	Laser Geodynamics Satellite 1 (LAGEOS-1)	
Sensors	GPS receivers	LAGEOS-1 Satellite Laser Ranging (SLR) Data	Radio telescopes, radio sources
Data sets	GPS Data Archive	500 meter Nadir BRDF-Adjusted Reflectance (NBAR)	Very Long Baseline Interferometry
Resolution	1 second	Global coverage	
Parameters	Latitude and longitude	Earth orientation	Earth rotation
Data centers	NASA Crustal Dynamics Data Information System (CDDIS)	CDDIS	CDDIS

On shaky ground

“Nobody was talking about earthquake risk in Haiti prior to January 2010.”

Alex Fischer
Columbia University

by Katherine Leitzell

On January 12, 2010, Alex Fischer and his colleagues from the Center for International Earth Science Information Network (CIESIN) at Columbia University were at work in the United Nations Environment Programme (UNEP) office in Port-au-Prince, Haiti. At 4:53 p.m., the building started to shake. The group scrambled outside, struggling to stay upright amidst bucking floors and falling shelves. Fischer said, “There were six people on our team and in the office complex. It was incredible luck that all of us were fine, with no injuries.”

Ironically, at the time of the earthquake, Fischer had been working on a project to help the Haitian people prepare for and reduce their vulnerability to natural disasters, such as hurricanes, floods, and landslides. The project, called the Haiti Regeneration Initiative, started as a collaboration between the Earth Institute and UNEP, and focuses on the links between ecosystem degradation and natural disasters.

Makeshift shelters dot Haiti after the January 2010 earthquake, as residents struggle to recover from its devastation. (Courtesy United Nations Development Programme)

Haiti is highly vulnerable to natural disasters. The island sits in a major storm track—in 2008 alone, the country was hit by four major hurricanes. But poverty and environmental degradation compound the problems resulting from storms.

The earthquake came as a surprise, even to researchers who study and plan for a multitude of possible natural disasters. By combining data on human and environmental factors, the researchers hoped that they could help Haiti not only prepare for disasters, but also reduce the impact of the disasters that do occur.

In the path of disaster

The earthquake gave Fischer and his colleagues, who usually work with demographic and scientific data, a first-hand perspective on the local realities of disaster. The next few days were a chaotic mess: without any medical supplies, and only basic first aid training, the scientists tried their best to help people injured by the quake, applying pressure to stop bleeding, splinting broken bones, and cleaning wounds with improvised supplies. Fischer said, "At the time of the earthquake, there was only one medical doctor in the compound. And for the first twenty-four hours, we didn't have any medical supplies, only a few first aid kits."

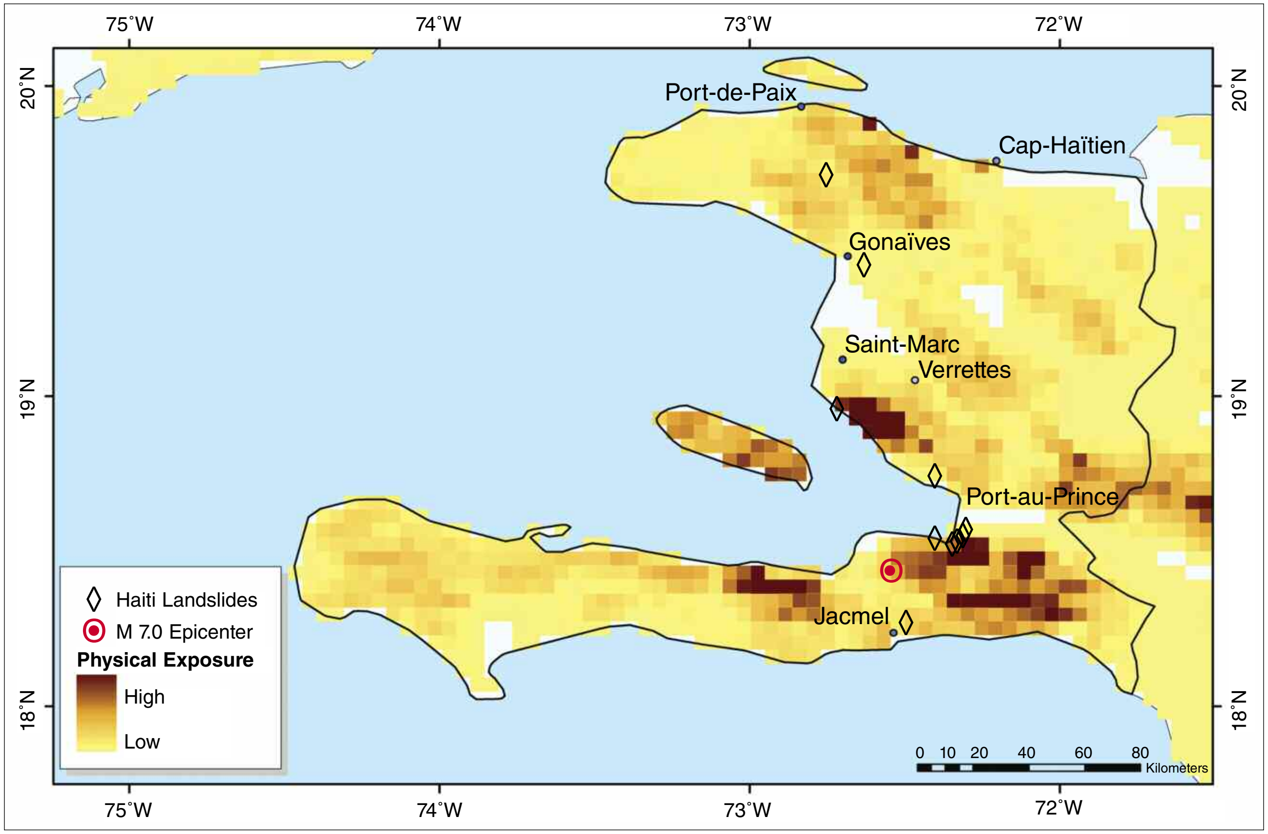
After the earthquake, the immediate concern was to help the people who were affected—making sure they had food, water, and medical care they desperately needed. But as soon as they got back to the United States, Fischer and his research group started thinking about the future: what impacts would the quake have when hurricane season rolled around? Would the shaking that occurred in January 2010 increase Haiti's vulnerability to other disasters later in the year? For example, the loss of data systems in the country meant that there could be less warning for hurricanes, floods, or landslides. Lacking adequate shelter, people displaced by the quake might be more at risk for injury from future disasters. And the quake itself may have shaken up hillsides, making them more likely to collapse when the rainy season hit.

This cleared hillside in Haiti now lacks the vegetation that used to stabilize its slopes. The 2010 earthquake may have loosened the soil, making it even more vulnerable to erosion and landslides following heavy rains. It is an example of how a degraded environment can compound problems from natural disasters. (Courtesy A. Fischer, CIESIN)

"One of the questions right after the earthquake was, what areas could have been destabilized from the movement of the ground? Did the earthquake increase vulnerability for landslides during the rainy season?" Fischer said. Landslides are not the most obvious danger on the list of disasters that Haiti is vulnerable to. But when a hill suddenly collapses, it can destroy homes and roads, and kill people. Since 2003, at least eleven landslides have been reported in Haiti, killing ninety-eight people and injuring hundreds more.

Like a handful of sand

When the ground shakes in an earthquake, it destabilizes the soil and makes it more likely to slide. Dalia Kirschbaum, a researcher at NASA Goddard Space Flight Center, combines satellite rainfall data with surface information to create a picture of possible landslide activity across the globe in near-real time. She said, "Think of a handful of sand. If you shake your hand, the sand will go all over the place. It's the same thing with soil on a hill. If it shakes enough it can fall down the hill." After the earthquake, Kirschbaum turned her attention



This map shows landslide physical exposure, identifying areas with both a high risk for landslide and with dense human populations. Sites of past landslides are marked with green diamonds, and a red dot marks the epicenter of the January 2010 earthquake. Brown colors indicate areas of high risk of human exposure to landslides. (Population data from SEDAC's Gridded Population of the World; map courtesy D. Kirschbaum)

to Haiti. In the aftermath of the earthquake, several teams of landslide experts used satellite and airborne imagery to identify slopes where soil and debris had been displaced. The researchers identified a number of landslides and rockfalls along the highway from Port-au-Prince to Jacmel and in smaller towns. However, there were surprisingly few landslides within the Port-au-Prince region during the earthquake. "As the rainy season comes, there will be more loose soil to mobilize into a landslide or debris flow," Kirschbaum said.

In the months following the earthquake, Kirschbaum worked on a series of maps to identify where people in Haiti are most vulnerable to landslides. Landslides are notoriously difficult to predict, particularly using broad-scale satellite data. "You are looking at a very small-scale feature that is barely resolvable in satellite imagery. You're not looking at a hurricane where it's hundreds of kilometers across and you can track it with satellite images," Kirschbaum said. But in Haiti, where there is little ground data on soil moisture or rainfall, satellite data may be the best tool.

Kirschbaum combines satellite data on rainfall with maps of land cover type and gridded population data from the NASA Socioeconomic Data and Applications Center (SEDAC). Kirschbaum said, "The approach we're taking is statistical and empirical. We look at satellite data to hypothesize the conditions in which landslides might be triggered. Then we look at where the people are. Where these two data sets intersect is where the populations will be most susceptible to landslides."

Knowing where people are concentrated is key, and means knowing where a landslide could have the largest impact. But human presence can also affect the stability of slopes. Kirschbaum said, "There's a feedback mechanism: people tend to cause more landslides because of their activities." On steep slopes the construction of roads and buildings can weaken an already precarious hillside, particularly if the structures are not built according to engineering standards. And extreme deforestation in the Haitian countryside has made the whole country more vulnerable to landslides, since there are fewer roots to protect the slope and absorb water during a major rainfall.

Human dimensions of disaster

Fischer and other researchers are now focusing on the links between people, their environments, and the impact of natural disasters in Haiti. Fischer said, "Haiti is even more vulnerable to disasters because they have poor construction standards, because they don't have proper communication systems, and they don't have proper shelters to evacuate to."

Inadequate construction standards make buildings more likely to collapse when hit by strong winds or flooding. Lack of an emergency warning system or adequate public shelters means that people have little warning of a storm and nowhere to go when it strikes. Those problems not only have the potential to increase the impact of disasters; they also confound the effort to rebuild and prepare for future disasters.

Kirschbaum said. "What's sorely needed in Haiti is not just hazard assessment, but a focus on the social dimension. How can we take the data we have and move it into action?"

The earthquake also refocused researchers like Fischer. "The earthquake was unexpected. Nobody was talking about earthquake risk in Haiti prior to January 2010," Fischer said. "So it completely changed our perspective on disaster risk and what was needed for preparation." Now, on top of hurricanes and floods, the researchers have to consider collapsed buildings, destroyed roads and communications, extensive debris blocking river channels and flood plains, and other problems that occur after an earthquake, such as landslides triggered by rainfall. They also think about how a slow recovery from the earthquake could affect response to future disasters. Fischer said, "The earthquake delayed our initial work, but it also broadened our focus into a national and regional scale, and made us think about how we could scale up local programs into broader risk management."

To access this article online, please visit http://nasadaacs.eos.nasa.gov/articles/2010/2010_landslides.html.

About the data used

Data set used	Gridded Population of the World
Spatial resolution	2.5 minutes, latitude/longitude
Temporal resolution	1990-2015, every five years
Parameter	Human population density
Data center	NASA Socioeconomic Data and Applications Center (SEDAC)

About the scientists

Alex Fischer is a researcher at the Center for International Earth Science Information Network (CIESIN) at the Columbia University Earth Institute, where he is project manager for the research and design team of the Haiti Regeneration Initiative, a long-term ecosystem restoration program in Haiti. The United Nations Environment Programme supported his research. (Photograph courtesy A. Fischer)

Dalia Kirschbaum is a research associate at the Earth System Science Interdisciplinary Center, University of Maryland, and works in the Hydrological Sciences Branch at NASA Goddard Space Flight Center. Her research focuses on identifying areas of potential landslide activity, using satellite precipitation observations as well as other remotely sensed and surface data. The NASA Postdoctoral Program supported her research. (Photograph courtesy D. Kirschbaum)

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For more information

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

Center for International Earth Science Information Network (CIESIN)
http://www.ciesin.columbia.edu

CIESIN Haiti Regeneration Initiative
http://haiti.ciesin.columbia.edu

Haiti Regeneration Initiative
http://haitiregeneration.org

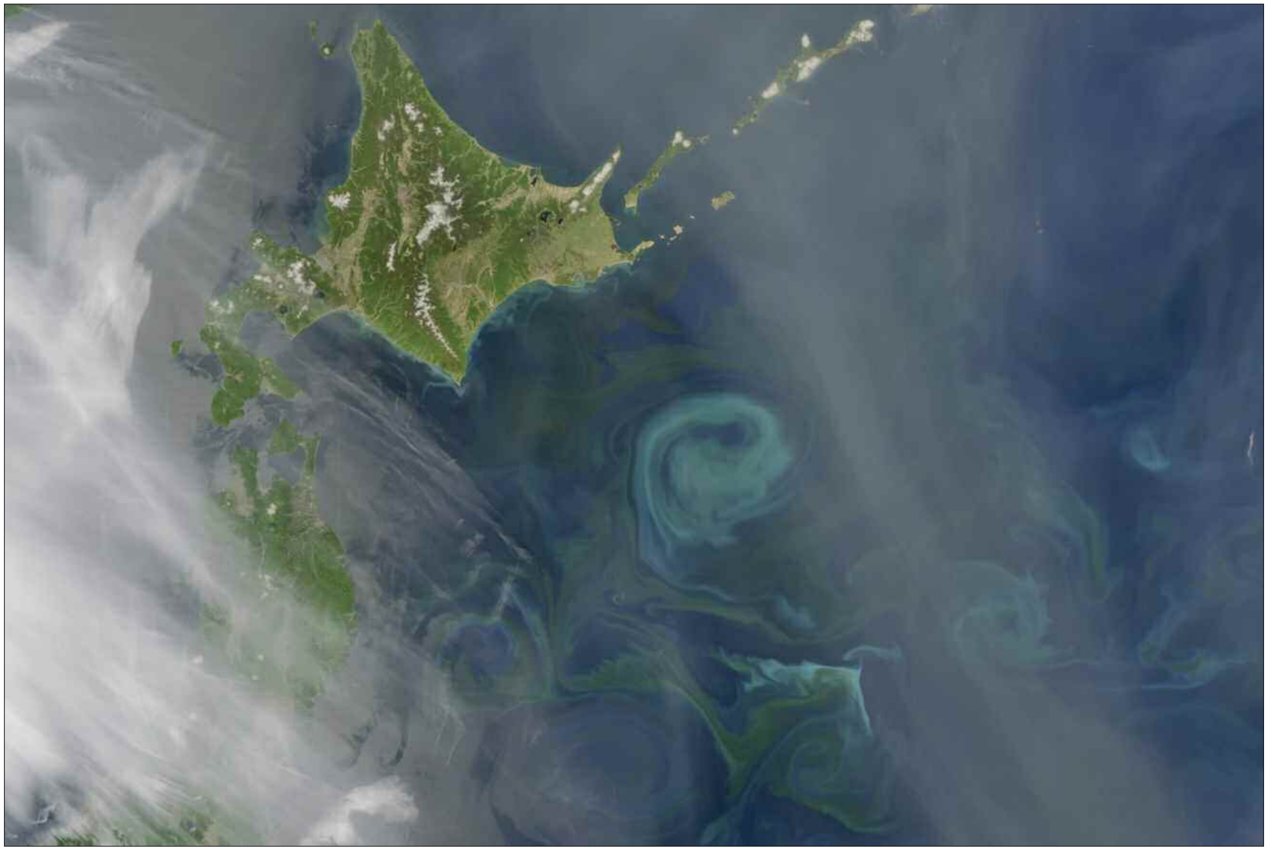
Probing the Black Current

“The ocean is getting a little bit more water all the time.”

Victor Zlotnicki
NASA Jet Propulsion Laboratory

by Natasha Vizcarra

Physical oceanographer Jae-Hun Park helped steady a pumpkin-sized, plastic-encased glass ball on the deck of the *Research Vessel Melville*. The ball contained scientific sensors and had been moored to the sea floor off the eastern coast of Japan for two years, collecting data about the rapidly flowing ocean current above it. Forty-two other such glass balls either had been retrieved or were still moored underwater. Park would spend almost a month at sea with other researchers, retrieving these instruments. But he was very excited about the data they would be getting on the eddies, gyres, and meanders that make up the most active region of the Kuroshio Current.



In this image from the NASA Aqua satellite, a swirling phytoplankton bloom becomes visible from space when warm waters from the Kuroshio Current collide with the frigid waters of the Oyashio Current off the eastern coast of Japan. (Courtesy N. Kuring, MODIS Ocean Color Team)

The Kuroshio, one of the three largest of the world's ocean currents, has long fascinated humans. Early fishermen and explorers took note of these currents because they either sped up their voyages or got them lost. Early Chinese mariners called the Kuroshio Current Wei-Lu, or the current to a world from which no man has ever returned. The Japanese named it Kuroshio, or black current, for its dark, cobalt blue waters. Physical oceanographer Steven Jayne said, "The Kuroshio is the strongest current in the Pacific Ocean, and is also one of the most intense air-sea heat exchange regions on the globe. It influences climate as far as North America."

Mapping the Wei-Lu

Just as the Kuroshio was mysterious to early mariners, much about it remains unknown to scientists studying its connections to climate. "There have been many studies about the Gulf Stream in the Atlantic Ocean, but there haven't been enough studies of the Kuroshio, which is the biggest and most important current in the North Pacific region," said Jayne, an expert on global ocean dynamics and one of the lead scientists of the Kuroshio Extension System Study (KESS). "We wanted to study the fluid dynamics of this current because it's interesting physics."

The Kuroshio flows particularly fast and deep, flowing at a rate of 2.5 meters (8.2 feet) per second and as deep as 1,000 meters (3,281 feet) below the surface. Driven by winds and the Earth's spin, it begins its journey in the tropical Philippine Sea and flows north to glide against Taiwan. When it reaches Japan, it is jolted into numerous eddies as it collides with a frigid, subarctic countercurrent from the Bering Sea. The current then vigorously meanders here and there, until it forms a free jet, shooting east toward North America, before it finally feeds into the larger North Pacific Ocean Gyre. Scientists think surface currents like the Kuroshio influence the path of hurricanes and typhoons, and affect climate in surrounding regions.

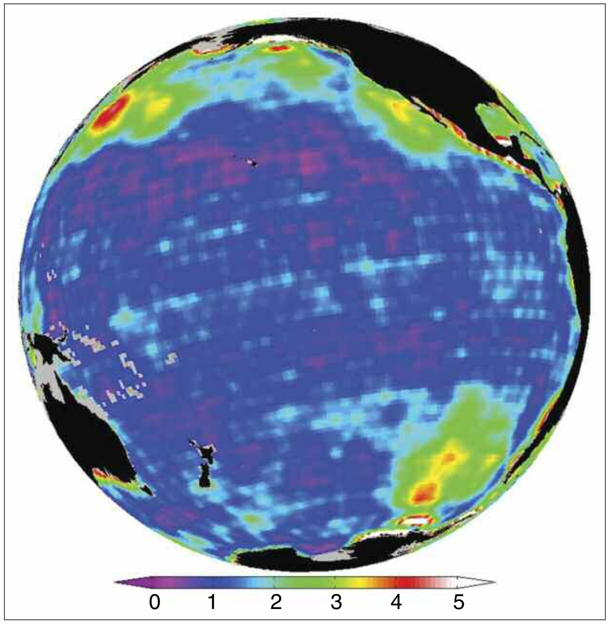
With data from a combination of drifting robotic probes, a sensor-mounted buoy, satellite data, and underwater sensors, KESS found recirculation gyres swirling both to the north and south of the Kuroshio jet. Jayne said, "We knew there was one to the south, but we didn't know there was one to the north before the KESS study." Recirculation gyres are spinning currents of water that are isolated from the surrounding circulation. "They can be places where fish and larvae can be moved around for long periods of time because water is just re-circulated around and around," Jayne said. Scientists are interested in the Kuroshio's gyres because these are some of the few places in the ocean where subtropical mode water is formed. Subtropical mode water is a layer of water with exceptionally uniform temperature and salinity that is believed to help stabilize climate in a region. The KESS study also successfully produced maps of how the Kuroshio Current flowed and changed over two years. "This is one of the first attempts to actually map the current where it is most active," Jayne said.

KESS researchers hope their results will offer other researchers a window into the processes behind the Kuroshio and the region's storm and climate formation. An international research initiative on ocean-atmosphere interactions, called Climate Variability and Predictability (CLIVAR), is already interested in taking the KESS results and comparing them with existing climate models. Jayne said, "The idea is to compare what we observed to numerical models and see if the models reproduce what the ocean is actually doing. It's the equivalent of validating a forecast in the atmosphere three days out. You predict it's going to be sunny in three days. Is it really sunny in three days?"

Physical oceanographer Jae-Hun Park (left) and University of Rhode Island graduate student Cristin Ashmankas (right) check an underwater sensor in the dry laboratory of the *Research Vessel Thompson* before it is deployed on the sea floor beneath the Kuroshio Current. (Courtesy Kuroshio Extension System Study)

Ground truth

Park, also a member of the KESS group, thought that the two years of ocean bottom pressure data recorded by the sea floor sensors could help study larger questions about oceans and climate. "I realized that our data set would be excellent ground truth data for validating ocean bottom pressure measurements made by the GRACE [Gravity Recovery and Climate Experiment] twin satellites," he said.



This map of the Pacific Ocean shows changes in ocean bottom pressure sensed by the Gravity Recovery and Climate Experiment (GRACE) satellites between 1993 and 2008. Reds and yellows show large pressure changes, and blues and purples indicate areas of little or no change. (Courtesy NASA Physical Oceanography DAAC)

Ocean bottom pressure, the weight of a column of atmosphere and ocean water above a point on the sea floor, helps oceanographers predict patterns in ocean circulation and the movement of currents. Park said, "Just as meteorologists need to keep tabs on atmospheric pressure to make weather maps, oceanographers need to measure ocean bottom pressure to map out ocean circulation."

The movement of waves and ripples on the ocean surface—minuscule changes in sea surface height—can change pressure at the bottom of the ocean. This movement of water from one area to the next, essentially a movement of mass, also affects gravity, allowing the GRACE satellites to measure changes in pressure at the bottom of the world's oceans. Flying 300 miles above the Kuroshio, these twin satellites pass over the eddy-rich waters, responding to changes in Earth's gravity. The lead satellite nudges towards or away from its trailing twin every time it senses a blip in the gravity field, or a mass shift from one area to the next. Surges or dips in the current can cause small variations in gravity as ocean water moves from one area to the next. When strong winds blow on the ocean surface, for example, sea surface height may go up, and the pressure at the bottom of the ocean also goes up.

The strongest weak signal

Victor Zlotnicki, an oceanographer at the NASA Jet Propulsion Laboratory, said there is good reason for Park to be validating GRACE ocean bottom pressure estimates with data from the Kuroshio Current. He said, "The Kuroshio is one of the strongest signals among weaker ocean signals, so it is a good one to study. Let's say, for example, that it rains cats and dogs over the Amazon Region in South America, and the rain makes its way southward through the Amazon River to the Orinoco basin. That's a huge signal—about twenty centimeters [eight inches] of water, a huge pile of water. Ocean signals, on the other hand, are the weakest. Changes in water mass in the ocean are in the order of merely two to five centimeters [one to two inches]."

Park compared the data from his array of ocean bottom pressure sensors to GRACE data from the NASA Physical Oceanography Distributed Active Archive Center (PO.DAAC). Park said, "I was pleased because the correlation between the two data sets was quite good." The satellite had less accurate estimates for ocean features smaller than its maximum resolution of 300 kilometers (162 miles). "It can't catch ocean features, like eddies and meanders, that are smaller than that," Park said. "But the experiment confirms GRACE as an ideal instrument to use when looking at processes in a much bigger picture." Zlotnicki added, "The strength of satellites is their ability to see the whole globe in days to weeks, or one month in the case of GRACE; on the other hand, most of the vast expanses of sea floor have never seen a bottom pressure recorder."

From ocean bottom to sea surface

One such big ocean process that scientists are watching closely using GRACE is sea level rise, a gauge for how global climate is changing. "Truth is, the average bottom pressure over the world's oceans is going up. That means the ocean is getting a little bit more water all the time," Zlotnicki said. "Sea level is rising at about three millimeters [0.1 inch] per year. Part of that is due to the expansion of seawater because of heat. The other part is due to the addition of water from glaciers in Greenland, Antarctica, and continental regions such as Alaska." These immense glaciers, like most of the world's glaciers, have been shrinking because of persistent climate warming. Their meltwater flows into the ocean, causing sea level to rise.

Previously, satellite altimeters could measure changes in sea surface height, but could not distinguish between effects from heat expansion and effects from the additions of glacier melt water. However, comparing ocean bottom pressure estimates with sea surface height measurements allows researchers to single out heat-related sea level change. "GRACE is a totally new measurement," Zlotnicki said. "We studied the world's oceans by keeping track of sea surface temperature for the last twenty years, and we have tracked sea surface height for over fifteen years. But since 2003 we have GRACE and its measurement of the Earth's time-varying gravity. It is changing the way we study the oceans."

To access this article online, please visit http://nasadaacs.eos.nasa.gov/articles/2010/2010_oceans.html.

About the remote sensing data used

Satellites	Gravity Recovery and Climate Experiment (GRACE)
Sensor	K-Band Ranging System (KBR)
Data set	GRACE Mass Grids
Resolution	1 degree
Parameter	Ocean bottom pressure
Data center	NASA Physical Oceanography Distributed Active Archive Center (PO.DAAC)

About the scientists

Steven R. Jayne is a senior scientist at the Woods Hole Oceanographic Institute (WHOI). His research interests focus on the dynamics of the global ocean circulation and its interaction with the Earth's climate, with an emphasis on western boundary currents, ocean modeling, and synthesizing ocean observations to map and understand large-scale ocean circulation. The National Science Foundation, NASA, and WHOI supported his research. (Photograph courtesy T. Kleindinst/WHOI)

Jae-Hun Park is an associate marine research scientist at the Graduate School of Oceanography, University of Rhode Island. His research interests include internal gravity waves with emphasis on dynamics of their interaction with mesoscale circulation, and barotropic ocean response to the atmospheric forcings from marginal seas to the open ocean, and its impact on the satellite altimetry and gravity measurements. NSF supported his research. (Photograph courtesy J.-H. Park)

Victor Zlotnicki is group supervisor for the NASA Jet Propulsion Labortatory's Ocean-Atmosphere Interaction Group. His research interests include the separation of geophysical from ocean circulation signals in satellite altimetry, GRACE gravimetry processing, and the management and effective delivery of large satellite data streams. NASA supported his research. (Photograph courtesy V. Zlotnicki)

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http://podaac.jpl.nasa.gov

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

Kuroshio Extension System Study
http://uskess.org

Steven Jayne
http://www.whoi.edu/hpb/Site.do?id=3852

Jae-Hun Park
http://www.gso.uri.edu/users/jpark

Victor Zlotnicki
http://science.jpl.nasa.gov/people/Zlotnicki

The dirt on tornadoes

> "Why would something that is one season away affect something as specific as tornadoes?"
>
> Dev Niyogi
> Purdue University

by Laura Naranjo

On the night of March 15, 2008, a massive tornado tore through downtown Atlanta. Winds of up to 130 miles per hour uprooted trees, shattered glass windows, and ripped roofs off buildings. Tornadoes occur every year in the southeastern United States, but they do not frequently strike urban areas. The 2008 twister took city residents by surprise, prompting researchers to take a closer look at the forces that contributed to this particular storm.

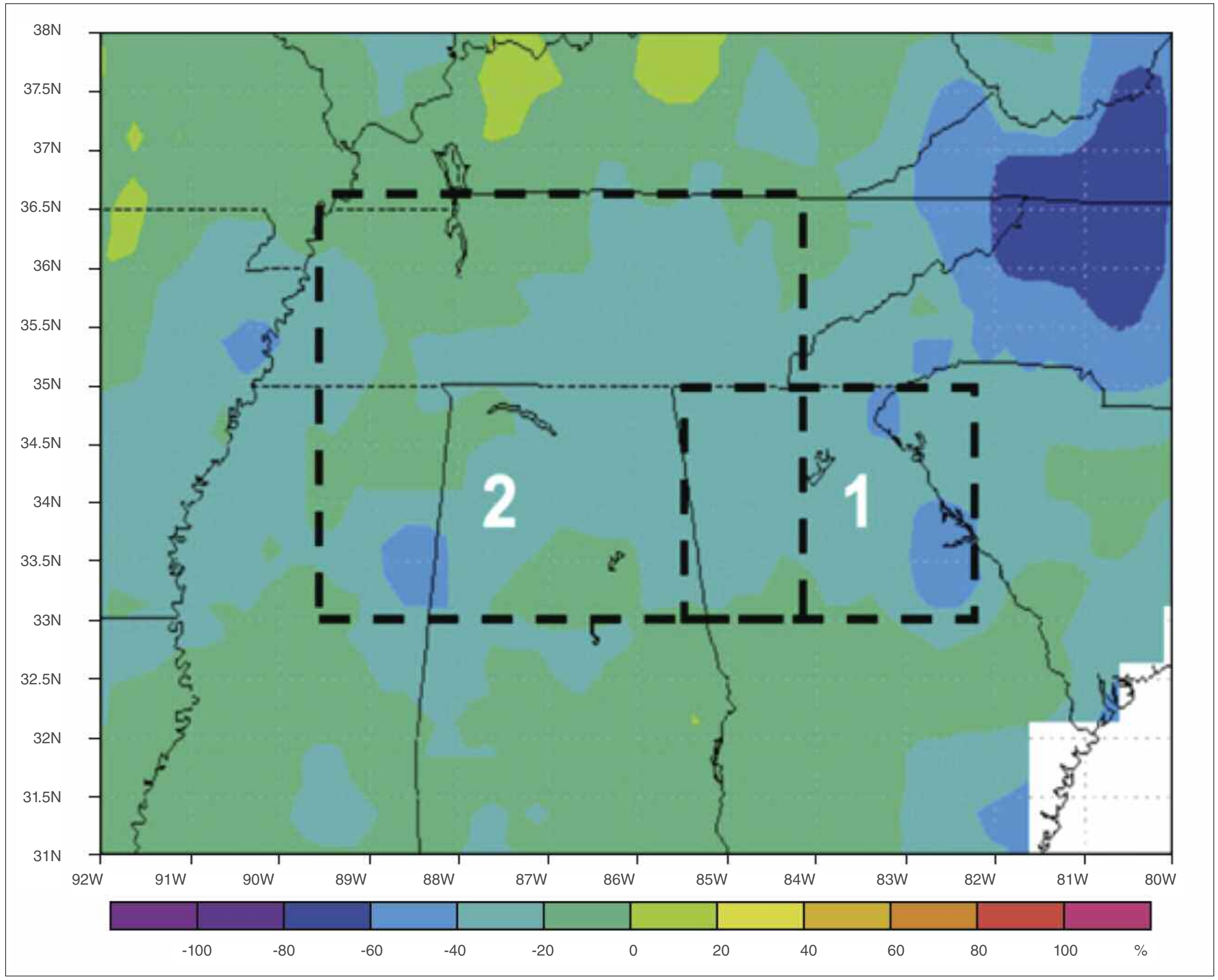
The United States averages about 1,000 tornadoes per year, and less than one percent of these tornadoes are strong enough to cause damage. However, the rare violent tornadoes can be both deadly and costly: the 2008 Atlanta tornado killed three people, injured dozens, and cost the city hundreds of millions of dollars in repairs. While tornadoes require specific local weather events to occur, scientists also wonder whether long-term changes in weather events played a role. Marshall Shepherd, a meteorologist at the University of Georgia, and Dev Niyogi, a climatologist at

This stovepipe tornado formed on May 31, 2010, near the border between Colorado and Oklahoma. Scientists are investigating how soil moisture might influence tornadoes—rotating columns of air that extend from storm clouds down to the ground. (Courtesy W. Owen)

Purdue University, are investigating that possibility. Prior to the 2008 Atlanta tornado, the southeastern United States was undergoing a severe drought. Shepherd and Niyogi wondered if the parched soil affected the region's weather patterns. "We tried to look at things from a different perspective. Was there anything inherently related to soil moisture that reflected larger-scale atmospheric patterns that might result in fewer tornadoes?" Shepherd asked.

Matching tornadoes to moisture

Tornadoes form most frequently during spring and summer, when cold fronts, or masses of cool air, move eastward across the country and collide with warm, moist air. This atmospheric mixing creates the storm clouds, high winds, and humidity that often produce thunderstorms. If violent enough, this mixing can also create tornadoes—rotating columns of air that extend from storm clouds down to the ground. Although tornado formation relies in part on moisture in the atmosphere, Shepherd and his colleagues wondered whether moisture in the soil, or the lack of it, might also play a role.



To investigate how drought might affect tornadoes, scientists looked at rainfall patterns from February 2006 through February 2008, using data from the Tropical Rainfall Measuring Mission (TRMM). The blue and green colors over the study area indicate the region was undergoing a strong drought. Dotted black lines indicate the study area; the researchers first focused on northern Georgia (box number 1), and then expanded to investigate a larger portion of the southeastern United States (box number 2). (Courtesy *Environmental Research Letters* and M. Shepherd)

To investigate this hypothesis, he and his colleagues first gathered tornado data ranging from the 1950s to the present over Tennessee and the northern portions of Georgia, Alabama, and Mississippi. But they found tornado-counting methods were not consistent over time. Populations have grown and filled in more of the rural landscape, meaning more people are likely to see and report tornadoes than in the past. And the increased use of Doppler radar made tornadoes easier to spot, skewing the count. To ensure consistency, the researchers chose to use a metric called a tornado day. Shepherd said, "Tornado day is a metric where we've said, 'Okay, on that day, there was a tornado somewhere in that study region.' That's a safer metric because it's not based on population changes or the advent of radar."

Next, they compared tornado days with drought periods. They identified droughts, or periods when their study area experienced less than 85 percent of normal rainfall, using precipitation measurements from the Global Historical and Climatological Network, and satellite data from the Tropical Rainfall Measuring Mission (TRMM), both available from the NASA

Boat ramps and docks at Lake Lanier, Georgia, were exposed during a severe drought that siphoned water levels to record lows. This photograph was taken in November 2007 from a point normally about 150 yards from the shore. (Courtesy S. Vore)

Goddard Earth Sciences Data and Information Services Center (GES DISC).

When the researchers compared the tornado and precipitation data between 1950 and the present, they did not find a direct link between drought and tornado days. But when they looked for seasonal patterns, they discovered a long-term relationship. Their study identified when droughts occurred during the fall and winter seasons, and then counted how many tornado days occurred during the following spring and summer seasons, primarily during March through June. "When there are drought conditions in the South during the previous winter and fall, there are fewer days the following spring that have tornadoes," Shepherd said. In fact, the number of tornado days decreased by almost half when preceded by fall drought. These findings established a connection between soil moisture and tornado activity. Although the relationship suggests that tornado days are less frequent after drought, severe tornadoes can still occur, such as the 2008 Atlanta tornado.

Seasonal soil moisture

The study reinforced the theory that long-term weather patterns, such as drought, might influence tornado seasons. But the study raised questions too. "Why would something that is one season away affect something as specific as tornadoes?" asked Dev Niyogi, Indiana's state climatologist and one of Shepherd's colleagues in the study. And why would something seemingly unrelated to severe weather, like drought, affect tornado seasons?

Drought reduces the amount of water available in ways that are obvious, such as receding lakes and dwindling river flow. Drought also dries up the moisture held in the soil, so that less evaporates into the air. Niyogi said, "Soil moisture is a means by which the Earth's atmosphere, particularly the land surface, partitions solar energy." When solar energy, or sunlight, reaches moist soil, most of the energy is used to evaporate some of that moisture. When sunlight reaches dry soil, most of the energy goes into heating the air. Over time, drier soil contributes to drier air.

However, dry soil might have a longer-term influence on atmospheric moisture than previously thought. Shepherd and Niyogi theorized that the effects of droughts might carry over into subsequent seasons, a kind of soil moisture memory, in which drought conditions during the fall and winter lag into the following spring and summer. This lag may help suppress the local weather components, such as moist air, that generate storms and tornadoes. Shepherd said, "During the spring, you can still have a storm, based on the meteorological conditions on that particular day. But if there's an overarching drought condition that is kind of a hangover from the fall and winter, it may reduce the moisture available for storm development if you have all other conditions in place." The researchers also found that dry soil conditions in the fall proved a stronger predictor of spring tornado days than wet fall conditions.

Converging theories

Shepherd and Niyogi are continuing to investigate other questions about soil moisture and tornadoes, including whether pockets of soil moisture can affect the severity of seasonal tornado activity. Pockets occur when bursts of heavy rainfall create areas of moist soil in an otherwise dry region. Niyogi said, "When you have regions of wet versus dry soil next to each other, under certain special conditions, they can create atmospheric circulations where winds are going from dryer soils to wetter soils." This airflow can exacerbate the atmospheric mixing that already occurs during thunderstorms.

"The Atlanta tornado was one possible example where pockets of soil moisture might have played a role in intensifying the thunderstorms, which subsequently produced a tornado," Niyogi added. Prior to the Atlanta tornado, Georgia had been experiencing a severe drought for more than a year. Water in lakes and reservoirs had been drying up, and by December 2007, water levels had reached record lows. But during the spring of 2008, bands of rain may have created localized pockets of wet soil near Atlanta that enhanced already severe weather.

Although Shepherd and Niyogi's findings hint at a connection between drought and seasonal tornado activity, their research is still in the early stages. It cannot predict tornadoes in any way. The researchers are testing their findings against a variety of other data sets to reproduce the results, and are expanding their study area to see if they find similar results in other parts of the United States. In fact, Shepherd and graduate student Theresa Andersen recently confirmed the study's finding over a different portion of the southeastern United States. Shepherd said, "Our theory right now is that the relationship is somehow tied to this notion of soil moisture and soil moisture memory."

To access this article online, please visit http://nasadaacs.eos.nasa.gov/articles/2010/2010_tornadoes.html.

About the remote sensing data used

Satellite	Tropical Rainfall Measuring Mission (TRMM)
Sensor	TRMM Microwave Imager
Data set	Multi-satellite Precipitation Analysis
Resolution	25 degree
Parameter	Precipitation
Data center	NASA Goddard Earth Sciences Data and Information Services Center (GES DISC)

About the scientists

Dev Niyogi is an associate professor of regional climatology at Purdue University and serves as Indiana State Climatologist. He studies land surface processes and the effects of vegetation-atmosphere interactions on environmental processes. NASA Water and Energy Cycle programs, the Department of Energy, and the National Science Foundation supported his research. (Photograph courtesy D. Niyogi)

Marshall Shepherd is a member of the NASA Precipitation Measurement Missions Science Team. He is also an associate professor at the University of Georgia, where he conducts research, teaches, and advises in atmospheric sciences, climatology, water cycle processes, and urban climate systems. NASA Water and Energy Cycle programs, the Department of Energy, and the National Science Foundation supported his research. (Photograph courtesy University of Georgia)

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http://daac.gsfc.nasa.gov
Tropical Rainfall Measuring Mission (TRMM)
http://trmm.gsfc.nasa.gov
Dev S. Niyogi
http://www.ag.purdue.edu/agry/Pages/dniyogi.aspx
J. Marshall Shepherd
http://www.ggy.uga.edu/people/faculty/marshgeo/Welcome.html

Invasion of the ctenophores

"There isn't widespread information about the distribution of *Mnemiopsis*. It's sort of this invisible thing, munching away, that nobody really notices."

Jennifer Purcell
Western Washington University

by Katherine Leitzell

When fisheries biologists Marianna Giannoulaki and Apostolos Siapatis noticed clear, lemon-sized gelatinous blobs floating in their sampling tanks, they were concerned. The researchers were on a cruise of the Aegean Sea, surveying anchovy and sardine populations for a study of commercial fish stocks. But as the study went on, the two researchers saw more of the blobs, jellyfish-like organisms called ctenophores. Giannoulaki said, "It was a little bit frightening: we started to see more and more of them each year, and the spatial distribution was spreading."

Ctenophore hunting

Giannoulaki and Siapatis, both of the Hellenic Centre for Marine Research in Heraklion and Athens, Greece, recognized the blob as a potentially destructive invasive species. In the late 1980s the same invader, a predatory ctenophore called *Mnemiopsis leidyi* (nee-mee-OP-sis LEE-dee-eye), had turned the once fertile fisheries of the Black Sea into an unhealthy gelatinous food web. The ctenophores arrived in the ballast waters of ships, transported from their native environment off the east coasts of North and South America. Once in the Black Sea, the ravenous population quickly increased and spread, feasting on plankton, fish eggs, and fish larvae. Without a natural predator to halt its expansion, the ctenophore's population grew rapidly, depleting commercial fish stocks in the Black Sea and ravaging the ecosystem, eating up the fish larvae as well as the plankton that the fish feed on. The Black Sea fisheries have only recently started to recover, thanks to the introduction of another ctenophore species that eats *Mnemiopsis*.

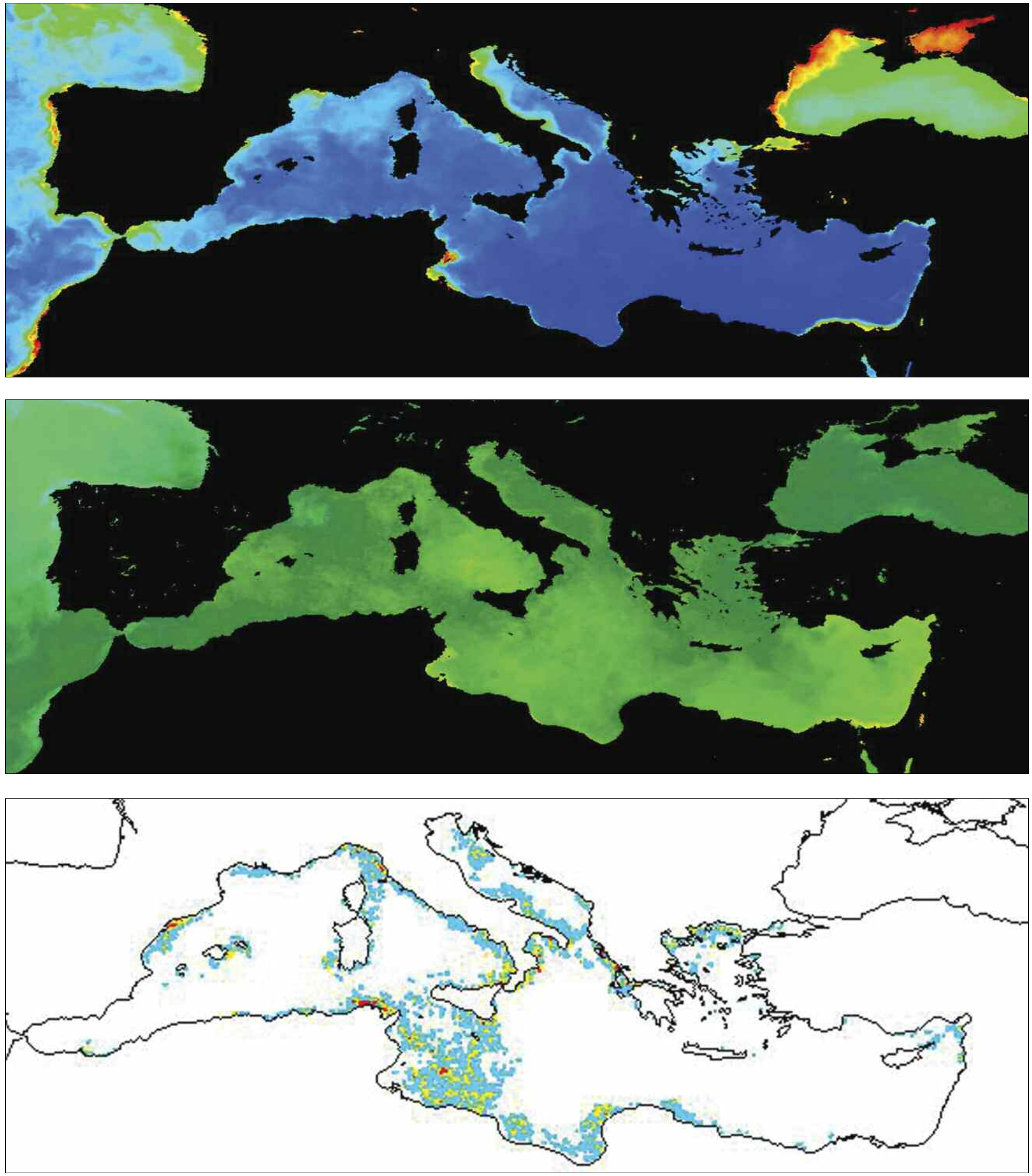
Siapatis first spotted the species in the Aegean Sea in 2001, and by 2004, the ctenophore was on the increase. Giannoulaki said, "The problem with *Mnemiopsis* is that it's an invasive species. We know it's created a lot of problems in the Black Sea. If a big bloom occurs, then we might have a problem in the ecosystem."

Mnemiopsis leidyi is a species of ctenophore, or comb jelly, that is native to the western Atlantic Ocean and invasive in many European seas. Ctenophores get their name from the ctenes, or combs, that run down their bodies and help them to swim. In the 1980s, *Mnemiopsis* was introduced in the Black Sea, where it rapidly multiplied and outcompeted other small species. (Courtesy E. Ovis)

Despite the terrible outcome that *Mnemiopsis* had in the Black Sea, biologists do not regularly monitor the species. The animal is colorless and small, with the adults usually smaller than twelve centimeters (five inches) in length, and its delicate jelly-like consistency allows it to slide through fishing nets without getting caught. Though they look similar to jellyfish, comb jellies are classified in a different phylum, and unlike true jellyfish, they sting neither prey nor unsuspecting tourists. Jennifer Purcell, a marine scientist at Western Washington University, said, "There isn't widespread information about the distribution of *Mnemiopsis*. It's sort of this invisible thing, munching away, that nobody really notices."

Giannoulaki and Siapatis decided to keep an eye on the invasive species, using the equipment that they had already set up. Giannoulaki said, "Our survey didn't target *Mnemiopsis*, but since we had plankton sampling stations every five miles, we thought, 'Why not?' We can go a little further and use the stations to record the presence or absence of the species."

Sampling data showed that the population of the ctenophores increased from 2004 to 2008.



Researchers used environmental data to build a model of potential habitats for the invasive ctenophore, *Mnemiopsis leidyi*. The top image shows NASA Aqua Moderate Resolution Imaging Spectroradiometer (MODIS) chlorophyll concentration in June 2005. Reds, yellows, and oranges indicate higher chlorophyll concentrations, while blues and purples are lower concentrations. The middle image shows Aqua MODIS nighttime sea surface temperatures in June 2005. The green areas indicate higher temperatures. The bottom image is a map of the probability of potential *M. leidyi* presence in June 2005; colored regions indicate a higher probability that the ctenophore could be present. The map incorporates data on depth, temperature, and productivity. (Courtesy A. Siapatis)

This photograph shows what a populous *Mnemiopsis leidyi* bloom looks like on the sea surface. The ctenophore can be hard to see in the water, even when the species reaches an extremely high abundance. Because of its gelatinous body texture, the ctenophore often remains invisible. (Courtesy H. Mainzan)

Siapatis said, "In the first years we found *Mnemiopsis* at about 20 percent of the stations. By the end, we found it at more than 50 percent of the stations."

Although the species was on the increase, the researchers did not know if it would reach the high population levels that caused such big problems in the Black Sea. It can be difficult to tell how an invasive species will respond in a new environment. The scientists knew that the ctenophore species was adaptable, a hardy organism that can tolerate a variety of temperatures and salinity. But would *Mnemiopsis* survive in the Aegean Sea? And if it thrived, would it have the same disastrous effect on the ecosystem as it had in the Black Sea?

The spread of a species

What the researchers really wanted to know was if conditions in the Aegean Sea would allow the comb jelly to multiply and spread, and which regions were most vulnerable. So in addition to ctenophore counts from the plankton sampling stations, they looked at satellite data to learn which environments would best suit the ctenophore. Giannoulaki had done similar work for sardine and anchovy populations. She said, "Sampling data doesn't tell you about the whole population: it's just a small piece of information. So we tried to combine this information with the environmental satellite data to get the whole story."

Giannoulaki used sea surface temperature data from the German Aerospace Agency and from the NASA Moderate Resolution Imaging Spectroradiometer (MODIS) sensor, and photosynthetically active radiation and chlorophyll data from the NASA Ocean Biology Processing Group (OBPG). Together, these data indicate the amount of chlorophyll, which gives an indication of how much food is available in the water. "We combined the satellite data with information about the presence of the species," Giannoulaki said. "Then we used this information to estimate whether the environmental conditions in an area would be suitable for the species. The aim was to estimate potential areas of the invasive species expansion."

The researchers then used that model to determine where and when the species was most likely to thrive. Shallow waters, high temperatures, the influx of Black Sea water, which might contain the ctenophore, and high productivity, or food availability, all seemed key for encouraging the growth of ctenophore populations. "Several areas in the western Mediterranean appeared to be good potential habitat for *Mnemiopsis*," Giannoulaki said. "We were trying to get the whole story about the spatial distribution of the species. But what you estimate is probabilities—potential habitats. You don't know if it's going to be there or not. What you get is whether there are suitable conditions for the species to survive there."

In their study, published in 2008, Giannoulaki, Siapatis, and their colleagues identified several specific places where the ctenophore was likely to thrive, including parts of the Aegean Sea, the Catalan Sea, and the Adriatic Sea. In 2009, their predictions came true: researchers noticed blooms, or big populations, of the ctenophore off the coasts of Spain and Israel, as well as in the Adriatic. Purcell, who identified the blooms in a recent study, said, "Giannoulaki and Siapatis predicted, in advance of anybody else noticing that the comb jellies were there, that they could be there. I think this study was an excellent example of people using new technologies to creatively look at bigger scale issues."

An invisible invader

Because so few people study *Mnemiopsis*, researchers do not know exactly how far or how fast the species is spreading. Many reports of its presence come serendipitously from fishers and people who notice it while studying other animals. Purcell said, "I can say that *Mnemiopsis* was found near shore in Israel, near shore in Italy, and in the Adriatic last year. But there isn't actually any information on its real distribution—there are only a few people doing research on these gelatinous animals." There is little interest in monitoring the species unless it has a major effect on people or the ecosystem, and by then the damage is done.

Knowing where the ctenophore is likely to spread could mean that countries might impose rules on ships for filtering their ballast waters, to avoid introducing the species in a place it would likely thrive. But with so little data, some researchers worry that it is only a matter of time before it affects ecosystems and fisheries in other areas. For example, the ctenophore also appeared in the Caspian Sea, chomping on plankton and fish larvae as it had in the Black Sea.

Fortunately, unlike the Caspian and Black Seas, some predators of *Mnemiopsis* already live in the Mediterranean. That gives researchers some hope. Giannoulaki said, "It's too soon yet to know where it's going to distribute. You never know, because the species can tolerate a very wide range of temperatures and salinities, but I hope it will not turn out too badly."

To access this article online, please visit http://nasadaacs.eos.nasa.gov/articles/2010/2010_ctenophores.html.

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About the remote sensing data used

Satellites	GeoEye SeaStar	Terra
Sensor	Sea-Viewing Wide Field-of-View Sensor (SeaWiFS)	Moderate Resolution Imaging Spectroradiometer (MODIS)
Data sets	SeaWiFS Level 3 Photosynthetically Active Radiation (PAR)	Chlorophyll a
Resolution	4 kilometers	Milligrams per square meter
Parameters	Photosynthetically active radiation	Chlorophyll a concentration
Data centers	NASA Ocean Biology Processing Group (OBPG)	OBPG

About the scientists

Marianna Giannoulaki is a fisheries biologist at the Institute of Marine Biological Resources of the Hellenic Centre for Marine Research, in Heraklion, Greece. She studies fisheries acoustics, fish populations, and stock assessment of small pelagic fish. She also works on ecosystem modeling of species-environment relationships, particularly in the Mediterranean Sea. The Commission of the European Union helped support her research. (Photograph courtesy M. Giannoulaki)

Jennifer Purcell is a marine scientist at the Shannon Point Marine Center of Western Washington University, and a visiting researcher at the Coastal and Marine Resources Centre of the University College Cork, Ireland. She explores the roles of jellyfish as predators and competitors of zooplanktivorous fish, and climate effects on the formation of jellyfish blooms. The Catalan Water Agency supported her research. (Photograph courtesy J. Purcell)

Apostolis Siapatis is a researcher at the Institute of Marine Biological Resources of the Hellenic Centre for Marine Research in Athens, Greece. His previous research focuses on ichthyoplankton, or the eggs and larvae of fish species. The Commission of the European Union helped support his research. (Photograph courtesy A. Siapatis)

For more information

NASA Ocean Biology Processing Group (OBPG)
http://oceancolor.gsfc.nasa.gov

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

Hellenic Centre for Marine Research
http://www.hcmr.gr/index.php

Jennifer Purcell
http://www.ac.wwu.edu/~purcelj3/index.htm

Clues in the nectar

"The question was, were my bees seeing the same trends as the satellite sensors were seeing?"

Wayne Esaias
NASA Goddard Space Flight Center

by Natasha Vizcarra

Backyard beekeeper and NASA biological oceanographer Wayne Esaias admired the time series he made of his honeybees' nectar collection. He had been weighing his beehives daily for more than fifteen years to track how much nectar his bees were collecting from the flowers, tulip poplar trees, and black locust trees in his neighborhood in Maryland. "I plotted the data, out of curiosity," he said, "And lo and behold, the ebb and flow of my bees' nectar collection corresponded with climate events, like El Niños and La Niñas." But as he looked more closely, he saw a curious trend. His bees were gathering nectar earlier in the spring than they did when he began keeping bees in 1992.

Esaias has spent much of his career at the NASA Goddard Space Flight Center studying the patterns and rhythms of microscopic plant growth in the world's seas and oceans. He knew that on dry land, plants and bees had a delicate and interdependent rhythm of their own. The cycle starts in the spring, when days get warmer and longer. Bees emerge to collect nectar, pollinating flowers and aiding in plant reproduction in the process. As old bees die, queen bees lay as many eggs as they can to build up their colonies for next season. Everything relies on the bees and the flowers coming together when both are ready—when flowers brim with nectar and when hives buzz with enough healthy workers to collect food. When winter comes and days shorten and grow colder, honeybees stay in their hives and

Honeybees are helping remote sensing scientists understand how earlier spring arrival might affect plant-pollinator relationships. (Courtesy P. Stein) plants go dormant until spring arrives, and the cycle starts anew. "But as temperatures get warmer, winters get warmer," Esaias said. "And when winters are warmer, spring comes earlier. This could cause the synchrony between the plants and pollinators to get out of kilter."

But is that even possible? "It's possible," Esaias said. "Plants and pollinators have different thermometers." Honeybees take their cue from air temperature because their hive boxes rest on the ground. Plants and trees take their cue mostly from soil temperature. "These are two different microclimates," he said. David Inouye, a professor of biology and an expert on pollination biology and flowering phenology, said that plants and pollinators could differ in their rate of response to an earlier spring, and that this could cause them to get out of sync. Inouye said, "If spring is arriving earlier and air temperatures are warming up sooner, then the bees are likely to be responding. But they may be more sensitive or less sensitive to the temperature change than the plants are, depending on where they are, and what their biology is."

Disappearing colonies

Honeybees were already in big trouble to begin with. In the early months of 2007, millions of honeybees across the United States suddenly, and quite inexplicably, disappeared. Hundreds of beekeepers found their hive boxes silent. West Coast beekeepers reported losses ranging from 30 to 60 percent. In the East Coast, beekeepers reported that more than 70 percent of their hives had gone empty. News of the disappearing honeybees sent apiarists and scientists scrambling to find an explanation. The disappearing act was given a name: Colony Collapse Disorder (CCD), but no one could directly identify a cause. Farmers became worried, as about a hundred crop species in the United States depend on pollination services by managed honeybee colonies. In a report to the U.S. House of Representatives, an entomologist warned that prior to CCD, honeybee populations were already declining at a fast rate, and could become extinct by 2035 if that trend continues.

It was in the midst of this news that Esaias started thinking of bees less as a hobby and more as partners in scientific data gathering. He wondered if honeybees elsewhere in the state were also collecting nectar earlier. Esaias compared data from a beekeeper in Chevy Chase, Maryland, and data from a researcher at the University of Maryland, to his own fifteen-year data set. "There was a very significant trend," Esaias said. "Spring nectar flow is now twenty-six days earlier than it was in 1970, about a half-day earlier each year on average."

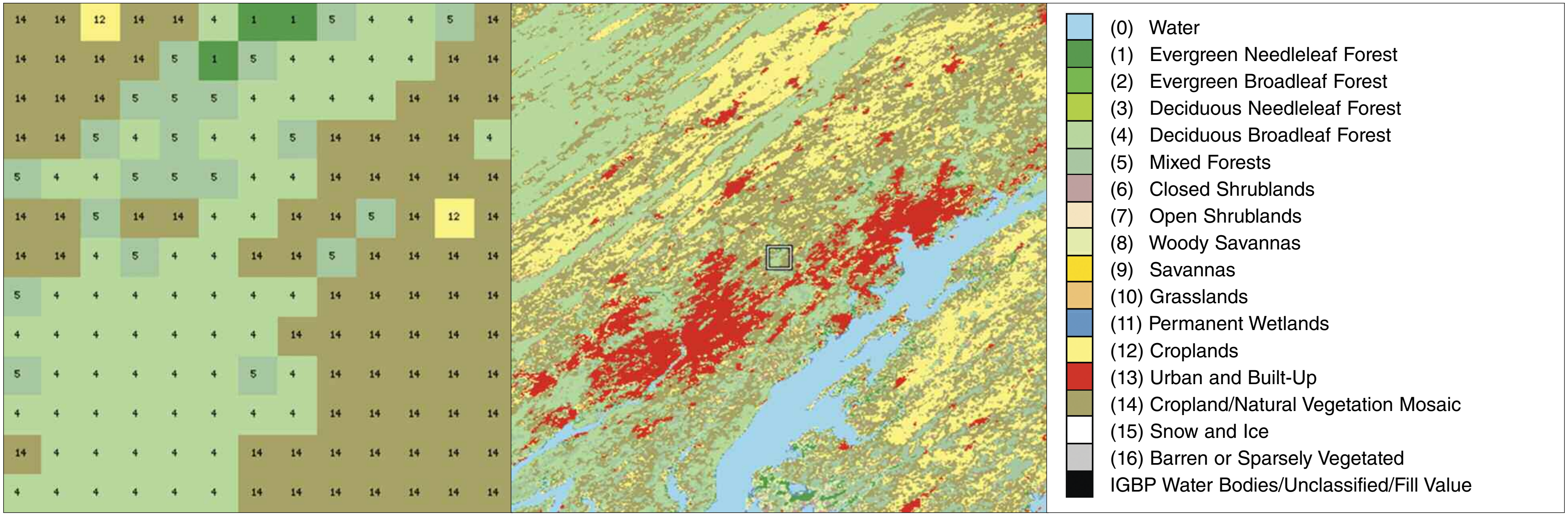
What the green means

Other scientists were also studying the trend of earlier springs, but from space. Scientists use the Advanced Very High Resolution Radiometer (AVHRR), a satellite sensor that measures Earth reflectance, to study spring green-up, when the Earth turns greener every year during spring. "A study reported that the United States was getting greener earlier as part of climate change," Esaias said. "The question was, were my bees seeing the same trends as the satellite sensors were seeing? And the answer was yes, they were spot on."

The AVHRR study found a trend of earlier spring green-ups in the northeast United States and delayed spring green-ups in the southeast United States. Esaias' data and that of other

HoneyBeeNet is a network of citizen scientist beekeepers who weigh their honeybee hives daily using huge, industrial-sized weighing scales like this one. A hive can weigh over 500 pounds, and can gain over 20 pounds per day at the peak of the nectar flow. (Courtesy C. Mark)

volunteer backyard beekeepers in the mid-Atlantic region showed earlier nectar collection dates in sync with the earlier spring green-ups mentioned in the study. Historical data from Baton Rouge, Louisiana, and from a volunteer beekeeper in Carencro, Louisiana, were also in sync with the delayed spring green-up that satellites detected in the southeast. "Plants and trees need a certain amount of chilling days to enter dormancy," Esaias said. "In the southeast United States, plants were not getting enough chilling days, so spring there was delayed." Esaias thinks that combining data from the honeybees with data from satellites can reveal a lot about



Land cover classification maps such as this one help researchers identify nectar sources and better understand bee colony health. The map on the left shows the different kinds of vegetation that surround Esaias' honeybee hive in Maryland: a swath of deciduous broadleaf forest (4), surrounded by a mosaic of cropland or natural vegetation (14), and mixed forests (5). The map on the right shows the location of the 6.5 kilometer square subset within a 201-kilometer square area. Red swaths indicate urban areas. (Courtesy NASA Oak Ridge National Laboratory Distributed Active Archive Center)

how climate change might impact plant-pollinator interactions. "When we have more confirmation that nectar flows from bees follow the vegetation signals we see from satellites, we can better understand how our ecosystems might change," he said. To do that, he needs data from more beekeepers.

HoneyBeeNet

Esaias has organized a network of backyard beekeepers, called HoneyBeeNet, now numbering more than eighty volunteers all over the country. Most reside in the mid-Atlantic region where he began his work. But he is rapidly getting more volunteers from different states. "HoneyBeeNet is a network of citizen scientist beekeepers who volunteer to get a scale, measure their beehives' weights daily, and send us the scale hive data," he said. Some volunteers start out not quite knowing what to make of the satellite data, but are pleased to see it alongside the data they collected from their beehives. "Others are keen on seeing how their backyard changes from year to year as seen through satellite eyes," he said. Esaias considers the scale hive data from volunteers as valuable records of the interaction between plants and pollinators, and how effective bees are in collecting nectar. "That's very hard data to come by," he said. "Satellite sensors can't necessarily see the plants blooming. They can only see foliage turning green. That's why the scale hive data is so valuable in validating what the satellites see," he said.

Esaias is using the scale hive data to validate vegetation data subsets from the Moderate Resolution Imaging Spectroradiometer (MODIS) sensor on NASA's Terra and Aqua satellites, available from the NASA Oak Ridge National Laboratory Distributed Active Archive Center (ORNL DAAC). Like the AVHRR sensor, MODIS also measures and maps the density of the Earth's green vegetation, but at a higher spatial resolution, which means MODIS can provide images over a given pixel of land in finer detail. "The subset data that we get from ORNL is 6.5 by 6.5 kilometers [4 by 4 miles], which means each hive is 3.25 kilometers [2 miles] away from the edge. Bees are sampling that whole area, which makes it nice for comparing with the satellite data. The bees would have already done an integration of the important nectar and vegetation sources as far as they're concerned. They've already done a lot of the work for us," Esaias said.

The research project, which has evolved from Esaias' hobby to a NASA-funded study, could help scientists and apiarists understand how plant and pollinator relationships are changing and might change in the future. Data from the volunteers will also be preserved for climate change and land cover change research. "I was a little nervous when I proposed the study to NASA because this was my hobby, you know," he said. "But there was a real signal in the scale hive data, and I thought it was important. Pollinators are important. It's crucial for us to understand if our pollination system and plants are going to get messed up or how will they change in response to climate change. I'm not so worried about them getting messed up, but how will they change and what measures can we take as beekeepers and food producers to minimize the impact of any changes that occur."

To access this article online, please visit http://nasadaacs.eos.nasa.gov/articles/2010/2010_honeybees.html.

About the remote sensing data used

Satellites	Terra and Aqua
Sensor	Moderate Resolution Imaging Spectroradiometer (MODIS)
Data sets	MODIS Subsets: Vegetation Indices; Land Cover Dynamics; Land Cover Type
Resolution	250 meter and 500 meter
Parameters	Normalized Difference Vegetation Index (NDVI), Enhanced Vegetation Index (EVI), land cover classification, phenology
Data centers	NASA Oak Ridge National Laboratory Distributed Active Archive Center (ORNL DAAC)

Standard MODIS land products are available from the NASA Land Processes Distributed Active Archive Center (LP DAAC).

About the scientists

Wayne E. Esaias is a biological oceanographer at the NASA Goddard Space Flight Center. He specializes in satellite observations of ocean optical properties to study oceanic phytoplankton distributions and carbon uptake on regional and global scales. Esaias is also a master beekeeper. NASA supported his research. (Photograph courtesy W. Esaias)

David W. Inouye is a professor of biology at the University of Maryland. He studies bumblebees, other wild pollinators, and wildflowers, on topics including pollination biology, flowering phenology, plant demography, and plant-animal interactions. The National Science Foundation supported his research. (Photograph courtesy D. Inouye)

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http://daac.ornl.gov

MODIS Land Products Subsets
http://daac.ornl.gov/MODIS/modis.html

HoneyBeeNet
http://honeybeenet.gsfc.nasa.gov/

David W. Inouye
http://chemlife.umd.edu/facultyresearch/facultydirectory/davidwinouye

Cosmic charges

"You can consider the atmosphere around the Earth a giant battery."

Themis Chronis
Hellenic Centre for Marine Research

by Laura Naranjo

Plug in your cell phone or even something as mundane as your toaster, and currents pulse obediently through cables and wing through wires. We have tamed electricity and put it to good use. Or so we think. Earth's entire atmosphere is bristling with electricity, but we are only aware of it when we see lightning—electricity made visible—sizzle across the sky.

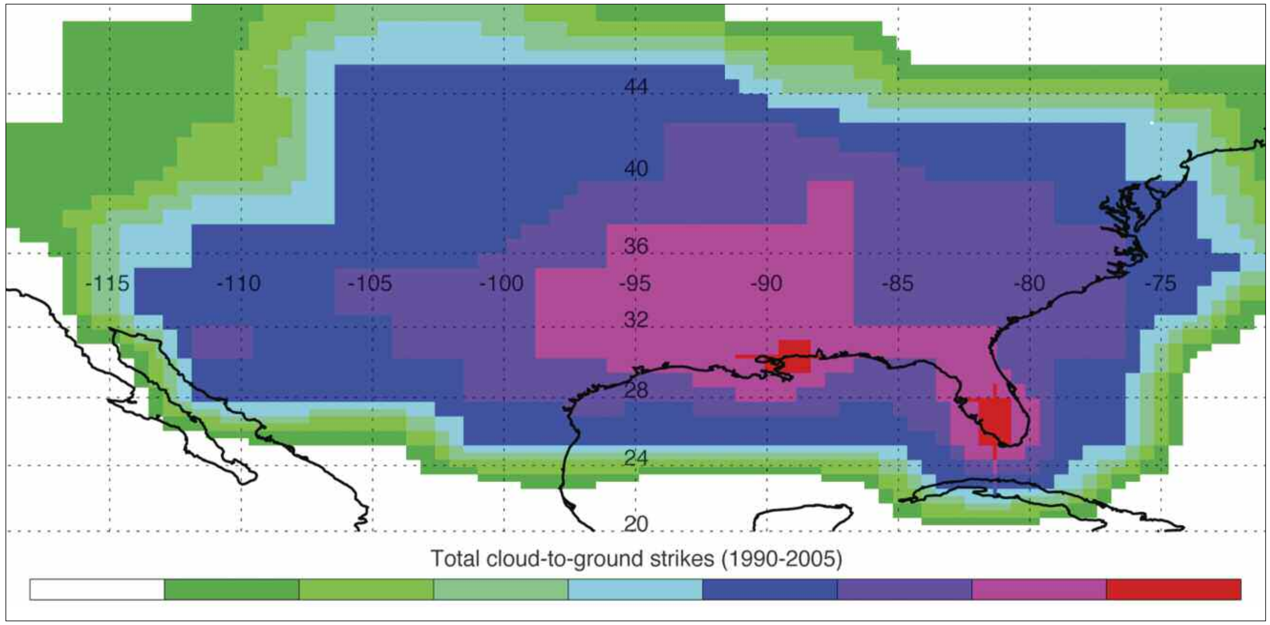
Scientists have discovered that lightning is more than just nature's light show: it can create dangerous weather, disable electrical utilities, and even contribute to air pollution. Earth's electrical environment, however, is not a closed

Thunderstorms discharge electricity as both cloud flashes and ground flashes, as shown in this photograph. Each type of lightning may have different effects on air quality and atmospheric electricity. (Courtesy K. Arnett) circuit. It may be receiving jolts from an unusual, extraterrestrial source: galactic cosmic rays. "Our atmosphere is bombarded with cosmic rays every single second," said Themis Chronis, at the Hellenic Centre for Marine Research. Galactic cosmic rays may seem the stuff of video games, but Chronis found that these rays might be fueling the ebb and flow of Earth's lightning strikes.

A giant battery

Despite their name, cosmic rays are not rays at all. When these were first discovered, scientists assumed they were rays beaming through space, similar to sunlight, and the misnomer stuck. In fact, they are tiny atomic particles released by distant and ancient interstellar events, such as supernova explosions. As these particles ricochet across the galaxy like billiard balls, the force and speed of their travels strips electrons away, often turning them into positively-charged protons by the time they reach Earth.

When cosmic rays enter the atmosphere, they can be one factor in the formation of lightning. "You can consider the atmosphere around the Earth a giant battery," Chronis said. Cosmic rays charge and electrify Earth's atmosphere, and lightning discharges some of that energy. Chronis was intrigued at how much of a role cosmic rays played in triggering lightning all over Earth. At the time, he was completing post-doctoral research at the NASA Global Hydrology and Climate Center, co-located with the Global Hydrology Resource Center (GHRC), which houses data from the National Lightning Detection Network (NLDN). "I had this entire data set that no one else has looked at in this way," he said. "It is the most sophisticated lightning detection system in the world, and the data go back to 1988."



This map of the United States shows the total number of cloud-to-ground lightning strikes from 1990 to 2005 over the United States. Green indicates the fewest strikes, and red indicates the most strikes. Lightning strikes occur most frequently in the southeastern part of the country, in states like Florida and Texas. Data are from the National Lightning Detection Network (NLDN). (Courtesy T. Chronis)

Forbush decreases

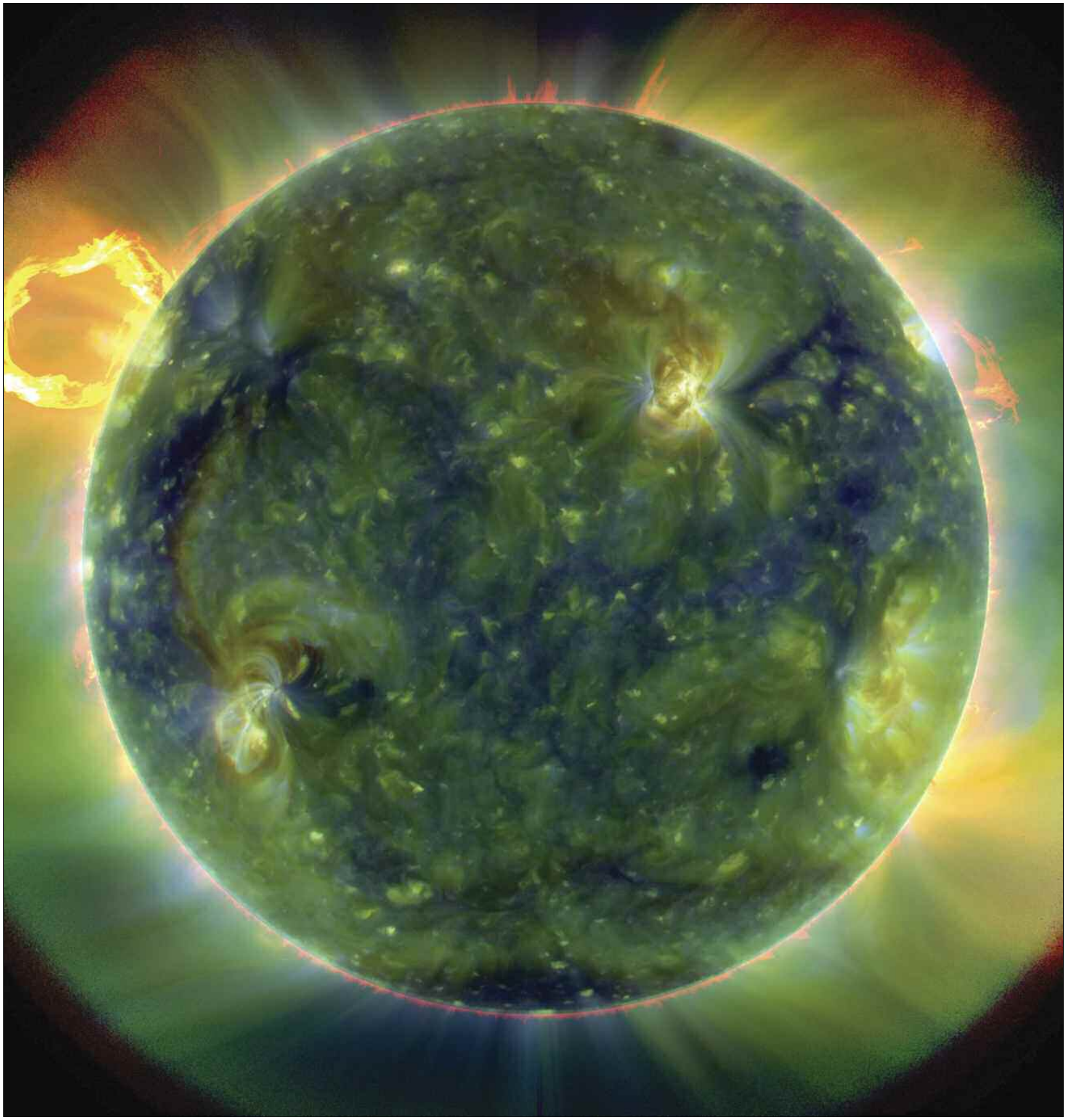
Using the NLDN data, Chronis compared daily cloud-to-ground lightning strikes to data on cosmic ray activity over the continental United States. He found that lightning frequency was indeed linked to the flow of cosmic rays, which in turn are governed by other galactic processes, such as solar flares.

"A solar flare may reduce the cosmic rays that are coming into Earth's atmosphere," Chronis said. During solar flares, the sun ejects massive amounts of plasma gas that diverts cosmic rays, temporarily sweeping them away from the Earth. Chronis discovered that these sudden decreases, called Forbush decreases, also reduced lightning for about four to five days afterwards: Forbush events temporarily made Earth's atmosphere less conductive, resulting in less lightning.

Chemistry in a flash

Although Chronis's findings are preliminary, such a large-scale connection between cosmic rays and lightning holds deeper implications for researchers. Scientists still do not completely understand Earth's electrical environment. But understanding lightning might help reveal how atmospheric electricity influences our everyday life, including the quality of the air we breathe.

William Koshak, a researcher at the Marshall Space Flight Center, studies how lightning affects air chemistry. He said, "Lightning is one of the most important sources of nitrogen oxides in the upper troposphere, and is coupled into the whole



This image of the sun captured a massive solar flare eruption. Intense solar flares can temporarily interrupt the galactic cosmic rays that normally stream into Earth's atmosphere. Scientists have found that these decreases in cosmic rays also reduce lightning frequency on Earth. (Courtesy NASA)

issue of air quality and global warming." Lightning produces the nitrogen oxide gases nitric oxide and nitrogen dioxide, which are toxic air pollutants. Through a chemical chain reaction in the atmosphere, these pollutants can form ozone, which mixes with man-made ozone generated by vehicle exhaust and power plants. In the upper atmosphere, ozone shields us from excessive solar radiation. In lower levels of the atmosphere, however, ozone is harmful to human beings, and has been linked to heart attacks, asthma, and other health problems.

Researchers who assess air pollution and help determine bad air days are equally interested, because current computer models do not adequately account for nitrogen oxides produced by lightning. In addition, scientists do not know enough about Earth's electrical environment to determine which type of lightning contributes more nitrogen oxides to the atmosphere: ground flashes or cloud flashes.

"If you have a better understanding of how many ground and cloud flashes you're dealing with, and better information on lightning channel lengths, currents, and altitudes, then you can do a better job estimating the amount of nitrogen oxides from lightning, which in turn helps you better estimate ozone. It is a complex problem," Koshak said.

Future needs

Scientists do not yet have all the tools needed to unravel this problem on a global basis. Most lightning networks, such as the NLDN, are data-rich. However, these networks are ground-based, which limits them to specific areas. Lightning sensors on satellites can record lightning strikes around the world, but they lack the ability to discern between ground and cloud flashes. "When you're viewing lightning from space, the cloud obscures your view," Koshak said. So Koshak is developing an algorithm that will enable space-based sensors to estimate what fraction of lightning strikes the ground.

Koshak, Chronis, and other lightning researchers hope that future sensors will uncover some of the mysteries about lightning and Earth's electrical environment. Currently, there is only one space-based lightning sensor and a few ground-based networks that observe lightning activity on a global scale. NASA and the National Oceanic and Atmospheric Administration are collaborating to launch a new Geostationary Operational Environmental Satellite-R series (GOES-R) mission, which will include a lightning mapping instrument. This sensor will continuously monitor lightning in the Western Hemisphere, helping to improve severe weather warnings and provide a better understanding of lightning nitrogen oxide production, crucial for improving regional air quality modeling.

Chronis's research revealed that galactic cosmic rays influence the number of lightning strikes over the United States. He still ponders larger questions about lightning, such as what happens to the electrical quality of clouds, and the water and ice within, after lightning discharges. Chronis plans to take advantage of the global view of lightning that the new sensor will provide. He said, "We'll have to wait for a few years to develop a time series, but we will have lightning observations every couple of milliseconds over an entire hemisphere."

To access this article online, please visit http://nasadaacs.eos.nasa.gov/articles/2010/2010_lightning.html.

About the data used

Network	National Lightning Detection Network (NLDN), operated by Vaisala, Incorporated
Sensor	Vaisala IMPACT ESP Lightning Sensors
Data sets	GAI Lightning Ground Strikes and Vaisala U.S. NLDN Flash Data
Resolution	Continental United States
Parameter	Lightning
Data center	NASA Global Hydrology Resource Center (GHRC)

About the scientists

Themis Chronis is a researcher at the Hellenic Centre for Marine Research in Greece. He studies climatological aspects of regional and global lightning activity, hydrology, and remote sensing of extreme weather. The Oak Ridge Associate Universities and the NASA Postdoctoral Fellowship Program supported his research. (Photograph courtesy T. Chronis)

William Koshak is an atmospheric physicist and lightning expert at the NASA Marshall Space Flight Center. His research has included a broad range of activities including mathematical inversion studies, remote sensing of lightning, lightning radiative transfer, lightning chemistry studies, and space sensor calibration and validation. NASA supported his research. (Photograph courtesy E. L. Given)

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For more information

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http://ghrc.nsstc.nasa.gov

National Lightning Detection Network
http://ghrc.nsstc.nasa.gov/uso/ds_docs/vaiconus/vaiconus_dataset.html

NASA Marshall Space Flight Center
http://www.nasa.gov/centers/marshall/home

Hellenic Centre for Marine Research
http://www.hcmr.gr

Seeing the forest for the carbon

“We are trying to provide people in tropical countries with the tools and techniques that they will need to generate their own data sets.”

Wayne Walker
Woods Hole Research Center

by Katherine Leitzell

Just as X-rays, Magnetic Resonance Imaging (MRI), and other imaging tools allow a doctor to examine the bones, muscles, and organs inside the human body, an ecologist can use satellites to peer deep into forests. Like doctors, ecologists can combine data from several tools to get multiple layers of information about the structure of forests, and learn more about the content of the forests and the health of the planet.

Josef Kellndorfer is a satellite data specialist at Woods Hole Research Center (WHRC) who is helping those ecologists by leading a project to map carbon all over the world’s tropical forests. He said, “How much carbon is stored in forests, and exactly how much is getting released, is a big

Wide-scale deforestation is a major concern in tropical countries. This forest in Bolivia once hosted diverse animals and plants, and protected rivers and streams from erosion. The release of carbon stored in the forests can tip Earth’s carbon balance. (Courtesy W. Walker) unknown. We can track a parcel of land being deforested, and we can estimate how much carbon is being released from that small area. But we need to be able to do that on a global or tropical scale." If tropical countries had this information, they might be able to reduce deforestation and carbon emissions, with support from international programs.

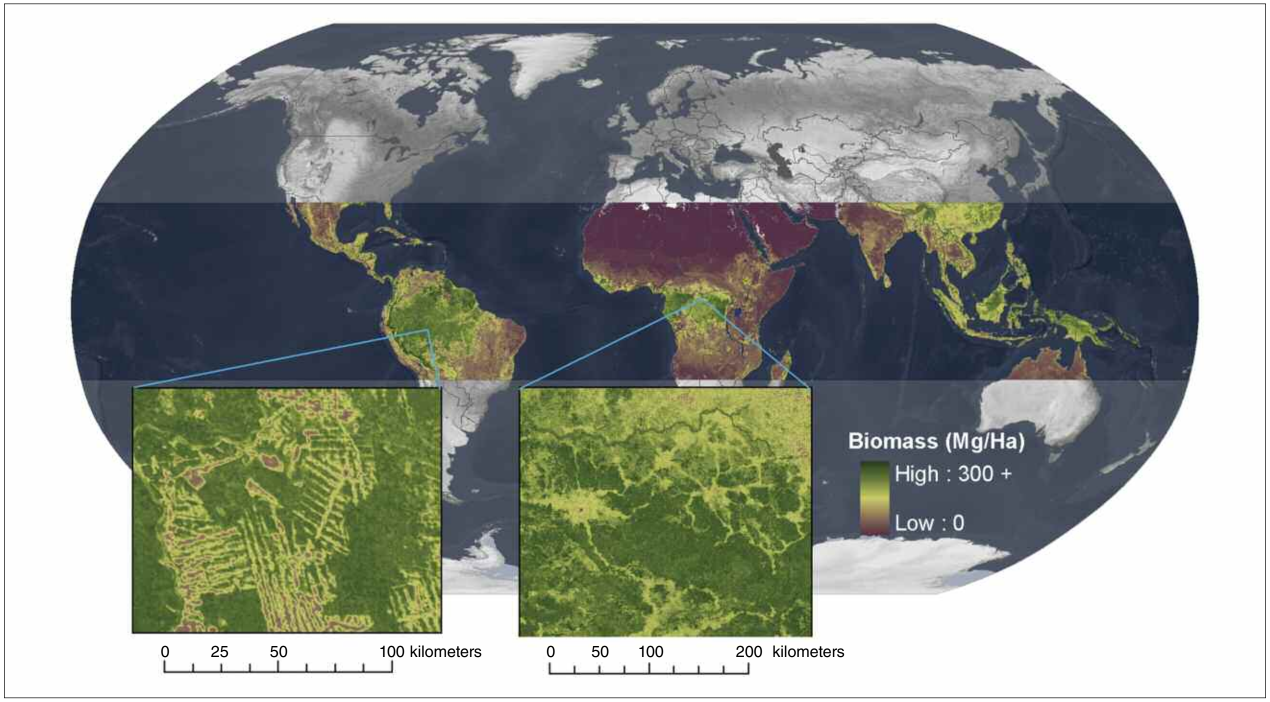
A multilayered carbon map

When a tree falls in the forest, carbon escapes into the air. While auto exhaust and industrial emissions make up the majority of carbon emissions, 15 to 20 percent of the carbon compounds humans release instead come from deforestation. Tim Pearson, who advises on climate change mitigation at Winrock International, said, "When wood is converted to lumber products, there's only about a 50 percent efficiency. Half of the tree goes up into the atmosphere. Even if you just let it decompose, the carbon in wood ends up in the atmosphere." In addition, burning forests to open land for farming—a widespread practice in the world's tropical rain forests—releases the carbon in tree roots, trunks, and branches, as carbon dioxide and carbon monoxide.

The most accurate way to measure the biomass, or carbon content, of a forest would be to chop down all the trees, dry them out, and weigh them: clearly not a realistic method. The next best option is to hike out into forests and measure the height and girth of a sample of trees. Scientists then use statistical formulas to estimate the amount of carbon in a region.

These field methods work well on a small scale, but to get a consistent global picture, researchers need a global tool. Satellite data provide this

A Woods Hole Research Center (WHRC) scientist, left, shows a Ugandan forest ranger how to measure trees to help calculate how much carbon a forest contains. Measurements from local people are vital in assembling a global satellite view of forest carbon stocks. (Courtesy WHRC)



This pantropical map of forest cover combines two types of remote sensing data to estimate the amount of carbon, or biomass, contained in the world's tropical forests. Green indicates regions with greater forest cover, and higher biomass, while purple represents regions with little or no biomass. Data are from the Moderate Resolution Imaging Spectroradiometer (MODIS) sensor on the NASA Terra and Aqua satellites, and from the Geoscience Laser Altimeter System (GLAS) instrument on NASA's Ice, Cloud, and Land Elevation (ICESat) satellite. (Courtesy Baccini et al. 2009)

bigger picture. However, the task is not so straightforward. Kellndorfer said, "What we're really trying to get at are measurements related to carbon. And no single sensor gives us the entire spectrum alone." So Kellndorfer and his colleagues at WHRC are using three different satellites.

To learn where forests exist versus non-forested land, Kellndorfer and WHRC researcher Alessandro Baccini used visual data from the Moderate Resolution Imaging Spectroradiometer (MODIS) sensor on the Aqua and Terra satellites. The MODIS data offer a continuous map of tree cover that spans a wide swath of tropical countries around the globe. WHRC researcher Scott Goetz said, "MODIS measures reflected radiation in the optical, visible and near-infrared, and mid-infrared ranges. It also provides an estimate of the canopy density."

To get a more detailed picture of the trees in the forest, they used lidar data from the Geoscience Laser Altimeter System (GLAS) instrument aboard the Ice, Cloud, and Land Elevation (ICESat) satellite. The lidar data provide a vertical profile of the forest structure, from trunk to treetop, allowing the researchers to determine the forest height and the complexity of its branch structure. Unlike MODIS, which supplies a continuous picture of tropical forest cover, the lidar data take only snapshots: circles 70 meters (230 feet) in diameter, separated by miles. However, the small snapshots give a unique picture of the forest structure. Goetz said, "The lidar penetrates the whole canopy all the way to the ground, and it is by far the best remote sensing tool we have to relate to biomass."

Finally, the scientists needed a tool to measure the density of the forest canopy, the leafy top part of the forest, which is closely related to carbon content. For that, they used the Phased Array Type L-band Synthetic Aperture Radar (PALSAR) sensor on the Japanese Advanced Land Observation Satellite (ALOS) satellite. The PALSAR data provide more information about the forest canopy. The radar also penetrates the thick clouds that often cloak tropical rainforests, and bounces off the small branches and leaves high up in the treetops. Kellndorfer said, "The cloud cover over tropical forests can hide the forests from satellite sensors. The radar lets us see through those clouds."

Field and algorithm

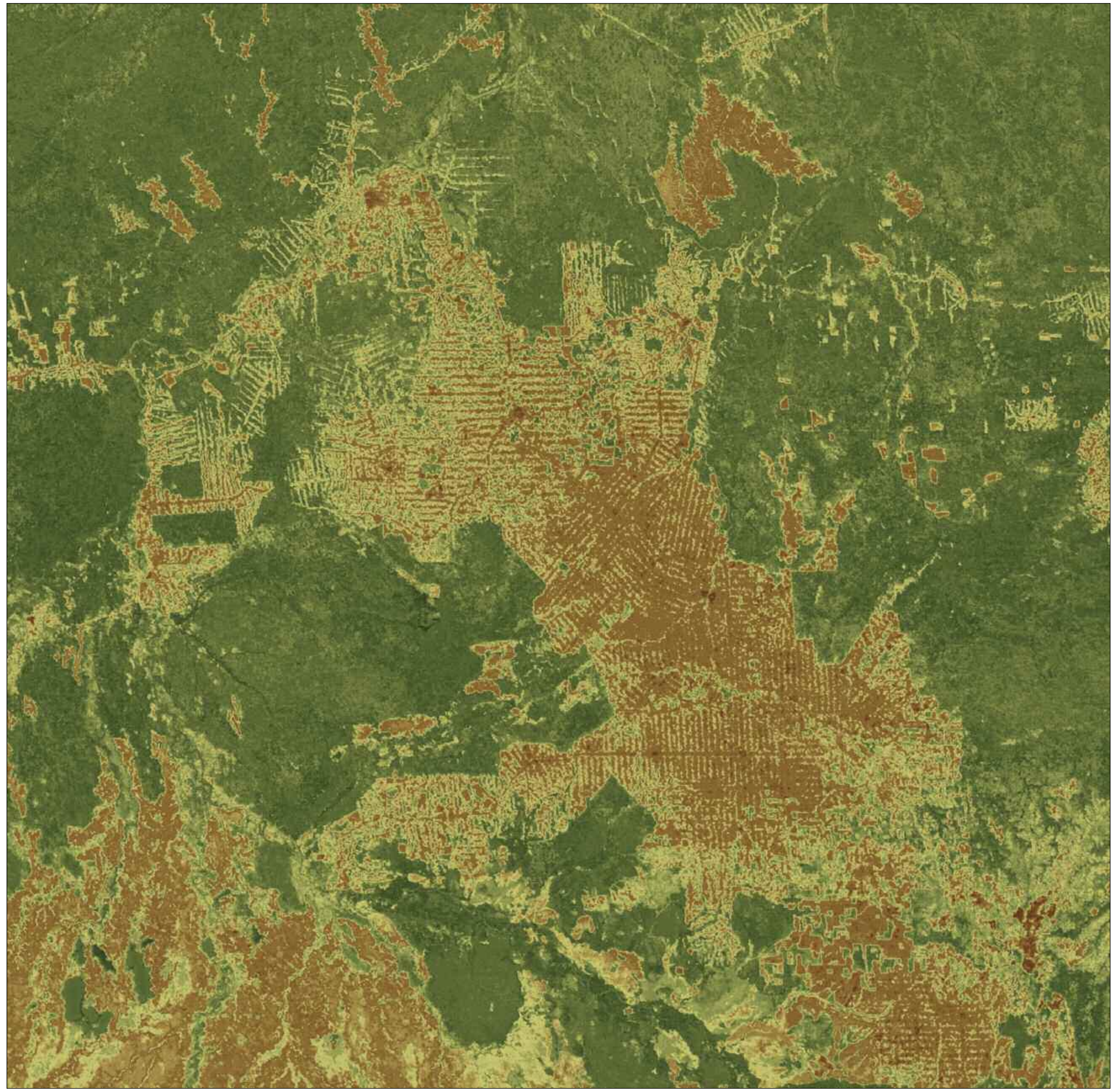
But even with data from multiple sensors, the satellite data alone cannot fully account for forest carbon. Goetz said, "Field measurements are essential. We need them to calibrate and verify the remote sensing measurements." Pearson agreed, saying, "The problem with remote methods is that they look at the spectral signatures or radar returns that come from a forest. The relationship between a spectral signature or a radar return and carbon content is not as simple as the relationship between the girth and height of the tree and its carbon content." To get at this relationship, the scientists need to tie their measurements to actual trees.

So the WHRC researchers travel to countries around the tropics and hike deep into the jungle to find the exact spots of lidar data. Wayne Walker, a WHRC researcher who has worked extensively on the field portion of the project, said, "During one field campaign in Vietnam, we had to rent scooters and motorcycles to get where we needed to go. A group of us traveled two hours to a field station, and then we had to hike for several hours to actually get to the location of the GLAS shot we wanted to sample."

The WHRC team, which also includes researcher Nadine Laporte, is also training local forest rangers, indigenous groups, and governments to conduct field measurements of the forests where they live, and to compare those measurements with satellite data. Walker said, "We are trying to provide people in tropical countries with the tools and techniques that they will need to generate their own data sets."

Kellndorfer said, "It's critical that we not impose our measurements of the biomass of a country, and that the people in the countries are involved. So we're setting up workshops in tropical countries, training people on how biometric surveys in forests are done, and how to relate them with the satellite measurements." In this way, each country gains an understanding of methods for quantifying carbon stocks, and an ownership of the process.

Preserving forests can also help these same local people, who get their livelihoods and food from the forests they live in, and can help maintain ecosystems by protecting soil from erosion and maintaining healthy rivers and streams. An abundance of animals and plants live in the tropical forests that are threatened by deforestation. Goetz said, "Countries all



This map shows spatial patterns of biomass density in the western Amazon Basin. Green represents areas of high biomass, while brown areas are bare ground. The herringbone road pattern in some of the brown areas represents areas of recent deforestation. Researchers hope that a map of carbon stocks for the whole tropical region will serve as a scientific basis for efforts to reduce deforestation and carbon emissions. Data are from the NASA Moderate Resolution Imaging Spectroradiometer (MODIS) sensor and the Geoscience Laser Altimeter System (GLAS) instrument. (Courtesy Baccini, et al. 2009)

A workshop participant practices stem diameter measurements, near Concepción, Bolivia. (Courtesy W. Walker)

want to know how much carbon they have standing in their forests, because it's worth money to protect it. But these forests are valuable not just in terms of carbon; they are also valuable in terms of biodiversity."

Global maps, local benefits

The WHRC team has now created two forest maps that span the tropics: one based on PALSAR radar data, and the other using MODIS and GLAS data to estimate biomass across the tropical region. The next step is to combine the two maps and validate the data with field measurements taken by the WHRC team and local people. Kellndorfer and his colleagues believe that the data will allow them to build an unprecedented map of tropical forest carbon. "We have data sets that cover the entire tropical belt, from 23 degrees north to 23 degrees south," Kellndorfer said. "Now we are trying to convert initial data sets to forest cover and carbon estimates."

When the carbon map is complete, the team plans to give it free of charge to people around the world. Countries will be able to use it for a reference, and add their own field data to improve regional carbon estimates. Walker said, "It's fitting that we'll be able to release this to the public for free, because the product doesn't just belong to us. It belongs to all those folks around the world who have contributed to it."

To access this article online, please visit http://nasadaacs.eos.nasa.gov/articles/2010/2010_forests.html.

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About the remote sensing data used

Satellites	Advanced Land Observation Satellite (ALOS)	Terra and Aqua	Ice, Cloud, and Land Elevation Satellite (ICESat)
Sensors	Phased Array Type L-band Synthetic Aperture Radar (PALSAR)	Moderate Resolution Imaging Spectroradiometer (MODIS)	Geoscience Laser Altimeter System (GLAS)
Data sets	23 centimeter L-band radar	500 meter Nadir BRDF-Adjusted Reflectance (NBAR)	GLAS/ICESat L2 Global Land Surface Altimetry Data
Resolution	10 to 20 meter	500 meter	70 meter circles
Parameters	Vegetation cover	Vegetation	Elevation
Data centers	NASA Alaska Satellite Facility SAR Data Center (ASF SDC)	NASA Land Processes Distributed Active Archive Center (LP DAAC)	NASA National Snow and Ice Data Center Distributive Active Archive Center (NSIDC DAAC)

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Schrope, M. 2009. When money grows on trees. *Nature Reports Climate Change* 3: September 2009, 101−103, doi:10.1038/climate.2009.78

For more information

NASA Alaska Satellite Facility SAR Data Center (ASF SDC)
http://www.asf.alaska.edu
NASA National Snow and Ice Data Center Distributed Active Archive Center (NSIDC DAAC)
http://nsidc.org
NASA Land Processes Distributed Active Archive Center (LP DAAC)
https://lpdaac.usgs.gov
Moderate Resolution Imaging Spectroradiometer (MODIS)
http://modis.gsfc.nasa.gov
Geoscience Laser Altimeter System (GLAS)
http://glas.gsfc.nasa.gov
The United Nations Collaborative Programme on Reducing Emissions from Deforestation and Forest Degradation in Developing Countries
http://www.un-redd.org
Woods Hole Research Center Pan-Tropical Mapping of Forest Cover and Above-Ground Carbon Stock
http://www.whrc.org/pantropical
Josef Kellndorfer
http://www.whrc.org/about/cvs/jkellndorfer.html
Scott Goetz
http://www.whrc.org/about/cvs/sgoetz.html
Wayne Walker
http://www.whrc.org/about/cvs/wwalker.html

About the scientists

Scott Goetz is a senior scientist at the Woods Hole Research Center (WHRC). He works on analyses of ecosystem response to environmental change, including monitoring and modeling links between forest productivity, biological diversity, water quality, and disease vectors in relation to climate and land use change. The Gordon and Betty Moore Foundation, the David & Lucile Packard Foundation, Google, and NASA supported his research. (Photograph courtesy S. Goetz)

Josef Kellndorfer is an associate scientist at the WHRC. He uses remote sensing, geographic information systems, and image analysis technologies to study how ecosystems respond to land use, land cover, and climate change. The Gordon and Betty Moore Foundation, the David & Lucile Packard Foundation, Google, and NASA supported his research. (Photograph courtesy J. Kellndorfer)

Tim Pearson is a scientist at Winrock International. He studies climate change mitigation issues, including land use, forestry, and agriculture. The nonprofit Winrock International provides technical input to governments and organizations on the establishment of mitigation projects and the assessment of mitigation opportunities. Winrock International supported his research. (Photograph courtesy T. Pearson)

Wayne Walker is an assistant scientist at the WHRC. His research focuses on satellite measurement and mapping of forest structural attributes, land cover change, and terrestrial carbon stocks. He also works to build institutional capacity in the tools and techniques used to measure and monitor forests. The Gordon and Betty Moore Foundation, the David & Lucile Packard Foundation, and Google supported his research. (Photograph courtesy W. Walker)

Heart disease in the air

"Remote sensing can fill data gaps, where health data and other pollution monitoring are not available."

Zhiyong Hu
University of West Florida

by Jane Beitler

On any bright warm day, Americans head out to run, bike, or walk their way to fitness, building stronger hearts and bodies in hopes of a healthier and possibly longer life. But as they breathe in air that may be polluted, do they actually risk damaging their hearts and health? Increasingly, health researchers are finding connections between air pollution and heart disease, and they are getting help from environmental researchers in the form of satellite data on air pollution.

From lungs to heart

John Lanza is an epidemiologist and director of the Escambia County Health Department in Pensacola, Florida. His agency and others like it across the United States pay attention to disease

A brownish-white haze hangs low over New York City, as seen in this view from the Brooklyn Bridge. Haze is caused by fine particulate pollution in the air; breathing this polluted air may harm human health in unexpected ways. (Courtesy Health Head Images/Unlisted Images, Inc.)

and environmental connections, as they work to improve and safeguard public health. In his region and across the eastern United States, skies are often white with haze from dense automobile traffic in the cities, and coal-burning power plants spew more particulate matter to the skies. Researchers are still learning all the ways that these particulates may damage health.

Lanza said, "Anytime you burn something, you release particulate matter." Burning of fossil fuels loads the air with fine particulate matter, defined as particles smaller than 2.5 micrometers (in comparison, a human hair is 40 to 50 micrometers wide), and invisible to the human eye. These very small particles are especially hazardous to health; they are small enough to get deep into the lungs, where they can cause illnesses such as asthma, respiratory infections, and lung cancer.

It seems intuitive that breathing in pollutants could damage lung tissue, and in fact, research has strongly connected fine particulate pollution to respiratory disease. A less intuitive effect now drawing attention is the possible link between particulates and the heart. While medical studies have yet to conclusively prove this link, the evidence is mounting.

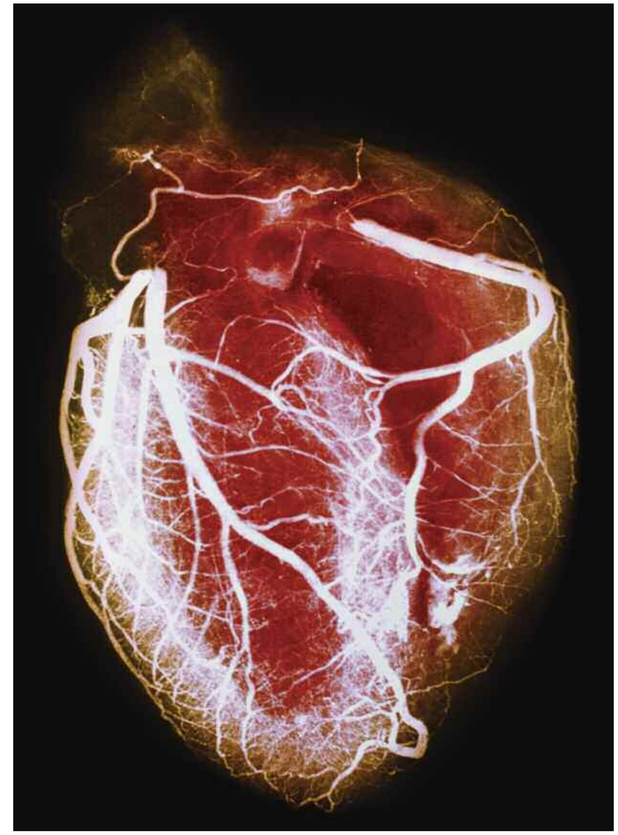
In 2004, a report by the American Heart Association cited an increasing body of evidence supporting the link between air pollution and heart disease. Studies have shown that fine and ultra-fine particulate pollution can pass through the lungs and enter the bloodstream, which carries the pollutants to other organs, inflaming heart tissue, triggering heart arrhythmias, and provoking plaque in the arteries to rupture and cause a clot. These are only a few of the ways that researchers think that particulate pollution accelerates heart disease or causes early death.

But while medical science has established the mechanisms that cause inhaled pollution to trigger illness in the human body, proof of the link between pollution and heart disease remains elusive. "Researchers have been trying to connect heart disease and pollution for a long time," Lanza said. The causes of heart disease are complex, and teasing out the effects of pollution from other causes, such as heredity, smoking, and diet, has been challenging to prove in carefully controlled prospective studies, which follow human subjects over long periods. These studies are expensive, and take decades to provide results. In the shorter term, more data and evidence will help add to the reasons to reduce particulate pollution in the interest of public health. "The more information we have, the more we can do," Lanza said.

Environment and health

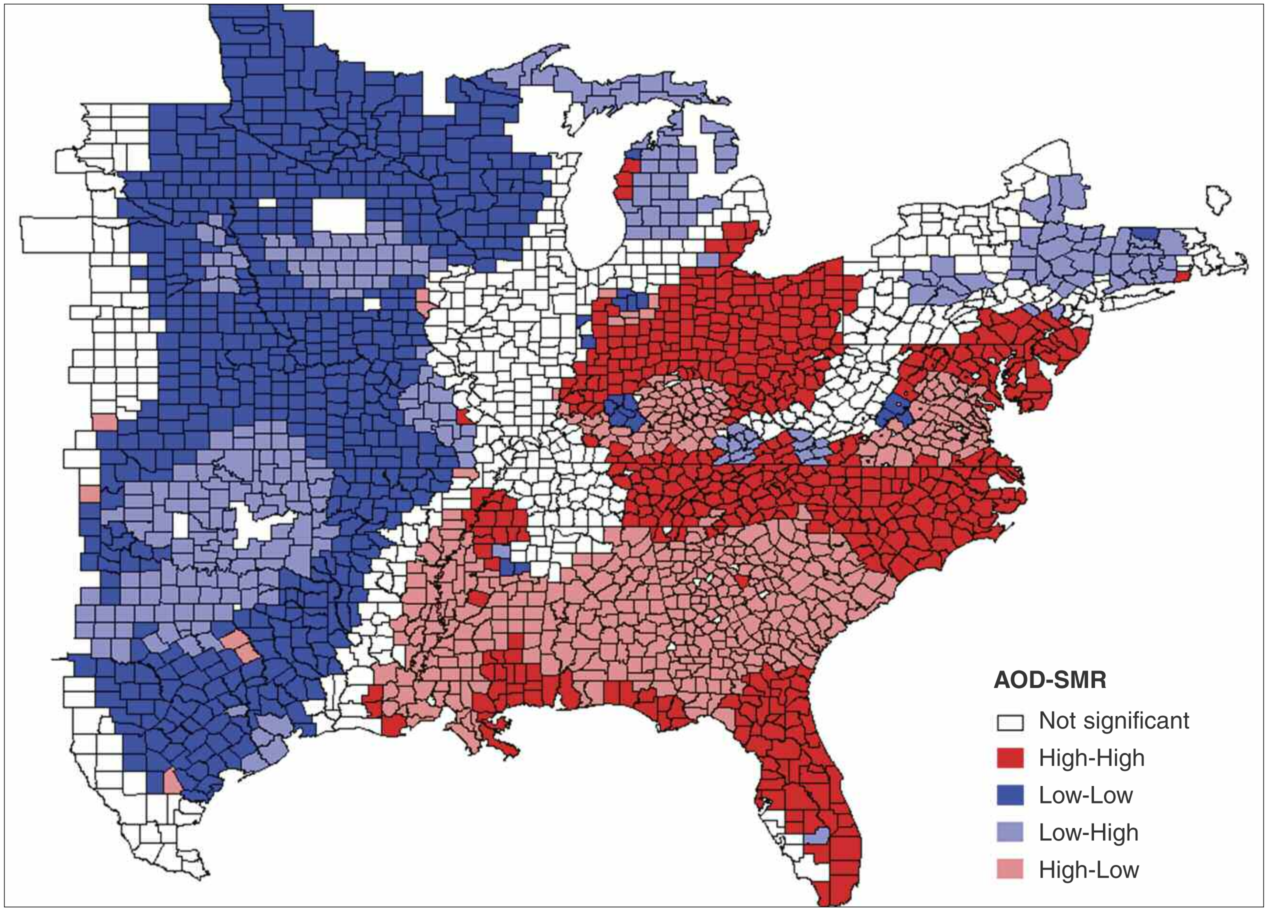
Geographer Zhiyong Hu at the University of West Florida in Pensacola thinks environmental satellite data could be helpful in advancing knowledge about particulate pollution and heart disease. He first became interested in air quality measurements for health studies when he participated in an earlier, broader health study, using ground monitoring equipment and air quality models.

But ground measurement stations are sparse, especially in rural areas and developing countries. Hu was familiar with air quality research using satellite data, which provides wider and more uniform spatial and temporal coverage. Hu said, "There have been a few projects using similar methods; normally they try to link satellite and ground measurements." Interest in such studies is growing, as research demonstrates how satellite data can detect pollution levels relevant to health; NASA researchers are currently working to integrate data on particulates and other environmental factors into a U.S. Center for Disease Control database of public health records.



This angiogram, an X-ray technique using an injected dye, reveals a healthy human heart. Diagnostic tools such as angiograms can help doctors detect and treat serious problems such as narrowed or blocked arteries. But researchers also seek ways to prevent heart disease, which kills millions of people worldwide each year. (Courtesy SPL/Photo Researchers, Inc.)

Hu's study focused on data from the NASA Moderate Resolution Imaging Spectroradiometer (MODIS) sensors. Flying on both the Aqua and Terra satellites, MODIS views the entire surface of the Earth every one to two days. Its spectral



This map of the eastern United States shows how data on aerosol optical depth (AOD) compares with data on mortality (standard mortality rate, or SMR) from heart disease. Red counties indicate where both AOD and deaths from heart disease were high; dark blue indicates where both were low. (Data from MODIS, obtained from the NASA MODAPS Level 1 Atmosphere Archive and Distribution System, courtesy BioMed Central and Z. Hu)

channels were designed to observe many features of land, oceans, and atmosphere, but it turns out that MODIS is also good at picking up aerosols for monitoring surface air quality. An algorithm retrieves aerosol optical depth (AOD), which researchers can use to estimate particulate matter concentrations.

The task was to put together a model that combines the air quality data with health data, as well as an algorithm to flag trouble spots. If it is true that air pollution plays a role in heart disease, Hu expected that areas with high AOD measurements would also show higher mortality rates than areas with low AOD.

Satellite pixels and disease polygons

Aligning two completely different types of data can be like comparing apples and oranges, so Hu and colleague Ranga Rao, who is skilled in working with health statistics, figured out how to standardize and geographically align MODIS data on air quality to heart disease mortality statistics. This work allowed the researchers to compare the data, and found that the correlation in the eastern United States was significant: areas with high mortality rates corresponded with high AOD concentrations during the one-year study period, from 2003 to 2004.

Besides its spatial and temporal coverage, Hu sees several advantages to satellite remote sensing data. It presents the possibility that satellite air quality data can point at health trouble spots. "Remote sensing can fill data gaps, where health data and other pollution monitoring are not available," he said. The environmental data also add to the increasing evidence of a pollution-heart disease connection that can stimulate further biological studies. And aggregated data on disease is in many ways more similar to a satellite pixel than to point data from a ground instrument.

Hu's work does not prove that air pollution causes heart disease. He said, "My research is indicative, not causative. I am a geographer, not a biomedical scientist; we do research from different perspectives. Mine is ecological, geographic, from space." He hopes that his research stimulates more inquiry into both health and into satellite monitoring of air quality. "This kind of research could help governments around the world make policies to target polluted areas in the interest of public health," he said.

With increasing evidence that links air pollution to heart disease, public health agencies are working to educate people in ways that will protect public health. Lanza said, "We put out public information on ways to reduce particulate matter in the air. We've helped get anti-idling laws for commercial trucks, and promoted the benefits of electric lawnmowers and leaf blowers, for example." Research on pollution and health also provides compelling evidence for bigger efforts to reduce pollution. Lanza said, "We worked with the local coal plant, which was grandfathered in and did not have to comply with EPA [Environmental Protection Agency] standards. They have decided to spend almost a billion dollars installing scrubbers to reduce their emissions." In the near future, Lanza and other health officials will be monitoring the 2010 Gulf oil spill for air quality degradation and long-term health effects. "It's still too early to know," Lanza said.

Of Hu's study, Lanza said, "It is one way of looking at a disease causation that will be useful because it is a lot less expensive than prospective studies. It's a fifty thousand foot view."

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About the remote sensing data used

Satellites	Terra and Aqua
Sensor	Moderate Resolution Imaging Spectroradiometer (MODIS)
Data set	MODIS Level 2 Aerosol
Resolution	10 kilometer
Parameter	Aerosol optical depth
Data center	NASA MODAPS Level 1 Atmosphere Archive and Distribution System (MODAPS LAADS)

About the scientists

Zhiyong Hu is an associate professor at the University of West Florida. His work includes land use and land cover classification, GIS-based modeling of spatio-temporal dynamics and human dimensions in land use and land cover changes, spatial analysis of environmental health, and remote sensing of air pollution. The U.S. Environmental Protection Agency supported his research. (Photograph courtesy University of West Florida)

John Lanza is director of Escambia County Health Department and an instructor at the School of Allied Health and Life Sciences at the University of West Florida. He is a board-certified pediatrician with a PhD in Nuclear and Radiological Engineering (Medical Radiation Physics) from the University of Florida, and a clinical assistant professor in the Department of Clinical Sciences at the Florida State University College of Medicine. (Photograph courtesy University of West Florida)

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For more information

NASA MODAPS Level 1 Atmosphere Archive and Distribution System (MODAPS LAADS)
http://laadsweb.nascom.nasa.gov

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

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NASA's view from space reveals our dynamic planet