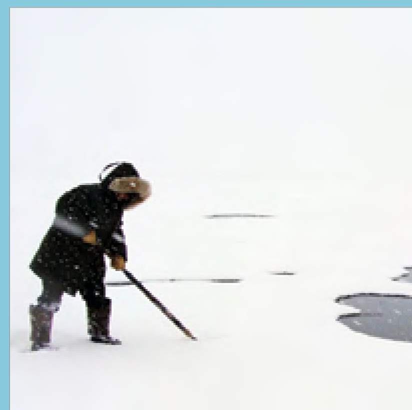
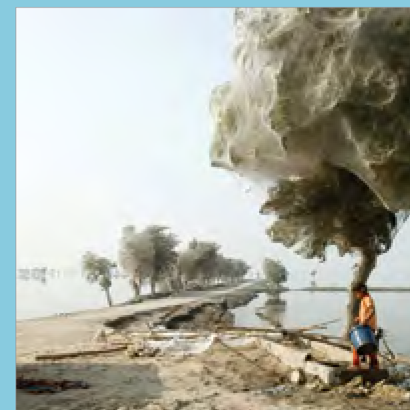
National Aeronautics and Space Administration

Sensing Our Planet




NASA Earth Science Research Features 2012

Sensing Our Planet

NASA Earth Science Research Features *2012*

National Aeronautics and Space Administration

NASA Earth Observing System Data and Information System (EOSDIS)
Distributed Active Archive Centers

Front cover images

Top row, left to right:

Krill are small, shrimp-like sea creatures that form the basis of an entire marine food chain. Along the northern Antarctic Peninsula, penguins and whales feed on krill. Southern Ocean krill are similar to the northern krill shown in this photograph. See the related article, “Fleeting phytoplankton,” on page 2. (Courtesy Ø. Paulsen)

Researcher Melanie Engram prods the snow on the lake surface to check for thin ice, before approaching the snow-free circles that suggest methane seeping from underneath the lake. See the related article, “Leaking lakes,” on page 22. (Courtesy K. W. Anthony)

Polar stratospheric clouds, also known as mother-of-pearl clouds for their colorful pastel appearance, form when extremely cold conditions in the high Arctic and Antarctic atmospheres cause nitric acid and water to freeze into tiny crystals. Reactions on the surfaces of these clouds convert chlorine compounds into the forms that rapidly destroy ozone. See the related article, “A new pole hole,” on page14. (Courtesy Alfred Wegener Institute)

A girl stands next to a tree covered in webs in a heavily flooded area in Sindh, Pakistan. Millions of spiders have climbed into the trees to escape the flood waters. See the related article, “A kink in the jet stream,” on page 6. (Photograph by R. Watkins courtesy Department for International Development)

Bottom row, left to right:

Resource manager Rafael Manzanero stands atop the great temple at Caracol Archaeological Reserve, located inside the Chiquibul National Park. See the related article, “Orbiting watchtowers,” on page 48. (Photograph by J. Houston courtesy Rare)

Pacific bluefin tuna are prodigious swimmers, able to cross the Pacific Ocean in less than a month. Their mobility can make their now-sparser populations hard for fishermen to find. See the related article, “Shadowing the tuna boats,” on page 36. (Courtesy T. Ichishima)

Researchers Shaila Shodean (left) and Andy Hawk (right) take measurements and collect tree litter, such as twigs, bark, and needles, from juniper trees in central New Mexico. See the related article, “Biomes in the balance,” on page 40. (Photograph by K. Anderson-Teixeira courtesy Smithsonian)

Back cover images

Top row, left to right:

New York City shines brighter than any other U.S. city at night. Nighttime lights can indicate relative economic prosperity. See the related article, “Prosperity shining,” on page 28. (Courtesy R. Fernandez)

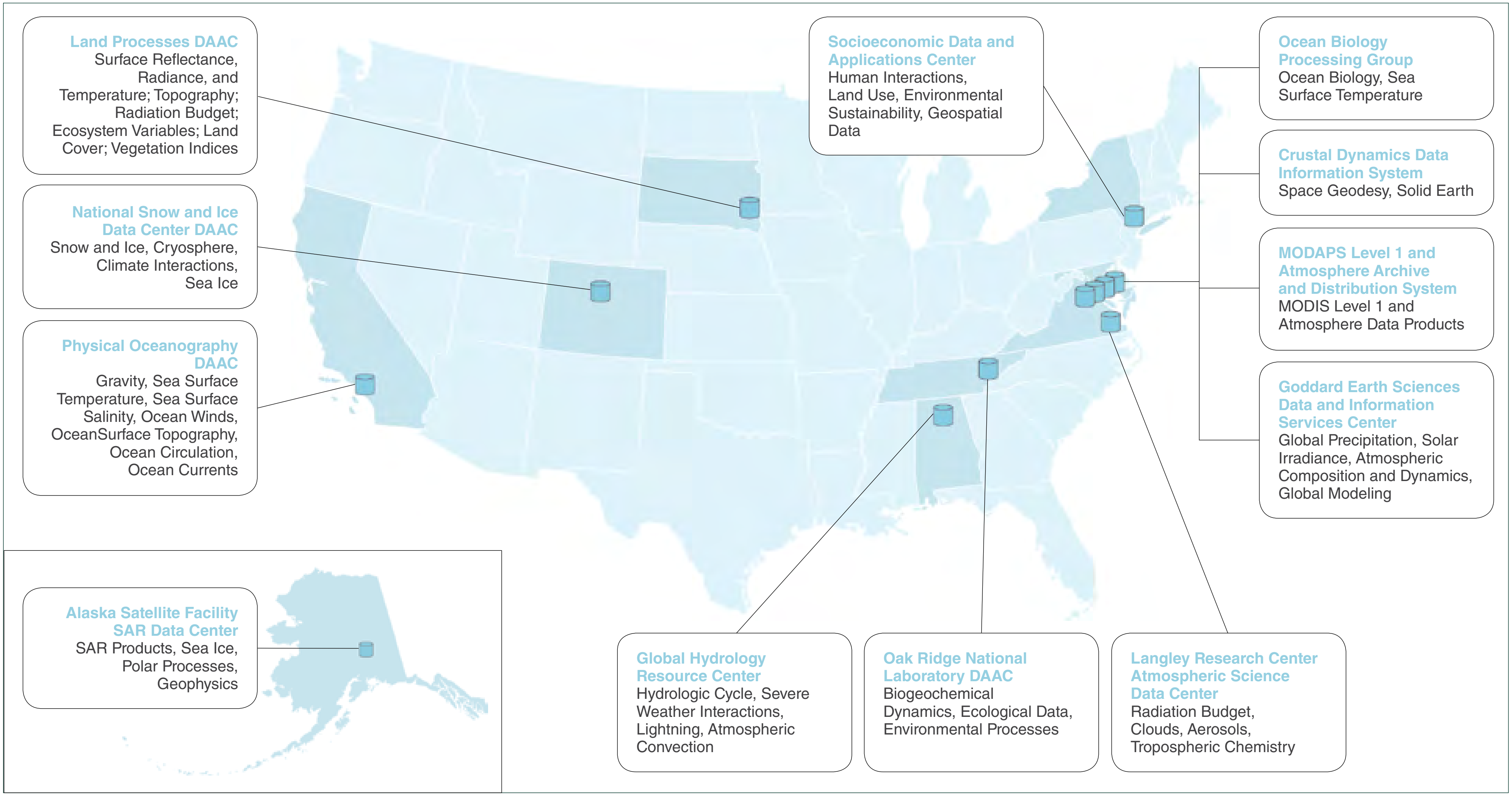
Snowmelt swells the Colorado River from high Rocky Mountain trickle to the largest river in the southwestern United States. The Glen Canyon Dam is one of several dams along the river, which continues to flow to the Gulf of California, providing drinking water for Los Angeles and irrigating California’s Imperial Valley. See the related article, “Winter’s water,” on page 32. (Courtesy C. Mehlführer)

Bottom row, left to right:

The scraggy branches of a South African baobab tree catch the last rays of sunlight for the day. See the related article, “New angles,” on page 18. (Courtesy Flickr/whl.travel)

Geese roam about on a typical farm in the Samara region in central Russia. Many farms in Russia are in remote areas hundreds of miles from major cities, and may lack modern amenities such as telephones and television. See the related article, “Foot and plow,” on page 44. (Courtesy K. de Beurs)

U.S. Navy officer Jonathan Myers explains to his colleague April Beldo how to use a marine sextant during a demonstration of celestial navigation. See the related article, “Where on Earth,” on page 10. (Photograph by T. K. Mendoza courtesy U.S. Navy)



About the EOSDIS Distributed Active Archive Centers (DAACs)

The articles in this issue arose from research that used data from NASA Earth Observing System Data and Information System (EOSDIS) Distributed Active Archive Centers (DAACs). The DAACs, managed by NASA's Earth Science Data and Information System Project (ESDIS), offer more than 5,000 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 programs. These data enable the study of Earth from space to advance scientific understanding.

For more information

"About the NASA Earth Observing System DAACs" (page 52)
NASA Earth Data Web site
http://earthdata.nasa.gov
NASA Earth Science Web site
http://science.nasa.gov/earth-science

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 2012* are available online at the NASA Earth Data Web site (http://earthdata.nasa.gov/sensing-our-planet). A PDF of the full publication is also available on the site.

For additional print copies of this publication, please e-mail nsidc@nsidc.org.

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 waves. Several stories for 2012 spotlight how satellite and ground observations can help researchers look below the surface of water on Earth. See "Fleeting phytoplankton," page 2; "Leaking lakes," page 22; "Winter's water," page 32; and "Shadowing the tuna boats," page 36.

Acknowledgements

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

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Sensing Our Planet

NASA Earth Science Research Features *2012*

Fleeting phytoplankton

"Changing the arrival and departure of sea ice changes the timing of phytoplankton growth."

Martin Montes-Hugo
Southwest Research Institute

by Laura Naranjo

Over the long, dark winters, sea ice forms across the Southern Ocean surrounding Antarctica. During the short summer much of the sea ice melts, and the ocean bursts into a brief flurry of life, feeding everything from fish to penguins to massive humpback whales. This annual summer boom is based on phytoplankton, microscopic plant-like creatures that live near the ocean surface. Dormant during the winter, in the summer sunlight they reproduce and bloom prolifically. Or they used to.

Scientists working on the Antarctic Peninsula noticed that over the past several decades, phytoplankton blooms have been on the wane. At the same time, the length of the ice season has shortened by nearly three months. On average, ice along the Peninsula now forms fifty-four days later and melts thirty-one days earlier. The shorter ice season means more sunlight reaches the ocean surface. More sunlight should mean more phytoplankton, and consequently, a booming ecosystem further up the food chain. But the researchers discovered that was not happening. They

Krill are small, shrimp-like sea creatures that form the basis of an entire marine food chain. Along the northern Antarctic Peninsula, penguins and whales feed on krill. Southern Ocean krill are similar to the northern krill shown in this photograph. (Courtesy Ø. Paulsen) began to wonder, was disappearing sea ice to blame for the disappearing plankton? And what happens to the animals that depend on the microscopic creatures?

Receding ice

As it turns out, sea ice creates just the environment that phytoplankton need to thrive. Although the ocean is constantly swirling and mixing, it settles into layers that stratify the water. Phytoplankton prefer the topmost layer, nearest the sun, which is why their brilliant red or green blooms are often visible. They also like the fresher water contained in this surface layer, as it allows them to float above the saltier and denser layers below.

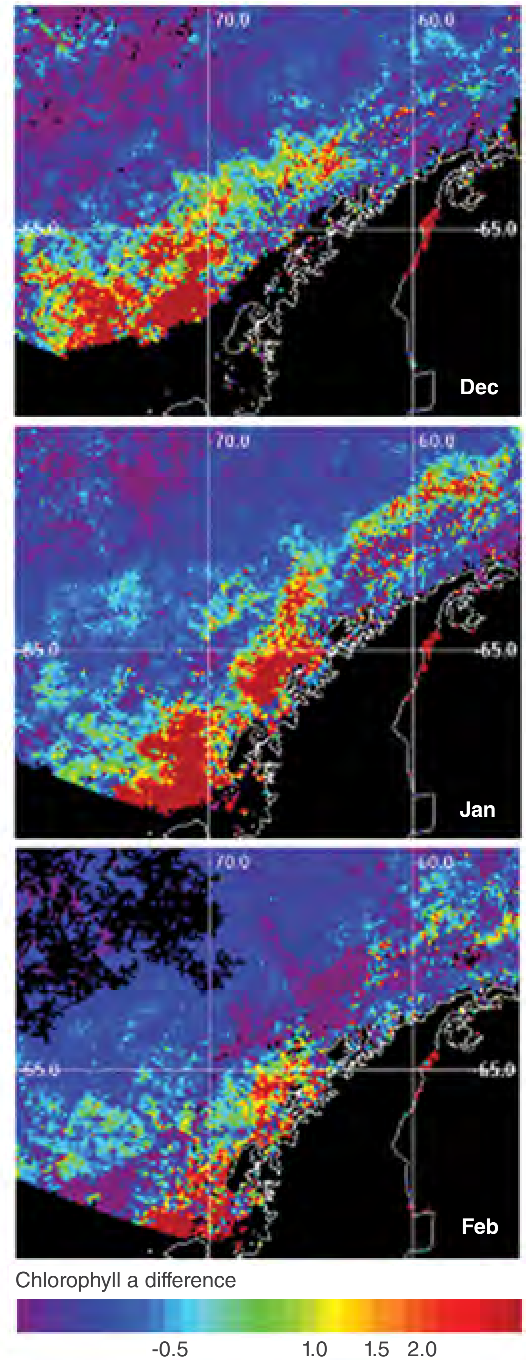
In the Southern Ocean, the annual spring sea ice melt helps create this top layer. Because salt does not freeze, it is slowly expelled as ocean water freezes, meaning sea ice contains almost no salt. “Melting sea ice means fresh water, which is going to help stratify salty water. It creates a cap of fresh water near the surface that helps phytoplankton to grow,” said Martin Montes-Hugo, a researcher at the University of Quebec. Montes-Hugo collaborated with colleagues conducting research at Palmer Station, situated on the western coast of the Peninsula, to see how sea ice might be affecting phytoplankton.

North and south

Although phytoplankton blooms are sometimes visible to the naked eye, seeing their full extent often requires an aerial view. Satellite sensors can be ideal for this, because they capture the large swaths of ocean colored by blooms. For the scientists, the trick was to find satellite data that extended back in time far enough to reveal a trend they could compare to decades of sea ice records. They could get data collected by the NASA Coastal Zone Color Scanner from 1978 to 1986, and by the NASA Sea-Viewing Wide Field-of-View Sensor from 1998 through 2006, from the NASA Ocean Biology Processing Group. To fill the time gap between the two data sets, the scientists used meteorological and oceanographic data gathered on annual cruises, along with records from their colleagues at Palmer Station.

They found that the northern and southern parts of the Peninsula told very different stories. The northern tip of the Peninsula was experiencing the most change, including the most drastic sea ice loss, and the plankton populations there were decreasing dramatically. But on the southern end, where the Peninsula broadens into the continent, sea ice was not diminishing as fast, and plankton were still thriving.

These differences between north and south carried consequences for the food chain along the Peninsula. The vast blooms of microscopic phytoplankton feed krill, which are larger, shrimp-like plankton. In turn, fish, penguins, nd whales live on the krill. “Changing the arrival and departure of sea ice changes the timing of phytoplankton growth,” said Montes-Hugo.



These satellite images show how chlorophyll a populations decreased during the Southern Hemisphere summer months along the Antarctic Peninsula. Chlorophyll a indicates the presence of phytoplankton, which are at the base of the marine food chain. Blue and purple indicate decreasing phytoplankton; orange and red indicate stable or increasing populations. Land is shown in black. Data are monthly average satellite-derived chlorophyll difference between 2001 and 2006 from the Coastal Zone Color Scanner and the Sea-Viewing Wide Field-of-View Sensor. (Courtesy M. Montes-Hugo)

This Adelie penguin (top) is regurgitating krill to feed its chick. Adelie populations have crashed along the northern Antarctic Peninsula, as their food source of krill diminishes. Adelies have been replaced by other species, like Chinstrap penguins (bottom), that do not rely as heavily on krill. (Top: Courtesy L. Quinn; bottom photograph by Lieutenant P. Hall courtesy NOAA Corps)

"The krill are disappearing in the north and are actually increasing in the south. The food web is moving south and is being replaced by a different food web to the north."

Plankton blooms in the north now favor smaller organisms instead of the large diatoms that krill prefer. As the krill move south, a form of plankton called salps are taking over the northern part of the food chain. Salps are large, translucent, barrel-shaped plankton that resemble jellyfish. They are mostly composed of water and are not as nutritious as krill, so some penguin and whale species cannot survive on them.

Receding sea ice in the north was pushing certain species to the more stable ice conditions remaining along the southern Peninsula. But when the researchers looked at the entire region, they discovered that disappearing sea ice was only part of what was causing such a dramatic shift in phytoplankton populations.

Wind, clouds, and currents

At first glance, it seemed that a shorter sea ice season would prime the ocean for more frequent or more extensive blooms. "Typically, you'd think that as the ice retreats, it opens the water up to let more light in and stratify the water. That's very good for the phytoplankton," said Scott Doney, a senior scientist at the Woods Hole Oceanographic Institution, and one of Montes-Hugo's colleagues. But as they pored through the data, the team discovered that over the same time period, changes in weather were exacerbating the changes in sea ice and plankton.

Receding ice was leaving the ocean surface vulnerable to intense wind. Some wind mixing is beneficial because it helps dredge up nutrients from deeper ocean layers without disturbing the stratified layers that keep fresh water, and phytoplankton, near the surface. But the winds around Antarctica are notoriously strong, and were becoming even more intense. Doney said, "A lot of wind mixing destroys that stratification, and the phytoplankton mix down deeper in the water column where there's less light." The lack of sea ice left phytoplankton to the mercies of an increasingly wind-whipped surface, particularly along the northern Peninsula. And even if phytoplankton managed to stay near the turbulent surface, the stronger winds were blowing more clouds over the northern Peninsula, obscuring sunlight and further restricting blooms.

In addition, the Peninsula may be receiving a double dose of warming: changes in atmospheric circulation are sweeping warmer, sub-polar air across the region while at the same time the temperature of the Antarctic Circumpolar Current that surrounds the continent may be rising. This current normally helps chill Antarctica and acts as a barrier against more temperate currents. But the circumpolar current is now bathing the coasts in slightly warmer water. Doney said, "The whole climate change story is connected. In the north, you're getting changes in wind, and that's also linked to cloudiness. So you have less sea ice, more northerly winds, more cloudy conditions, and warmer conditions. Those are all linked together."

Fluctuating food webs

Sea ice may have been the most obvious indicator of phytoplankton health, but the entire climate of the Peninsula has been shifting for decades, and these changes are starting to propagate up the region's food chain. Doney said, "We've seen almost a complete collapse of the local Adelie penguin population." Adelie colonies along the Peninsula have been replaced by Chinstrap penguins, which do not depend on krill. Montes-Hugo added, "Now these food chains are going to be replaced by a different food chain, based on a different kind of penguin." Likewise, baleen, fin, and humpback whales also feed on krill, and will be affected by changes in phytoplankton blooms and locations.

Disappearing sea ice is causing a cascade of change throughout the ecosystem. Although sea ice is more stable along the southern coasts, environmental change may be creeping to that portion of the Peninsula. With more ecological shifts in store, scientists wonder whether these changes will soon manifest in other parts of Antarctica. Montes-Hugo asked, "How will the future be, in terms of wind, in terms of cloudiness, in terms of sea ice? How are all of them going to impact the timing and magnitude of the blooms?"

To access this article online, please visit http://earthdata.nasa.gov/sensing-our-planet/2012/fleeting-phytoplankton

Reference

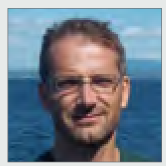
Montes-Hugo, M., S. C. Doney, H. W. Ducklow, W. Fraser, D. Martinson, S. E. Stammerjohn, and O. Schofield. 2009. Recent changes in phytoplankton communities associated with rapid regional climate change along the western Antarctic Peninsula. *Science* 323(5920): 1470−1,473, doi:10.1126/science.1164533.

About the remote sensing data used

Satellites	Nimbus 7	SeaStar
Sensors	Coastal Zone Color Scanner	Sea-Viewing Wide Field-of-View Sensor
Data sets	CZCS Monthly Climatologies	SeaWiFS Monthly Climatologies
Resolution	4.5 kilometer	4.5 kilometer
Parameters	Chlorophyll a	Chlorophyll a
DAACs	NASA Ocean Biology Processing Group (OBPG)	NASA OBPG

About the scientists

Scott C. Doney is a senior scientist in marine chemistry and geochemistry at the Woods Hole Oceanographic Institution. He studies marine biogeochemistry and ecosystem dynamics. The National Science Foundation supported his research. (Photograph courtesy S. Doney)



Martin Montes-Hugo is a professor and researcher at the Institut des Sciences de la Mer de Rimouski at the University of Quebec. He specializes in polar marine ecosystems and remote sensing of marine environments. The National Science Foundation supported his research. (Photograph courtesy M. Montes-Hugo)

For more information

NASA Ocean Biology Processing Group (OBPG)
http://oceancolor.gsfc.nasa.gov
Coastal Zone Color Scanner (CZCS)
http://oceancolor.gsfc.nasa.gov/CZCS
Sea-Viewing Wide Field-of-View Sensor (SeaWiFS)
http://oceancolor.gsfc.nasa.gov/SeaWiFS
Palmer Station Antarctica
Long Term Ecological Research
http://pal.lternet.edu
Scott C. Doney
http://www.whoi.edu/profile/sdoney
Martin Montes-Hugo
http://www.ismer.ca/Montes-Hugo-Martin?lang=en

A kink in the jet stream

"To have a fifth of the country flooded like that is very rare."

William K. M. Lau
NASA Goddard Space Flight Center

by Natasha Vizcarra

In northern Pakistan, a hot, western wind blows through the land on summer afternoons. It dries ponds, wilts plants, and sends people and their pets scurrying indoors. The locals are used to it, and pass the time cooling off with lassis and refreshing sherbets made of rose or phalsa flowers. At the tail end of one such summer in July 2010, dark, heavy clouds brought monsoon rains to northwestern Pakistan and a welcome relief from the heat. But these were not the light rains that people were used to. Unexpected waves of torrential rain came one after another, day after day, becoming a nightmarish two months of almost nonstop rains. By mid-August, the

A girl stands next to a tree covered in webs in a heavily flooded area in Sindh, Pakistan. Millions of spiders have climbed into the trees to escape the flood waters. (Photograph by R. Watkins courtesy Department for International Development) rains had plunged a fifth of Pakistan underwater, killed 1,600 people, and destroyed 1.7 million homes.

The magnitude of the rainstorms and the scale of destruction they had caused baffled William K. M. Lau, an atmospheric scientist at the NASA Goddard Space Flight Center. "Northwestern Pakistan doesn't normally get those kinds of storms," he said. Intrigued by what could have caused the anomalously heavy rains, Lau pored through rain gauge records and remote sensing data for Pakistan. What he stumbled on gave him important clues in understanding not just the extreme rains and floods in Pakistan but also the worst ever heat wave happening thousands of miles away in western Russia.

Monsoon shift

Northern Pakistan is an arid region and does not get a lot of rain even during the monsoon season. It sits in the rain shadow of the Hindu Kush Mountains and is barely touched by the Southwest Monsoon that sweeps through the Indian Subcontinent from June through September. Rain gauge data show that northern Pakistan only gets 160 to 180 millimeters (6 to 7 inches) of total average rainfall at the peak of the monsoon period, a puny amount compared to the 1,600 to 2,000 millimeters (63 to 79 inches) that pours on the Bay of Bengal in India. "The Bay of Bengal usually bears the brunt of the rainfall during that time of the year," Lau said.

Which is why the country was caught off guard by the heavy rains in 2010. On July 4, torrential rains poured over the northwestern provinces of Khyber Pakhtunkhwa, Sindh, Punjab, and Balochistan. The rains tapered off a few days later, only to pound the provinces with three-day bouts of heavy rain three more times that month. By July 29 the Indus River, which runs the length of Pakistan from India in the north all the way to the Arabian Sea in the south, had overflowed. It burst dams, wrecked bridges and roads, and flooded heavily populated areas. The rains continued to fall through August 8 and by that time, the United Nations stepped in to help with emergency relief efforts.

"To have a fifth of the country flooded like that is very rare," Lau said. He looked at twelve years of average rainfall data from the NASA Tropical Rainfall Measuring Mission (TRMM) and found that the magnitude of the 2010 rains far exceeded the historical range of weather variability—it was out of the ordinary and not just a particularly bad monsoon season. Lau looked at more TRMM data, focusing on rainfall anomaly for Pakistan and the larger South Asian area, and saw that the entire South Asian Monsoon system had shifted to the northeast. Normally concentrated over the Bay of Bengal, heavy monsoon rains skipped the bay and instead moved north to pour over Pakistan and northeastern India. Intense rain also poured over the northeastern Arabian Sea. What had caused the monsoon to shift and disperse like that?

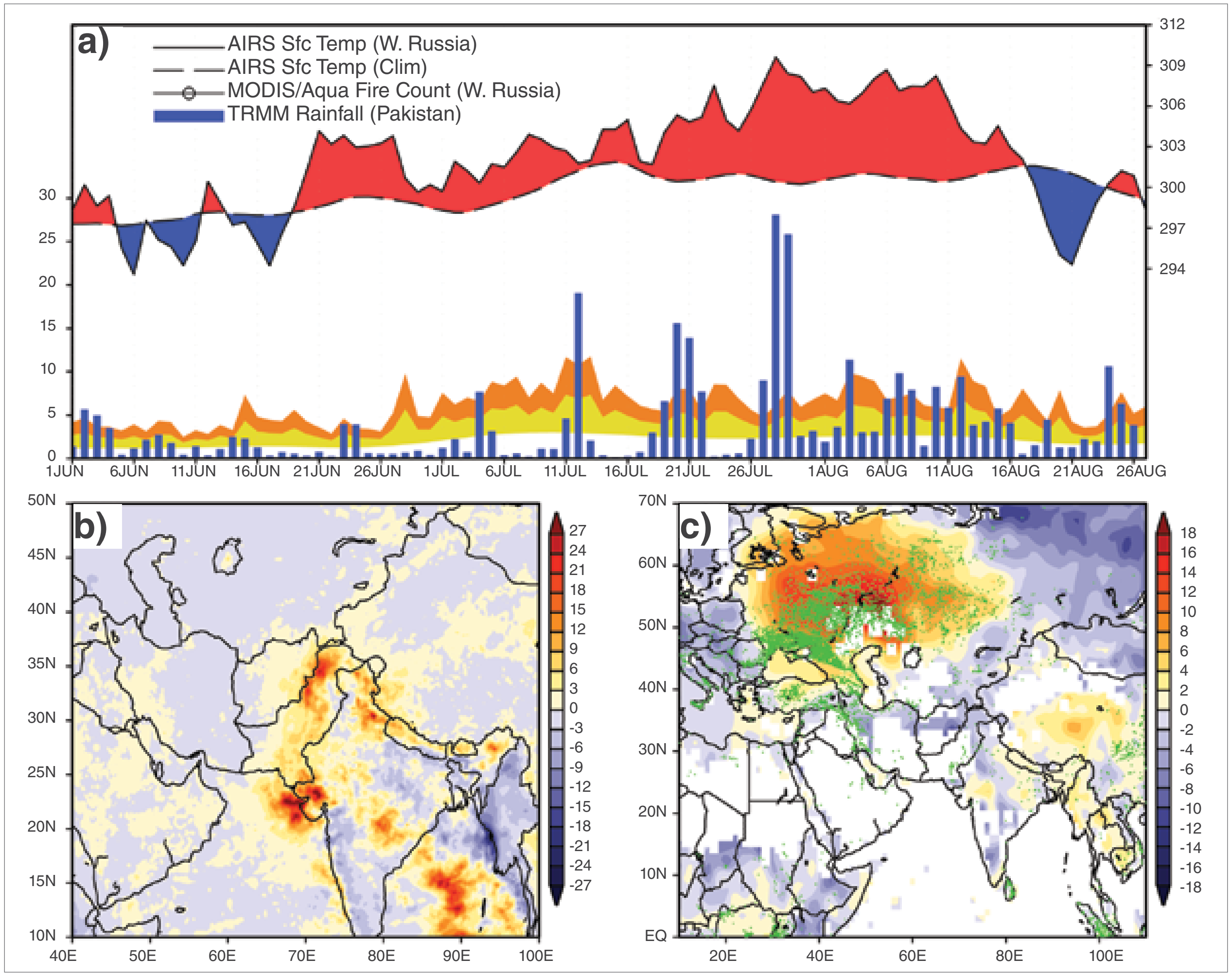
A wave impinges

"It was all very strange, so we decided to pick into more data and again look at a much bigger domain," Lau said. This time he looked at surface temperature data from the NASA Atmospheric Infrared Sounder (AIRS), cloudiness data from the NASA Moderate Resolution Imaging Spectroradiometer (MODIS), and atmospheric pressure, wind, and moisture data from the NASA Modern Era Retrospective Analysis for Research and Applications (MERRA).

A firefighter attempts to extinguish a ground fire to prevent it from reaching a village near Elektrogorsk, Moscow Region, in August 2010. (Courtesy I. Solovey/strf.ru)

Studying an area that extended to Europe and China, Lau found evidence that a series of Rossby waves spanning western Russia and south Asia could have caused the monsoon to shift. Rossby waves are giant meanders in any of the Earth's jet streams, rivers of wind that circle the globe. Opposing masses of cold polar air sliding south and masses of warm tropical air pushing north can force a jet stream to meander across continents. Areas of low pressure typically develop in the troughs of the waves, while high-pressure areas form in their ridges.

In this case, it was the unusual high-pressure area over western Russia that caused wind patterns to shift the entire South Asian monsoon north and east. It also pulled cold, dry Siberian air over the lower latitudes, which collided with the seasonal warm, moist air arriving over Pakistan from the Bay of Bengal. This was what caused the freakishly heavy rains over northwestern Pakistan.



These images show conditions over Russia and Pakistan during the Russian fires and Pakistan flooding in 2010. Image (a) shows a time series of daily surface temperatures averaged over western Russia, from the NASA Atmospheric Infrared Sounder (AIRS). Red indicates higher than average temperatures, and blue indicates lower than average temperatures. The blue bars also show daily rainfall over northern Pakistan for June 1 to August 26, 2010, from the Tropical Rainfall Monitoring Mission (TRMM). The orange and yellow shading shows the two standard deviation range of the TRMM data. Image (b) shows TRMM rainfall anomalies over Pakistan and the South Asian monsoon region for July 25 to August 8. Image (c) shows AIRS surface temperature anomalies, and possible fire locations (green dots) for the same period, from the NASA Moderate Resolution Imaging Spectroradiometer (MODIS). (Courtesy W. K. M. Lau, K. -M. Kim)

Lau also saw what had caused the formation of these Rossby waves. The map of atmospheric pressure and wind speeds from NASA MERRA showed a pattern called an atmospheric block hovering over Russia during the last two weeks of the Pakistan rains, an area of high pressure that gets stuck in the jet stream and causes kinks in the normal circulation of wind, temperature, and atmospheric pressure. Atmospheric blocks are natural, but rare; where they form, it gets extremely warm and dry—and downstream of a block, extremely cool or wet.

What hovered over Russia

While the block pushed rains onto Pakistan, under the block, Russia was experiencing its worst heat wave. Record temperatures of up to 100 degrees Fahrenheit and widespread drought caused thousands of peat and forest fires to break out in western and central Russia from late June to early September 2010. The fires caused heavy smog in many urban regions, ravaged 2.3 million acres, and cost the equivalent of 15 billion dollars in damages. About 56,000 people lost their lives from the effects of the heat wave.

Lau said certain interactions between the land and the atmosphere may have intensified Russia's heat wave and prolonged the atmospheric block. Data from MERRA showed that the initial drought dried the soil, and the lack of moisture slowed the formation of clouds. The 20 percent reduction in cloud cover over western Russia was enough to cause a positive feedback, amplifying the heat wave. This in turn intensified and prolonged the atmospheric block and increased transport of cold, dry Siberian air over the Pakistan region, Lau said.

"We never went in thinking that the two events were remotely related," Lau said. "But when a meteorologist sees a picture like this, an atmospheric blocking, an upper level trough and rainfall over Pakistan, it's entirely consistent. There's no question that this atmospheric blocking over Russia was what was causing the rainfall

About the remote sensing data used

Sensors	Terra and Aqua	Tropical Rainfall Monitoring Mission (TRMM)	Aqua
Satellites	Moderate Resolution Imaging Spectroradiometer (MODIS)	TRMM Microwave Imager	Atmospheric Infrared Sounder (AIRS)
Data sets	MODIS Cloud Product	TRMM Daily Rainfall	AIRS IR Geolocated Radiances
Resolution	1 kilometer, 5 kilometer	Daily	Horizontal: 1 x 1 deg Vertical: up to 24 pressure levels
Parameters	Cloud fraction	Precipitation rate	Radiance
DAACs	NASA MODAPS Level 1 and Atmosphere Archive and Distribution System (MODAPS LAADS)	NASA Goddard Earth Sciences Data and Information Services Center (NASA GES DISC)	NASA GES DISC

in Pakistan." Lau said it is probably hard to imagine that the two events could be physically related, just because they are separated by at least 1,500 miles. But scientists have suspected that Rossby waves can cause one weather anomaly to trigger another one thousands of miles away.

"This is the first time that this kind of scenario has ever been proposed," Lau said. While the evidence looks strong that the block triggered both of these weather extremes, Lau wants to delve into weather models to rule out any other causes. He also wants to find out what might trigger a repeat in the future. Lau is plugging in data on the Russian heat wave and the Pakistan rains into climate models to run different climate change scenarios. He said, "We can find out if such an event has a higher or lower chance of occurring in a warming world."

To access this article online, please visit http://earthdata.nasa.gov/sensing-our-planet/2012/kink-jet-stream

About the scientist

William K. M. Lau is head of atmospheric sciences at the NASA Goddard Space Flight Center. His research interests include climate dynamics, atmospheric processes, air-sea interaction, aerosol-water cycle interactions, and climate variability and global change. NASA supported his research. (Photograph courtesy W. Lau)

Reference

Lau, William K. M., and K. -M. Kim. 2012. The 2010 Pakistan flood and Russian heat wave: Teleconnection of hydrometeorological extremes. *Journal of Hydrometeorology*, doi:10.1175/JHM-D-11-016.1.

For more information

NASA Fire Information for Resource Management System (FIRMS)
http://earthdata.nasa.gov/firms

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

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

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

William K. M. Lau
http://atmospheres.gsfc.nasa.gov/personnel/index.php?id=9

Where on Earth

“That’s the cutting edge driver of ITRF accuracy, to monitor sea level change.”

Jim Ray
National Geodetic Survey

by Jane Beitler

For as long as humans have trod the Earth, they have wanted to know just where they are along the way. Landmarks and coastlines first helped people sight their way, but mathematics made it possible to cross faceless deserts and oceans, and get home again. We have become so skilled at determining our position that we dared to explore the vastness of space, and created technologies like Global Positioning System (GPS) devices to guide ordinary people on their rambles.

Those devices are extremely accurate because of a set of reference points, forming the International Terrestrial Reference Frame (ITRF), and an incredibly sophisticated math- and physics-based system of measurements behind it.

U.S. Navy officer Jonathan Myers explains to his colleague April Beldo how to use a marine sextant during a demonstration of celestial navigation. (Photography by T. K. Mendoza courtesy U.S. Navy)

It took a lot of knowledge to get this far, but scientists are not finished. They are still tuning their measurements to drive out the tiniest errors. But how and why?

Earth's geometry

Two thousand years ago, an Arab mariner sailed his dhow out of sight of land without GPS, compass, or sextant to judge his position. But he knew a little geometry. He measured the distance between the horizon and Polaris, the Pole Star, by holding up his thumb against the night sky. This told him his north or south position on Earth—what we call latitude. He could sail north or south until it matched the latitude of his port, then right or left as needed, keeping Polaris at the same height in the sky all the time.

While the ancient mariner was satisfied to get within sight of port, today's sailors, aviators, space agencies, engineers, and scientists require more accuracy that is not subject to clouds or pitching ship decks. Measurement technologies today may triangulate with a satellite, which in turn is calibrated against the ITRF, a set of very accurate reference points around the Earth that have been measured using lasers, satellites, and telescopes.

The Earth that your GPS sees is theoretical and needs constant syncing with the real one. On paper, latitude and longitude divide the Earth's sphere neatly into uniform minutes and seconds. But Earth is not quite round. It is slightly flattened at the poles. Like a sailor bobbing on the waves, we too are bobbing on Earth's surface. Earth rotates, wobbles, and shifts its crust, introducing a real-time element into the calculation of position.

An imaginary Earth

Earth's crust moves sometimes imperceptibly, sometimes violently during earthquakes. The crust is still slowly uncompressing itself after being squashed under the weight of thick ice sheets during the Ice Ages, a process called glacial rebound. The crust can move by meters or by a few millimeters, but enough to frustrate precision.

For all these reasons, scientists use a theoretical sphere, defined by where sea level would be if the Earth were perfectly round. In theory, gravity makes the sea level by pulling on it equally everywhere, so gravity is a good substitute for sea level. Altimeters calculate altitude as a function of gravity. But if you ran an altimeter all over Earth and plotted out all the points of equal gravity, instead of getting an ideal sphere, you would get something lumpy and irregular, like a potato. Scientists call this potato the geoid.

It turns out that gravity is not equal over the same distance from the center of the Earth. Large lakes, seas, and aquifers and certain types of rock can affect gravity. Tides and winds can push ocean waters around and change gravity. So scientists pinned measurements to Earth's rotation axis. But that turned out to be a slippery problem, too.

Earth's axis is a theoretical location, but its physical center of mass is of great importance to scientists. Like an out of balance washing machine, Earth wobbles when its crust, the atmosphere, or the ocean get slightly redistributed by plate tectonics, winds, or tsunamis, for example. National Oceanic and Atmospheric Administration researcher Jim Ray, who analyzes data for GPS satellites, said, "This is one of the weaknesses in GPS data. It's challenging to know where the center of mass for Earth is at any moment, any day."

Space science

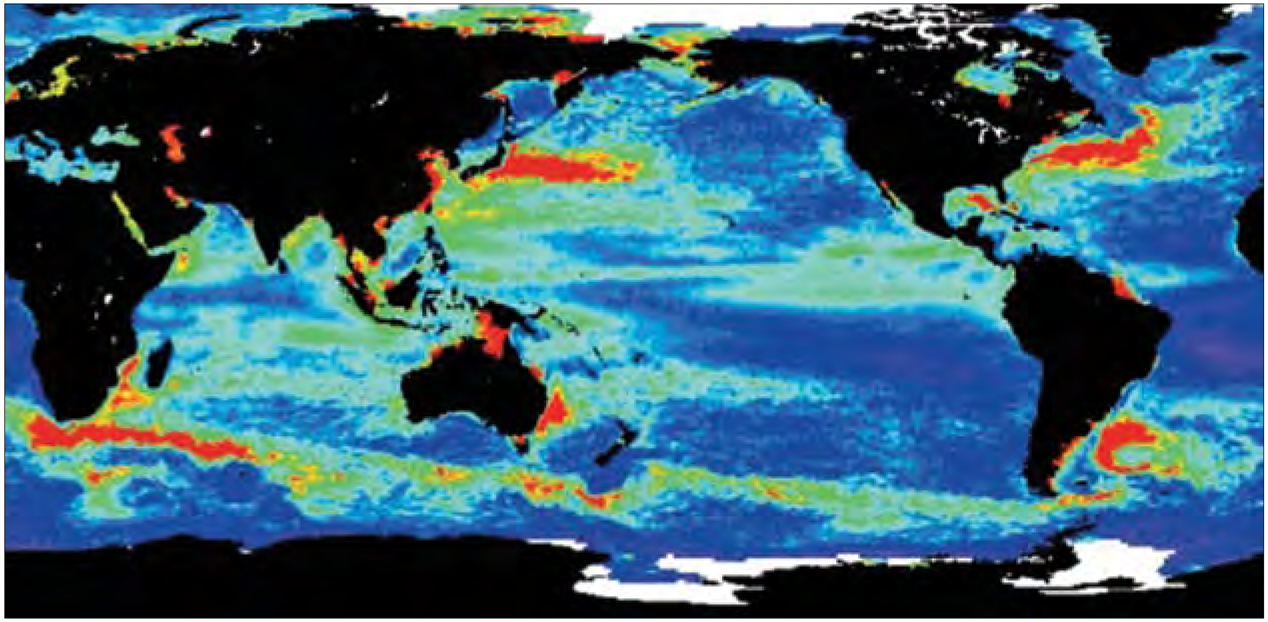
Scientists look for ways to overcome measurement problems such as these. They seek more stable points to measure against, or they measure a point several ways, and compare the measurements to help calibrate out the errors. Networks of ground stations pepper the Earth, using satellites and telescopes, radio waves and laser beams to measure position. None of the methods are perfect, but together they increase accuracy, especially when the different technologies are located side by side.

Two of these technologies make Earth-based measurements: the French Doppler Orbitography Radiopositioning Integrated by Satellite (DORIS) network, and GPS receivers on the ground. These instruments constantly measure an Earth-based triangle using Earth's axis, a receiver or transmitter on the satellite, and a receiver or transmitter on the ground.

GPS has the advantage of being almost everywhere. Research-quality GPS receivers are also fairly inexpensive, and have many research applications besides navigation. "There are some tens of thousands of continuously operating GPS reference stations around the world," Ray said. "We use data from the best-controlled stations, about 400. GPS is the contributing technique par excellence in terms of precision."

Measure four times, cut once

GPS stations, however, get errors from being attached to Earth's crust, when the crust shifts, sinks, or bulges. Earth's imperfect rotation also introduces a miniscule distortion of time into GPS accuracy. So space-based techniques help balance out Earth-based measurements. Very Long Baseline Interferometry (VLBI) aims a



This image shows anomalies in sea level, from October 1992 to October 1997, combining data from the European Remote Sensing (ERS) satellite and the joint NASA/French Space Agency Ocean Topography Experiment (TOPEX)/Poseidon satellite. Greens, yellows, and reds indicate greater anomalies. (Courtesy European Space Agency)

radio telescope at very distant quasars. The quasars, extra-galactic objects, are so far away that their movement in space does not matter. For practical purposes, it is as if they are fixed points.

VLBI can lose some precision as radio signals sometimes get bent passing through the Earth's atmosphere. GPS calculations help adjust for those errors.

Satellite Laser Ranging (SLR), which bounces a laser beam off a small, very heavy and passive satellite, helps calibrate errors out in the other sources. Ray said, "GPS satellites are very large, unwieldy things, with large solar panels that can cause wobble. This random, minute-to-minute motion is hard to monitor. SLR satellites are very simple, like little bowling balls covered with mirrors."

No fixed position

Calibration also needs to account for how Earth's crust may be moving underneath a specific instrument site. Some crustal activity can be estimated. Zuheir Altamimi is research director at the Laboratoire de Recherche en Géodésie (LAREG) in France, which maintains the ITRF. He is one of many researchers around the world who help tune the system of reference points. He said, "We can compare the vertical and horizontal motion of instrument sites with geophysical models, such as post-glacial rebound models, and models that describe the tectonic motion of the plates." Other crustal activity may be erratic. "Many sites that are near the epicenters of earthquakes exhibit non-linear motion, which is hard to model accurately by mathematical equations," Altamimi explained.

As well, at a multi-instrument site, the distances between the various instruments have to be accurately known when comparing measurements, and combining them together to build the ITRF. So these sites are physically surveyed by terrestrial measurements that are then compared to measurements by space techniques.

Rising seas

Position measurements are now accurate enough for most navigation uses. More accuracy is interesting mainly to scientists studying the Earth. For example, the ITRF can help track the exact rate of global sea level rise, which is increasing because of glacier and ice sheet melting. "This question is hard to answer, because there are so many error sources in the measurements," said Altamimi.

Ray said, "That's the cutting-edge driver of ITRF accuracy, to monitor sea level change. ITRF does not actually allow you to measure sea level change, but it is the underlying structure that allows measurement systems like altimetry to do the job." Altimeters bounce radar signals off the ocean surface, but those altimetry measurements depend on a measurement frame centered at Earth's center of mass. "That only makes sense if you have a really high accuracy ITRF," Ray said.

Sea level rise will be a hard-felt impact of climate warming. The changes each year are small, but over time rising seas can inundate low-lying areas where millions of people work and live. Tide gauge records over the last century estimate an average of 1.7 millimeters of sea level rise per year, while satellite altimetry data, which have a more global coverage but cover only the most recent decades, estimate 3.4 millimeters. So scientists ask if sea level rise is accelerating and

About the remote sensing data used

Techniques	Global Navigation Satellite System (GNSS)	Satellite Laser Ranging (SLR)	Very Long Baseline Interferometry (VLBI)	Doppler Orbitography and Radio-positioning Integrated by Satellite (DORIS)
Satellites	Global Positioning System (GPS) and other Global Navigation Satellite Systems	LAGEOS-1 and 2, Etalon-1 and -2		TOPEX/Poseidon, Jason-1 and -2, Envisat, Cryosat-2, HY-2A, and SPOT-2, -3, -4, and -5
Ground Instruments	~400 GNSS reference receivers	~40 Laser Ranging systems	~40 radiotelescopes	~60 radio beacons
DAACs	NASA Crustal Dynamics Data Information System (CDDIS)			

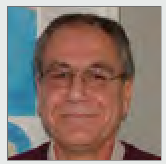
if that can be reliably measured. "For this problem, we need a really high accuracy ITRF, one that is stable over decades," Ray said.

The ITRF 2014

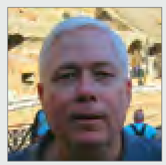
Researchers are busy on the next version of the ITRF, planned for release in 2014. Detailed surveys of the ITRF instrument sites are high on the list of ways to drive errors out of the measurements. The ITRF researchers can test their methods with an archive of data from the four measurement methods at the NASA Crustal Dynamics Data Information System (CDDIS). These archived data help them model the effects of various improvements to the instruments, the sites, or the data analyses.

Altamimi said, "When we started to construct the first reference frame that combined different techniques, in 1985, at that time the precision was at the decimeter level. Now it is reaching a few millimeters." The goal for the next version of the ITRF is an accuracy approaching the science requirement: 1 millimeter of average error, and 0.1 millimeter per year of instability. "It is a small number, but it has an impact," Altamimi said.

About the scientists



Zuheir Altamimi is research director at the Laboratoire de Recherche en Géodésie (LAREG) in France. His work focuses on geodesy, and theories and applications of terrestrial reference systems. The Institut National de L'Information Geographique et Forestiere supports his research. (Photograph courtesy LAREG)



Jim Ray is a geodesist in the Geosciences Research Division of the National Geodetic Survey, where he works on GPS data analysis. He was previously the Analysis Center coordinator for the International GNSS Service (IGS) and the head of the Earth Orientation Department at the U.S. Naval Observatory. The National Oceanic and Atmospheric Administration supports his research. (Photograph courtesy J. Ray)

To access this article online, please visit http://earthdata.nasa.gov/sensing-our-planet/2012/where-earth

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For more information

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http://cddis.nasa.gov
The International Terrestrial Reference Frame (ITRF)
http://itrf.ensg.ign.fr
Laboratoire de Recherche en Géodésie (LAREG)
http://recherche.ign.fr/labos/lareg/page.php
Sea Level Rise and Coastal Flooding Impacts Viewer
http://csc.noaa.gov/digitalcoast/tools/slrviewer

A new pole hole

“In the Northern Hemisphere, before this past winter, we had seen only moderate amounts of chemical ozone loss. We hadn’t seen anything comparable to the Antarctic ozone hole.”

Gloria Manney
NASA Jet Propulsion Laboratory

by Katherine Leitzell

High over the Earth’s surface, suspended in our stratosphere, an invisible blanket of ozone quietly protects all life on Earth from dangerous ultraviolet (UV) rays. The gas, made up of three oxygen atoms, has an incredible ability to absorb UV radiation in the particular range that is most harmful to plants and animals. In 1985, scientists noticed something wrong with that blanket. In the Southern Hemisphere spring, the ozone layer over Antarctica was disappearing. This phenomenon, now known as the ozone hole, has reappeared over Antarctica every spring since then, varying in intensity from year to year.

The ozone hole over Antarctica is worrisome, but on that frozen continent there are few animals and fewer people for harmful UV rays to damage. However, when ozone-depleted air moves from Antarctica northwards to more populated regions like Australia and New Zealand, it can become a serious health concern. In middle latitudes and the Northern Hemisphere, ozone has declined much more slowly. If something like the Antarctic ozone hole happened over the more-populated Arctic, it would expose far more people to high UV radiation. So in 2011, Gloria Manney, a researcher at the NASA Jet Propulsion Laboratory (JPL), was concerned when she and her colleagues spotted a major decline in Arctic

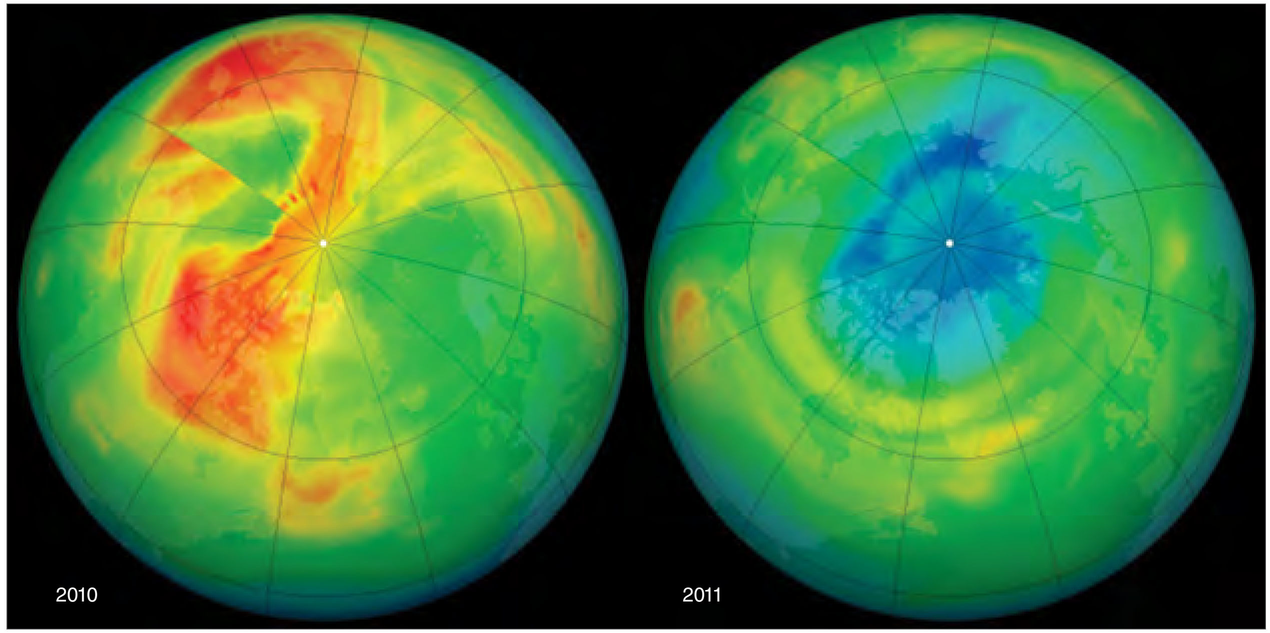
Polar stratospheric clouds, also known as mother-of-pearl clouds for their colorful pastel appearance, form when extremely cold conditions in the high Arctic and Antarctic atmospheres cause nitric acid and water to freeze into tiny crystals. Reactions on the surfaces of these clouds convert chlorine compounds into the forms that rapidly destroy ozone. (Courtesy Alfred Wegener Institute) ozone. She said, "In the Northern Hemisphere, before this past winter, we had seen only moderate amounts of chemical ozone loss. We hadn't seen anything comparable to the Antarctic ozone hole." What was causing the new ozone hole? And would it happen again?

The ozone hole over Antarctica

When Manney and other researchers announced their finding, many people were surprised. Pieternel Levelt, principal investigator for the Ozone Monitoring Instrument (OMI) on the NASA Aura satellite, said, "A lot of people thought that the problem was already solved." Indeed, governments signed an international treaty in 1989 that banned production of chlorofluorocarbons and other ozone-destroying chemicals. And data show that chlorine in the stratosphere has started to decline. But the chemicals are so long lived that it will be many decades before the Antarctic ozone hole stops forming each winter. "We still have an ozone hole at the South Pole, but we expect that it will recover by 2050 to 2070," said Levelt.

Starting in the 1970s, scientists had suspected that the ozone layer might be at risk. Chlorine-based compounds known as chlorofluorocarbons, very stable and long-lived on Earth's surface, were slowly making their way into the upper atmosphere, where the additional UV light broke them apart into highly reactive chlorine molecules that tear ozone molecules apart. But researchers did not expect anything as extreme as an ozone hole; ozone destruction normally proceeds slowly in the stratosphere. At the same time, new ozone is always forming through reactions between sunlight and oxygen compounds.

Scientists first spotted the ozone hole in 1985, using ground-based sensors to study the Antarctic atmosphere. Earlier data from the Total Ozone Monitoring Satellite (TOMS), a satellite launched in 1979, had shown the same low ozone levels, but because levels were so extremely low, researchers had assumed that the data were incorrect. When they looked at the data again, they confirmed that the hole was real.



Data from the Ozone Monitoring Instrument (OMI) show averaged, total ozone levels over the Arctic. Blues indicate where there is the least ozone, and yellows and reds indicate more ozone. In March 2010 (left), average ozone levels were near normal. In March 2011 (right), ozone levels were substantially reduced. (Image courtesy R. Simmon, NASA/ data courtesy Ozone Hole Watch)

Researchers soon figured out the cause of the ozone hole. Long-lasting extreme cold in the Antarctic stratosphere in winter created the perfect conditions for chemical reactions that destroy ozone at a much faster pace than those that take place elsewhere in the atmosphere. When temperatures are very low in the stratosphere, nitric acid and water can turn from gas into liquid or solid forms, resulting in a wispy multicolored cloud called a polar stratospheric cloud. These frozen particles of acid and water provide surfaces on which the chemical reactions that convert chlorine into ozone-destroying forms can take place. Michelle Santee, another JPL researcher studying the Arctic ozone loss, said, "If you just had gaseous molecules, as is the case in most of the atmosphere, these reactions would not occur."

Measuring Arctic ozone loss

Outside of Antarctica, stratospheric temperatures rarely get low enough for polar stratospheric clouds to form, nor do they typically stay low long enough for chlorine to persist in ozone-destroying forms. So when Santee and Manney saw a large decrease in ozone over the Arctic during routine inspection of data from the NASA Microwave Limb Sounder (MLS), they wondered how bad

Researcher Jürgen Gräser from the Alfred Wegener Institute (AWI) releases an ozonesonde balloon from his camp on an ice floe in the Arctic Ocean in April 2011. The balloon-borne ozone measurements added high-resolution data to the broader picture provided by satellite data. (Courtesy J. Gräser, AWI)

the problem was. MLS data archived at the NASA Goddard Earth Sciences Data and Information Center (GES DISC) showed that about 80 percent of the ozone at 18 to 20 kilometers altitude had been destroyed—far more ozone loss than ever previously seen over the Arctic. Confirming the MLS data, balloon-borne ozonesondes released every year over the Arctic provide a high-resolution series of data dating back to the 1990s, before the MLS record began; balloons have also provided measurements of ozone over the Antarctic since the 1980s. Manney said, "These comparisons were important in establishing that the ozone loss in 2011 was unprecedented in the Arctic, and that it was comparable to that in some Antarctic ozone holes."

But while MLS and the balloon-borne ozonesondes measure ozone at different altitudes, they do not provide a measurement of the total ozone column. Manney said, "If you're standing on the surface of the Earth, worried about getting a sunburn, what you really want to know is the total amount of ozone overhead." For that information they turned to Levelt and her colleagues who work with OMI, which measures the vertical column of ozone. Levelt said, "The definition of whether an ozone hole is present or not has historically been based on total column measurements."

The OMI data, also archived at GES DISC, showed extremely low total ozone values over a much larger region than had ever been seen in the Arctic since satellite measurements started in 1979. However, the ozone loss was not as severe as that in the annual Antarctic ozone hole, which has grown in size and intensity over the last twenty years. Manney said, "The amount of ozone that was destroyed was comparable to what we saw a couple of decades ago in the Southern Hemisphere, when we first started studying the Antarctic ozone hole."

Manney and Santee also needed to know whether the ozone loss was caused by chlorine-containing chemicals, and whether polar stratospheric clouds were present in the Arctic atmosphere. Temperatures in the Arctic stratosphere had been unusually low, which meant that the polar stratospheric clouds that catalyze ozone destruction were likely to form. Data from the Cloud Aerosol Lidar with Orthogonal Polarization (CALIOP) sensor on the NASA/French Space Agency CALIPSO satellite, archived at the Langley Research Center Atmospheric Science Data Center (LaRC ASDC), confirmed the team's suspicions, showing that polar stratospheric clouds were indeed present during the time ozone values were decreasing.

Together, the data gave a comprehensive picture of the conditions that led to the unprecedented Arctic ozone depletion. "The data from all of these instruments played vital roles; they all provided pieces of the puzzle," Santee said.

An altered Arctic atmosphere

The Arctic ozone hole was both expected and unexpected. "We knew that this could happen," said Manney. "What was a surprise was that it happened this particular year. Because the temperatures are so variable in the Arctic, we can't predict from year to year whether a given winter is going to be particularly cold."

That means that the obvious question—will the Arctic have another ozone hole next year, or the year after—is difficult to answer. Some evidence suggests that climate change may be making the stratosphere more conducive to ozone loss. Manney said, "Because of radiative effects, if you make the lower atmosphere warmer, you'd expect the stratosphere to get cooler." If stratospheric temperatures get lower, the conditions that lead to ozone loss may become more common.

The researchers emphasize that people should not be alarmed about a persistent Arctic ozone hole. The protocols that banned ozone-destroying chemicals have been very effective, chlorine levels are beginning to decline, and even the annual Antarctic ozone hole is expected to end by around

About the remote sensing data used

Satellites	Aura	Aura	Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO)
Sensors	Ozone Monitoring Instrument (OMI)	Microwave Limb Sounder (MLS)	Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP)
Data sets	Aura OMI Total Ozone Data Product	Trace Gas Profiles, Ozone Profile	Polar Stratospheric Cloud, Aerosols
Resolution	13 by 24 kilometers	4 kilometers	5 kilometers
Parameters	Ozone	Trace gas profiles and ozone profile	Clouds, aerosols
DAACs	NASA Goddard Earth Sciences Data and Information Services Center (GES DISC)	NASA GES DISC	NASA Langley Research Center Atmospheric Science Data Center (LaRC ASDC)

CALIPSO is a joint satellite mission between NASA and the French Agency, CNES.

2050. But as we wait for chlorine to slowly filter out of the stratosphere, ozone holes in the Arctic could become more common—potentially damaging plant life and making sunburns and skin cancer more of a problem for people who live in the Arctic. "Because of climate change, the stratosphere is not exactly the same place it was in the 1970s," Santee said. "If because of climate change the stratosphere gets colder in the future, we could be looking at more severe and more persistent ozone holes in the Arctic."

To access this article online, please visit http://earthdata.nasa.gov/sensing-our-planet/2012/new-pole-hole

About the scientists

Pieternel Levelt is head of the Climate Observations department at the Royal Netherlands Meteorological Institute (KNMI) and Professor at Delft University of Technology in the Netherlands, and is also the principal investigator of the Ozone Monitoring Instrument (OMI). (Photograph courtesy P. Levelt)

Gloria Manney is a researcher at the NASA Jet Propulsion Laboratory, California Institute of Technology in Pasadena, California and the New Mexico Institute of Mining and Technology in Socorro, New Mexico. She is a member of the science team for the NASA Microwave Limb Sounder instrument, which measures ozone and other related chemicals in the atmosphere. (Photograph courtesy G. Manney)

Michelle Santee is a researcher at the NASA Jet Propulsion Laboratory, California Institute of Technology in Pasadena, California. She is a member of the science team for the NASA Microwave Limb Sounder, and studies atmospheric chemistry and the polar ozone layer. (Photograph courtesy M. Santee)

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http://aura.gsfc.nasa.gov/instruments/omi.html
Gloria Manney
http://science.jpl.nasa.gov/people/Manney
Michelle Santee
http://science.jpl.nasa.gov/people/Santee
Pieternel Levelt
http://www.knmi.nl/~levelt

New angles

“For non-specialists, the data were impenetrable. We have taken the complexity out of it.”

Bob Scholes
Council for Scientific and Industrial Research

by Karla LeFevre

On a relatively cool day, Michel Verstraete and Bob Scholes swish through knee-deep wild grass. They stop, position a laser scanner on its tripod legs, and wait a moment as its red eye records the beautiful geometry of South African trees, the bonsai shape of the knobthorn, or the clumped, erratic canopy of the red bushwillow.

They are sampling these intricate features to create a ground reference for the savanna environment, a map of sorts for how the sun's rays glint off tree and shrub leaves every which way, bounce off the ground, and shoot skyward into the atmosphere. When combined with a view from a satellite flying above, a more complete picture of this fragile ecosystem will emerge and help them monitor how the landscape is changing. And having that complete picture is crucial for studying all ecosystems, not just savannas in Africa.

The problem is, no satellite instrument has mapped the myriad structural features of the land surface both closely enough and

The scraggy branches of a South African baobab tree catch the last rays of sunlight for the day. (Courtesy Flickr/whl.travel) frequently enough to monitor change on a small scale. Or at least none had until now. Seeing things a little differently helped these researchers uncover a hidden perspective, a multi-dimensional view of the Earth's surface that once looked flat.

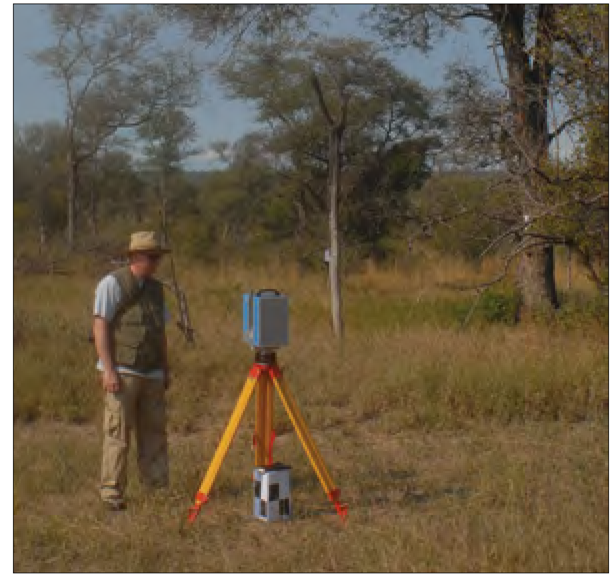
The nature of reflectance

Scientists like Verstraete and Scholes have been studying the reflectance of the Earth's surface a long time now. The first Earth Observation satellites were launched in the mid-1970s. Advanced at the time, these space behemoths could see in just two or three channels of the spectrum and were primitively calibrated by today's standards, like an outdated eyeglass prescription. To sort out the reflectance measurements and deal with other constraints, like large volumes of data, scientists devised simple ratios and formulas by combining the channels in different ways to end up with a single value for each pixel. Basic patterns of the landscape emerged. One such formula is the Normalized Difference Vegetation Index or NDVI, which highlights where vegetation occurs. Pixel by pixel, scientists have long used NDVI to reveal vegetation patterns and have mapped most of Earth's surface this way.

Yet, as satellite sensing has advanced, it is now possible to get more meaningful measurements. Michel Verstraete, an atmospheric physicist with the Joint Research Centre's Institute for Environment and Sustainability in Ispra, Italy, said, "Now that we have better instruments with many more channels, there is no reason to continue to use those old vegetation indices." Biodiversity expert and ecologist with South Africa's Council for Scientific and Industrial Research, Bob Scholes, agrees. But much of the science community studying vegetation continues to rely on NDVI, in part due to its simplicity. Speaking at a recent forests conference, Scholes said, "I'm very fond of that quote by Einstein, 'Everything should be as simple as possible,' and he goes on to warn, 'but no simpler.'"

The fact is, scientists know that sorting out how solar radiation interacts—with the atmosphere, the surface, and the instrument, to name but a few factors—is no trivial matter. First, consider bidirectional reflectance, named for the interplay between two main factors: the direction of illumination and the direction of the viewer. Put another way, if the direction of the sun or your position changes, the object you are observing will look very different. Now add in a wide variety of surfaces, from the mirror-like surface of a calm lake to the spiky texture of a pine forest, and the equation gets complicated rather quickly.

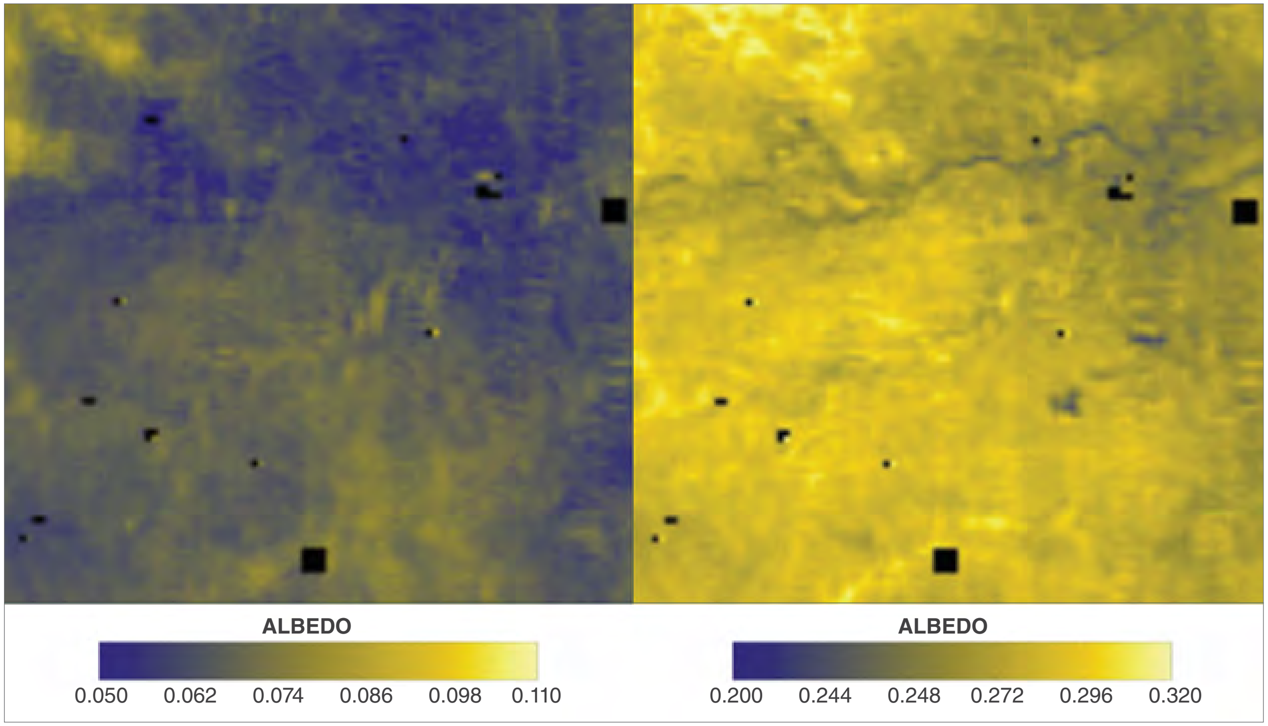
Next, consider how the instrument sees. Most satellite instruments look straight down, or nadir. "At least that is what people believe," Verstraete said. But since this downward view from space on a swath of land is typically on the order of hundreds or even thousands of kilometers across, it is like looking through a very large wide-angle lens. The outer edges of the shot fan out and only the middle is nadir. Verstraete explained, "That means you are actually looking at quite a range of different angles. The environment could be absolutely homogenous, and even if it is illuminated the same way, you will still have quite a lot of variation just because you are looking at it from different directions. So the problem is that, for many years, people have rarely taken that into account."



Researcher Michel Verstraete pauses while a laser scanner records the geometric properties of a savanna landscape in Kruger National Park, South Africa. (Photograph by R. Scholes courtesy Council for Scientific and Industrial Research, South Africa)

From every angle

Yet how might an instrument better capture this complicated reality? The answer seemed to lie with MISR, the Multi-Angle Imaging Spectroradiometer on the NASA Terra satellite. "For all these years, most instruments flying until MISR were observing the environment from only one vantage point," Verstraete said. MISR has not one, but nine cameras: four in front, one at nadir, and four in back. What is more, each camera quickly views the same spot in four channels, for a total of thirty-six channels. "So now you can start documenting how the reflectance changes with the angles because you have those nine views in only a few minutes, and the environment doesn't have time to change in between," Verstraete said. MISR could provide those multiple views, but there was a major hurdle.



The two maps above show land surface reflectance collected on April 25, 2009 for the same research area in Kruger National Park, South Africa in both the visible spectrum (left) and near-infrared spectrum (right). In the northwestern corner of each map, bright areas reveal a degraded landscape from human settlements just outside the park, in contrast to darker areas of healthy landscape inside the park. Data are from the Multi-Angle Imaging Spectroradiometer (MISR) instrument on the NASA Terra satellite. (Courtesy L. Hunt/Langley Research Center Atmospheric Science Data Center)

To truly capture changes happening in living systems, like the savanna environment Scholes specializes in, they would need to zoom closer. "Biodiversity is extremely variable in space," Verstraete said. "Sometimes there's a species that's only available on one hectare." Unfortunately, the smallest area of ground view from MISR was 1.21 square kilometers, a view of more than a hundred hectares (299 acres).

So Verstraete enlisted the help of colleague and computer scientist, Linda Hunt. At the time, Hunt worked at the Langley Atmospheric Science Data Center in Virginia, where the MISR data are housed. Original MISR data were actually captured at a finer 275 meters (902 feet), but had been downgraded on board the satellite so that ground stations receiving the data could process a manageable number of bytes. They wondered if there was a way to reliably restore those original data. It would be tough, if not impossible, and there was little funding for this work. In her spare time, Hunt chipped away at the monumental task of writing new software that would untangle the many steps the satellite had taken to process the data to a lower resolution. Care was taken to also add in other enhancements, like sharpening algorithms, which Verstraete and colleagues had refined over the years. By the time she had finished, she had written and implemented an entirely new processing system. The team finally had the close, detailed view they needed, and from a satellite that flew over the same ground roughly once a week.

In the process, they also ended up with a more accurate and easier-to-use product. Scholes explained, "What's important about this product is it moves us away from space images simply as pictures, towards images as information in a form which is exactly as people on the ground need it. So I don't have to construct rather dodgy correlations between what the image says and what I measure on the ground." This was a breakthrough with implications for all kinds of uses, from water management to drought monitoring to agriculture and beyond.

Future angles

To test this, the team unveiled their results at an intensive, hands-on workshop in Cape Town, Africa in October 2011. Twenty-two researchers from eleven African countries and many different focus areas were carefully selected to be the first to work with the new, high-resolution MISR data. Scientists from a variety of agencies also contributed, including the European Space Agency and the newly formed South African National Space Agency, or SANSA.

This sharing cultivated a strong partnership. With the full support of NASA, Verstraete gave SANSA the opportunity to be the first institution worldwide to run the new system and generate the new MISR data locally. SANSA has since made it a flagship program of their Earth

Observation division and, with the initial help from Hunt, is adopting the processing of all MISR orbits over Africa. Soon they will be able to offer the new high-resolution MISR data not only to scientists, but to forestry managers, policy makers, and others who could benefit from the data. And that, according to SANSA chief Sandile Malinga, is of utmost priority. “One pressing issue for Africa as a whole, for instance, is food security, so monitoring drought is very, very important,” he said.

Meanwhile, scientists like Scholes and Verstraete are also eager to mine this new-found data cache for insight on nagging problems, like desertification. When drought and other conditions converge, like soil erosion, they set off a domino effect that transforms fertile land into desert. Rich, life-giving topsoil that supports crops takes centuries to build up, but just a few seasons to be blown or washed away. Famine then ensues. It is a problem that has plagued the African continent for decades and is difficult to reverse.

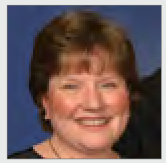
Scholes and Verstraete are optimistic about how the new measurements can help. Like the ability to detect cancer cells in a patient, pinpointing where the process begins is critical to limiting its spread. Scholes said, “We wish to get repeatable, reliable measures of ecologically important features of the land surface. That would help us answer questions such as ‘where is desertification occurring?’” With that, Scholes added, “The results allow us to track the state of the land surface in ways which are directly important to people.”

To access this article online, please visit http://earthdata.nasa.gov/sensing-our-planet/2012/new-angles

About the remote sensing data used

Satellite	Terra
Sensor	Multi-Angle Imaging Spectroradiometer (MISR)
Data set	MISR Level 1B2 Terrain Top of Atmosphere (TOA)
Resolution	275 meter
Parameter	Spectral and directional reflectance
DAAC	NASA Langley Research Center Atmospheric Science Data Center (LaRC ASDC)

About the scientists



Linda Hunt is a senior computer scientist with a background in atmospheric science at Science Systems and Applications, Inc. (SSAI) in Virginia. She is currently investigating the energy budget and the chemistry of the thermosphere and mesosphere. (Photograph courtesy L. Hunt)

Robert J. Scholes is a systems ecologist with the Council for Scientific and Industrial Research, South Africa. He studies how human activities affect the global ecosystem, particularly in regards to African woodlands and savannas. Scholes is a lead author for the Intergovernmental Panel on Climate Change and a board member of the South African National Space Agency. (Photograph courtesy R. Scholes)

Michel M. Verstraete is a senior scientist in atmospheric physics at the European Commission Joint Research Centre in Ispra, Italy. Verstraete has been a long-term member of the NASA Jet Propulsion Laboratory MISR Science Team, and is currently focused on characterizing land surfaces using advanced remote sensing techniques. (Photograph courtesy M. Verstraete)

Reference

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For more information

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

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

South African National Space Agency (SANSA)
http://www.sansa.org.za

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http://www-misr.jpl.nasa.gov/aboutUs/scienceTeam/index.cfm?FuseAction=ShowPerson&pplID=291

Robert J. Scholes
http://www.csir.co.za/fellows/BiographicalSketchDrBobScholes.html

Leaking lakes

“Methane is a very potent greenhouse gas that is 25 to 28 times more powerful than carbon dioxide at retaining heat in the atmosphere.”

Melanie Engram
University of Alaska Fairbanks

by Jane Beitler

It was nearly winter in Greenland, the tundra patchworked with rumples of earth holding lakes sheathed in smooth ice and snow. Researcher Katey Walter Anthony trudged through the light snow around yet another lake on her survey list, looking for bubbles trapped in the lake ice. “We stumbled across something really weird in a lake right in front of the ice sheet,” she said. “We saw a huge open area in the lake that looked like it was boiling.” Walter Anthony and her team were visiting lakes to measure methane bubbling up. But the roiling seep looked like none other she had seen.

“It looked like something deeper and larger, large plumes of bubbles rushing upward,” Walter Anthony said. “So I got curious: where is this gas coming from and what is the mechanism for its release and how widespread is it?” It was a new twist in the problem of lake ice and methane emissions across the changing Arctic.

Thawing out the freezer

Walter Anthony had been studying methane seeping from Arctic lakes, beginning in northeast Siberia in 2000. Under the lakes, a thick layer of carbon from plants that died hundreds or thousands of years ago stays mostly locked up in permanently frozen ground, like broccoli

Researcher Melanie Engram prods the snow on the lake surface to check for thin ice, before approaching the snow-free circles that suggest methane seeping from underneath the lake. (Courtesy K. W. Anthony) in the freezer. Today, soils in Siberia and northern Alaska are particularly rich with that organic matter. Now Arctic tundra hovers at a colder temperature that sprouts no trees and only low shrubs and plants, but millions of ponds and lakes. In areas where that permafrost is warming, that organic matter is thawing, rotting, and producing gases that must escape through the lakes.

Guido Grosse studies how these lakes, called thermokarst lakes, form and change. "Permafrost keeps the lakes from draining," Grosse said. "That's why there are so many lakes." In recent years, the Arctic has warmed even more strongly than lower latitudes. Now in many areas, the ground is thawing deeper than it used to. "As permafrost degrades, lakes can drain," said Grosse, at the Permafrost Laboratory at University of Alaska Fairbanks. In other areas, permafrost thaw results in a sinking land surface where new ponds and lakes form, exposing underlying permafrost to even more warming, thawing, and decay. Grosse said, "The lakes are a big emitter of methane in a warmer climate scenario, a warmer Arctic."

Some organic material from vegetation and frozen lake banks normally falls in the lake, thaws, and decays around its edges. This decay stops during the cold season in shallow lakes that freeze to the bottom in harsh Arctic winters. But most lakes deeper than 1.5 meters (5 feet) no longer freeze all the way to the bottom. In these lakes, the organic carbon is beginning to thaw and rot year-round, and the permafrost underneath the lake is beginning to thaw out deeply. Microbes decompose organic carbon in the lake sediments, and in the thawed-out zone under the lake, into methane gas that bubbles to the

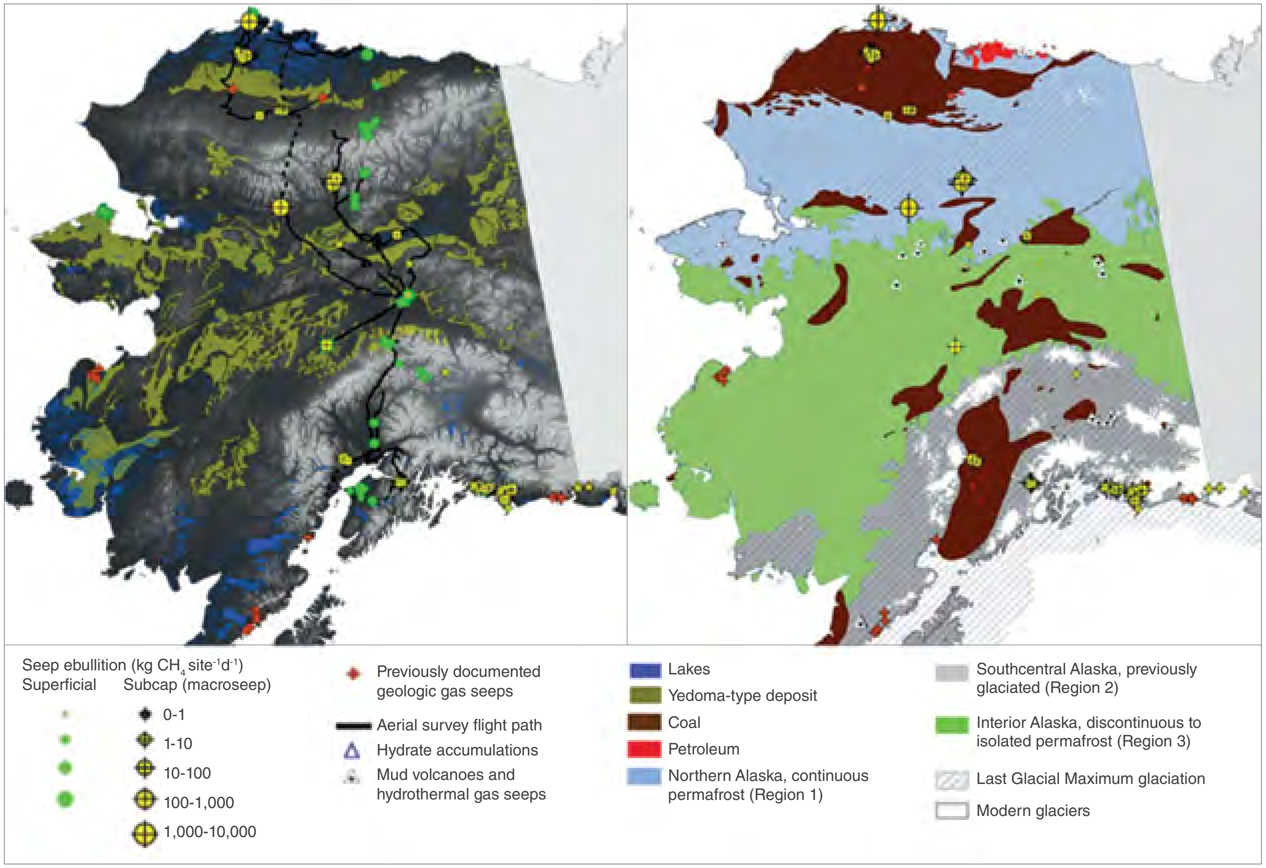
Sergey Zimov, director of the Northeast Science Station in Cherskii, Russia, stands near the base of this massive, exposed yedoma permafrost ice wedge, in this August 2001 photo taken at Duvanni Yar. The soil trapped behind the ice wedge is high in organic content, which could be released as carbon dioxide and methane if the yedoma thaws and rots. (Courtesy K. W. Anthony)

surface. As the lake surface refreezes in fall, researchers can see the bubbles, trapped in the ice. But they lacked wide-scale measurements of the escaping methane.

Bubble, bubble, toil, and trouble

In search of methane bubbles, Walter Anthony's team traveled to lakes by snow machine, helicopter, hiking in, canoe, and bush airplane. "We've gone out now on hundreds of lakes and mapped out these methane seeps, in Alaska, Russia, Canada, Finland, Sweden, and Greenland," she said. It is painstaking work conducted on often dangerously thin first ice in early winter.

Melanie Engram, who works with Walter Anthony on the methane studies, explained what it takes to measure emissions at a single lake. Engram said, "There often is snow on top of the ice, so first you shovel a 1-meter wide by



These maps of Alaska show surveyed methane seeps and the geological features associated with seeps. Left: Yellow dots represent seventy-seven subcap seep sites identified across Alaska, defined as methane seepage related to the thawing of glaciers and permafrost; green dots (superficial study lakes) are scaled by the magnitude of methane flux at each site. Black dashed lines show sections of the flight path omitted from analysis due to fog. Right: This map of the study regions shows yedoma deposits, areas of frozen ground that are especially rich in organic carbon, and hydrocarbon basins. (Courtesy K. W. Anthony et al./*Nature Geoscience*)

50-meter long [3-foot by 164-foot] transect. Then we drill a hole in the ice on one side, and get a bucket of water and pour it over the transect to remove the last specks of snow so we can see through the ice. Then you can easily see, count, categorize, and measure methane bubbles."

As lakes freeze over in fall, bubbles released from lake sediments get trapped under the freezing surface. The researchers can see stacks of bubbles, separated by thin films of ice, like a time-lapse photograph showing where the bubbles are coming from under the lake.

The bubbles and the rate of gas release vary across a lake, and from lake to lake. "If the bubbles are coming up slowly enough, the ice has a chance to grow around them," Engram said. "Katey has been working to categorize the bubbles. Type A is slow and indicates a small gas flux hardly keeping up with lake ice growth; with type B, some of the bubbles have grouped together by the time the ice forms. Type C has quite large pillows of gas before the ice forms around it. Each of these categories corresponds to a certain rate of gas seepage." The "boiling" lakes became a fourth type, called "hotspot," where methane is nearly continuously seeping out at very high rates. The researchers were able to measure seepage rates for each category by installing automated bubble traps, which look like underwater umbrellas, to measure the gas escaping year round.

As the permafrost thaws

The ultimate goal of the team's project is Arctic-wide estimates of lake methane emissions. Such estimates are needed for computer climate models, which help test and deepen scientists' understanding of how Arctic climate responds to change. But with millions of lakes and millions of square miles of Arctic, Engram said, "We can't go measure every lake. There's no way of traveling everywhere."

The team thought they could inspect the lakes and compare field observations with satellite images on a larger scale. Then they could apply the bubble cluster classifications and the measurements from their ground studies to estimate how much methane each lake is emitting. This would give them a way to estimate methane emissions from lakes across the entire Arctic.

Engram said, "Katey had the idea of looking at Synthetic Aperture Radar (SAR) data." Other researchers had published studies noting that SAR can detect brighter areas corresponding to tubular bubbles in floating ice. Engram said,

Methane seeps to the surface of this Arctic lake. Open areas in the ice indicate seeps strong enough to prevent the surface from completely freezing over. Round, whitish areas indicate weaker seeps, where bubbles remain trapped under the surface. (Courtesy K. W. Anthony)

A researcher sits on the surface of an Arctic lake. In front of his feet, he has lit a plume of escaping methane, a flammable gas, released when organic material thaws and decays under the lake. (Courtesy K. W. Anthony)

"We thought, well, if we see brighter ice where there are tubular bubbles, maybe we can find a SAR wavelength that would be sensitive to the various methane bubble types."

Engram was then working for the Alaska Satellite Facility SAR Data Center (ASF SDC), which distributes RADARSAT-1 SAR data. A major challenge was to align the data very precisely with the locations of individual lakes, and she thought she knew how to solve it with a new tool from ASF SDC. "We took SAR data and pushed it through the Convert tool," Engram said. The tool converted the SAR data into geolocated files that could be used in ArcGIS, a data mapping software. Engram compared the images with their ground observations. The brighter the ice in the SAR imagery, the more bubbles. Early winter SAR images showed the highest correlation with field measurements of methane bubbles.

Engram said, "It's important to know how much methane comes out of northern lakes, because methane is a very potent greenhouse gas that is 25 to 28 times more powerful than carbon dioxide at retaining heat in the atmosphere on a 100-year time scale. If we can do this with SAR remote sensing in a way that's inexpensive, using NASA's already available data and tools, we could contribute useful estimates to the Arctic methane budget."

Uncapping the cryosphere

But what about the wildly boiling gas plumes? Walter Anthony still wanted to understand what was happening under the ground to cause such a high flow rate. "My husband and I got in little airplanes and started flying around looking for places in the winter where lakes were open because of methane seepage," she said. "We flew around and looked at about 6,700 lakes in Alaska, but then we needed to ground truth it. So we went to fifty out of the seventy-seven of the sites where we had seen open areas. We found that yes, every one of them does indeed have very large plumes of methane coming up. But the weird thing is, it was only in certain places."

Walter Anthony and her colleagues studied the geology of the areas where they located the big seeps. In the Arctic, frozen ground can keep gas trapped for thousands of years. "Permafrost is a thick cap that seals off deeper geologic layers by blocking pathways through pore spaces with ice," she said. "There is natural gas underneath some permafrost regions, and that gas cannot escape into the atmosphere because the permafrost is impermeable." The team did a geospatial analysis, and found that the gas plumes were near places where glaciers and ice sheets are retreating, and where the thickest, most extensive layers of permafrost are now disintegrating from warming and thawing.

These methane emissions are strong, but transient. "If you've got a pot of water boiling on the stove with a lid on top, you have a bunch of steam that's building up inside of there, you take the lid off, that steam goes up, poof! But then the air clears," Walter Anthony said. "And in the same way you pull back this cryosphere cap, it lets the methane out in a poof, over probably a century to thousands of years." On a human scale, that poof of methane means large amounts of carbon added to an already warming atmosphere. "The lakes are much bigger emitters than we thought before, now that we have come to understand how much methane is actually bubbling out of the lakes," Walter Anthony said. "In the future we don't know what will happen. It is a bit of a wild card."

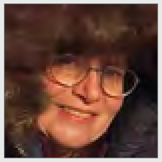
Sorting out all of these contributions helps scientists factor methane emissions into the overall study of Earth's climate. "Our work is another piece of the puzzle, closely linked to other processes associated to a changing world, and important if you want to know how much methane and carbon dioxide will be emitted in the future," Grosse said.

To access this article online, please visit http://earthdata.nasa.gov/sensing-our-planet/2012/leaking-lakes

About the remote sensing data used

Satellite	Canadian Space Agency RADARSAT-1
Sensor	Synthetic Aperture Radar (SAR)
Data set	Level 1
Resolution	25 meters
Parameter	Reflectance
DAAC	NASA Alaska Satellite Facility SAR Data Center (ASF SDC)

About the scientists



Melanie J. Engram is a research assistant at the Water and Environmental Research Center at the University of Alaska Fairbanks. Her current research interests include the application of Synthetic Aperture Radar (SAR) remote sensing to detect and quantify methane bubbles trapped by lake ice. NASA and the National Science Foundation supported her research. (Photograph courtesy M. J. Engram)

Guido Grosse is a research assistant professor at the Permafrost Laboratory at the Geophysical Institute, University of Alaska Fairbanks. His research interests include remote sensing of polar and subpolar geomorphological and hydrological dynamics; climate change and the cryosphere; Arctic climate feedbacks; and paleo-environmental reconstruction of cold-climate landscape dynamics. NASA and the National Science Foundation support his research. (Photograph courtesy University of Alaska Fairbanks)

Katey M. Walter Anthony is an aquatic ecosystem ecologist and assistant professor at the Water and Environmental Research Center at the University of Alaska Fairbanks. Her research interests include methane in the Arctic, lakes, biogeochemistry, climate change, permafrost and thermokarst, carbon cycling, and isotopes. NASA, the Department of Energy, and the National Science Foundation supported her research. (Photograph courtesy K. M. Walter Anthony)

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http://www.asf.alaska.edu
Canadian Space Agency—RADARSAT-1
http://www.asc-csa.gc.ca/eng/satellites/radarsat1
Katey Walter Anthony
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Melanie J. Engram
http://ine.uaf.edu/werc/people/melanie-jane-engram
Guido Grosse
http://permafrost.gi.alaska.edu/users/ggrosse

Prosperity shining

"We have this new tool, and we are really just at the start of what we can do with it."

Adam Storeygard
Tufts University

by Katherine Leitzell

They say that New York City never sleeps. Even at three in the morning, subway cars trundle through dark tunnels, cabs zip across surface streets, and the city glitters with streetlights and brightly lit billboards. In a satellite image of the United States at night, New York City shines brighter than anywhere else on the continent.

It is no coincidence that New York City is also one of the top economic centers in the world. Economists first connected economic activity with night lights when the U.S. Department of Defense released satellite images of world-wide lights in the 1970s. Adam Storeygard, an economist at Tufts University, said, "When the satellite lights data were declassified in the 1970s, researchers published papers showing pictures

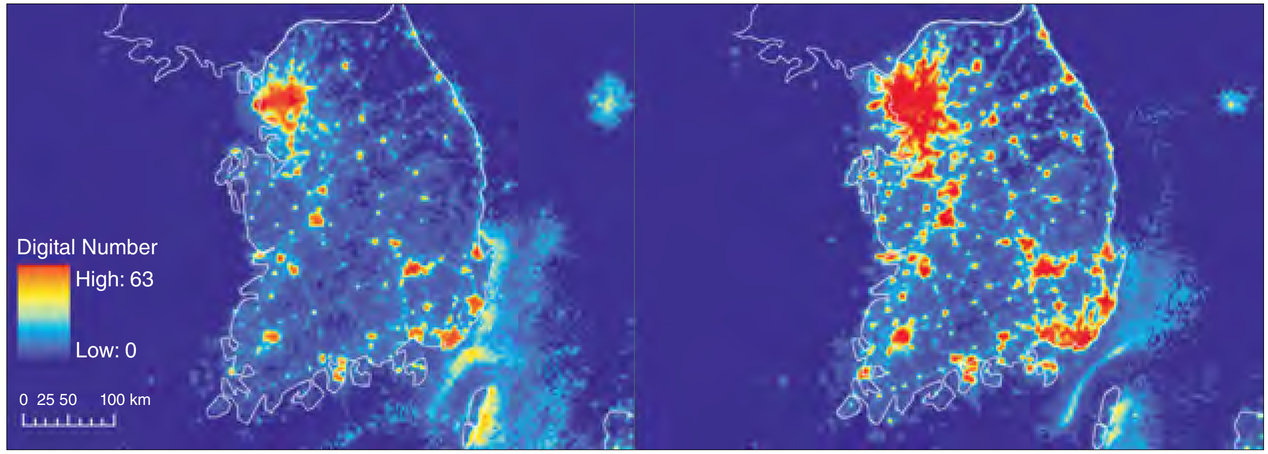
New York City shines brighter than any other U.S. city at night. Nighttime lights can indicate relative economic prosperity. (Courtesy R. Fernandez) of lights, and how they correspond to human settlement and economic activity."

But while the data were an interesting tidbit thirty years ago, nobody thought to harness them to look at serious economic questions. Now Storeygard and Brown University economists Vernon Henderson and David Weil have turned those pretty nighttime satellite pictures into a unique measure for economic growth, allowing them to fill in data gaps and answer questions that have traditionally stumped economists.

Measuring production

Normally, when economists talk about economic growth, they use a measure called Gross Domestic Product (GDP), an index that measures the value of all the goods and services in a country's economy. Essentially, GDP is a score that tells economists how a country's economy is faring with respect to other countries, and how it is growing or declining. To calculate a country's GDP, Weil explained, researchers need a lot of data, including an accounting of all of the goods and services produced in a country, and the prices people paid for them.

"In a developed, corporatized, organized economy those numbers are at least in principle observable," said Weil. "There are problems, but you can do an okay job." But in developing countries, it is harder to get enough data to accurately estimate GDP—a fact well recognized by economists and the organizations that track GDP. Weil said, "There are estimates of GDP for every country in the whole world. There are also grades corresponding to how accurate these estimates are thought to be. Rich countries get an A, while poor countries might get a D."



This pair of satellite images show the growth in city lights from 1992 (left) to 2008 (right) in South Korea. Red areas show regions of higher light concentration, whereas blue areas are regions with very little nighttime light. During this time period, South Korea's Gross Domestic Product, a measure of overall income, grew by 119 percent. (Courtesy National Oceanographic and Atmospheric Administration National Geophysical Data Center, from Defense Meteorological Satellite Program data)

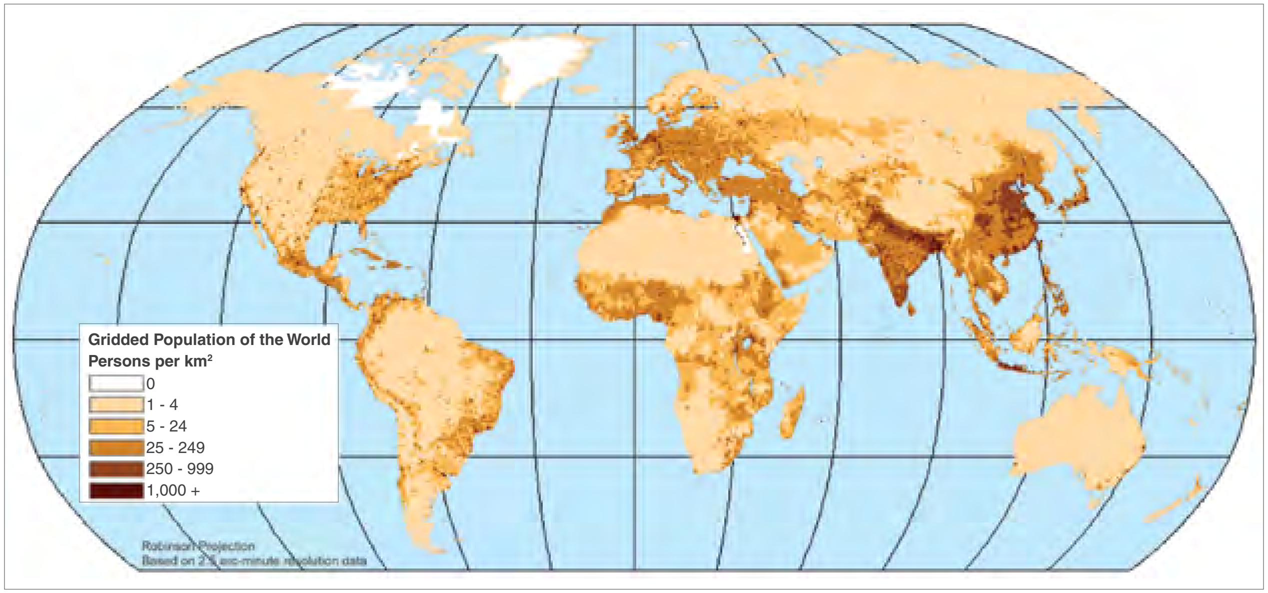
The problem with getting good GDP data is that in poor countries, much economic activity does not get recorded in official measures. People might hide their business from the government to avoid taxes, or they might be bartering for goods and services, in ways that the government does not track. That makes it difficult to estimate the true GDP, which in turn makes it difficult for economists to analyze what is going on economically in poor countries, and whether new development policies are working or not.

The lights go on

Although researchers in the 1970s had established that city lights were linked to economic activity, they had not gone very far beyond that basic observation. The data series was short, and the correlation between lights and economic activity was rather rough. Storeygard said, "There are other reasons why you might have more lights in one area than another. For example, even if they have the same level of economic activity, you might have more lights in Las Vegas than you would in Salt Lake City."

Storeygard, Weil, and Henderson decided to look at changes over time, focusing on the growth or decline in one area, instead of comparisons between locations. They also aligned the data on lights with population data from the NASA Socioeconomic Data and Applications Center (SEDAC) to determine the location of large cities and to define land area and data coverage. Most census data, like economic data, are organized by country or county—artificial boundaries that satellites do not recognize. In contrast, the SEDAC population data are tied to a geographic grid, making them easy to relate to satellite data. Storeygard said, "The SEDAC data are a useful intersection point between natural sciences data and population data."

The resulting lights data showed a clear correlation with economic activity, although they were



This map shows the Gridded Population of the World data set from the Socioeconomic Data and Applications Center (SEDAC). SEDAC population data are organized using a geographical grid, which makes them easier to link with satellite data. (Courtesy SEDAC)

not as accurate as standard GDP data. "We don't think that lights data give us a better estimate than what we currently have, but we think that it gives us a different estimate," Weil said.

The researchers combined their lights-based estimate of economic activity with traditional GDP data to get an even better measure. "Two uncorrelated measures are better than one," Storeygard said. Because the errors in the two data types came from different sources, he said, a combined indicator reduced the overall error.

The lights data also have a few other advantages. First, lights data are available worldwide, and are no less accurate in poor nations than in rich countries. Storeygard said, "The lights data are even available for places like North Korea that don't report traditional economic data."

Secondly, lights data are geographical, not national, so they allowed the researchers to look more closely at particular regions within countries where previously the only data were nationwide. Weil said, "To a large extent economics has been restricted to looking at countries, because that is the unit from which the data have come. These lights data give us, albeit imperfectly, data at much smaller scale."

New perspective on production

Researchers can now start to tackle difficult questions that have long challenged them. In a 2012 study, Weil, Henderson, and Storeygard asked several questions about economic growth in Sub-Saharan Africa, a region with particularly bad economic data. First, they wondered whether economies in coastal regions were growing faster than those in land-locked areas. Because coastal cities in Africa tend to be bigger economically, the researchers suspected that they might also be growing faster. But when they examined the data, they found the opposite. Second, the team wanted to know how quickly big capital and coastal cities, known as primate cities, were growing in comparison to smaller cities. Again, the team's initial guess was wrong: the economies of big cities were growing more slowly than those of the smaller ones.

Finally, the scientists asked whether malaria, a deadly disease spread by mosquitoes, was stunting economic growth. Weil said, "A lot of economic work has theorized that malaria has an important effect on economic growth." It seems likely that if malaria were eradicated, economies would grow faster. But without good economic data, nobody could answer this question for sure. The researchers used lights data in regions where malaria had been reduced, and found that in fact, the disease had not seemed to affect aggregate economic growth.

While the researchers' initial hypotheses were wrong, they noted that before this study, nobody had been able to tackle these questions. "For most countries in Africa, not only are the data very bad, but there are very little of them," Weil said. "If you want to look at this kind of question, the lights data are the only data that are available." Storeygard said, "We have this new tool, and we are really just at the start of what we can do with it."

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http://sedac.ciesin.columbia.edu

NASA Visible Earth
http://visibleearth.nasa.gov/view.php?id=55167

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Adam Storeygard
https://sites.google.com/site/adamstoreygard

David Weil
http://www.econ.brown.edu/faculty/David_Weil

About the data used

Data sets	Gridded Population of the World	Global Rural-Urban Mapping Project, version 1 (GRUMPv1)
Resolution	2.5 arc-minute	30 arc-second
Parameters	Population	Population
DAAC	NASA Socioeconomic Data and Applications Center (SEDAC)	NASA SEDAC

About the scientists

Vernon Henderson is a professor of economics at Brown University. His research focuses on urbanization, productivity, and industry. (Photograph courtesy V. Henderson)

Adam Storeygard is an assistant professor of economics at Tufts University. His research focuses on economics and population in developing countries. (Photograph courtesy A. Storeygard)

David Weil is a professor of economics at Brown University. He studies economic growth around the world. (Photograph courtesy D. Weil)

Winter's water

"Satellite data are critical for that extended vision into the mountain reservoir of water in the snowpack."

Tom Painter
NASA Jet Propulsion Laboratory

by Laura Naranjo

Everyone loves a snow day, especially city water managers in the arid western United States. A good winter snowpack in the mountains means rushing rivers and streams during the spring snowmelt, followed by a summer of full reservoirs, fresh drinking water, open swimming pools, and lush golf courses. A poor snowpack, on the other hand, leads to depleted reservoirs and possibly water restrictions. Mild restrictions may prevent residents from using sprinklers or washing cars, but harsher restrictions can inflict water rationing and steep fines. Severe restrictions can even force businesses like meat-packing plants to temporarily shut down because there is not enough water to clean and sanitize equipment.

Water restrictions can be unpleasant, so western water managers rely on good forecasts to avert hardships by promoting water conservation in advance of potential shortages. But traditional ground methods of forecasting may not be good enough in a warming climate, where the West is drying and snow retreats to higher elevations. Researchers are now peering into satellite data and computer models to help water managers adapt to increasing drought and changing snow patterns.

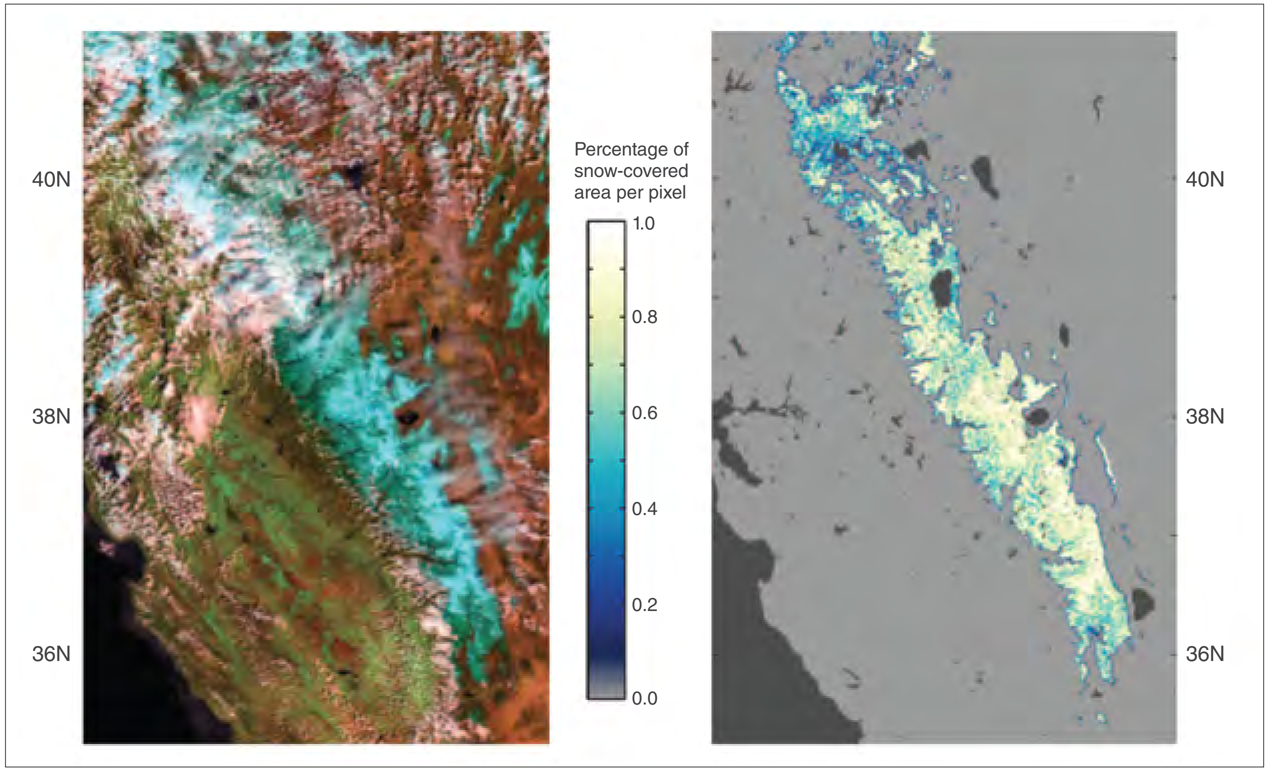
Snowmelt swells the Colorado River from high Rocky Mountain trickle to the largest river in the southwestern United States. The Glen Canyon Dam is one of several dams along the river, which continues to flow to the Gulf of California, providing drinking water for Los Angeles and irrigating California's Imperial Valley. (Courtesy C. Mehlführer)

Remote reservoirs

Much of the western United States receives water from major mountain chains, such as the Rocky Mountains and California's Sierra Nevada. The deep snow blanketing those mountains in winter will melt to provide water downstream for millions of people and irrigation for billions of dollars worth of crops in the summer. Water managers want to know how much water is in that snow. So they need to know where the snow is, and how dense that snow is. They are particularly interested in denser snow, which has more water for a given depth. Skiers may love light, powdery snow, but that may only have 10 percent water. The heavy, wet snow that most people dread shoveling from their sidewalks may have 40 to 60 percent water.

Mountains in the western United States are dotted with snow telemetry stations, which take continuous measurements at remote sites and transmit data to water managers who monitor the snowpack while snug and warm in their offices. Called SNOTEL sites, the stations feature snow pillows that record the weight of the snow on top of them, and thereby the water equivalent. "The problem with the snow pillow sites is they're all on flat ground, so they don't represent the terrain very well," said Jeff Dozier, a snow hydrologist at the University of California. SNOTEL sites are also few and far between, and do not account for the variations in mountain landscape. Most snow pillows are only about 80 square feet (7.4 square meters) in size, which is negligible among the millions of square kilometers of snow that cover the United States each winter.

In addition, the snowpack itself often changes over the course of a season. Each layer of snow is slightly compressed by the weight of subsequent snowfalls, gradually compacting and becoming denser. By the end of the season, the densest snowpack, usually in the Cascade Mountains of Washington and Oregon, can be 40 to 50 percent water. The extent of the snowpack changes as well. In October, only a few spots will have received snow, but by February, nearly half of the United States may be covered in snow.



These maps from the NASA Moderate Resolution Imaging Spectroradiometer (MODIS) satellite instrument show snow cover over the Sierra Nevada in California. The image at left shows snow cover extent; the right image shows the fraction of area covered by snow of any depth, providing a more realistic estimate of snow. (Courtesy J. Dozier)

SNOTEL stations are valuable, however, because they are the only reliable source of snow water equivalent data. So scientists are trying to pair these ground measurements with remote sensing to form a more comprehensive picture of mountain snowpack and its potential water supply.

Sensing snowpack

Satellites fly over these mountains regularly and can offer widespread snow measurements over the region. However, water managers are leery of satellites, and for good reason. Most satellites have a lifespan of less than ten years, and may not provide the long-term context water managers seek. Dozier said, "They hesitate to use an experimental satellite or a data source that may be around for only a few years." So Dozier and others have been developing other meaningful ways that water managers can use satellite data in their models, and finally, they might be on to something.

Snow telemetry (SNOTEL) sites are equipped with meteorological instruments that help scientists gauge the mountain snowpack. The rectangular shapes on the ground are snow pillows that estimate the water equivalent of the snow. (Courtesy A. Slater)

Dozier and his colleague Tom Painter at the NASA Jet Propulsion Laboratory have been testing satellite-based measurements of snow cover. Although they are analyzing the data for mountain ranges across the globe, several of their studies have focused on California's Sierra Nevada mountain range, which offer SNOTEL sites for comparison. One of the best satellite instruments to look at snow is the NASA Moderate Resolution Imaging Spectroradiometer (MODIS), which offers broad, global coverage that allows the researchers to see snow extent across entire mountain ranges. Dozier and Painter downloaded MODIS data from the NASA Land Processes Distributed Active Archive Center (LP DAAC), using the satellite's broad coverage to fill in the gaps between SNOTEL measurements and other ground data. Painter said, "You can stick all of the SNOTEL pillows that exist well within a single MODIS pixel."

Satellite data complement the SNOTEL sites, which are often installed in middle to lower elevations, not at the highest elevations where there is more snow that lasts longer into the melt season. Climate warming models predict that the mountain West will become drier in coming decades: the snow season will start later in fall and end earlier in spring. "As the climate continues to warm, the snow-covered duration at each of the SNOTEL sites will become shorter, but there will still be snow up in the mountains," Painter said. "Satellite data are critical for that extended vision into the mountain reservoir of water in the snowpack."

Modeling snow

To help assemble the many complexities of snowfall into a water supply forecast, Dozier and Painter also run computer models that combine ground measurements and remote sensing data. It is the fusion of all three views that Dozier and Painter hope will form a more complete picture. One such model is the National Weather Service's Snow Data and Assimilation System (SNODAS), generated by the National Operational Hydrologic Remote Sensing Center. The model data, distributed by the NASA National Snow and Ice Data Center Distributed Active Archive Center (DAAC), simulates snow cover and water equivalent in near-real time, offering a view of the snowpack as it develops. Dozier said, "We are using MODIS to improve the results from models such as SNODAS." Modeling can also help span temporal and geographic gaps in the various data sources. Painter added, "There's still a lot that is simply not observed yet, so we are squeezing the MODIS spectrum for better snow observations to help improve the community's current and new models."

As scientists like Dozier and Painter create meaningful ways to use remote sensing, forecasters and water managers have become more open to including it in their models. In fact, Painter will begin providing his near-real-time MODIS Snow Covered Area and Grain size (MODSCAG) data to the Colorado Basin River Forecast Center (CBRFC), which models conditions for the massive Colorado River drainage basin and generates streamflow forecasts. The basin includes all the streams and rivers that feed into the Colorado River, and covers seven western states plus northern Mexico. The river itself originates in the high mountains of Colorado and flows to the Gulf of California, providing water to Los Angeles, the Imperial Valley, and numerous communities along the way. "Roughly 30 million people get their fresh water supply from the Colorado River," Painter said. At least 65 percent of that water comes from snowmelt.

Managing the melt

Kevin Werner at CBRFC is collaborating with Painter. Werner said, "I work with the water managers to understand what they do, how they do it, how they use forecasts, and bring that information back so that we can meet their needs better." The CBRFC models will use the MODSCAG record to nudge their estimates of snow extent, helping to produce better forecasts of river flow and water availability downstream. "The MODIS data are a really nice complement to traditional in situ measurements," Werner said. "Right now, we're looking at the snow-covered area from MODIS, and eventually we'll start looking at snow water equivalent. We have a snow model that we run for all of our basins that simulates the snowpack as a function of elevation in each one of those basins. That's where MODIS fits into our paradigm."

MODIS data have proven they can be a reliable addition to historic methods, laying a foundation for its follow-on mission, the Visible Infrared Imaging Radiometer Suite (VIIRS), already in orbit. VIIRS was launched as a partnership between NASA and the National Oceanic and Atmospheric Administration, and will extend the MODIS record of snowpack and reflectivity. Dozier said, "Water managers now have some confidence that this kind of data will continue to be available."

In addition, these solutions may also work in more remote regions of the world. Dozier said, "What I'd really like to do is look at all mountains all over the world and use these methods in ranges where there isn't as much infrastructure." Painter said, "It's very important in places like the Hindu Kush and all along the Himalayan nations, because they have little to no instrumentation in the mountains." Millions of people in those regions rely heavily on snowmelt to replenish their water supplies, particularly during annual dry seasons, and estimating snow water equivalent remotely may be one of the only viable solutions to help them manage this essential resource.

To access this article online, please visit http://earthdata.nasa.gov/sensing-our-planet/2012/winters-water

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About the remote sensing data used

Satellites	Terra and Aqua	
Sensor	Moderate Resolution Imaging Spectroradiometer (MODIS)	
Data sets	Surface Reflectance Bands 1-7, M0DO9	Snow Data and Assimilation System (SNODAS)
Resolution	500 meters	30 arc seconds
Parameters	Surface reflectance	Snow cover, snow water equivalent
DAACs	NASA Land Processes Distributed Active Archive Center (LP DAAC)	NASA National Snow and Ice Data Center (NSIDC) DAAC

About the scientists

Jeff Dozier is a professor at the University of California, Santa Barbara, and was a founding dean of the Bren School of Environmental Science and Management. He studies snow hydrology and the integration of environmental science and remote sensing using computer science and technology. NASA, the U.S. Army Cold Regions Research and Engineering Laboratory, and Mammoth Mountain Ski Area supported his research. (Photograph courtesy Bren School)

Tom Painter is a research scientist at the NASA Jet Propulsion Laboratory and an adjunct professor at the University of California, Los Angeles, and at the University of Utah. His research focuses on snow hydrology and water resources, energy balance and albedo of snow and ice, and remote sensing. NASA supported his research. (Photograph courtesy Western Water Assessment)

Kevin Werner is a hydrologist with the National Oceanic and Atmospheric Administration (NOAA) at the Colorado Basin River Forecast Center. Werner works to connect water predictions and science with people and organizations. NOAA supports his work. (Photograph courtesy K. Werner)

For more information

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

NASA National Snow and Ice Data Center (NSIDC DAAC)
http://nsidc.org/daac

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

Snow Data Assimilation System (SNODAS)
http://nsidc.org/data/g02158.html

Jeff Dozier
http://www.bren.ucsb.edu/people/Faculty/jeff_dozier.htm

Tom Painter
http://science.jpl.nasa.gov/people/Painter

Kevin Werner
http://www.nws.noaa.gov/ost/climate/STIP/FY11CTBSeminars/kwerner_081211.htm

Shadowing the tuna boats

"The most frustrating challenge is to take these data, which are governed by strategies and decisions made by fishermen, and to turn them into sound information about the fish's location, distribution, and habitat."

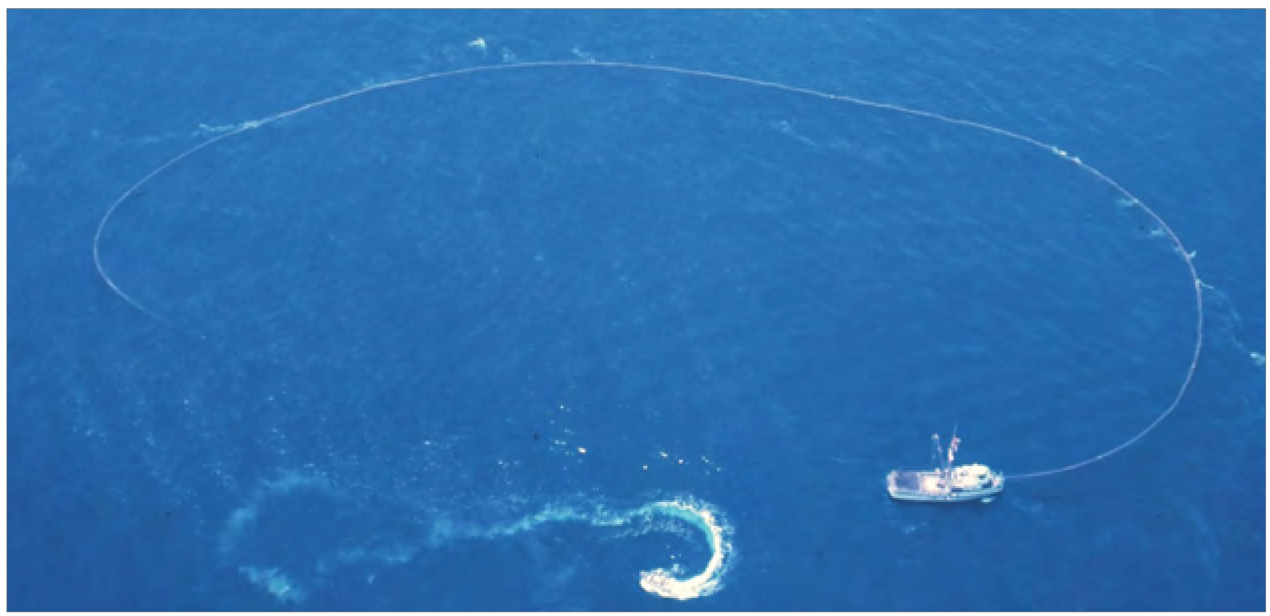
Dale Kiefer
University of Southern California

by Natasha Vizcarra

In the National Archives in Boston, stacks of fishing logbooks from the 1880s detail the once abundant catches of cod off the coast of New England. The skippers who kept these logbooks 150 years ago would have been sad if they had known the rest of the story. So in demand that Europeans called it "British gold," the cod's mild-flavored flesh sparked a Cod War between Iceland and the United Kingdom in the 1950s. Then trawlers increased catches dramatically, and the fish population crashed by the 1990s. Cod catches in New England are now a measly five percent of what fishermen used to catch in the 1880s.

Today in San Diego, California, logbooks tell a similar story: forty years of skippers' notes and statistics from the Inter-American Tropical Tuna Commission (IATTC) detail increasing catches and growing fishing efforts in the eastern Pacific Ocean. The IATTC, whose member countries manage fish stocks in the region, imposes an annual quota on how much fish each country is allowed to catch—in hopes of averting a fate similar to the cod.

With three of four major species of tuna in the eastern Pacific Ocean fully exploited, scientists think that better fish forecasts and quotas could save the tuna. Biological oceanographer Dale Kiefer said, "Fishermen use a lot of satellite



A tuna boat uses a purse seine net to surround a school of tuna in the eastern Pacific Ocean. The net is drawn closed at the bottom, like a purse, to prevent the fish from escaping. (Photograph by C. Orange courtesy NOAA Photo Library) imagery. We want to catch up with them." Kiefer and his colleagues have some novel ideas about fusing logbook data with satellite data to keep boats away from younger fish and allow the tuna population to recover.

Ode to the tuna

Like cod, the tuna is much sought after, whether for humble casseroles or elegant sushi. The fish is also a swimming machine. The bluefin tuna, for example, is so streamlined that its silver gunmetal body can swim across the Pacific Ocean in twenty-six days. Its speed comes from its unique red muscles—that tasty sashimi flesh—which stay 20 degrees Fahrenheit warmer than the surrounding water, allowing the fish to feed on fast prey in a huge range of environments. Tagged Pacific bluefin tuna, which spawn off the coast of Japan, have been caught off the coasts of Mexico and southern California.

Their prodigious range used to make the fish hard to find. Before the 1950s, fishermen watched for frolicking porpoises, or small marine life like squid, tuna crabs, and birds. Skippers tracked the sea surface temperatures that different species of tuna favored. They also hunted tuna on the fringes of murky, chlorophyll-rich areas of the ocean, finding them feasting on plankton-feeding fish.

But technological improvements in the 1950s, like the invention of nylon, made the tuna easier to catch. Instead of multiple fishing poles, stronger and larger nylon nets stretched for miles, snagging huge catches. By the 1960s, scientists saw a decline in yellowfin tuna in the eastern Pacific Ocean. The nets also snagged sharks, porpoises and turtles, prompting protests by conservation groups. The IATTC brought together all countries fishing in the region to address these problems through stock assessments and quotas.

The pursuit of fish

In spite of these measures, tuna continued to decline. In the 1980s, tuna boats began using radars and satellite data on sea surface temperature, sea surface height, thermocline depth, and chlorophyll concentrations to find fish. Smaller boats that hugged the coastline evolved into fleets of ships with larger holding tanks that could fish longer and farther from shore.

Responding to public pressure, the IATTC member countries called for a new approach. It was the push Kiefer and his colleague Michael Hinton, fisheries oceanographer and scientist with the IATTC, needed for their project. The IATTC's scientific team provides stock assessments to fisheries managers to help them decide when to close areas to fishing, and what fishing quotas to assign to each country. Conservation organizations pointed out that as of 2011, yellowfin, bigeye, and Pacific bluefin tunas are overfished, which could mean the quotas are too high. Kiefer and Hinton think regulators need more precise tools to help with their decision making.

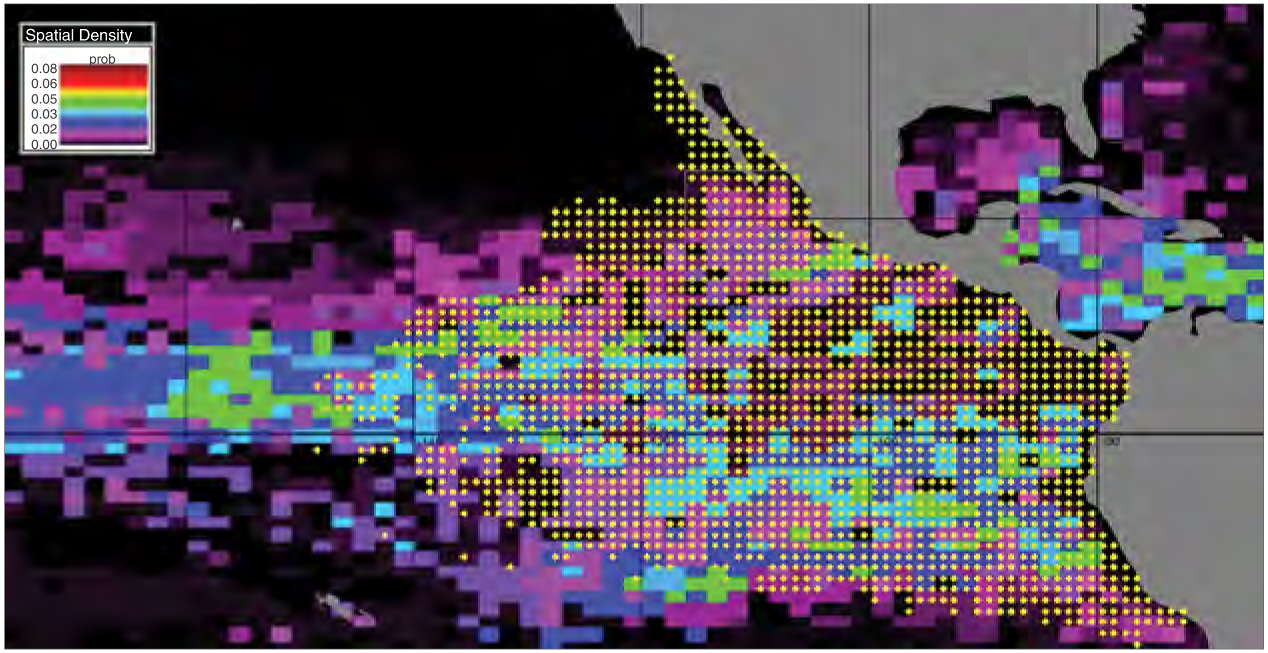
"The problem with stock assessments is that they are mostly based on numbers from fishing logbooks," Kiefer said. He wanted to put the ecosystem in the equation. "There is surprisingly little use of satellite imagery in managing fisheries," he said. "The eastern Pacific Ocean is enormous and dynamic. Large climate patterns like the El Niño affect how tuna move around." Kiefer and Hinton thought that the satellite data could give decision makers a better picture of the fish's habitat.

Pacific bluefin tuna are prodigious swimmers, able to cross the Pacific Ocean in less than a month. Advanced fish-finding gadgets allow fishermen to track their now-sparser populations. (Courtesy T. Ichishima)

Dynamic maps

Kiefer and his team developed the Pelagic Habitat Analysis Module (PHAM), which combines logbook data with satellite data, including sea surface temperature data from the Moderate Resolution Imaging Spectroradiometer (MODIS) sensor, and ocean chlorophyll data from the Sea-Viewing Wide Field-of-View (SeaWiFS) sensor. PHAM also uses tuna tagging data, ocean circulation models, and global information system data. To limit catches, regulators restrict the number of tuna boats and fishing days, and where boats can go. But the distribution of tuna is not static. Tuna move with the season, ocean currents, water temperature, and with the concentration of chlorophyll on the sea surface.

"PHAM generates dynamic maps of the tuna habitat, giving regulators more information, in addition to the stock assessments, when deciding



This map of the critical habitat of skipjack tuna around North and South America was generated by the Pelagic Habitat Analysis Module (PHAM), as calculated from habitat analysis and current satellite imagery. Red, yellow, and green show a higher probability of fish, while purple and blue show a lower probability. The yellow dots show fishery stations recognized by the Inter-American Tropical Tuna Commission (IATTC). (Courtesy E. Armstrong, D. Kiefer, F. O'Brien, D. P. Harrison, M. Hinton, S. Kohin, and S. Snyder)

on quotas and when temporarily closing areas to fishing to allow stocks to recover," Kiefer said. Hinton, who developed the stock assessment model for PHAM, said "Some people find working with satellite and environmental data a big morass of intractability. PHAM gives them the ability to take these satellite products and use them in their statistical analysis."

Scientists who put together the IATTC's yearly stock assessments are currently testing PHAM. Tester Alexandre Aires-da-Silva said, "We often have to produce these stock assessments under a lot of pressure. This tool allows us to rapidly manipulate these satellite data sets that we wouldn't have had time to put together." Mark Maunder, who heads the IATTC stock assessment team, said PHAM's biggest value is in identifying areas where tuna boats might accidentally harvest by-catch species like dolphins.

A fisherman's mind

Kiefer was still unsure about the dependability of the fishing logbook data. He said, "The most frustrating challenge is to take these data, which are governed by strategies and decisions made by fishermen, and to turn them into sound information about the fish's location, distribution, and habitat." Scientific studies are traditionally based on random sampling or a fixed array. "Getting information from a biased party is not the way scientists do things," Kiefer said.

Kiefer's colleague, environmental studies professor D. G. Webster, saw this weakness as an opportunity to learn more about the fish and its pursuers. Kiefer said, "She wanted to put the mind of the fisherman right in the software." Webster is taking PHAM and integrating it onto another software called Fishscape, an ambitious effort to create a four-dimensional mathematical model of the entire fishery in the eastern Pacific Ocean—from the fish in the water, to the regulations made by fisheries managers, to the skippers and their fleets. Webster said, "We will use PHAM to combine data on the ocean with Fishscape's data on the fishers, the markets, and even the political policies to fully understand the dynamics of a fish stock's resilience or its collapse."

Virtual fishermen

Fishscape is a little like SimCity, a simulation game where the city's residents react to changes in the environment introduced by the game's player. Like SimCity, Fishscape will be populated by residents—in this case, virtual fishermen. Webster interviewed dozens of fishermen to model how they behave in different situations. She is using this information to create virtual fishers who will fish in the simulation using real environmental and fish fleet data from PHAM. "We want to find out if there are behaviors of the fishermen that allow them to keep catching fish, even though there aren't many fish out there," Webster said.

Although it uses computer modeling that borrows elements from game theory, Webster does not want Fishcape to be taken lightly. "We're not going to have cute little avatars going out on virtual fishing boats, selling fish in virtual markets with prices that have no relationship with supply or demand," she said. When Fishscape is completed in 2013, Webster will test and study three scenarios. "We want to know how climate change, an increase in the price of oil, and further technological improvements in the fishing fleets could impact the sustainability of fisheries—that is, the ability of the fish, the fishers, and fish consumers to thrive now and in the future," she said.

Webster is optimistic that Fishscape can shed light on the relationship between ocean currents, food availability, and fishes' reproductive success. More importantly, it could help prevent the eastern Pacific tuna and other fish stocks from crashing like the North Atlantic cod. "It will break down barriers to cooperation by moving the focus away from conflict over who gets what—and the related inability to prevent the decline of stocks—to agreement on management that can improve conditions for everyone, even the fish," she said.

To access this article online, please visit http://earthdata.nasa.gov/sensing-our-planet/2012/shadowing-tuna-boats

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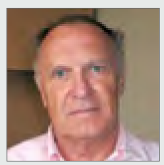
About the remote sensing data used

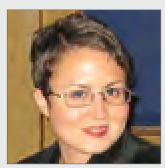
Satellites	Terra and Aqua	SeaStar
Sensors	Moderate Resolution Imaging Spectroradiometer (MODIS)	Sea-Viewing Wide Field-of-View Sensor (SeaWiFS)
Data sets	GHRSST Sea Surface Temperature	SeaWiFS Daily Chlorophyll Data
Resolution	0.25 degree	4 kilometer, 9 kilometer
Parameters	Sea surface temperature	Ocean color
DAACs	NASA Physical Oceanography Distributed Active Archive Center (PO.DAAC)	NASA Ocean Biology Processing Group (OBPG)

About the scientists

Michael Hinton is a senior scientist with the Inter-American Tropical Tuna Commission (IATTC), where he heads the Fisheries Oceanography group. His research focuses on pelagic systems ecology and on modeling populations of large pelagic predators. NASA supported his research. (Photograph courtesy M. Hinton)



Dale A. Kiefer is a professor of biological sciences at the University of Southern California. His research focuses on the population dynamics of microbial populations in the sea, particularly material and energy flow within planktonic populations of phytoplankton, microzooplankton, and bacteria. NASA supported his research. (Photograph courtesy D. Kiefer)



D. G. Webster is an environmental studies professor at the Dartmouth College. She studies feedbacks within global scale social-ecological systems, like climate change and international fisheries. The National Science Foundation supported her research. (Photograph courtesy D. G. Webster)

For more information

NASA Ocean Biology Processing Group (OBPG)
http://oceancolor.gsfc.nasa.gov
NASA Physical Oceanography Distributed Active Archive Center (PO.DAAC)
http://podaac.jpl.nasa.gov
Moderate Resolution Imaging Spectroradiometer (MODIS)
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D. G. Webster
http://www.dartmouth.edu/~envs/faculty/webster.html
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Fishscape
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Inter-American Tropical Tuna Commission (IATTC)
http://www.iattc.org

Biomes in the balance

"Anything that happens in pinyon-juniper woodlands is going to make a huge dent in the carbon balance across the whole U.S."

Marcy Litvak
University of New Mexico

by Karla LeFevre

Just a few hours south of central New Mexico, a gust of hot wind spills over a rim rock canyon, gathers upon itself during its fast descent to the bottom, then spins and eddies as it tumbles out of the canyon and over the landscape. From high to lower and lower elevations, it flows through and over a Ponderosa forest, across a range of pinyon and juniper trees, meanders through a juniper savanna, then fans out over a vast desert grassland. As it makes its way along this journey and mixes with the air of these different biomes, or ecosystems, Marcy Litvak's

Researchers Shaila Shodean (left) and Andy Hawk (right) take measurements and collect tree litter, such as twigs, bark, and needles, from juniper trees in central New Mexico. (Photograph by K. Anderson-Teixeira courtesy Smithsonian) towers of instruments record its speed, direction, and carbon dioxide content. These are just a few of the measurements she and her team need in order to study carbon cycling across the region.

Litvak, an ecologist with the University of New Mexico, already knows that the Southwest stores a great deal of carbon. But with predictions for hotter and drier climes looming for the region, the big mystery they hope to unravel is just how much change the landscape can absorb. Will these biomes continue to clean up excess carbon in the atmosphere as they have for millennia? Or will they be decimated by drought, beetles, fire, and other factors, never to return?

Surprising sink

Scientists the world over are studying the balancing act of carbon dioxide between the ocean, soil, shrubs, trees, and atmosphere. Yet the American Southwest is not what comes to mind when most people think of carbon storage; they may think instead of Earth's rain forests, with their tall and lush vegetation. However, the Southwest is as ecologically diverse as it is vast. For Kristina Anderson-Teixeira, a forest ecologist at the Smithsonian and a former member of Litvak's team, that makes it a perfect, living laboratory.

Anderson-Teixeira said, "One of the best things about New Mexico, and what allowed us to do this study there, is that you have great ranges in elevation with the mountain ranges. So you can go within a short space from a desert grassland or shrubland—hot and dry ecosystems with low biomass storage, like grasses and scattered, smallish shrubs—all the way up to conifer forest. By the time you get up there you're in a relatively cool, moist forest with tall trees and high biomass storage."

And it is a very large laboratory. "The extreme advantage we have in using a network such as this," Litvak said, "is that we have six of the most dominant biomes that are represented throughout the Southwest. But if you look across Colorado, Utah, Arizona, and New Mexico, it represents about sixty percent of the total land area." That amounts to millions and millions of acres, and a lot of carbon storage. But exactly how much?

It takes a network

To answer that question, the team has been diligently monitoring carbon cycling across the biomes for six years now. Armed with a dozen or so instruments apiece, each tower records a range of data, like carbon dioxide in the air, precipitation, temperature, and energy exchange. Meanwhile, Litvak and her crew regularly head out to kneel in the dirt, scoop up soil, measure tree trunks and branches, and record a wide range of other biomass measurements. When combined, this array of data helps reveal the inner workings of each biome: how it normally functions and how it responds to variations in weather and climate. When temperatures rise and rain is sparse, for instance, they watch to see how one component responds across all biomes, such as the amount of water in the soil.

The team's preliminary study focused on two related components, temperature and precipitation, and was a springboard for more complicated investigations to come. It confirmed most of what they expected. They found that the ability of these ecosystems to store carbon was indeed reduced under hotter and drier conditions. As temperatures rise, trees become stressed. And when less water is available, they are stressed further, less able to photosynthesize: breathe

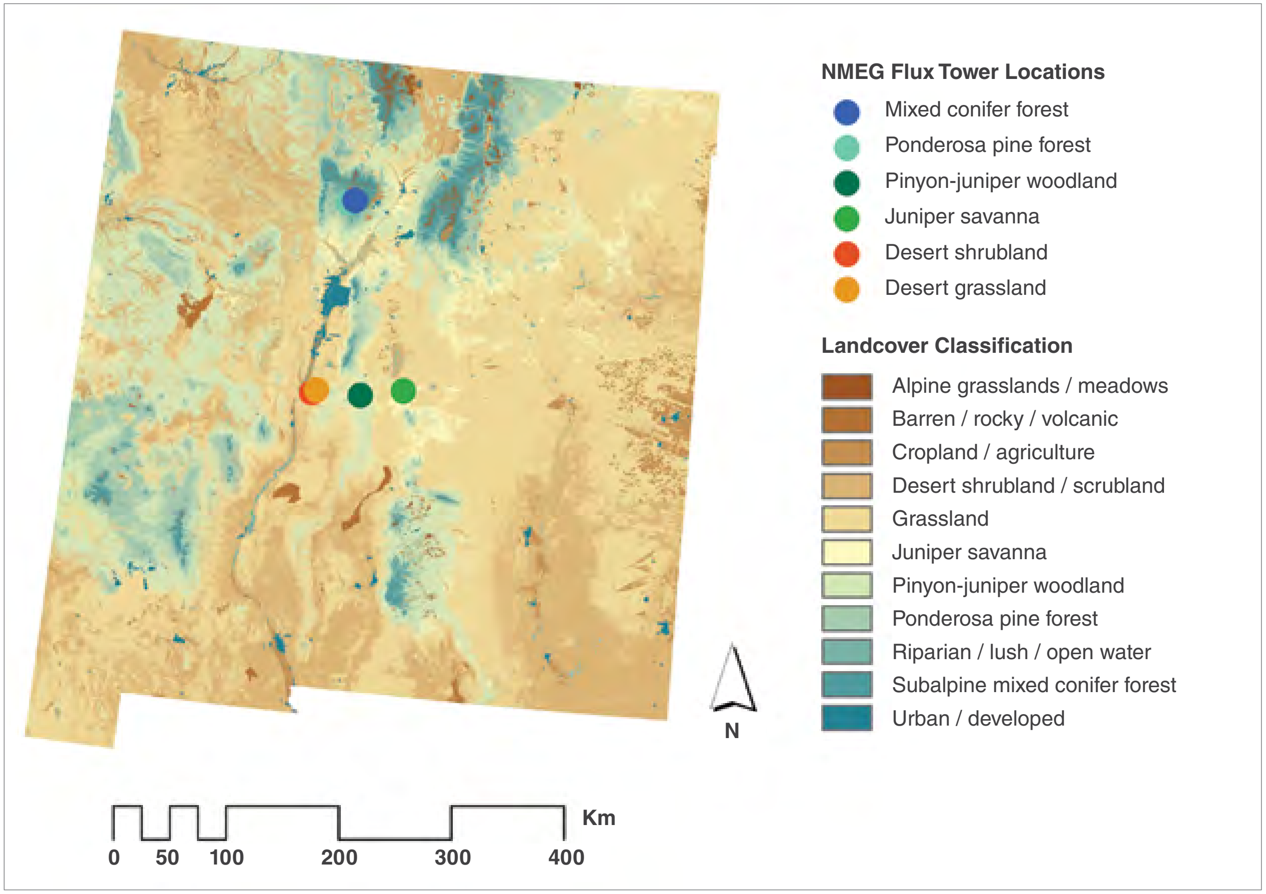
This juniper-covered savanna is one example of a biome in arid New Mexico that includes carbon-sequestering vegetation. (Courtesy K. Anderson-Teixeira)

in carbon dioxide and exhale oxygen. That makes them much less effective at safeguarding carbon, but that is not all.

"What's really interesting to me, and somewhat surprising actually, is how much both the middle and the high elevation sites were storing," Litvak said. They found that these sites, such as pinyon-juniper woodlands and conifer forests, can store anywhere between 150 and 350 grams of carbon per square meter per year. "Compared with eastern U.S. forests, it's true," she said, "the amount of carbon that they take up per square meter is relatively low, but if you look at the extent of these biomes—across the Southwest, the United States, and across the globe—the total amount of carbon that they sequester is amazingly large."

The end of a biome

Unfortunately, trees stressed by drought are easy targets for other threats like beetle infestation. Cooler temperatures in the past not only kept



This map of New Mexico classifies the different types of land cover present throughout the state (rectangles), and shows the locations of monitoring towers maintained by Marcy Litvak and her team. The towers (circles) were placed in six different types of biomes across varying elevations, forming a network called the New Mexico Elevation Gradient or NMEG. (Courtesy D. Krofcheck/M. Litvak/University of New Mexico/United States Geological Survey)

pinyon trees healthy, but also periodically killed off bark beetles in the winter. Anderson-Teixeira said, "If you drive around New Mexico, one of the dominant features of the landscape that you notice is that there's a huge number of dead pinyon pine trees. And then at higher elevations there's been some mortality of other species."

Another complicating factor is that trees like pinyons are especially slow growers. They can take as long as one hundred years to produce cones and can live as long as one thousand years. And though even dead trees continue to store some carbon in their bark, an event like fire quickly releases this carbon into the atmosphere, creating a feedback loop. Litvak said, "So we can ask, all right, how long does it take them to recover? In effect, are we turning those pinyon-juniper woodlands into a juniper savanna after they die?"

That question has led the team to begin recording major disturbances across the sites, like drought and bark beetle infestation. To do so means stockpiling more data. More ground data, combined with satellite and even lidar data from planes are helping them track the quiet processes at work within each biome. Optical satellite imagery from sensors like the Moderate Resolution Imaging Spectroradiometer (MODIS) and Landsat, for instance, are helping them analyze millions of acres of vegetation to tackle carbon balance from a different vantage point.

A crossroads for change

Litvak's ultimate goal is to keep the network going as long as possible. That the sites are clustered across a range of biomes, and are in a small enough area to experience similar weather patterns, makes it is easier to compare how they respond. And that the data are all processed the same way lends confidence to their results. "These are really bellwether biomes for change across this region, because they are so well represented," she said. "So my big take home message would be how crucial it is to keep monitoring them."

To get started, they looked at satellite imagery from the MODIS sensor, made available by the Oak Ridge National Laboratory Distributed Active Archive Center (ORNL DAAC). MODIS vegetation images from the Terra satellite helped them pinpoint where distinct plant communities end and others begin, and where to erect each tower. Financing the effort was a hurdle, not to mention getting permission to erect the semi-permanent towers on various properties, from privately owned ranches to federally owned land. But they are already seeing the rewards of that effort. "What gets me really excited about this," Litvak said, "is that we are able to directly monitor how these biomes are responding. You can actually see the sensitivity of all these biomes."

The team is also gaining more ground, literally. They have managed to expand the network from six to nine towers. And though maintaining the tower network and its suite of instruments is demanding, it will continue to capture and catalog how the Southwest is changing over time. That information will go a long way toward helping scientists understand just how much carbon similar biomes can absorb, both locally and globally. "I don't think anyone knows what's going to happen," Litvak said. "But drought, temperature—these are huge factors that are going to change in a significant way across these ecosystems and we're going to be able to quantify how they are responding."

To access this article online, please visit http://earthdata.nasa.gov/sensing-our-planet/2012/biomes-balance

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About the remote sensing data used

Satellite	Terra
Sensor	Moderate Resolution Imaging Spectroradiometer (MODIS)
Data set	MODIS Vegetation Indices 8-Day L4 Global (MOD15A2)
Resolution	1 kilometer
Parameter	Leaf Area Index (LAI)/Fraction of Photosynthetically Active Radiation (FPAR)
DAACs	NASA Oak Ridge National Laboratory Distributed Active Archive Center (ORNL DAAC) NASA Land Processes DAAC (LP DAAC)

About the scientists

Kristina Anderson-Teixeira is a forest ecologist with the Smithsonian who specializes in terrestrial ecosystem ecology, global change ecology, and sustainability. Her research focuses on understanding how climate shapes ecosystems and how ecosystems in turn regulate climate. NASA supported her research. (Photograph courtesy K. Anderson-Teixeira)

Marcy Litvak is an associate professor of biology at the University of New Mexico. Her research focuses on ecosystem ecology and plant physiology, with a primary focus on investigating how processes that exchange carbon, water, and energy between the land surface and the atmosphere vary across ecological gradients. NASA supported her research. (Photograph courtesy M. Litvak)

For more information

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NASA Oak Ridge National Laboratory DAAC (ORNL DAAC)
http://daac.ornl.gov
Moderate Resolution Imaging Spectroradiometer (MODIS)
http://modis.gsfc.nasa.gov
Kristina J. Anderson-Teixeira
http://www.life.illinois.edu/teixeira/about.html
Marcy Litvak
http://biology.unm.edu/litvak/index.html

Foot and plow

"Land abandonment is transforming Russia from a blanket of human colonization, to more of an archipelago, islands of settlement with nothing in between."

Grigory Ioffe
Radford University

by Katherine Leitzell

Kirsten de Beurs trod out into yet another field, her boots sinking into the soft dark soil. She stopped for a moment to write her Global Positioning System (GPS) coordinates in a lined notebook, then lifted her camera to snap a photo. The lush rows of young green wheat stretched as far as she could see, broken only by the occasional dirt road or wooden shack. Samara Oblast in southern Russia is still the center of the Russian grain belt and one of the most productive farming regions in the country. Yet even here, farmers are raising fewer cattle and leaving some of their fields fallow.

In the spring of 2010, de Beurs and her colleagues were on a road trip of sorts through the Russian countryside, taking copious notes and photographs, and interviewing farmers and officials in farming regions around the country. De Beurs, a geographer at the University of Oklahoma, had come there to study how agriculture is changing. "We know that agriculture in Russia declined in the early 1990s," she said, "but what is happening now?" While the fields in Samara remained productive, many of the fields the team visited in other regions had been abandoned, reclaimed by forests or overtaken by weeds. Just how much land had been left behind? De Beurs said, "It's important for

Geese roam about on a typical farm in the Samara region in Russia. Many farms in Russia are in remote areas hundreds of miles from major cities, and may lack modern amenities such as telephones and television. (Courtesy K. de Beurs) us to understand what is going on in these areas because we want to know how it is going to change in the future." Russia supplies food not only for its own 140 million inhabitants, but also for the rest of the world.

Waves of grain

In the early 1990s, farming changed dramatically in Russia. Where the Soviet government had once determined everything about agriculture, running huge, centralized farms all over the country, farmers were now largely left to their own devices to navigate the new market economy.

"When the Soviet Union collapsed, the whole economic system collapsed, and they pulled back a lot of the subsidies for fertilizers and pesticides and machinery," De Beurs said. "The farmers had to figure out for themselves: is this sustainable?" In many cases, she said, those large farms were neither sustainable nor profitable. The Soviet government had pushed agriculture far beyond the country's most fertile regions, spreading north into inhospitably cold environments, and south into areas with desert-like conditions and bad soil.

After the Soviet Union broke up, many farmers, particularly young people, gave up on their traditional livelihoods. By 1998, crop-farming output was only 56 percent of what it was in 1990, according to geographer Grigory Ioffe. Ioffe has studied Russian agriculture and population for years, first in the Soviet Union and now as a professor of Geography at Radford University in Virginia. He said, "In areas which are far from the major urban cores, the population has been leaving in droves. At some point lands would be abandoned because there is nobody to work that land." The left-behind fields were overgrown by weeds or conquered by the surrounding forest. In 2006, Ioffe and colleagues estimated that 20 to 30 million hectares of farmland had been abandoned in European Russia, the area west of the Ural Mountains.

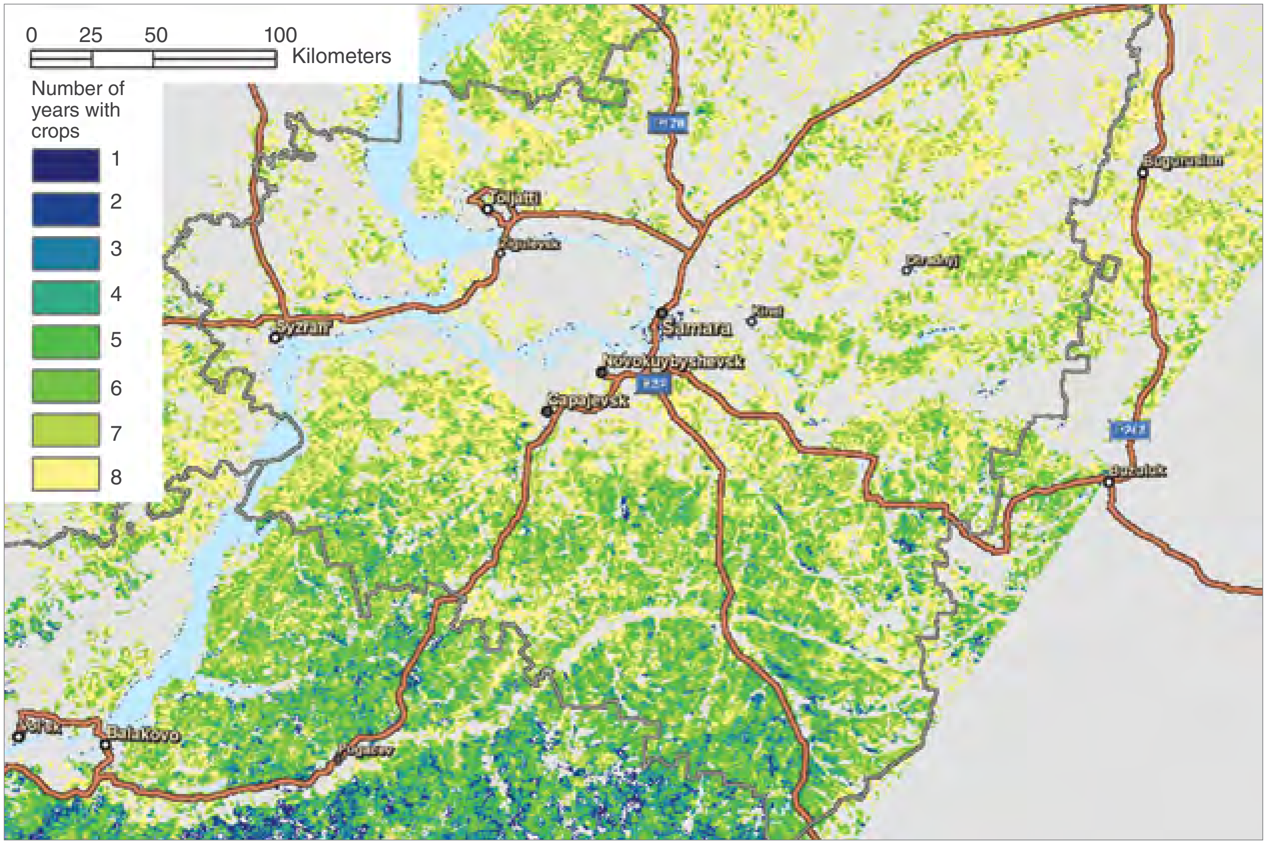
Russia provides much of the grain in the global food market, and the country became an even more important grain producer after cattle farming dramatically declined in the early 1990s. But a continued decline in agriculture could threaten food availability around the world, especially in poor regions that rely on cheap grain from large producers like Russia. Some initial research in the early 2000s suggested that farming was starting to recover. But in such a large country, it is difficult to say exactly how farming is evolving. And what will happen in the future as the country deals with a mobile population and a changing climate that could bring more challenges to farmers? Researchers expect climate change to lead to more droughts and wildfires that may prove damaging to crop production.

Abandoned lands

De Beurs invited Ioffe to work together to address the looming questions about agriculture in Russia, combining Ioffe's expertise in Russian agriculture with de Beurs' remote sensing background. While fieldwork would give the researchers a first-hand view of the situation, an exhaustive field study would be impossible to manage over Russia's vast countryside. De Beurs thought that remote sensing could provide another window into agriculture in fast-changing areas of Russia.

The two researchers outlined a project that looked at four different areas in Russia: the northern region of Kostroma, the southern region of Stavropol, and two middle-latitude areas called Chuvash and Samara. They visited each area during the summer of 2010 and the fall of 2011, along with colleague Tatyana Nefedova, a researcher at the Russian Academy of Sciences in Moscow. The team talked to farmers, agricultural officials, and other experts in the area to gain a local perspective on farming. They took photographs of fields and farms, noting where fields had been left vacant and taken over by weeds, and where farmers were growing crops year after year. And they collected any available statistics for the regions of their study. De Beurs said, "We did a ton of interviews. We spoke with whoever we could find who could tell us something about agriculture in the region."

Kirsten de Beurs (left), Tatyana Nefedova (center), and Grigory Ioffe (right) photograph a grassland in Samara Oblast in Russia. (Courtesy K. de Beurs)



This map of the Samara region uses the NASA Moderate Resolution Imaging Spectroradiometer (MODIS), Landsat, and field studies to locate where crops were grown and for how many years. Blue areas show land that was cropped for one year, while green and yellow show land that was cropped for multiple years during the study from 2002 to 2009. Beige areas indicate locations where crops were not grown. Gray indicates where satellites did not collect data. (Courtesy K. de Beurs)

But just looking at fields and talking to people did not tell them everything they needed to know. The areas were vast, and the local agricultural data were sometimes sparse. In addition, De Beurs said, "There has been a push from the government to bring some agricultural areas back into production." So sometimes, farmers would bring an unused area back into production, but then do not use it every year, giving the appearance of greater production, but growing no more crops than before.

Satellite data added another layer of information about what was really happening on the ground, and allowed the researchers to look at changes over a longer period, from 2002 to 2009. De Beurs said, "What we were after is where there are crops and where there are no crops. In addition, we want to know for every year, is the land cropped or not?" She accessed vegetation data from the NASA Moderate Resolution Imaging Spectroradiometer (MODIS) instrument archived at the Land Processes Distributed Active Archive Center (LP DAAC), and land cover data from the joint NASA–U.S. Geological Survey Landsat satellite. MODIS can sense vegetation greenness, indicating the start and end of the growing season, while the Landsat data help to classify land into different land-cover types such as forest or prairie. With those two data sets, de Beurs could classify and compare broad swaths of land year by year.

De Beurs and Ioffe are now working to make sense of the data. Their preliminary analysis showed a few trends, for example that farmlands in southern regions and near cities were doing better than more remote areas, such as Kostroma to the north. Ioffe said, "In Russia, the quality of life depends upon proximity to a large city. The closer you are, the better the quality of life." Farms in remote parts of Russia remain cut off from many of the luxuries of modern life, lacking reliable roads and plumbing.

Whether farmers stick to their land also depends on tradition and culture, the researchers found. For example, the Tatar ethnic group, a significant minority group in the Samara region, has held on to farming to a greater extent than many of their neighbors. Ioffe said, "The tenacity with which some people are holding onto land despite the general trends is really surprising. Some people are continuing to do crop farming or animal husbandry in desperate circumstances."

Feeding Russia and the world

The researchers say that changing populations and agriculture are transforming the Russian countryside into something new. But the results of those changes remain hard to predict. Ioffe said, "Land abandonment is transforming Russia from a blanket of human colonization, to more

About the remote sensing data used

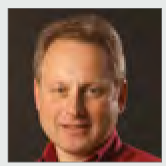
Sensors	Terra	Terra	Terra
Satellites	Moderate Resolution Imaging Spectroradiometer (MODIS)	MODIS	MODIS
Data sets	Nadir Bidirectional Reflectance Distribution Function (BDRF) Adjusted Reflectance (NBAR)	Normalized Difference Vegetation Index (NDVI)	Land Surface Temperature (LST)/Emissivity
Resolution	500 meters	500 meters	1,000 meters
Parameters	Reflectance	Vegetation	Land surface temperature
DAACs	NASA Land Processes Distributed Active Archive Center (LP DAAC)	NASA LP DAAC	NASA LP DAAC

of an archipelago, islands of settlement with nothing in between. This is a crucial change in a significant part of northern Eurasia, and it affects the ecology, environment, and Russia's ability to feed itself." It also affects how much food Russia provides for the rest of the world. In addition to producing food for its own people, Russia is a major player in the global food economy. That became vividly clear in the summer of 2010, when seven people were killed in food riots in Mozambique after grain shortages in Russia caused the price of bread to rise more than 30 percent in just a couple of weeks.

To access this article online, please visit http://earthdata.nasa.gov/sensing-our-planet/2012/foot-plow

About the scientists

Kirsten de Beurs is an assistant professor of geography at the University of Oklahoma. NASA and the Northern Eurasia Earth Science Partnership Initiative (NEESPI) supported her research. (Photograph courtesy K. de Beurs)



Grigory Ioffe is a geographer who focuses on agricultural issues in Russia. He works at Radford University in Virginia. NASA and the Northern Eurasia Earth Science Partnership Initiative (NEESPI) supported his research. (Photograph courtesy G. Ioffe)

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NASA Land Processes Distributed Active Archive Center (LP DAAC)
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Moderate Resolution Imaging Spectroradiometer (MODIS)
http://modis.gsfc.nasa.gov

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Orbiting watchtowers

"When FIRMS gives us evidence of a fire and its exact coordinates, that is very valuable information."

Rafael Manzanero
Friends for Conservation and Development

by Natasha Vizcarra

When Rafael Manzanero checks his e-mail from the remote village of San Jose Succotz in Belize, he scans his inbox for the words "fire alert" and "NASA." The e-mails appear in his inbox three hours after NASA's Terra and Aqua satellites sense fire in the Chiquibul National Park. Manzanero heads a nonprofit that watches over the park, the largest protected forest in Belize and home to the biggest Mayan archaeological site in the country. Oceans away, researcher Veerachai Tanpipat also watches out for such e-mails from his office in the busy city of

Resource manager Rafael Manzanero stands atop the great temple at Caracol Archaeological Reserve, located inside the Chiquibul National Park. (Photograph by J. Houston courtesy Rare)

Bangkok. Tanpipat helped the Thai government monitor forest fires that blanketed the city of Chiang Mai in dense haze in 2007.

Manzanero and Tanpipat are among thousands of subscribers to the NASA Fire Information for Resource Management System (FIRMS), which uses remote sensing and geographic information systems (GIS) to help managers of protected areas respond faster to fires. While the technology helps Manzanero and Tanpipat keep an eye on vast and remote forests in their countries, they are also uncovering a tension between forest conservation and an old way of farming that wildlands can no longer support.

Under the shade, I flourish

In Belize's Chiquibul National Park, towering broadleaf trees like the Nargusta, the Santa Maria, and the mahogany grip the Earth with thick, buttressed trunks. Their canopies grow so dense that only mild rays of sunlight break through to the ground. Belize's flag bears the image of such a tree, and the words *Sub umbra floreo*, or "Under the shade, I flourish." Manzanero oversees Friends for Conservation and Development (FCD), which helps the government manage the 264,000-acre park and the extensive cave system underneath it. "The words symbolize the importance of Belize's timber resources to the country's early colonists," Manzanero said.

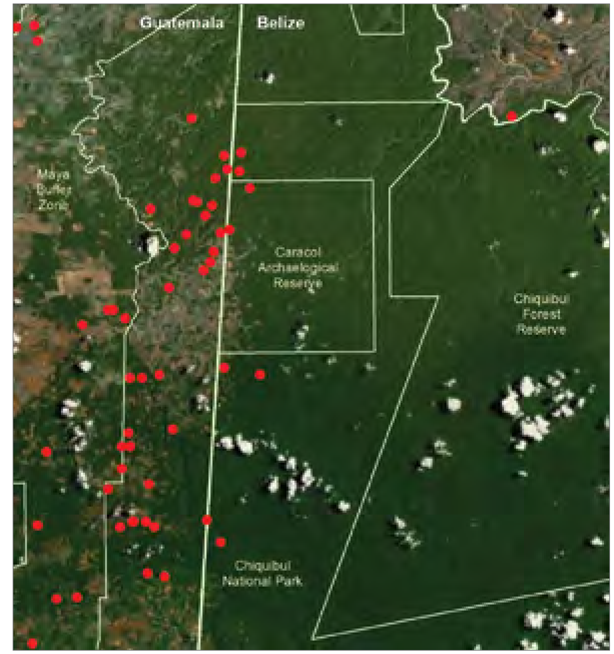
The slogan also explains quite succinctly why Belize's rainforests are so special—the forest and its wildlife literally flourish under the shade. Below the canopies, shrubs and small plants thrive in the understory. Because the forest is so moist, the climate so temperate, and the tree canopies so thick, it is not prone to naturally-caused fires. Drier forests elsewhere in the world are vulnerable to lightning, spontaneous combustion, or even sparks from rock falls. "Any fire in the Chiquibul would have likely been caused by humans," Manzanero said.

Fire in the Chiquibul is very bad news. "It causes a domino effect of changes in the ecosystem and opens the area to other illegal activities," Manzanero said. When Manzanero gets an e-mail from FIRMS about fire in the park, he worries not just about the fire burning uncontrolled. He also worries about the fire razing through ancient Mayan monuments, or worse, sparking territorial conflict with neighboring Guatemala. "Nationals from Guatemala illegally cross the Belize border and hack away at the forest," Manzanero said. Trespassers take animals and ornamental plants to sell on the black market, and steal artifacts from the Caracol Archeological Reserve, a Mayan site deep within the Chiquibul, and from forty miles of cave passages that wind up in Guatemalan territory. "When the dry season arrives they set fire to the cuttings and plant black beans, pumpkins, and corn," Manzanero added.

Furtive farming

Manzanero was describing an old agricultural practice called slash and burn. Subsistence farmers cut young trees and plants just before the dry season and burn the dried "slash" just before the rainy season. Then they plant directly in the ash-covered and nutrient-rich soil and hope for a kind season of rain to water their crops.

Unfortunately, slash and burn farming destroys forests and encroaches on Belize's protected areas. When a cleared area stops giving farmers a good yield of crops, the farmers move on and



This image from the NASA Fire Information for Resource Management System (FIRMS) shows hotspots or possible fires, indicated in red, in the Chiquibul National Park near the Guatemalan border. Park officials and conservationists used this map and the hotspot coordinates to validate fires, which had been set by slash and burn farmers crossing the border. (Courtesy FIRMS/map by M. Wong)

clear a new part of the forest. The abandoned fields take a long time to heal, and the practice gouges huge holes in the forest canopy. "A broken tree canopy disturbs the Chiquibul's delicate and moisture-dependent ecosystem," Manzanero said. "A burnt area takes forty to forty-five years to recover and it would probably never grow the same kind of forest cover."

In 2008, Manzanero signed up for FIRMS fire alerts, paying special attention to part of the park close to the Guatemalan border. "When the dry season begins in February, I get e-mails about hotspots, or areas of possible fires," he

This image from the Fire Information for Resource Management System (FIRMS) Web Fire Mapper shows hotspots on March 8, 2007, in eastern Myanmar, northern Thailand, and western Laos. The fires brought low-lying haze to Thailand which lingered for two months. (Courtesy Web Fire Mapper, FIRMS, NASA LANCE)

said. FIRMS hotspots need validation. When a satellite senses intense heat and radiation on the ground, it cannot tell if it is a fire or just hot metallic rocks, but it will tag the area as a hotspot. In the Chiquibul, hotspots are often reported in remote areas, far from forest trails. When it looks too difficult to reach on foot, the park manager sends a plane to check it out. "Whenever our people conduct surveillance near the Guatemalan border, they are vulnerable to situations of threat and danger," Manzanero said. "So when FIRMS gives us evidence of a fire and its exact coordinates, that is very valuable information."

Trial by fire

In Thailand, Tanpipat faced challenges similar to Manzanero's. Slash and burn farmers were illegally planting crops in protected parks, but the fires caused a totally different set of problems. When fires razed forests in northern Thailand in 2007, Tanpipat worked as a government consultant and had just finished setting up fire alerts for Thailand's forest parks. News reports said farmers and Pak-wan tree and mushroom gatherers who were clearing brush and plants caused the fires.

Unfortunately, a weather phenomenon trapped the smog right over Chiang Mai, the largest city in northern Thailand, making a lot of people sick. Tanpipat said, "It wasn't a normal year and it was very hot. High air pressure over China caused air to sink over northern Thailand, trapping the smoky air. The smoke just hung over northern Thailand for two months." It was so bad in some areas that people could not see past half a mile. An air quality measurement of 120 micrograms per cubic meter of particulates is considered hazardous to humans. When measurements hit 240 and 290 micrograms per cubic meter, the number of people admitted to hospitals for respiratory problems surged by 20 percent.

"The Thai government set up a war room where FIRMS hotspots data played an important role," Tanpipat said. "A fire situation report based on FIRMS data was presented to the Deputy Prime Minister and his decision-making team every day." The data helped officials decide which fires to respond to and who could get there the fastest. Members of the fire monitoring team were signed up for the e-mail alerts, especially those who worked in the field. "The rains finally came two months after the fires started and that released the smog that was trapped over Chiang Mai," Tanpipat said. By that time, the Thai media had written so much about hotspots that ordinary people in Thailand knew what these were.

Alerts on fire

Manzanero's and Tanpipat's stories are not unique. According to the United Nations Global Fire Monitoring Center, humans cause the majority of the world's forest fires. Although it is not clear how many acres of forests are lost to slash and burn, it is known that about 250 million people practice it worldwide. In addition, people burn acres of forests for grazing and hunting. FIRMS fire alerts currently help natural resource managers, policy makers, and scientists protect forests from slash and burn farming, and other causes of fire, in over 120 countries.

The Aqua and Terra satellites carry the Moderate Resolution Imaging Spectroradiometer (MODIS) instrument, which was originally designed for Earth science research, but has proven to detect many other surface features, including the thermal signal of a fire. FIRMS project manager Diane Davies said, "FIRMS transitioned from serving the NASA community to serving a global community. In this sense, this is a success story." This success included getting the data quickly to users and in a way that was practical for them. Davies said, "We know that many of our users have poor internet access. This was the main reason we developed the e-mail alert service." Davies used to monitor fires in Namibia's Etosha National Park using satellite data and knew how hard it was to access remote sensing data from the field. She helped develop the first version of the FIRMS fire alerts for protected areas in Bolivia, Madagascar, Namibia, Paraguay, and South Africa. Since FIRMS was launched in January 2007, subscribers to the fire alerts have grown from 580 to 4,064. The United Nations Food and Agriculture Organization (FAO) began offering FIRMS data in 2010 through its Global Fire Information Management System (GFIMS) Web site.

Like Manzanero and Tanpipat, subscribers are discovering that the fire alerts highlight other aspects about human life affected by the fires. Subscribers use the alerts to educate farmers about the environmental impacts of fire, create fire maps for decision-makers and the general public, and to improve air quality studies. Subscribers have even used them to keep an eye on humanitarian situations. Using a fire as a proxy for conflict situations, policymakers monitored possible "genocide fires" in the Darfur region of Sudan. "Our goal is to get fire information into the hands of users so it can be used for informing decisions," Davies said.

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About the remote sensing data used

Satellites	Terra and Aqua
Sensor	Moderate Resolution Imaging Spectroradiometer (MODIS)
Data sets	Level 2 Fire Product MOD14 (Terra), MYD14 (Aqua)
Resolution	1 kilometer
Parameters	Fire and thermal anomalies
Data access	NASA Earth Data Web site

About the scientists

Diane Davies is the program manager for the NASA Fire Information for Resource Management System (FIRMS). Her research interests focus on making satellite data easily accessible to users. She has a master's degree in land resource management from Cranfield University and a degree in geography from Nottingham University, both in the United Kingdom. NASA funded her research. (Photograph courtesy D. Davies)

Rafael Manzanero is the executive director of Friends for Conservation and Development in Belize. His research interests are environmental ethics, protected areas management, and environmental education. Manzanero has a degree in forestry and conservation from the University of Montana in Missoula. (Photograph by J. Houston, courtesy Rare)

Veerachai Tanpipat is a remote sensing and geographic information system consultant at the Hydro and Agro Informatics Institute. His research interests include forest fire detection and flood monitoring. He has a degree in remote sensing and geographic information systems from the Asian Institute of Technology in Thailand. (Photograph courtesy V. Tanpipat)

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http://earthdata.nasa.gov/firms

United Nations Food and Agricultural Organization Global Fire Information Management Systems (GFIMS)
http://www.fao.org/nr/gfims/en

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NASA's view from space reveals our dynamic planet