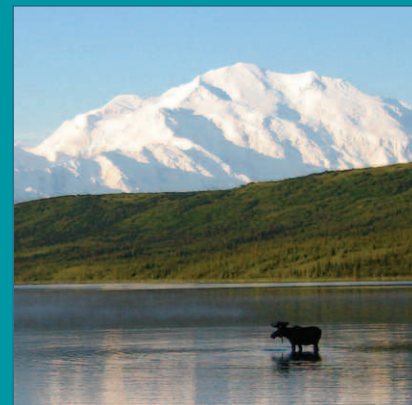
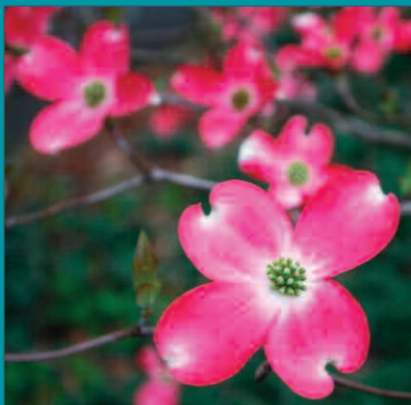


Sensing Our Planet



Sensing Our Planet

NASA Earth Science Research Features **2009**

National Aeronautics and Space Administration

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

Front cover images

Top row, left to right:

A man walks through the Acropolis while smoke plumes billow from a forest fire near Athens on July 25, 2007. More than 3,000 forest fires burned in Greece that summer, mostly in areas where there were no ground instruments to observe the impact of the smoke on air quality. See the related article, “Smoke over Athens,” on page 46. (Courtesy V. Berger)

Students in Kirsten de Beurs’ Remote Sensing and Phenology class observed the trees on campus for phenological events, such as the bloom of this dogwood tree. They compared these field observations to satellite vegetation data to obtain a broader and more accurate interpretation of these start-of-season signals. See the related article, “Notebook and satellite,” on page 42. (Courtesy A. R. Laurent)

This aerial photograph shows a small section of the sprawling boreal forests in the Karelia Republic, Russia. Much of this mosaic of forests, lakes, rivers, and wetlands, dominated by spruce trees, is virgin forest. However, the region is rapidly changing because of logging. See the related article, “Finite forests” on page 20. (Courtesy V. Kantor)

When most people think of Alaska, they imagine glacier-capped mountains such as Mount McKinley, the peak in this photograph. But shallow lake wetlands occupy nearly half of Alaska’s landmass, providing critical habitat for moose, muskrats, beaver, and waterfowl. See the related article, “Drying in Denali,” on page 38. (Courtesy T. O’Dea)

Bottom row, left to right:

The ocean food web is filled with little-known varieties of fish and marine animals; here, a black and yellow rockfish swims in Monterey Bay, California. See the related article, “An ocean full of deserts,” on page 30. (Courtesy J. Pederson)

This maize in Zimbabwe appears to be thriving in its early stages, but its grain yield will depend on proper timing of rains. See the related article, “Distant fields of grain,” on page 2. (Courtesy C. Reynolds, United States Department of Agriculture, Foreign Agricultural Service)

The eruption of Chaitén Volcano in Chile in May 2008 triggered dramatic lightning displays, illuminating the ash and smoke plume. Until this day, Chaitén had been inactive for thousands of years. See the related article, “Experiment in the sky,” on page 24. (Courtesy C. Gutierrez/UPI)

Back cover images

Top row, left to right:

Piles of sardines await buyers in a market near Lake Tanganyika. Thousands of people in East Africa depend on fish from the lake for protein. However, fish catches in Lake Tanganyika are declining because of the effects of global climate change on the lake. See the related article, “A catalog of change,” on page 52. (Courtesy C. O’Reilly)

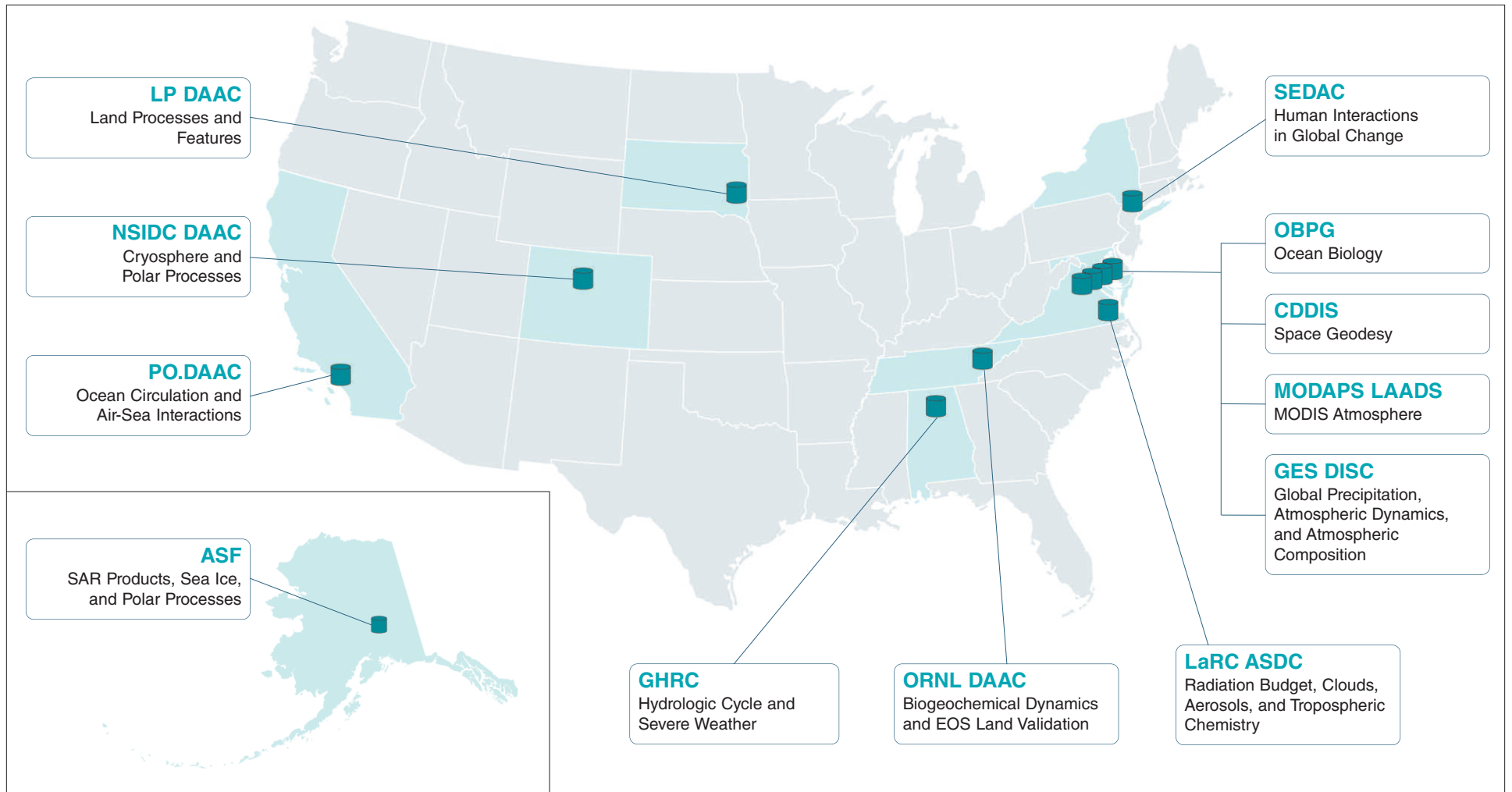
Atlantic leatherbacks are the largest species of sea turtle. While they have few natural predators, they often become entangled in fishing nets and drown. Leatherbacks were declared critically endangered in 2000. See the related article, “The mysterious lives of leatherbacks,” on page 16. (Copyright H. Segars)

Bottom row, left to right:

A view from an airplane window reveals some of the pollution that smothers the Arctic each spring and summer. Instruments on board the airplane collected data from the smoke plume, generated by a forest fire over Canada on July 1, 2008. See the related article, “Probing the Arctic atmosphere,” on page 34. (Courtesy NASA)

An artistic rendering shows that Earth’s rotation has dragged space-time with it. A particle dropping from infinity towards the center of the planet would not fall in a straight line; it would be dragged along a curved path. In the foreground, the Laser Geodynamics Satellites (LAGEOS) spin in an orbit high above Earth. In the background, the Gravity Recovery and Climate Experiment (GRACE) satellites pass over Earth; their data have revealed the detail in Earth’s gravitational field, shown as color relief on the surface. Warmer colors indicate stronger gravity, and cooler colors indicate weaker gravity. See the related article, “A snag in space-time,” on page 6. (Courtesy F. Ricci and I. Ciufolini, globe by GFZ Potsdam)

The surface above Lake Vostok, hidden under more than a kilometer of ice, looks like most of Antarctica’s landscape—flat, barren, and icy. The best way to detect a subglacial lake is through remote sensing. See the related article, “Fathoming Antarctica,” on page 10. (Courtesy M. Studinger, LDEO)



About the EOSDIS data centers

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

For more information about the EOSDIS data centers, see "About the NASA Earth Observing System Data Centers" on page 56, or visit the NASA Earth System Science Data and Services Web site (<http://nasadaacs.eos.nasa.gov>). For more information about ESDIS and EOSDIS, visit the NASA Earth Science Data and Information Project Web site (<http://esdis.eosdis.nasa.gov>).

About *Sensing Our Planet*

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

Articles and images from *Sensing Our Planet: NASA Earth Science Research Features 2009* are available online at the NASA Earth System Science Data and Services Web site (<http://nasadaacs.eos.nasa.gov/articles/index.html>). A PDF of the full publication is also available on the site.

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

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



The icon featured in this issue represents a humpback whale, living deep in the ocean. Several articles for 2009 explore hidden and often mysterious features of Earth and its life. See “Fathoming Antarctica,” page 10; “The mysterious lives of leatherbacks,” page 16; and “An ocean full of deserts,” page 30.

Acknowledgements

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

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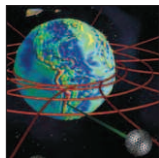
NASA Earth Science Research Features **2009**



Distant fields of grain

Remote estimates of crop yields help international aid agencies decide how to act.

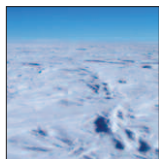
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A snag in space-time

Astrophysicists use Earth science satellites to explore general relativity.

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Fathoming Antarctica

Lakes hidden under the Antarctic ice sheet may play a role in its stability.

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The mysterious lives of leatherbacks

Knowing how leatherback sea turtles migrate could keep them safer.

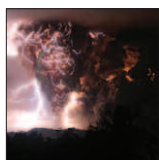
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Finite forests

Remote sensing proves ideal for watching rapid changes to Russia's remotest forests.

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Experiment in the sky

A train of satellites follows the atmospheric effects of a volcanic eruption.

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An ocean full of deserts

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Probing the Arctic atmosphere

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Drying in Denali

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Notebook and satellite

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Smoke over Athens

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A catalog of change

Researchers assemble a picture of climate change impacts around the world.

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Distant fields of grain



“When you are trying to get people to spend money or act, you need clear information.”

Chris Funk

University of California
at Santa Barbara

by Jane Beitler

From his Santa Barbara office, geographer Chris Funk is trying to watch ears of maize in Zimbabwe fill with kernels. Funk knows that years of drought and turmoil in Zimbabwe make it urgent to know exactly how well crops are growing there. As of February 2009, an estimated seven million people in Zimbabwe faced serious food shortages, many surviving on

just one meal per day. Zimbabwe’s once-thriving agricultural production had fallen by more than half, and both political upheaval and drought contributed to the prospects of widespread hunger. The unraveling of the agricultural system also made it difficult to get good estimates of crop production. Funk said, “Governmental numbers don’t really exist. As a result, there were different ideas about the level of crop production in Zimbabwe.”



Zimbabwe farmers lay out maize to dry after harvesting it on their community-run farm. Drought and political turmoil have threatened food supplies in Zimbabwe in recent years. (Courtesy K. Holt, HelpAge International)

But organizations poised to send famine-mitigating aid need clear and early answers to questions about food security. Funk and his colleague, geographer Michael Budde, are helping provide that clarity, with a breakthrough in the accuracy of satellite data in estimating crop production. Funk said, “When you are trying to get people to spend money or act, you need clear information. Remote sensing is a visually compelling way of showing how crops are performing.”

A hunger for knowledge

Zimbabwe depends on its own farms in ways that many nations have forgotten. In the United States, grocery stores are always well stocked; our supply chains stretch around the world, so affordable imports can replace local shortfalls. But in Zimbabwe, the food supply chain is not so resilient. Once one of Africa’s breadbaskets, Zimbabwe now has many farms lying fallow after struggles over farm ownership. Other segments of the economy are in tatters as well, limiting the ability to shift to imported food supplies. A failure of Zimbabwean crops means that citizens will face severe food shortages and inflated prices. Add on Zimbabwe’s inflation rate, exceeding 10,000 percent, and it becomes a recipe for hunger.

Funk and Budde are studying Zimbabwean food issues as part of an interagency effort on world food security. Funded by the United States Agency for International Development (USAID), the project includes several partners, including NASA and the United States Geological Survey (USGS), with which both Funk, at the University of California at Santa Barbara, and Budde, at the USGS Earth Resources Observation and Science (EROS) Center, are affiliated. Not so long ago, outsiders became aware of a nation’s food crisis only when

it had reached a dire stage: images of starving children flooded the news, as well as images of aid workers struggling to send relief in time. Satellites are among the technologies that now help people determine ways to intervene earlier, and in a more targeted manner. More than ten years ago, Funk worked on his first project to study crop production in southern Africa, using satellite data. Funk said, “I got hooked on the idea of using satellite information to help people in the developing world.”

Funk knew how valuable data from the sky could be when the situation on the ground was tumultuous. He persisted in digging into the variables of climate, weather, plant growth, and time, sure that there must be a way to remotely estimate yields of staple crops like maize and wheat. Funk said, “We thought that the Moderate Resolution Imaging Spectroradiometer [MODIS] sensor with its high-resolution data was a great resource that had yet to be used routinely in Africa.” In the end, Funk and Budde solved the complexities of satellite crop estimates by making the problem simpler.

A matter of rain and time

The climate and weather of Zimbabwe, in southeast Africa, lie under the influence of the Indian Ocean to the east. Most years, easterly trade winds bring heavy summer rains from October to April. Some years, winds flow more southward, drawing that moisture away from southern Africa.

Previous work had compared rainfall and plant health. Satellites orbiting over Africa can measure energy reflected from vegetation, resulting in measures of plant health such as the Normalized Difference Vegetation Index (NDVI). Researchers worked for years to take the leap to

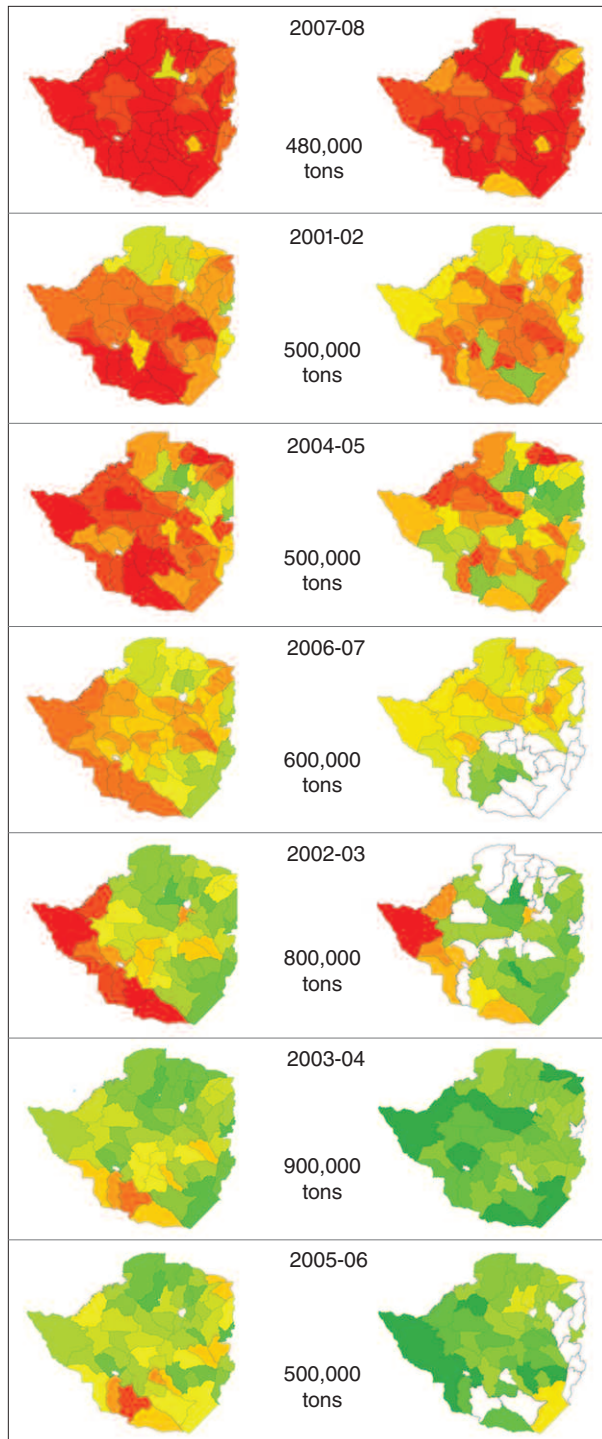


This maize in Zimbabwe appears to be thriving in its early stages, but its grain yield will depend on proper timing of rains. (Courtesy C. Reynolds, United States Department of Agriculture, Foreign Agricultural Service)

crop production estimates from rainfall and NDVI data. Satellite and ground data showed a tantalizing relationship, but remote sensing alone could not estimate crops.

Funk and Budde thought the answer would be not in season averages, but well-timed samples. Maize needs a certain amount of water at each phase of development, especially early season growth and grain filling. Funk said, “One of the reasons it’s tricky is that there are two stages. First, in the vegetative stage, plants emerge and put out a lot of leaves. That ‘greenness’ is not really related to the amount of cereal they produce in the end.”

Funk and Budde used the life cycle of maize to take a new look at rain and vegetation data. Farmers plant in hopes of rain, and the seed



waits. Rains come and swell the seed, and even more rains let the water-thirsty maize fill their ears with kernels. How would the researchers know, on the other side of Earth, when the growing season really started?

Satellite rainfall estimates helped them pinpoint early growth. These estimates, provided by the National Oceanic and Atmospheric Administration (NOAA) to USAID, use data from a complex ensemble of NASA, NOAA, and European satellites. Budde said, “We looked at each pixel of rainfall data, and when 25 millimeters [0.98 inch] of rain fell in a ten-day period, then we looked for a subsequent 20 millimeters [0.79 inch] in the next twenty days.” This start-of-season approach helped them unlock the information in the NDVI data: the two scientists could then look ahead in the vegetation data for the next growth stage and get NDVI measures of how well the maize was faring. Funk said, “We use some pretty simple thinking about how plants grow to find the right time to look at the NDVI. We think the crop started growing here, then we jump forward a couple of months in time.” By checking in at each critical stage of plant development, they had a much more accurate picture of the plants’ success. They also worked hard to make the data as clean as possible.

These map pairs compare maize production estimates for Zimbabwe over seven growing seasons, sorted from lowest- to highest-production years. The maps illustrate the variability in production from year to year. The poor 2007 to 2008 season stands out as one of the worst years in the series. Maps on the left use greens and reds to indicate higher and lower estimates respectively, from the phenologically-sensitive Normalized Difference Vegetation Index (NDVI) sum analysis. Maps on the right show anomalies, with greens and reds indicating above and below average NDVI sums. Production numbers in tons are from ground-based estimates. (Courtesy C. Funk)

The researchers looked back at years of NDVI data, captured by MODIS and distributed through the NASA Land Processes Distributed Active Archive Center. Funk said, “First we created a time series for each district in Zimbabwe for the seven and a half years we had data, using satellite rain data to decide the start of season date for each year. Then we jumped forward in the future and looked at NDVI for a thirty-day period. It really does simplify the problem.” Now rain and time and vegetation could be entered into an equation that would produce a crop estimate from remote sensing data.

Problem presents opportunity

Funk and Budde responded to United States government calls during the 2006 to 2007 season for inputs on Zimbabwean crop production. Drought was causing aid groups to pay closer attention to Zimbabwe’s food supplies, already complicated by national unrest. Funk and Budde were ready to put their crop estimates on the table for comparison with other analyses. Funk said, “The NASA data providers completed special processing so we could get data in a timely fashion.”

The results were as they had hoped. Their crop estimates were close to figures on the ground, and closer than the seasonally averaged NDVI that had until now been the best approximation for crop production. Budde said, “Our analysis contributed to a clear picture of the situation in Zimbabwe: a 55 percent shortfall in production. This information led to an appropriate and timely international request for aid in 2007.”

The following season provided an even more challenging test of their approach. Again during the 2007 to 2008 season, Zimbabwe experienced

drought. But this time, when seed distribution delays forced many farmers to plant late, Funk and Budde used ground information to help establish the start of the growing season for their analysis. The scientists were able to replicate the lower yields of the late-planting districts, which were off-timed with the rainy season. The season demonstrated the flexibility and accuracy of their method, which in turn increased confidence in the data for groups planning aid.

Information for action

Budde and Funk continue watching crops in Zimbabwe and other struggling nations around the world, recently completing a study of winter wheat production in Afghanistan. They make their results available through the Famine Early Warning System Network (FEWS NET), which collects data from many sources to construct the clearest picture of food security in nations at risk.


Budde said, “We’re studying very large areas that lack good ground information. We throw our hat into this ring: here’s our estimation, does that fit with others? If all the evidence points towards a certain situation, it is more likely to be true.” Funk added, “You’re making decisions. People might put food on a boat and ship it over. If you make the wrong call it can be devastating; unnecessary food aid can cause crop prices to drop, punishing farmers and creating a disincentive for development and investments in agriculture. You want to try to get the answer right.”

To access this article online, please visit http://nasadaacs.eos.nasa.gov/articles/2009/2009_crops.html.




About the remote sensing data used	
Satellite	Terra
Sensor	Moderate Resolution Imaging Spectroradiometer (MODIS)
Data set	MODIS Vegetation Indices 16-Day (MOD13A1)
Resolution	500 meter
Parameters	Normalized Difference Vegetation Index (NDVI) and Enhanced Vegetation Index (EVI)
Data center	NASA Land Processes Distributed Active Archive Center

About the scientists



Michael Budde is a geographer at the United States Geological Survey Earth Resources Observation and Science Center (USGS EROS). He specializes in satellite remote sensing applications for monitoring vegetation dynamics, surface energy balance, and other landscape processes to support early warnings of food insecurity in the developing world. USAID funded his Zimbabwe research. (Photograph courtesy M. Budde)



Chris Funk is a senior research geographer with the USGS EROS, and a collaborator with the Climate Hazard group within the University of California, Santa Barbara Geography Department. His research focuses on drought monitoring and food security analysis for Africa, including early warning applications using remote sensing, rainfall modeling and prediction, and climate change and agricultural development analyses. USAID funded his Zimbabwe research. (Photograph courtesy S. Barattucci)

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Funk, Chris. 2009. New satellite observations and rainfall forecasts help provide earlier warning of African drought. *The Earth Observer* 21(1): 23–27.

Funk, Chris, and Michael E. Budde. 2009. Phenologically-tuned MODIS NDVI-based production anomaly estimates for Zimbabwe. *Remote Sensing of Environment* 113: 115–125.

British Broadcasting Corporation: Zimbabwe <http://www.bbc.co.uk/topics/zimbabwe>

British Broadcasting Corporation News: Zimbabwe in facts and figures <http://news.bbc.co.uk/2/hi/africa/7304635.stm>

For more information

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

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

Famine Early Warning Systems Network (FEWS NET) Zimbabwe food security update, February 2009 http://www.fews.net/docs/Publications/Zimbabwe_2009_02%20final.pdf

A snag in space-time

“To approach Einstein’s general theory of relativity, you have to change the way you think. It touches the imagination.”

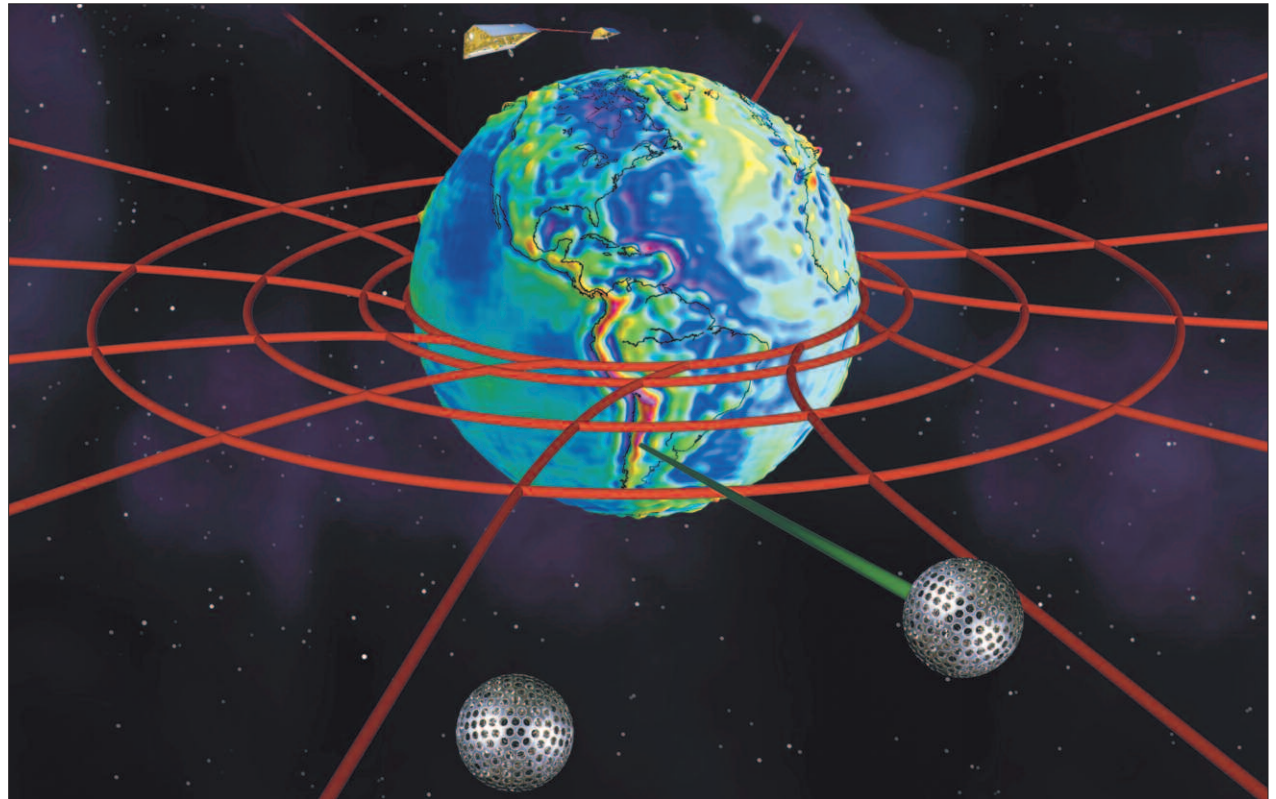
Ignazio Ciufolini
Università del Salento

by Stephanie Renfrow

Einstein’s general theory of relativity is a bit like a handle attached to a very large and mysterious object; when you grab on to the handle and tug, a whole bunch of unexpected possibilities come along with it. Ignazio Ciufolini, an astrophysicist who specializes in general relativity, said, “To

approach Einstein’s general theory of relativity, you have to change the way you think. It touches the imagination.”

Einstein’s theory helps provide a framework for physicists who have dedicated their careers to exploring questions that capture the human imagination: Can time flow backwards? Is the



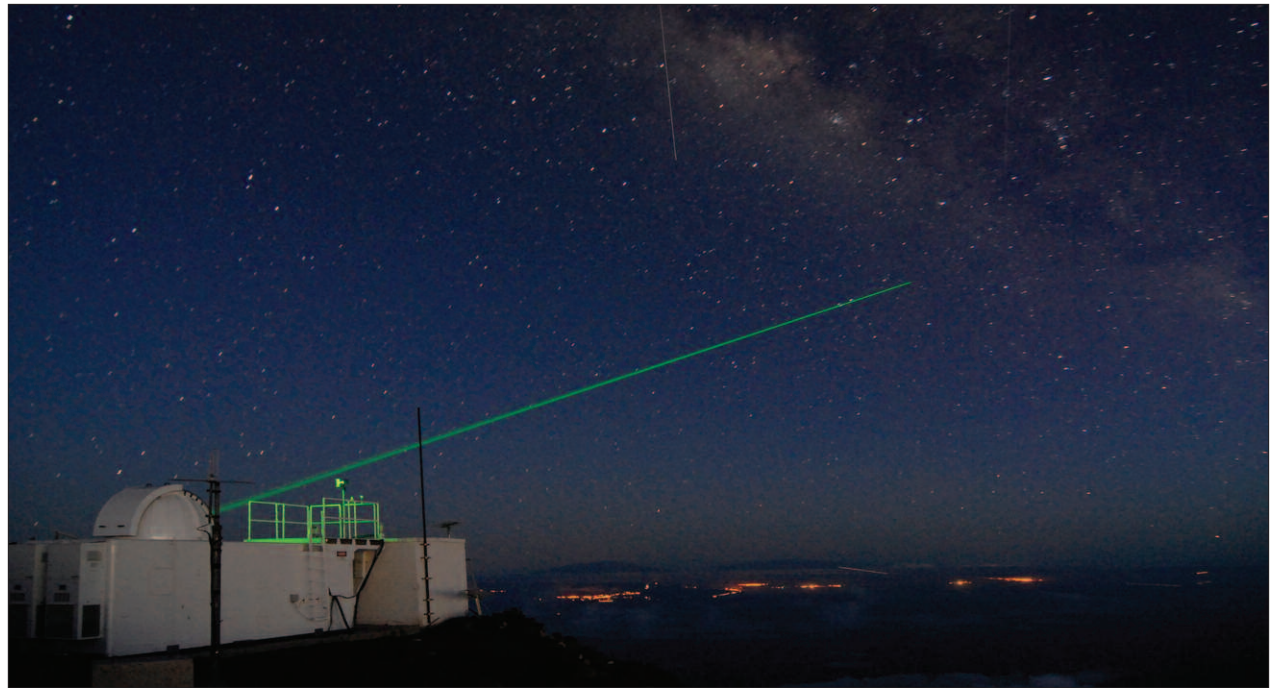
An artistic rendering shows that Earth’s rotation has dragged space-time with it. A particle dropping from infinity towards the center of the planet would not fall in a straight line; it would be dragged along a curved path. In the foreground, the Laser Geodynamics Satellites (LAGEOS) spin in an orbit high above Earth. In the background, the Gravity Recovery and Climate Experiment (GRACE) satellites pass over Earth; their data have revealed the detail in Earth’s gravitational field, shown as color relief on the surface. Warmer colors indicate stronger gravity, and cooler colors indicate weaker gravity. (Courtesy F. Ricci and I. Ciufolini, globe by GFZ Potsdam)

universe infinite? What happens if you get sucked into a black hole? The theory also has implications for slightly more mundane questions, such as how to determine accurate satellite orbits around Earth or the most efficient way for a probe to travel through outer space to visit other planets.

But do we even know that the general theory of relativity is real? “One couldn’t believe it to be true if it were not for the math and experiments that have been done. Reality is much more complex than our everyday experience makes us think,” Ciufolini said. “Scientists have seen an incredible number of tests showing relativity to be true.” Ciufolini would know; he and fellow scientist Erricos Pavlis have focused their research on measuring a particular effect predicted by Einstein’s theory. The effect, called frame-dragging, occurs when a massive rotating object drags particles along with it, causing them to skip through space and time in an unexpected way. But how on Earth can scientists measure that?

Frame-dragging and time

One way to observe frame-dragging would be to put two clocks high up in space near Earth, then send them in opposite directions on the same path around Earth. Ciufolini said, “When the two clocks complete a full circle and come back to where they started, they’ll arrive at the same time, but the one that was going with the direction of Earth’s rotation will show a later time than the one that went against the Earth’s rotation.” In other words, time goes faster with the planet’s rotation and slower against the planet’s rotation. “This is not a speed-dependent effect,” Ciufolini said. “The clocks would have moved through space at the same very low speed. The change in the passing of time is simply because they were



This laser-ranging station, at the Haleakala Observatory on the island of Maui, Hawaii, makes extremely precise measurements of laser-ranging satellite positions by bouncing pulses of laser light off the satellites as they orbit Earth. (Courtesy R. Ratkowski, University of Hawaii)

moving near a current of mass—generated by the rotating Earth—and that current of mass has dragged space-time around it.”

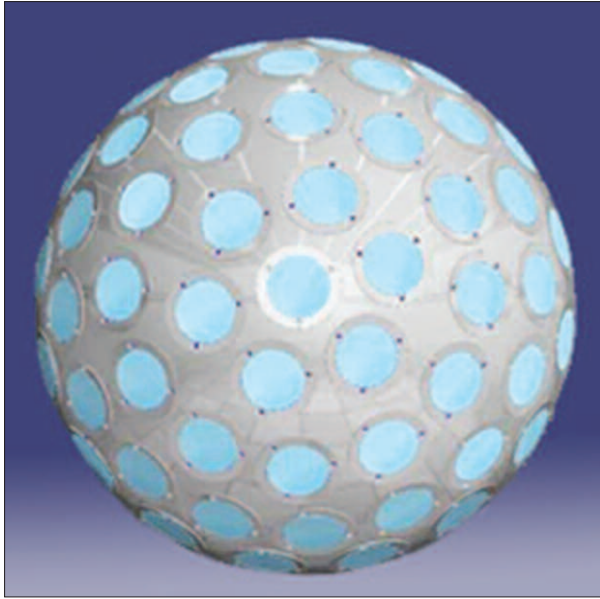
The effect of frame-dragging on the passage of time is strange, but it is real. Although the effect is quite minute around Earth, which has a relatively weak gravitational pull, frame-dragging affects time around dense objects much more. “For example,” Ciufolini said, “if you exaggerated the clock analogy and placed twins who were born at exactly the same time in spacecraft going around a black hole in opposite directions in the same orbit—and if they circled many many times—there would be a real effect on their age,” Ciufolini said. “The twin going against the rotation of the black hole would be younger than

the twin going with the rotation because the black hole’s current of mass caused time to skip.”

However, performing either the clock or twin experiment offers logistical challenges that relegate them to the realm of the purely hypothetical. “So instead of clocks or people,” Ciufolini said, “we used satellites.”

Real observations of relativity

Ciufolini and Pavlis teamed up to devise a way to observe and even measure frame-dragging, using tools already available to them. Their work has spanned many decades, and the accuracy of their measurement has improved as their tools have improved. Their most recent effort corresponds with the effects predicted by



The planned Laser Relativity Satellite (LARES) will increase the precision of laser-ranging data, aiding studies of general relativity. LARES will be an extremely dense sphere of tungsten, covered by 92 corner cube reflectors. (Courtesy Italian Space Agency)

Einstein's theory to approximately 99 percent, with only 10 percent error. How did they do it?

To measure the effect of frame-dragging, the scientists used data from two satellite missions: the NASA Laser Geodynamics Satellites (LAGEOS) mission, and the Gravity Recovery and Climate Experiment (GRACE) mission, which was a joint effort between NASA, the Center for Space Research at the University of Texas at Austin, and the German Research Center for Geosciences (GeoForschungsZentrum Potsdam). Ciufolini and Pavlis retrieved the LAGEOS laser-ranging data from the NASA Crustal Dynamics Data Information System (CDDIS), and the GRACE data from the NASA Physical Oceanography Distributed Active Archive Center.

The LAGEOS mission was primarily designed to gather data to explore topics such as plate tectonics and the measurements of Earth's shape. The two LAGEOS satellites currently orbiting Earth are physically identical, and orbit at about 6,000 kilometers (4,000 miles) above Earth so that they experience as little of Earth's gravitational pull as possible. Pavlis said, "They are basically like cannonballs put up in space; they have no power or sensors and they don't transmit anything." So what do they do? Put simply, they reflect light back to Earth. Each LAGEOS satellite is a perfect sphere covered with 426 glass prisms. Light entering these prisms bounces back in exactly the same direction, in this case back down to international laser ranging stations polka-dotting Earth. The laser-ranging data (accurate to a few millimeters) gave Ciufolini and Pavlis a reliable measurement of the satellites' location in their orbit around Earth, accurate to a fraction of a centimeter. The scientists needed extremely precise measurements in order to observe the minute effects of frame-dragging on the orbits.

Accounting for gravity

However, before Ciufolini and Pavlis could measure the effects of frame-dragging on the LAGEOS satellites, they first needed to account for and remove other effects, like the pull of Earth's gravity on the two satellites. To account for gravity and other effects in their equations, the scientists used a model of Earth's gravitational field, based on data from the GRACE satellite mission. The GRACE mission, like LAGEOS, happens to rely on two identical satellites. However, the similarities between the missions end there. Pavlis said, "The GRACE satellites fly in a low 450-kilometer [280-mile] orbit so that the effects of Earth's gravitational pull will be as strong as possible to capture more detail." The twin satellites work as a team to

maintain continuous data on the distance between them, sending radio frequency signals back and forth to each other and receiving Global Positioning System (GPS) signals; laser stations on Earth also track the satellites. As the satellites pass over the planet, features like mountains and bodies of water tug at them because of their varying densities, allowing the satellites to map the details of Earth's gravitational field. Pavlis said, "Using GRACE data improved the models of Earth's gravitational field by several orders of magnitude almost overnight, and that meant we improved the accuracy of our measurements of the tiny effects of frame-dragging on the LAGEOS satellites."

The scientists put the data from the LAGEOS and GRACE satellite missions together to measure the effect of frame-dragging on the LAGEOS satellites' orbit. "Removing the effects of tides, atmosphere, gravity, and so on from the data, we could determine where the satellites were in their orbital arcs," said Pavlis. "We could see the orbital plane change because of the effects of relativity." The effects of frame-dragging on the LAGEOS satellite orbits are small, but measurable. Ciufolini said, "We're observing differences of just small fractions of a second of arc, about 10 to the minus 5 degrees, between the two satellites. But it's still proof that frame-dragging is real, and it's another important test validating the general theory of relativity."

The future of frame-dragging

Ciufolini and Pavlis have long pushed for an addition to the LAGEOS mission; with a third satellite in orbit, the accuracy of their measurements could be improved even further. Talk of launching a hypothetical LAGEOS-III has long subsided. However, the Italian Space Agency, ASI, has designed a new satellite for

launch in the next year. Laser-ranging data from the new Laser Relativity Satellite (LARES) would likely be archived at NASA CDDIS. Ciufolini said, “Unless there’s an unknown denser asteroid in our solar system, LARES will be the densest single object: about 387 kilograms [853 pounds] of tungsten in a sphere 36 centimeters [14 inches] in diameter.” Pavlis looks forward to studying the data from LARES, after its planned launch in early 2010.

In addition to a third laser-ranging satellite, the two scientists also hope to see additional laser-ranging stations placed on Earth, improving the coverage of the LAGEOS satellite orbit and, in turn, their frame-dragging measurements. Pavlis said, “Right now, we only have snapshots of the orbit over land; if we don’t have real estate, we can’t put up a station.” Another challenge is the cost of the stations, which require high levels of onsite infrastructure and support; not all countries have stations where they are needed. Automated stations, and new locations in the near future, would help fill in the gaps.


Why do Ciufolini, Pavlis, and so many other scientists spend vast amounts of their time trying to improve our understanding of Einstein’s theory? Ciufolini said, “Space research is incredibly important. We can discover new things, new ways of thinking about our universe and our own lives. And the discoveries that will be made in the future, building on what we’re doing now . . . like Einstein’s theories, they will break our way of thinking about the universe.”

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About the remote sensing data used		
Satellites	Laser Geodynamics Satellites 1 and 2 (LAGEOS-1 and -2)	Gravity Recovery and Climate Experiment (GRACE)
Data sets	ILRS Normal Points for 1993 to 2003	GRACE Level 2 Gravity Products
Resolution	Global coverage	Not applicable
Parameters	Laser ranging data	Global gravity fields
Data centers	NASA Crustal Dynamics Data Information System (CDDIS)	NASA Physical Oceanography Distributed Active Archive Center (PO.DAAC)

About the scientists



Ignazio Ciufolini is a researcher in general relativity and gravitation. He teaches physics at the University of Salento in Italy and won the 2001 International Tomassoni-Chiesi Award for Physics. He co-authored *Gravitation and Inertia* with John Archibald Wheeler; the Association of American Publishers named it the best 1995 physics book. He is the principal investigator of the Laser Relativity Satellite (LARES). The Italian Space Agency (ASI) funded his research. (Photograph courtesy I. Ciufolini)



Erricos Pavlis is a geodesist and research professor at the University of Maryland Joint Center for Earth Systems Technology with NASA Goddard Space Flight Center. He is the analysis coordinator for the International Laser Ranging Service, a team member of the Gravity Recovery and Climate Experiment, and a co-principal-investigator for LARES. NASA and the National Geospatial-Intelligence Agency funded his work. (Photograph courtesy E. Pavlis)

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For more information

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

NASA Physical Oceanography Distributed Active Archive Center (PO.DAAC)
<http://podaac.jpl.nasa.gov>

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

Laser Relativity Satellite (LARES)
<http://www.asi.it/en/activity/cosmology/lares>

PO.DAAC GRACE Home
<http://podaac.jpl.nasa.gov/grace/>

Fathoming Antarctica



“Suddenly these lakes went from being just this cool ecosystem to being a fundamental part of ice sheet dynamics and how ice is delivered to the oceans.”

Robin Bell
Columbia University

by Natasha Vizcarra

On a brisk April day in a Colorado Springs lecture hall, geophysicist Robin Bell showed the audience three photographs of water. The first was a placid lake dotted with sailboats. The second was a gushing river. The third was not of a body of water at all, but a thin film of water trapped under a melting ice cube. Bell said, “My colleagues and I wonder whether subglacial lakes in Antarctica look like any of these—minus the sailboats, of course,” and drew a collective chuckle from the audience.

Bell, a senior research scientist at Columbia University’s Lamont-Doherty Earth Observatory in New York, has a knack for inspiring an audience to pause and consider the seemingly inconceivable. Just what does a body of water look like when it is buried under a two-mile thick slab of ice? “Is it calm or turbulent down there?” she asked. “Or is it a very thin film of water, like what would form between an ice cube and your warm hand? What does that tell us about processes happening deep under the Antarctic ice?”



The surface above Lake Vostok, hidden under more than a kilometer of ice, looks like most of Antarctica’s landscape—flat, barren, and icy. The best way to detect a subglacial lake is through remote sensing. (Courtesy M. Studinger, LDEO)

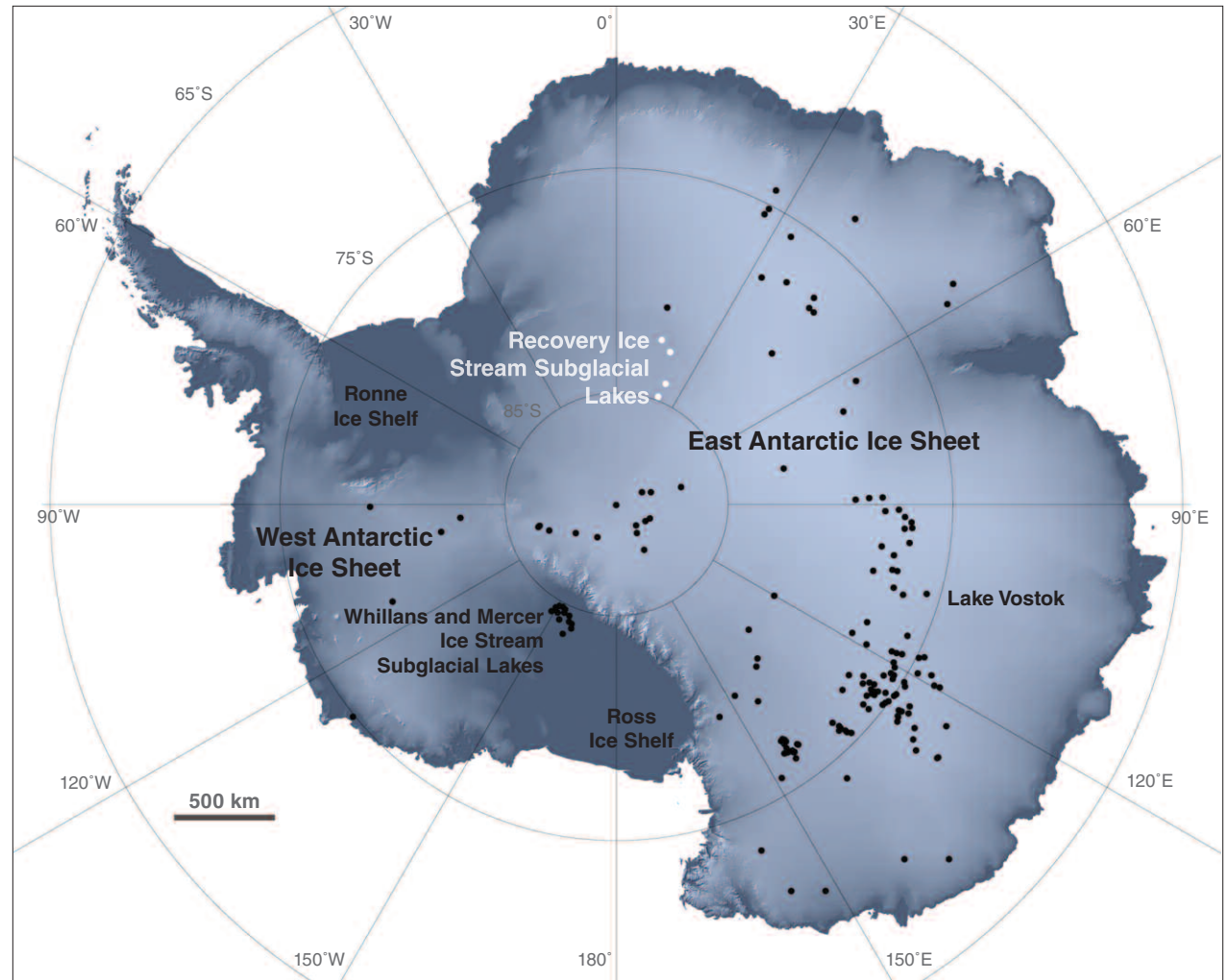
In the last fifty years, researchers like Bell have found unexpected clues about what lies beneath the barren ice desert of Antarctica. One of the most exciting finds has been the detection of subglacial lakes scattered underneath the East and West Antarctic ice sheets. Bell suspects that these mysterious, hidden lakes are key to understanding the interplay between ice sheets and the world's oceans.

Flat lines in the ice

Antarctica, an island continent larger than Australia, is almost completely covered by ice and remains the most mysterious terrain on Earth. The stormy waters of the Southern Ocean isolate it from other lands. And because it is the coldest, windiest and driest place on the planet, it has been difficult to study and explore. “It seemed at first that the study of Antarctica was falling through the cracks,” Bell said. “Because it was so difficult to get to, the biologists didn’t care, and because the environment was so extreme, the glaciologists didn’t care.”

But some scientists did care. They thought that the ice sheets concealing Antarctica might also conceal clues to the continent, and to the climate in this remote part of the Earth and beyond. In the 1950s, glaciologist Gordon de Quetteville Robin was captivated by the idea that water could be present under the ice sheet. He suggested that geothermal heat from Antarctica’s bedrock could be hot enough to heat the ice sheet base, and that the ice sheet itself could be thick enough to insulate its base from its cold surface. Robin could not prove this until the 1970s, when ice-penetrating radar was developed.

“Scientists flew around Antarctica in C-130 airplanes that sent electromagnetic waves through

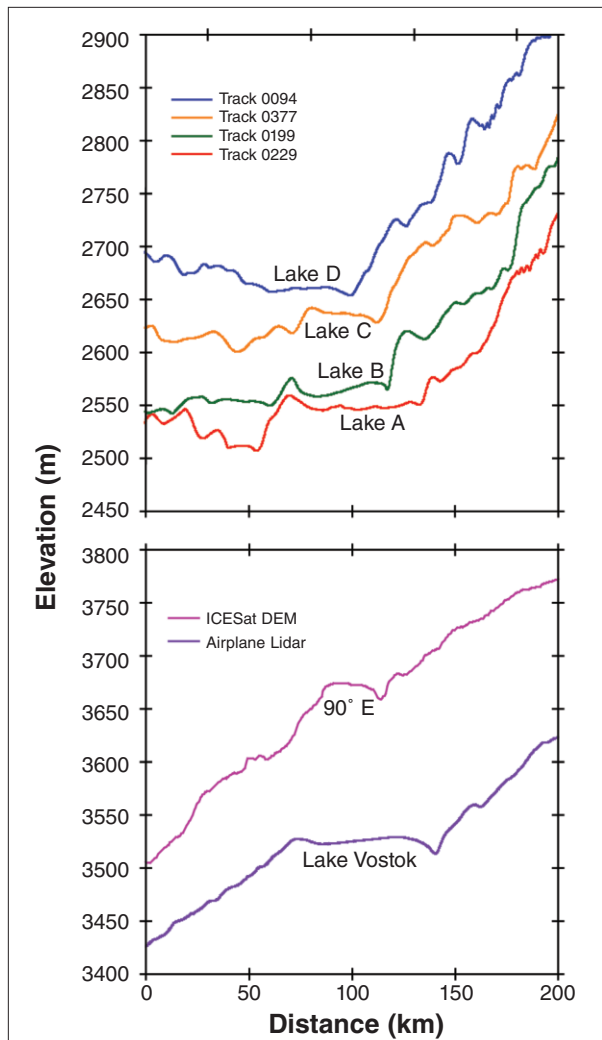


In the 1950s, glaciologist Gordon de Quetteville Robin suggested that liquid water could be present between Antarctica’s geothermal bedrock and its ice sheet. More than fifty years later, over 200 subglacial lakes have been discovered underneath the ice of Antarctica, some of which are marked with white and black with dots on this map. (NASA map by R. Simmon, based on data from the RADARSAT-1 Antarctic Mapping Project, T. Scambos, C. Shuman, and M. J. Siegert)

the ice sheet,” Bell said. “It turns out that an ice sheet is very much like a layer of sedimentary rock. At the bottom were outlines of rugged mountains. But in some places, the layers looked really flat. These were actually subglacial lakes, our first indication that there was indeed water underneath the ice sheet.”

The Lake Vostok surprise

Still, scientists did not know what to make of these mysterious features. “In the 1970s, we thought that those flat layers were tiny, isolated ponds sprinkled around in obscure little canyons, speckles on top of the continent,” Bell said. “Quite frankly they didn’t seem to be important.”



Subglacial lakes show up in satellite data as upstream troughs and downstream ridges bounding relatively flat, featureless regions. At top, ice surface elevation data from the Ice, Cloud, and Land Elevation Satellite (ICESat) show the profiles of the four Recovery subglacial lakes, with blue, yellow, green, and red lines. At bottom, ICESat and aircraft-borne lidar show profiles for Lake Vostok and Lake 90°E, in purple and lavender. Although the profile for 90°E lacks a flat surface, it does show the characteristic depression over the upstream shore line and a ridge over the downstream shoreline. (Courtesy C. A. Shuman and V. Suchdeo, NASA Goddard Space Flight Center)

We didn't have a sense that the lakes were actually very big."

To learn more, Bell and colleagues had to wait until the 1990s, when the European Remote Sensing satellite (ERS-1) completed the first comprehensive map of Antarctica's ice surface, using radar altimetry. European scientists examining the map noticed a curiously flat region in the center of the ice sheet, roughly the size of Lake Ontario in Canada. Bell said, "It turns out that ice stuck on top of a mountain, even when it is a couple of kilometers [1 to 2 miles] thick, will preserve the shape of the mountain underneath. The ice surface will look rugged. But if water is underneath, the ice surface will look very flat." This enormous subglacial lake was named Lake Vostok, after the Russian research station located on the ice above it.

It would take another decade and improvements in remote sensing technology before scientists could learn more. By that time, other subglacial lakes had been discovered, and scientists were also interested in ice sheet dynamics, the processes that add to or subtract from the mass of an ice sheet, and affect its stability. In 2006, Bell and Chris Shuman, at the NASA Goddard Space Flight Center (GSFC), obtained new data from the NASA Ice, Cloud, and Land Elevation Satellite (ICESat). The ICESat data, which are archived and distributed by the National Snow and Ice Data Center Distributed Active Archive Center (NSIDC DAAC), had been specially processed at NASA GSFC.

Bell, Shuman, and Michael Studinger, also at the Lamont-Doherty Earth Observatory and Bell's co-investigator, looked at ice surface elevation profiles for a portion of Queen Maud Land in East Antarctica, a region previously

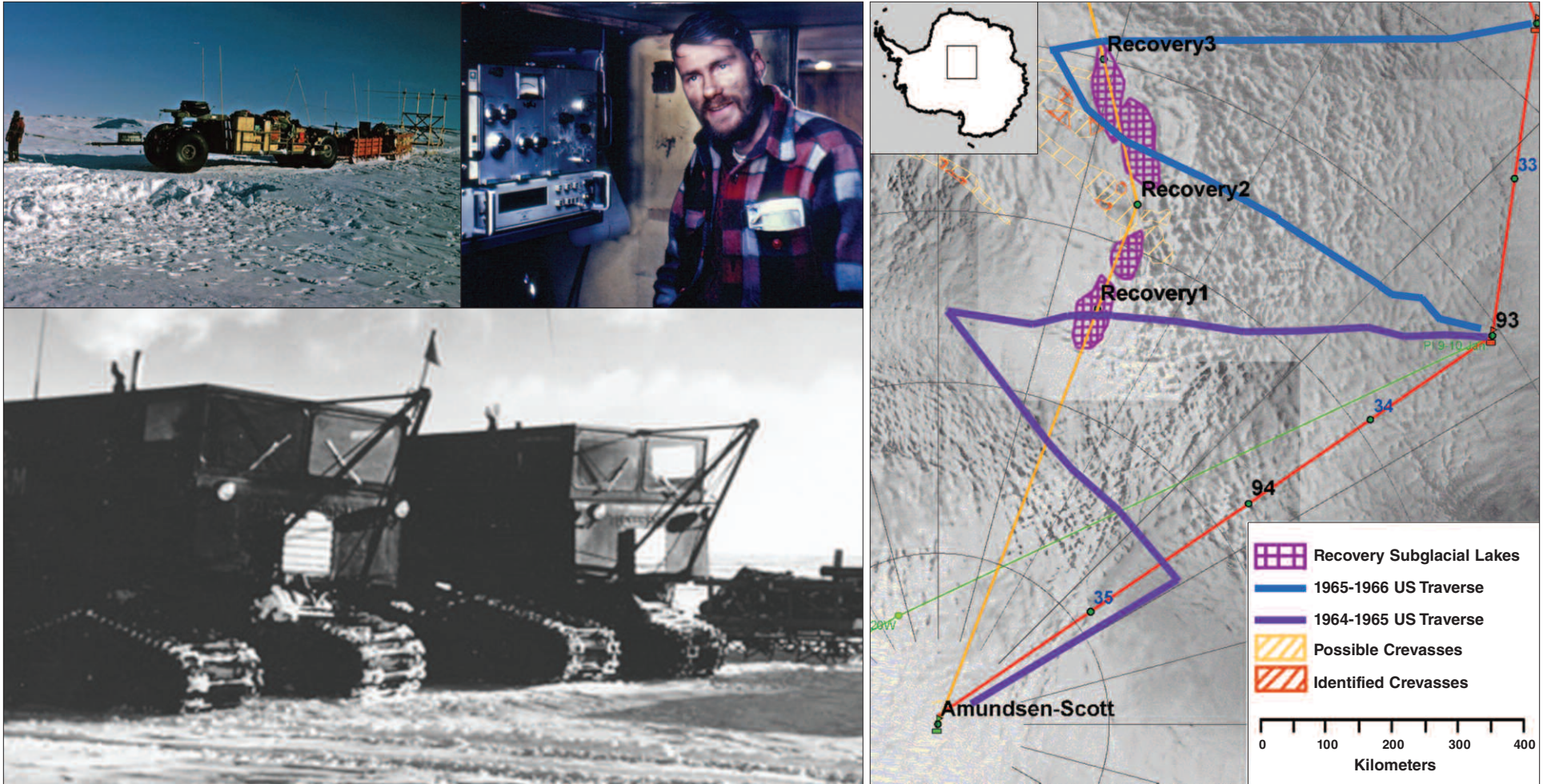
beyond the coverage of many satellites. They found not only one, but four new subglacial lakes. Their location made Bell curious about what role the new lakes might play in the flow of ice from Antarctica's higher elevations down to sea level, where the ice sheet calves icebergs into the oceans.

Flats, ridges, and troughs

Subtle features in the ICESat data tipped off the researchers to the lakes. Studinger said, "There are a few ways to recognize a subglacial lake. The ice surface is very flat and is bounded by troughs about 2 to 15 meters [7 to 49 feet] deep, and ridges about 2 to 5 meters [7 to 16 feet] high." Looking at ICESat ice elevation profiles east of Filchner Ice Shelf and the Recovery Ice Stream, the team spotted four features that bore these characteristics.

On a hunch, Bell requested unpublished radar data from a 1964 to 1966 surface traverse in Queen Maud Land, a little-explored region of the East Antarctic ice sheet. Bell said, "That traverse went across where these lakes should be, but nobody had ever looked at the data." She received old, smudged notebooks of radar readings and had the data digitized. True enough, whenever the traverse was over any of the lakes, the logs showed consistent ice thicknesses. "Those researchers in 1964 thought something was terribly wrong because they kept getting the same measurements," Bell said. "What they didn't know was that they were over subglacial lakes."

With the ICESat data and the old traverse notebooks confirming the signal of the lakes, Bell wanted to know how large they were. She sought a larger-scale view of the area, so she consulted a digital image map, constructed



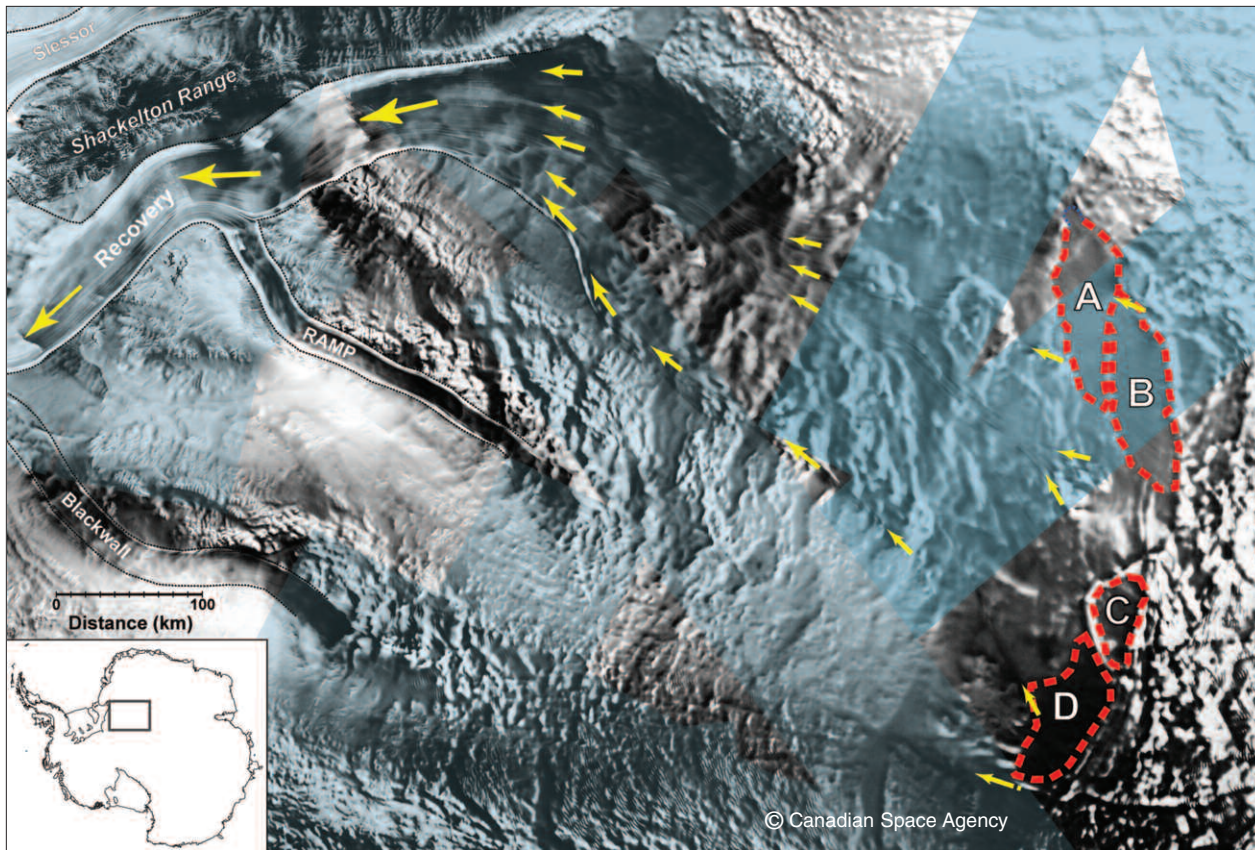
The Queen Maud Land Traverse in the late 1960s measured ice thicknesses using radar equipment, dragged across the ice by sledges (upper left) and by tracked all-terrain vehicles (bottom). The data they recorded puzzled the traverse team; only recently have scientists decoded it as evidence of lakes beneath the ice. The traverse crew sat in tight compartments in the Sno-Cat vehicles, taking measurement readings (top, center). The map at right shows the 1964 to 1966 traverse routes in purple and blue. (Upper left photograph courtesy O. Orheim; upper right photograph courtesy J. Clough; bottom photograph courtesy C. Bentley; map courtesy S. Tronstad/Norsk Polarinstitt)

from Moderate Resolution Imaging Spectroradiometer (MODIS) data, which are available from NASA's MODAPS Level 1 Atmosphere Archive and Distribution System (MODAPS LAADS). The map, called the Mosaic of Antarctica (MOA) and distributed by NSIDC, is a cloud-free image of the continent composed of 260 orbital swaths of imagery acquired in

2003 and 2004. A close look at the map revealed four slug-shaped depressions on the ice surface with a combined total area of 13,300 square kilometers (5,130 square miles), comparable to that of Lake Vostok at 15,690 square kilometers (6,058 square miles). Each of the new lakes ranked among the largest of all previously identified subglacial lakes in Antarctica.

Giant conveyor belts of ice

Something else was different about these four features. "Instead of being in the middle of the ice sheet like most previously discovered subglacial lakes, they were near a huge and rapidly flowing ice stream," Bell said. Ice streams are rivers of ice within an ice sheet that transport inland ice into the ocean, like giant conveyor belts that move



The Recovery Lakes supply water that lubricates the bottom of Antarctica's ice sheet, speeding the Recovery Ice Stream's flow toward the ocean. The lakes are indicated with dotted, red lines and identified with the letters A, B, C, and D. Yellow arrows indicate the Recovery Ice Stream's flow. Light blue indicates the coverage of Synthetic Aperture Radar data from the RADARSAT-1 satellite, which was used to measure the velocity of the flow. (Courtesy C. A. Shuman and V. Suchdeo, NASA Goddard Space Flight Center)

as fast as 152 meters (499 feet) per year in some areas and as slow as 3 meters (10 feet) per year in others. The proximity of four subglacial lakes to a rapidly flowing ice stream suggested that these bodies of water were more like gushing rivers than the placid lakes she had imagined.

The four new lakes are located where the Recovery Ice Stream widens and accelerates. Ice streams typically get narrower upslope, but the Recovery Ice Stream widens from 30 kilometers (20 miles)

to 90 kilometers (60 miles) eastward near the lakes. Ice velocity data from the Synthetic Aperture Radar (SAR) instrument on the RADARSAT-1 satellite, distributed by the Alaska Satellite Facility SAR Data Center, showed accelerated ice movement of 20 to 30 meters (70 to 100 feet) per year farther east, downstream of the four lakes. MOA images of this area of accelerated ice flow showed that it was full of crevasses, or open fissures in the ice. "When ice accelerates, it stretches and cracks," Bell said.

The researchers now see a strong connection between the four Recovery Lakes and the ice stream. Bell and Studinger concluded that the Recovery Ice Stream originates at the lakes. It is the first time subglacial lakes have been connected to ice streams. "Suddenly these lakes went from being just this cool ecosystem to being a fundamental part of ice sheet dynamics and how ice is delivered to the oceans," she said. Bell thinks that subglacial lakes warm up the underbelly of an ice sheet. She also suggested that subglacial lakes provide a supply of water that lubricates the bottom of the ice sheet, allowing it to move faster toward the ocean.

To date, over 200 subglacial lakes have been discovered underneath the ice of Antarctica. Studinger said, "What scientists now know is that these lakes are not as isolated as once thought." Remote sensing has shown that the ice surface above these subglacial lakes can either drop or pop up thirty to forty feet in two months. Based on this information, colleague Helen Fricker suggested that water moves out of one lake and into the next. Studinger said it is important to ask how the presence of water under the ice sheets can impact their stability.

Bell said, "Liquid water plays a crucial and, until quite recently, underappreciated role in the internal movements and seaward flow of ice sheets. Understanding how liquid water forms under an ice sheet, where it occurs and how climate change can intensify its effects on the world's polar ice are paramount in predicting—and preparing for—the consequences of global warming on sea level."

To access this article online, please visit http://nasadaacs.eos.nasa.gov/articles/2009/2009_antarctica.html.



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For more information

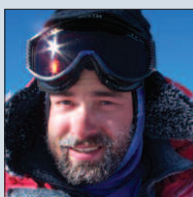
- NASA National Snow and Ice Data Center Distributed Active Archive Center (NSIDC DAAC)
<http://nsidc.org>
- NASA Alaska Satellite Facility SAR Data Center
<http://www.asf.alaska.edu>
- Geoscience Laser Altimeter System (GLAS)
<http://glas.gsfc.nasa.gov>

- Moderate Resolution Imaging Spectroradiometer (MODIS)
<http://modis.gsfc.nasa.gov>
- Mosaic of Antarctica (MOA)
<http://nsidc.org/data/moa>
- Robin E. Bell
<http://www.ldeo.columbia.edu/~robinb>
- Michael Studinger
<http://www.ldeo.columbia.edu/~mstuding>

About the scientists



Robin E. Bell is a senior research scientist at Columbia University's Lamont-Doherty Earth Observatory in New York. Her research interests include linkages between ice sheet processes and subglacial geology, tectonic uplift, and feedback mechanisms. The Doherty Endowment Fund of the Lamont-Doherty Earth Observatory and the Palisades Geophysical Institute supported her research. (Photograph courtesy A. Block)



Michael Studinger is a research scientist at Columbia University's Lamont-Doherty Earth Observatory in New York. His research interests include physical processes in polar regions linking tectonics and ice sheet dynamics, and life in extreme environments, such as subglacial lakes. The Doherty Endowment Fund of the Lamont-Doherty Earth Observatory and the Palisades Geophysical Institute supported his research. (Photograph courtesy M. Studinger)

About the remote sensing data used

Satellites	Ice, Cloud, and Land Elevation Satellite (ICESat)	Terra and Aqua	Terra and Aqua	Canadian Space Agency RADARSAT-1
Sensors	Geoscience Laser Altimeter System (GLAS)	Moderate Resolution Imaging Spectroradiometer (MODIS)	MODIS	Synthetic Aperture Radar (SAR)
Data sets	GLA06 Release 424	MODIS Level 1B Calibrated Radiances MOD02QKM (Terra), MYD02QKM (Aqua)	Mosaic of Antarctica (MOA)	Antarctic Mapping Mission
Resolution	172 meter along track	250 meter	250 meter	1.0 kilometer (velocity)
Parameters	Ice sheet elevation profiles	Radiances	Digital image map	Ice velocity
Data centers	NASA National Snow and Ice Data Center Distributed Active Archive Center (NSIDC DAAC)	NASA MODAPS Level 1 Atmosphere Archive and Distribution System (MODAPS LAADS)	NSIDC Antarctic Glaciological Data Center	NASA Alaska Satellite Facility SAR Data Center

The table above lists the public NASA archive for these remote sensing data sets. Bell and Studinger used the GLA06 data set with a spatial resolution of 172 meters along track (plus DEM v1, gridded at 500 meters), with additional processing from the NASA Goddard Space Flight Center.

The mysterious lives of leatherbacks



“This animal was, and remains, an enigma.”

Michael James
Dalhousie University

by Laura Naranjo

When biologist Michael James captured and tagged his first leatherback sea turtle off the eastern coast of Canada in 1999, he was pursuing a mysterious animal. No one knew why Atlantic leatherbacks appeared in the frigid northern waters each year. In fact, researchers knew little at all about leatherbacks, except that they were endangered.

“This animal was, and remains, an enigma,” James said. “Although fishermen had known for

a long time that leatherbacks had been sighted off Canadian coasts, these were considered incidental reports.” James, then a graduate student at Dalhousie University in Nova Scotia, Canada, had begun studying leatherbacks with one satellite-linked transmitter attached to a turtle. Long thought to be tropical creatures, the records that James and his colleagues collected suggested otherwise: leatherbacks spent up to five months foraging in Canadian waters before migrating south. Now, more than ten years later, James has tracked over sixty turtles by satellite. Tagging and tracking leatherbacks exposed their



Atlantic leatherbacks are the largest species of sea turtle. While they have few natural predators, they often become entangled in fishing nets and drown. Leatherbacks were declared critically endangered in 2000. (Copyright H. Segars)

behavior and yielded new insights about leatherback biology. But James didn't yet know what triggered their movements. To discover the answer, he and his colleagues turned to environmental satellite data.

Turtles at risk

During migration, leatherbacks travel the open ocean in relative safety. But between migrations, they spend several months foraging along the continental shelves. "When leatherbacks concentrate in these coastal feeding or breeding areas, they're most at risk because these are also the environments where fishing activity is most concentrated," James said.

This overlap between turtle habitat and commercial fisheries poses a problem for leatherbacks. In near-shore waters, the turtles are more likely to become entangled in nets or the vertical lines associated with fishing gear. Leatherbacks are the largest species of sea turtle, growing more than 2 meters (7 feet) long, and weighing up to 650 kilograms (1,400 pounds). When captured in the large, conical nets used in trawl fishing, they are often too large to be released from common turtle excluder devices, and are unable to swim backward to escape.

By studying how turtles use coastal foraging areas, and observing when they migrate to and from them, James hoped to glean information that may help ensure turtle safety and promote less harmful fishing practices.

Migration clues

Each year, James conducted summer fieldwork off the coast of Nova Scotia, capturing and equipping turtles with tracking devices. Every fall the turtles migrated south, and every summer the

turtles returned to northern waters to feed on jellyfish and other gelatinous prey. James was beginning to understand their migration routes, but he did not yet understand the factors influencing when the turtles migrated. "Was there some kind of cue, such as day length or declining water temperature?" James asked. "Was it declining food availability? Could we predict when they were going to leave based on any of these variables?"

Turtle tracking devices relayed location and movement, but to understand potential environmental cues affecting migration, James needed more information. So he worked with Scott Sherrill-Mix, a graduate student at Dalhousie University in Nova Scotia. They studied data from twenty-seven turtles, tracked between 1999 and 2004, and matched turtle locations with environmental satellite data to see if changes in ocean temperature and food supply affected their behavior.

To complement the incomplete ocean temperature records obtained from the turtle tracking devices, Sherrill-Mix obtained sea surface temperature data from the Geostationary Operational Environmental Satellite (GOES) and the Advanced Very High Resolution Radiometer (AVHRR) Oceans Pathfinder instrument, available from the NASA Physical Oceanography Distributed Active Archive Center.

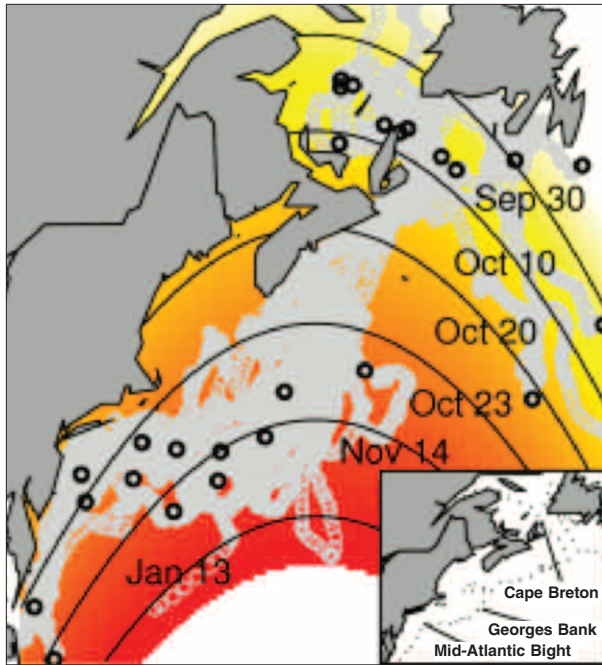
Observing leatherback food supply was more difficult than determining sea surface temperature. Sherrill-Mix said, "We were really interested in changes in jellyfish abundance, but there are no counts of jellyfish in the open ocean." Part of the reason there is little data on jellyfish is because satellite sensors cannot measure jellyfish populations directly. However, satellites can detect



The satellite tracking device attached to this leatherback sea turtle helps biologist Michael James learn more about the turtle's migration routes and behavior. His work depends on help from commercial fishermen, who work as field assistants and lend their boats. (Courtesy Canadian Sea Turtle Network)

a common jellyfish food source, phytoplankton, the microscopic plants that float near the ocean's surface. Because phytoplankton contain a green pigment called chlorophyll, large concentrations of them can color the ocean green; satellites can observe these changes in ocean color. "We hoped that chlorophyll data would approximate jellyfish concentrations," Sherrill-Mix said. He used ocean color data from the Moderate Resolution Imaging Spectroradiometer (MODIS) sensor and from the Sea-Viewing Wide Field-of-View Sensor (SeaWiFS), both available from the NASA Ocean Biology Processing Group.

James said, "We were able to tap into these databases pretty quickly and grab values relative to each turtle's position. I want to stress the value of making the environmental data free, and making it available on the Web. The continuity is really important for projects like ours."



Researchers studied the migration patterns of leatherback sea turtles in hopes of learning more about protecting their populations. Dates indicate when 50 percent of the turtles departed that contour line. Each contour line marks a ten-fold increase in turtle departure rates from the line below. Gray circles indicate turtle movement, and black circles mark individual departures. Red indicates the lowest departure rates and yellow the highest rates. The inset shows locations discussed in the study. (Courtesy S. Sherrill-Mix)

Modeling turtle timing

Individual leatherbacks began their southward migration over a four-month span, ranging from September 8 to January 13. Sherrill-Mix combined the turtle departure dates they had observed with remotely sensed temperature and chlorophyll data, adding day length, water depth, and turtle gender and size to generate a model. The scientists hoped the model would reveal which of these factors prompted migration, and they initially focused on decreasing food supply and water temperatures. But the model results

suggested that the turtles did not leave for the reasons they expected. The largest factor in migration timing turned out to be turtle location.

The leatherbacks in their study tended to congregate in two locations: one group foraged in the waters off Newfoundland and Nova Scotia, and the other group foraged off the northeastern coast of the United States. “We thought that cold water might trigger turtle migration,” Sherrill-Mix said. “But the northern-most turtles left sooner from warmer water. And we thought the same with chlorophyll. We figured that green water would have lots of food for them. But they left earlier from waters rich in chlorophyll.” Sherrill-Mix and James also noticed that once the northern turtles began migrating, they did not stop to forage in the southern location. Sherrill-Mix said, “The northern turtles swim right past where the southern turtles are foraging. If they needed more food, they could easily stop and eat.”

How could the researchers explain the unexpected results? The difference in migration distance between the northern and southern turtles was only 500 kilometers (300 miles). Leatherbacks could cover that distance in about ten days, so distance alone could not account for the wide range of departure dates. Sherrill-Mix and James thought one possible explanation was that jellyfish might have more extreme blooms in warmer, prey-filled waters. Sherrill-Mix said, “Increased prey and temperature speed up the jellyfish lifecycle. Since jellyfish die off after mating, this may mean that warm, chlorophyll-rich waters provide a more condensed jellyfish season for the turtles.” The researchers theorized that seasonal jellyfish die-offs occurred earlier at higher latitudes, prompting turtles in these areas to begin migrating while waters were still warm. By

contrast, turtles in the southern comparison group were able to feed on jellyfish later into the season.

While some of the results were unexpected, the study provided new questions for James and Sherrill-Mix to explore. They were the first scientists to model and investigate potential migration cues and timing in leatherbacks, which required broader investigation into how seemingly unrelated factors, such as jellyfish lifecycles, might influence turtle behavior.

“This work relates fundamentally to the leatherback’s status as an endangered species,” James said. “We need a context in which to look at leatherback behavior and discover what we can do to help them recover.” Knowing when leatherbacks leave or return to an area may aid conservation regulations and promote changes in fishing practices, particularly in near-shore environments where turtles forage and are most at risk. James collaborated extensively with fishermen, and is mindful that simple solutions, such as closing off entire areas, are not always the



Leatherback sea turtles have a thick layer of ridged, leathery skin on their backs instead of a bony shell, so researchers needed to develop safe ways to attach satellite tracking equipment. (Courtesy Canadian Sea Turtle Network)

answer. Having detailed information about turtle migration and behavior can lead to flexible conservation measures that protect both leatherbacks and local fishing industries. “We want to predict leatherback behavior and ultimately, we want fisheries and turtles to co-exist,” James said.

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For more information

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<http://podaac.jpl.nasa.gov>

Moderate Resolution Imaging Spectroradiometer (MODIS)
<http://modis.gsfc.nasa.gov>
 Sea-Viewing Wide Field-of-View Sensor (SeaWiFS)
<http://oceancolor.gsfc.nasa.gov/SeaWiFS>
 Canadian Sea Turtle Network
<http://www.freethel Leatherback.com>

About the scientists



Michael James is an adjunct professor at Dalhousie University in Nova Scotia, Canada, and the director of science for the Canadian Sea Turtle Network (CSTN). James founded the CSTN to involve fishermen, conservation agencies, and coastal communities in marine turtle research and conservation initiatives in Atlantic Canada. Fisheries and Oceans Canada, National Marine Fisheries Service (USA), and Natural Sciences and Engineering Research Council of Canada funded his research. (Photograph courtesy CSTN)



Scott Sherrill-Mix is a programmer analyst with the University of Pennsylvania. He studied fishery interaction and stock abundance before attending Dalhousie University in Canada, where he received a master’s degree studying leatherback sea turtles. He will begin his PhD in bioinformatics at the University of Pennsylvania in fall 2009. Fisheries and Oceans Canada, National Marine Fisheries Service (USA), and Natural Sciences and Engineering Research Council of Canada funded his research. (Photograph courtesy S. Sherrill-Mix)

About the remote sensing data used

Satellites	Geostationary Operational Environmental Satellite (GOES)	NOAA Polar Orbiting Satellites	GeoEye SeaStar, Aqua	Aqua, GeoEye SeaStar
Sensors	GOES I-M Imager	Advanced Very High Resolution Radiometer (AVHRR)	Sea-Viewing Wide Field-of-View Sensor (SeaWiFS) and Moderate Resolution Imaging Spectroradiometer (MODIS)	MODIS, SeaWiFS
Data sets	GOES L3 6km Near Real-Time SST	AVHRR Pathfinder SST v5	OC3 and OC4 chlorophyll a concentration	Aqua MODIS merged chlorophyll product (with SeaWiFS)
Resolution	6 kilometer	4 kilometer	9 kilometer	9 kilometer
Parameters	Sea surface temperature	Sea surface temperature	Chlorophyll a concentration	Chlorophyll a concentration
Data centers	NASA Physical Oceanography Distributed Active Archive Center (DAAC)	NASA Physical Oceanography DAAC	NASA Ocean Biology Processing Group	NASA Ocean Biology Processing Group

Finite forests



“There are not so many areas left in the world that are close to completely natural. We need these virgin forests.”

Lars Laestadius

World Resources Institute and Global Forest Watch Russia

by Katherine Leitzell

The quiet expanses of pine and spruce that sprawl across northern Russia are the largest forests in the world, and the major source of lumber for rapidly growing markets in Asia and Europe. Demand for wood in neighboring countries has encouraged Russian logging operations to move continuously north in search of old-growth trees. While Russia’s supply of trees may seem endless, some forestry experts are concerned that expanded logging will fragment one of the last intact virgin forests in the world.

But determining the extent of forest change is challenging. Russian forests cover an area larger

than the contiguous United States. The forests span vast, unpopulated regions with no permanent road system, making it difficult to evaluate forest cover from the ground. So scientists and foresters are now testing new methods to survey forests, using satellite sensors that gather data over broad areas. The data they collect may help Russian foresters sustainably manage timber harvesting in the region.

Clear-cuts expand in virgin forest

Hans-Jürgen Stibig, a researcher who studied forest change in Russia, said, “Russian forests are important in terms of environmental protection, biodiversity, and carbon storage. While tropical forests get a lot attention, there is strong interest



This aerial photograph shows a small section of the sprawling boreal forests in the Karelia Republic, Russia. Much of this mosaic of forests, lakes, rivers, and wetlands, dominated by spruce trees, is virgin forest. However, the region is rapidly changing because of logging. (Courtesy V. Kantor)

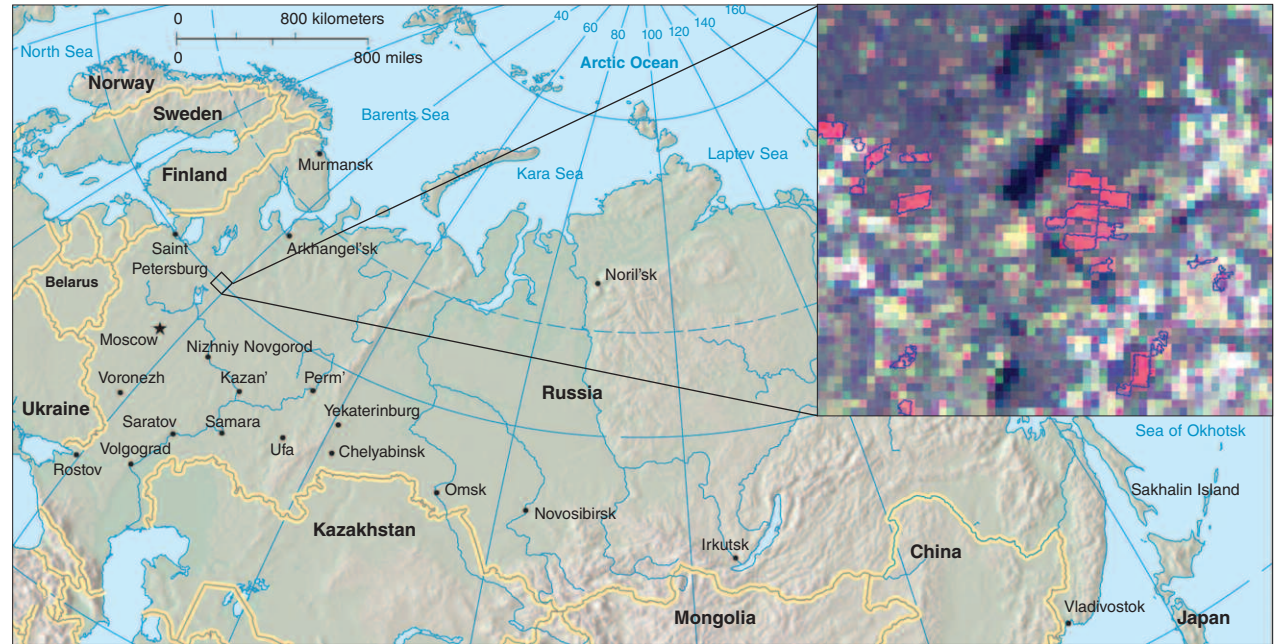
in Europe in promoting the sustainable use of our planet's boreal forests, especially those of our close neighbor Russia." Stibig works at the Joint Research Centre (JRC) of the European Commission in Italy, whose goal is to provide research support for environmental policy in Europe.

Some scientists and policy makers say that logging poses a growing threat to the virgin forests of northern Russia. Clear-cutting, a common method of logging, removes all of the trees in an area, fragmenting intact forests. Lars Laestadius, a researcher at the World Resources Institute and project manager for Global Forest Watch Russia, said, "There are not so many areas left in the world that are close to completely natural. We need these virgin forests, both as a reference area, so we can see how we have impacted other forests, and to preserve biodiversity." Boreal forests also store carbon that could contribute to climate change if it escaped, whether through forest fires, thawing soils, or forest degradation from extensive logging.

Logging in Russia removes as many as 20,000 square kilometers (8,000 square miles) of trees per year, much of that in previously untouched boreal forest. Clear-cuts account for most of this logging, and while the cut areas eventually regrow, it can take hundreds of years for a boreal forest to reach maturity. "The logging industry in Russia keeps pushing the timber frontier up to the north. The problem is that as you go further north, the trees grow back more slowly," Laestadius said. Trees grow more slowly in northern regions because less solar radiation reaches the ground in northern latitudes and the growing season is shorter.

The right sensor for the job

Researchers have already used satellites to measure forest cover in tropical rainforests. Using the visual



The Moderate Resolution Imaging Spectroradiometer (MODIS) image, inset, upper right, shows clear-cut areas (in red) in the Karelia region of Russia's boreal forests between 2000 and 2002. MODIS is a medium-resolution sensor that provides broad spatial coverage, yet enough detail to capture relatively small clear-cuts that would otherwise be difficult to observe in vast, remote areas. (Courtesy T. Bucha, H. Stibig, from *Remote Sensing of the Environment*)

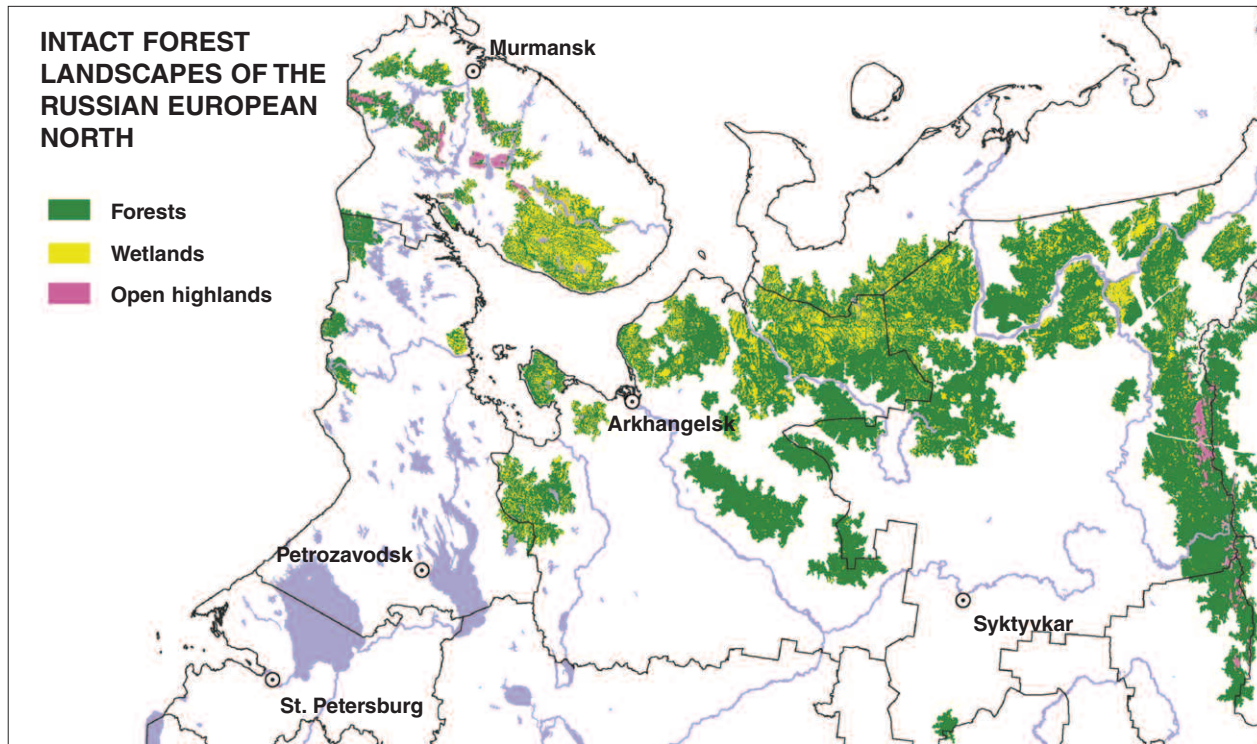
contrast between dark green trees, lighter clear-cuts, croplands, and grasses, scientists can distinguish areas of forest from other land cover types. By collecting data over long periods of time, researchers can figure out how forests are changing.

But while tropical forests are well studied, remote sensing studies of Russia's boreal forests are rare. Because the forests are so expansive, researchers attempting to map entire regions generally use coarse-resolution data that cover thousands of kilometers. However, coarse-resolution sensors cannot pick up smaller changes, such as clear-cuts, which present Russia law limits to fewer than 50 hectares (120 acres), approximately 700 meters by 700 meters (2,300 feet by 2,300 feet). High-resolution sensors can pick out details that escape the coarse-resolution sensors, but cannot easily

cover broad areas because the huge volumes of data are difficult to obtain and work with.

To find the right data, Stibig worked with fellow JRC researcher, Tomáš Bucha. They used NASA Moderate Resolution Imaging Spectroradiometer (MODIS) data, available from the MODAPS Level 1 Atmosphere Archive and Distribution System (MODAPS LAADS), to see if it could provide the missing link between detail and coverage. Bucha said, "The MODIS sensor is great for studying large geographical areas while providing good detail. We wanted to find out if this medium spatial resolution satellite imagery could support large-scale forest research."

Stibig and Bucha selected two test sites for their experiment, in the Karelia and Komi Republics



This map, compiled by Global Forest Watch Russia, shows in green the remaining areas of intact forest in northwestern Russia. As logging moves north into these untouched forests, researchers worry that one of the last, large old-growth forests in the world could be lost. (Courtesy International Arctic Research Center)

of northwestern Russia. Karelia and Komi are home to slender pine and spruce forests that produce lumber destined for northern Europe. The JRC and the Russian Space Research Institute (IKI) had already studied those test sites using high-resolution satellite imagery. In 2002, Global Forest Watch Russia and JRC identified both regions as hot spots of forest cover change. “In these areas the main forest change from humans is due to clear-cuts,” Stibig said.

With a resolution of 250 meters (270 yards), MODIS data were right at the edge of being able to detect clear-cuts; a single MODIS pixel covers 62,500 square meters (74,800 square yards). Most of the logged areas at the two sites were

made up of clear-cuts ranging in size from about 100,000 to 500,000 square meters (120,000 to 600,000 square yards), sometimes aggregating to larger logging patterns. Stibig said, “We wanted to see where the limits were. How far could we go with this medium resolution sensor?”

To distinguish forested areas from clear-cuts, Stibig and Bucha looked for color differences. “In MODIS images, the contrast between coniferous forest and clear-cut is quite strong, so we can spectrally detect this change quite well,” Stibig said. The scientists then designed a computer program to automatically identify clear-cuts. Their method caught 90 percent of clear-cuts larger than 15 hectares (37 acres),

and about 60 to 75 percent of clear-cuts between 10 and 15 hectares (25 to 37 acres).

Stibig and Bucha’s study demonstrates that the MODIS data could be useful in large-scale efforts to map change in Russia’s boreal forests. Bucha said, “The objective of this study was to see whether we could estimate forest change for large areas. MODIS data are perfect because they are freely available and easy to get.”

New view of a changing landscape

Stibig and Bucha see their study as a first step in coherently mapping the changes in Russian forest cover. Stibig said, “The idea is to test such forest monitoring approaches in a large area, for example, for all the boreal forests in the northwest of Russia, in collaboration with Russian scientists.” Such efforts could help support sustainable forest management and contribute to climate change research. While both Stibig and Bucha have now moved on to other projects, other researchers are picking up where they left off, expanding the idea to larger areas and combining MODIS with other sensors. The next challenge is to turn these short-term forest research projects into a long-term data series.

Tom Stone, a researcher at the Woods Hole Research Center, said, “Remote sensing is an ideal tool to study Russia. But we need to monitor these areas on a continuing basis. If we have just one date, we can’t say anything about the rate of change.” Mapping Russian forests over time could help researchers understand how changes in the extent of the carbon-rich Russian forests might affect global climate change. “Russia’s forests are the world’s largest, so they are very important in terms of understanding the global carbon cycle,” Stone said. “But we don’t even know whether

they are an overall source of carbon dioxide to the atmosphere, or a sink for carbon dioxide coming out of the atmosphere.”

Forestry experts say that such efforts might also help people understand the limits of a seemingly endless resource. To keep the logging industry viable, loggers have to use harvesting methods that keep forests healthy. Laestadius said, “Every country has had the same problem historically. It just depends on when you run into a wall and you see that the resource will run out.”

To access this article online, please visit
http://nasadaacs.eos.nasa.gov/articles/2009/2009_forests.html.



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For more information

NASA MODAPS Level 1 Atmosphere Archive and Distribution System (MODAPS LAADS)
<http://ladsweb.nascom.nasa.gov>
Moderate Resolution Imaging Spectroradiometer (MODIS)
<http://modis.gsfc.nasa.gov>

About the remote sensing data used	
Satellite	Terra
Sensor	Moderate Resolution Imaging Spectroradiometer (MODIS)
Data set	Level 1B Calibrated Radiances
Resolution	250 and 500 meter
Parameter	Surface reflectance
Data center	NASA MODAPS Level 1 Atmosphere Archive and Distribution System (MODAPS LAADS)

About the scientists



Tomáš Bucha is a forestry researcher at the National Forest Centre in Slovakia. He previously worked at the Global Environment Monitoring Unit of the Institute for Environment and Sustainability at the Joint Research Centre of the European Commission, where he researched remote sensing and forest management. The European Commission funded his research. (Courtesy T. Bucha)



Lars Laestadius is a forest policy researcher at the World Resources Institute and project manager for Global Forest Watch Russia. His research focuses on forestry and land use policy in Russia. He previously served as a scientific secretary for the European Commission. The World Resources Institute funds his research.



Hans-Jürgen Stibig is a researcher in the Global Environment Monitoring Unit of the Institute for Environment and Sustainability at the Joint Research Centre of the European Commission. Stibig specializes in the use of remote sensing to map and monitor forests. The European Commission funded his research. (Courtesy H. J. Stibig)

MODIS Rapid Response System
<http://rapidfire.sci.gsfc.nasa.gov>
European Commission Joint Research Center Institute for Environment and Sustainability
<http://ies.jrc.ec.europa.eu>

Global Forest Watch Russia
<http://www.globalforestwatch.org/english/russia/overview.htm>
Woods Hole Research Center
<http://www.whrc.org>

Experiment in the sky



“Volcanic eruptions are a sort of atmospheric chemistry experiment.”

Simon Carn
Michigan Technological University

by Jane Beitler

Asleep for nearly nine thousand years, Chaitén Volcano in Chile awakened from its long nap on May 2, 2008. That morning, a tall plume of smoke rose from the caldera, surprising villagers in its namesake town six miles away. Day after day, it continued a violent, pyroclastic eruption, spewing hot ash, gas, and rock. Just ten days

later, all the residents had evacuated. The town, now buried in ash mud up to three feet deep, remains abandoned.

But Chaitén’s tale was not finished; the second act of its drama took place in the Earth’s atmosphere, where sulfur dioxide gases from the eruption lingered. Simon Carn, a researcher at Michigan Technological University, follows what becomes



The eruption of Chaitén Volcano in Chile in May 2008 triggered dramatic lightning displays, illuminating the ash and smoke plume. Until this day, Chaitén had been inactive for thousands of years. (Courtesy C. Gutierrez/UPI)

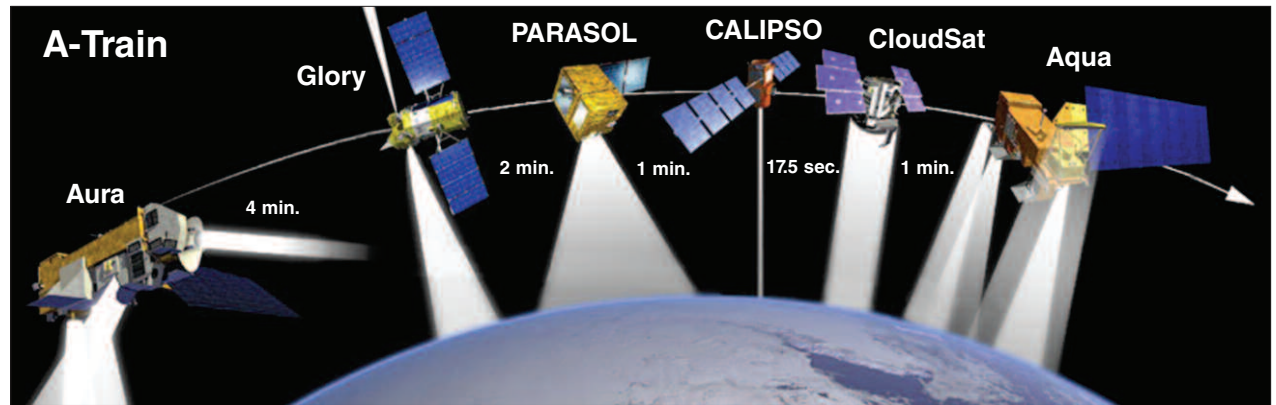
of these gases. “Volcanic eruptions are a sort of atmospheric chemistry experiment; they stick a large amount of gas into the atmosphere quickly,” he said. Scientists do not know with certainty what will result from such an experiment. They have learned that over time, the gases may transform into tiny droplets or particles called aerosols.

Suspended in the upper atmosphere in the right quantities, these aerosols can cool the Earth below. Carn said, “We know that some eruptions in the past had pretty big effects on climate.” Exactly how big is what Carn and other researchers would like to measure, using a multi-dimensional view from the A-Train, a set of satellites flying in a choreographed orbit. The satellites can witness an eruption almost simultaneously, whether expected or unexpected, like Chaitén. Researchers hope the data gathered will help weigh more precisely how volcanoes affect atmosphere and climate.

Sleeping giants

Until the launch of atmospheric-sensing satellites about thirty years ago, catching data on the atmospheric effects of eruptions could be hit or miss: only 20 percent of the world’s thousands of volcanoes have active instrument arrays on the ground, and sleepers like Chaitén can erupt at any time, with or without warning.

Earth-observing satellites can fill the data gaps in either case. Clusters of earthquakes, steam, and other visible changes tipped off scientists before the Philippines’ Mount Pinatubo erupted in 1991, after more than 500 years of slumber. Carn said, “Pinatubo was not considered active, but it gave a lot of advance warning, so scientists set up equipment in the area.” Resulting measurements confirmed that a major eruption



An artist's rendering illustrates the close flying formation of the five A-Train satellites, which carry instruments focused on atmospheric observations. These instruments can capture near-simultaneous views of atmospheric events, such as volcanic eruptions. NASA plans to add a sixth satellite, Glory, in October 2010. (Courtesy A. McClung, NASA)

was imminent; officials warned and relocated nearby residents, and researchers were able to study the outpouring of materials from Pinatubo.

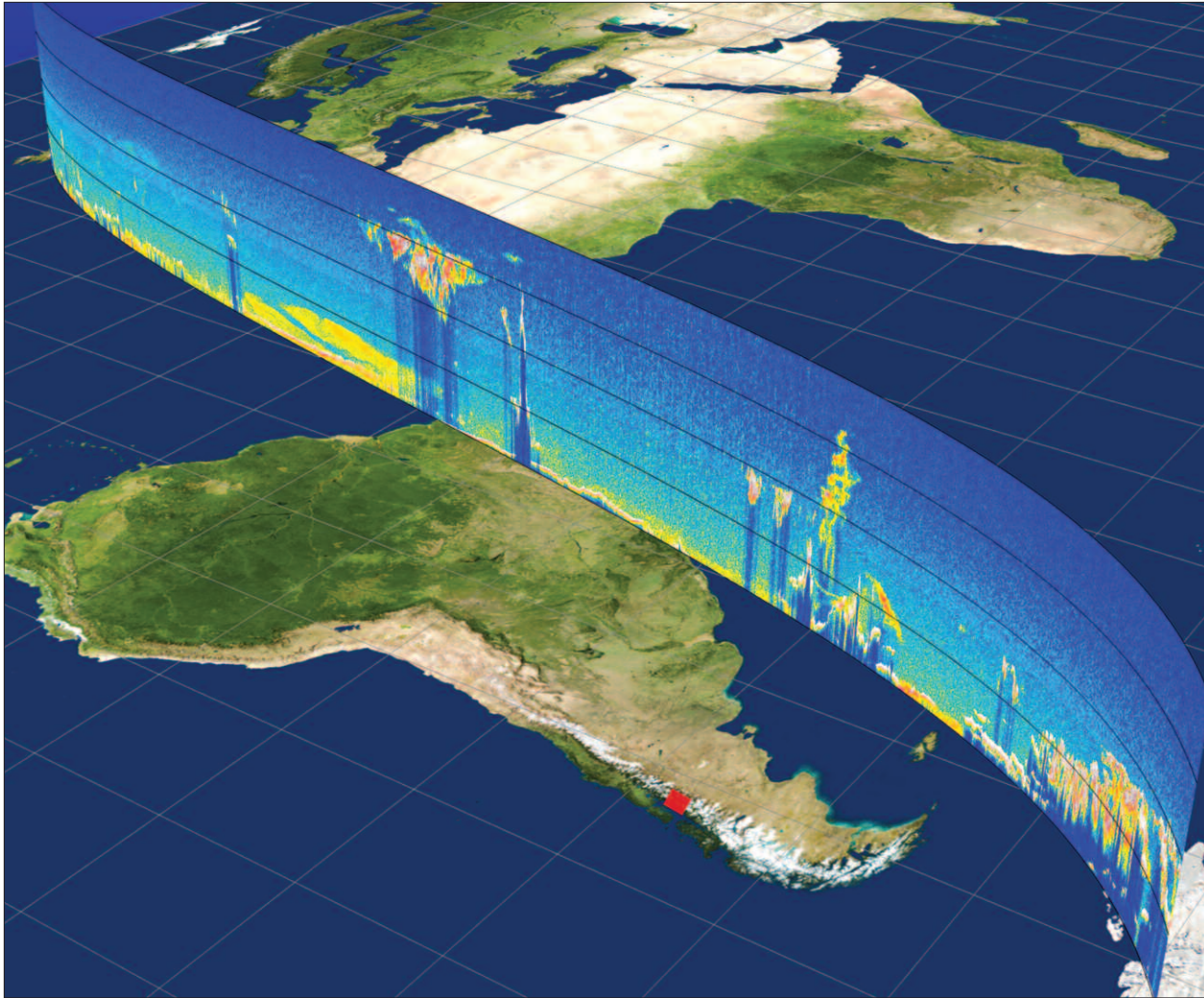
The massive eruption, about ten times larger than the 1980 eruption of Mount St. Helens in the United States, ejected about 10 cubic kilometers (2.4 cubic miles) of magma into the atmosphere. It was a case study in atmospheric effects. NASA's Total Ozone Mapping Spectrometer (TOMS), aboard the NIMBUS-7 satellite, measured twenty million tons of sulfur dioxide emissions from the Pinatubo eruption.

Over the next days and weeks, the sulfur dioxide gas converted to sulfuric acid aerosols in the atmosphere, tiny droplets that reflect solar radiation. Carn said, “If the sulfuric acid gets up into the stratosphere, it can persist a long time. In the case of Pinatubo, this resulted in a measurable decrease in surface temperatures around the Earth, a half a degree for two years after the eruption.” This knowledge can help researchers distinguish any natural events, such as volcanic eruptions, from measures of human climate impacts.

A many-faceted problem

The TOMS data were enlightening, but limited. Researchers needed to study these atmospheric interactions from many scientific angles. They worked for years after Pinatubo to piece together data on the event, which intrigued them with even more questions. A plume is not static; the materials rise, drift, and change. How high did the plume rise? Where did it drift? How does the ejected material change over time? And how long did the aerosols and ash persist in the atmosphere? To answer these questions, researchers needed to track and analyze a plume from eruption through its transport and transformation in the upper atmosphere.

Carn was interested in a particular type of plume. He said, “To have a global effect, an eruption needs to be located in the tropics; from there, the aerosols and gases can spread over the whole globe. If the eruption is too far north or south, the aerosols and gases stay in the same hemisphere. The material must be injected at least seventeen kilometers [eleven miles] high, and there has to be a lot of sulfur dioxide.”



The A-Train Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP) sensor captured a vertical view of ash and aerosols from Chaitén's May 6 eruption. This May 7, 2008, image shows a column of aerosols (reds, yellows, and oranges) east of Chaitén Volcano, which is indicated by a red square near Chile's coast. The top of the aerosol column is approximately 16 kilometers (10 miles) in altitude, reaching into the stratosphere. CALIOP reveals ash throughout the troposphere as well. Images such as this also helped show that May 6 was the largest of the three Chaitén eruptions. (Courtesy K. Severance and C. Trepte, NASA Langley Research Center)

Carn's colleague Mike Fromm, a meteorologist at the United States Naval Research Laboratory who studies clouds and aerosols, wanted satellites to sniff the aerosol soup cooked up by an eruption. Fine particulate ash can also form

aerosols, remaining suspended in the air to be transported around the globe, and mixing with potentially climate-altering sulfur dioxide aerosols. Fromm said, "The more of these little particles that form, the more the chance for a

climatic impact." He also needed to track the sulfur dioxide to sulfuric acid conversion over time; he said, "This gas-to-particle conversion can take four to six weeks."

For such complex Earth observations, NASA conceived the A-Train, so called because a set of remote sensing instruments are closely strung in orbit around the Earth. The A-Train can collect many kinds of atmospheric data around events such as eruptions, forest fires, air pollution, and more. It would not be long before these data began to help researchers answer questions, and raise new ones.

The train leaves the depot

The five A-Train satellites, launched one at a time between 2002 and 2006 by NASA, the European Space Agency, and the Canadian Space Agency, each carry several instruments that measure different aspects of the atmosphere. Flying in formation, the satellites are separated by a few minutes to a few seconds. The result is a wealth of near-simultaneous data for analyzing atmospheric events such as the Chaitén eruption. Fromm said, "Our understanding of the Earth's atmosphere has increased because of A-Train. We get all these views within fifteen minutes of each other. The varied types of measurements give you a complete picture, twice daily, covering both vertical and horizontal slices of the atmosphere."

A-Train sensors that can detect volcanic effects include the Ozone Monitoring Instrument (OMI) and the Atmospheric Infrared Sounder (AIRS), which can detect trace gases such as sulfur dioxide; the Moderate Resolution Imaging Spectroradiometer (MODIS) instrument, which provides visible images and measurements of ash mass loading;

the Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP), which provides vertical profiles of aerosols and clouds; and CloudSat, a space-based weather radar.

A-Train data are available to researchers through NASA data centers: AIRS, OMI, and collocated MODIS data from the NASA Goddard Earth Sciences Data and Information Services Center (GES DISC); MODIS images from the NASA MODIS Rapid Response System; and CALIOP data from the NASA Langley Research Center Atmospheric Science Data Center. Recently, GES DISC created the A-Train Data Depot, where scientists can work with multiple A-Train data sets, using a single online tool. They can now preview, browse, and subset the data, and visualize data from several A-Train instruments at once in Google Earth.

Just after the most recent of its satellites was launched in 2006, the A-Train captured its first eruption, of Soufrière Hills Volcano on the Caribbean island of Montserrat. The instruments provided a rich view of how the plume dispersed, and how aerosols formed and were transported. For the first time, researchers could directly measure the altitude of a fresh volcanic cloud, instead of inferring altitude from indirect measures. Fromm said, “When the data from Montserrat started to come in, we began learning for the first time how high the material went and the composition of the aerosols.”

Chaitén speaks

Chaitén was one of the most intriguing eruptions observed with the A-Train. The first of three explosions occurred on May 2, 2008, sending up a tall, visible plume of ash and smoke. On May 3 and 4, both CALIOP and OMI detected aerosols at 12 kilometers (7.5 miles) altitude; OMI detected

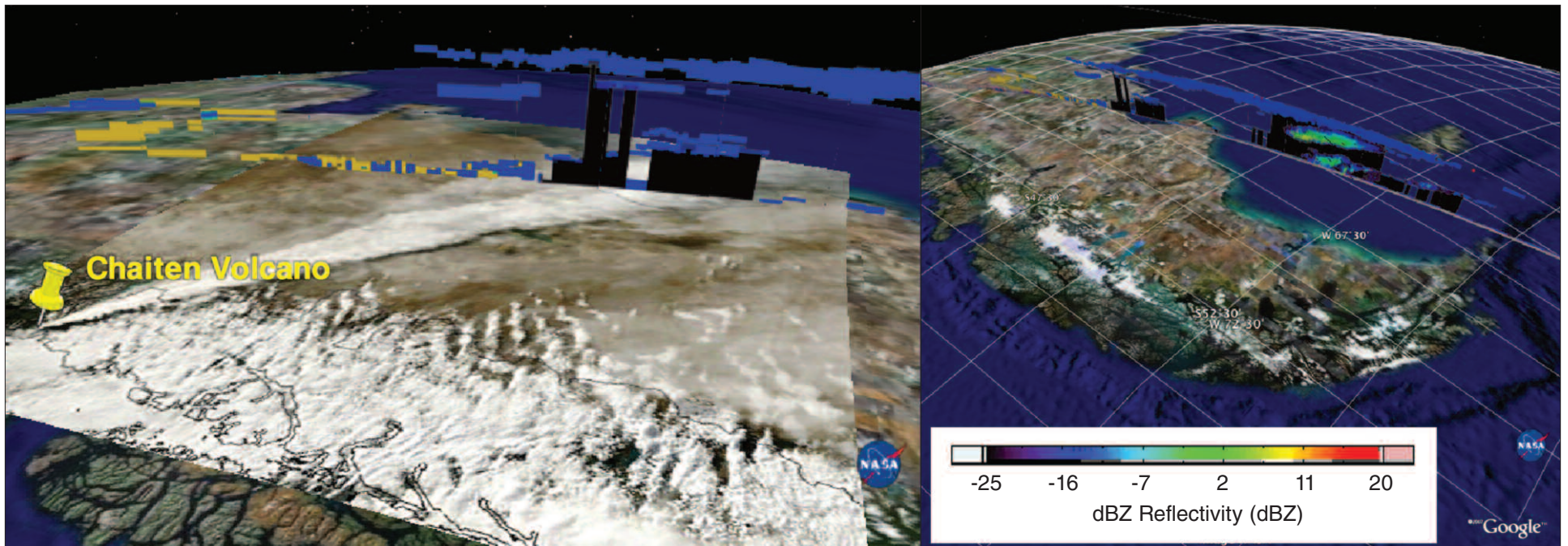


The village of Chaitén in Chile was buried in mud and ash after the unexpected eruption of Chaitén Volcano in May, 2008. All of the residents evacuated, and the village remains abandoned; authorities say it will be rebuilt six miles away. Chaitén's plume is visible in the background. (Courtesy J. R. Donoso)

sulfur dioxide, while CALIOP sensed solid particles from the fine volcanic ash and ice crystals in the plume. A second, larger explosive eruption occurred on May 6, emitting a cloud that drifted east and deposited ash over a large swath of Argentina. On May 8, CALIOP detected aerosols at 18 to 20 kilometers (11 to 12 miles) altitude. And on May 8, a third eruption produced aerosols,

detected by CALIOP on May 9 at an altitude of 13 kilometers (8 miles). CALIOP later detected aerosols from Chaitén in the stratosphere, drifting over southeastern Australia, suggesting long-range transport of fine ash.

Researchers watched the eruption's atmospheric effects unfold in the A-Train data, as the plume



As Chaitén Volcano's eruption progressed, researchers were able to quickly visualize and compare atmospheric data from several satellite instruments, using the A-Train Data Depot tools. At left are Chaitén's ash plume and cloud cover (in white) on May 2, from the Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP) instrument, overlaid on a true-color image from the Moderate Resolution Imaging Spectroradiometer (MODIS). At right, adding CloudSat data shows an even larger cloud event. Black, blue, green, and yellow indicate particles and aerosols transported into higher layers of the atmosphere. (Courtesy S. Kempler, P. Smith, and A. Savtchenko, NASA GSFC)

drifted, and as sulfur dioxide gases combined with water in the upper atmosphere to create sulfuric acid aerosols. Fromm said, "We were having e-mail discussions while watching Chaitén over a month. Aerosols began to show up the first day, and each and every day more showed up. When you would have expected ash to go away, we were seeing very strong layers over the Southern Hemisphere. It gave us a new understanding that aerosols formed much more quickly and persisted longer than we had previously thought."

More importantly, while volcanic eruptions normally emit high levels of sulfur dioxide, OMI measured strikingly low sulfur dioxide emissions during the three eruptions, due to the composition of the lava. The OMI data promise to help

distinguish the sulfur dioxide-heavy eruptions that can affect climate from eruptions such as Chaitén, thought to have little climate impact in spite of its size.

Data for climate studies

Fromm and Carn continue to study the A-Train data. Fromm said, "It is too soon to say how much climate impact these particular eruptions had, but we have a much better understanding of how frequently these eruptions occur, and a new understanding of the types of gases and particles they produce." The data are valuable for testing and refining computer models that simulate eruptions and inform climate models. Carn said, "Now we can do a much better job of assessing the role that volcanoes play in global climate.

An eruption like this is a rare event, a test we can use on climate models that are designed to predict how the climate will react. Working with these data in the models tells us how well the climate models work."

Fromm said, "I continue to monitor the A-Train for new events, because each one brings new surprises. I'm keeping an open mind. We still don't quite have all of the questions answered."

To access this article online, please visit http://nasadaacs.eos.nasa.gov/articles/2009/2009_volcanoes.html.



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For more information

- NASA Goddard Earth Sciences Data and Information Services Center (GES DISC)
<http://disc.sci.gsfc.nasa.gov>
- NASA Langley Research Center Atmospheric Science Data Center (LaRC ASDC)
<http://eosweb.larc.nasa.gov>

- NASA MODAPS Level 1 Atmosphere Archive and Distribution System (MODAPS LAADS)
<http://ladsweb.nascom.nasa.gov>
- GES DISC A-Train Data Depot
<http://disc.sci.gsfc.nasa.gov/atdd>

About the scientists



Simon Carn is an assistant professor in the Department of Geological and Mining Engineering and Sciences, Michigan Technological University. His research focuses on satellite and ground-based remote sensing for volcano monitoring, volcanic hazard mitigation, air pollution measurements, and long-range transport of atmospheric trace gases. NASA, the National Science Foundation, and the National Geographic Society funded his research. (Photograph courtesy Michigan Technological University)



Mike Fromm is a meteorologist at the Remote Sensing Division of the Naval Research Laboratory in Washington, D.C. His research interests include satellite observations of atmospheric aerosols and clouds in the troposphere and stratosphere. He is currently participating in several climate and atmospheric composition studies related to the Arctic. The United States Navy and NASA funded his research. (Photograph courtesy Naval Research Laboratory)

About the remote sensing data used

Satellites	Aura	Aqua	Aqua	Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO)
Sensors	Ozone Monitoring Instrument (OMI)	Atmospheric Infrared Sounder (AIRS)	Moderate Resolution Imaging Spectroradiometer (MODIS)	Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP)
Data sets	OMI/Aura Near-UV Aerosol Optical Depth and Single Scattering Albedo	AIRS IR geolocated radiances	Level 1B Calibrated Radiances (MOD021KM)	CALIPSO Lidar Level 2 Vertical Feature Mask data
Resolution	13 x 24 kilometer	13.5 kilometer	1 kilometer	30 to 180 meter vertical; 333 to 1667 meter horizontal
Parameters	Aerosol optical depth	Radiance	Radiance	Aerosol backscatter
Data centers	NASA Goddard Earth Sciences Data and Information Services Center	NASA Goddard Earth Sciences Data and Information Services Center	NASA MODAPS Level 1 Atmosphere Archive and Distribution System (MODAPS LAADS)	NASA Langley Research Center Atmospheric Science Data Center

An ocean full of deserts



“With chlorophyll and temperature data, we could begin to find out what was happening to global ocean productivity.”

Jeffrey Polovina

Pacific Islands Fisheries Science Center

by Stephanie Renfrow

The world’s oceans provide us with the seafood that fills our plates and tempts our taste buds: tuna, salmon, lobster, scallops. All of this sea life is part of a complex food web that can support an abundant and diverse range of plants and animals. Like a house of cards, that food web rests on its lowest and least-known participants; if the first level gets shaky, all the levels above teeter, too. The lowest level in the ocean food web consists of historically abundant and productive phytoplankton, tiny ocean plants that convert carbon dioxide to organic carbon, and whose green chlorophyll is visible from

space. Satellites can detect this chlorophyll, and scientists use the data to estimate ocean productivity, a measure of the amount of organic carbon available to support the food web.

However, the abundance of phytoplankton appears to be shrinking. Ocean biologist and satellite data enthusiast Jeffrey Polovina said, “We saw that the low-productivity area of the west Pacific was expanding, and we wondered if it was unique or if it was happening globally.” Models predict that the warmest portions of the world’s oceans will become less productive because of climate change. Some people call these low-productivity regions “biological deserts.” Polovina



The ocean food web is filled with little-known varieties of fish and marine animals; here, a black and yellow rockfish swims in Monterey Bay, California. (Courtesy J. Pederson)

said, “The climate models are on century timescales and suggest that the rate of expansion of these expected low-productivity areas will be slow.” But the scientists wanted to compare those modeled expectations with observations.

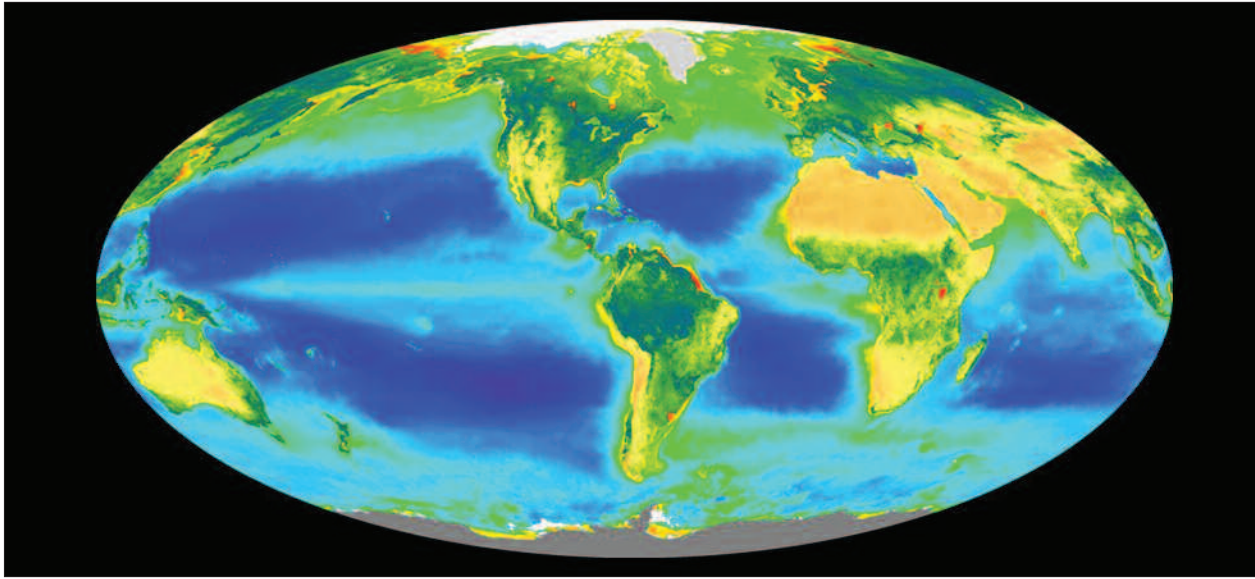
Phytoplankton and ocean temperature

To evaluate ocean habitat from space, scientists first have to understand it close up. The mixing of different layers of water is one reason that high-productivity areas exist in the world’s oceans. One of the signatures of global warming is rising ocean temperatures. As the surface layer of the ocean warms, the water becomes less dense and stays on top rather than mixing down to allow cooler, nutrient-rich water to well up. Over time, areas with less mixing show reduced productivity, less phytoplankton, and so less chlorophyll. Polovina said, “Regions that have the lowest level of chlorophyll are akin to biological deserts; there’s less energy propagating up through the food web.”

To study the formation of ocean deserts, Polovina worked with colleagues Evan Howell and Mélanie Abécassis to use surface chlorophyll data. The data, from the NASA Sea-Viewing Wide Field-of-View Sensor (SeaWiFS), which is operated by GeoEye and processed, archived, and distributed by the Ocean Biology Processing Group at NASA’s Goddard Space Flight Center, helped them locate areas where low-chlorophyll regions were expanding during their nine-year time series of data. Abécassis, who helped process the data, said, “The data set is amazing, with fantastic resolution and global coverage.” In addition, the data offered the team quality information. “The only challenge with working with the data was also one of the best things about it: we had to download all the data again and reprocess it because NASA released a new version after correcting for a sensor defect,” she



Beneath the ocean’s surface, its food webs depend on creatures small and large, such as this school of chub at the Kure Atoll State Wildlife Refuge in the Papahānaumokuākea National Monument. (Courtesy P. Marin)



Phytoplankton are microscopic ocean plants that form the base of ocean ecosystems; they are so abundant that they are visible from space. Here, average chlorophyll from 1998 through 2006 is shown in green and indicates areas of high biological productivity. (Courtesy SeaWiFS Project/NASA GSFC and GeoEye, Inc.)

said. “It took more time, but it made our results increasingly accurate.”

The team also used sea surface temperature data from the Advanced Very High Resolution Radiometer (AVHRR), available at the NASA Physical Oceanography Data Center (PO.DAAC). While many factors can reduce ecosystem productivity—overfishing, for example, or El Niño, a cyclic condition characterized by higher-than-normal sea surface temperatures—global warming is expected to herald particularly large reductions in productivity. Studies predict that if global warming intensifies, areas with decreasing chlorophyll will match up with areas of increasing sea surface temperature.

Polovina said, “With chlorophyll and temperature data, we could begin to find out what was happening to global ocean productivity.”

The growing desert

The team’s results were noteworthy. Polovina said, “We were very surprised. We looked at the North Atlantic, the South Atlantic, the Indian Ocean—we saw the same trends all over the globe. Over nearly the past decade, regions with low surface chlorophyll were expanding into nearby ocean basins. The total area lost was quite enormous.” The area of new global ocean desert added up to 6.6 million square kilometers (2.5 million square miles), representing about a 15 percent expansion in the area of the least productive waters between 1998 and 2006. Plus, the connection to sea surface temperature was clear. “The expansion of low-productivity waters matched up with significant increases in sea surface temperature,” Polovina said.

The team also noticed that the changes over the past decade were seasonal. “There was greater

expansion from one winter to the next than from one summer to the next,” Polovina said. “In the summer, regions of low chlorophyll expanded; in the winter, those areas would naturally contract—but to a larger size than we saw the previous years.” So the expansion of ocean deserts proceeded in a step-by-step fashion over the nine-year time series.

But perhaps the most surprising aspect of the team’s findings was the rate of expansion: this step-by-step desertification has led to a 1 to 4 percent loss in productive waters per year. Abécassis said, “The actual rate of expansion was much bigger than the models predicted.”

A recent study using six climate models suggested that between the beginning of the Industrial Revolution and 2050, the total growth in low-productivity areas in the Northern and Southern Hemispheres would range from 0.7 percent to 8.1 percent, depending on various parameters. Polovina said, “We’ve measured more than even the high range in only nine years.”

An unproductive future

The question that remains unanswered, in Polovina’s mind, is why ocean deserts are expanding. “We’re seeing these changes in all the world’s oceans,” he said, “which is suggestive of either a ten-year global signal or a long-term global warming trend.” So which is it?

The team is careful to point out that their study covers nine years, approximately the length of time that SeaWiFS has been taking data. Although nine years is a reasonably long time series, scientists prefer to base their research on longer time series of thirty or more years to ensure that natural cycles, such as El Niño and

its opposite, La Niña, characterized by lower than normal sea surface temperatures, have been taken into account. “During the period of our study there have been several La Niña events, so the large-scale climate has been unique,” Polovina said. “It’s possible that the trend will reverse in the coming decade. Or, it could be that the trend holds and the losses really are worse than what models are indicating they should be.” Either way, Polovina feels that the research bears on global warming. He said, “Even if this trend is just a decadal signal that gets reversed, this is the type of expansion we would expect to see under global warming. This sort of change is something we need to be prepared for.”

The growth of biological deserts in the world’s oceans, and what may come along with it in the future, has Polovina’s attention. “This is a unique biological signal that we’re seeing. What this means is that the ability of the oceans to support life has decreased,” he said. “The density of mahi-mahi, shark, tuna, et cetera, will be less.” Abécassis agreed, saying, “The expansion of poor productivity areas is a major concern—with implications for ocean food webs and potentially a lot of changes for fisheries.” Scientists like Polovina and Abécassis can help tell the story of the unfolding changes now happening to our oceans. With scientific information behind them, fisheries and policy makers may be able to plan and prepare, softening the blow on particular species and preserving the ocean ecosystem’s long-standing food web.

To access this article online, please visit http://nasadaacs.eos.nasa.gov/articles/2009/2009_oceans.html.



About the remote sensing data used

Satellites	GeoEye SeaStar	NOAA Polar Orbiting Satellites
Sensors	Sea-Viewing Wide Field-of-View Sensor (SeaWiFS)	Advanced Very High Resolution Radiometer (AVHRR)
Data sets	Ocean color	AVHRR Pathfinder SST
Resolution	9 kilometer	9 kilometer
Parameters	Surface chlorophyll	Sea surface temperature
Data centers	NASA Ocean Biology Processing Group	NASA Physical Oceanography Distributed Active Archive Center

Note: The researchers used data reprocessed by NOAA Pacific Islands Fisheries Science Center. The reprocessed data are available at http://oceanwatch.pifsc.noaa.gov/map_hrpt_sst.html.

About the scientists



Mélanie Abécassis is a research analyst with the Joint Institute for Marine and Atmospheric Research at the University of Hawaii. She specializes in tag and oceanographic data analysis. She received her masters in oceanography and engineering from the University of Paris in 2006. The National Oceanic and Atmospheric Administration (NOAA) provided funding for her ocean habitat research. (Photograph courtesy M. Abécassis)



Jeffrey Polovina is currently the Chief of the Ecosystem and Oceanography Division at the Pacific Islands Fisheries Science Center in Honolulu, where he focuses on the changing habitats of turtles, tunas, whale sharks, and other animals, using satellite data. NOAA funded his research. (Photograph courtesy J. Polovina)

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- NASA Physical Oceanography Distributed Active Archive Center (PO.DAAC) <http://podaac.jpl.nasa.gov>
- Sea-Viewing Wide Field-of-View Sensor (SeaWiFS) <http://oceancolor.gsfc.nasa.gov/SeaWiFS>
- Advanced Very High Resolution Radiometer (AVHRR) <http://nssdc.gsfc.nasa.gov/nmc/experimentDisplay.do?id=1978-096A-01>

Probing the Arctic atmosphere



“Arctic haze has been observed from the ground for a long time, but we don’t completely understand it.”

Louisa Emmons

National Center for Atmospheric Research

by Katherine Leitzell

In a bustling room in Fairbanks, Alaska, a group of researchers watched two blips move eastward on a map of the Arctic. After an eight-hour flight collecting atmospheric data over northern Canada, the blips—two airplanes riddled with sensors—had almost reached Thule, Greenland. Jennifer Olson, an atmospheric chemist, worked on data archiving and flight planning during the 2008 Arctic Research of the Composition of the Troposphere from Aircraft and Satellites

(ARCTAS) experiment. Olson said, “We were about to leave for the day, when we saw that one of the airplanes had not stopped in Thule. It was continuing on.”

Strong winds in Thule, Greenland, forced the pilots of the NASA McDonnell Douglas DC-8 to look for a calmer spot to land. The scientists had to rethink their carefully planned research flight. Flight time was limited during the mission, and the researchers in Fairbanks found themselves scrambling through satellite



A view from an airplane window reveals some of the pollution that smothers the Arctic each spring and summer. Instruments on board the airplane collected data from the smoke plume, generated by a forest fire over Canada on July 1, 2008. (Courtesy NASA)

data, weather maps, and pollution forecasts to rebuild a flight plan that would allow the scientists on the airplane to take a few more measurements. Getting the most out of each research flight was key to the success of the field experiment. Olson said, “We just wanted to squeeze any science that we could out of the situation.”

ARCTAS, a NASA field campaign that took place during two separate missions in 2008, explored many details of the Arctic atmosphere. Researchers want to learn more about air quality and aerosols in the Arctic, because increasing pollution in the region will likely impact delicate ecosystems and climate.

Airplanes, satellites, and scientists

In the control room in Fairbanks, the researchers used a new tool called the NASA Real-Time Mission Monitor (RTMM) to look for places that the diverted DC-8 could collect data as it swung back from Greenland to land in Iqaluit, Canada. Scientists at the NASA Global Hydrology Resource Center developed RTMM to provide real-time information and communication tools during field missions. While most of the forty-four spring flights during ARCTAS went smoothly, RTMM proved especially helpful for the flight diverted from Thule.

Using RTMM, the scientists in Fairbanks looked through pollution models, satellite data, and weather, overlaid on a Google Earth map. They quickly located a nearby area that showed high levels of bromine oxide, a chemical that contributes to ozone depletion. The team on the ground discussed the options with the team in the air, using a special text-messaging server located in Colorado, and the aircraft’s Internet gateway at NASA Dryden Flight Research Center in



During the Arctic Research of the Composition of the Troposphere from Aircraft and Satellites (ARCTAS) field campaign, scientists flew eighty-six research flights to gather data on the Arctic atmosphere. This Google Earth image shows the flight tracks for the three NASA airplanes that collected data on pollutants and atmospheric properties during spring and summer of 2008. (Image courtesy L. Emmons, NASA)

California. Armed with information and the ability to communicate between ground and air, the team was able to quickly work out a plan to take further measurements.

“Having that capability was great,” Olson said, “We had the satellite data and the airplane information, and we were able to communicate directly with people on the airplane. In the past, they most likely would have just gone straight to

the other airport, but we were able to get a little more work done.”

Data from the Arctic sky

In recent decades, the Arctic has warmed more than any other region on Earth. However, scientists know less about the Arctic atmosphere than they do about most other places on the planet. The spring portion of ARCTAS focused on Arctic haze, the heavy air pollution that



University of California, Irvine, graduate student Katrine Gorham operates an air sampler on a NASA DC-8 airplane during an Arctic Research of the Composition of the Troposphere from Aircraft and Satellites (ARCTAS) flight. (Courtesy NASA/Eric James)

obscures the sky in spring. Louisa Emmons, an atmospheric chemist at the National Center for Atmospheric Research (NCAR) worked in Fairbanks during the field experiment. She said, “Arctic haze has been observed from the ground for a long time, but we don’t completely understand it.” During the spring portion of ARCTAS, researchers explored the effect of Arctic haze on climate, studied where the haze came from, and compared airplane measurements to ground and satellite measurements.

Scientists think that Arctic haze probably has an effect on temperatures, an effect called radiative forcing. Emmons said, “Adding more aerosols to

the air can heat or cool the atmosphere.” But it is not clear whether the dominant effect is warming or cooling. Like the insulation in a house, the aerosols that make up air pollution can trap heat close to the Earth. They can also work the opposite way to keep temperatures cool, by reducing the amount of heat that gets to the ground in the first place.

ARCTAS researchers also wanted to find out exactly where Arctic haze originates. “For many years, we assumed that Arctic haze came mostly from power plants in Europe,” Emmons said. However, recent studies have shown that pollution from North America and Asia, and forest fires in northern Asia, also contribute to the haze.

During ARCTAS, airplanes outfitted with a variety of sensors flew through pollution plumes and measured chemicals that can show what type of combustion initiated the plume. These sensors gathered data that could not be measured with current satellite-based pollution sensors. Emmons said, “Several current satellite instruments measure carbon monoxide, and that gives us a nice picture of pollution plumes around the globe. But there are many sources of carbon monoxide: fires, traffic, and power plants. If we look at the relative contributions of other gas-phase species and aerosols, we can sort out whether a plume came from fires in Canada or anthropogenic pollution in China.”

Finally, ARCTAS researchers took advantage of the multiple research flights to collect data for comparison with existing satellite measurements. “It’s a challenge to get good information over snow- and ice-covered regions,” Emmons said. Just as the reflection off the shiny surface of a glacier makes it hard to see, the reflective ice and snow in the Arctic can make it challenging for satellites to collect accurate data. Collecting data from an airplane at the same place and time that a satellite passes over allows scientists to compare the data. Emmons said, “This is an opportunity to see what the limits of satellite retrievals are in the Arctic, and to get more information out of them.”

ARCTAS researchers are now working to integrate the information collected from the mission into pollution and climate models. Emmons said, “If our models work well for this experiment, we can then do future scenarios, and better understand how climate might change under different conditions.”

Arctic climate and pollution

The Arctic serves as a waste bin for air pollution, which builds and persists through the Arctic spring and summer. But scientists know little about how that pollution may affect regional climate and ecosystems. Scientists hope that research stemming from the ARCTAS field mission will bring some much-needed clarity to the hazy information on the Arctic atmosphere.

The ARCTAS experiment was the largest field mission ever to explore the Arctic atmosphere. Emmons, Olson, and the other researchers who worked on the experiment still have a challenge ahead of them: making sense of the thousands of data points collected during the experiment. Emmons said, “We’re putting everything together

now. It's a pretty complex system, but if we improve our models for regional pollution transport, we could better understand the climate implications of pollution in the Arctic.”

To access this article online, please visit http://nasadaacs.eos.nasa.gov/articles/2009/2009_arctic.html.



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NASA Global Hydrology Research Center (GHRC)
<http://ghrc.msfc.nasa.gov>

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

Arctic Research of the Composition of the Troposphere from Aircraft and Satellites (ARCTAS) Data at the NASA Langley Research Center

<http://www-air.larc.nasa.gov/missions/arctas/arctas.html>

ARCTAS Mission Page

http://www.nasa.gov/mission_pages/arctas

About the remote sensing data used

Sensors	Various airborne sensors
Data sets	Arctic Research of the Composition of the Troposphere from Aircraft and Satellites (ARCTAS): DC-8 aircraft data P-3B aircraft data B200 aircraft data
Resolution	Various
Data center	NASA Langley Atmospheric Science Data Center

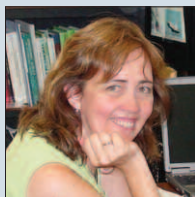
About the data tool used

Tool	Real Time Mission Monitor
Products provided	Simultaneous aircraft tracking for the NASA DC-8, P-3B, and B200 Satellite imagery, aircraft state information, and surface data sets
Data center	NASA Global Hydrology Resource Center

About the scientists



Louisa Emmons is an atmospheric chemist at the National Center for Atmospheric Research in Boulder, Colorado. Emmons uses satellite, aircraft, and ground measurements to study pollution in the atmosphere. NASA supported her work on Arctic Research of the Composition of the Troposphere from Aircraft and Satellites (ARCTAS). (Photograph courtesy C. Calvin, University Corporation for Atmospheric Research)



Jennifer Olson is an atmospheric chemist in the Science Directorate at the NASA Langley Research Center in Hampton, Virginia. She focuses on the measurement of trace species in the atmosphere, including chemicals that come from pollution and forest fires. During ARCTAS, Olson worked on flight planning and data management. Her funding comes from NASA. (Photograph courtesy G. Chen)

NASA Real Time Mission Monitor (RTMM)

<http://rtmm.nsstc.nasa.gov>

NASA Research Environment for Vehicle Embedded Analysis

http://www.nasa.gov/centers/dryden/research/ESCD/OTH/Tools_Technologies/reveal.html

National Center for Atmospheric Research (NCAR)

Atmospheric Chemistry Division

<http://www.acd.ucar.edu>

Drying in Denali



“Are these lakes really drying and disappearing?”

Amy Larsen

United States National Park Service

by Laura Naranjo

Alaska’s wetlands, dotted by thousands of small, shallow lakes, have existed for about 8,000 years. But now, this vibrant summer habitat is drying up. Ecologist Amy Larsen said, “We’d been hearing stories from native elders, community members, and bush pilots that lakes were drying up.” She wondered what had changed. “Are we just in some kind of hydrologic low, and we haven’t had a big recharge that fills the lakes up over time? Or are these lakes really drying and disappearing?” Larsen asked.

Wetlands occupy almost half of Alaska, including much of the state’s public lands. These wetlands abound in life during the summer. Moose forage

in the swamps for tender willow shoots. Beaver and muskrat build lodges in shallow ponds, and birds nest in lakeside sedges. Plants reproduce and animals raise their young during the short summer months before winter refreezes Alaska’s landscape. Larsen was concerned about what would happen to the state’s wildlife and plants if lake levels continued to dwindle.

Larsen, an aquatic ecologist with the United States National Park Service in Alaska, began studying wetlands in Denali National Park and Preserve. Because Alaska’s short summer season limits fieldwork to June, July, and August, Larsen and her team could only gather data from a few lakes each year. So Larsen teamed up with University of Alaska remote sensing specialist



When most people think of Alaska, they imagine glacier-capped mountains such as Mount McKinley, the peak in this photograph. But shallow lake wetlands occupy nearly half of Alaska’s landmass, providing critical habitat for moose, muskrats, beaver, and waterfowl. (Courtesy T. O’Dea)

Dave Verbyla. Larsen and Verbyla combined remote sensing's broad view of the wetlands with observations of individual lakes. They hoped to discover why lakes were shrinking and assess the survival prospects for these rich ecosystems.

Defining the drying

Verbyla had just completed a study using satellite images and aerial photographs, which revealed that many of Alaska's shallow lakes had shrunk or disappeared in the last fifty years. His findings mirrored records indicating that temperatures in interior Alaska, where the park is located, had risen nearly two degrees Celsius (four degrees Fahrenheit) over the same time period. During the same time, however, precipitation had remained the same. So why was water disappearing from lakes? Were rising temperatures increasing evaporation? Was warmer weather thawing the frozen soils that exist under much of Alaska's interior, and if so, why would that affect water levels?

It was hard to tell, because there was little field data to complement temperature records, and the historical satellite and aerial images of the lakes that Verbyla used had been taken only sporadically. Larsen said, "The information we had was very patchy."

During the 2006 pilot year for their study, the researchers focused on shallow lakes in Minchumina Basin, in the northwestern corner of the park. The basin provided a representative sample of the state's wetlands. To measure lake surface area, Verbyla used Synthetic Aperture Radar (SAR) data from the Canadian Space Agency RADARSAT-1 satellite, available from the Alaska Satellite Facility SAR Data Center. Verbyla said, "From April through October, about every ten days or so, we had a RADARSAT-1 pass



Thousands of small lakes dot Alaska's interior wetlands. Over the past fifty years, many of these shallow lakes have been drying up, reducing habitat for the state's wildlife populations. (Courtesy United States National Park Service)

of Minchumina Basin." Satellite imagery provided a large-scale view of the wetlands and allowed the researchers to track lake changes over the course of the study.

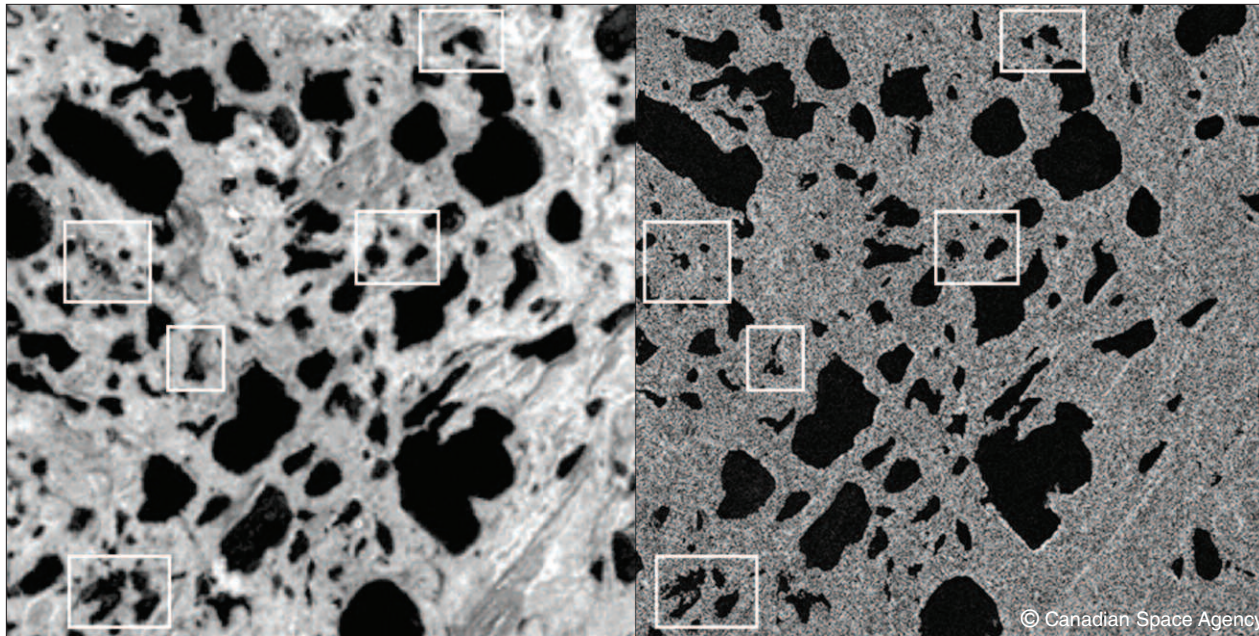
Over the same time period, Larsen and her team visited thirty lakes in the basin to obtain details about changes in lake habitat. She sampled water quality and surveyed plant life in and around the lakes, because changes in these features could also indicate changes occurring in wetland habitat.

In Minchumina Basin, Larsen and Verbyla observed that lakes were shrinking, but only some

of them. Verbyla said, "We found that there are areas where lakes are fairly stable, and then areas where lakes change quite a bit." If rising temperatures and evaporation were the culprits, why were not all lakes in the area drying up?

Porosity, permafrost, and plants

Larsen and Verbyla returned in 2007 hoping to discover other factors that might contribute to lake drying, such as soil conditions or permafrost thaw. When they compared the shrinking lakes to soil type, they found a connection. Verbyla said, "In certain places the soil texture itself could be controlling some of the drainage." Larsen said, "Between 2006



This pair of satellite images reveals drying in some of Alaska's lakes. Black areas indicate water; shades of gray indicate land and vegetation. The Landsat image on the left shows lake extent on July 21, 1985; the RADARSAT-1 image on the right shows lake extent twenty years later, on July 8, 2005. Comparing the imagery revealed which lakes had shrunk, highlighted in white boxes. (Courtesy D. Verbyla, RADARSAT-1 image copyright Canadian Space Agency)

and 2007, we saw about a 16-centimeter [6.3-inch] water level drop in areas underlain with sand." During the same time, lakes surrounded by fine silt or clay lost little water.

Frozen soils provided another clue to the shrinking lakes. Most of the Minchumina Basin is located over discontinuous permafrost, meaning that some of the soil surrounding the lakes is frozen. While the ground directly under a lake may not be frozen, permafrost often forms a protective ring around the lake. "It's almost like a bathtub," Larsen said. "The permafrost surrounding the lake prevents water from going anywhere."

Areas of discontinuous permafrost are particularly vulnerable, because the ice trapped in the soil is near the melting point and thaws easily

in response to slight temperature increases. But plants and other ground cover, such as peat, an accumulation of dead and decaying vegetation, can help insulate permafrost. During the summer, Larsen looked for peat around lakes. "We wanted to see how much peat and organic material was lying on the surface of that soil, protecting the ice in the frozen layers below from melting," Larsen said.

Larsen and Verbyla discovered that lake drying did not depend directly on temperature, but on factors underneath and around the lakes that may respond to temperature changes. A warming climate would not affect soil type, but it could thaw permafrost and cause changes in the overlying vegetation, leaving lakes more susceptible to drying.

Adapting to change

Drying lakes in Minchumina Basin reflect similar changes happening across the state. Decreasing water levels affect many wildlife populations such as muskrats, small, semi-aquatic rodents similar to beavers. Larsen said, "Muskrats need open water under the ice in order to survive. So if more of these lakes get so shallow that they freeze during the winter, then muskrats are losing habitat." Shrinking lakes and other habitat changes may be contributing to the unexplained decline of muskrats across North America.

The researchers are now trying to place shrinking lakes into a larger climate context: Is lake drying temporary and reversible, or are disappearing lakes a permanent consequence of climate change? While temperature records across Alaska and many other Arctic and sub-Arctic areas confirm



Muskrats need open water year-round to survive. They feed on aquatic plants like cattails, and build their lodges in ponds and lakes. But many of Alaska's lakes have become so shallow that they freeze during winter; researchers think that declines in muskrat populations may be linked to the drying of Alaska's lakes. (Courtesy M. Soveran)

warming, regional climate variations also play a role. Interior Alaska's climate is governed by a larger pattern, which alternates between warm, dry periods and cool, wet periods. Since the 1970s, Alaska has experienced a warm phase, but recent evidence indicates that the state may be returning to a cooler phase of the pattern. Scientists are not yet sure whether this oncoming shift will restore lower temperatures, or if global warming will prevent significant cooling. Larsen, Verbyla, and other scientists will capture data during the shift, to observe how Alaska's wetlands and other sub-Arctic ecosystems respond.

Past lake changes may also provide clues. Verbyla said. "I'm going back in time, using historical aerial photography and satellite imagery to delineate where the lake shorelines were. That will tell us what the variability has been over the last twenty to twenty-five years." Larsen will take sediment cores to see whether the lakes fluctuated over the past 8,000 years, and determine if Alaska's wetlands have undergone, and recovered from, a similar drying period.

Larsen and Verbyla plan to continue combining satellite data and fieldwork to create a long-term time series of data for interior Alaska's wetlands. Wetlands provide habitat and feeding grounds for large wildlife populations, and Larson wonders how these changes will affect the state's national parks. She asked, "How are we going to sustain moose populations in these regions once these important feeding areas are gone? What about muskrats? What about beavers? What happens if we're losing the lakes that support them?"

To access this article online, please visit http://nasadaacs.eos.nasa.gov/articles/2009/2009_lakes.html.



About the remote sensing data used

Satellite	Canadian Space Agency RADARSAT-1
Sensor	Synthetic Aperture Radar (SAR)
Data set	Fine-beam SAR data
Resolution	8 meter
Parameter	Land cover
Data center	NASA Alaska Satellite Facility SAR Data Center

About the scientists



Amy Larsen is an aquatic ecologist with the United States National Park Service (NPS) in Fairbanks, Alaska, specializing in monitoring shallow lake dynamics. Her work focuses on monitoring lake level dynamics and the corresponding impacts on lake chemistry, geomorphology, and food web dynamics. The Central Alaska and Arctic Networks of the NPS Inventory and Monitoring Program supported her work. (Photograph courtesy A. Larsen)



Dave Verbyla is a professor in the Department of Forest Sciences, University of Alaska Fairbanks. His research interests include landscape-level changes in Alaska's boreal forest associated with climate warming, estimating wildfire severity from remote sensing, and validation of remote sensing products. The NASA Land Cover/Land Use Change Program and the Bonanza Creek Long-Term Ecological Research program funded his research. (Photograph courtesy D. Verbyla)

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- Canadian Space Agency RADARSAT-1 <http://www.asc-csa.gc.ca/eng/satellites/radarsat1/default.asp>
- National Park Service Central Alaska Network <http://science.nature.nps.gov/im/units/cakn/index.cfm>
- Dave Verbyla <http://nrm.salrm.uaf.edu/~dverbyla>

Notebook and satellite



“How do you link a big pixel with field observations?”

Kirsten de Beurs
Virginia Polytechnic Institute
and State University

by Jane Beitler

Travis Belote had not planned on making space in his already-packed brain for much new information. Just finishing doctoral studies in biology at Virginia Tech, he was about to head for Flagstaff, Arizona, to study the Colorado Plateau drylands. He thought he might squeeze in an overview of one last topic, taught by professor Kirsten de Beurs: Remote Sensing and Phenology. He decided to audit the course, attending one lecture a week.

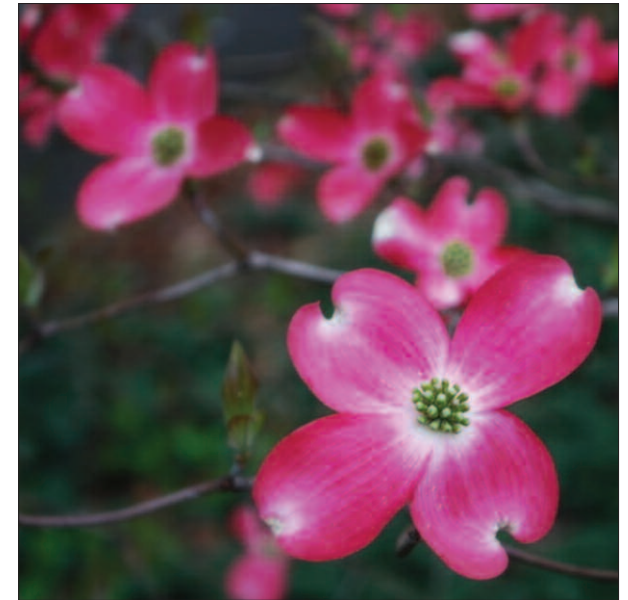
But soon after the start of the class with the abstract-sounding name, Belote changed his mind. He said, “I ended up coming every day. I looked forward to every lecture because of the fascinating material.” Belote, who anticipated a career of field studies, was inspired to see new angles and scales for research, using satellite instruments that cover the globe. Belote said, “It was eye-opening to see the scale of the data that were being collected with this frequency, all the questions you could potentially ask with the data, all the different applications.” So what hooked him?

Observing seasonal changes

As he attended the lectures, Belote found that he and de Beurs had a common thread in their research interests: that of ecosystem disturbance. Belote wanted to sort out the factors that can push a landscape over the edge. A dry grassland, such as the Colorado Plateau, might remain stable even after disturbances like fire, drought, or heavy animal and human activity. But

sometimes, disturbances can change a grassy prairie to scrubby desert. Belote was especially interested in how land use, such as the intense grazing from ranching, affects an area; at what point can it transform an ecosystem long-term?

Similarly, as a phenologist, de Beurs studies how disturbances change a system, by observing the subtle evidence of plant and animal life cycle events. Triggered by seasons and climate, these life cycles are a closely connected chain of events that sustain an ecosystem. Plants bud when



Students in Kirsten de Beurs' Remote Sensing and Phenology class observed the trees on campus for phenological events, such as the bloom of this dogwood tree. They compared these field observations to satellite vegetation data to obtain a broader and more accurate interpretation of these start-of-season signals. (Courtesy A. R. Laurent)

temperature and moisture are just right, bearing flowers, fruit, and seeds that support insects and animals; insects hatch and become food for birds. If something is introduced that disturbs these patterns of timing, effects can cascade through the system, and changes show up on a larger scale.

De Beurs has a radar-like curiosity for detecting all kinds of disturbances in satellite data, piqued during her own doctoral work, a study of Kazakhstan after the former Soviet Union fell apart in 1991. De Beurs said, “We asked, what is the effect of the collapse of the Soviet Union on land use? You can take the concept that the political collapse is an ecological disturbance, too. We can see evidence of land use in remote sensing data, when things green up and brown down. I wondered if we could see the changes in land use that we heard were occurring there, using satellite vegetation data.” Rapid social change had driven farmers to abandon agriculture and migrate to cities. Her interest in the topic continues, as she currently prepares for a more detailed, multi-year study of Russian agriculture, which is projected to decline due to an expected 29 percent population decline by 2050.

Plant and animal evidence

Typical of her all-angles approach, de Beurs’ upcoming Russian study will integrate field, satellite, demographic, and socioeconomic data. It was de Beurs’ integrative approach to phenology that opened new ways of thinking for Belote. De Beurs proved how studies can be conducted with satellite data and computer, as well as notebook and pencil, even for a subject as small as the gypsy moth. De Beurs said, “The gypsy moth larva eats leaves until trees are almost bare.” The Moderate Resolution Imaging Spectroradiometer (MODIS) instrument, on

NASA’s Aqua and Terra satellites, could detect the defoliation by sensing leaf reflectance, but the window is small. “The trees re-leaf within the same growing season; that makes it hard to track what’s happening,” she said.

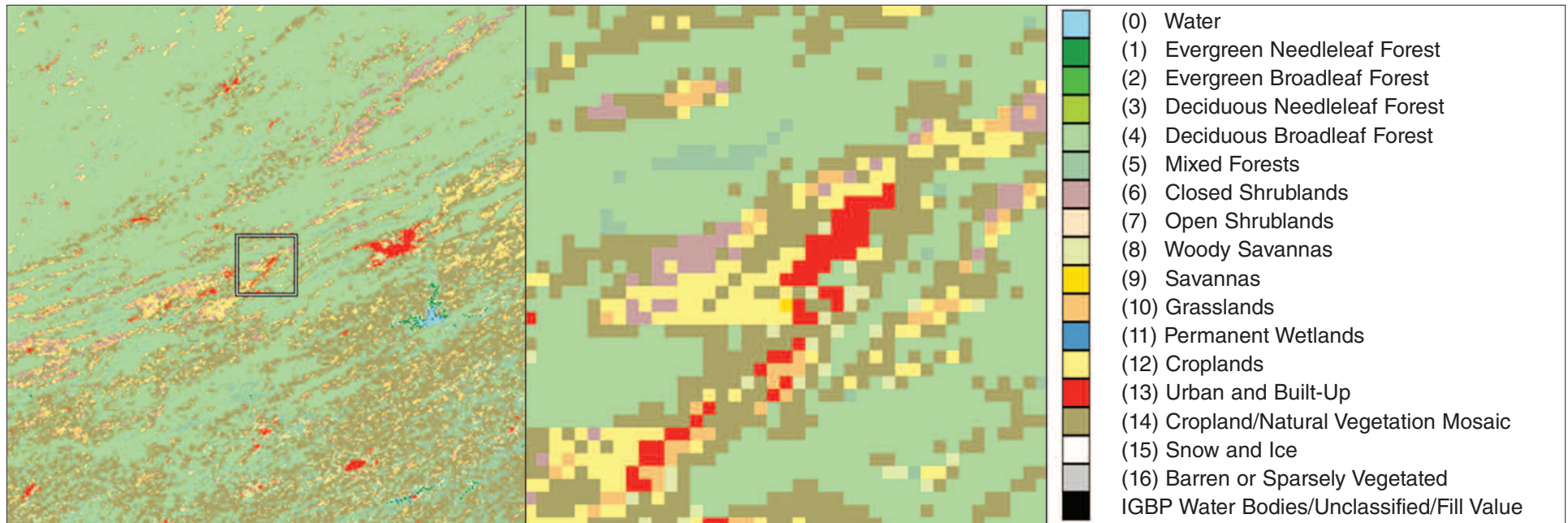
Field data collected on moth lifecycles told her when and where to look in the MODIS data, and she spotted the damage. De Beurs said, “Traditionally, when people look at land cover change, they use a high-resolution sensor like Landsat, but those data are not available as often—they’re like little postage stamps. MODIS offers a much broader overview, helping you see the large-scale effects.”

Over the course of the semester, Belote was surprised to learn the many angles for studying phenology. Belote said, “She lectured on so many different ways we can approach the subject. You can look at the phenology of animals, such as the timing of bird migration or frog breeding. And it’s possible to use historical resources, such as records of cherry blossom festivals in Japan, going back thousands of years, or even Thoreau’s journals.” Henry David Thoreau, better known for works such



Nomadic people, such as this woman and her cattle, formed the pastoral society common in Kazakhstan before the Soviet Union converted thousands of acres to large-scale modern farm operations. After the Soviet Union collapsed, many large farms disbanded. Satellites detected the changes in land cover, indicating these areas were reverting to their former, uncultivated state. (Courtesy A. C. Braime)

as *Walden*, also recorded detailed bud and bloom observations from 1852 to 1858. His phenological observations serve as valuable records of pre-Industrial Revolution climate, and a point of comparison for more recent field or satellite observations.



Land cover classification maps such as this one, including the Virginia Tech campus at Blacksburg, help researchers and students alike interpret a subset of Moderate Resolution Imaging Spectroradiometer (MODIS) vegetation data. Each of the classifications may have a different characteristic in the data. The buildings and pavement associated with the campus are clearly visible as red pixels on the land cover map. The classification maps are also derived from MODIS data. (Courtesy NASA Oak Ridge National Laboratory Distributed Active Archive Center)

Zooming in

De Beurs works to give her students hands-on experience with this sort of integrated study. During the class experiments, Belote realized the value of combining data from various sources. De Beurs said, “I try to get them to link satellite data with field observations. Students are interested in the effects of climate change, so I ask them to choose some area of the globe to study. I have them look at start of season changes, so they get to figure out how that works.” Recent studies have shown that spring is coming earlier to mid-latitudes in the Northern Hemisphere, so de Beurs asks them to look at trends in start of season dates, from 2000 to 2008. “The data register is still really short,” she said. “But it can pick up large climate oscillation

patterns, and it can pick up disturbances even with coarse resolution data.”

The students must first obtain the MODIS data for their study area, so de Beurs refers students to the Oak Ridge National Laboratory Distributed Active Archive Center (ORNL DAAC). The ORNL DAAC developed a data access tool for field researchers, the MODIS subsetter, permitting her students to select a very small amount of data that corresponds to a particular study area. De Beurs said, “The ORNL DAAC tool is very nice for students to work with. The information comes with data quality statements along with ancillary information like a land cover map. The oodles and oodles of data that I work with would be too much for students, even if they just

download one tile. You can’t process a whole bunch of tiles in a fifty-minute lab.” De Beurs also gives students a program she wrote that processes the MODIS data and calculates start of season dates.

Next, she asks them to compare the data to a nearby area. “How do you link a big pixel with field observations?” she said. “I ask them to go outside and monitor the green up of trees on campus. It works quite well with the satellite data.” Other assignments taught students to combine data to interpret variability across an area. Belote said, “In one assignment, we studied large areas called biomes, such as temperate, deciduous forests, or tropical systems. But we also pulled out anthromes, different land use classes, such as rural village, agricultural, urban, and

wildland, and looked at how they influenced phenology across the biomes. Why might agricultural zones differ? We tried to see if crops were planted at a certain time, when they green up, when they would be harvested. So then we could speak broadly about what was happening.”

Now out of class and in the midst of his Colorado Plateau study, Belote remains inspired by the potential for remote sensing data on phenology to lead him to larger insights. He said, “It was such a cool link across organisms, and also across ways of exploring the questions. In the midst of taking that class, I ended up pulling MODIS net primary productivity data to compare to forest inventory and analysis plots. It’s an idea that still intrigues me. What can we learn from satellites to help us manage an ecosystem?”

To access this article online, please visit http://nasadaacs.eos.nasa.gov/articles/2009/2009_plants.html.



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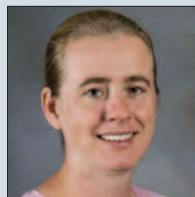
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About the remote sensing data used		
Satellites	Aqua and Terra	Aqua and Terra
Sensors	Moderate Resolution Imaging Spectroradiometer (MODIS)	Moderate Resolution Imaging Spectroradiometer (MODIS)
Data sets	MODIS Subsets—Vegetation Indices	Vegetation Indices, Surface Reflectance
Resolution	250 meter, 500 meter, and 1 kilometer	250 meter, 500 meter, and 1 kilometer
Parameters	Normalized Difference Vegetation Index (NDVI) and Enhanced Vegetation Index (EVI)	Normalized Difference Vegetation Index (NDVI), Enhanced Vegetation Index (EVI), Normalized Difference Water Index (NDWI), Normalized Difference Infrared Index (NDII)
Data centers	NASA Oak Ridge National Laboratory Distributed Active Archive Center (DAAC)	NASA Land Processes DAAC

About the scientists



Travis Belote is a postdoctoral researcher at the United States Geological Survey in Flagstaff, Arizona. He received his doctoral degree in biological sciences from Virginia Polytechnic Institute and State University in 2008. His research interests include the study of ecological thresholds and the response of native ecosystems to human impacts. (Photograph courtesy T. Taylor)



Kirsten de Beurs is an assistant professor in geography at Virginia Polytechnic Institute and State University, where she teaches a course in Remote Sensing and Phenology. Her research interests include analysis of land cover and land use change, integrating long satellite image time series, meteorological data, and political and socioeconomic analysis; and land surface phenology changes. NASA and the United States Forest Service supported her research. (Photograph courtesy Virginia Polytechnic Institute and State University)

For more information

NASA Land Processes Distributed Active Archive Center (LP DAAC)
<https://lpdaac.usgs.gov>
 NASA Oak Ridge National Laboratory (ORNL DAAC)
<http://daac.ornl.gov>
 MODIS Land Data Products and Services
https://lpdaac.usgs.gov/lpdaac/products/modis_products_table

MODIS Land Products Subsets
<http://daac.ornl.gov/MODIS/modis.html>
 Kirsten de Beurs
<http://filebox.vt.edu/users/kdebeurs/PhenologyLab/KirstendeBeurs.html>
 Travis Belote
<http://filebox.vt.edu/users/rtbelote>

Smoke over Athens

“We are entering the age of air quality monitoring from space.”

Yang Liu
Emory University

by Natasha Vizcarra

On the tail of three scorching heat waves in the summer of 2007, massive forest fires broke out across Greece and destroyed thousands of acres of forest, olive groves, and farmland. Heavy plumes of smoke billowed from burning forest canopies, and ash from the fires dusted ancient and modern buildings in nearby cities and towns. Numbering 3,000 from June to early September, the fires were the worst that Greece had seen in fifty years.

Athens is already one of the most polluted cities in Europe, more so in the summer when humidity and the intense Mediterranean sun heat up industrial and vehicular pollutants lingering in the atmosphere. Did the forest fires cause the city’s air pollution levels to get worse? Researchers in Greece could not answer this question easily. Most of the fires burned in rural areas where there were no ground-based instruments to measure pollution. The fires also produced gigantic smoke plumes that blew



A man walks through the Acropolis while smoke plumes billow from a forest fire near Athens on July 25, 2007. More than 3,000 forest fires burned in Greece that summer, mostly in areas where there were no ground instruments to observe the impact of the smoke on air quality. (Courtesy V. Berger)

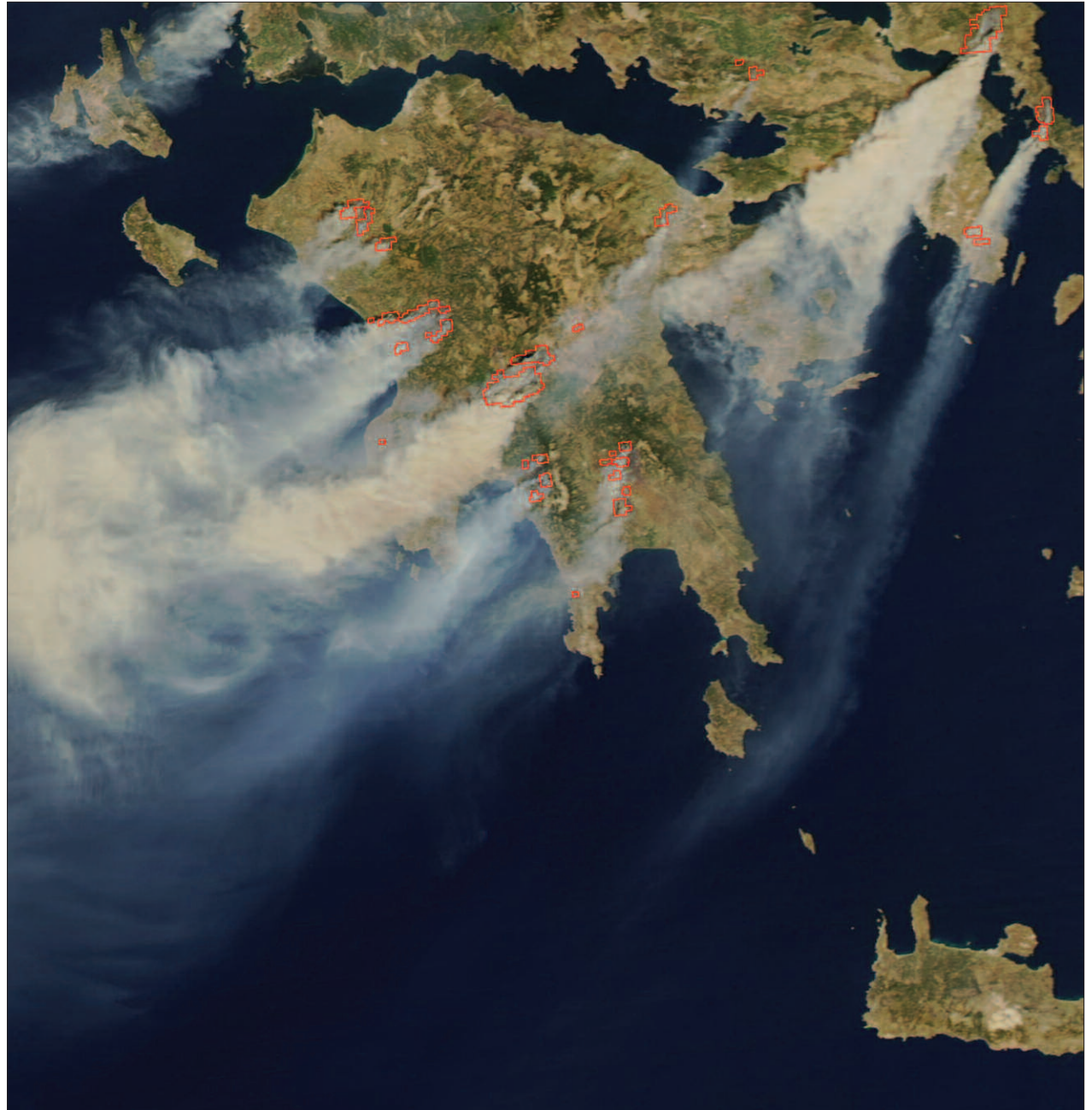
hundreds of miles from inland, across coastlines, and on to the Ionian Sea. These plumes were difficult to study using available ground monitoring networks alone.

The Greek government turned to the Harvard School of Public Health for help. Yang Liu studies air quality using remote sensing data and was a research associate there at the time of the Greek fires. He said, “The best tool was satellite remote sensing. We happened to have cloud-free days during most of the fire episodes, and that was ideal for satellites to observe the transport and the evolution of those plumes.” Liu, now an assistant professor at Emory University’s Rollins School of Public Health, knew that satellite sensors were a fairly new information source for air pollution studies. But he suspected that the right combination of satellite sensors could reveal how the forest fires affected Athens’ already fragile air quality.

Two pollution spikes

Pollution peaked twice in the Athens area during the last week of August and the first week of September. From August 24 to 28 and then again from August 30 to September 3, the average concentration of air particles in Athens reached a density of nearly 100 micrograms per cubic meter. These measurements were far above the European Union Ambient Air Quality Standard of fifty micrograms per cubic meter. “We wanted to know if some or all of these pollution peaks were caused by the fire plumes,” Liu said.

To find out if the pollution episodes could be traced to the fires, Liu first needed to know if smoke plumes from the fires had drifted to Athens. Liu checked for smoke plumes using true color satellite images of Athens and the vicinity



Smoke from forest fires in Greece on August 25, 2007, is evident in this satellite image from the Moderate Resolution Imaging Spectroradiometer (MODIS) instrument. The active forest fires, outlined in red, occurred in the Peloponnese and Attica regions, and on the island of Evia. Long-range smoke plumes from Evia extend west over the city of Athens toward the Ionian Sea. (Courtesy MODIS Rapid Response Project, NASA Goddard Space Flight Center)



Smoke obscures the midday Athens sky in this August 25, 2007, photo. A portion of the forest on Mount Hymettus was burning. (Courtesy A. Babilii)

from the Moderate Resolution Imaging Spectroradiometer (MODIS) instrument on the NASA Terra and Aqua satellites.

He determined plume height and direction by using numerical weather models, and then validated the information with data from the Multi-Angle Imaging Spectroradiometer (MISR) sensor on the Terra satellite, available from the NASA Langley Research Center Atmospheric Science Data Center. Ralph Kahn, a senior research scientist at the NASA Goddard Space

Flight Center, worked with Liu on the study. He said, “Plume height is important. How high the smoke is injected into the atmosphere by the fire determines how far the smoke particles travel from these fires, in which direction they travel, and how long they stay in the atmosphere. Numerical weather models complement the snapshots from MISR and MODIS, filling in what the polar-orbiting satellite instruments miss.”

During the first pollution episode, MODIS true color images showed smoke plumes southwest of

Athens in the Peloponnese region, and northwest in the country of Albania. MODIS also detected fire spots on the island of Evia, northeast of Athens, and in nearby forested areas northwest of the city. MISR detected plume heights from the Peloponnese fires that were 2.5 kilometers (1.6 miles) high. But weather and wind data showed that a southwesterly wind blew the smoke plume away from Athens and into the Ionian Sea. The same wind blew the smoke plumes from the Evia Island fires right into the city. Liu said, “As a result, the Evia fire is probably a major contributor to increased pollution in Athens during this period.” In the second episode, MODIS only detected minor fire spots in the Peloponnese region, and several fire spots in Albania. MISR detected no major smoke plumes.

With two very different pollution episodes, the first with smoke plumes blowing into Athens from Evia, and the second without any dominant smoke plume blowing into the city, Liu and Kahn then needed to figure out what quantities of aerosols—tiny particles of solid or liquid suspended in the air—were present in the atmosphere. They also needed to find out what kinds of aerosols were hovering over the city.

Slicing through smoke

To observe aerosol abundance, Liu and Kahn needed an instrument that could observe huge areas, such as the length and breadth of the Peloponnese smoke plume. They used total column aerosol optical depth (AOD) data from MODIS, distributed by the NASA MODAPS Level 1 Atmosphere Archive and Distribution System. Kahn said, “MODIS was the ideal instrument because it has a swath of 2,300 kilometers [1,400 miles] and observes the entire Earth at least once in two days.” Liu superimposed these data over MODIS true color images of

the fire sites during the two episodes, and used this combination to determine pollution intensity and source location. The MODIS AOD data confirmed what the weather and plume height observations suggested for the first pollution peak: that smoke from Evia had blown into Athens, and residual, circling smoke from the Peloponnese region drifted into Athens from the south toward the end of the period. MODIS AOD data for the second episode showed that aerosol abundance was higher in Athens than in surrounding areas.

At this point, it seemed clear that smoke from the forest fires might not have affected Athens during the second pollution episode. But were the fires responsible for the first one? To answer this question, Liu and Kahn needed to know what kinds of aerosols were present in Athens during the two periods. They used data from the Ozone Monitoring Instrument (OMI) on NASA's Aura satellite, archived at the NASA Goddard Earth Sciences Data and Information Services Center, and aerosol type data from ground instruments. Kahn said, "OMI can distinguish particles by the way they reflect light back into the sensor. This tells something about what the particles are made of, and gives us clues to where they come from. We also added ground-based measurements to the mix because they are much more precise." Liu and Kahn's colleagues—Archontoula Chaloulakou, at the National Technical University of Athens, and Petros Koutrakis, at the Harvard School of Public Health—provided the ground instrument data.

What Liu and Kahn found out surprised them. The combination of aerosol type data showed that during the first episode, the average



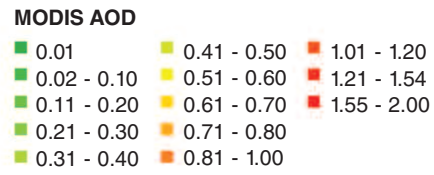
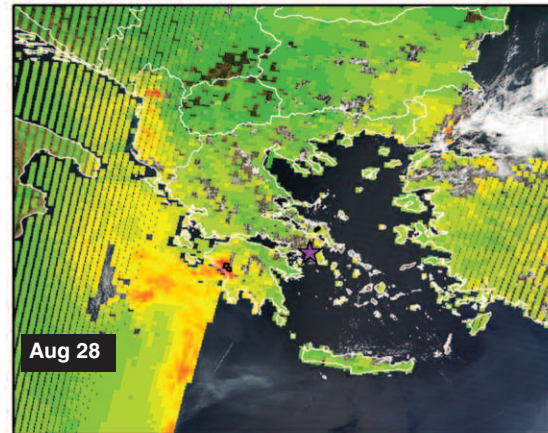
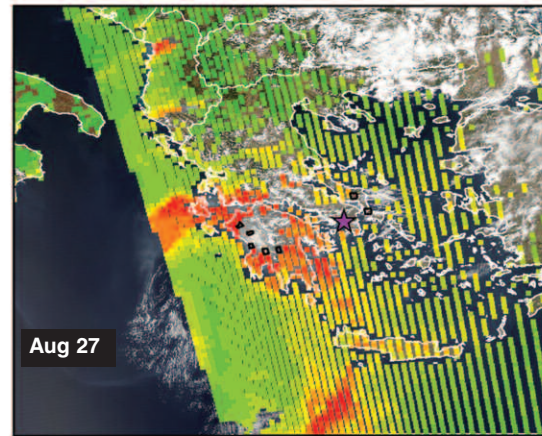
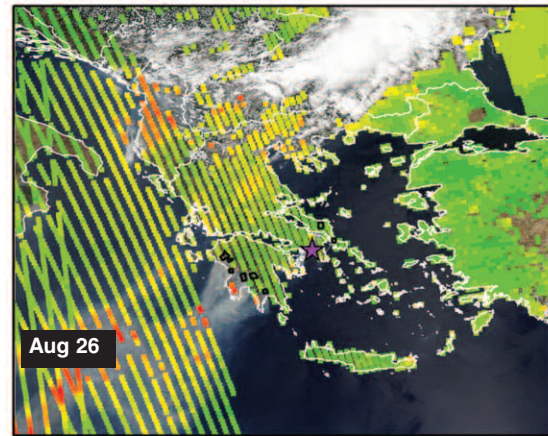
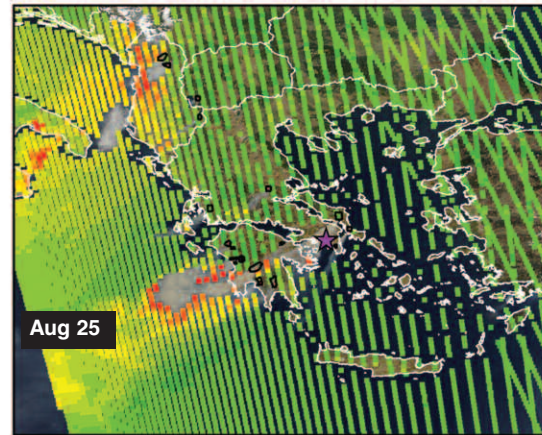
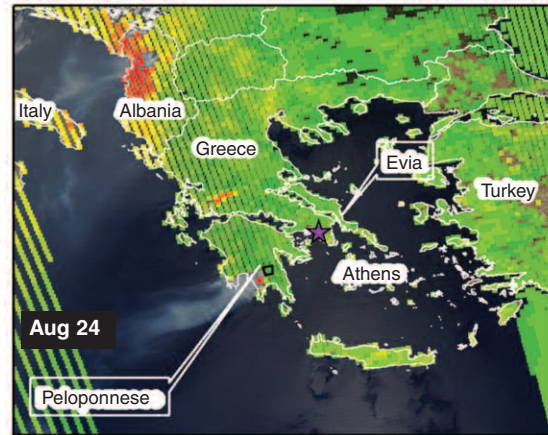
A forest fire burns on the island of Zakynthos in Greece on the evening of July 25, 2007. Heat waves, a strong wind, and arson caused many fires in Greece that summer, adding smoke plumes to an already polluted skyline. (Courtesy C. Osbourn)

pollution contribution from forest fires was 28 micrograms per cubic meter, but pollution from traffic emissions and other sources was 33 micrograms per cubic meter. During the second episode, forest fires contributed an average of 17 micrograms per cubic meter, but traffic emissions contributed 48 micrograms per cubic meter. Liu said, "Fire plumes contributed aerosols more significantly to the pollution spike in the first episode, and to a lesser extent in the second episode. But during both episodes, emissions from vehicles in Athens still dominated the aerosol composition."

Smog versus smoke

To Liu and Kahn, the results were consistent with what researchers have observed in other countries. Liu said, "Even during the height of the forest fires, local traffic remained the number one contributor to air pollution levels. In Athens, as in many cities all over the world, the major contributor to air pollution is still vehicular traffic."

The use of multiple remote sensing instruments helped paint a more detailed picture of the forest fires' impact on the air quality in Athens. "Multiple instruments tell a better and more



complete story than any individual instrument can, and they also cross-validate each other,” Liu said. Kahn agreed, saying, “We have the tools. In situ air quality measurements are made routinely from the surface. But combining them with satellite data gives you a much broader perspective.”

Liu and Kahn even discovered new possibilities for one sensor. Liu said, “It’s interesting to note that MODIS behaved very well during the two episodes. It tracks ground level pollution very well.” MODIS works best when the pollution is sulfate-dominated, the kind that comes from industrial sites. But during the two pollution peaks, pollution was dominated by motor vehicle emissions. “In our two episodes, pollution was composed of nitrate, black carbon, and organic carbon. But the MODIS instrument still worked very well,” Liu said.

Remote sensing is proving to be an important tool in monitoring air quality in major urban areas worldwide. Liu said, “We are entering the age of air quality monitoring from space. Carefully interpreted satellite data can give us valuable information about air pollution conditions and forest fire episodes. Although still at its infancy, satellite-based air quality

These images, from the Moderate Resolution Imaging Spectroradiometer (MODIS) on NASA’s Aqua and Terra satellites, show total column aerosol optical depth (AOD) overlaid on MODIS true color images. The images reveal a concentration of aerosols from the island of Evia drifting to Athens on August 25, and another concentration of aerosols drifting into the city from the Peloponnese region on August 27. Black polygons represent fire spots, and the purple star represents the city of Athens. Orange and red indicate higher aerosol levels, while blue and green indicate lower levels. (Courtesy Y. Liu)

monitoring has started to provide early warnings of pollution events to major urban areas all over the world.”

To access this article online, please visit http://nasadaacs.eos.nasa.gov/articles/2009/2009_smoke.html.



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For more information

NASA Langley Research Center Atmospheric Science Data Center
<http://eosweb.larc.nasa.gov>
 Moderate Resolution Imaging Spectroradiometer (MODIS)
<http://modis.gsfc.nasa.gov>
 MODIS Rapid Response System
<http://rapidfire.sci.gsfc.nasa.gov>

Multi-Angle Imaging Spectroradiometer (MISR)
<http://www-misr.jpl.nasa.gov>
 Ozone Monitoring Instrument (OMI)
<http://aura.gsfc.nasa.gov/instruments/omi.html>
 Yang Liu
<http://www.sph.emory.edu/faculty/YLIU74>

About the scientists



Ralph Kahn is a senior research scientist at the NASA Goddard Space Flight Center. His research interests include aerosols, wildfire smoke, desert dust, pollution aerosols, volcanic aerosols, and multi-angle remote sensing. He is the aerosol scientist for the Multi-Angle Imaging Spectroradiometer (MISR) instrument. NASA’s Climate and Radiation Research and Analysis Program and the EOS-MISR instrument project supported his work on this study. (Courtesy NASA Jet Propulsion Laboratory)



Yang Liu is an assistant professor at the Rollins School of Public Health at Emory University in Atlanta, Georgia. His research interests include the spatial and temporal distribution of atmospheric aerosols, and applications of satellite remote sensing in air pollution monitoring and public health research. The Harvard School of Public Health Cyprus Initiative and the Environmental Protection Agency Center for Ambient Particle Health Effects supported Liu’s research. (Courtesy S. Body)

About the remote sensing data used

Satellites	Terra and Aqua	Terra	Aura
Sensors	Moderate Resolution Imaging Spectroradiometer (MODIS)	Multi-Angle Imaging Spectroradiometer (MISR)	Ozone Monitoring Instrument (OMI)
Data sets	MODIS Level 2 Aerosol	MISR Level 2 Products	Near-UV Aerosol Optical Depth and Single Scattering Albedo
Resolution	10 kilometer, derived from Level 1 radiance data at 0.5 and 1.0 kilometer	1.1 kilometer	13 x 24 kilometer nominal resolution at nadir
Parameters	Aerosol optical depth	Stereo height	Aerosol Index and associated aerosol types
Data centers	NASA MODAPS Level 1 Atmosphere Archive and Distribution System (MODAPS LAADS)	NASA Langley Research Center Atmospheric Science Data Center	NASA Goddard Earth Sciences Data and Information Services Center

A catalog of change



“Our task was to see if the temperature changes we’ve been seeing are affecting the natural world.”

Cynthia Rosenzweig
NASA Goddard Institute
for Space Studies

by Katherine Leitzell

Lake Tanganyika, the second-deepest lake in the world, is dying. Since the late 1970s, fish catches in the East African lake have declined by a third or more, and scientists say that the problem is a direct result of climate change. Catherine O’Reilly, an aquatic ecologist at Bard College

who studies the lake, said, “As Lake Tanganyika warms up, the water density changes and it doesn’t mix as easily. That means fewer nutrients are moving up to the surface of the lake, so there is less food available to the entire food web.”

Lake Tanganyika is not the only place where climate change has manifested its effects. All over



Piles of sardines await buyers in a market near Lake Tanganyika. Thousands of people in East Africa depend on fish from the lake for protein. However, fish catches in Lake Tanganyika are declining because of the effects of global climate change on the lake. (Courtesy C. O’Reilly)

the world, researchers have documented changes in physical and biological systems that they attribute to rising temperatures. In the Rocky Mountains of North America, marmots emerge from hibernation more than a month before they used to. Worldwide, birds have changed their migration patterns, reaching their summer destinations in Europe and North America earlier in the spring. Plants in Canada, the United States, and Europe are flowering sooner. Meanwhile, shrinking Arctic sea ice, thawing permafrost in Canada and Siberia, and retreating glaciers around the world show the impact of climate change on the physical world.

Researchers are now working to catalog and understand those changes. In 2007, a group of scientists, led by NASA scientist Cynthia Rosenzweig, compiled information on climate change effects into a comprehensive database of more than 600 studies on organisms and physical systems around the world. Scientists hope that this information will help define how climate change is affecting the planet, and how the natural world and the people who depend on it might respond to increased warming in the future.

Compiling the impacts

The Observed Climate Change Impacts Database started as an effort by scientists involved with the 2007 Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report. Rosenzweig was the Coordinating Lead Author for the first chapter, focusing on detecting observed impacts of climate change. She said, “Our task was to see if the temperature changes we’ve been seeing are affecting the natural world.” Rosenzweig and her colleagues compiled the database from hundreds of

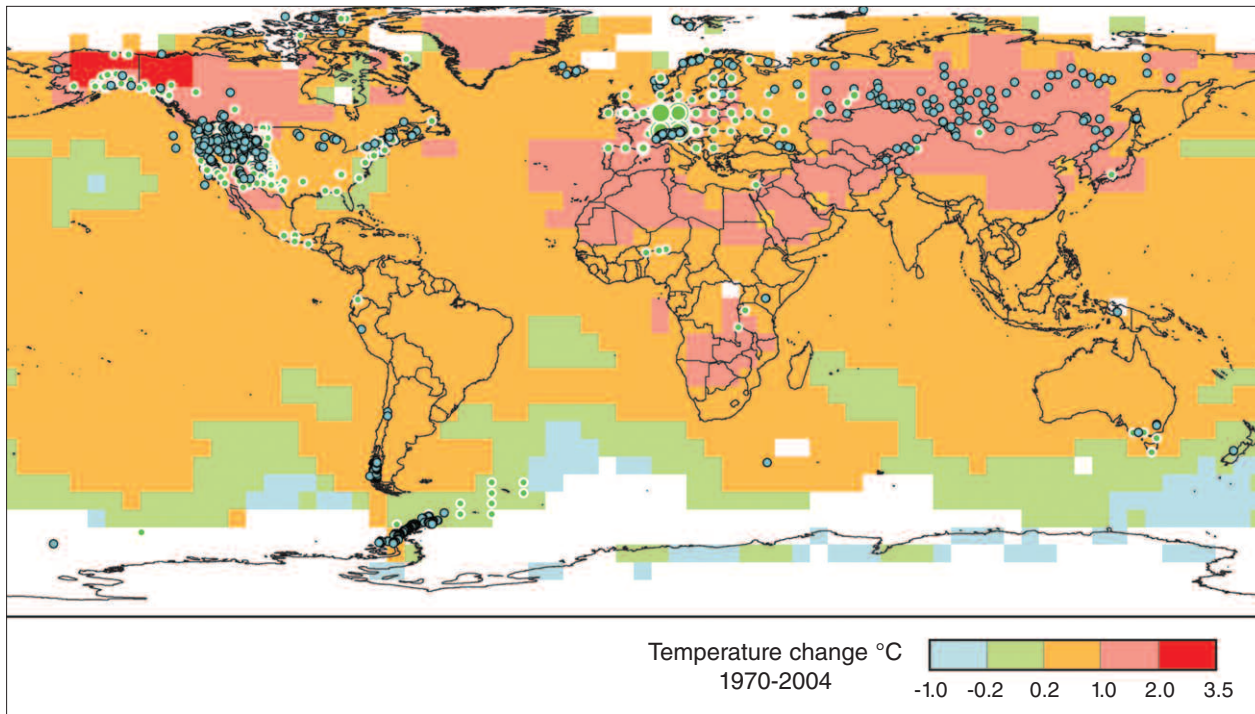


Yellow-bellied marmots in Colorado’s Rocky Mountains now emerge from hibernation about a month earlier than they used to. The change is just one of the impacts identified in the IPCC Observed Climate Change Impacts Database. (Courtesy A. Schaefer)

scientific studies connected to climate change, such as those of Lake Tanganyika, analyzing each study to determine whether the observed effect was actually caused by global warming.

The database serves as a starting point for research into current and future impacts of climate change. The data are freely available to the public through the IPCC Data Distribution Center, a joint service of the NASA

Socioeconomic Data and Applications Center (SEDAC), the British Atmospheric Data Centre, and Germany’s High Performance Computing Centre for Climate and Earth System Research (Deutsches Klimarechenzentrum). “The data can be used in many ways,” Rosenzweig said. International agencies can use the database to explore the global impacts of climate change. Government leaders can learn how climate change is affecting their country



The Observed Climate Change Impacts Database catalogs climate-related impacts ranging from changes in bird migration patterns to receding glaciers. On the map above, blue circles represent documented changes in physical systems, and green circles show changes in biological systems. Blocks of color show regional temperature change from 1970 to 2004; blue indicates cooling of up to 1 degree Celsius (2 degrees Fahrenheit), green denotes regions with less than 0.2 degrees Celsius (0.4 degrees Fahrenheit) change, and yellow and red indicate warming up to 3.5 degrees Celsius (6.3 degrees Fahrenheit). (Courtesy IPCC)

or region. And scientists can use the data to understand how climate change is affecting the planet both now and in the future.

“People often want to know what changes are happening where they live,” Rosenzweig said. “With our database, you can explore the physical and biological changes that have occurred and whether they are responding in the direction of temperature changes. Researchers can also see where there are data gaps, and we hope that this will encourage future work in the lower latitudes and developing countries, where more studies are urgently needed.”

Is it really climate change?

In building the Observed Climate Change Impacts Database, IPCC scientists first had to determine whether each specific change was caused by global warming, or whether there was another explanation. Other factors, such as changes in land use, increased pollution, invasive species, and the urban heat island effect—warmth generated in cities and suburbs—can also lead to changes consistent with climate change.

To demonstrate a significant link to climate change, a study must not only show that warmer temperatures could account for the change, but

also that no other explanation was sufficient. Cynthia Rosenzweig and her team examined each study in the database to assess how likely it was that a specific impact, such as a change in animal behavior or a shrinking glacier in the Swiss Alps, was related to climate change. The IPCC scientists asked whether the study authors had ruled out other explanations for the changes, and whether or not they were in the direction expected with warming. They then related the changes to gridded temperature trends from a global temperature data set.

After careful examination of each study in the database, Rosenzweig and her group were surprised to find how many impacts were closely linked to climate change. Rosenzweig said, “By far, out of the hundreds of cases, only a handful of the impacts might actually be caused by something else.”

Warming hits home

By themselves, scattered changes in bird migrations or water temperature may not seem alarming. “What the database shows is that ecosystems are responding to climate change. In essence they’re doing what they’re supposed to be doing; they are re-acclimating. Whether that’s good or bad is a human judgment, and it has to do with the values that we place on our natural world,” Rosenzweig said. “However, we have seen widespread changes with just the 0.7 degrees Celsius [1.3 degrees Fahrenheit] of warming, and this is just a fraction of what is expected. Eventually, the rate of change will outstrip the species’ phenotypic and genetic adaptive capacity, and then some serious problems might arise.” Also, since humans rely on the natural world for food, water, and resources, changing ecosystems can cause serious problems for human health and economies.

Rosenzweig and O'Reilly point out that the impact of climate change may prove to be especially damaging in the regions with the scarcest data—primarily tropical and subtropical areas in Latin America, Africa, and Asia, where fewer scientists have studied the effects of climate change. O'Reilly said, “Some of the ecosystems humans depend on most heavily are the ones that we have the fewest and shortest data sets for.” In the region surrounding Lake Tanganyika, for example, the combination of decreasing fish catches and increasing human population means that hunger and malnutrition may not be far behind. O'Reilly said, “In Africa, around this lake, it’s going to lead to a huge problem which hasn’t really been realized or planned for.”

Researchers and policy makers all over the world are now working to understand how climate change will affect people where they live. How will climate change impact water supplies for growing populations? How will cities respond to sea level rise? How will farmers deal with environmental changes that affect their crops? The United States Global Climate Change Research Program recently reported on observed and potential regional impacts of climate change within the United States. The report emphasized that many changes have already occurred, and that climate change will have some impacts, whether or not people reduce carbon emissions in the future. O'Reilly said, “We’re at the point right now in human society where we need to be thinking about adaptation to climate change.”

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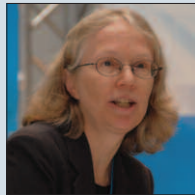
About the data used

Data set	IPCC Fourth Assessment Report (AR4) Observed Climate Change Impacts Database
Parameter	Physical and biological impacts of climate change
Data center	NASA Socioeconomic Data and Applications Center

About the scientists



Catherine O'Reilly is an assistant professor of biology at Bard College in Hudson, New York. She studies aquatic ecology, particularly in tropical systems, climate change, and biogeochemical cycles. The National Science Foundation and the United Nations Development Programme Lake Tanganyika Biodiversity Project provided funding for her work on Lake Tanganyika. (Photograph courtesy Bard College)



Cynthia Rosenzweig is an agricultural scientist at the NASA Goddard Institute for Space Studies (GISS). Her research focuses on interdisciplinary methods for assessing the impacts of global environmental change. Rosenzweig was the leader of the 2007 Intergovernmental Panel on Climate Change (IPCC) Working Group 4. NASA funded her research. (Photograph courtesy NASA)

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- Rosenzweig, C., et al. 2008. Attributing physical and biological impacts to anthropogenic climate change. *Nature* 453: 353–357.
- United States Global Climate Change Research Program. 2009. Global climate change in the United States. <http://www.globalchange.gov/publications/reports/scientific-assessments/us-impacts>

For more information

- NASA Socioeconomic Data and Applications Center (SEDAC) <http://sedac.ciesin.columbia.edu/index.html>
- IPCC Fourth Assessment Report (AR4) Observed Climate Change Impacts Database <http://sedac.ciesin.columbia.edu/ddc/observed/index.html>
- Catherine O'Reilly <http://www.bard.edu/academics/faculty/faculty.php?action=details&cid=1554>
- Cynthia Rosenzweig <http://www.giss.nasa.gov/staff/crosenzweig.html>
- United States Global Change Research Program <http://www.globalchange.gov/about>



About the NASA Earth Observing System Data Centers

Alaska Satellite Facility SAR Data Center

Synthetic Aperture Radar, Sea Ice,
Polar Processes, Geophysics
Geophysical Institute, University of Alaska Fairbanks
Fairbanks, Alaska
+1 907-474-6166
asf@eos.nasa.gov
<http://www.asf.alaska.edu>

Crustal Dynamics Data Information System

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

Global Hydrology Resource Center

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

Goddard Earth Sciences Data and Information Services Center

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

Land Processes DAAC

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

MODAPS Level 1 Atmosphere Archive and Distribution System (MODAPS LAADS)

Radiance, Atmosphere
NASA Goddard Space Flight Center
Greenbelt, Maryland
+1 866-506-6347
modapsuso@sigmaspace.com
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NASA Langley Research Center Atmospheric Science Data Center

Radiation Budget, Clouds, Aerosols,
Tropospheric Chemistry
NASA Langley Research Center
Hampton, Virginia
+1 757-864-8656
larc@eos.nasa.gov
<http://eosweb.larc.nasa.gov>

National Snow and Ice Data Center DAAC

Snow, Ice, Cryosphere, Climate
University of Colorado at Boulder
Boulder, Colorado
+1 303-492-6199
nsidc@nsidc.org
<http://nsidc.org/daac>

Oak Ridge National Laboratory DAAC

Biogeochemical Dynamics, Ecological Data,
Environmental Processes
Oak Ridge National Laboratory
Oak Ridge, Tennessee
+1 865-241-3952
uso@daac.ornl.gov
<http://daac.ornl.gov>

Ocean Biology Processing Group

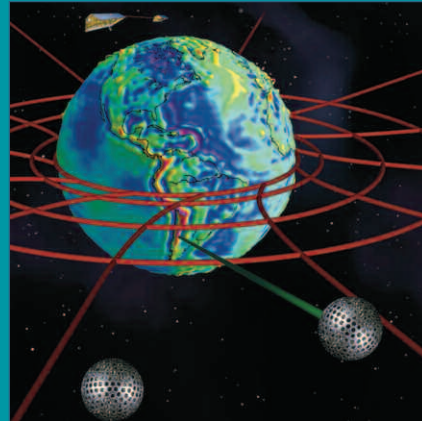
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Sea Surface Temperature
NASA Goddard Space Flight Center
Greenbelt, Maryland
<http://oceancolor.gsfc.nasa.gov>

Physical Oceanography DAAC

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

Socioeconomic Data and Applications Center

Human Interactions, Land Use, Environmental
Sustainability, Geospatial Data, Multilateral
Environmental Agreements
CIESIN, Earth Institute at Columbia University
Palisades, New York
+1 845-365-8988
ciesin.info@ciesin.columbia.edu
<http://sedac.ciesin.columbia.edu>



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