Supporting Earth Observing Science 2004

Earth-Sun System

NASA Science Mission Directorate

Featuring a special 10th anniversary section highlighting 10 years of publishing research uses of Earth science data and information.

Supporting Earth Observing Science 2004

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Earth–Sun System

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Cover Images

Front, *clockwise from top left:*

Cumulus clouds gather over southern Wyoming. (Image courtesy of Laurie J. Schmidt)

This aerial view of the main plaza at Tikal, Guatemala, shows Mayan structures that have stood for centuries. (Image courtesy of Tom Sever)

Captured on June 6, 2001, this MODIS image of the Rondonia region of Brazil shows massive deforestation in the south-central Amazon Basin. (Image courtesy of Jacques Descloitres, MODIS Land Rapid Response Team)

A 1990 lava flow from Kilauea Volcano creeps toward the community of Kalapana on the island of Hawaii. (Image courtesy of U.S. Geological Survey)

Adéile penguins nest and breed on rocky, ice-free beaches in large colonies of ten thousands of birds. More than 2.5 million breeding pairs live in the Antarctic region. (Image courtesy of NOAA)

This image from the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) shows the termini of the glaciers in the Bhutan Himalaya. (Image courtesy of Jeffrey Kargel, U.S. Geological Survey)

Periodic flooding in the Mississippi Valley may affect residents as far north as Minnesota and as far south as Louisiana. In May 2001, the Mississippi River flooded this house south of Red Wing, Minnesota. (Image courtesy of NOAA)

Researchers from Université Laval study the main crack in the Ward Hunt Ice Shelf during the summer of 2002. (Image courtesy of Vicki Sahanatien, Parks Canada)

Urbanized areas in Houston, Texas, are up to 8° F hotter than surrounding rural areas, demonstrating the Urban Heat Island effect. (Image from Photos.com)

In 2003, MODIS captured this image of Tropical Cyclone Inigo approaching northwest Australia. (Image courtesy of Jeff Schmaltz, MODIS Rapid Response Team, NASA/GSFC)

Back, *left to right:*

MODIS captured this image of Hurricane Jeanne as it moved over Martin and St. Lucie Counties in east central Florida on September 26, 2004. (Image courtesty of Jacques Descloitres, MODIS Rapid Response Team)

This composite ASTER image shows how the Gangotri Glacier terminus has retracted since 1780. Contour lines are approximate. (Image courtesy of Jesse Allen, NASA Earth Observatory, based on data provided by the ASTER Science Team)

This image captured over New York City on October 2, 1999, is a false color composite combining surface temperature and vegetation abundance information. Red indicates surface temperature, green indicates vegetation abundance, and blue indicates visible brightness. (Image courtesy of Chris Small, Lamont-Doherty Earth Observatory, Columbia University)

Earth Science Data and Information System Project
National Aeronautics and Space Administration
Goddard Space Flight Center
Greenbelt, MD 20771

Dear Friends and Colleagues:

This year, NASA's Earth Science Data and Information System (ESDIS) Project and our Distributed Active Archive Centers (DAACs) celebrate the first 10 years of the Earth Observing System Data and Information System (EOSDIS) DAAC Annual publication, a decade of publishing the benefits and research uses of Earth science data and information products. I take great pride in the outstanding efforts of the DAACs and of the many behind-the-scenes people who contributed to the success of NASA's Earth science operations, including the DAAC and Earth Science Data and Information System Project staff members and contractors, the EOS science team members, and the many contributors, writers, and artists who have worked hard to make each edition of the DAAC Annual unique and informative.

In this special 10th anniversary edition of the DAAC Annual publication, we highlight the progress of NASA's Sun-Earth science programs by contrasting imagery taken from NASA's previous satellites with recent imagery from the Earth Observing System. Over the past 10 years, EOSDIS has provided a steadily growing level of support to an ever-increasing number of research and applications users, and we are pleased to highlight those trends in this special edition. I hope you enjoy the science articles in this edition, and that you join us in celebrating the tremendous achievements of the past 10 years.

Vanessa L. Griffin
Science Operations Manager
Earth Science Data and Information System Project
NASA Goddard Space Flight Center

Acknowledgements

We extend our gratitude to the Earth Science Data and Information System (ESDIS) Project for its support of this publication; to the DAAC managers and User Services personnel for their direction and reviews; and to the DAAC scientists who alerted us to the research and investigations that made use of DAAC data in 2004. A special thanks goes to the investigators whose accomplishments we are pleased to highlight here.

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Supporting Earth Observing Science 2004 is also available online in PDF format at: **http://nasadaacs.eos.nasa.gov/articles/index.html**.

For additional print copies of this publication, please contact **nasadaacs@nsidc.org**.

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

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The ornamental graphic featured throughout the pages of this edition is based on a Mayan textile design that originated in the Chiapas Mountains of southwestern New Mexico. For centuries, Chiapas women have woven intricate designs into their textiles by adding colored yarn to their backstrap looms. Known as a *brocade*, this ancient design technique is still an art form among the 200,000 Maya who live in the Chiapas region.

The traditional designs of the Chiapas Maya are drawn from local history and mythology. The undulating flower, the design featured in this edition, symbolizes the fertile Earth with its abundance of holy plants and animals.

Using satellite data archived at the NASA DAACs, scientists are looking at land use practices in the Mesoamerican Biological Corridor to determine what enabled the Mayan civilization to flourish, as well as what ultimately led to its demise (see "Mayan Mysteries," page 37).

Flower design replica by Nancy Geiger Wooten

Supporting Earth Observing Science 2004

DISTRIBUTED ACTIVE ARCHIVE CENTERS

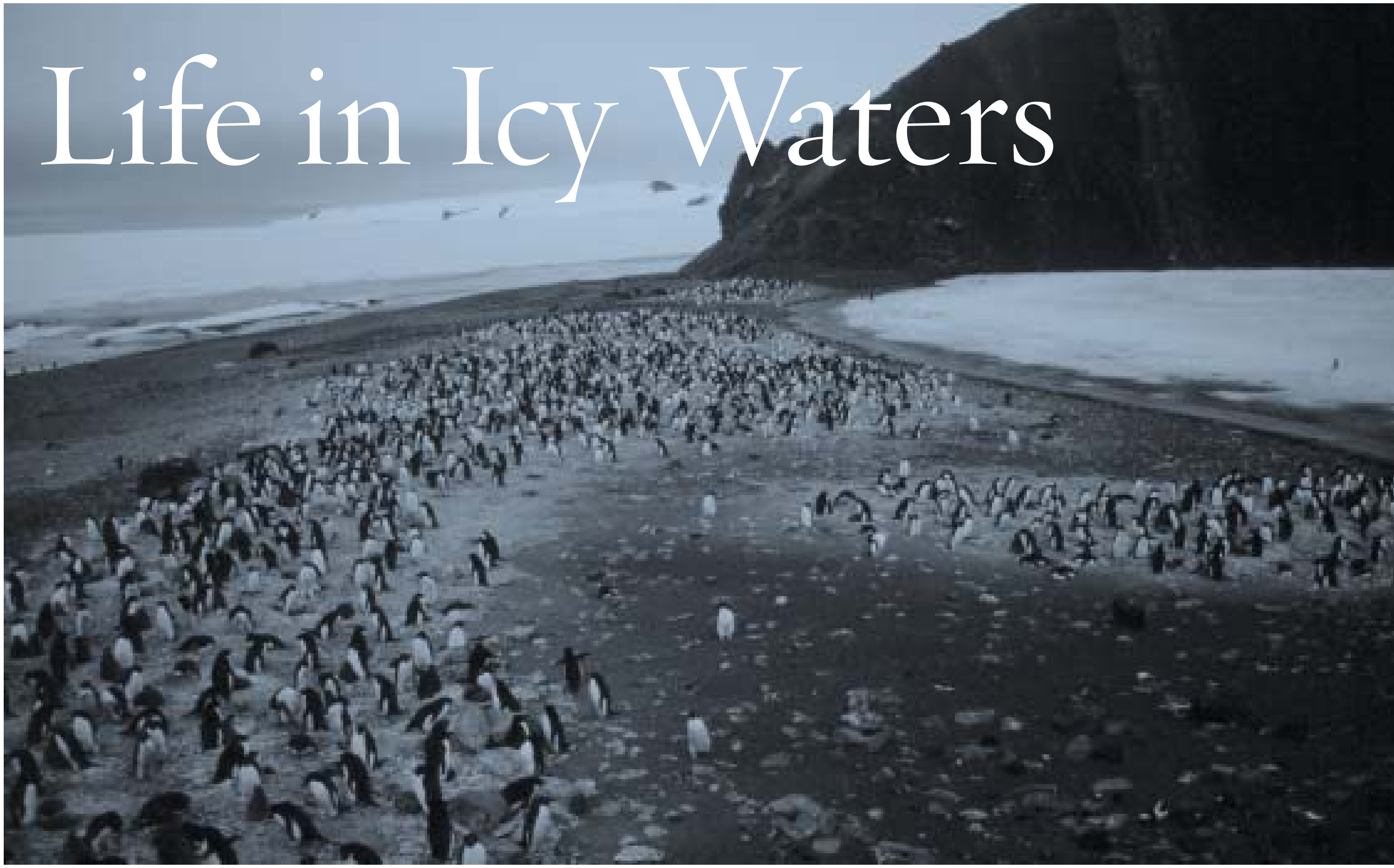
"When you think of polynyas as a concentrated food source for larger organisms, then it becomes clear how important they are."

National Snow and Ice Data Center DAAC

GSFC Earth Sciences DAAC

by Jason Wolfe

Life in Icy Waters



Adéile penguins nest and breed on rocky, ice-free beaches in large colonies of thousands of birds. More than 2.5 million breeding pairs live in the Antarctic region. (Image courtesy of NOAA)

At the bottom of the globe, darkness permeates the harsh landscape for months at a time. Just a glimpse of this quiet desolation makes one wonder what could possibly survive there. But as summer slowly approaches and the sun brings light and warmth to the sea around Antarctica, the vast expanse of winter ice that blanketed the sea slowly weakens. Long, ragged cracks wind their way through the ice, revealing areas of open water.

At first glance these open water areas, known as polynyas, might seem too bleak to harbor life. But during brief periods each year the biological productivity increases, meaning that organic matter is produced at a higher rate. More nutrients in the water means a greater ability to support a variety of organisms.

Few studies have looked at the biology of these open water patches until recently. Aided by high-resolution satellite data, Kevin Arrigo conducted a comprehensive inventory of the polynyas surrounding the coast of Antarctica. The five-year study showed that during a typical year, many polynyas are not very productive, while others are teeming with life for just a few short months, providing a feeding ground for larger animals like the Adéile penguin.

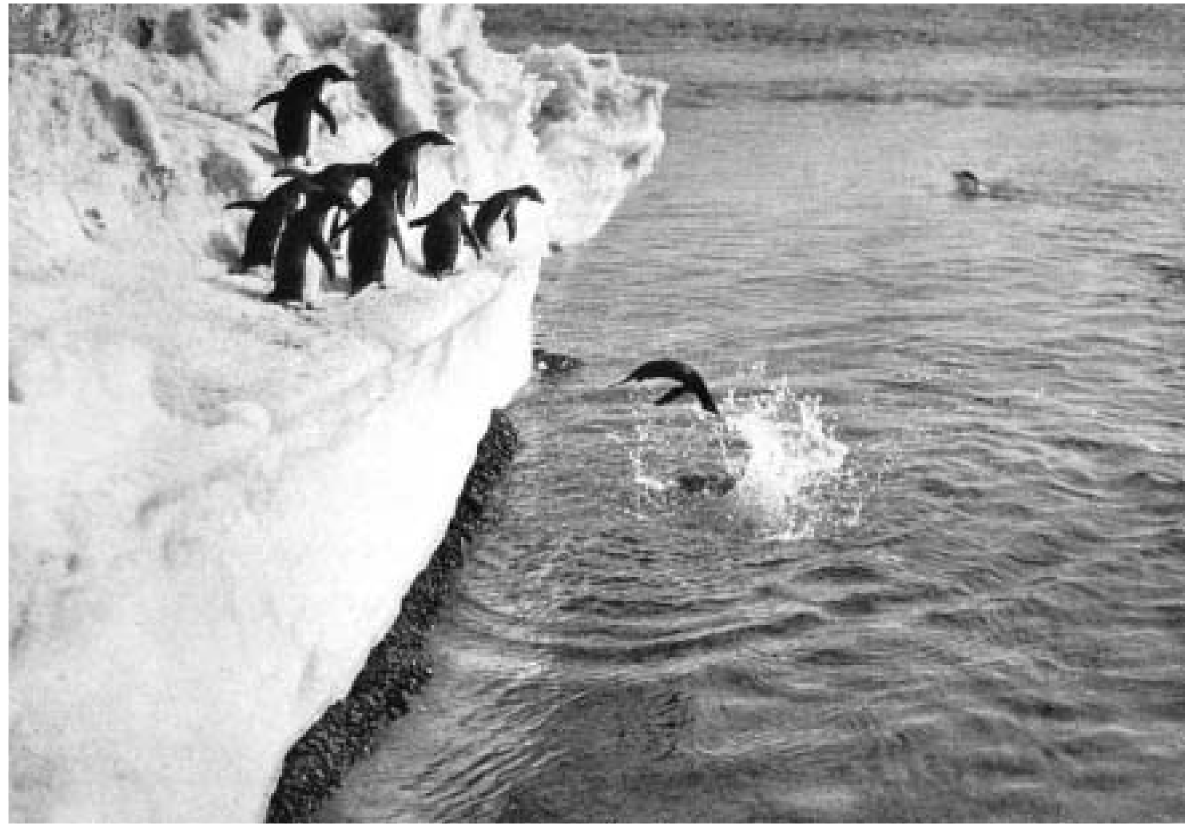
“We didn’t have any information about how productive these polynyas were, so our motivation was to find out what fraction of the Southern Ocean production the polynyas are responsible for,” said Arrigo, biologist and assistant professor of geophysics at Stanford University. Arrigo also hoped to learn more about the relationship between polynya productivity and the overall food chain.

Polynyas support the growth and accumulation of plantlike organisms, called phytoplankton, which consist mostly of algae and bacteria and are the foundation of the marine food chain. Ocean surface waters where polynyas occur are the first areas in polar regions to be exposed to increasing springtime solar radiation, either because they lack ice cover or because their weak ice cover is more susceptible to early breakup. This exposure to the sun, in turn, promotes the livelihood of phytoplankton and other marine organisms.

Understanding the distribution of polynyas around Antarctica is one of the first steps toward identifying biological habitats in the region, according to Arrigo. “We knew there were quite a few polynyas, but no one has ever tried to quantify their productivity before,” he said.

To locate the Antarctic polynyas, Arrigo and a team of researchers analyzed data from the Special Sensor Microwave/Imager (SSM/I), a passive microwave sensor that measures the amount of radiation emitted by the Earth’s surface, known as brightness temperatures. Brightness temperatures are a gauge of emissivity, or the ability of water or ice to emit radiation at microwave frequencies. The data, archived at the National Snow and Ice Data Center (NSIDC) DAAC, were collected from June 1997 to May 2002.

According to Arrigo, the coastal polynyas of Antarctica have never been studied in detail before, largely because of the region’s persistent cloudiness, which prevents satellites from “seeing” the surface. But passive-microwave sensors such as SSM/I measure the Earth’s emitted microwave energy that easily penetrates clouds. The SSM/I data enabled the researchers to study the sea ice in great detail, even in cloudy conditions.

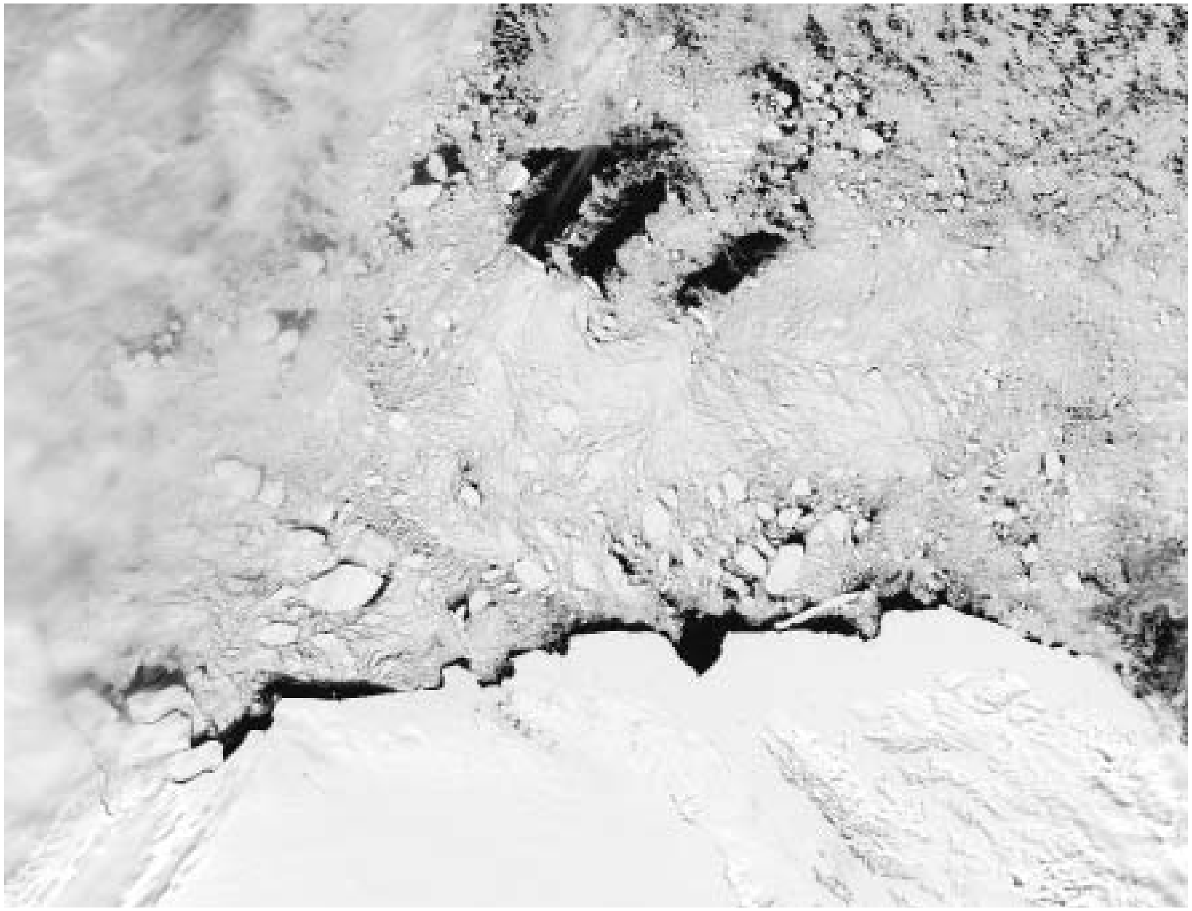


Adéile penguins form colonies on island beaches and headlands around the Antarctic coast. Like other penguin species, they like to play by sliding on ice and diving into the water. (Image courtesy of NOAA)

Using these data, Arrigo identified 37 coastal polynyas around Antarctica. The largest, located in the Ross Sea, was 153,090 square miles (396,500 square kilometers), and the smallest, located in the West Lazarev Sea, was 401 square miles (1,040 square kilometers).

The team also obtained Sea-viewing Wide Field-of-view Sensor (SeaWiFS) ocean color data for the same time period from the Goddard Earth Sciences (GES) DAAC. Ocean color data distinguish variations in ocean color caused by chlorophyll and other plant pigments that harvest light for photosynthesis. The SeaWiFS data identify the areas of greatest biological productivity, based on the amount of light absorbed by phytoplankton chlorophyll.

“Some of the polynyas were not as productive as I would have expected,” said Arrigo. “The Southern Ocean



This image of the Oates and Pennell Coasts of Antarctica, acquired by MODIS on December 3, 2002, shows several large polynyas. (Image courtesy of NASA)

as a whole is not considered a very biologically productive place, and some of the polynyas are even less productive than the average for the Southern Ocean, which surprised me because we tend to think of these areas as little 'hot spots' of productivity."

But, Arrigo explained, polynyas can indeed be hot spots during a short period of time during the Southern Hemisphere summer, typically December to February each year. This is when phytoplankton concentrations are highest, providing nutrients for a wide variety of larger organisms. "Total productivity may not be that high when averaged over an entire year, but when concentrated in a brief time span, it's significant. When you think of polynyas as a concentrated food source for larger organisms, then it becomes clear how important they are," said Arrigo.

In fact, Arrigo found that Adéile penguins depend on these nutrient-rich polynyas throughout much of their life. Besides providing a concentrated food source, the polynyas affect the penguin's reproductive schedule. "The penguins time their cycles [with] when the food is available," said Arrigo. "Adéile and Emperor penguins have their chicks in the middle of the winter, so when spring comes, they will have food for the chicks."

Arrigo also learned that polynya development is not constant. "We usually think of polynyas as persistent, recurrent features that happen in the same place year after year, but in fact, they are incredibly variable. The amount of open water within the 37 Antarctic polynyas varies by more than two orders of magnitude both during the winter and summer."

Next, Arrigo plans to study the polynyas on an individual basis, with a longer time series of satellite imagery, including data from the Coastal Zone Color Scanner (CZCS) sensor from the 1970s. He hopes to use this detailed information about each polynya to evaluate patterns of Adéile penguin colonies and focus on their food sources, and to learn why some regions are more nutrient-rich than others. "We've looked at polynyas and productivity in a broad sense, so now I'd like to start taking the polynyas apart and study individual colonies of organisms," he said.

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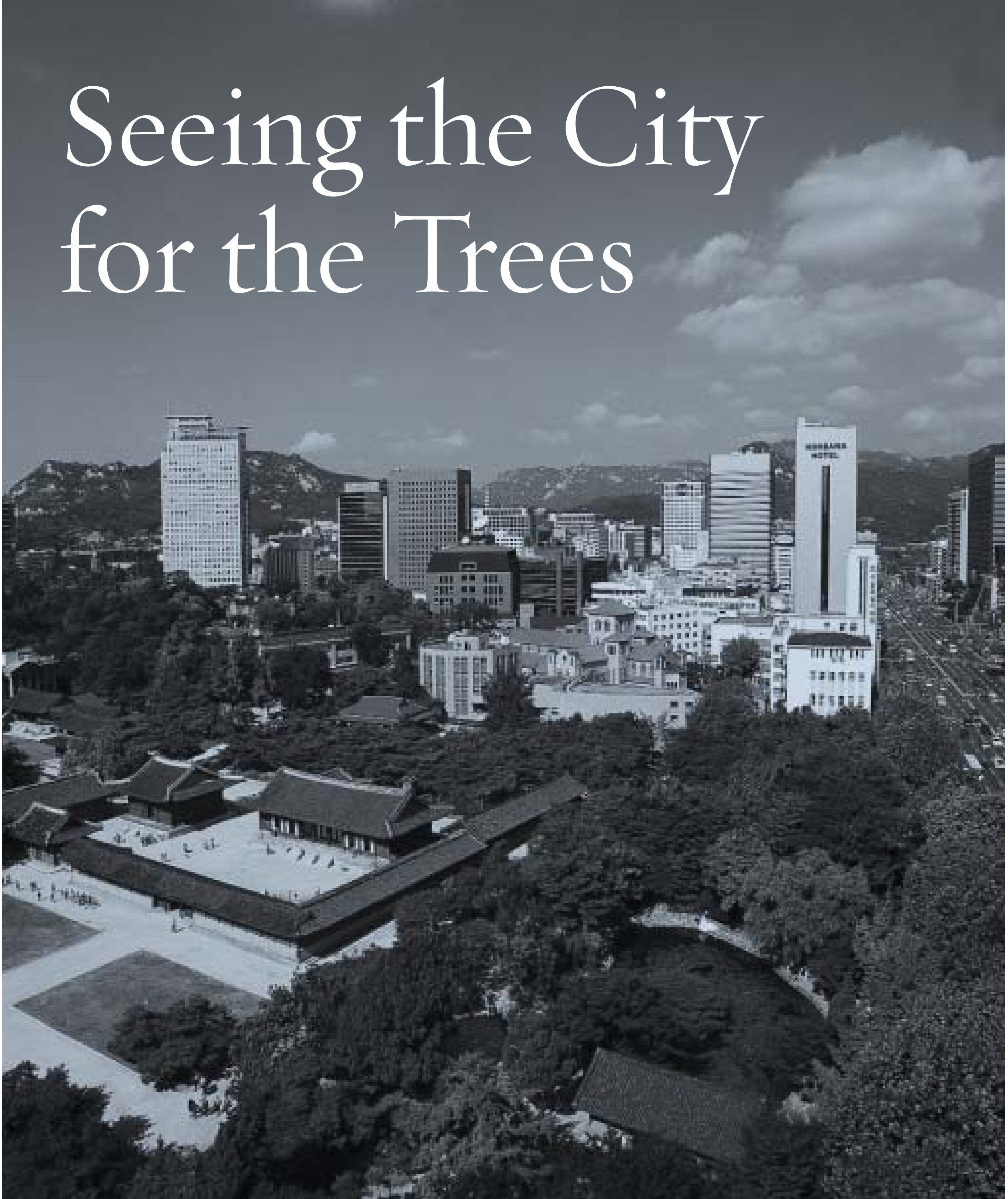
Antarctic penguins thrive in ocean oases. Accessed January 9, 2004. http://www.gsfc.nasa.gov/topstory/2003/0930penguins.html.

Kevin R. Arrigo is a biologist and assistant professor of geophysics at Stanford University. As a biological oceanographer, his principal interest is in the role marine algae play in biogeochemical cycles. His interdisciplinary research incorporates satellite remote sensing, ecophysiological modeling, and laboratory and field studies. Arrigo holds a PhD in biology from the University of Southern California.

Seeing the City for the Trees



"Satellite and other remote sensing data are extremely useful for assessing the overall pattern, condition, and spatial extent of trees across the urban landscape."

Land Processes DAAC

Socioeconomic Data and Applications Data Center

by Laura Naranjo

In 1971, a greenbelt was established around the entire city of Seoul, Korea, in which construction was prohibited in an effort to prevent uncontrolled urban sprawl. In the mid-1980s, the urbanization leaped over the greenbelt. Seoul is part of an agglomeration of 19 large cities in the Seoul Capital Region, which is home to 19.4 million inhabitants. (Image from Photos.com)

When most people think of islands, they imagine sunny beaches and palm trees, not sweltering summer days and polluted air. But hot, smoggy cities often become what scientists call "urban heat islands," where the air temperature can be 1 to 4 degrees Celsius (about 2 to 8 degrees Fahrenheit) warmer than surrounding rural areas.

Urban heat islands occur because cities tend to have large areas of dark roofing and paving material that absorb instead of reflect sunlight, causing surface and air temperatures to rise. Higher temperatures, in combination with air pollutants emitted by cars and industrial facilities, spur chemical reactions in the air that lead to more intense concentrations of ground-level ozone, which is the main ingredient in smog.

Higher temperatures and smog are more than just inconveniences to city dwellers; they can be a health hazard. But to understand how urbanization contributes to the heat island effect, scientists must analyze the urban landscape.

Dale Quattrochi, geographer and senior research scientist at the Marshall Space Flight Center, studies the urban heat island effect in Atlanta. Using data from NASA's Advanced Thermal and Land Application Sensor (ATLAS), flown onboard a Lear jet, Quattrochi measured temperatures across Atlanta. He then analyzed Landsat satellite data, obtained from the EROS Data Center, to study the city's land cover patterns.

Quattrochi found that Atlanta's dramatic growth and extensive land cover change over the past few decades exacerbated the heat island effect. Landsat images of metropolitan Atlanta between 1973 and 1992 revealed that developers had cleared almost 380,000 acres of trees, replacing them with retail centers, roads, and about 270,000 acres of tract housing. Landsat data also revealed that an additional 180,000 acres of trees were cleared between 1993 and 1999.

Quattrochi's advice to city managers? Plant more trees. Trees and other vegetation help alleviate the urban heat island effect by providing shade, intercepting solar energy, cooling the air, and reducing air pollution.

While Quattrochi admits that shade is mostly a local effect, he stresses the importance of urban forests, or large collections of trees, such as those found in parks. Aside from providing large areas of shade, "The urban forest intercepts a significant amount of solar energy that would otherwise be used to heat up non-natural urban surfaces," he said.

When trees absorb sunlight, they don't heat up like urban materials do. In fact, trees transform solar energy into cool air through a process called evapotranspiration. Trees transpire, or release, water through pores in their leaves, and sunlight helps evaporate this water from the leaf surface. In other words, trees "sweat" to cool off, just like people do.

Trees also improve air quality by absorbing air pollutants such as sulfur dioxide and carbon monoxide. But not just any tree will do. Trees like oak and sycamore emit higher amounts of biogenic volatile organic compounds (BVOCs). BVOCs are naturally occurring pollutants that contribute to the development of ground-level ozone. Planting trees such as maple and elm, which are low BVOC emitters, can improve a city's air quality more effectively than high BVOC emitting trees.

Besides planting trees, cities can also "lighten up" and reduce the amount of dark surfaces that absorb heat. "A number of roofing companies are very proactive in Atlanta, and they're trying to use highly reflective roofing materials for warehouses and other buildings with very large square footage," said Quattrochi. Chicago and Atlanta are also starting to use reflective roofing for new construction.

Other cities have initiated the planting of rooftop gardens on city buildings to help cool the urban surface. Rooftop gardens insulate buildings and reduce energy consumption by intercepting solar energy that would otherwise heat the roof surface. And because rooftop gardens are irrigated, evapotranspiration helps cool the air.

Although Quattrochi's studies have focused on individual cities, the ATLAS sensor that he relied on for local data collection has become too costly to use. Quattrochi now expects to build on the archive of ATLAS data with remote sensing data from the Landsat and

Quickbird satellites, as well as from NASA's Moderate Resolution Imaging Spectroradiometer (MODIS) sensor to monitor urban vegetation and land cover changes in metropolitan areas.

To avoid the expense of localized studies, scientists like Quattrochi are trying to develop remote sensing methods to observe urban land cover. As opposed to one-time localized data collection, satellite data provide long-term records of how land changes over time. Additionally, said Quattrochi, "Satellite and other remote sensing data are extremely useful for assessing the overall pattern, condition, and spatial extent of trees across the urban landscape."

Mapping the abundance and distribution of vegetation in cities with satellites presents its own unique challenges. Remote sensing techniques usually rely on thematic classification, which involves assigning a single general land cover type (vegetation, water, urban area, etc.) to each pixel in an image. But because pixels classified as urban area may contain significant portions of vegetation, and vice versa, misclassification of mixed pixels can cause scientists to inaccurately map an urban area. In addition, how different classes of land cover are defined may be specific to a particular city or study, so the criteria can't reliably be applied to other urban areas.

Chris Small, research scientist at Columbia University's Lamont-Doherty Earth Observatory and project scientist at NASA's Socioeconomic Data and Applications Center (SEDAC), is using an approach designed for broader application.

Using Landsat data, Small and his colleagues are developing a model based on three categories of physical properties common to all urban environments: vegetation (usually trees), dark surface (deep shadow, asphalt, and other materials that absorb sunlight), and bright substrate (soil, concrete, and other reflective materials).

Landsat measures light reflected by and emitted from the Earth. The method Small is using, called Spectral Mixture Analysis, involves using Landsat data to divide urban land cover into these three categories. For most satellite data, the smallest unit of measurement is usually a pixel. But by running each pixel's reflectance characteristics through a computer model, Small can break a pixel down into fractions based on how each category reflects or absorbs light.

Spectral Mixture Analysis allows "mixed" pixels that can contain more than one class of land cover, reducing misclassification and allowing scientists to more accurately map the amount and distribution of vegetation in relation to urban building materials. This method represents an improvement over thematic classification, in which pixels must be classified as one type, even if they contain another type of land cover. "Instead of lumping a variety of different surface types into one thematic class and assigning one single value to that area, we're using Spectral Mixture Analysis to estimate fractions of urban land cover types," said Small.

To study vegetation in a number of cities around the world, Small and his colleagues at the SEDAC used Landsat data from NASA's Land Processes Distributed Active Archive Center (LP DAAC) and the Global Land Cover Facility, as well as data from commercial satellites such as Quickbird and Ikonos.

Relying on Landsat data, Spectral Mixture Analysis proved consistently effective at mapping urban vegetation, regardless of the city, making it flexible and broadly applicable. "Compared to many other types of urban data, the big advantage of Landsat is that it works exactly the same way over every place in the world," said Small.

An urban mapping technique based on satellite data that provides continuous coverage will allow city managers to observe changes in urban land cover over time to see whether growth patterns in their cities are alleviating or exacerbating the urban heat island effect.

For example, the New York City Parks Department is now using Landsat-derived vegetation maps to study vegetation changes in the New York metropolitan area.

"Now we can investigate whether tree cover is increasing or decreasing in various neighborhoods. Spectral Mixture Analysis gives us a simple and systematic way to look at total forest loss in a city," Small said.

A panoramic aerial view of New York City shows the extensive urban tree canopy in Central Park. Trees and other vegetation help mitigate the urban heat island effect. (Image copyright Joseph Pobereskin/NYC & Company, Inc.)

Tucson, Arizona is one example of a city in the southwestern United States that has experienced rapid growth and urban sprawl over the last several decades. Land use modifications that accompany urban growth often lead to urban heat islands. (Image from Photos.com)

Small added that vegetation maps may help city managers monitor re-vegetation efforts, such as when a community plants or preserves trees, or when vacant land begins to support plant life again. Conversely, city managers could also watch for vegetation loss, which tends to occur when urban areas spread and replace natural vegetation.

Although Small and Quattrochi are using different approaches to monitor how vegetation changes impact the urban environment, they agree that understanding the urban heat island effect is a priority for many cities. According to recent United Nations estimates, at least 47 percent of the world's population currently lives in urban areas, and that percentage is expected to grow dramatically in the next few decades. Understanding the urban environment will become crucial to managing growth and mitigating the urban heat island effect. "We can begin to compare different cities, look at growth patterns, and hopefully provide a way for city managers to study their own regions," said Small.

For more information, visit the following web sites:

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

Land Processes DAAC
http://lpdaac.usgs.gov/main.asp

Socioeconomic Data and Applications Center (SEDAC) Urban Remote Sensing
http://sedac.ciesin.columbia.edu/urban_rs/

Urban Remote Sensing
http://www.ldeo.columbia.edu/~small/Urban.html

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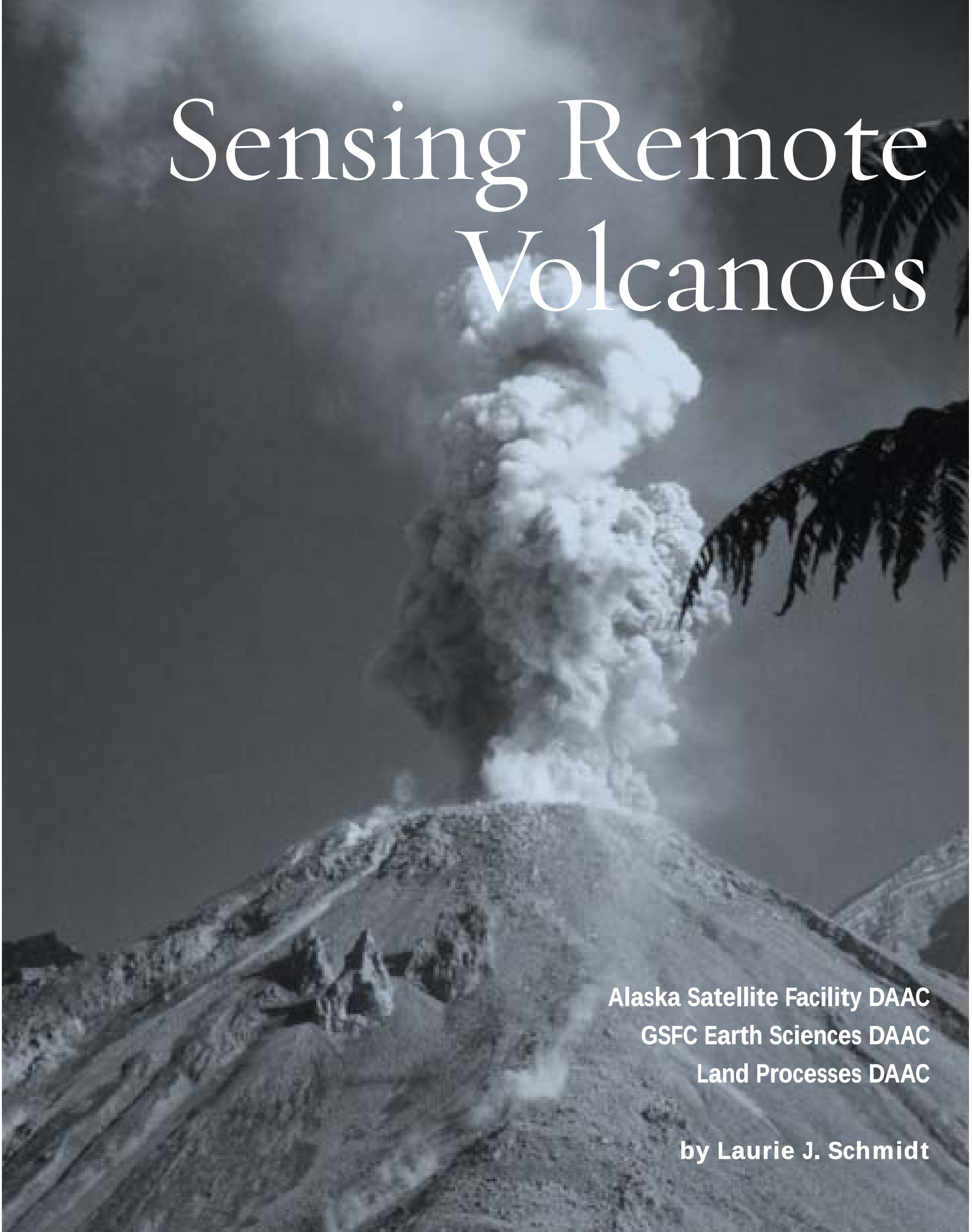
Dale Quattrochi is a research scientist in the Earth System Science Division at NASA's Marshall Space Flight Center. His thermal remote sensing research focuses on analyzing the urban thermal landscape as an important component in urban climatology. Quattrochi is also an adjunct faculty member in the atmospheric science department at the University of Alabama, Huntsville, and in the Department of Plant and Soil Science, Center for Hydrology, Soil Climatology and Remote Sensing, at Alabama A&M University. He holds a PhD in geography/remote sensing from the University of Utah.

Christopher Small is a Doherty research scientist at the Lamont-Doherty Earth Observatory at Columbia University. His current research focuses on the use of satellite remote sensing to quantify changes in the Earth's surface and the causes and consequences of these changes. Small earned his PhD in geophysics from the Scripps Institution of Oceanography at the University of California, San Diego.

Sensing Remote Volcanoes

Alaska Satellite Facility DAAC
GSFC Earth Sciences DAAC
Land Processes DAAC

by Laurie J. Schmidt



"What's important is the global perspective and the way volcanoes work on different timescales. We now have this remote capability to study volcanoes anywhere in the world."

In October 2001, a sleeping volcano in the remote South Sandwich Islands began spewing ash and lava from its summit. It was Mount Belinda's first eruption in recorded history. Less than 24 hours after the eruption began, a research team based nearly 9,000 miles away at the University of Hawaii was already estimating how much energy was pouring out of the volcano.

That the researchers were making calculations so soon after the start of Mount Belinda's eruption is remarkable, considering the volcano's remote location. The South Sandwich Islands are situated between the southern tip of South America and mainland Antarctica, one of the most isolated areas of volcanic activity on Earth.

More than 1,500 potentially active volcanoes dot the Earth's landscape, of which approximately 500 are active at any given time. Although scientists keep watch over many of the Earth's volcanoes using traditional ground observation methods, satellite-based remote sensing is quickly becoming a crucial tool for understanding where, when, and why the Earth's volcanoes periodically boil over.

Satellite technology now makes it possible to monitor volcanic activity in even the most isolated corners of the globe, and to routinely observe changes in the Earth's surface that may signal an impending eruption. In addition, remote sensing data offer scientists the chance to prevent

This volcanic explosion occurred at Santiaguito lava dome in Guatemala. The lava dome grew in the crater that remained after the 1902 eruption of Santa Maria Volcano, one of the largest eruptions of the 20th century. The MODVOLC Thermal Alert System regularly detects thermal emissions from Santa Maria Volcano. (Image courtesy of Rob Wright, Hawaii Institute of Geophysics and Planetology) catastrophic damage to life and property by determining how and where volcanic debris spreads after an eruption.

"Hot Spots" Around the Globe

Just 10 years ago, Mount Belinda's eruption might not have been detected for weeks or even months. "Normally, this remote volcano would have gone unmonitored," said Rob Wright, research scientist at the Hawaii Institute of Geophysics and Planetology (HIGP). "However, when our system detected hot spots on Montagu Island, we decided to take a closer look. Inspection of high-resolution satellite imagery confirmed that the hot spots were indeed the result of volcanic activity."

The "system" Wright refers to is the MODIS Thermal Alert System, known as MODVOLC, which now enables scientists to detect volcanic activity anywhere in the world within hours of its occurrence. MODVOLC uses data acquired by the Moderate Resolution Imaging Spectroradiometer (MODIS) sensors, which fly aboard NASA's Terra and Aqua satellites. "The algorithm we've developed scans each 1-kilometer pixel within every MODIS image to see if it contains high-temperature heat sources, or *hot spots*. These heat sources may be active lava flows, lava domes, or lava lakes. Since MODIS achieves complete global coverage every 48 hours, this means that our system checks every square kilometer of the globe for volcanic activity once every two days," said Wright.

For each hot spot identified, MODVOLC records the date and time at which it was observed, its geographic coordinates, the position of the satellite and the Sun, and the spectral radiance (the amount of energy emitted by the Earth's surface at various wavelengths in the electromagnetic spectrum). Since active lava flows or growing lava domes emit vast amounts of energy, these hot spots are relatively easy to detect in MODIS imagery, even when they are smaller than MODIS' 1-kilometer resolution. "The lava lake at Mount Erebus in Antarctica is only about 10 meters in diameter, but it's clearly identifiable in MODIS images and, therefore, by our monitoring system," said Wright.

One potential problem with a near-daily monitoring system like MODVOLC is the large volume of data generated. "If you want to study large regions at high temporal resolution, you'll have to download a huge amount of MODIS data to get the job done," said Wright. The problem was overcome, however, by operating MODVOLC via NASA's Goddard Space Flight Center (GSFC) Earth Sciences (GES) DAAC. "Running the algorithm at the GES DAAC basically allows us to rapidly compress large amounts of image data into a handful of text files that include the details of only the pixels containing hot spots. As a result, we can monitor the entire globe in near-real time," said Wright.

The information that MODVOLC records at the GES DAAC is then sent electronically to HIGP, located at the University of Hawaii on the island of Oahu, where the results are displayed on the system's web site. "If you go to the web site, you can see all of the hot spots detected during the previous 24-hour period," said Wright. "It takes about 8 hours from the time MODIS images the erupting volcano to the time the eruption is reported on the web site."

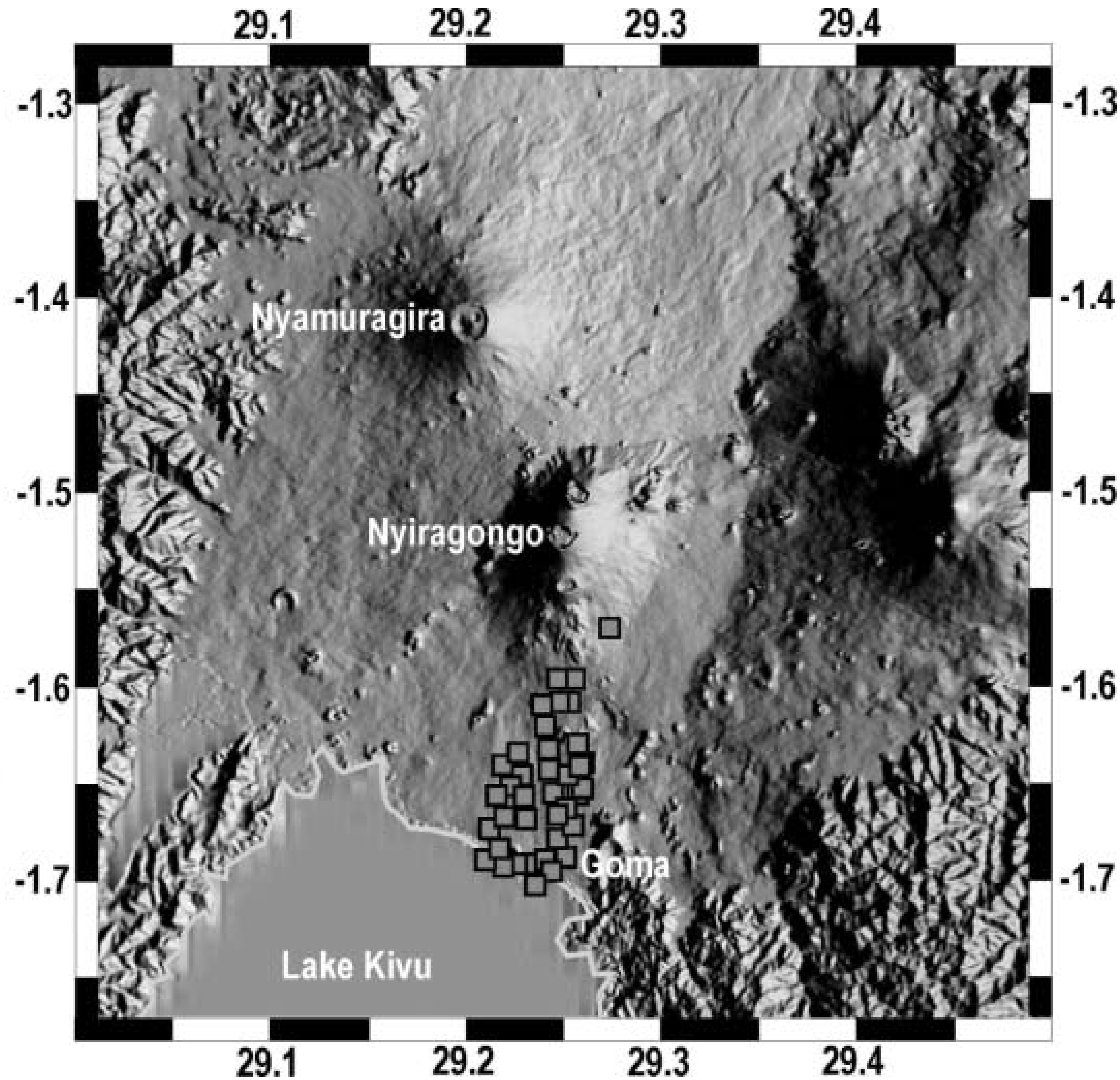
The web site also allows users to click on any area of the globe and "zoom in" on individual eruptions or make comparisons between two erupting volcanoes. "You can compare, for example, the behavior of the lava dome at Soufriere Hills Volcano on the island of Montserrat with the behavior of the dome at Colima Volcano in Mexico," said Wright.

Using MODVOLC, Wright and his colleagues have seen many active volcanoes that previously went undetected. An example is the 2002 eruption of a submarine volcano off the coast of the Solomon Islands in the South Pacific. "Kavachi Volcano is usually below sea level, but in late 2002 we began seeing hot spots in the exact location where Kavachi should be," said Wright. "It turned out that erupting lava caused the volcano to grow so that its summit reached just above sea level, and when it popped its head above the waves, our system detected the emitted heat."

Wright's team also detected the first recorded activity at Anatahan Volcano in the Mariana Islands in 2003. "This volcano has no recorded eruption history and is located in an isolated part of the world. It's not the sort of volcano you would choose to monitor," said Wright. "However, we have in effect been monitoring it since September, 2000." In May 2003, an explosive eruption at

Lava erupted by Kilauea Volcano between 1983 and 1990 repeatedly invaded communities along its southern coast, destroying more than 180 homes, a visitor center in Hawai`i Volcanoes National Park, highways, and treasured historical and archaeological sites. Flows entered Kalapana briefly in November 1986, then moved through the entire community in 1990. (Images courtesy of U.S. Geological Survey)

This image shows hot spots detected by the MODVOLC Thermal Alert System during Nyiragongo's 2002 eruption. Each square represents a single hot spot pixel detected by MODVOLC's algorithm. (The size of each square is equivalent to the 1 km MODIS resolution.) The hot spots are overlaid on a shaded relief representation of Shuttle Radar Topography Mapping (SRTM) mission digital elevation, for geographic context. (Images courtesy of Rob Wright, Hawaii Institute of Geophysics and Planetology)



Anatahan began, accompanied by the growth of a lava dome. "MODVOLC detected the eruption and pinpointed exactly where on the island it was occurring," Wright added.

Signs of an Impending Eruption

Because of the near-daily global coverage, MODIS data are ideal for quickly providing researchers with information about new eruptions. Other types of satellite data, such as Synthetic Aperture Radar (SAR), are better suited to looking at the geologic changes that often precede an eruption. Although these data don't yet provide the quick turnaround time required for detecting new activity, they instead provide the spatial coverage necessary for scientists to see how the ground surface is deforming over a broad region.

Surface changes were key to understanding a major volcanic eruption in 2002. Mount Nyiragongo, located in the Democratic Republic of the Congo, is one of Africa's most active volcanoes. During an eruptive phase in 1994, a lava lake formed in the volcano's summit crater. Lava lakes consist of large volumes of molten lava contained within a vent, crater, or broad depression. After its lava lake formed, Nyiragongo calmed down for about eight years. Then, on January 17, 2002, a major eruption occurred—with little warning.

Lack of warning at Nyiragongo has grave implications: the city of Goma sits about 9 miles (15 kilometers) south of the volcano. "About 500,000 people live in Goma and its immediate vicinity," said Michael Poland, geophysicist at Cascades Volcano Observatory in Vancouver, Washington. "Nyiragongo has a reputation for spawning pretty nasty lava flows. The potential hazard to human life there is significant."

Ground data are not easy to come by in the region of Nyiragongo. "It's a dangerous place for field research," said Poland. "There's the Ebola virus and an ongoing civil war. Top that off with an erupting volcano, and you have a pretty volatile situation for a field researcher."

Add to those dangers the region's lack of technology, and it's no surprise that Nyiragongo has little monitoring history. "Collecting and recovering data in the Congo is made more difficult because there are problems with equipment being stolen," Poland added. "So in addition to putting monitoring equipment in place, you have to hire three or four people to guard it. It gets to be quite costly."

Despite the lack of ground data, Poland learned of some anecdotal evidence of deformation from Congolese researchers. "The local townspeople typically wash their clothes in Lake Kivu, which is located adjacent to Goma. One day, they noticed that the rocks they normally used to dry their clothes on the shoreline were actually under water, so the lake level had come up—indicating subsidence," said Poland. Measurements of the lake level before and after the eruption later confirmed this evidence.

Poland recognized the 2002 Nyiragongo event as an opportunity to use SAR satellite imagery to analyze how the eruption deformed the ground on and around the volcano. Ground deformation refers to surface changes on a volcano, such as subsidence (sinking), tilting, or bulge formation, due to the movement of magma below the surface. Deformation changes at a volcano, such as those related to magnitude or location, may indicate that an eruption is about to occur. An example of visible deformation occurred in 1980 when a bulge appeared on the north flank of Mount St. Helens prior to its May 18 eruption. Scientists estimated that just before the eruption, the bulge was growing at a rate of 5 feet (1.5 meters) per day.

To determine whether deformation preceded the Nyiragongo eruption, Poland requested SAR data from the Alaska Satellite Facility Distributed Active Archive Center (ASF DAAC). SAR interferometry, or InSAR, is one of the few methods available for remotely analyzing ground deformation that accompanies or precedes volcanic activity. The technique operates on the premise that if the radar signal reflected back to the sensor differs between two images of the same object, taken at two different times, then the object has moved or changed.

"It was obvious that an eruption at Nyiragongo had occurred, but the extent and cause of the activity were unclear. Without InSAR, we wouldn't have learned much about this particular event," said Poland. "The satellite imagery gave us some clues to what happened in a location where surface-based measurements are scarce."

Poland's study showed that significant deformation across the entire rift valley occurred at the time of the eruption. "Based on the data, we determined that all the deformation happened somewhere between three days before to about 15 days after the eruption," he said. "This means there was no long-term deformation warning, which is interesting because typically with volcanoes, you see inflation or uplift that precedes the eruption by weeks, months, or even years."

Poland explained that an earlier Nyiragongo eruption, in 1977, formed a fracture system that led partway down to the city of Goma. "Then, during the 2002 eruption, that fracture system was reactivated, and the flowing magma propagated the fractures closer to the city. The lava actually flowed right down Main Street—right through the business district," he said.

According to Poland, seeing deformation across the entire rift zone suggests that the Nyiragongo eruption was no small event; it was a major tectonic episode. "We believe there must have been a large event that allowed magma stored high in the volcano to drain into the old fracture system and head downhill," he said. "The implication is that you can have a lot of lava come out in a very bad place—like right above your city—with very little warning."

Twice in the past 30 years, Nyiragongo's lava flowed along the fracture system on the south flank, and this flow path leads right to Goma. "If we can start using InSAR data to monitor deformation, we might be able to better assess the likelihood of eruption events before they happen," Poland said.

Tracking Ash Clouds

Studying volcanoes by looking at changes in surface features falls into the category of long-term monitoring, which means that the study is done over a longer time period and doesn't require the immediate availability of data. Short-term monitoring, on the other hand, demands a quick and rapid response, especially when the objective is to prevent or mitigate hazards.

Kenneson Dean, associate research professor at the University of Alaska's Geophysical Institute, studies a unique hazard related to volcanic eruptions—one that didn't concern Alaska until the rise of air traffic across the Bering Strait in the 1980s. The Alaskan skyway is one of the busiest air traffic areas in the world and, according to Dean, sometimes resembles a Los Angeles freeway. The skyway also runs along the northern boundary of the "Ring of Fire," a zone of frequent earthquakes and volcanic eruptions that encircles the Pacific.

"Large-body jets fly across this region carrying about 2,000 passengers and $1 billion in cargo daily," said Dean, who heads the satellite monitoring program at the Alaska Volcanoes Observatory (AVO) at the University of Alaska. "If a plane is flying towards an ash cloud, and the cloud is moving towards the plane, they will cross paths very quickly. Even if the cloud is not moving towards the plane, an aircraft still needs plenty of time to adjust its course and avoid the cloud."

Jet engines operate at a temperature that melts volcanic ash or glass, and this melted material can then cause the engines to slow and shut down. "The problem in this area is that the eruptions tend to be explosive. They eject volcanic material, gas, and ash well into the atmosphere, and many of these eruptions rise to 40,000 feet (about 12,000 meters) in height, which is the height of jet air traffic," said Dean. "A lot of people and property are at risk."

The AVO uses satellite data for short-term monitoring, which means that data are received, processed, and analyzed just minutes after a satellite pass. "The region we monitor covers several thousand kilometers and includes about 40 volcanoes in Alaska and about 60 in the Kamchatka Peninsula, Russia," Dean said. "We get the data directly from the MODIS and Advanced Very High Resolution Radiometer (AVHRR) sensors, and we analyze those data routinely every morning and afternoon."

In 1993, the University of Alaska's Geophysical Institute received a NASA grant to purchase its own AVHRR receiving station and, in 2001, a MODIS receiving station. Prior to having its own station, AVO used a Domestic Communications Satellite station at the University of Miami to collect the data and then send them electronically to Fairbanks for analysis. "Having our own stations on site reduced monitoring time from one hour to about 10 minutes," said Dean.

And minutes are important when you consider the hazard faced by aircraft that encounter ash clouds.

In 1982, a British Airways Boeing 747 carrying 240 passengers flew into an ash cloud near Indonesia's Galunggung Volcano. All four of the aircraft's engines shut down, nearly forcing the aircraft to ditch in the Indian Ocean. In 1989, a KLM 747 encountered an ash cloud over Talkeetna, Alaska. Again, all four engines failed and the jet descended to within a few thousand feet of the mountaintops before pilots were able to restart one of the plane's engines and make an emergency landing in Anchorage.

Between 1980 and 1999, more than 100 jet airliners sustained some damage after flying through volcanic ash clouds, according to the U.S. Geological Survey (USGS). "Aviation safety is one big reason we need to monitor active volcanoes in Alaska," said Dean. "Right now we're seeing hot spots almost daily at Shiveluch, Kliuchevskoi, and Bezymianny Volcanoes. When an explosive eruption occurs, you need an information turnaround time that's really fine-tuned, so that aircraft pilots have time to make decisions about whether to continue on their route, turn around, or change routes," said Dean. "Available fuel becomes a critical issue, too."

AVO's short-term monitoring program is obviously making a difference. "When an eruption occurs and the warnings go out, the airline industry often contacts us directly," said Dean. "We also follow Federal Aviation Administration reports, which reveal that aircraft are sometimes re-routed or even returned to their home port if the situation is bad," said Dean.

Not all eruptions are explosive, like those that tend to occur in the Alaska region. Some volcanoes, such as those in the Hawaiian Islands, are known for more quiet flows of fluid lava. Although Hawaiian eruptions usually do not result in loss of life, they can have devastating effects on land and property.

Kilauea Volcano, on the island of Hawaii, is the most active volcano on Earth. During the past 1,000 years, more than 90 percent of the volcano's surface has been covered by lava flows. Between 1983 and 1991, lava flows repeatedly struck communities located on the east coast of Hawaii. In 1990, flows covered the village of Kalapana, destroying more than 180 homes, a visitor center in Hawaii Volcanoes National Park, and historical and archaeological sites, according to the USGS.

"Hawaii volcanoes are known for long-term eruptions, wherein you have a small amount of gas emitted year in and year out for decades," said Peter Mouginis-Mark, research scientist and current acting director at HIGP. Mouginis-Mark heads a HIGP-based program called Hawaii Synergy, a cooperative effort to provide disaster management organizations and federal hazard agencies with access to current satellite data, including imagery from Landsat 7 and the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER), archived at the Land Processes Distributed Active Archive Center (LP DAAC).

According to Mouginis-Mark, perhaps the greatest benefit offered by satellite-monitoring technology will be an enhanced understanding of exactly how volcanoes work. "What's important is the global perspective and the way volcanoes work on different timescales," he said. "Some volcanoes produce lava flows, and other volcanoes explode so that you have to worry about big eruption columns. We now have this remote capability to study volcanoes anywhere in the world."

Although scientists will continue to use ground-monitoring techniques to keep an eye on the Earth's volcanoes, satellite data will increasingly allow scientists to see "the big picture" and, as a result, better predict volcanic activity.

"Satellite data are brilliant for understanding the levels of eruption intensity and for monitoring the impact an eruption is having on the surrounding environment," said Mouginis-Mark. "The ability to draw on ASTER or MODIS data and put together a one- to three-year sequence of observations really lets us look at whether there are real changes going on in a volcano."

"Compiling a global database of volcanic thermal unrest has allowed us to look at long-term trends," said Wright. "We're currently analyzing the entire MODVOLC data set to identify patterns that help us better understand how all the Earth's volcanoes behave."

For more information, visit the following web sites:

MODVOLC: Global spaceborne thermal monitoring with MODIS
http://modis.higp.hawaii.edu/

Alaska Volcano Observatory
http://www.avo.alaska.edu/

Cascades Volcano Observatory (USGS)
http://vulcan.wr.usgs.gov/

Hawaiian Volcano Observatory (USGS)
http://hvo.wr.usgs.gov/

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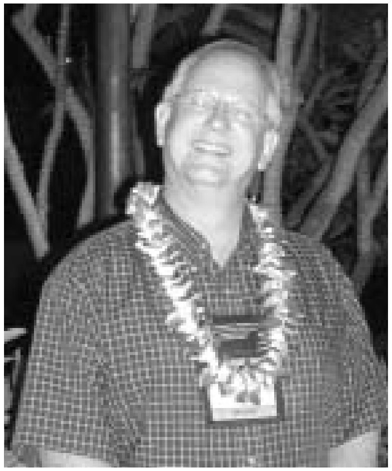
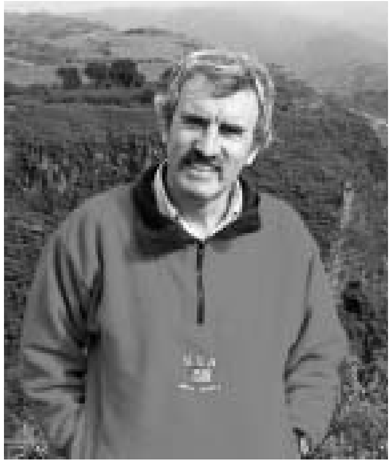
USGS Fact Sheet 144-02: The Pu'u 'O'o-Kupaianaha Eruption of Kilauea Volcano, Hawai'i, 1983 to 2003. http://geopubs.wr.usgs.gov/fact-sheet/fs144-02/



Kenneson Dean is a research professor and co-leader of the Remote Sensing Group at the Geophysical Institute, University of Alaska, Fairbanks. His research focuses on using satellite and meteorological data to monitor and analyze volcanic eruptions in the north Pacific region for the Alaska Volcano Observatory. Dean led the team that developed and refined techniques to detect and track eruption clouds, estimate their height, and detect volcanic hot spots. He is also the lead scientist for "Puff," an ash dispersion model. Dean earned a MS in geology from the University of Alaska, Fairbanks.



Peter Mouginis-Mark is a research scientist and acting director of the Hawaii Institute of Geophysics and Planetology at the University of Hawaii. His research focuses on planetary volcanology, impact cratering, and the use of remote sensing data to study active volcanoes on Earth. He has written over 90 papers on the analysis of active volcanoes on Earth using satellite and aircraft data sets, and on the geology of Mars. Mouginis-Mark holds a PhD in environmental sciences from the University of Lancaster, England.

Michael Poland is a geophysicist at the U.S. Geological Survey's Cascades Volcano Observatory in Vancouver, Washington. His research has included physical volcanology, dike emplacement in the western U.S., and volcano geodesy using GPS and SAR interferometry (InSAR) techniques. Poland holds a PhD in geology from Arizona State University.

Rob Wright is an assistant researcher at the Hawaii Institute of Geophysics and Planetology, University of Hawaii, Manoa. His research focuses on the use of satellite data in understanding the behavior of erupting volcanoes. He holds a MS in remote sensing from the University College/Imperial College, London, and a PhD in remote sensing from the Open University.

Breakup of the Ward Hunt Ice Shelf

Alaska Satellite Facility DAAC

by Michon Scott

Above: This Canadian RADARSAT image, acquired in August 2002, shows the central crack in the Ward Hunt Ice Shelf running down the center of the image. (Image courtesy of the Alaska Satellite Facility, Geophysical Institute, University of Alaska Fairbanks)

"Climate change models usually predict gradual, continuous change, but real-life impacts are not continuous. Changes can be relatively small, and then suddenly you can move to a new threshold."

In the summer of 2002, graduate student Derek Mueller made an unwelcome discovery: the biggest ice shelf in the Arctic was breaking apart. The bad news didn't stop there. Lying along the northern coast of Ellesmere Island in northern Canada, the Ward Hunt Ice Shelf had dammed an epishelf lake, a body of freshwater that floats on denser ocean water. This epishelf lake, located in Disraeli Fiord, was host to a rare ecosystem, and it was the largest and best-understood epishelf lake in the Northern Hemisphere. When the Ward Hunt Ice Shelf fractured, the epishelf lake suddenly drained out of Disraeli Fiord, spilling more than 3 billion cubic meters of fresh water into the Arctic Ocean.

Mueller and his graduate advisor Warwick Vincent, both of Laval University in Quebec City, realized something unusual was happening to the ice shelf when they found unexpected fractures while doing fieldwork on the ice and during helicopter overflights. They contacted geophysics professor Martin Jeffries at the University of Alaska Fairbanks. Fortunately, Jeffries had planned ahead.

"Knowing that Derek and Warwick would be doing fieldwork, I'd already placed data acquisition requests with the Canadian Space Agency through the Alaska Satellite Facility DAAC," Jeffries said. Jeffries requested data from the agency's RADARSAT-1 satellite. Equipped with a Synthetic Aperture Radar (SAR) sensor, RADARSAT-1 can acquire imagery in almost any kind of weather, with or without sunlight. "I had almost real-time RADARSAT data on my computer in a very short time, and I could confirm Derek's observation."

In their final flight over the Ward Hunt Ice Shelf on August 11, 2002, Mueller and his party learned something else: new icebergs had just calved from the front of the ice shelf. Using the RADARSAT data again, Jeffries confirmed that the icebergs had calved sometime between August 6 and August 11, 2002. "We made an almost real-time detection through a combination of field observations and RADARSAT data," he explained.

By September 2002, the Ward Hunt Ice Shelf had split several times. By looking at historical RADARSAT data, Mueller, Vincent, and Jeffries determined that the ice shelf actually began to crack as early as April 2000, culminating a century-long decline in the shelf's extent. Though the Ward Hunt is very small compared to Antarctic ice shelves, its breakup and the resulting drainage from Disraeli Fiord concerned the researchers for several reasons.

When the Ward Hunt Ice Shelf originally formed, it blocked the mouth of Disraeli Fiord, cutting it off from the Arctic Ocean. In the process, the ice shelf trapped driftwood inside the epishelf lake and kept other pieces of driftwood from entering. Pieces of driftwood found along the shores of Disraeli Fiord have been there since the ice shelf formed, and by radiocarbon dating the wood, researchers have been able to estimate the minimum age of the ice shelf. "There simply are no radiocarbon dates more recent than 3,000 years before present," said Jeffries. This ice shelf, in existence for at least three millennia, has now encountered conditions it can no longer survive.

In just the last century, scientists have discovered dramatic changes in the Ward Hunt Ice Shelf. Changes became apparent in the 1950s when ice-shelf investigators examined early 20th-century records of Arctic explorer Robert Peary. "It was already clear there was a vast region—much greater than today—of thick, ancient ice floating on the ocean. We estimate that this ice has now retreated by about 90 percent relative to Peary's observations," said Vincent.

Drainage of the epishelf lake worries Jeffries and Vincent as much as the loss of the ice shelf. Although the fresh water in Disraeli Fiord floated on top of denser salt water, a small amount continually flowed out of the fiord under the ice shelf. Because the Ward Hunt Ice Shelf is not fed by glaciers, its existence depends on snow and ice accumulation on top and freshwater freezing on the bottom. "Some of our earlier studies indicated that the most likely source of freshwater freezing was water flowing out of Disraeli Fiord," Jeffries explained. "The freshwater freezing was important because it was happening at the same time that ice was melting off the top, but now that source of fresh water is gone." Without the freshwater freezing on the bottom of the ice shelf, Jeffries fears that the shelf may start to thin, or thin at a faster rate.

The Ward Hunt Ice Shelf breakup comes at the same time as news of unprecedented melting of sea ice in the Northern Hemisphere. "Sea ice cover has been shrinking about 3 percent per decade over the past few decades. We saw a record minimum in September 2002, and the summer of 2003 almost set a new record," said Mark Serreze, a research scientist at the National Snow and Ice Data Center in Boulder, Colorado.

Loss of sea ice can have major implications for global climate. Because of its light appearance, sea ice reflects most of the Sun's energy back into space, whereas darker seawater absorbs most of the incoming radiation and could potentially warm Earth's climate. As sea ice continues to melt, more radiation will be absorbed by the ocean.

Biodiversity loss concerns Vincent as much as potential climate change. Both the ice shelf and the epishelf lake it dammed hosted uncommon microenvironments. "As you fly over in a helicopter, you see these beautiful Mediterranean-blue lakes on the ice. Within these lakes are remarkable microbial communities. A lot of them are bright orange because they're rich in carotenoids, a pigment that protects them from UV radiation. They look like alien life forms, but they're actually micro-worlds of bacteria, and microscopic plants and animals. As we're losing sections of the ice, we're losing portions of these communities," he said.

Another type of community also disappeared with the epishelf lake. Disraeli Fiord's combination of fresh, brackish, and salt water created a rare ecosystem of cold-adapted, salt-tolerant organisms. According to Vincent, further research on the epishelf lake's microbial community might have discovered brand new species. "Unfortunately, we didn't have enough time for the molecular techniques needed to identify new species," he said.

Beyond improving knowledge of modern biodiversity, polar communities may help scientists understand Earth's past. A hypothesis that has gradually developed since the 1960s postulates that between 800 and 600 million years ago, the Earth underwent a series of global glaciations, a time nicknamed the Neoproterozoic "Snowball Earth." It was after this period of worldwide freezing that multicellular life forms began leaving a rich fossil record. "One of the arguments against the Snowball Earth hypothesis is that life might not have survived the massive freeze-ups," said Vincent. "But those of us working in the polar regions see incredible opportunities for life in surprising places."

Unfortunately, researchers may not get the chance to test their hypotheses by examining modern life forms. “We’re really running out of time to understand these unique environments and their biota before they disappear,” Vincent said.

Understanding the impact of declining sea ice on marine wildlife may be easier to assess, though the news is not encouraging. Microbial ecosystems in sea ice comprise the base of much of the food chain in the Arctic Ocean. Directly or indirectly, zooplankton, fish, whales, seals, and polar bears depend on the energy provided by those microbial ecosystems. “In western Hudson Bay, satellite data reveal a significant change in sea ice cover, and we know from studies by the Canadian Wildlife Service that polar bears have been adversely affected by changes in their habitat that limit their access to seals,” said Jeffries.

Ice shelf decline may affect humans as well as wildlife. During its breakup in 2002, the Ward Hunt Ice Shelf calved a number of ice islands, and the heavily fractured ice shelf now has the potential to release many more. Ranging in sizes up to tens of kilometers, these ice islands could eventually drift into the Beaufort Sea and jeopardize shipping and offshore development, such as oil rigs. “An ice feature of this size could exert tremendous force on an offshore structure, and there wouldn’t be much we could do to divert it,” said Jeffries.

Although researchers wouldn’t be able to divert ice islands, they could use satellite data to track ice island movement. RADARSAT data was instrumental in tracking the movement of the giant B-15 iceberg that calved from the Ross Ice Shelf in Antarctica in March 2000, and the data may have similar applications in the Northern Hemisphere.

Big as the ice islands are, the Ward Hunt Ice Shelf breakup does not approach the scale of ice shelf deterioration observed in Antarctica. “The Ward Hunt Ice Shelf is a fairly small feature, and in terms of global climate impact, the breakup of this ice shelf is trivial. Yet it’s another indication of what’s happening in the Arctic,” said Serreze. Among the changes in the Northern Hemisphere that Serreze has recently reported are earlier spring breakups of river ice, increased freshwater runoff, shrinking glaciers, and trees and shrubs invading Arctic tundra. “The Arctic is changing. This is fact,” he said.

Researchers from Université Laval study the main crack in the Ward Hunt Ice Shelf during the summer of 2002. (Image courtesy of Vicki Sahanatien, Parks Canada)

Changes observed in the Arctic confirm climate model predictions. “We know from global circulation models—the results of which are broadly accepted among the polar climate and global climate community—that if global change is occurring, the effects will be felt first and amplified in the polar regions, particularly the Arctic,” said Jeffries. “We’ve seen changes in the Arctic, and in recent years, the changes seem to be occurring faster.”

Vincent agrees. Prior to the Ward Hunt Ice Shelf breakup, his team monitored Disraeli Fiord for five years. Though he had observed gradual decreases in the lake’s fresh water, its sudden disappearance caught him off guard. “I think it underscores a fundamental problem we have in climate change research,” he said. “Climate change models usually predict gradual, continuous change, but real-life impacts are not continuous. Changes can be relatively small, and then suddenly you can move to a new threshold. This ice shelf survived 3,000 years of human civilization, but now it’s gone.”

Researchers Derek Mueller (left) and Milla Rautio (right) study a luxuriant microbial mat on the Markham Ice Shelf, one of the last remaining ice ecosystems on the northern coast of Ellesmere Island. (Image courtesy of Warwick Vincent, Université Laval)

How much change can be attributed to human activity is difficult to estimate. "We know the climate can vary on many different time scales due to natural processes," said Serreze. "But when we look at the longer-term record of paleoclimate information, the warming we're seeing does appear to be very unusual. Carbon dioxide concentrations in ice cores today are probably the highest they've been in 400,000 years. There's a growing consensus between the things we're observing and climate model projections of change. I'm still a fence-sitter, but I'm leaning more to the side of human causes for at least some of what we're seeing."

Jeffries and Vincent plan to continue monitoring the Ward Hunt Ice Shelf and Ellesmere Island. "It's at the northern limit of North America, right in the bull's-eye of the region that climate models predict will change most rapidly, most abruptly, and most severely," said Vincent. RADARSAT data will continue to play a role in that monitoring. "We have been especially impressed with RADARSAT imagery resolution. In combination with our field measurements, it's provided an unprecedented time series showing the magnitude of change."

"I think this ice shelf breakup is another example of how valuable remote sensing is, and how important it is that scientists have easy access to these data on a frequent basis. Otherwise, we miss things we really need to know," said Jeffries.

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Martin Jeffries is a research professor of geophysics at the Geophysical Institute, University of Alaska, Fairbanks. He credits an inspiring 7th grade teacher for his interest in geography and a professor at the University of Sheffield for his fascination with ice and snow. Jeffries has studied glacier hydrology in Norway, ice shelves and ice islands in the Canadian High Arctic, sea ice in Antarctica, lake ice in Alaska, and is currently organizing the Alaska Lake Ice and Snow Observatory Network (ALISON). He earned a MS in geography from the University of Manchester, U.K., and a PhD in geography from the University of Calgary, Canada.

A research scientist at the National Snow and Ice Data Center in Boulder, Colorado, **Mark Serreze** has been doing fieldwork in the Arctic since 1982 and was the lead author describing the 2002 record minimum of Arctic sea ice extent. He has served on the science steering committee for the Study of Environmental ARtic CHange (SEARCH), and he currently chairs a panel for atmospheric reanalysis products for the Arctic Region for the Cryosphere and Climate (CliC) Program. He also serves on the science steering committee of the National Science Foundation's Arctic Climate System Study (ARCSS). Serreze holds a PhD in geography from the University of Colorado, Boulder.

Warwick Vincent is a professor and holds a Canada Research Chair in the Department of Biology and the Center for Northern Studies (Centre d'Études Nordiques) at Laval University, Quebec City, Canada. His research focuses on life in extreme environments, including lake and river ecosystems at high latitudes, and ecosystem responses to ultraviolet radiation and climate change. Prior to the breakup of the Ward Hunt Ice Shelf, Vincent monitored the epishelf lake in Disraeli Fiord for five years. He earned a PhD from the University of California, Davis.

Special 10th Anniversary Section

"In 1994, the 1st edition of the DAAC Annual was produced as a means of highlighting the wide variety of research being conducted with data archived at the NASA DAACs. Since then, the publication has evolved to include the addition of scientist biographies and photos, full color cover designs, color data images, and more in-depth article content written at a level that is both understandable to the lay reader and interesting to the science community. Working in tandem with the publication's evolutionary process were the tremendous improvements made to the data and information acquired for NASA's Earth science research and applications. On the following pages of this 10th Anniversary Section of the DAAC Annual, we are pleased to present a few examples of these improvements."

Vanessa Griffin
Manager, ESDIS Science Operations Office

Earth–Sun System

NASA Science Mission Directorate

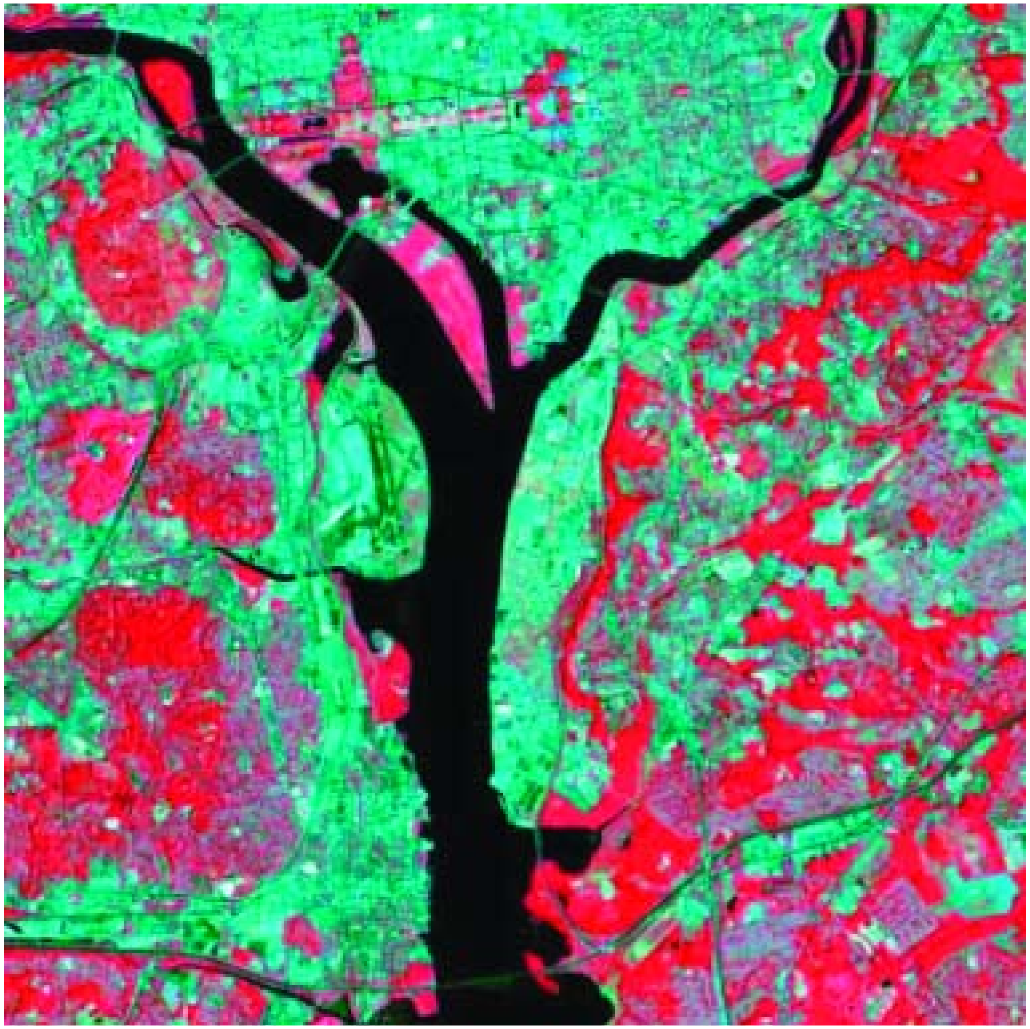
Then and now . . . 10 years of publishing research uses of Earth science data and information.

MODIS and AVHRR

These two images of Lake Michigan in the United States represent a comparison of MODIS Level-1B and AVHRR Level-1B imagery. The MODIS image (left) is a true-color composite of bands 1, 4, and 3 at 250-meter resolution, captured on August 5, 2004. The GSFC Earth Sciences DAAC distributes this data set (MODIS/Aqua Calibrated Radiances 5-Min L1B Swath 1km).

The AVHRR image (right) is a grayscale image of band 2 at 1,100-meter resolution, captured on May 1, 1990, and is available from the NOAA Satellite Active Archive.

MODIS represents a substantial improvement over AVHRR, providing greater accuracy, better spatial and spectral resolutions, and improved global coverage. MODIS spatial resolutions (at nadir viewing) range from 250 to 1,000 meters (1 kilometer) per pixel, compared to AVHRR's 1 to 4 kilometer resolution per pixel. MODIS also provides 36 spectral bands, while AVHRR provides only 5 spectral bands. MODIS observations can be applied to a wider range of applications than those from AVHRR. For example, more detailed and more accurate information about land vegetation and ocean biological processes can be obtained using MODIS data, as well as more accurate surface temperatures, snow and ice properties, and information on atmospheric water vapor and clouds.

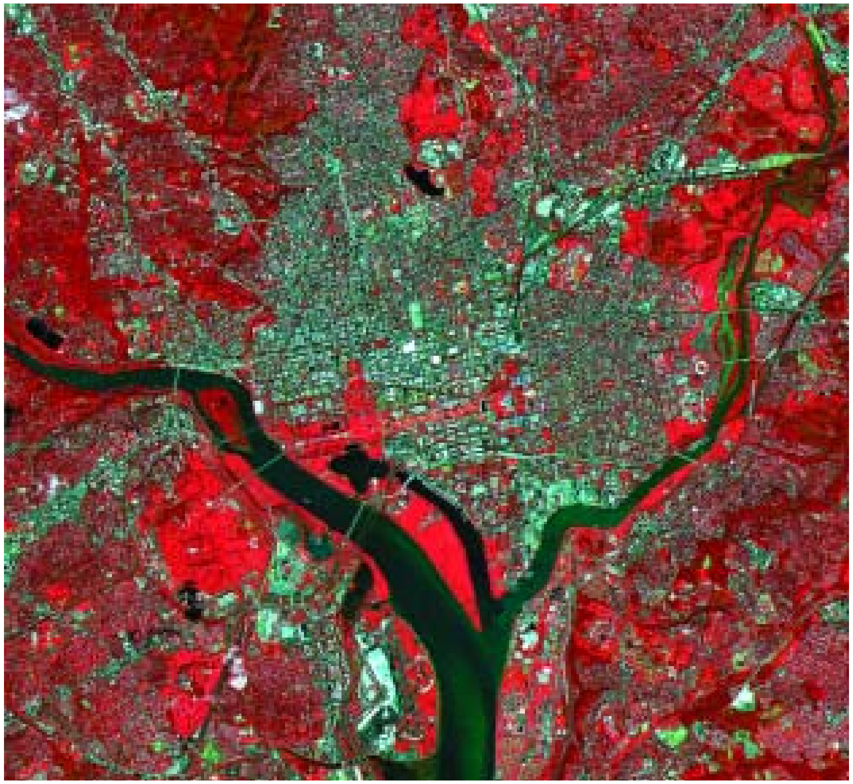


Landsat and ASTER

The Landsat 7 image (left) is a subset of a full scene that shows the District of Columbia, United States. Launched in 1999, Landsat 7 is the latest in a series of Landsat missions.

The ASTER image below (band 3n, 2, and 1), which represents the same region, was acquired on June 1, 2000. The red areas indicate vegetation. ASTER's spatial resolution provides a four-fold improvement (in area) over Landsat for vegetation applications, resulting in sharper images. With more thermal channels than Landsat, ASTER is better equipped to distinguish between heat-emitting objects. It also provides superior mineral exploration capability.

ASTER data are archived at the Land Processes DAAC.

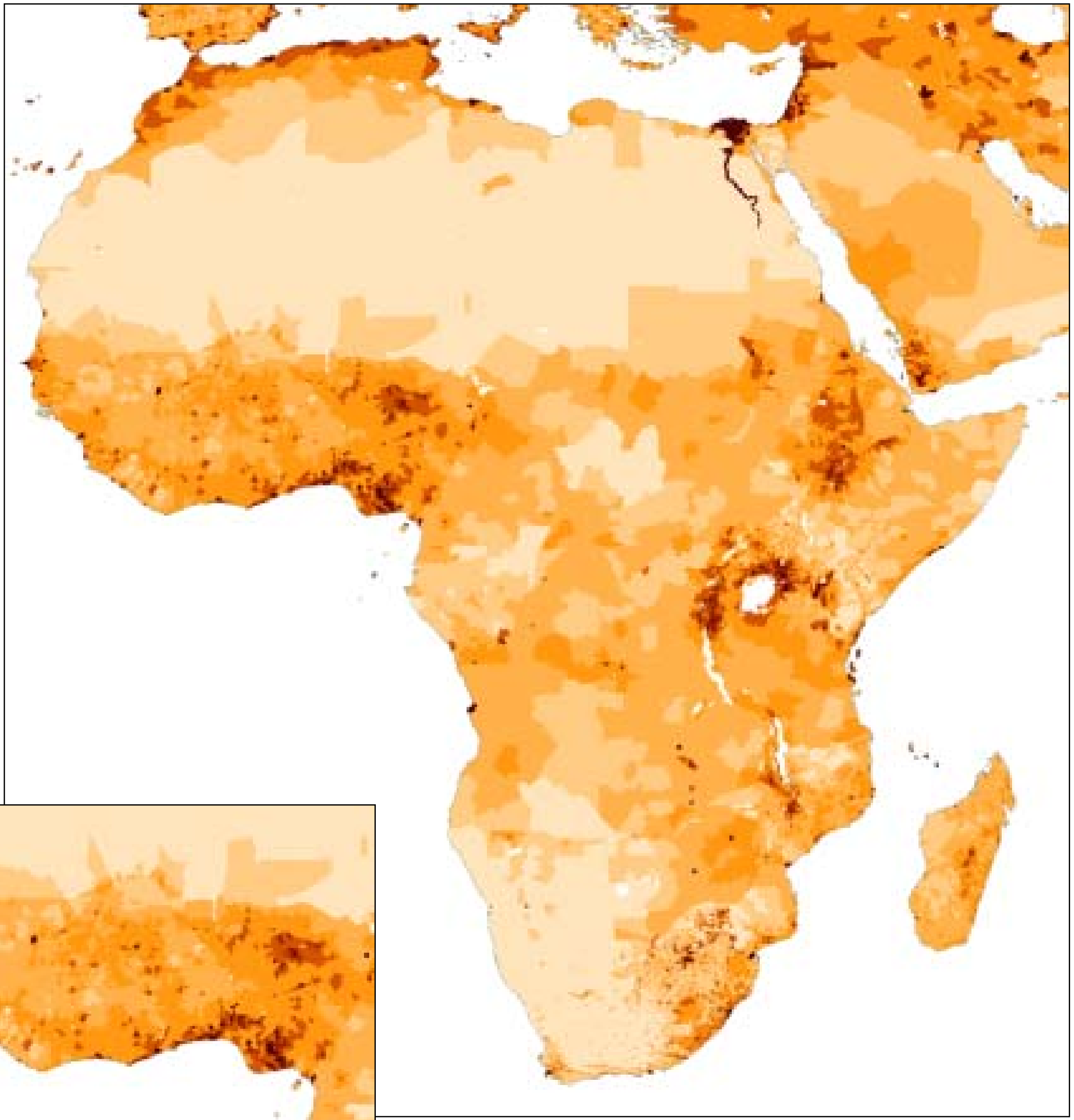


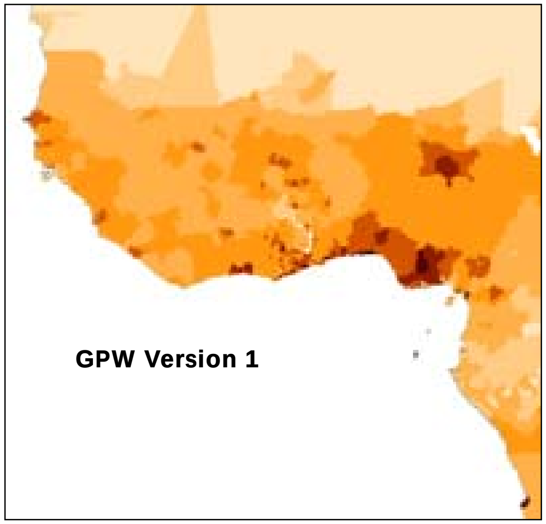
World Population Data

The Gridded Population of the World (GPW) data set has undergone substantial improvement since the first version was released in 1995. The number of administrative input units increased from 19,000 in the first version to 375,000 in the recently released third version, thus improving the spatial resolution of the data set. GPW, version 3, contains more than 100,000 input units for Africa alone. The increase in administrative units and resulting spatial resolution gives a more accurate representation of urban locations and extent based on population density.

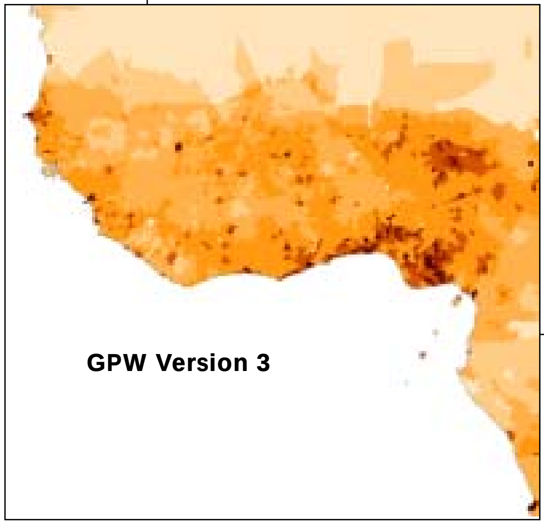
The mean resolution for the GPW, version 3, is 47 kilometers, with over 25 percent of the input data having a mean spatial resolution of 30 kilometers or less. The GPW, version 1, data set only included one year of estimation: 1994. The most recent version includes population estimates for 1990, 1995, and 2000.

The image at right shows population density for the continent of Africa, with two subsets (shown below) of the western region (roughly Sierra Leone to Nigeria) that show the increased coverage of GPW, version 3. Areas with the lightest color have zero people per square kilometer, while the darkest colors represent a maximum density of 8,600 people per square kilometer (GPW, version 1) and 26,000 people per square kilometer (GPW, version 3). The greater value is a result of higher-quality input data. The GPW data set is archived at the Socioeconomic Data and Applications Data Center (SEDAC).

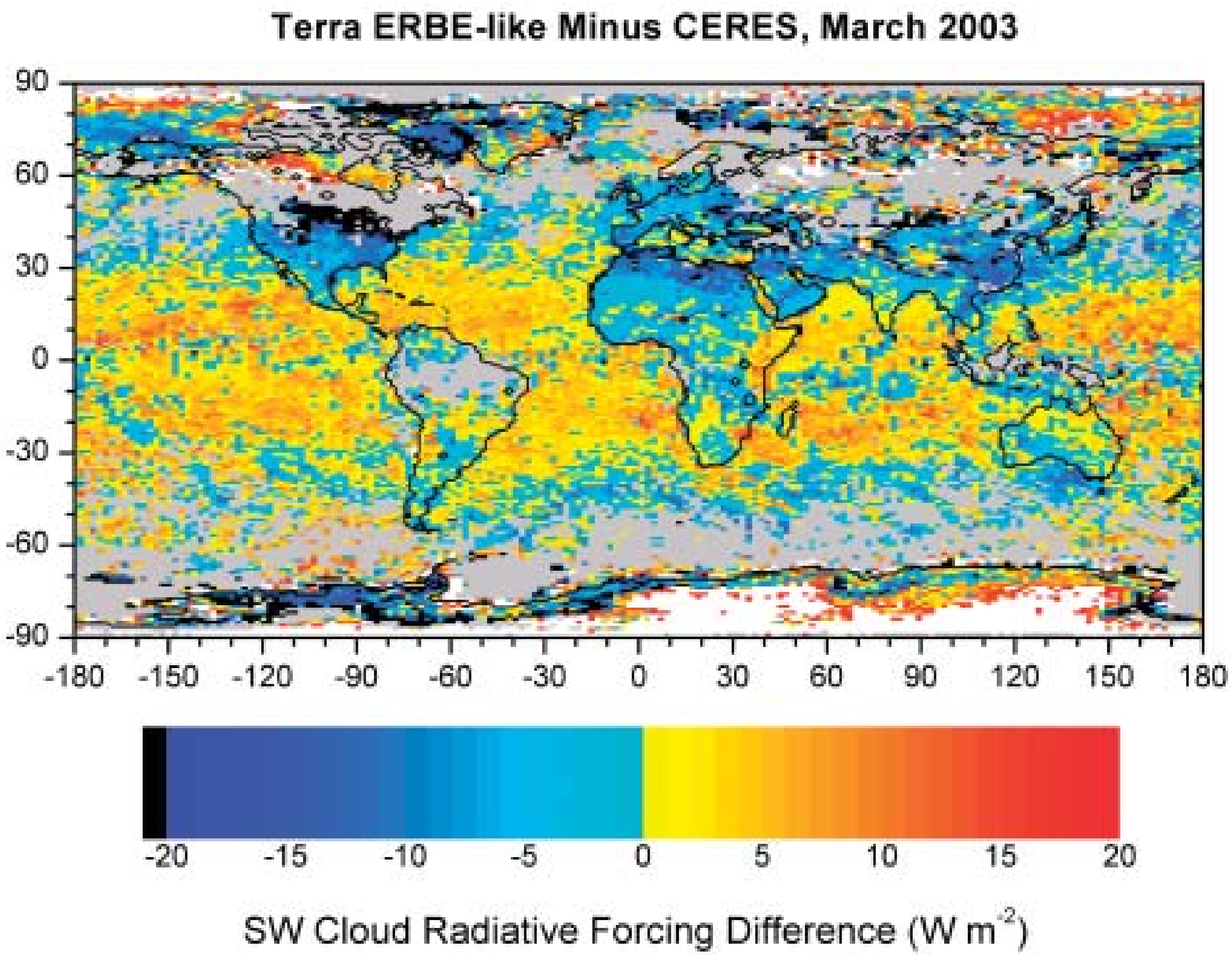


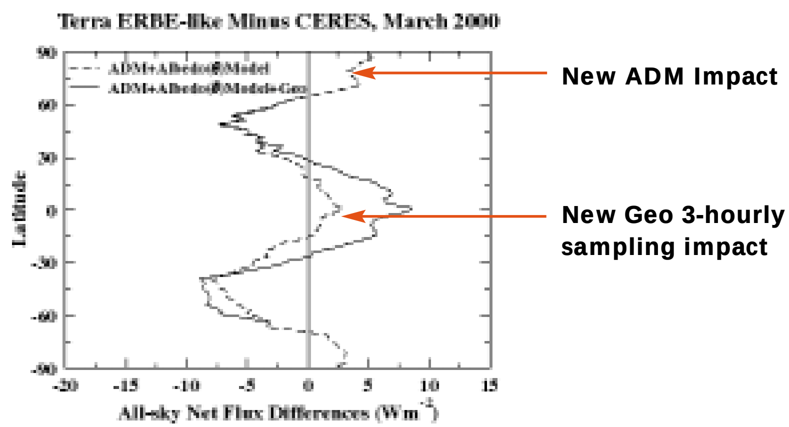


GPW Version 1



GPW Version 3





ERBE and CERES

The image at left illustrates changes in solar energy reflected from Earth back to space due to clouds, or cloud radiative forcing, from global satellite observations in March 2003. The changes show the difference in observed shortwave cloud radiative forcing between the previous state-of-the-art ERBE production, and the new CERES production. A positive (negative) difference means the ERBE approach produces less (more) shortwave radiative cooling than does CERES. ERBE-like produces less shortwave cloud radiative cooling over ocean and more shortwave cloud radiative cooling over land, compared to CERES.

Large differences are also observed over regions covered by snow and sea ice. The differences are due to (1) improved clear sky determination in CERES obtained by merging the MODIS imager determined cloud conditions into each CERES field-of-view, and (2) new CERES Angular Distribution Models (ADMs) that produce more accurate radiative fluxes by cloud type. The results are significant to the validation of climate models, which must accurately estimate the regional distribution of cloud radiative forcing in order to predict climate.

The graph at left shows the impact of ADMs and 3-hour sampling on estimates of all-sky net flux differences by latitude.

The ERBE-like product was designed to mimic heritage ERBE data to extend the historical ERBE record. As the superior results of CERES observations accumulate, CERES data will improve our understanding of the impact of clouds on Earth's atmosphere.

CERES data are archived at the Langley Atmospheric Sciences Data Center DAAC.

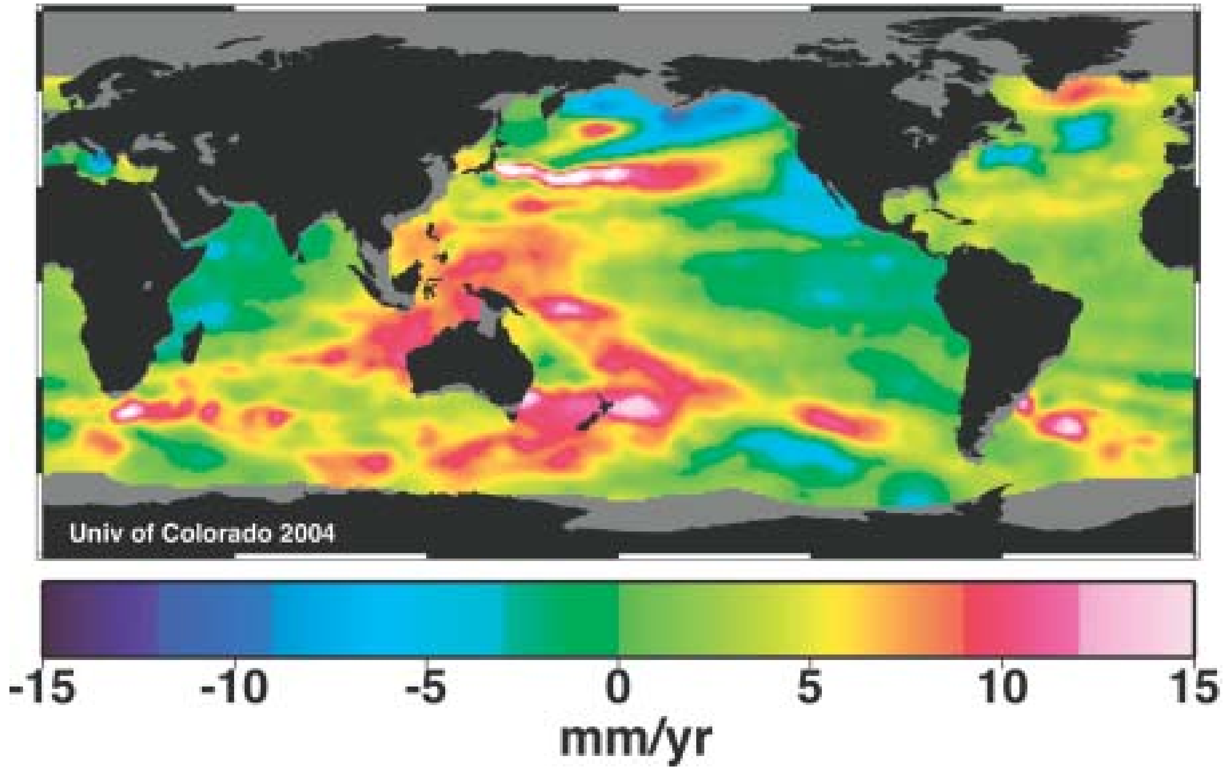
TOPEX/POSEIDON and Jason

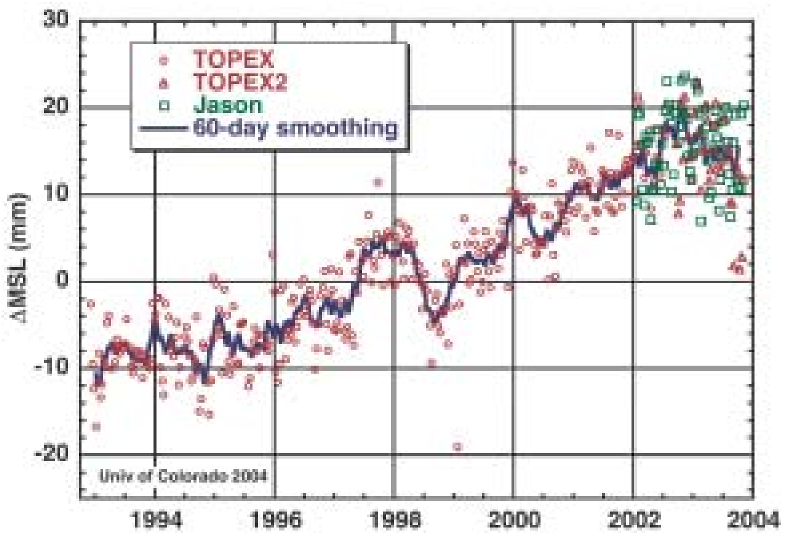
The top image shows trends in mean sea level for the years 1993 to 2003. The color scale ranges from blue values of -15 millimeters per year to white values of +15 millimeters per year. Negative values indicate decreasing sea level for that time period, while positive values indicate increasing sea level.

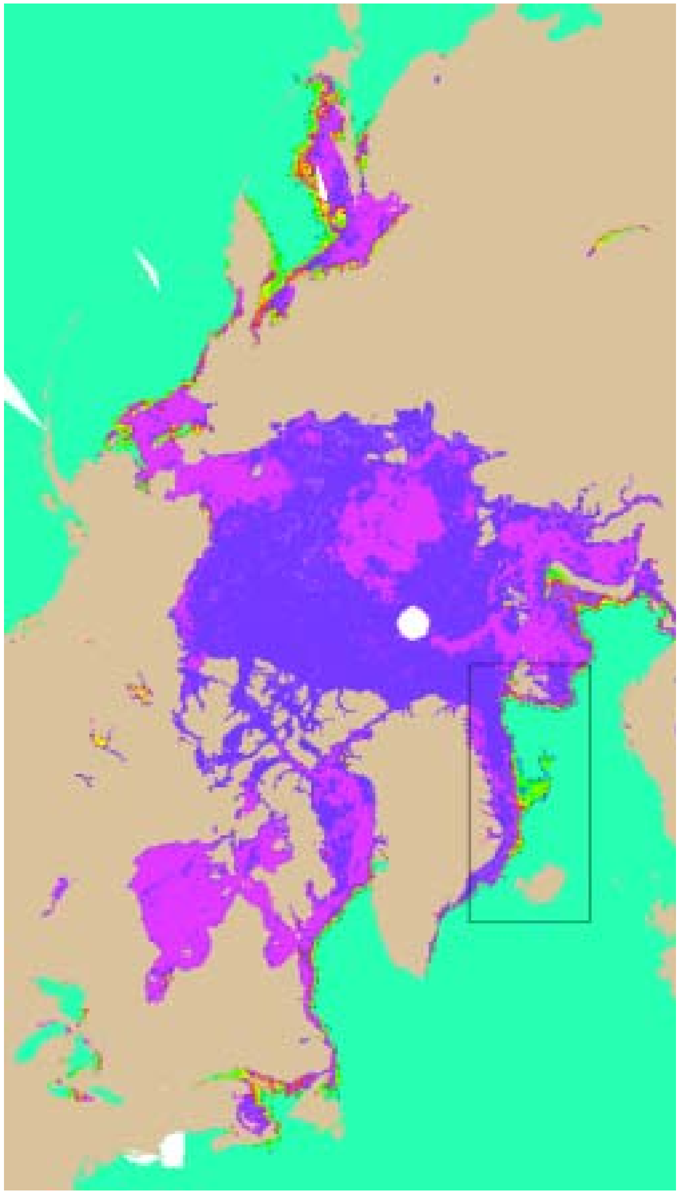
The bottom plot shows the global mean sea level between 1993 and 2003, derived from the TOPEX/POSEIDON and Jason satellites. The vertical axis represents mean sea level in millimeters, while the horizontal axis indicates the time period by year. The blue line indicates a 60-day smoothing of the values and a trend of rising sea level since 1993. TOPEX 2 data, shown as red triangles, indicate the TOPEX/POSEIDON tandem mission that began in September 2002.

As the follow-on to TOPEX/POSEIDON, Jason is a mini-satellite that carries an altimeter, a radiometer, and three location systems. Like TOPEX/POSEIDON, Jason has a 1,300-kilometer orbit and a 10-day repeat cycle. Jason measures sea surface height accurate to within three centimeters, whereas TOPEX/POSEIDON provided measurements accurate only to within four centimeters. This improved accuracy, combined with the instrument's ability to chart 90 percent of the world's oceans every 10 days, will further improve understanding of ocean phenomena such as circulation, tides, and El Niño, as well as long-term changes in sea level.

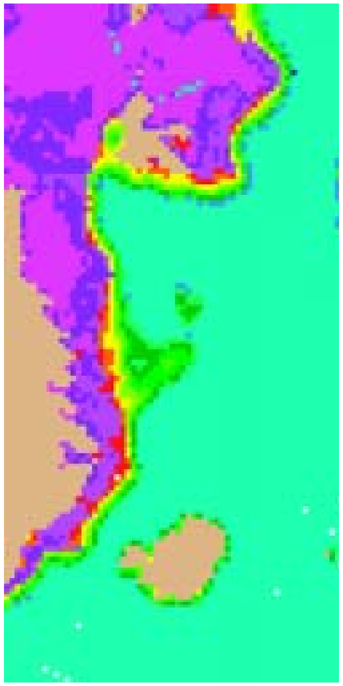
Jason and TOPEX/POSEIDON data are archived at the Physical Oceanography DAAC at NASA's Jet Propulsion Laboratory/California Institute of Technology.(Images courtesy of E.W. Leuliette, R.S. Nerem, and G.T. Mitchum, University of Colorado Global Mean Sea Level Team.)



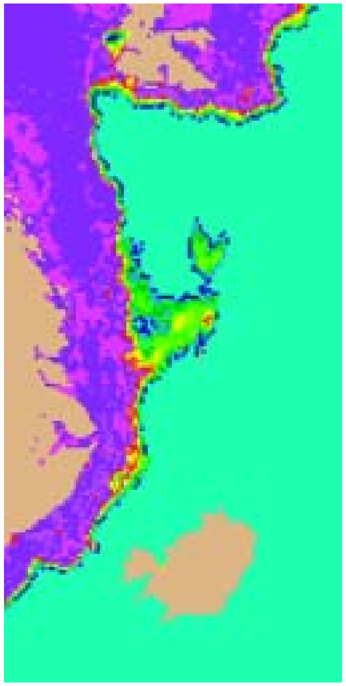




Sea ice concentration for the Arctic based on AMSR-E data (March 4, 2004).



Sea ice concentration, 25-km pixels, derived from SSM/I data (March 4, 2004).



Sea ice concentration, 12.5-km pixels, derived from the AMSR-E sensor (March 4, 2004).

Passive Microwave

Passive Microwave (PM) satellite data have been used to monitor sea ice since 1978, using a succession of sensors including the Nimbus-7 Scanning Multichannel Microwave Radiometer (SMMR), the Special Sensor Microwave Imager (SSM/I), and the Advanced Microwave Scanning Radiometer for EOS (AMSR-E).

The larger image at far left shows sea ice concentration in the Arctic region, based on AMSR-E data acquired on March 4, 2004. The two subset images show sea ice concentration derived from SSM/I data (middle image) and AMSR-E data (right image), both acquired on March 4, 2004. More accurate brightness temperatures and higher resolutions from the AMSR-E instrument (down to 6.25 kilometers) contribute to more detailed sea ice concentration products.

Through the years, advances in sensor hardware technology, additional channels, and improved algorithms have greatly enhanced the quality of sea ice concentration estimates from passive microwave sensors. The AMSR-E represents the current state-of-the-art technology, with double the spatial resolution of its predecessor, SSM/I. Passive microwave sea ice data are archived at the National Snow and Ice Data Center DAAC.

User Metrics

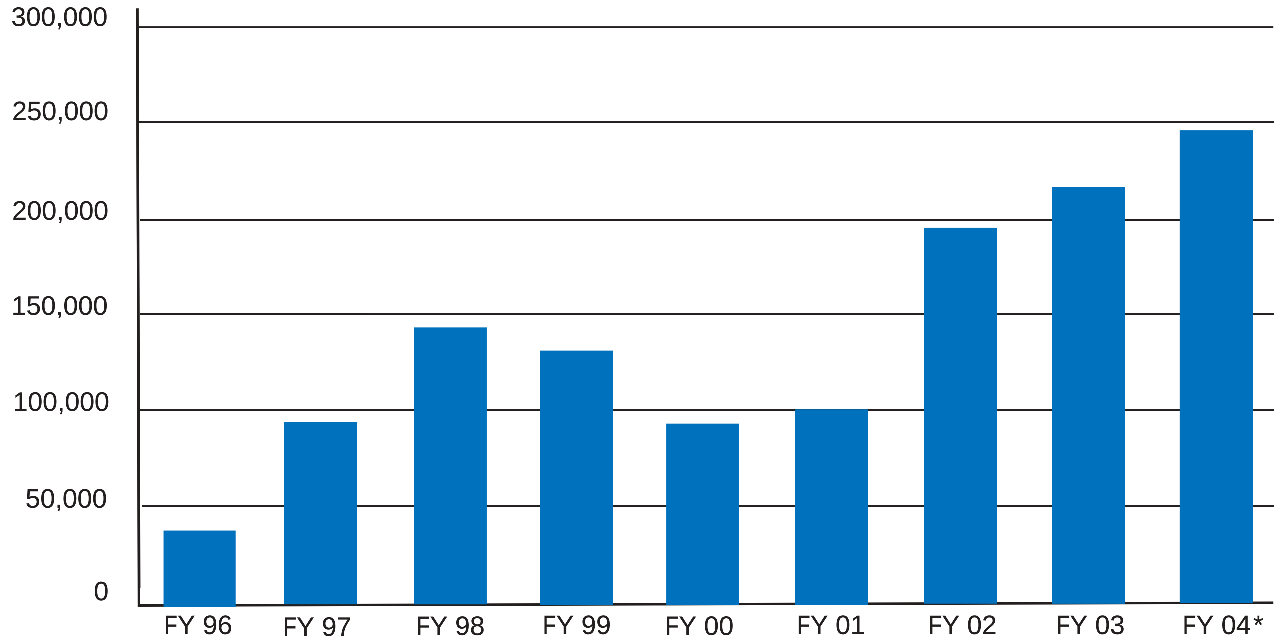
One indicator of the decade-long success of NASA's Earth Observing System (EOS) Program is the steadily increasing use of EOSDIS data by researchers and applications users in many different domains. Since 1996, the ESDIS project has documented the metrics on customer activity, and several important trends emerge from the analysis of these usage metrics that cover the past eight years. Between 1996 and 2003, EOSDIS saw a six-fold increase in the number of distinct customers requesting data and information products from the DAACs, from an initial 40,000 users to more than 229,000 users in 2003 (see Figure 1). When World Wide Web contacts are included, the number of distinct customers contacting the DAACs increased to about 2.5 million users in 2003. Over two-thirds of the users requesting products were from the United States, and it is interesting to note that this ratio has remained relatively stable over each of the eight years (see Table 1).

Further analysis of the usage statistics (not shown) suggests that users are making increased use of geophysical parameter data sets. For example, land products from the MODIS, Landsat7, and ASTER instruments remain in high demand. Increases in usage of MODIS snow, ocean color, and atmospheric products have been noted in more recent years. Newer users tend to request higher level data sets, which might indicate they trust these data sets and their calibration and are willing to forego individual derivation of geophysical parameters from lower level data.

More users are downloading data electronically than are requesting media distributions. During the past four years, the number of products retrieved immediately from web sites, FTP servers, and the EOSDIS Data Pools has dramatically increased. In 2003, 58% of all products were delivered immediately, compared to just 27% in 2000. After a decade of success, NASA EOSDIS will continue to meet the evolving needs of its research and applications users. Continued efforts to collect user metrics and measures of customer satisfaction will provide a firm foundation for the evolution of the system.

Figure 1: Number of Distinct Users Requesting DAAC Data and Information Products

Users are counted by recording unique e-mail addresses used. The FY04 totals are extrapolated from actual data collected through June 2004.



* FY04 totals not yet complete at the time of this publication.

Table 1: Characterization of Users Requesting Products Each Fiscal Year

Fiscal Year	*U.S. Government*	*Educational*	*Commercial*	*Non-Profit*	*Other U.S.*	*Total U.S.*	*Foreign*	*Unknown*	*Total*
FY96	3,550	8,215	12,036	732	559	25,092	9,192	6,440	40,724
FY97	6,398	14,332	36,865	1,207	742	59,544	26,883	19,719	106,146
FY98	7,922	16,397	53,708	1,440	923	80,390	46,518	26,080	152,988
FY99	6,148	14,582	50,257	1,252	874	73,113	45,604	25,181	143,898
FY00	4,340	12,409	33,669	1,097	815	52,330	21,749	28,411	102,490
FY01	3,528	11,695	42,839	1,219	714	59,995	18,606	35,308	113,909
FY02	4,123	19,243	82,451	1,712	1,057	108,586	39,501	60,297	208,384
FY03	5,238	20,965	89,920	1,943	1,485	119,551	54,042	55,991	229,584

Index of DAAC Annual Articles, 1994–2004

During the past decade, more than 150 feature articles have appeared in ten editions of the DAAC Annual, highlighting research uses of data from all of NASA's Earth Observing System satellites and archived at NASA's nine data centers.

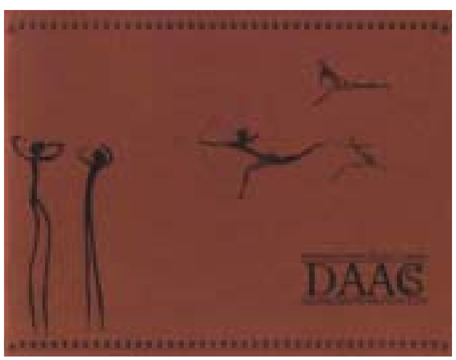
The following is an index of all DAAC Annual feature articles, from the inaugural 1st edition in 1994 to this 2004 10th anniversary edition. The articles are indexed both by year and by the six categories within NASA's Earth System Science Theme, and by two additional categories that encompass the many articles focusing on data management and human dimensions topics:

- Atmospheric Composition
- Carbon Cycle and Ecosystems
- Climate Variability and Change
- Earth Surface and Interior
- Water and Energy Cycles
- Weather
- Human Dimensions
- Data Management and Tools

To request print copies of previous editions of the *DAAC Annual*, please contact **nasadaacs@nsidc.org**. (Supplies are limited for some editions.) Some articles are also available online at **nasadaacs.eos.nasa.gov/articles/index.html**.

1994

1995



1996

Index of Articles

Atmospheric Composition

Carbon Cycle/Terrestrial and Marine Ecosystems

Climate Variability and Change

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At the Edge, 2nd edition, Page 22
Ice Happens, 2nd edition, Page 24

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Oceanic Convection in the Greenland Sea Odden Region as Interpreted in Satellite Data, 1st edition, Page 14

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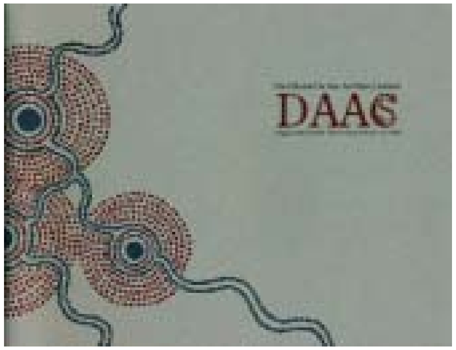

1997

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1999

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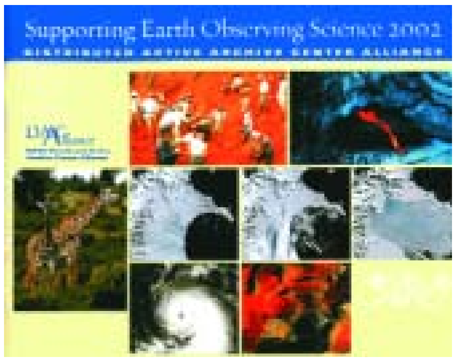
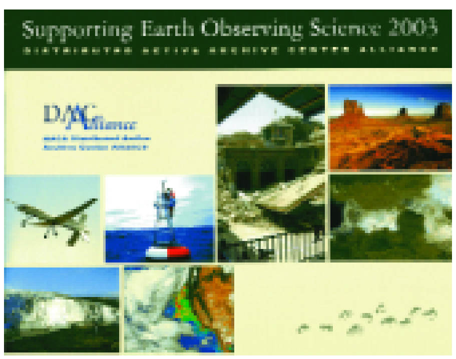
2000/2001



2002



2003

Human Dimensions

Data Management and Tools

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Upper Atmosphere, Atmospheric Dynamics, Global Land Biosphere, Global Precipitation, and Ocean Color
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Voice: +1 845-365-8920 • Fax: +1 845-365-8922
E-mail: sedac@eos.nasa.gov
Web: http://sedac.ciesin.columbia.edu/

"Cyclones have a potent effect on the carbon in the area. The catch is that for most people, they are a destructive force. But if you look at it another way, they enhance life."

GSFC Earth Sciences DAAC

Physical Oceanography DAAC

by Kelly Kennedy

Stirring Up Life

Damage from a category 5 typhoon completely wiped out a coconut and breadfruit plantation in the Caroline Islands, located east of the Philippines in the Pacific Ocean. Inhabitants dug a pit on the highest part of the island and covered it with coconut logs for shelter from the storm. (Image courtesy of NOAA Photo Library)

When Typhoon Kai-Tak crashed into the shores of Taiwan, Japan, and the Philippines in July 2000, it left up to a million people homeless and 40 dead in the Philippines, according to a BBC report. In Japan, three people died, and in Mito, a town northeast of Tokyo, landslides crushed dozens of homes. Japanese disaster officials estimated damage at about $2.6 million. According to the *Taipei Times*, gusts caused a large-scale blackout in eastern and southern Taiwan and left nearly 10,000 families without electricity.

But just like the storm-chasers who realize they have much to learn from the Midwest's tornados, scientists hovered near the South China Sea hoping to discover whether cyclones help increase phytoplankton production and, therefore, reduce carbon-dioxide gases in the Earth's atmosphere.

"Scientists knew something was eating up carbon dioxide, but they hadn't been able to prove any theories," said Timothy Liu, principal investigator for NASA's QuikSCAT and Tropical Rainfall Measuring Mission (TRMM) projects at the Jet Propulsion Laboratory in Pasadena, California.

Tropical cyclones are one of the most intense storms on Earth, with torrential rains and winds that sometimes exceed 175 knots (320 kilometers) per hour. The term "typhoon" is a regionally specific name that refers to a *severe* tropical cyclone in the western Pacific. Wind speeds must reach 64 knots (118 kilometers) per hour for a tropical cyclone to rank as a typhoon.

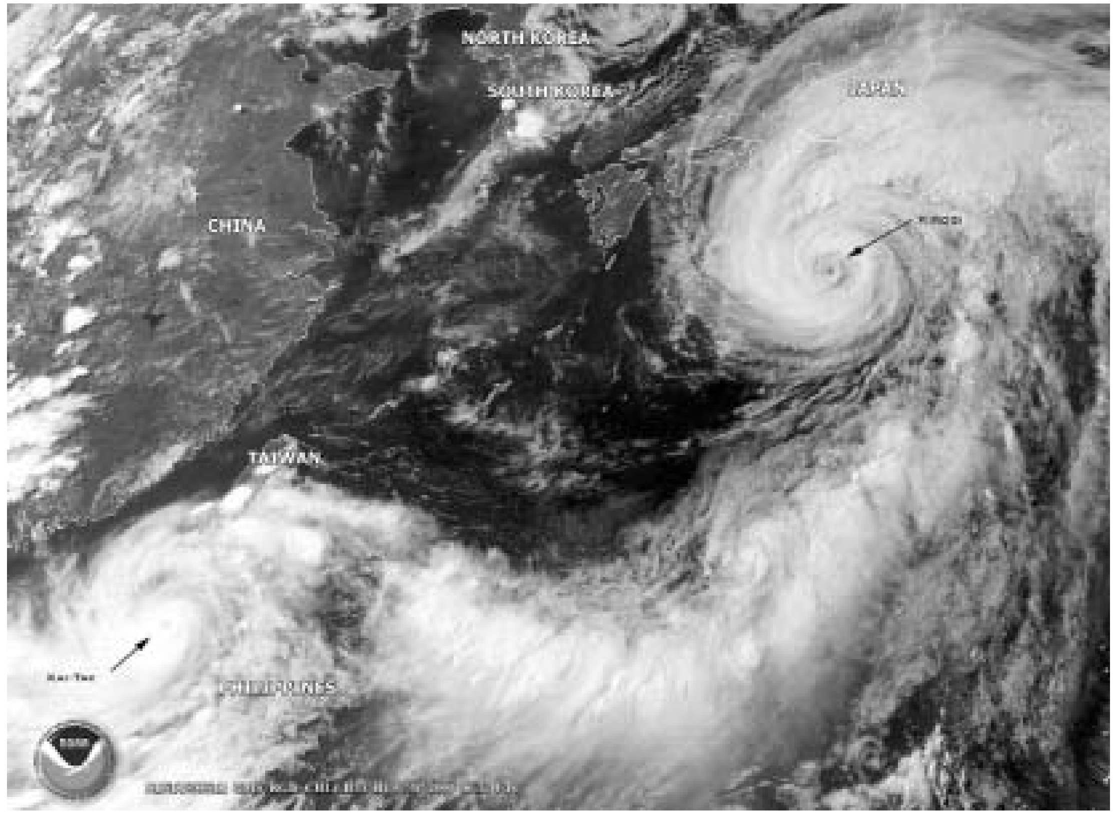
In the past, gathering scientific data by ship about typhoons appeared impossible for the same reasons coast-dwellers fear them: high winds and tumultuous rains. In addition, the cloud cover that follows typhoons creates a foggy barrier that most satellites can't "see" through. Sensors must capture wind speeds and ocean temperatures as they're happening, because they change so quickly.

But in 2000, a team of scientists in Taiwan patiently monitored 20 typhoons in the South China Sea, hoping for a convergence of circumstances that could aid them in their research: satellites in the right places at the right times and a slow-moving storm. After Kai-Tak subsided, the researchers discovered serendipity in its wake.

"In fact, we discovered this event by accident," said I-I Lin, research scientist at Taiwan's National Center for Ocean Research in Taipei. "During our routine processing of high resolution SeaWiFS (Sea-viewing Wide Field of View Sensor) images, we observed an unusually high level of chlorophyll-a concentration during Kai-Tak. This prompted us to start a series of studies on the subject."

Phytoplankton are tiny, floating algae, or plantlike organisms, that produce half the world's oxygen and provide a major food source for marine life. They are almost invisible, but after the typhoon, NASA's SeaWiFS ocean color sensor detected the phytoplankton's pigment, known as chlorophyll-a. The team then discovered that the phytoplankton bloom occurred in the same spot where TRMM data showed a 16-degrees Fahrenheit (-9 degrees Celsius) temperature drop after the storm.

QuikSCAT, a NASA-operated satellite that measures wind speeds over water, determined Typhoon Kai-Tak's wind speeds and path, which revealed that Kai-Tak had lingered in exactly the same spot where the lower temperature and phytoplankton bloom occurred. SeaWiFS and TRMM data are archived at the Goddard Space Flight Center Earth Sciences (GES) DAAC, and QuikSCAT data are available from the Physical Oceanography Distributed Active Archive Center (PO.DAAC).



Twin typhoons churned in the western Pacific Ocean in July 2000. Typhoon Kai-Tak (lower left) was located in the South China Sea, and Typhoon Kirogi (upper right) was located south of Honshu, Japan. Both storms had maximum sustained winds of 75 knots. (Image courtesy of NOAA)

The images caught by the three satellite instruments showed that Kai-Tak's winds pulled nutrient-rich water from deep below the South China Sea's surface, thus exposing those nutrients to sunlight. Phytoplankton bloomed and, by using carbon dioxide for photosynthesis, removed harmful greenhouse gases from the Earth's atmosphere.

The scientists estimated that Kai-Tak accounted for 2 to 4 percent of the total new production of phytoplankton in the South China Sea that year. Liu said an average of 14 typhoons storm through the South China Sea each year and could contribute as much as 20 to 30 percent of new phytoplankton growth. The idea wasn't new—it just hadn't been proven before Typhoon Kai-Tak.

"Lo and behold, we caught this high-tech synergism of many satellite observations at the right moment," Liu said. "It is difficult to find observations by three sensors at the same spot in appropriate time sequence. That is why such direct cause (wind forcing) and effect (temperature and biological response) have not been demonstrated before. Without the data from all three instruments, we could not have done it."

Both Liu and Lin grew up understanding the harmful effects of cyclones. Liu spent his childhood in Hong Kong before moving to the United States as a teenager, and he remembers typhoons as "exciting and scary." "In Hong Kong, there were a lot of typhoons, and I was always fascinated by them," he said.

Lin, who served as a team member in Taiwan's "Integrated Typhoon Research Project," also has lived under the constant threat of the storms. "In Taiwan, typhoon research is a top priority because each year, cyclones cause damage to many Asian countries," she said.

For both Liu and Lin, it's encouraging to find good news in such a disastrous force—especially when it had been so difficult to prove their theory in the past. "Cyclones have a potent effect on carbon in the South China Sea," said Liu. "The catch is that for most people, they are a destructive force. But if you look at it another way, they enhance life."

Typhoon Kai-Tak hovered from July 5 to July 8 over the same 93-mile (150-kilometer) area in the South China Sea, generating winds from 44.8 to 89.6 mph (20 to 40 meters) per second. "It's rare for a cyclone to stay in the same place for one or two days," Liu said. "The South China Sea happens to be a closed sea, so there is little outside influence (from ocean currents) on the thermal and biological responses."

Because Kai-Tak lingered, the researchers had more time to look at the ocean water movement than they would have if they typhoon had rushed past. And because the South China Sea is closed, they knew all the water movement was caused directly by Kai-Tak.

Normally, currents in the South China Sea cause the water to remain in static layers, so water on top always stays on top, and water deep below the surface always stays below the surface. This is because in a subtropical ocean, the normal large-scale surface circulation is clockwise, Liu explained.

But Kai-Tak, like all Northern Hemisphere cyclones, moved counterclockwise (Southern Hemisphere cyclones move clockwise). This created a hollow in the sea, similar to the funnel that forms above a drain when water leaves a bathtub. But in the sea there is, of course, no drain, so water from below the hollow moved up to fill the empty spot.

"The wind, and therefore, the induced current, in a typhoon is anticlockwise (cyclonic), causing surface water to diverge," Liu said. "When surface water diverges, it has to be replaced by water from the deep. Although the area covered by a typhoon is very small compared with the whole ocean basin, and a typhoon lasts only a short time, we suggested that the cumulative effect of many typhoons might be sufficient to offset the basin-wide circulation patterns."

So, as Kai-Tak, a category 2 typhoon on the Saffir-Simpson hurricane scale, floated over the sea, it forced cold water up from 230 feet (70 meters) below the surface, which caused the cold spot detected by the TRMM sensor. The deeper the water, the more nutrient-rich it is. But since sunlight only reaches surface water, phytoplankton cannot grow deep below the surface. When the cyclone forced the deep water to the surface, sunlight hit the nutrients, which caused phytoplankton to form. SeaWiFS then captured the increase in chlorophyll-a.

"When cold water comes up, it brings nutrients with it," Liu said. "It is a dramatic event that we can see in the satellite imagery. The cool water is a strong blue color, and the biological bloom is visible in the same spot."

Before Kai-Tak, SeaWiFS measurements showed chlorophyll-a measurements at levels typical for summertime tropical waters. But after the cyclone, chlorophyll-a measurements increased 30 times, Liu said. "We knew the cyclone would bring up nutrients from below, but no one had really seen this before," Liu said. "The satellite data now enable us to detect things we could not see through the clouds—it's really revolutionary."

Scientists had long suspected that strong winds cause entrainment, or vertical mixing, in tropical and subtropical oceans, explained Lin and colleagues in a paper published in the October 2003 issue of *Geophysical Research Letters*. But it took measurements from the three satellite sensors to prove it.

"This research is important because it confirms that the impact of cyclones on ocean primary production is significant, at least in the South China Sea," Lin said. "It also points to the potential impact tropical cyclones have on climate change, since primary production is critical to global climate."

The new technology has also illuminated future research options for the scientists. "We've now established a method to quantify the cyclone-induced phytoplankton growth using a combination of remote-sensing data and models," Lin said. "This method can be applied to other typhoon cases and in different oceanic regions, too. Previously, it was impossible to do such work due to the lack of observations by traditional means."

For more information, visit the following web sites:

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

SeaWiFS Project
http://seawifs.gsfc.nasa.gov/SEAWIFS.html

NASA Quick Scatterometer (QuikSCAT)
http://www.jpl.nasa.gov/missions/current/quikscat.html

Air-Sea Interaction & Climate
http://airsea-www.jpl.nasa.gov

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I-I Lin is an assistant professor in the Department of Atmospheric Sciences at the National Taiwan University in Taiwan. From 1995 to 1999, she worked as a research scientist at the Centre for Remote Imaging, Sensing, and Processing (CRISP) at the National University of Singapore. She also served as principal investigator at the Remote Sensing Laboratory at the National Center for Ocean Research in Taiwan. Lin holds a PhD in remote sensing from the University of Cambridge, England.

W. Timothy Liu is a senior research scientist at the Jet Propulsion Laboratory, California Institute of Technology. His research focuses on ocean-atmosphere interactions and satellite oceanography. Liu is leader of the Air-sea Interaction and Climate Team and principal investigator for both the NASA Scatterometer (NSCAT) and TOPEX/Poseidon projects. He holds a MS and PhD in atmospheric sciences from the University of Washington.

> *"Before the era of satellite remote sensing, and particularly before MODIS, there was no way to map flooding over large regions."*

GSFC Earth Sciences DAAC

Physical Oceanography DAAC

by Laura Naranjo

The Flood Hunters

Each year, floods around the globe pose serious risks to human life. A growing archive of reliable flood data increases the possibility of predicting where and when major flooding will occur. (Image courtesy of NOAA Photo Library)

During the summer season of 2004, monsoon rains swelled rivers in India, Bangladesh, and Nepal, killing more than 1,500 people and displacing millions. Flooding lasted for weeks, inundating thousands of villages and leaving half of Bangladesh under water.

Annual monsoon rains occur every year in Southeast Asia and other parts of the world, but it's difficult to predict how much rain will fall on specific areas, or which rivers will flood. Because periodically flooded soil is so fertile, people use the land during the dry seasons to grow crops and raise livestock. If emergency workers and aid organizations knew in advance which areas might be flooded, they could develop more effective evacuation and flood-response plans for the millions of people who farm floodplains.

While flood prediction is not yet possible, a growing archive of satellite imagery is allowing scientists to go where aid workers can't. With satellite data, scientists can map floods remotely and piece together long-term trends that will reveal a global picture of flooding.

Fluvial geomorphologist Bob Brakenridge first tested the idea of using satellite imagery to map flooding when the Mississippi River overflowed its banks in 1993. With images from the European Space Agency's ERS-1 satellite in hand, he flew over the river valley and found that the flood extent in the satellite images matched the flooding he saw on the ground. Realizing that it was possible to map floods using satellite data, he established the Dartmouth Flood Observatory (DFO), which tracks floods worldwide and archives related information and data.

As satellite technology became more sophisticated, Brakenridge began using imagery from NASA's Moderate Resolution Imaging Spectroradiometer (MODIS), obtained from the MODIS Rapid Response web site and the GSFC Earth Sciences Distributed Active Archive Center (GES DAAC). He also uses a QuikSCAT data product developed by Son Nghiem and archived at NASA's Physical Oceanography DAAC.

Although MODIS wasn't specifically designed to observe water levels, Brakenridge said it's the perfect tool. "Before the era of satellite remote sensing, and particularly before MODIS, there was no way to map flooding over large regions," he said.

Because of MODIS' 1-kilometer resolution, the sensor is unable to identify smaller rivers and flood events. But, according to Brakenridge, the wide-area coverage is invaluable for mapping floods. "Some of these flood events affect very large areas. A satellite with high spatial resolution isn't very useful if it means you need 30 scenes to get a complete image of the flood," he said.

To determine what rivers looked like prior to a flood event, Brakenridge's team used MODIS data to develop a baseline map for many of the world's major rivers. Based on the reflective characteristics of each pixel in an image, the researchers can distinguish water from other land cover types. "It's important to have a standard reference so that when we map a flood, we don't mistakenly include areas that are normally under water, such as lakes, reservoirs, or wetlands," he said.

Brakenridge's team at the Dartmouth Flood Observatory posts maps and information on the DFO web site in near-real time. However, when weather agencies and aid organizations need information during or immediately after a flood, they sometimes contact the Observatory directly. In February 2004, parts of New Zealand's North Island experienced severe flooding. Rob Bell of New Zealand's National Institute of Water and Atmospheric Research contacted the DFO to obtain flood maps. The maps showed how much water remained in the affected areas several days after the flood occurred, which was important for emergency managers. The Institute also used the maps to demonstrate the role of remote sensing in assessing such a widespread event and to calibrate and verify proposed computer modeling of the flood, according to Bell.

Periodic flooding in the Mississippi Valley may affect residents as far north as Minnesota and as far south as Louisiana. In May 2001, the Mississippi River flooded this house south of Red Wing, Minnesota. (Image courtesy of NOAA)

But while New Zealand, the United States, and other industrialized nations have agencies equipped to provide flood warnings, developing countries have no similar protections in place. "Within large parts of Africa, Asia, and South America, there are no flood warning systems. Aid agencies need information about where flooding is occurring," said Brakenridge. By making flood maps available online in near-real time, he hopes to make it easier for aid organizations to use satellite data.

Informing aid organizations about the Observatory's online resources, however, is a difficult process. So, Brakenridge teamed up with the AlertNet web site to help get flood maps to the international aid community. Established by the Reuters Foundation, AlertNet provides news and information to international humanitarian aid and disaster relief organizations.

With support from the European Space Agency, remote sensing specialist Oliver Greening of ESYS Consulting produced satellite image content for AlertNet. Having worked in the satellite and Earth observation industry, Greening understands the obstacles associated with using satellite data. "The humanitarian aid community has a strong need for timely satellite imagery," he said. "But many individual organizations don't have the financial resources to purchase the data."

Even though satellite data are freely available from NASA, humanitarian relief agencies don't have the expertise or resources to directly download and process data. AlertNet presents satellite data as imagery that is easy to understand and more meaningful to emergency managers. "It has taken a long time for the international aid community to recognize the value of satellite imagery, but this is beginning to change because of services such as AlertNet," said Greening.

Along with finding new ways to disseminate flood information, Brakenridge is also looking for methods to improve the quality of the maps. He recently started incorporating Shuttle Radar Topography Mission (SRTM) data, obtained from the U.S. Geological Survey, into the flood maps. Because topographic data reveal the elevation of land surfaces beneath flooded areas, Brakenridge can remotely estimate how deep flood waters are by determining which features they cover up.

"SRTM data allow us to do a lot more than we thought we could when we started," said Brakenridge. In addition to improving flood maps, the team can also use the topographic data to map seasonal wetlands, such as those created during monsoons or periodic flooding.

From space, Brakenridge explained, Asia during a normal monsoon season looks dramatically different than it does during the dry season. But as more people crowd into flood-prone areas, or as watersheds change, the normal flood cycle of a river can be seen as dangerous or unusual. "We don't want to make a big fuss about major flooding along a particular river when, in fact, it floods every year," he said. Developing an archive of flood data will help scientists differentiate between normal monsoon flooding and an exceptional flood event.

Normal flooding cycles often produce seasonal wetlands, which contain distinctive types of soil and vegetation that affect larger biochemical cycles. Wetlands are the largest natural source of methane emissions worldwide, according to the U.S. Environmental Protection Agency. Scientists need to know how much methane seasonal wetlands contribute to the atmosphere in order to model methane emissions and understand the role of naturally occurring greenhouse gases.

Wetlands also store large quantities of carbon, giving them a significant role in the Earth's carbon cycle. Scientists modeling the carbon cycle and methane emissions lack accurate global maps of wetlands, said Brakenridge, adding that SRTM and MODIS data will generate the detailed maps that modelers need.

Brakenridge and his colleagues continually update flood information and work to make it easily accessible from the DFO web site. "It's been a mammoth job to compile the information and verify its accuracy. There's a lot of valuable anecdotal information that we don't want to lose, but it's hard to categorize and quantify it," said Brakenridge.

But flood by flood, map by map, the team is developing a long-term archive of satellite data that will help hydrologists monitor floods, allow aid agencies to pinpoint flood-prone regions, and provide information for modeling some of the Earth's complex hydrologic cycles.

For more information, visit the following web sites:

The Dartmouth Flood Observatory
http://www.dartmouth.edu/~floods/index.html

Reuters AlertNet Satellite Images
http://www.alertnet.org/thefacts/satelliteimages/

New Zealand's National Institute of Water and Atmospheric Research
http://www.niwa.cri.nz/

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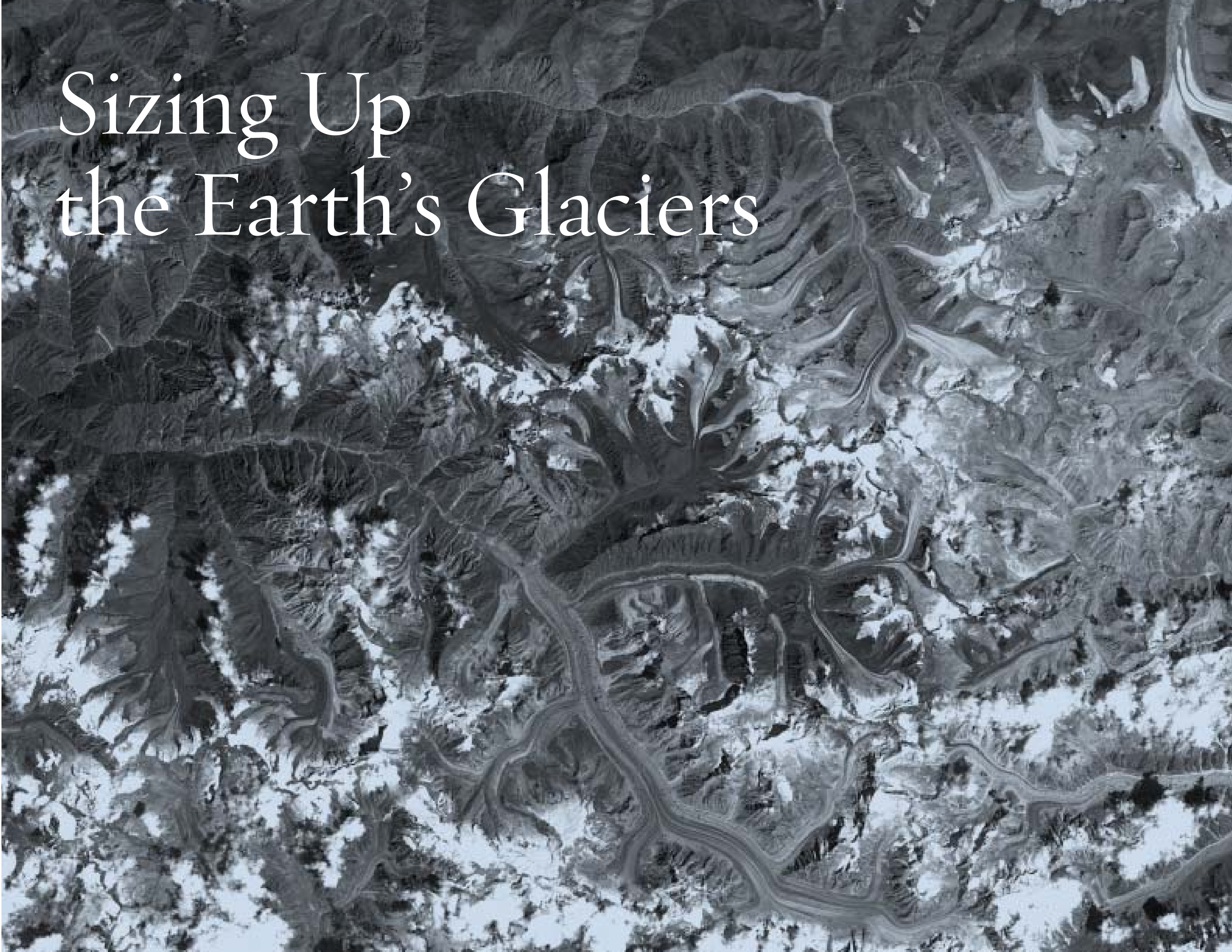
http://www.alertnet.org/thefacts/satelliteimages/

New Zealand's National Institute of Water and Atmospheric Research. Accessed April 9, 2004.
http://www.niwa.cri.nz/

G. Robert Brakenridge is the director of the Dartmouth Flood Observatory and a research associate professor in the geography department at Dartmouth College. With a background in fluvial geomorphology and river processes, his research interests include hydrological remote sensing, floodplain sedimentation, planetary geology, and geoarcheology. Brakenridge holds a PhD in geosciences from the University of Arizona.

Oliver Greening works as a consultant for ESYS, a British public limited company, where he specializes in satellite earth observation data application and exploitation. He has been instrumental in developing and implementing geographic information services for the Reuters Foundation's AlertNet (www.alertnet.org), the news and information service for international humanitarian aid organizations. Greening holds a MS in remote sensing from the University of London.

Sizing Up the Earth's Glaciers



Visit the world's high mountain ranges and you'll probably see less ice and snow today than you would have a few decades ago. More than 110 glaciers have disappeared from Montana's Glacier National Park over the past 150 years, and researchers estimate that the park's remaining 37 glaciers may be gone in another 25 years. Half a world away on the African equator, Hemingway's snows of Kilimanjaro are steadily melting and could completely disappear in the next 20 years. And in the Alps, glaciers are retreating and disappearing every year, much to the dismay of mountain climbers, tourist agencies, and environmental researchers.

"Receding and wasting glaciers are a telltale sign of global climate change," said Jeff Kargel, head of the Global Land Ice Measurements from Space (GLIMS) Coordination Center at the United States Geological Survey (USGS) in Flagstaff, Arizona. Kargel is part of a research team that's developing an inventory of the world's glaciers, combining current information on size and movement with historical data, maps, and photos.

In response to climate fluctuations, glaciers grow and shrink in length, width, and depth. Because glaciers are sensitive to the temperature and precipitation changes that accompany climate change, the rate of their growth or decline can serve as an indicator of regional and global climate change. Tracking and comparing recent and historical changes in the world's glaciers can help researchers understand global warming and its causes (such as natural fluctuations and human activities). Glacial changes can also have a more immediate impact on communities that rely on glaciers for their water supply, or on regions susceptible to floods, avalanches, or landslides triggered by abrupt glacial melt.

Scientists track glacial change by measuring individual glaciers and comparing their size over time with records of the local and regional climate. But measuring every major glacier on Earth would be a monumental task. Approximately 160,000 glaciers occupy the Earth's polar regions and high mountain environments, and sending a team to each one every year would be costly and difficult to coordinate. In addition, although a few research teams travel to a few glaciers each year to measure ice depth, size, movement, and water content, the data from individual glaciers don't necessarily reveal how other glaciers in the same region—much less in other parts of the world—are changing. Even glaciers within the same region can react differently to environmental changes. For example, while most glaciers in Glacier National Park are retreating, some are advancing.

The GLIMS team uses high-resolution satellite images from the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) instrument and the Landsat Enhanced Thematic Mapper Plus (ETM+), archived at the Land Processes Distributed Active Archive Center (LP DAAC), to track the size and movement of glaciers. For the first time, scientists will be able to assess and track glacial change on a global scale through a worldwide database of glacier information.

More than 100 investigators in 24 countries are helping to build the GLIMS database. "These investigators collect and analyze satellite images of the glaciers in their own region, such as the Alps or the Andes, and then send their analyses and results to the Coordination Center for inclusion in the GLIMS database," Kargel explained. The researchers also compare the satellite images with historical maps and information to determine a glacier's advance or retreat over the past few decades. Satellite imagery can help reveal short- or long-term trends in glacier activity that could impact water supplies or cause glacial hazards.

About three-quarters of the Earth's fresh water is held in ice sheets and mountain glaciers, so recognizing glacial changes is crucial to monitoring water supplies. "Glaciers serve as a natural regulator of regional water supplies," said Kargel. During periods of warm weather and intense sunlight, such as during dry seasons and droughts, glaciers melt vigorously and provide a water source for the surrounding ecosystems and communities. Conversely, during colder rainy seasons, glaciers produce less meltwater. "Glacier changes, especially recent melting, can affect agriculture, drinking water supplies, hydroelectric power,

"Glaciers are critical storehouses of water, and the GLIMS database of images and data is essential to the ongoing study of glaciers and their response to global climate change."

Land Processes DAAC

National Snow and Ice Data Center DAAC

by Evelyne Yohe

Far left: This composite ASTER image shows how the Gangotri Glacier terminus has retracted since 1780. Contour lines are approximate. (Image courtesy of Jesse Allen, NASA Earth Observatory, based on data provided by the ASTER Science Team)

This image from the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) shows the termini of the glaciers in the Bhutan Himalaya. (Image courtesy of Jeffrey Kargel, U.S. Geological Survey) transportation, tourism, coastlines, and ecological habitats," he added.

In areas with very large glaciers, increased melting could result in temporary increases in meltwater available for human use. But as the world's glaciers continue to melt and shrink, over time there will be less water to sustain the communities that have come to depend on that meltwater. In Kazakhstan, for example, glaciers feed many of the rivers used for agricultural irrigation, and the recent glacial retreat in that region is now compromising the area's water supply. "It's kind of like a bank account—when you've withdrawn all the water, there isn't any more," said Kargel.

Excessive glacial melt can also result in increased hazards or disasters for communities living near glaciers. "Glaciers don't always behave nicely. They're a type of natural reservoir with a temper, in some cases. Some glaciers have a nasty habit of storing up large amounts of water and then releasing it suddenly in a massive melt or calving episode, which may involve floods, landslides, or avalanches," said Kargel.

As settlements, farming, and tourism extend toward the edges of glaciated regions, melting glaciers and the avalanches and floods that often accompany rapid melt increasingly threaten lives and infrastructure in mountain regions. The ASTER images acquired for the GLIMS project allow researchers to recognize and track changes in glacial hazard indicators such as crevasses, avalanche and debris-flow traces, and glacial lakes.

While current melting trends can't be slowed or reversed, the information collected through the GLIMS project will enable researchers to better understand the relationship between climate and glaciers, and to better predict areas of future glacier changes.

The ASTER images of each glacier, along with the data collected and analyzed by the GLIMS team, are stored in a large database jointly developed by the USGS in Flagstaff and the National Snow and Ice Data Center (NSIDC) in Boulder, Colorado. Previous glacier databases stored information such as location, length, orientation, type, and altitude for one point near the center of each glacier. "The GLIMS database will store detailed information for the entire outline of each glacier, providing more complete spatial data," said Bruce Raup, technical lead for the GLIMS project at NSIDC. "As the data become available in the database, users will be able to do online searches and see the resulting data in multiple formats, including views of glacier extent and elevation superimposed on ASTER images."

One of the challenges of the GLIMS glacier inventory is the accurate identification of each glacier. "While it may seem easy to define what a glacier is, it can be quite difficult to identify individual glaciers in highly glaciated areas where the glaciers branch or run together," said Raup. Also, recent glacial melt has resulted in some dramatic glacial changes; for example, some large Y-shaped glaciers that are numbered and described in the older World Glacier Inventory have recently shrunk into two separate ice masses. "We're currently creating protocols that enable us to draw accurate boundaries around individual glaciers and properly classify glaciers that previously were part of other glaciers," Raup added. This process will help identify the extent to which large, glaciated areas have become smaller and more fragmented.

Although the GLIMS project is still in a formative stage, the yearly satellite data being compiled and stored with historical data from the last three to five decades will enable scientists to track worldwide glacier changes and the effects of such change on surrounding communities and habitats. "I think we'll have some interesting data that will be publicly accessible within the coming year," said Raup. "It won't be global coverage yet, but there should be some good snapshots of glacier health within a few regions. This is a fascinating time to study and inventory the world's glaciers because of the recent dramatic changes."

"I think a hundred years from now, the GLIMS effort to study the world's glaciers will still be going strong," said Kargel. "There will still be glaciers to study, although far fewer than there are today. But GLIMS will eventually consist of well over a century's worth of glacial data."

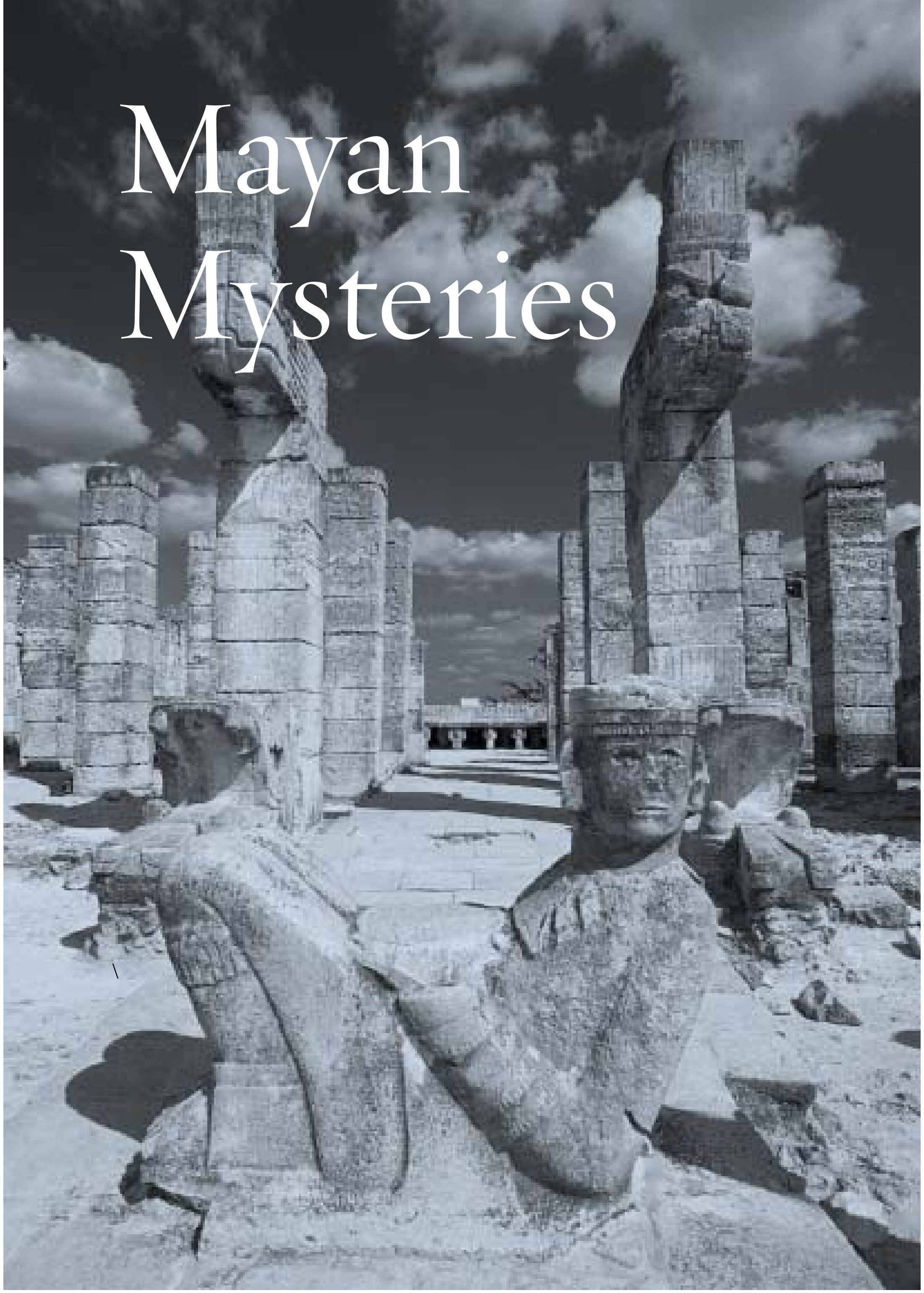
For more information, visit the following web site:

Global Land Ice Measurement from Space
http://www.glims.org/

Jeff Kargel is director of the GLIMS Coordination Center in Flagstaff, Arizona. He became interested in glaciers through his research on the Martian cryosphere and its geologic/climatic history. He is also involved with HIGH ICE (High Asian Institutes of Glaciology: Hydrology, Ice, Climate, and Environment), a science-for-peace effort directed toward scientific cooperation and peaceful relations between India and Pakistan in the Kashmir region. He earned a MS in geological sciences from Ohio State University and a PhD in planetary sciences from the University of Arizona.

Bruce Raup is a research scientist at the National Snow and Ice Data Center in Boulder, Colorado, and the primary designer of the GLIMS glacier database. His primary research interests are glacier dynamics, mass balance, and application of remote sensing techniques to the study of glaciers. Raup holds a MS in geological sciences from the University of Colorado, Boulder.

Mayan Mysteries



Global Hydrology Resource Center

by Michon Scott

> *"We want to know how the Maya used this landscape because we don't know how to use it successfully today."*

Centuries before Europeans arrived, an advanced civilization flourished in Mesoamerica, a region extending from southern Mexico through Central America. The Maya mastered astronomy, developed an elaborate written language, built towering monuments, and left behind exquisite artifacts.

According to NASA archaeologist Tom Sever, the Mayan civilization in Mesoamerica was one of the densest populations in human history. Around 800 a.d., after two millennia of steady growth, the Mayan population reached an all-time high. Population density ranged from 500 to 700 people per square mile in the rural areas, and from 1,800 to 2,600 people per square mile near the center of the Mayan Empire (in what is now northern Guatemala). In comparison, Los Angeles County averaged 2,345 people per square mile in 2000. Yet by studying remains of Mayan settlements, Sever found that by 950 a.d., the population had crashed. "Perhaps as many as 90 to 95 percent of the Maya died," he said.

For Sever, figuring out how the Maya flourished—but ultimately failed—in Mesoamerica is about more than simply solving a 1,200-year-old mystery. Since the 1980s, he has tried to understand the history of the Maya and their natural environment, a story that may hold important lessons for people living there today. Using satellite data and climate models, Sever and his colleagues hope to help governments and citizens throughout Mesoamerica ensure that the region can continue to support the people who live there. By learning from the Maya, modern humans may avoid sharing their fate.

Page 37: These ruins in the sacred city of the Itza, called Chichén-Itzá in Maya, are located 75 miles east of Mérida, the capital of the state of Yucatán, Mexico. (Image from Photos.com)

Mayan Deforestation

Before its collapse, the Mayan empire stretched out from its center in northern Guatemala's Petén region across the lowlands of the Yucatán Peninsula. Pollen samples collected from columns of soil that archeologists have excavated across the region provide evidence of widespread deforestation approximately 1,200 years ago, when weed pollen almost completely replaced tree pollen. The clearing of rainforest led to heightened erosion and evaporation; the evidence of the erosion appears in thick layers of sediment washed into lakes.

"Another piece of evidence," explained Sever, "is the thickness of the floor stones in the Mayan ruins. They would have needed about 20 trees [to build a fire large and hot enough] to make a plaster floor stone that is about one square meter. In the earliest ruins, these stones were a foot or more thick, but they progressively got thinner. The most recently built ones were only a few inches thick." Sever's colleague, atmospheric scientist Bob Oglesby of Marshall Space Flight Center, calls the Mayan deforestation episode "the granddaddy of all deforestation events." Studies of settlement remains show that this deforestation coincided with a dramatic drop in the Mayan population.

"After the Mayan collapse, this area was abandoned and the forest recovered. But as people have returned over the last three decades, the deforestation has returned," Sever explained. Today, the regenerated forests of the Petén are the largest remaining tropical forests in Central America. While present-day deforestation in the Petén region hasn't yet occurred on a Mayan scale, today's technology could easily enable modern residents to surpass the Maya in cutting trees. According to the Food and Agriculture Organization of the United Nations, deforestation in Guatemala averaged 1.7 percent annually between 1990 and 2000.

Besides a cautionary tale about what can happen to civilizations when they clear-cut surrounding forests, the long-gone Mayan civilization also offers clues to a more sustainable use of the landscape. Before their catastrophic decline, the Maya thrived in Central America for two millennia. "We want to know how the Maya used this landscape because we don't know how to use it successfully today," said Sever. Although the Maya's secrets for success are harder to discern than their reasons for failure, Sever has at least one idea.

Populations in densely forested regions often rely on slash-and-burn agriculture. At first glance, this might seem like the approach the Maya used, but Sever doesn't think so. "In slash-and-burn agriculture, people clear the land to plant corn, for instance," he said. "They get 100 percent productivity the first year, 60 percent the next year, and something less than that afterwards. So in three to five years, the land is basically useless, and they have to move on." In a sparsely populated region, slash-and-burn agriculture might work, but Mesoamerica around 800 a.d. was one of the most densely populated areas in the pre-industrial world. "Slash and burn wouldn't have enabled a population to grow to that size," he said.

Sever believes the Maya took a different approach to farming: effective water management. "The biggest threat we face doing fieldwork in this region is dying of thirst," Sever explained. Even the rainforest experiences an annual dry season; the trees hang on by tapping groundwater. "The Maya couldn't use groundwater because it was 500 feet below them, and they had no technology to reach it, so they depended on rainwater."

In the Petén region Sever studies, rainwater accumulates in swamplands, known as *bajos*, that cover about 40 percent of the landscape. Today, that rainwater evaporates before anyone can use it effectively, but excavations and satellite images have revealed networks of canals among the *bajos*, apparently dug during the time of the Maya. Sever suspects that the Maya used the canals to redirect and reuse the rainwater. This labor-intensive agriculture, which probably kept farmers working diligently all day, would have barely outpaced demand. If the Maya farmed the *bajos*, however, they took advantage of an additional 40 percent of the landscape, which would have made a significant contribution to food production.

Modern Mesoamericans consider the *bajos* worthless and ignore them. “We’re trying to understand how to control water and enable this landscape to support current populations, to reduce some of the stress on the economy and environment,” Sever said.

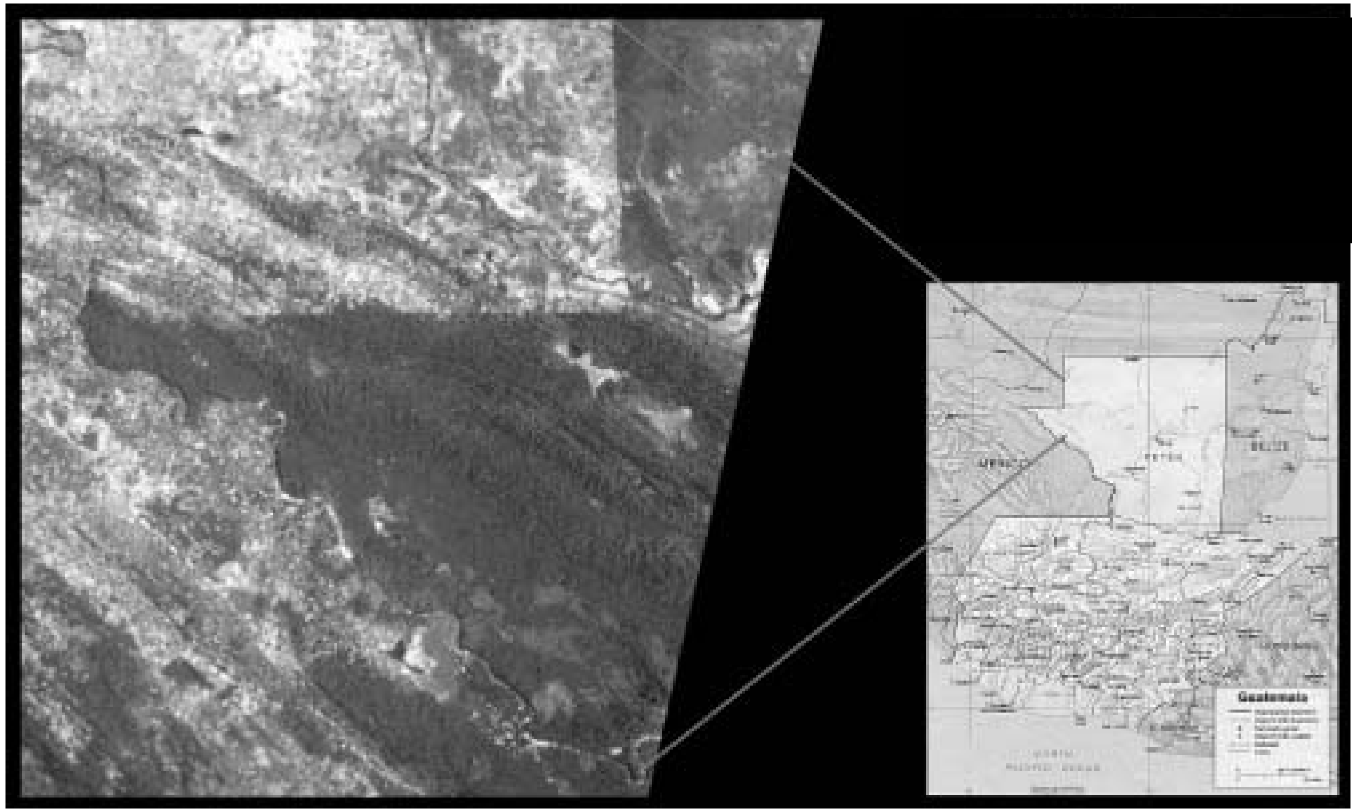
Climate Change

In the end, Oglesby speculated, the increased productivity the Maya gained by farming the *bajos* might have made them too successful. “Population pressure might then have led to their having to clear more and more land, both for settlement and for agriculture,” he said. Oglesby has used three-dimensional regional climate models to help visualize the Mayan demise, and what he has found so far is intriguing.

“If we completely deforest the area and replace it with grassland, we find that it gets considerably warmer—as much as 5 to 6 degrees Celsius,” Oglesby said. Sunlight that normally evaporates water from the rainforest canopy would instead heat the ground. Although his model paints a more extreme picture than what actually happened (the region was heavily, but probably not completely deforested), Oglesby suspects that deforestation contributed to a drought. Lake sediment cores indicate that the Mayan deforestation appears to have coincided with natural climate variability that was already producing a drought. “Combined with the land-use changes, the drought was a double whammy,” he said. By 950 a.d., the Mayan lowland cities were largely deserted.

Learning from the Mayan Legacy

Today, population density in Central America is only a fraction of what it was during the Mayan peak. In Belize, for example, population density may be as low as 26 people per square mile (10 people per square kilometer). Yet human pressure on the environment is still significant.



The razor-sharp border between Mexico and Guatemala, as seen in this 1988 Landsat image, shows the impact of high rural population on the rainforest. Guatemala's sparsely populated Petén district stands in stark contrast to the stripped and tilled landscape of Mexico. (Image courtesy of NASA.)

The effectiveness of modern tree-cutting technology became clear to Sever in the late 1980s. NASA and the National Geographic Society hired him to study the potential impact of a hydroelectric dam on the Usumacinta River in Guatemala. Sever, who had pioneered the use of remote-sensing data in finding archaeological sites, turned to satellite imagery once again. Using Landsat data, he produced an image showing part of the border between Guatemala and Mexico. Most political borders are invisible in satellite images, but this border was obvious. The rainforest—still intact in Guatemala—stopped abruptly at the Mexican border, where the landscape had been stripped.

Sever's images stunned Guatemala's president. "There had been tensions along the Mexico-Guatemala border for about 150 years," said Sever. After seeing the satellite image, however, both nations' presidents "decided that the environment must unite them." In a ceremony on a river bridge between the countries, Guatemalan President Vinicio Cerezo and Mexican President Carlos Salinas shook hands and pledged to protect the dwindling rainforest. It marked the beginning of a larger effort to protect the environment in Mesoamerica.

Mesoamerican Biological Corridor

Dan Irwin, one of Sever's colleagues, is a remote-sensing specialist who uses satellite data to study the environmental health of Mesoamerica. Regarding the image Sever showed to the Guatemalan president, Irwin remarked, "It may be the single most important image for conservation purposes that I know of on the planet, because it prompted Guatemala and Mexico to work together. More importantly, that one image was directly responsible for the Guatemalan Congress declaring the Maya Biosphere Reserve in northern Guatemala, which is the largest protected area in all of Central America."

The Maya Biosphere Reserve is part of the larger Mesoamerican Biological Corridor. Originally known as *Paseo Pantera* (Path of the Panther), the corridor is a network of protected areas extending from southern Mexico to Colombia, through Belize, Costa Rica, El Salvador, Guatemala, Honduras, Nicaragua, and Panama. The corridor preserves Mayan ruins, along with habitat and migration routes for wildlife. "Mesoamerica has less than half a percent of the Earth's landmass, but it has over 7 percent of the world's biodiversity," said Irwin.

Irwin began working with Sever in the early 1990s as an employee of Conservation International. "I planned to be in Central America for two months and came back five years later," Irwin said. He distinctly remembers the moment he decided to stay and continue his work there, which occurred one evening when he showed some of Sever's satellite images to a rural Guatemalan community.

Unlike their president, the villagers initially had trouble understanding the images. "They had never worked with maps or any type of spatial data," Irwin said. "Part of the process was showing them, 'This is a road near you' and 'This is a lake.' All of a sudden, the light bulbs turned on and they became very interested."

Once the villagers understood what they were seeing, they shared the Guatemalan Congress's concern for the rainforest. "This society was an agricultural community, and the people had assumed that you could keep on developing more fields and bringing more people up, and the forest would last forever," he said. "But I showed them that the Mexican border really wasn't that far away, and that Mexico's side had been completely deforested. It was an amazing moment that I'll never forget. With that, I made the decision to continue on and do this type of work."

Choosing a Sustainable Future

Remote sensing observations provided by NASA's data centers have been critical for monitoring the health of the Mesoamerican Biological Corridor. Through routine satellite observations, researchers can monitor important ecosystem vital signs, such as rainfall, vegetation productivity, cloudiness, and forest gains or losses over the entire area. Oglesby and his colleagues will be archiving the results from their modeling experiments on the climate impacts of the Mayan deforestation at the Global Hydrology Resource Center at NASA's Marshall Space Flight Center.

While they hope Central American forests can be spared the kind of clear-cutting seen in Mexico, the researchers don't want to stop all development in the region. "The purpose isn't to discourage any development, but to encourage improved development," Irwin said.

Remote-sensing data and modeling technology have already enabled natural resource managers in Mesoamerica to predict and avoid environmental damage. Irwin recalled a proposal to build a road through the middle

The Maya built monuments that have stood for centuries, but they were not able to sustain their way of life. (Image from Photos.com)

of a reserve to connect two archaeological sites. Using data on how deforestation spreads outward from roads, the scientists developed a model that examined the road's distance from water, the surrounding soil type, and other factors. "We made an animation of what the place would look like in one year, two years, four years, etc. That particular study was a factor in the decision to build the road around the reserve instead," Irwin said.

Irwin is also encouraged by improved agricultural practices, such as shaded coffee. In a traditional coffee plantation, farmers typically cut down all the trees, a process that's harmful to wild birds, including local species like macaws and quetzals, and migrating songbirds. By planting shade-tolerant coffee around existing trees, farmers can strike a balance. "You can find all kinds of birds on shaded coffee plantations. It's a type of agriculture that goes along with the theme of the corridor," he said.

Using Satellite Data to Study the Corridor

Sever and Irwin are now providing Mesoamerican scientists, policymakers, and land managers with direct access to satellite data and models. "The Guatemalan Minister of the Environment wants to replace his old topographic map with a plasma TV showing the latest data," Irwin said.

To improve general access to remote-sensing data, NASA has partnered with the U.S. Agency for International Development, the World Bank, the Central American Commission for Environment and Development, and several U.S. universities to develop the SIAM-SERVIR web site (**http://servir.nsstc.nasa.gov**). The site offers a satellite data archive and distribution system for professional researchers, maps for more casual users, visualizations, and a decision support system that provides information to researchers and policymakers.

The web site, initially developed at NASA's Marshall Space Flight Center, will ultimately be hosted in Panama, with nodes throughout Central America. "We're proud of the decentralized control," said Irwin. "Users can post data and make them available to anyone." Another source of pride for Irwin is the rapid spread of remote-sensing expertise. "I'm the first to admit that there are people in Central America I've trained who know more than I do now when it comes to some of the imagery," he said. "I have to read the book to keep up with them."

Remote sensing and climate modeling have given today's Mesoamericans a chance to understand their environment in a unique way—one that would probably have been as surprising to the Maya as it was to the Guatemalan farmers seeing the satellite photos of their surroundings for the first time. Archeological studies have likewise given modern Mesoamericans clues to Mayan success and eventual failure.

The Mesoamerican Biological Corridor may give the region's tropical forest ecosystems a chance to thrive despite increased population pressure. The environment around Petén recovered only after the Maya deserted, but scientists involved in the corridor hope to strike a balance between human needs and environmental health. "We're trying to protect the forest to avoid what happened at the time of the Mayan collapse," Sever explained. "This project shows how various organizations, researchers, and new technology can come together to make something productive, something that's beneficial for everyone."

Reliable information on the state of Mesoamerican environment and how it reacts to natural and human-produced change is fundamental to helping Mesoamerica's modern residents recreate the Maya's successes without repeating their mistakes.

For more information, visit the following web sites:

SIAM-SERVIR
http://servir.nsstc.nasa.gov

Gridded Population of the World
http://sedac.ciesin.columbia.edu/gpw

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Dan Irwin *(above right)* is a remote sensing specialist at NASA's Marshall Space Flight Center and has also worked with Conservation International. To encourage alternatives to slash-and-burn agriculture, he has helped establish a library, ferryboat service, Internet café, and other businesses in Mesoamerica. Irwin holds a MS in environmental science from Miami University of Ohio.

Tom Sever *(above left)* is a remote sensing specialist and archaeologist at the Global Hydrology and Climate Center at NASA's Marshall Space Flight Center. He pioneered the use of using remote sensing in archeology and anthropology, locating ancient human settlements and footpaths and assessing the impact of modern deforestation. His work has been featured in *National Geographic, Archaeology Magazine, Omni Magazine, Discovery, Newsweek, The New York Times, Smithsonian Air and Space*, and the Discovery Channel. Sever holds a MS from the University of Illinois, Springfield, and a PhD from the University of Colorado.

Bob Oglesby is an atmospheric scientist and climate modeler at NASA's Marshall Space Flight Center, and an adjunct associate professor in the atmospheric sciences department at the University of Alabama. He earned his MS and PhD in geology/geophysics from Yale University.


Clouds from a
Different Angle

Have you ever put together a jigsaw puzzle only to discover you were missing some pieces? The picture just doesn't look quite right. This is the scenario that scientists sometimes face when trying to create a picture of what the Earth's future climate will look like. The climate puzzle may look almost complete, but there is a piece missing—and it's a vital one.

Climate models use mathematical equations to simulate how the Earth's climate, both past and future, responds to changes in levels of greenhouse gases, aerosols, and solar energy. Since they take into account factors such as the size of the Earth, the shape and elevation of continents, the composition of the atmosphere, atmospheric and oceanic circulation, and the amount of sunlight striking the Earth, climate models can create "artificial" climates that mathematically resemble the real world.

Researchers rely increasingly on climate models to explore the Earth's climate system. But according to a recent Intergovernmental Panel on Climate Change (IPCC) report, one of the biggest challenges in building a reliable climate model is representing the effects of clouds, particularly the way they reflect sunlight and emit thermal energy.

"Traditional climate models have a rather simple view of clouds and their effects on climate, partly because the models can't duplicate the wide range of cloud processes," said Norman Loeb, a professor at Hampton University and research scientist at the Langley Research Center (LaRC).

Clouds play an important role in climate, not only because they produce precipitation, but also because they help regulate the Earth's radiation balance, where the energy absorbed from the sun must equal the energy radiated back into space. By reflecting incoming sunlight and blocking the flow of radiation from the surface back to space, clouds play a pivotal role in a delicate balance that sets the temperature on Earth.

Without this balance, the Earth's average temperature would increase or decrease, so a change in cloud cover can ultimately influence climate. "Cloud properties change over time, and understanding how these changes affect the Earth's radiation is critical for improving model predictions of future climate," said Loeb, who studies cloud properties and devotes much of his current research efforts to developing satellite-based global climate data that will improve the way cloud effects are represented in climate models.

Since scattered radiant energy, or light, helps control the Earth's energy balance, accurate measurements are essential to long-term climate change studies. Satellite data enable scientists to study the Earth's atmosphere from space, a perspective that renders the effects of scattered light more noticeable. According to Loeb, the path that light travels is very different if you observe an object from a straight, downward view than if you observe it from an oblique view, where light scatters through a longer path. When you look straight up at the sky, for example, its color is increasingly blue, but it fades to white as you look toward the horizon where light scatters through a longer path.

Looking down at a body of water (while flying, for example) also illustrates how perspective can influence the path that light travels. If you face the sun when the sky is cloud-free, light reflected from the water is very bright, but when the sun is behind you, the reflection appears darker. In contrast, if a thick cloud layer covers the water, the light appears more uniform in all directions. "Because we don't live in space, visually speaking, we tend to have a very surface-dependent view of the world," said Loeb.

To accurately represent the radiative flux from clouds, or how much the radiance is distributed in different directions within a given area, Loeb needed data from a satellite sensor that measured radiance in several directions. The Clouds and the Earth's Radiant Energy System (CERES) instrument, which flies onboard NASA's Tropical Rainfall Measuring Mission (TRMM), Terra, and Aqua satellites, was designed to measure radiation escaping from the Earth to deep space.

But even though CERES scans the Earth at many different angles, a single satellite cannot measure *all* of the light reflected and emitted from *all* directions at the same

"Cloud properties change over time, and understanding how these changes affect the Earth's radiation is critical for improving model predictions of future climate."

Langley Atmospheric Sciences Data Center

by Jason Wolfe

Far left; Cumulus clouds gather over southern Wyoming. (Image courtesy of Laurie J. Schmidt)

Cumulus clouds tower over Coconut Creek, Florida. (Image courtesy of NOAA Photo Library)

instant in time. This would require thousands of satellites, which is just not feasible. To compensate for the lack of measurements, Loeb built angular distribution models, or models that account for the various angles at which light travels through clouds. The models incorporate more than a billion CERES radiance observations from the LaRC Atmospheric Sciences Data Center Distributed Active Archive Center (DAAC), which archives and distributes the data.

"Because the angle and path through which light travels vary, models must be tied to specific areas, or 'scenes,' on the Earth that have similar properties, such as clear ocean, thick and thin clouds, or water and ice clouds," said Loeb. To accomplish this, he combined the CERES radiance data with observations from the Moderate Resolution Imaging Spectroradiometer (MODIS) instrument, which also flies onboard NASA's Terra satellite. Since MODIS can view features on the Earth as small as 250 meters, the instrument's data helped Loeb identify different scenes, which significantly improves the accuracy of the angular distribution models.

But the puzzle wasn't complete yet. Clouds are often represented in climate models as one-dimensional features that exhibit the same properties in all locations. In the real world, however, clouds are three-dimensional features with different, complex behavior. Clouds also vary significantly by location, time of day, changing weather, and season. The tropics, for example, typically have more clouds than other latitudes, and clouds there also tend to be one to two kilometers higher than in midlatitude regions.

For the first time, Loeb's new angular distribution models enable researchers to look at different cloud types (such as convective, stratus, stratocumulus, and cumulus) with sufficient accuracy and clarity to detect subtle, but crucial, climate signals caused by clouds. Kuan-Man Xu, also a research scientist at the LaRC DAAC and one of Loeb's colleagues, is using this breakthrough to develop new ways of using satellite data to test different cloud types in climate models.

"Scientists can easily alter the characteristics of a few clouds in climate models, but to do so for hundreds of thousands of clouds would be much more difficult," said Xu. Grouping clouds into distinct systems allows Xu to describe a large number of clouds, while significantly reducing the amount of time required to enter the information into climate models. "The ability to explain variations in cloud properties in different geographic locations is key to further evaluating the performance of cloud models," he said.

In the future, Xu plans to analyze more data to look at how cloud types are influenced by meteorological conditions, such as temperature and humidity. "Improved cloud models significantly improve the accuracy of global climate models, which can lead to more accurate predictions of climate change," said Xu.

By learning more about cloud properties and how to accurately represent them in models, Loeb and Xu are one step closer to filling in the missing piece of the climate puzzle.

For more information, visit the following web sites:

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

International Satellite Cloud Climatology Project
http://isccp.giss.nasa.gov/index.html

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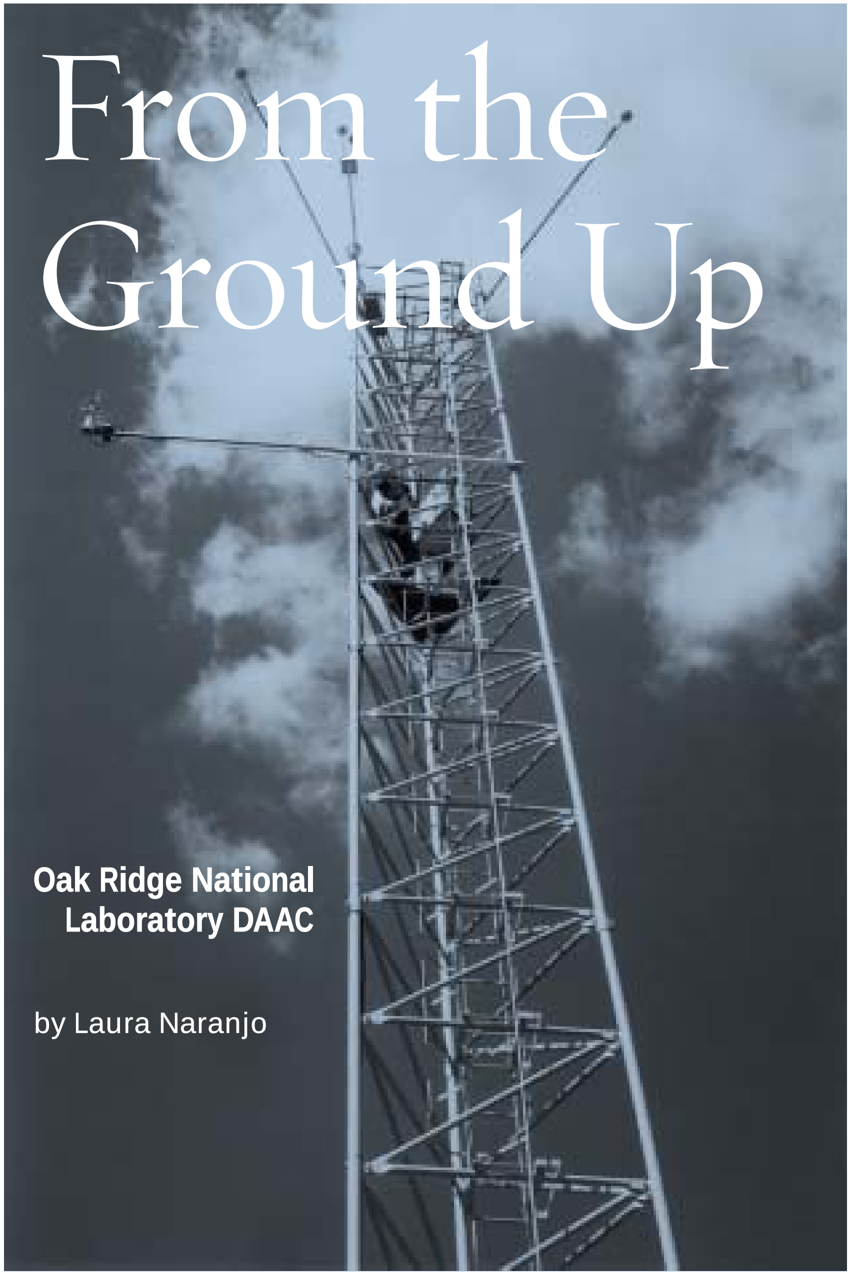
Norman Loeb is a research professor in the Center for Atmospheric Sciences at Hampton University, and a co-investigator for NASA's Clouds and the Earth's Radiant Energy System (CERES) experiment. His research focuses on satellite remote sensing of clouds and aerosols and estimation of the Earth's radiation budget. Loeb earned a MS in atmospheric sciences from York University in Toronto, Canada, and a PhD in atmospheric sciences from McGill University in Montreal, Canada.

Kuan-Man Xu is a research scientist at the NASA Langley Research Center. His research focuses on improving cloud parameterizations in climate models and the study of distinct cloud systems. He leads a NASA EOS interdisciplinary study project, participates in the NSF Climate Process Team, and was involved in the establishment of the NSF Science and Technology Center on Multi-scale Modeling of Atmospheric Processes. Xu earned a MS in meteorology from Massachusetts Institute of Technology and a PhD in atmospheric sciences from the University of California, Los Angeles.

From the Ground Up



Oak Ridge National Laboratory DAAC

by Laura Naranjo

"When users request MODIS data, we like to give them the validation status so that they understand the quality and uncertainty of the data and have an appreciation for its limitations."

South Africa's Kruger National Park, a subtropical savanna speckled with acacia and baobab trees, is providing scientists with a look at the Earth's metabolism. All over the world, in fact, scientists are exploring a variety of ecological communities to understand how each one exchanges water, sunlight, and carbon between the land surface and the atmosphere.

Because the Earth supports a variety of different communities, such as savannas, deserts, tropical forests, and wetlands, making sense of these complex relationships is no small task. To measure the land-atmosphere exchanges for each ecological community, or biome, scientists are turning to satellite remote sensing. Satellite data provide a reliable, long-term way to measure land-atmosphere exchanges on a global basis. But satellites monitor these processes from hundreds of kilometers above the Earth's surface. How do scientists know that what they're seeing is an accurate snapshot of what's happening on the ground?

Oddly enough, the best way scientists can determine the accuracy of what the satellite shows them is by validating the data with information collected on the ground.

Validation confirms the accuracy of satellite data by comparing them to independent reference data collected via stationary instruments, field campaigns, and even other satellites. Validation differs from data quality assurance, which involves identifying specific sensor malfunctions or problems with certain data products that the satellite generates.

Scientists working with NASA's Moderate Resolution Imaging Spectroradiometer (MODIS) sensors onboard the Terra and Aqua satellites have formed teams to validate MODIS land cover data. Although validation is a work in progress, it has already improved MODIS data quality, incorporated more data sources, and made data more accessible to remote sensing investigators and field researchers.

Because validation is costly and involves an extensive network of measurements, it requires long-term collaboration. "We don't have the resources to travel throughout the network, so we're trying to interact with other people doing field work in different

The Skukuza FLUXNET tower in Kruger National Park, South Africa, houses a variety of instruments that measure atmospheric chemistry, humidity, air temperature, soil temperature, and soil water content. (Image courtesy of Bob Cook, Oak Ridge National Laboratory) parts of the world," said Jeff Morisette, validation coordinator for the MODIS Land Team, or MODLAND. Morisette serves as science lead and primary contact for the team, facilitating communication between the validation groups and maintaining the land validation web site. Obtaining a continuous and reliable stream of ground-based measurements, however, is a challenge. Much of the validation effort relies on FLUXNET, a worldwide network of sites centered on flux towers, such as the one in South Africa, that record the exchanges of carbon dioxide, water vapor, and solar energy between land and the atmosphere. This network allows scientists to compare MODIS data to a variety of ground-based measurements taken from different biomes around the globe.

In 2001, FLUXNET included 140 long-term sites, but by 2003, that number had jumped to 252. By integrating U.S. meteorological networks with others in Europe, Canada, Asia, Australia, and Brazil, FLUXNET gave the MODLAND team a broader sample of biomes for validating satellite data. "The flux towers are probably the single most valuable and most globally distributed validation network we have," said Steve Running, ecology professor in the school of forestry at the University of Montana.

In addition to providing more extensive meteorological data, the proliferation of flux towers has also fostered collaboration between ground teams and satellite data providers. Sharing resources and exchanging data with ground teams provides more opportunities to validate MODIS products. "Validation tends to be expensive because you need people on the ground," said Crystal Schaaf, associate professor in the department of geography and the Center for Remote Sensing at Boston University. "We try to arrange a reciprocal agreement where we provide satellite imagery in exchange for ground data. In turn, we hope they can do some validation work for us."

However, because most ground teams don't include remote sensing staff, members are often unfamiliar with using satellite data. "We needed to make MODIS data simple and easy for flux tower ground teams to use," said Running. The MODLAND team members coordinated with the validation community to generate "subsets" of data. Making subsets involved cutting out a portion of data imagery located directly over flux towers and other field sites and providing the data in ASCII (plain text), which is a more accessible format for ground teams.

This image is a south view from the Skukuza FLUXNET tower in South Africa's Kruger National Park. The tower straddles two distinct savanna types to collect information about land-atmosphere interactions. (Image courtesy of Bob Cook, Oak Ridge National Laboratory)

Site-specific 7 x 7-kilometer ASCII subsets of MODIS data are available from the Oak Ridge National Laboratory Distributed Active Archive Center (ORNL DAAC). The Land Processes Distributed Active Archive Center (LP DAAC) distributes larger 200 x 200-kilometer subsets that provide regional data coverage for each tower.

"Providing subsets encourages some of our users. Now they can just download a small collection of data in ASCII format that's relevant to their needs," said Schaaf. For instance, ground teams looking at the Kruger National Park site in South Africa can download a text file of MODIS data pertaining to their site, or look at files specific to other similar savanna sites around the world.

To improve data accessibility, the ORNL DAAC also released an online browse tool in August 2004. "We're providing a couple of different ways to visualize the data so that ground teams can compare the MODIS products very easily with results from their field studies," said Bob Cook, a research scientist at the ORNL DAAC. Ground teams can now view the 7 x 7-kilometer data subsets as a time series in graphical format. Field campaigns, such as the current Large-Scale Biosphere-Atmosphere Experiment in Amazonia (LBA), also contribute valuable reference data for validation, allowing scientists to obtain more detailed data. According to Nikolay Shabanov, a post-doctoral research associate in the department of geography at Boston University, taking ground measurements of vegetation density from several different biomes helps scientists develop samples of specific biomes against which to compare satellite data.

However, according to Shabanov, "A broadleaf forest in North America is somewhat different from a broadleaf forest in Amazonia, so we sample both areas to provide more accurate validation." Shabanov and his colleagues at Boston University sampled Harvard Forest in North America and used LBA data to compare the same biomes on different continents.

"We also developed a sampling strategy to scale from field measurements to fine-resolution data," said Shabanov. Because field campaigns gather fine-resolution data, his team needed to scale the data through a series of steps so they could more accurately compare field data with lower-resolution MODIS data.

Morisette credits the MODIS investigators for many of the data improvements. "They're looking at independent reference data to see how their product is doing and using that information to improve it," he said. To incorporate new software fixes, update algorithms, or fill in missing data, investigators periodically reprocess the validation data. The most recent reprocessing, called Collection 4, was completed in 2003. Releasing periodic updates helps scientists and other data users apply the improvements to their current studies. MODIS validation is divided into three stages, with each successive stage indicating an increased level of accuracy. "When users request MODIS data, we like to give them the validation status so that they understand the quality and uncertainty of the data and have an appreciation for its limitations," said Cook. By December 2003, all of the land products had achieved Stage 1 validation.

According to Morisette, achieving Stage 2 validation will require more extensive international collaboration. Morisette, who chairs the land product validation subgroup for the Committee on Earth Observation Satellites (CEOS), hopes to cultivate more international participation for future MODIS validation.

Reliable, validated satellite data are vital for studying the Earth's broad range of unique biomes. By measuring and quantifying land-atmosphere interactions, scientists can better study individual biomes, as well as understand how the Earth's communities collectively interact with the atmosphere on a larger scale.

For more information, visit the following web sites:

Oak Ridge National Laboratory Distributed Active Archive Center
http://daac.ornl.gov/

MODIS Land Team Validation Web Site
http://landval.gsfc.nasa.gov/MODIS/index.php

MODIS ASCII Subsets
http://public.ornl.gov/fluxnet/modis.cfm

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http://daccl.esd.ornl.gov/FLUXNET/

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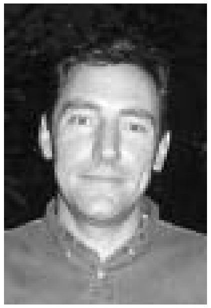
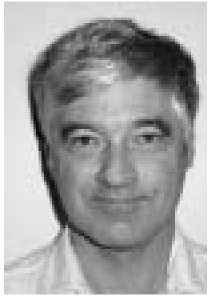
http://landval.gsfc.nasa.gov/MODIS/

Robert Cook is a research scientist in the Environmental Sciences Division at the Oak Ridge National Laboratory. His research interests include biogeochemistry, global change, aqueous geochemistry, transport and fate of contaminants in aquatic ecosystems, and water resources management. Cook received his PhD in geochemistry from Columbia University.



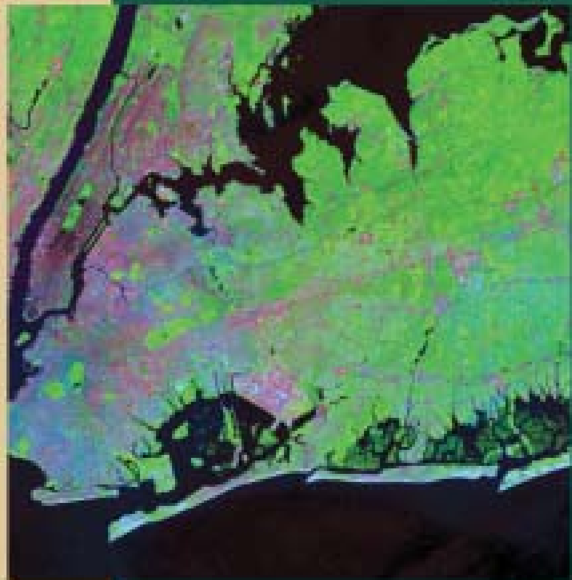
Jeffrey Morisette is validation coordinator for the MODIS Land Team validation activities. His current research focuses on the application of multi-resolution and time series satellite imagery to the validation of global land products and ecological studies. Morisette holds a PhD from North Carolina State University, where he focused on geostatistics, accuracy assessment, and satellite-based change detection.



Steve Running is a professor in the school of forestry and director of the Numerical Terradynamic Simulation Group at the University of Montana. He currently serves as the principal investigator for MODIS Net Primary Production products. Running earned a PhD in forest ecophysiology from Colorado State University.

Crystal Schaaf is a research professor in the department of geography and the Center for Remote Sensing at Boston University. As a MODLAND associate team member, she is currently working to develop operational products for MODIS. Her research interests include modeling reflectance and albedo, and using remote sensing data to reconstruct reflectance characteristics of land surfaces. Schaaf earned a PhD in geography from Boston University.

Applications of Earth observing data from the NASA Science Mission Directorate



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