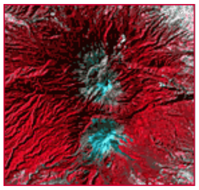


Sensing Remote Volcanoes

Alaska Satellite Facility DAAC • GSFC Earth Sciences DAAC • Land Processes DAAC

by Laurie J. Schmidt

July 13, 2004

▶ 2

"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 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.

This image shows an eruption of Kavachi Volcano, an undersea volcano located off the coast of the Solomon Islands. When Kavachi's lava reached the sea surface in 2002, the MODVOLC thermal alert system detected the emitted heat. (Image, available from NOAA, courtesy of Brent McInnes, Commonwealth Scientific and Industrial Research Organization, Australia)

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 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

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.

1 ◀▶ 3

This aerial view of Mount St. Helens shows the summit and the highly fractured bulge that developed on the volcano's north flank in late April 1980. (Image courtesy of Dan Miller, USGS)

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.

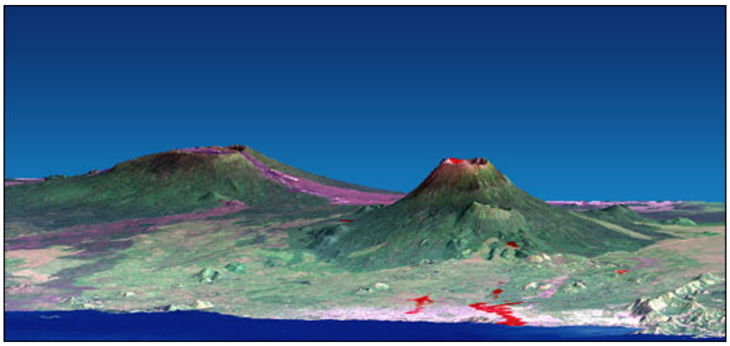
Lack of warning at Nyiragongo has grave implications: the city of Goma sits about 9 miles (15 kilometers) south of the volcano. "About 500,000 people live in Goma and its immediate vicinity," said Michael Poland, geophysicist at Cascades Volcano Observatory in Vancouver, Washington. "Nyiragongo has a 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.

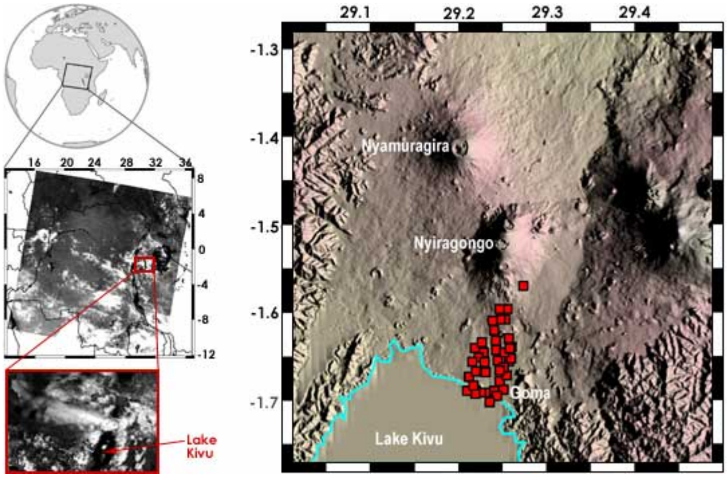


This computer-generated visualization combines a Landsat satellite image and an elevation model from the Shuttle Radar Topography Mission (SRTM) to provide a view of Nyiragongo Volcano (right of center) and the city of Goma (pink area along shoreline in foreground), located in the Democratic Republic of Congo. Additionally, image data from the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) on NASA's Terra satellite supplied a partial map of the recent lava flows, shown in red. (Image courtesy of SRTM Team NASA/JPL/NIMA, Advanced Spaceborne Thermal Emission and Reflection Radiometer, and Landsat 7 Science Team) Click here for more information.

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 3 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."



MODIS acquired an image of Nyiragongo Volcano in the Democratic Republic of Congo, Africa (location shown top left, satellite image shown middle left) on January 17, 2002, less than one hour after the eruption began. The red box in the middle left image (which indicates the area enlarged at bottom left) shows an eruption plume that extended 200 kilometers west from Nyiragongo. The town of Goma is located on the edge of Lake Kivu (indicated by red arrow). The image at right shows hot spots detected by the MODVOLC Thermal Alert System during Nyiragongo's 2002 eruption. Each red 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 mission (SRTM) digital elevation, for geographic context. (All images courtesy of Rob Wright, Hawaii Institute of Geophysics and Planetology)

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
◀ Sensing Remote Volcanoes

Tracking Ash Clouds

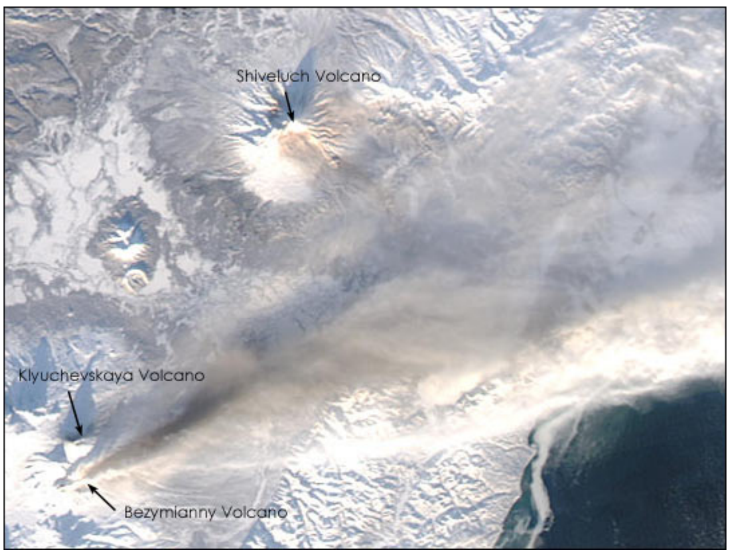
2 ◀

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."



This MODIS image shows an ash plume from the January 13, 2004, eruption of Bezymianny Volcano on Russia's Kamchatka Peninsula. According to the Alaska Volcano Observatory, the plume eventually reached a height of 3.75 miles (6 kilometers). (Image courtesy of Jeff Schmaltz, MODIS Land Rapid Response Team at NASA GSFC) Click here for more information.

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 1 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.

In 1990, slow-moving pahoehoe lava from Kilauea Volcano gradually spread through the community of Kalapana, burning homes and covering parks, roads, and gardens. (Image courtesy of USGS)

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.”

Walter’s Kalapana Store and Drive Inn was burned and covered by lava in early June 1990 as flows from Kilauea Volcano moved through the Kalapana area on the island of Hawaii. These images were taken on April 23, June 6, and June 13, 1990. (Image courtesy of USGS)

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.”

References:

Wright, R., L. Flynn, H. Garbeil, A. Harris, and E. Pilger. 2002. Automated volcanic eruption detection using MODIS. *Remote Sensing of Environment*. 82:135-155.

T.P. Miller and Casadevall, T.J. Volcanic Ash Hazards to Aviation, in *Encyclopedia of Volcanoes*, ed. H. Sigurdsson. 2000. San Diego: Academic Press.

The Pu’u ‘O’o-Kupaianaha Eruption of Kilauea Volcano, Hawai’i, 1983 to 2003. December 2002. *USGS Fact Sheet*. 144-02.

Links:

MODVOLC: Global spaceborne thermal monitoring with MODIS. Accessed July 12, 2004.

Alaska Volcano Observatory. Accessed July 12, 2004.

Cascades Volcano Observatory (USGS). Accessed July 12, 2004.

Hawaiian Volcano Observatory (USGS). Accessed July 12, 2004.

For more information:
Alaska Satellite Facility DAAC
GSFC Earth Sciences DAAC
Land Processes DAAC
Puff: A Volcanic Ash Tracking Model