

Experiment in the sky



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

Simon Carn
Michigan Technological University

by Jane Beitler

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

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

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



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

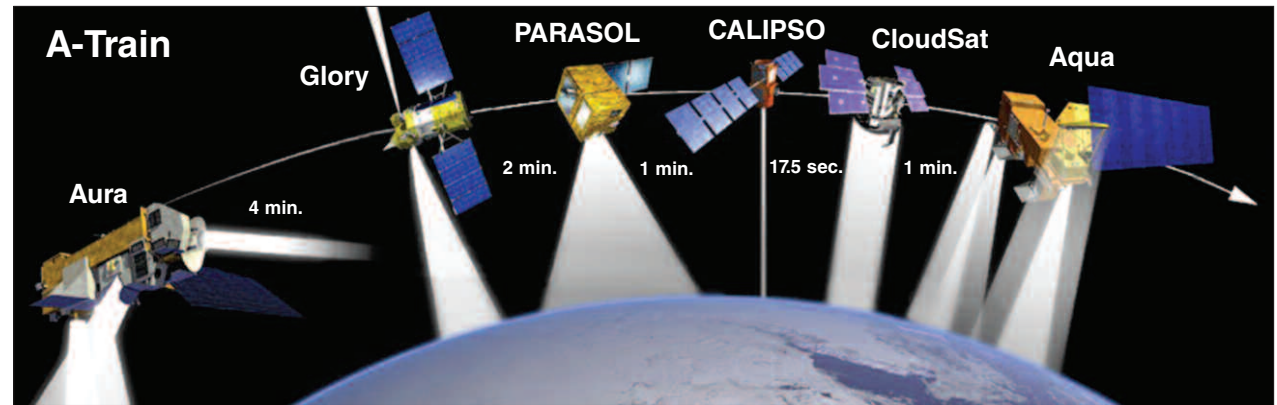
of these gases. “Volcanic eruptions are a sort of atmospheric chemistry experiment; they stick a large amount of gas into the atmosphere quickly,” he said. Scientists do not know with certainty what will result from such an experiment. They have learned that over time, the gases may transform into tiny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

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

Sleeping giants

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

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



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

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

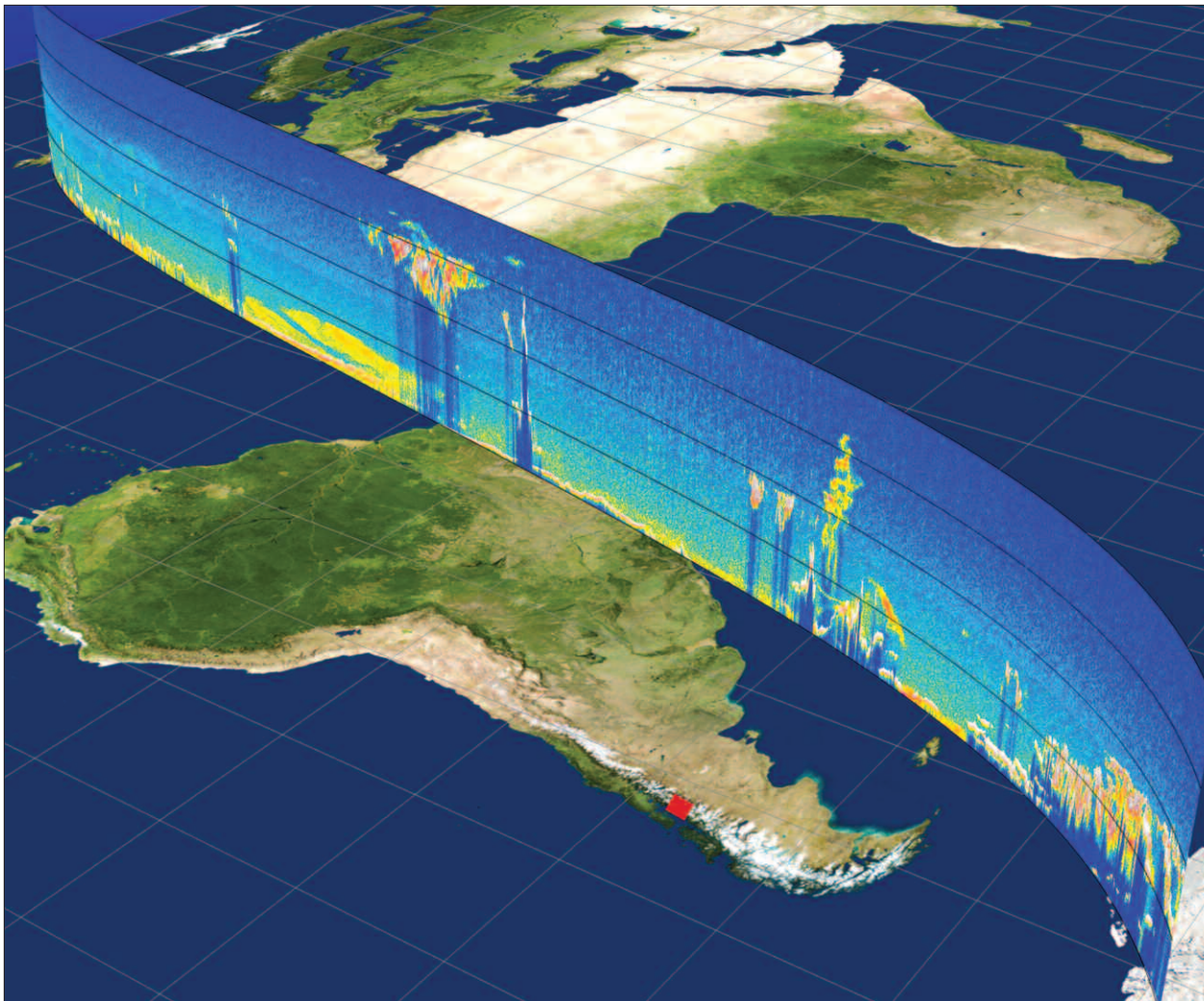
The massive eruption, about ten times larger than the 1980 eruption of Mount St. Helens in the United States, ejected about 10 cubic kilometers (2.4 cubic miles) of magma into the atmosphere. It was a case study in atmospheric effects. NASA’s Total Ozone Mapping Spectrometer (TOMS), aboard the NIMBUS-7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

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

A many-faceted problem

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

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



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

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

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

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

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

The train leaves the depot

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

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

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

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

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

Chaitén speaks

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

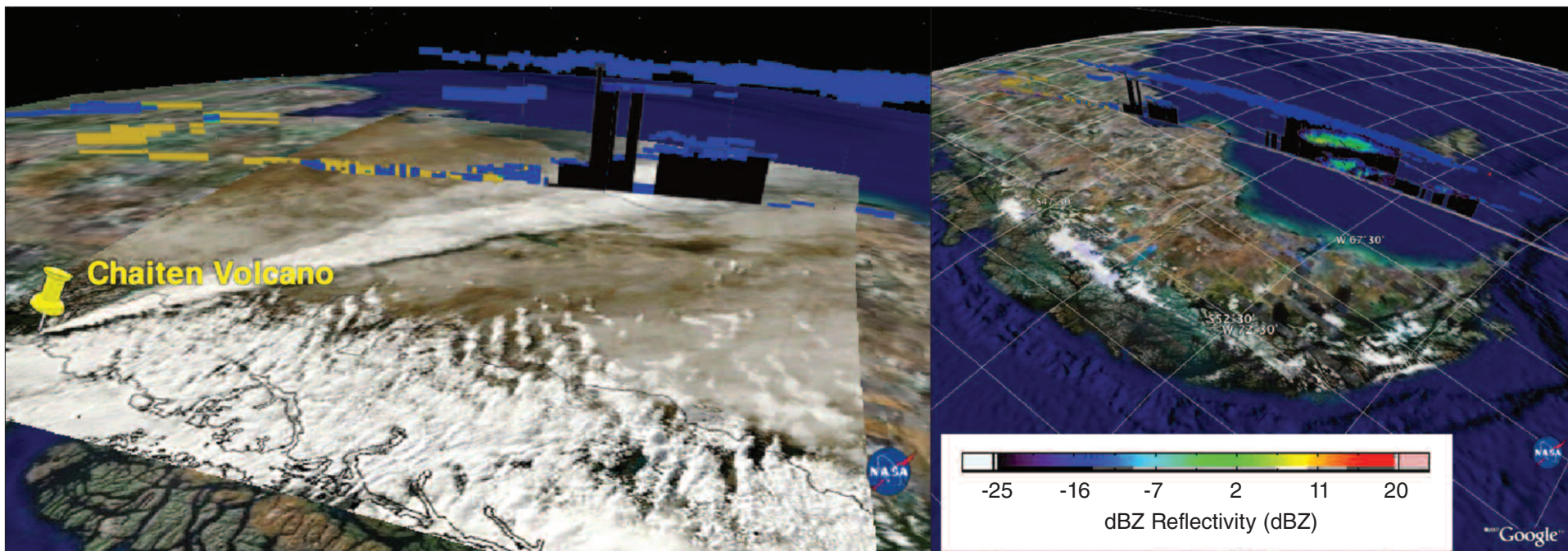


The village of Chaitén in Chile was buried in mud and ash after the unexpected eruption of Chaitén Volcano in May, 2008. All of the residents evacuated, and the village remains abandoned; authorities say it will be rebuilt six miles away. Chaitén's plume is visible in the background. (Courtesy J. R.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

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

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

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



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

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

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

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

Data for climate studies

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

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

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

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



References

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- Prata, A. J., S. A. Carn, A. Stohl, and J. Kerkmann. 2007. Long range transport and fate of a stratospheric volcanic cloud from Soufrière Hills volcano, Montserrat. *Atmospheric Chemistry and Physics* 7: 5093–5103.

For more information

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

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

About the scientists



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



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

About the remote sensing data used

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