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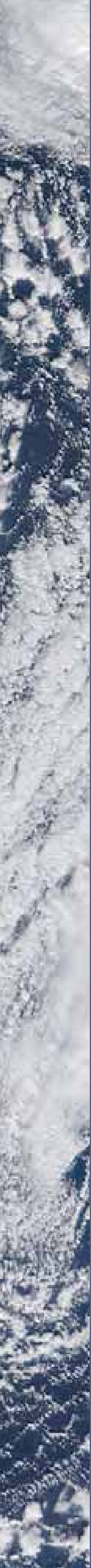
Pictured: A dense plume of volcanic ash drifts south of Eyjafjallajökull volcano (southern Iceland) in this NASA MODIS satellite image captured on April 19, 2010. Most European airspace remained closed until April 20, 2010.



# Volcanic cloud sensing

## Predicting eruptions from space

The impacts of volcanic eruptions can extend anywhere—from the immediate flanks of the volcano to regions thousands of kilometers downwind. This was brought starkly to the world's attention during the eruption of Iceland's Eyjafjallajökull volcano in April 2010. Volcanic ash clouds from Eyjafjallajökull drifted over Europe, resulting in the shutdown of highly frequented airspace over the continent and major economic impacts. The eruption highlighted the need to accurately forecast volcanic eruptions and track the resulting volcanic ash and gas clouds as they drift through the atmosphere.

Simon A. Carn's research addresses both of these problems through the use of state-of-the-art satellite remote sensing data to predict eruptions and map volcanic clouds. A major focus is on measurements of atmospheric concentrations of sulfur dioxide ($SO_2$), a gas produced in significant quantities by active volcanoes, along with water vapor and carbon dioxide ($CO_2$). Measurements of $SO_2$ emissions have been used to monitor volcanic unrest for several decades, but only recently has it become possible to detect $SO_2$ emitted by volcanoes in a pre-eruptive state from space. Carn and his collaborators lead efforts to demonstrate the value of the satellite $SO_2$ measurements and incorporate them in volcano monitoring programs. The same satellite techniques are critical for tracking volcanic eruption clouds, in order to avoid aircraft encounters with these hazardous mixtures of gas, ash particles and acid aerosol.

Measurements of volcanic $SO_2$ emissions are also needed to mitigate and understand the climate, environmental and health impacts of volcanic degassing. "After emission, $SO_2$ eventually converts to sulfuric acid aerosol that reflects sunlight and cools the underlying atmosphere, particularly if emitted into the stratosphere by a large volcanic eruption," Carn explains. "The potential climate impacts of $SO_2$ are so significant that there are proposals to artificially counteract global warming by injecting $SO_2$ into the stratosphere using rockets or balloons, so-called 'geoengineering'." Carn's research group maintains a database of $SO_2$ emissions from global volcanic activity that is widely used to model volcanic effects on climate and to monitor natural fluctuations in atmospheric $SO_2$ abundance.

Events such as the 2010 Eyjafjallajökull eruption may happen only once in a generation, but they have the potential to alter the future course of volcano science and policy. "Because of its impacts and the media spotlight on the eruption, satellite remote sensing tools used to track volcanic clouds will be subject to increased scrutiny in the future," notes Carn.

Another focus of Carn's group is validation of satellite measurements of $SO_2$. "Remote sensing algorithms ultimately depend on our understanding of the physics of the atmosphere and on several assumptions, but validation is rare—the amount of $SO_2$ present in the atmosphere estimated by remote sensing is rarely confirmed independently," he explains. After every large volcanic eruption, Carn and his collaborators gather validation datasets, such as in-situ measurements from aircraft, balloons or unmanned aerial vehicles (UAVs), or coincident ground-based measurements, for comparison with the satellite data. One successful validation was achieved after an eruption of Okmok volcano (Alaska) in July 2008, which produced a $SO_2$ cloud that drifted from Alaska over the northern USA, including Lake Superior. "Careful validation will become increasingly important as satellite measurements become incorporated in volcano monitoring programs, and more stringent post-Eyjafjallajökull requirements for volcanic cloud sensing are enforced."