Chapter 17

Volcano monitoring from space

M. Poland

17.1 Defining the problem

Unlike many natural hazards, volcanoes usually give warnings of impending eruptions that can be detected from hours to years prior to any hazardous activity (Sparks et al., 2012). The Eyjafjallajökull eruption, for example, was preceded by several discrete episodes of subsurface magma accumulation that highlighted the potential for future eruption (Gudmundsson et al., 2010). Once it begins, an eruption can last for decades, during which time the changing conditions of associated hazards, such as ash plumes and lava flows, must be continuously assessed. Unfortunately, the resources and infrastructure needed to conduct ground-based monitoring of a volcano - especially those located in remote areas of Earth that might still have the potential to impact air traffic, like in the north Pacific (Figure 17.1) are extreme, and less than 10% of the world's volcanoes are monitored in any systematic way (Bally, 2012). Space-based methods offer a means of bridging this monitoring gap.

Figure 17.1 2009 eruption of Sarychev Peak, Kuril Islands, seen from the International Space Station (courtesy NASA).

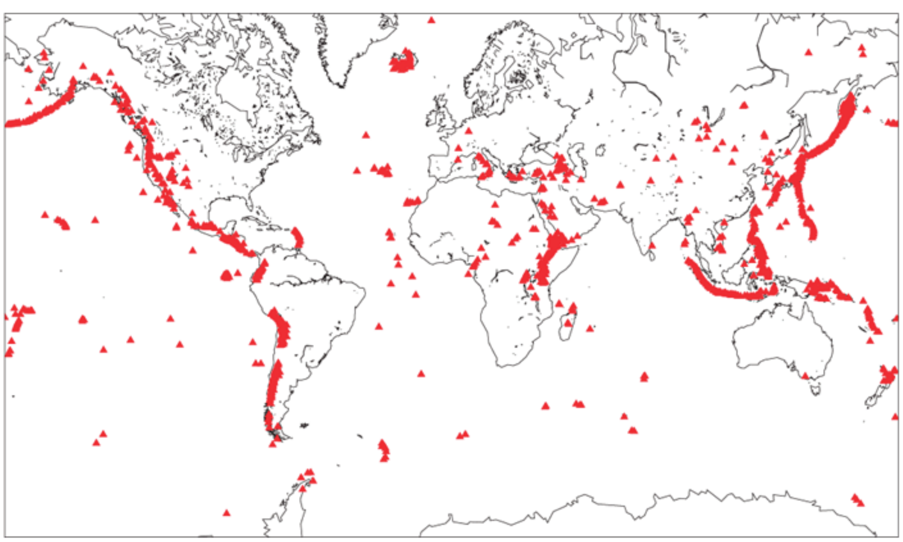

Figure 17.2 Global map of volcanoes that have erupted within the past 10,000 years (volcano locations from Siebert et al. 2010).

Poland, M. (2015) Volcano monitoring from space. In: S.C. Loughlin, R.S.J. Sparks, S.K. Brown, S.F. Jenkins & C. Vye-Brown (eds) *Global Volcanic Hazards and Risk,* Cambridge: Cambridge University Press.

17.2 Early warnings

Prior to eruption, most volcanoes provide an indication that magma is ascending towards the surface - most notably through seismicity, ground deformation, thermal anomalies and elevated gas emissions (Sparks et al., 2012). While earthquake monitoring remains rooted to the terrestrial domain, other expressions of rising magma can be detected from space. Ground deformation, for example, can be mapped by synthetic aperture radar interferometry and sometimes occurs even before earthquake swarms, providing warning of restless volcanoes that might erupt within months to years (Dzurisin, 2003). Unlike ground-based monitoring networks, satellites acquire data over broad swaths, enabling regional surveillance of volcanoes. Observations of entire volcanic arcs - for example, the Andes of South America (Pritchard & Simons, 2004) - have identified numerous volcanoes that are deforming but not erupting (Figure 17.3). Remote sensing therefore provides leverage for more time- and cost-effective deployment of ground-based resources to the volcanoes that are most likely to erupt and expose population and infrastructure to hazards.

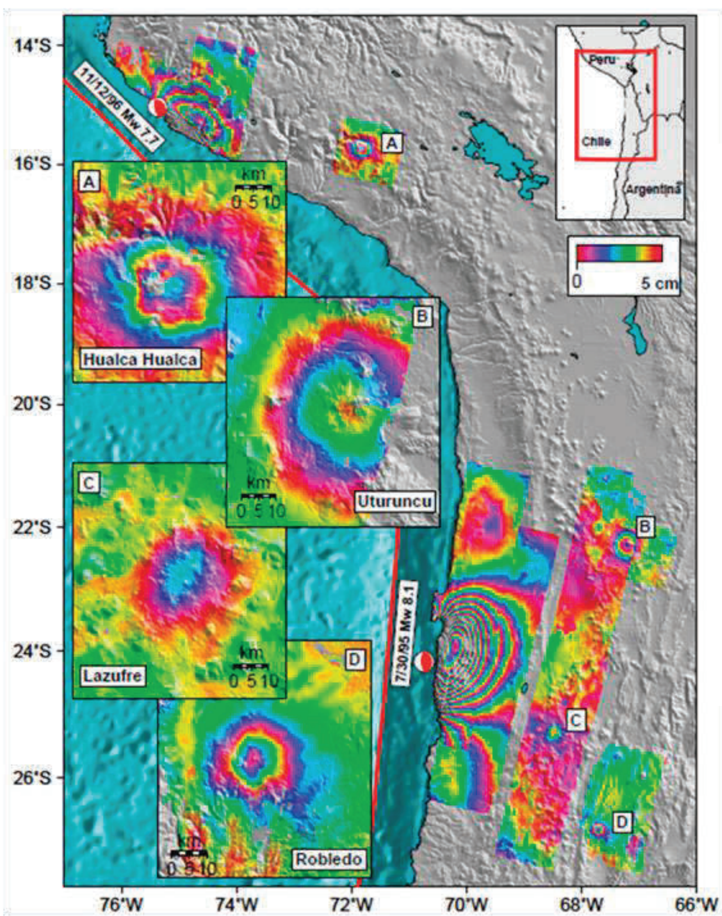

Figure 17.3 Colour contours of ground deformation draped over shaded relief from three subduction zone earthquakes along the coast and four volcanic centres in Peru, Bolivia, Argentina, and Chile. Each contour corresponds to 5 cm of deformation in the radar line-of-sight direction. Inset maps show higher-resolution interferograms at the four centres of active deformation. Reference map in upper right corner places study area in regional context. Modified from Pritchard and Simons [2004].

Remote-sensing data, primarily from meteorological satellites, also often provide the first indication of unrest or eruptive activity at a volcano. Thermal emissions are tracked by a number of satellite systems, many of which acquire images multiple times per day of the same area on the ground. Near-real-time automated analysis of thermal data is an important alerting tool for eruption onsets and is currently being applied at volcanoes around the world, especially in remote areas (Dehn et al., 2000, Wright et al., 2004). The Alaska Volcano Observatory relies on meteorological sensors for detecting thermal anomalies that can represent precursory heating or lava extrusion, ash clouds, and gas emissions across the 52 historically active volcanoes of the several-thousand-kilometre-long Aleutian volcanic arc, which, although sparsely populated, is heavily traversed by passenger and cargo aircraft (Schneider et al., 2000). Similarly, daily remote sensing of Kamchatkan and Kurile volcanoes by Russian volcanological authorities is in many cases the sole means of surveillance of dozens of volcanoes that can threaten trans-Pacific aircraft (Neal et al., 2009). At volcanoes that are not monitored by ground-based instruments, satellite data provide the best indication of eruptions that may pose hazards to air travel.

17.3 Tracking volcanic hazards

Once an eruption is in progress, timely and repeated satellite data are critical for tracking the evolution of volcanic hazards. Synthetic Aperture Radar (SAR), with meter-scale resolution and ability to “see” through clouds and ash, can detect changes on the surface that might be obscured from thermal/optical satellite data and ground observers. Near-real-time analysis of SAR imagery aided the decision to maintain evacuation zones around Merapi, Indonesia, in 2010 - a decision that likely saved several thousand lives when that volcano experienced a large eruption (Pallister et al., 2013). Tracking ash clouds is best accomplished using space-based observations (Pavolonis et al., 2013) and can be used with forecast models to warn downwind communities of impending ash fall and alert air traffic of ash location (Figure 17.4). Worldwide, Meteorological Watch Offices and Volcano Ash Advisory Centres rely on satellite data for issuing SIGMETs and Volcanic Ash Advisories, which report and forecast ash distribution. The evolution of thermal anomalies in satellite data can track lava and pyroclastic flows, and volcanic gas emissions - an under-appreciated hazard to downwind communities - can be imaged from orbit with better spatial resolution and at lower cost than from the ground (so2.gsfc.nasa.gov/), allowing for automated alerts of volcanic plumes.

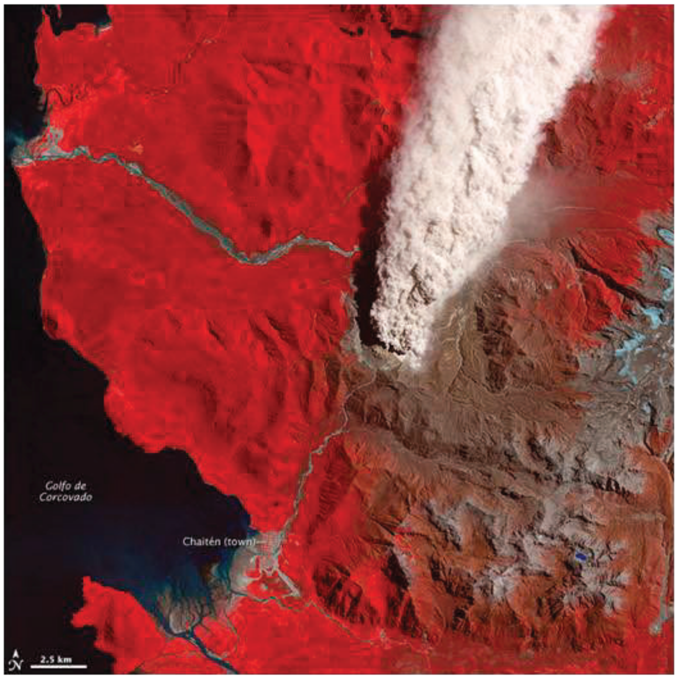

Figure 17.4 False-colour visible-infrared image acquired by the Aster satellite over Chaiten volcano, Chile, on 19 January 2009. Vegetation is red, bare or ash-covered ground is grey/brown, ash is light brown, and water is blue. Image shows a thick plume of ash and gas extending to the NNE of the volcano. Image courtesy of NASA (http://earthobservatory.nasa.gov/IOTD/view.php?id=36725).

17.4 Bridging the gap

A variety of satellite sensors have repeatedly demonstrated their ability to monitor volcanic unrest, detect eruption onsets, and track eruptive hazards; nevertheless, remote sensing is not yet a globally operational tool for volcano monitoring - some data are costly and not available in near-real time, and resources needed utilise satellite imagery are lacking in many countries. In addition, volcano-monitoring operations are rarely 24/7, so real-time alerting systems, in addition to data management and visualisation software, are required to exploit the volume of potentially available data. To bridge this monitoring, low- or no-cost data are needed with low temporal latency and adequate spatial resolution. In addition, data management systems and capacity-building must be developed to ensure broad use of those data for volcano hazard mitigation and good collaboration across international boundaries where hazards pose more than a local risk. The implementation of this vision, shared throughout the geohazards community, is underway through a number of multi-national projects dedicated to use of remote sensing data for natural hazards risk reduction, including:

- The 2012 "International Forum on Satellite EO and Geohazards," which articulated the vision for volcano monitoring from space (www.int-eo-geo-hazard-forum-esa.org/);
- The Geohazard Supersites and Natural Laboratories initiative, which aims to reduce loss of life from geological disasters through research using improved access to multi-disciplinary Earth science data (supersites.earthobservations.org/);
- The European Volcano Observatory Space Services (EVOSS), which has the goal of providing near-real-time access to gas, thermal, and deformation data from satellites at a number of volcanoes around the world (www.evoss-project.eu/);
- The Disaster Risk Management volcano pilot project of the Committee on Earth Observation Satellites (CEOS), which is designed to demonstrate how free access to a diversity of remote sensing data over volcanoes can benefit hazards mitigation efforts

https://doi.org/10.1017/CBO9781316276273.019 Published online by Cambridge University Press

Ultimately, realisation of this vision will depend on commitments from national governments and space agencies to make these data available for disaster risk reduction purposes.

References

Bally, P. 2012. Scientific and technical memorandum of the international forum on satellite EO and geohazards, 21–23 May 2012. *Santorini, Greece. doi,* 10, 5270.

Dehn, J., Dean, K. & Engle, K. 2000. Thermal monitoring of North Pacific volcanoes from space. *Geology,* 28, 755-758.

Dzurisin, D. 2003. A comprehensive approach to monitoring volcano deformation as a window on the eruption cycle. *Reviews of Geophysics,* 41.

Gudmundsson, M. T., Pedersen, R., Vogfjörd, K., Thorbjarnardóttir, B., Jakobsdóttir, S. & Roberts, M. J. 2010. Eruptions of Eyjafjallajökull Volcano, Iceland. *Eos, Transactions American Geophysical Union,* 91, 190-191.

Neal, C., Girina, O., Senyukov, S., Rybin, A., Osiensky, J., Izbekov, P. & Ferguson, G. 2009. Russian eruption warning systems for aviation. *Natural hazards,* 51, 245-262.

Pallister, J. S., Schneider, D. J., Griswold, J. P., Keeler, R. H., Burton, W. C., Noyles, C., Newhall, C. G. & Ratdomopurbo, A. 2013. Merapi 2010 eruption—Chronology and extrusion rates monitored with satellite radar and used in eruption forecasting. *Journal of Volcanology and Geothermal Research,* 261, 144-152.

Pavolonis, M. J., Heidinger, A. K. & Sieglaff, J. 2013. Automated retrievals of volcanic ash and dust cloud properties from upwelling infrared measurements. *Journal of Geophysical Research: Atmospheres,* 118, 1436-1458.

Pritchard, M. E. & Simons, M. 2004. Surveying volcanic arcs with satellite radar interferometry: The central Andes, Kamchatka, and beyond. *GSA Today,* 14, 4-11.

Schneider, D., Dean, K., Dehn, J., Miller, T. & Kirianov, V. Y. 2000. Monitoring and analyses of volcanic activity using remote sensing data at the Alaska Volcano Observatory: case study for Kamchatka, Russia, December 1997 *In:* Mouginis-Mark, P. J., Crisp, J. A. & Fink, J. H. *Remote Sensing of Active Volcanism, AGU Mongraph 116.*

Siebert, L., Simkin, T. & Kimberley, P. 2010. *Volcanoes of the World, 3rd edn,* Berkeley, University of California Press.

Sparks, R., Biggs, J. & Neuberg, J. 2012. Monitoring volcanoes. *Science,* 335, 1310-1311.

Wright, R., Flynn, L. P., Garbeil, H., Harris, A. J. & Pilger, E. 2004. MODVOLC: near-real-time thermal monitoring of global volcanism. *Journal of Volcanology and Geothermal Research,* 135, 29-49.