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Author Information

Jacob C. Yde, Center for Geomicrobiology, Aarhus University, Århus, Denmark; E-mail: yde@phys.au.dk; and Øyvind Paasche, Bjerknes Centre for Climate Research, University of Bergen, Bergen, Norway

NEWS

Eruptions of Eyjafjallajökull Volcano, Iceland

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The April 2010 eruption of Eyjafjallajökull volcano (Figure 1), located on Iceland's southern coast, created unprecedented disruptions to European air traffic during 15–20 April, costing the aviation industry an estimated $250 million per day (see the related news item in this issue). This cost brings into focus how volcanoes can affect communities thousands of miles away.

Eyjafjallajökull rises to 1666 meters above sea level and hosts agricultural land on its southern slopes, with farms located as close as 7 kilometers from the summit caldera. In the past 1500 years, Eyjafjallajökull has produced four comparatively small eruptions. The eruption previous to 2010 began in December 1821 and lasted for over a year, with intermittent explosive activity spreading a thin layer of tephra (ash and larger ejected clasts) over the surrounding region. In contrast, the explosive 2010 eruption, sourced within the ice-capped summit of the volcano, so far is larger and characterized by magma of a slightly different composition. This may suggest that deep within the volcano, the 1821 magma source is mixing with new melt, or that residual melt from past intrusive events is being pushed out by new magma.

In Iceland, volcanic eruptions occur every 3–4 years, with more than half occurring beneath glaciers. Explosive eruptions are common due to interactions between water and magma in ice-covered volcanoes, notably in the Grímsvötn and Katla volcanoes. The heat from these types of eruptions melts overlying ice, increasing the possibility of floods to inhabited areas. For Eyjafjallajökull and neighboring Katla, an automated monitoring network has been in place since 1999, and a risk assessment and an evacuation plan for nearby communities were made in 2005. These plans were put to the test during the ongoing eruption.

Monitoring Systems and Field Campaigns

To monitor volcanism in Iceland, the Icelandic Meteorological Office (IMO) operates several permanent networks (see Figure 2): an automated, 56-station seismic network; a continuous Global Positioning System (GPS) network of more than 70 stations; a network of automated hydrological stations for monitoring runoff in regions close to glaciers; and a regional network of six borehole strainmeters, which monitor deformation of the Earth's crust in their vicinity. Additionally, a weather radar at the international airport in southwestern Iceland, near Reykjavík, is used to follow the dispersal of volcanic plumes. Additional information on meteorological conditions and fallout of tephra is supplied by more than 200 weather stations. Volcanic lightning is observed via a four-station lightning location system.

Knowing that an eruption was imminent, the University of Iceland's Institute of Earth Sciences (IES) established several temporary continuously recording GPS stations and seismic stations around Eyjafjallajökull before the eruption. Once the eruption occurred, satellite imagery was used to monitor plume transport, and regular reconnaissance flights enabled direct monitoring of volcanic activity and volcano-ice interactions. A synthetic aperture radar (SAR) on board the Dash 7 aircraft of the Icelandic Coast Guard proved important for monitoring crater development and melting of the ice cap when the summit was covered in cloud because clouds are transparent to the radar. The IES is also undertaking extensive mapping of the tephra deposits from the eruption. They are also performing chemical analysis of ash and magma products as well as conducting volcanological observations of the crater.

Eruption Precursors and Earlier Flank Eruption

The 2010 Eyjafjallajökull eruption was preceded by almost 20 years of intermittent unrest. In 1994 an earthquake swarm began in the middle to upper crust, followed by a swarm at the base of the crust in 1996 and shallower swarms in 1999 and 2009–2010. Recorded by GPS and interferometric SAR (InSAR) data, the 1994 and 1999 swarms were associated with considerable crustal deformation and were interpreted as intrusions of magma sheets (sills) at 4–6 kilometers in depth.

Large temporal and spatial variations are evident in the surface deformation associated with the 2009–2010 swarm, but

Fig. 1. The Eyjafjallajökull eruption on 17 April 2010. A heavy black plume engulfs the neighboring district of Eyjafjöll.

deformation signals were of the same magnitude as previous swarms. Earthquake rates preceding the 2010 eruption were substantially larger than observed during previous episodes. Earthquakes became progressively shallower over time, reflecting the ascent of an intrusion toward the surface. Seismicity migrated east to the volcano's flank, where a fissure eruption began around 2330 UTC on 20 March. Ending on 12 April, this eruption was effusive and caused no damage.

The Summit Eruption

At 2300 UTC on 13 April the seismic system alerted IMO of increased seismicity at Eyjafjallajökull. This swarm, located at shallow depth beneath the summit caldera, lasted a few hours. Pronounced low-frequency tremor indicated that the eruption commenced around 0115 UTC. An eruption plume was first visible in the early hours of 14 April, and the first signs of glacial flooding were seen at 0650 UTC at a gauging station north of the volcano. Formation of cauldron-sized holes in the ice in the caldera and a flood path toward north were detected via the airborne SAR through the plume and the cloud covering the region during the first 3 days of the eruption.

The eruption plume reached heights of almost 10 kilometers on the first day of the eruption. Lightning in the ash cloud was first detected at 1930 UTC. Three days of sustained tephra production followed, leading to ash dispersal toward the southeast and the closure of airspace over large parts of Europe. By the fifth day of the eruption, explosive power, plume height, and ash production had decreased significantly. Between 21 April and 2 May, lava flowed northward from the crater, oozing its way down the valley glacier Gígjökull, melting ice in its path. During this period of lava progression, tremor levels amplified, despite plume heights mostly below 3 kilometers above sea level. Around 1 May, explosive activity picked up again with renewed earthquake activity, a drop in seismic tremor, increased plume height, and fallout of ash. This resurgence in activity led to further disruption to air traffic in Europe. Shock waves were heard tens of kilometers downwind from the volcano due to gas explosions in the crater.

Civil Protection Measures

People in communities around the volcano that were vulnerable to flooding received immediate orders to evacuate through an automated phone alert. This system, supervised by the local police chief, worked well: Some 800 people were evacuated before daybreak on 14 April; most were allowed to return the following day, but residents at some locations were not permitted to stay overnight. Fallout of ash in the region south of the volcano caused damage to farms, but mitigation measures such as cleaning of farmland are being implemented.

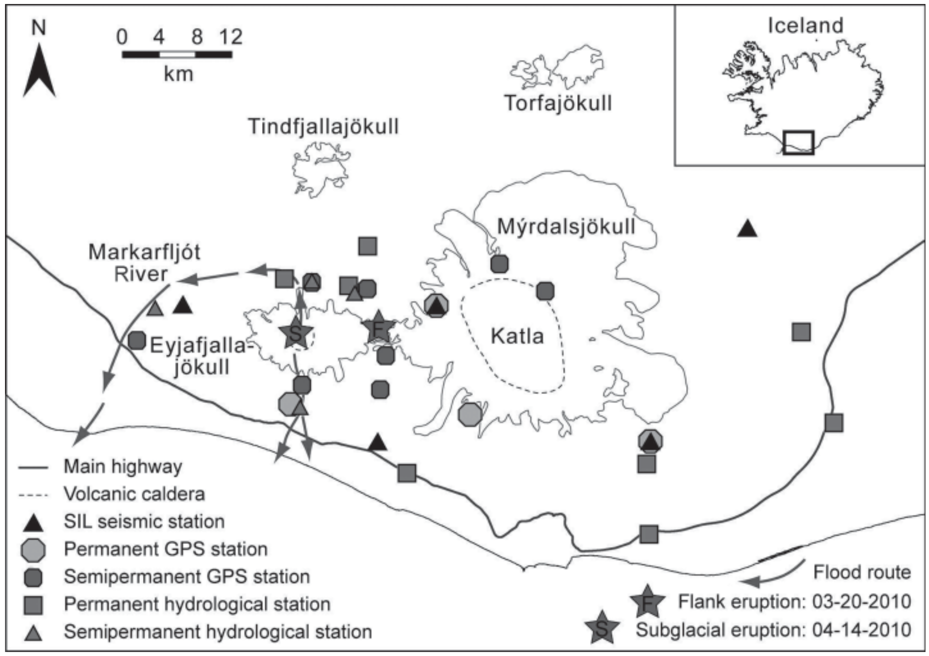

Fig. 2. Monitoring stations, including South Iceland Lowland (SIL) seismic stations and Global Positioning System (GPS) stations, around Eyjafjallajökull and Katla volcanoes. The shoreline is the thin line below the main highway; the irregular contour lines indicate the overlying ice caps.

Aviation hazards due to ash dispersal are dealt with by the IMO, which provides regular updates on volcanic activity in Iceland to the London Volcanic Ash Advisory Center (VAAC). In this instance, IMO notified London VAAC at 0523 UTC on 14 April that the eruption of Eyjafjallajökull was imminent. In turn, London VAAC issued immediate alerts to European aviation authorities and other VAAC centers. Ash dispersal simulations from London VAAC, available within hours of the eruption beginning, showed that air travel disruption over Europe was inevitable due to a strong northwesterly wind at high elevation over Iceland. Since the onset of the eruption, ash advisories have been dispatched to London VAAC every 3–6 hours.

Ongoing Research

Eyjafjallajökull continues to erupt—a rough estimate of magma erupted by early May is 0.1 cubic kilometer. A wide spectrum of activity has been observed: a well-documented intrusive event and a brief subglacial eruption, progressing to an explosive eruption amplified by the influence of melted ice, followed by mildly explosive magmatic activity and flow of lava confined by ice.

As long as the eruption continues in the summit caldera, it remains a threat to local communities and has the potential to disrupt air traffic again. The widespread disruption to air traffic caused by this volcano highlights the need for major efforts to reduce the impact of volcanic ash on air traffic, ranging from improving estimates of input of ash into the atmosphere from erupting volcanoes to construction of jet engines more resistant to ash.

Monitoring of the various types of volcanism observed at Eyjafjallajökull provides important data on a range of problems in volcano geodesy, seismology, physical volcanology, and petrology and in studies of volcanic plumes. However, analysis of these data is at a very early stage and the eruption is ongoing. Additionally, the fact that the volcano is in an easily accessible location and along high-traffic flight routes between North America and Europe allows disaster managers to analyze this eruption as a case study, from which hazard assessments and communication can be further improved.

Further information and a bibliography of scientific literature important to this eruption are available at http://www.earthice.hi.is and http://en.vedur.is.

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—Magnús T. Gudmundsson and Rikke Pedersen, Nordic Volcanological Center, Institute of Earth Sciences, University of Iceland, Reykjavík; and Kristín Vogfjörd, Bergthóra Thorbjarnardóttir, Steinunn Jakobsdóttir, and Matthew J. Roberts, Icelandic Meteorological Office, Reykjavík, Iceland