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Geodetic constraints on volcanic plume height at Grímsvötn volcano, Iceland

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In 2011 a VEI 4 explosive eruption took place at Grímsvötn volcano, Iceland. Grímsvötn is a subglacial basaltic volcano beneath the Vatnajökull ice cap. It is Iceland's most frequently erupting volcano, with recent eruptions in 1983, 1998, 2004, and 2011. The volcano has a low seismic velocity anomaly down to about 3 km depth, interpreted as a magma chamber. A continuous GPS station and a tiltmeter are located on a nunatak, Mount Grímsfjall, which protrudes from the ice at the southern rim of the caldera.

The 21-28 May 2011 eruption was Grímsvötn's largest since 1873, resulting in airspace closure in northern Europe and the cancellation of about 900 passenger flights. The eruption was preceded by gradual inflation following the 2004 eruption and progressive increase in seismicity. Kinematic 1 Hz solutions were derived for the position of the GPS station in the hours immediately before and during the 2011 eruption. The onset of deformation preceded the eruption by one hour and reached maximum of 0.57 m within 48 hours. Throughout the eruption the GPS station moved consistently in direction N38.4+/-0.5W, opposite to the direction of movements during the 2004-2011 inter eruptive phase. The deformation characteristics suggest that the signal was mostly due to pressure change in a source at 1.7 +/- 0.2 km depth.

We use the geodetic measurements to infer co-eruptive pressure change in the magma chamber using the Mogi model. The rate of pressure drop is then used to estimate the magma flow rate from the chamber. Numerous studies have shown that plume height in explosive eruptions can be related to magma discharge. Using an empirical relationship between the volcanic plume height and magma flow rate (Mastin et al., 2009) we estimate the evolution of the plume height from the geodetic data. Two weather radars monitored the height of the volcanic plume during the eruption. A strong initial plume with peaks at 20-25 km was followed by a declining, pulsating activity. The observed plume height and the geodetically inferred plume height correlate closely in the first 24 h, showing pulsating behavior with peaks exceeding 15 km height in the first 12 h. After 24 h the measured plume height drops to 10 km or lower.

The time from the initiation of the pressure drop to the onset of the eruption was about 60 min, with about 25% of the total pressure change preceding the eruption. During the eruption we find constant scaling between the geodetic station velocity and eruptive flux evaluated from plume height data. If interpreted in near-real time, these observations could greatly improve forecasting of the onset and evolution of explosive eruptions and volcanic plume height.