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The 2010 inflation and deflation sources of Eyjafjallajökull: Modelling of geodetic data from InSAR and GPS

Andrew Hooper (1), Freysteinn Sigmundsson (2), Sigrún Hreinsdóttir (2), Thóra Árnadóttir (2), David Bekaert (1), Rikke Pedersen (2), Matthew Roberts (3), Páll Einarsson (1), Benedikt Ófeigsson (1), Kurt Feigl (4), and the Eyjafjallajökull Geodetic Team

(1) Delft Institute of Earth Observation and Space Systems, Delft University of Technology, Delft, The Netherlands, (a.j.hooper@tudelft.nl), (2) Nordic Volcanological Center, Institute of Earth Sciences, University of Iceland, Reykjavik, Iceland, (3) Icelandic Meteorological Office, Reykjavik, Iceland., (4) Department of Geoscience, University of Wisconsin-Madison, Madison, Wisconsin

Volcanic activity in Iceland is usually associated with pressure changes in a single magma chamber. From time series analysis of geodetic data (InSAR and GPS) we find that this simple picture does not apply to the 2010 Eyjafjallajökull eruptions however, but a complex series of magma movements occurs involving several distinct magma bodies.

For the InSAR processing, we use TerraSAR-X data, made available by the German Space Centre (DLR). Frequent acquisitions (up to three per 11 days) before, during and after the eruptions provide an unprecedented InSAR time series of the associated deformation. We first reduce the atmospheric signal in the time series of interferograms using the correlation of the signal with topography. To account for lateral variation in water vapour distribution we estimate this relationship locally. To avoid leakage of deformation into the atmospheric estimation, we estimate the relationship at various spatial wavelengths, and only used those wavelengths not significantly contaminated by deformation.

In our modelling we combine the InSAR data with contemporaneously acquired CGPS data, and split the time series into a number of periods with differing deformation patterns. We divide potential sources into multiple rectangular elements and solve for the opening of each element for a given hydrostatic overpressure, using a boundary elements approach. We assume a density difference between the magma and surrounding rock of 250 kg/m^3 and a traction-free interface. Our imposition of hydrostatic rather than uniform overpressure means that the overpressure decreases with depth. We apply Markov chain Monte Carlo sampling to build the probability distribution of the model parameters, assuming a uniform prior probability. We find that a number of distinct sills were intruded prior to the onset of the first eruption at 4-6 km depth (~ 0.05 km^3 total volume), none of which show significant depressurisation during either subsequent eruption. This is despite the fact that a dike that reached the surface on March 20, leading to the first eruption, appears to be connected to the earlier sill intrusions. We do however find evidence for a pressure drop of a previously undetected magma body during the explosive summit eruption, equivalent to a volume decrease of ~ 0.03 km^3.

We speculate that the complex nature of the magma distribution beneath Eyjafjallajökull is due to the low frequency of eruptions, with only four occurring in the last 1100 years. In more frequently erupting volcanoes, intrusions can coalesce over time to form a larger magma body that then captures future intrusions. This has not occurred at Eyjafjallajökull, as the separate intrusions presumably soldify during long periods of inactivity.