Estimation of Volcanic Deformation Source Parameters Through Optimization of Geodetic Data at Cotopaxi Volcano, Ecuador

J. Hickey[1], J. Gottsmann[1], P. Mothes[2]

[1]University of Bristol, Bristol, UK
[2]Instituto Geofísico, Escuela Politécnica Nacional, Quito, Ecuador

Abstract

Volcanic eruptions are often preceded by periods of unrest, where the behaviour of the volcano deviates from a background level towards one of increasing concern [1]. Understanding what causes and contributes to unrest is a key challenge in volcanology today, influencing risk mitigation and hazard forecasting.

Deformation of the volcanic edifice is one such indicator of unrest owing to a migration or accumulation of pressurized magma in the subsurface below. The stress changes associated with the magmatic intrusion manifest themselves at the surface, dependent on how the strain is partitioned through the Earth's crust. Where the Earth's surface is deformed, geodetic measurements using satellite and ground-based instruments can record the movements and provide the data needed to investigate the cause.

This study focuses on a period of non-eruptive unrest at Cotopaxi Volcano in the Eastern Cordillera of the Ecuadorian Andes (Figure 1), between 2001 and 2002. Increased seismicity (another indicator of volcanic unrest) marked the start [2], and by the end there was a significant inflation of the volcanic edifice. The deformation was recorded by an electronic distance meter (EDM) network (Figure 2), which showed contraction of seven baselines measuring the straight-line distance from a point at the base of the volcano to a point on its edifice (Figure 3).

Using COMSOL Multiphysics® software we model the deformation by representing the source as a finite pressurized cavity. This approach has been benchmarked against well-established analytical codes and utilises the Solid Mechanics interface [3]. The source is embedded in a section of the Earth's crust, taking into account elastic heterogeneities in material properties and accurate topography on the surface from a satellite digital elevation model. Inclusion of an infinite element domain removes any boundary effects that would arise from representing the model domain as a single, solitary block. The Optimization Module is then used to invert for the most favourable location, geometry and over-pressure of the source to best fit the EDM deformation data within its error.

We test for the influence of three different generic source shapes: a sphere, and a prolate or

oblate spheroid. For the case of the spheroids, their eccentricity is also examined as this influences the ratio of vertical and radial deformation produced. All three source shapes converge on a location beneath the south-west of the edifice at a centroid depth of 0.5 - 2.0 km above sea level. High-eccentricity oblate spheroids generally provide the best-fit for geologically-plausible conditions (e.g. Figure 4), and this may suggest that the unrest period was triggered by the intrusion of a thin magmatic sill.

Future work will couple a heat-transfer interface to assess the importance of thermal stresses and softening of crustal properties via viscoelastic effects, as well as estimate the change in local gravity arising from a magmatic intrusion of this type.

Reference

[1] Phillipson, G., R. Sobradelo, and J. Gottsmann (2013), Global volcanic unrest in the 21st century: An analysis of the first decade, Journal of Volcanology and Geothermal Research, 264, 183–196.

[2] Molina, I., H. Kumagai, A. García-Aristizábal, M. Nakano, and P. Mothes (2008), Source process of very-long-period events accompanying long-period signals at Cotopaxi Volcano, Ecuador, Journal of Volcanology and Geothermal Research, 176(1), 119–133.

[3] Hickey, J., and J. Gottsmann (2014), Benchmarking and developing numerical finite element models of volcanic deformation, Journal of Volcanology and Geothermal Research, in press.

Figures used in the abstract

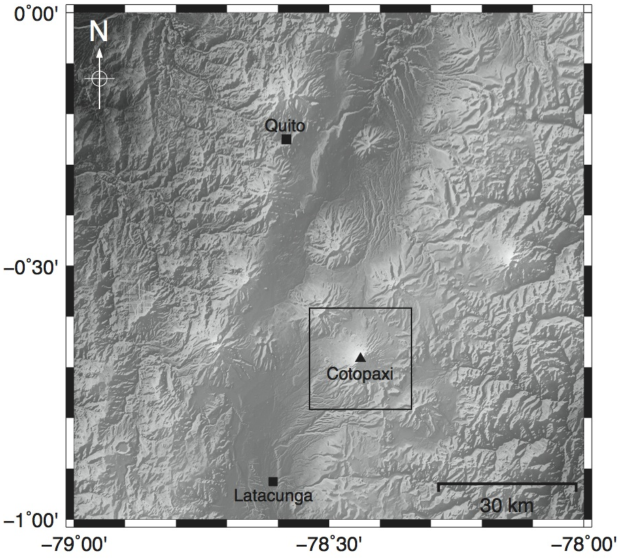

Figure 1: The area of interest in central Ecuador. The black box denotes the area shown in Figure 2.

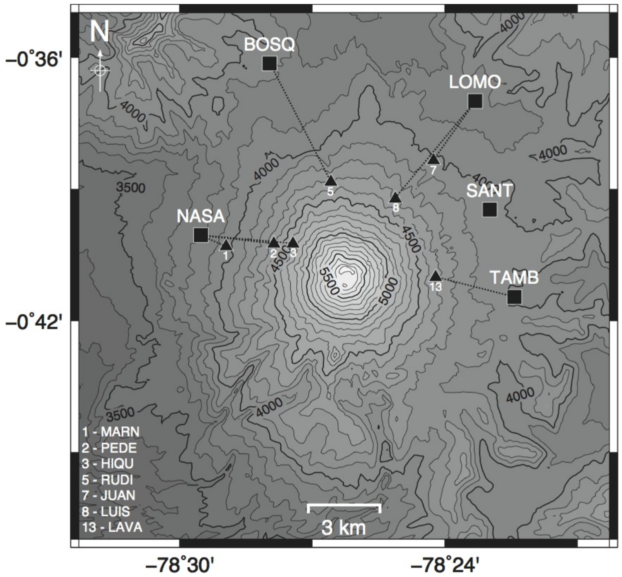

Figure 2: The EDM network around Cotopaxi Volcano. Black squares are EDM base stations, while black triangles show the locations of reflecting prisms.

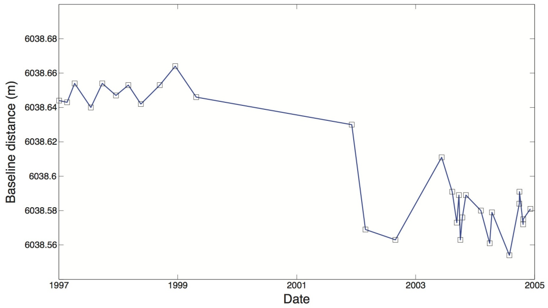

Figure 3: The change in baseline distance for the LOMO-LUIS EDM line.

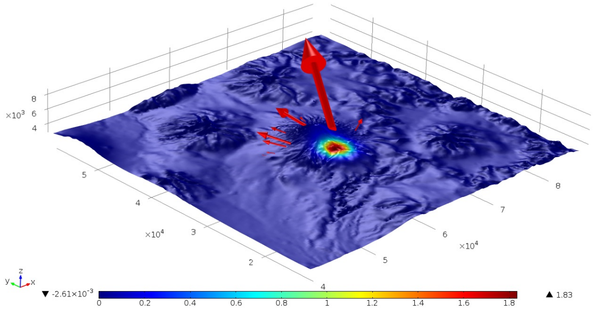

Figure 4: An example model result. The surface shows vertical displacement and the arrows are the displacement vectors at EDM base stations and prisms.