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Combined GPS, EDM and triangulation surveys of the rapid down-slope motion of the western flank of Arenal Volcano, Costa Rica

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Summary

Here we present initial conclusions of a one year-long combined geodesy campaign on Arenal Volcano, in Costa Rica (2008-2009). Our data shows evidence for an active local tectonic surrounding, and a 7cm/yr displacement field of the western flank of the volcano edifice that is in general agreement with recent INSAR studies. The study shows that a rigorous combination of simultaneous GPS, EDM (Electronic Distance Measurements) and triangulation measurements provide a time-cost effective approach to volcanic monitoring.

Introduction

Arenal volcano, in Costa Rica, is an active basaltic-andesite stratovolcano located at the southern end of the Guanacaste volcanic range. Arenal's recent persistent volcanic activity may be coming to an end but evidence for downslope motion of the western flank may indicate risk of sector collapse. During 2008 and 2009, we deployed a joint geodetic network, comprising GPS, EDM and triangulation measurements on a total of 12 benchmarks to quantify the flank instability. Nine benchmarks monitor movements of the western flank of Arenal while three external benchmarks, located away from the volcanic system, monitor local tectonic movements.

Methodology

The network can be occupied within 48 hours (2 overnights GPS). EDM and triangulation measurements are either single or reciprocal. In total, the network is made up by 35 distances, 70 angular observations and 32 GPS measurements. Within this framework the network is over-determinate and thus reliable.

4 campaigns have been carried out over the observation period from March 2008 to February 2009 (Δt 11 months) followed by a adjustment of the combined network using the following software:

- GAMIT to compute the GPS baselines
- TRINET+ to adjust all the geodetic measurements
- GLOBK to provide a Kalmann filter on the four campaigns.

The observation and the post processing achieve high precision and high accuracy for all campaign despite short field campaigns.

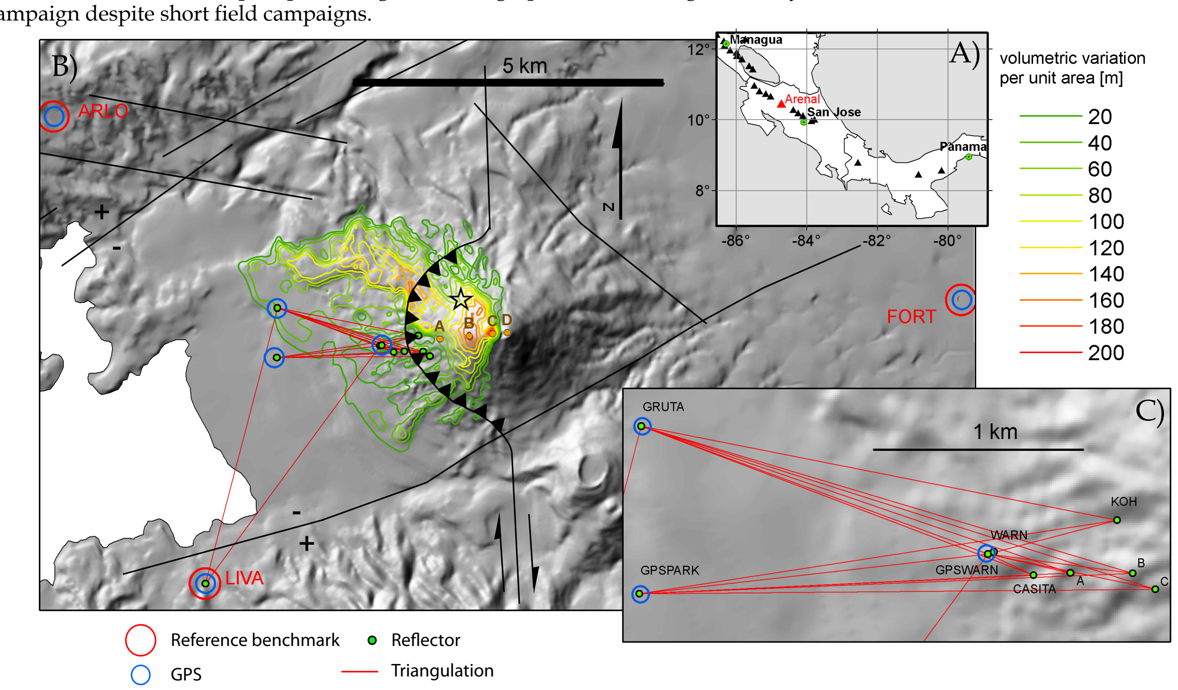


Figure 1. A) map of Central America, green dots are capital cities of the country, black and red triangles are the volcanoes.

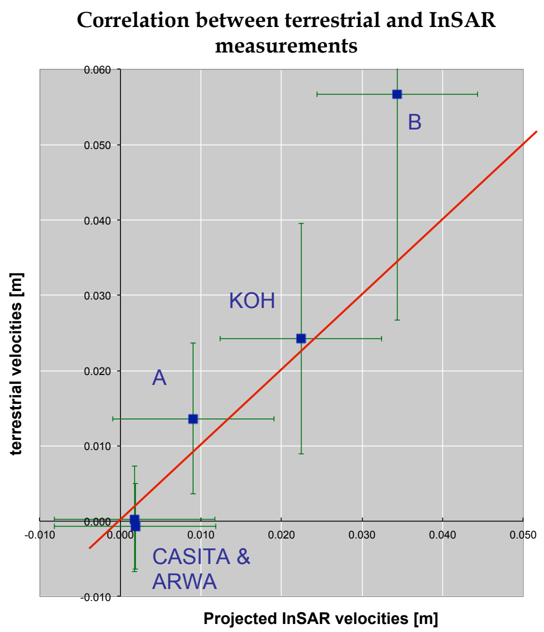
B) The red circles are the reference points. The red lines are the terrestrial relations (directions o horizontal angles, vertical angles, EDM (Electronic Distance Measurements)). The blue circles show the GNSS surveyed benchmarks. The iso-line are the lava thickness. The brown dots are the craters of the volcano. The black lines show the tectonic settings.

C) Close-up view of the internal geodetic network and the terrestrial measurements carried out.

INSAR

Interferometric Synthetic Aperture Radar is a technique which can provide very precise yet only one-dimensional displacements. For the case of the Arenal, InSAR: incidence angle of 39° and azimuth of 188°, InSAR observations may result in poor resolution of ground motion perpendicular to the LOS. Figure 3 shows that neither observed North-ward nor East-ward displacements of the slope and adjacent areas are resolvable by InSAR data.

In order to directly relate space borne with ground based geodetic observations, we have projected resulting vectors using their scalar product. The difference between them are within 2 sigma, see graph below, C benchmark is not on the graph because it is out of the InSAR coherence.



Results

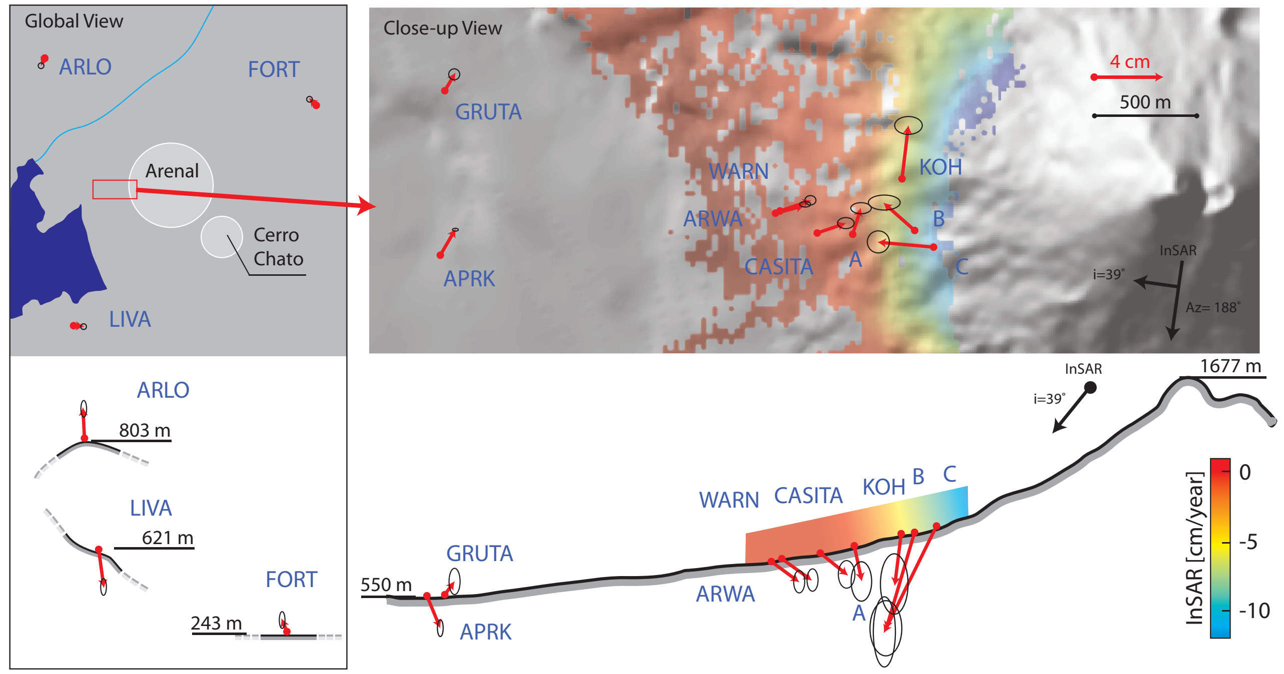


Figure 3: Calculated velocities of benchmarks (red arrows): plan view (top) vertical profile (bottom). 95% confidences uncertainties on vectors are shown by the black ellipses..

- Downward motion the flank of 7cm/yr
- Northward motion
- Relative velocities between ARLO and LIVA

Technical results

The strength of this methodology is in the fact that the network can be occupied and post-processed sinificantly faster than if the techniques were applied separately. The global overabundance equation [Hofmann-Wellenhof et al.(2001)] give: if this network had to be surveyed using a single geodetic technique would require much more time or even would not be possible.

By efficiently combining geodetic techniques according to their individual strengths, it allows to: perform a faster data acquisition (more cost-effective surveying) and provides results free of single methodology correlated errors.

Volcano dynamic

The vertical differential displacements between the three external benchmarks (FORT, LIVA and ARLO) suggest a normal fault between ARLO and LIVA. Benchmark instabilities can not be dismissed, however neotectonic studies corroborate the presence of an active fault in the North of the Arenal graben.

In agreement with a quantitative comparison with existing InSAR, our results show a downward displacement on the western flank. However, in this full 3D survey, we observe that these displacements shift to a northern and even north-eastern direction at the foot of the volcano. This suggests that if a sector collapse is underway it must have a north-west direction. Our favoured preliminary explanation is that the deformation is caused by the weight of the recent lava field which is shown in the Figure 1.

References:

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