UNIVERSIDAD DE CONCEPCIÓN
DEPARTAMENTO DE CIENCIAS DE LA TIERRA
10° CONGRESO GEOLÓGICO CHILENO 2003

COMBINATION OF SATELLITES AND GROUND-BASED MONITORING: APPLICATION TO LASCAR VOLCANO

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INTRODUCTION

Andesitic volcanoes internal dynamics is not yet fully understood. Recent models have been proposed in order to explain dome-growth like volcanoes evolution (Fink and Griffiths, 1998; Melnick and Sparks, 1999; Massol et al., 2001; Barmin et al., 2002), but direct observations that could test and validate these models are still very few. Among many physical aspects of internal acid volcano dynamics, ground deformation is one of major interest. A new magmatic pulse in closed systems generally produces edifice measurable deformation on surface and such signal can help to constrain the location, volume and shape of this pulse (Dvorak and Dzurisin, 1997; Voight et al., 1999; Beauducel et al., 2000). Deformation studies lead to new knowledge in volcanoes internal dynamics and better surveying. However, in open systems there is no such clear relationship between ground deformation style and edifice dynamics (Sparks, 1997). In order to understand this relationship a number of parameters should be measured to first clarify uprising magma conditions and then relate this internal flow behavior to ground-deformation styles. Surface temperatures at the vent, the presence or lack of dome and fumarolic activity, have straightforward implications in dynamical models (Massol et al., 2001; Barmin et al., 2002). For both of these aspects, satellite imagery has proven to be an effective solution to obtain quantified spatial and temporal information regarding deformation and thermal activity in remote areas.

SATELLITE MONITORING

Synthetic Aperture Radar Interferometry (InSAR) has been shown to be a useful technique for measuring ground deformations related with volcanic activity (Massonnet et al., 1995; Sigmundsson et al., 1999; Nishimura et al., 2001; Amelung et al., 2002). Nevertheless, explosive andesitic volcanoes appeared to be less suited for interferometry studies due to specific geometry, environmental conditions, and images availability (Zebker et al., 2000). As a matter of fact, very few studies have been conducted on stratovolcanoes even though significant topographic changes are likely to occur at various scales (lava dome collapse, flank destabilization, etc.). Moreover, the rough field conditions (elevation, access conditions) such as observed on Andean volcanoes, do not allow to properly perform ground monitoring tasks and precise geodetic observations are often rare or inadequate to improve our knowledge of ground deformation processes.

The use of Satellite thermal infrared images provided precious information regarding hot anomalies, lava flows evolution or extrusion rates (Bonneville and Gouze, 1992; Francis and Rothery, 1987; Dennis et al., 1998). In particular, data relating to thermal conditions at the vent can reveal the presence or lack of dome and fumarolic activity, as well as the size, heat flux and mass flux of the feature (Oppenheimer et al., 1993; Harris et al., 2003).

APPLICATION TO LASCAR (23°22'S, 67°44'W)

Lascar is an andesitic to dacitic stratovolcano and is one of the most active volcanoes in the Central Andes (Gardeweg et al., 1998). Its recent activity is characterized by repetitive dome growth and subsidence (4 cycles between 1984 to 1993) accompanied by vigorous degassing and explosive eruptions of various magnitude (Matthews et al., 1997). In April 1993 the largest historical eruption of Lascar produced ash column up to 25 km altitude. Due to its recent intense activity and favorable conditions for SAR imaging, this volcano is a suitable target for testing satellites complement ground-based monitoring methods (Pavez et al., 2002). Satellite data (InSAR, Thermal) acquired within the recent activity (1993-2000) have been analyzed to better understand internal processes. Concurrently, ground based field surveys including GPS, gravity and seismology have been carried out in 2002-2003 to better characterize the internal structure and dynamics.

We used in our study a time-series made of 14 SAR images, among which 9 were acquired by European Remote Sensing Satellites (ERS) and 5 acquired by Japanese Earth Resources Satellite (JERS). All these data correspond to descending orbits, and enabled us to image Lascar volcanic complex between July 1993 and October 2000. The differential interferograms were computed by the two-pass method using DIAPASON software developped by CNES (CNES, 1996) and the precise ERS orbits data produced by Delft Institute for Earth-Oriented Space Research (DEOS).
We processed our InSAR data in two steps. In order to image any large wavelength ground motion, we removed topographic contribution from our interferograms using a Digital Elevation Model (DEM) computed from 1:50.000 scale digitized IGM (Chile) maps. In a second step, we were looking for more subtle signatures at smaller spatial scale, so that we used an improved DEM to remove topographic fringe pattern from interferograms (Remy et al., 2003). This DEM was computed at IGN (France) using SAF'98 aerial photographs (1:50.000 scale), constrained by kinematic differential GPS ground control points (Fig.1). These latter were acquired during our fieldwork in February 2002.

We analyzed two scenes acquired by Landsat 7's Enhanced Thematic Mapper (ETM+), on May 16, 1999, and March 31, 2000, which were cloud free. Thermal analysis was implemented using a new approach described extensively elsewhere (Harris et al., 2003).

MAIN RESULTS

The successful InSAR processing on the archived ERS-2 C-band, JERS X-band data with intervals up to five years indicates that the selected site is suitable for this remote sensing technique. Interferometric analysis did not revealed any large wavelength ground deformation associated to recent volcanic activity (1993-2000). These results are coherent with those published recently (Prittchard and Simons, 2002). However during this period Lascar had at least three eruptions (December 1993, July 1995, July 2000) with non-negligible magmatic volumes involved (10^6-10^7 m^3) that should have deformed its flanks in a commonly used simple Mogi model (Pavez et al., 2003a). On another hand, the combination of precise DEM with InSAR data enabled us to image small spatial scale ground deformation. This high-resolution imaging clearly detected a small wavelength conduit-related deformation over the crater area associated to the 1995 eruption (Fig.2), whereas snow cover on upper parts of Lascar flanks inhibited coherency for July 2000 eruption (Pavez et al., 2003a; Remy et al., 2003). This result can be interpreted as a local (400x600 m^2) post-eruptive deflation up to 1.5 cm.

Thermal remote sensing analysis using Landsat 7 Enhanced Thematic mapper (ETM+) revealed an increase in temperature of a thermal feature nested within Lascars summit crater without an increase in feature area during 1999 - 2000. This would be consistent with an increase fumarole temperature rather than extrusion of new lava. This, in turn, squares with an increase in the level of the magma free surface within the conduit during the injection phase of the cycle (Pavez et al., 2003b). Additional thermal observations based on smaller spatial resolution satellites (GOES, ATSR) suggest that the size of Lascar thermal anomaly didn’t change substantially since 1993, however strong radiance variations were observed during periods close to eruptions, as it was described for older cycles (Pavez et al., 2003b).

CONCLUSION

Our InSAR results during July 1993 to October 2000 revealed no large wavelength ground deformations at Lascar volcano. Our high-resolution InSAR mapping allowed us to observe near-field deformations of limited extensions. Landsat 7 observations between 1999 and 2000 suggested that Lascar thermal anomaly seems to be related to fumarolic degassing, with increases in temperature probably due to a more important gas flux.

These results tend to confirm recent dynamical models proposed for such andesitic volcanoes. On another hand, they enhance the potentialities to combine satellite and ground observations to better detect and measure changes in the state of andesitic volcanoes as those related with degassing or lava dome extrusion/collapse processes.

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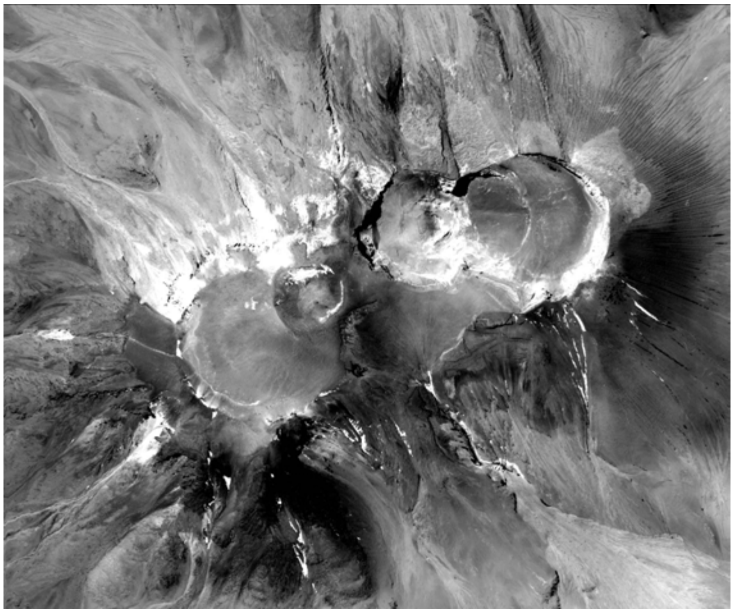

Figure 1. Aerial photography of active area of Lascar orthorectified using the precise DEM and GPS data. Arcuate fracture located along the older crater of the active crater is clearly visible in this photography.

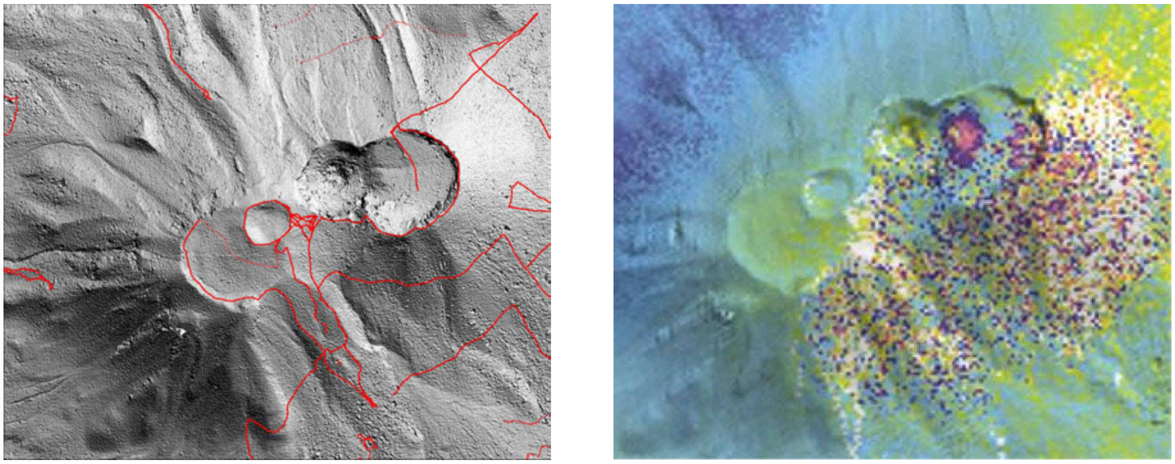

Figure 2.1 (left) : Digital photogrammetic D.E.M produced in collaboration with Institut Géographique National (France) and compiled based on 1:50.000 scale aerial imageries and constrained by differential GPS data. The kinematic GPS profiles appears in red dot. **Figure 2.2 (right) :** A small scale conduit related deformation over the older crater revealed by interferometry data. The phase signal, which is correlated with the arcuate fracture, corresponds to a variation of about 0.6 fringe occurred between July and September, 1995. This change in phase can be produced by a sight of the satellite and might result from a local subsidence.