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Application of INSAR interferometry and geodetic surveys for monitoring Andean volcanic activity : First results from ASAR-ENVISAT data

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INTRODUCTION

Within the last few years, several SAR interferometry studies mostly based on ERS-1/ERS-2 radar data have been conducted to monitor the volcanic deformations along the South American volcanic arc. They allowed a first evaluation of the potentialities of INSAR imaging in the northern, central and southern volcanic zones (respectively NVZ, CVZ and SVZ) as well as the first quantitative satellite measurements of volcanic unrest since the initial launch of ERS-1 satellite (1992) to nowdays. In their recent systematic large scale satellite SAR interferometry survey of CVZ and SVZ, Pritchard and Simons (2004) provided the first evidences of broad (tens of km wide) roughly axisymetric deformation signals over few Andean volcanic centers (uplift or subsidence rates of about 1 to 2 cm / year). They have been interpreted as volume changes in magmatic reservoirs at intermediate crustal depths between 5 to 17 km, providing new constrains on the deformation sources during volcanic unrest. Singularly, these deformation signals have been detected on centers which were not currently classified as potentially active whereas other edifices which have experienced eruptive activities during the period covered by the satellite observations, did not reveal any large scale deformations. Other SAR interferometry studies were also carried out in the NCZ and CVZ with the aim to monitor the most active volcanoes or to study current magmatic reactivations occurred during this last decade as for instance Guagua Pichincha, Cotopaxi (Ecuador), Sabancaya, Ubinas, Misti (Peru), Lascar (Chile) (Mothes et al, 2000 ; Bonvalot et al., 2002; Froger et al., 2004). In some cases, ERS-1/ERS-2 data could have been advantageously combined on these edifices with complementary geodetic observations provided by existing or new geodetic networks (first set up of GPS networks) or with high resolution Digital Elevation Models. In one hand, these studies confirmed that the recent eruptive activities did not produce detectable large scale ground deformations. In the other hand, they also provided the first measurements of small scale conduit-related ground deformations confined within summital craters areas as observed for instance during magmatic reactivation at Guagua Pinchincha, Ecuador (Mothes et al, 2000 ; Bonvalot et al., 2002) or at Lascar, Chile (Remy et al., 2003 ; Pavez et al., 2004). These previous works have clearly enhanced the interest of SAR interferometry to characterize deformation styles on a large variety of volcanic edifices in complement to existing monitoring networks or also as a unique tool for measuring ground deformations in remote or dangerous areas. New additional observations (both satellite and ground-based geodetic data) would be now required to better constrain the source model parameters and predict the internal dynamics producing the ground deformations on such volcanoes.

PROPOSED RESEARCH OBJECTIVES AND STRATEGIES

In the frame of collaborative research projects with several South American research institutions involved in the volcano monitoring, we started new satellite data collection of ASAR-ENVISAT radar data for systematic surveying of the most active volcanic centers where ground deformation signals have been clearly evidenced or are highly suspected (figure 1).

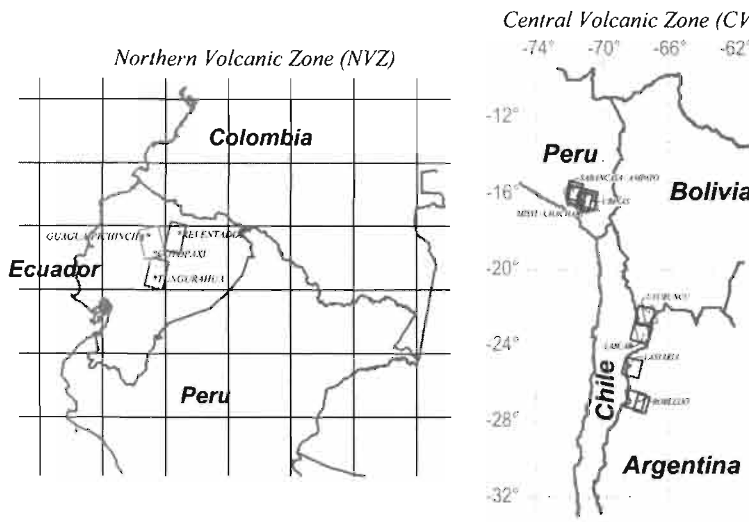


Figure 1 : Location of active volcanoes in NVZ and CVZ selected for repeated ASAR satellite surveying

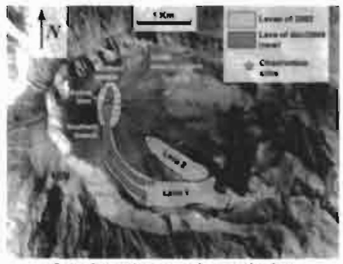
Thanks to the availability of the SRTM elevation data elsewhere for retrieving the topographic contribution in the interferograms and to the possible combination of new satellite data products (i.e. ASAR, MERIS, MODIS), we can now expect to produce high resolution ground deformation maps derived from satellite radar data for these setected targets. The new acquisition modes of ASAR radar data (ascending, descending, variable swaths) offer new data combination that can significantly improve the knowledge of the 3D surface motions (Froger et al., 2004). Along with ASAR data, satellite measurements of precipitable water vapor in the atmosphere (MODIS Moderate Resolution Imaging Spectroradiometer data) are also processed to produce interferograms free of tropospheric effects. Complementary geodetic surveys (precise GPS and Absolute Gravity) as well as geological field observations are planed to provide ground validations to satellite measurements and to estimate possible internal mass or density changes associated with surface topographic changes.

PRELIMINARY RESULTS

We present here the current status of this on-going project in light of the first results already obtained on various volcanoes. Clear fringe patterns corresponding to ground deformations related to present-day volcanic or tectonic activity have been detected from the analysis of a first set of about 100 ASAR radar images. Examples of such regional or local deformation signals, related to deep or superficial sources are discussed below. Implications of these preliminary results to the understanding of volcanological processes and to the improvement of monitoring strategies at active Andean volcanoes will be discussed.

<u>Evidence of active volcanic deformations : Reventador (Ecuador), Lastarria-Cordon del Azufre (Chile)</u>

Figure 2a : Recent lava flows and ASAR interferogram of Reventador (Ecuador)



(from http://www.volcano.si.edu)

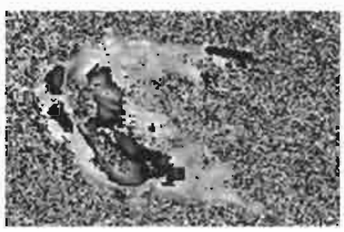
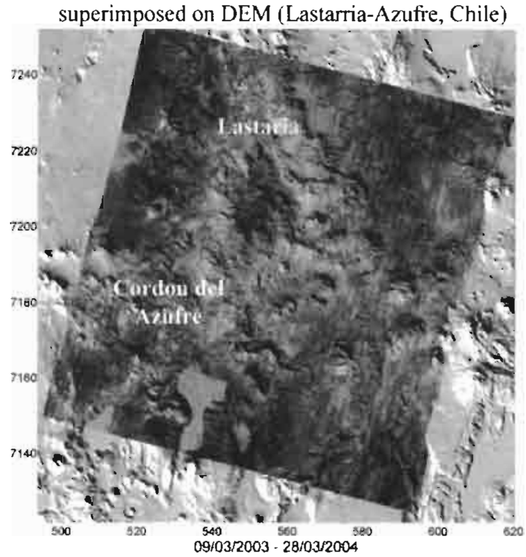


Figure 2b : ASAR interferogram superimposed on DEM (Lastarria-Azufre, Chile)



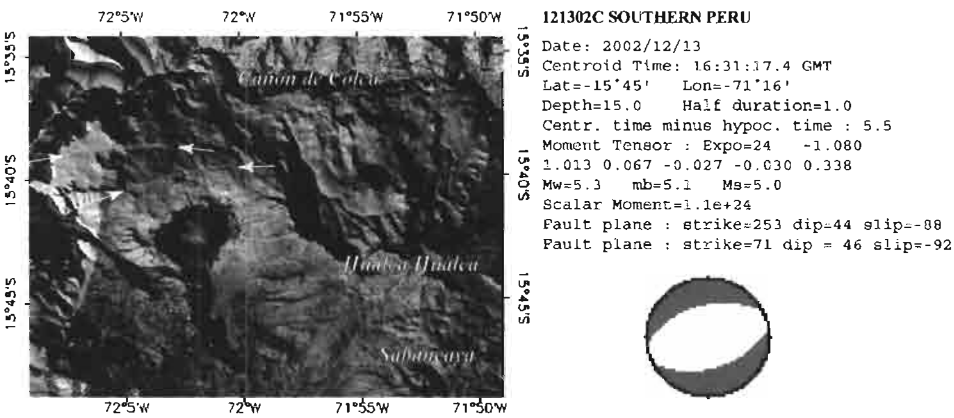
Ground deformations have been detected within the active caldera of Reventador volcano (Ecuador) during the last eruptive sequence (see on figure 2a interferogram computed for period 12/2004-01/2005). Distinct phase signals (up to 1-2 fringes) are evidenced over and around the central active cone. They are attributed to active vent deformation and to subsidence process consequently to lava flows emmited within 2002-2004 period.

Present-day active ground deformations have been also detected at large scale on the Azufre-Lastaria area (Chile) indicating that deformation processes identified during 1996-2000 by Pritchard and Simmons (2004) from ERS data are still active. The phase signal visible on ASAR interferogram (03/2003-03/2004) drapped on the DEM (figure 2b) is roughly elliptical with a 45 km NNE-SSW major axis with an amplitude increase as a function of time compatible with a ground uplift in the line of sight of the satellite. The ASAR time series (up to 385 days) indicate a deformation rate of about 2.5 cm per year, significantly higher than the value previously estimated for the 1996-2000 period and migth confirm the hypothesis of a non uniform deformation process.

<u>Evidence of active extensional tectonic displacement NW of Hualca Hualca volcanic complex (Peru)</u>

The ASAR interferogram (12/2002-09/2003) presented on figure 3 shows a subsiding area to the north west of the Hualca Hualca volcanic complex (south of the Colca Valley, Peru). The affected area is 13 km (EW) by 7 km (NS), with a deformation rate of about 3 cm per year. No evidence of recent volcanic activity, like fresh lava flows, fumaroles or hot springs can be found in the field, suggesting that the origin of the subsidence is not volcanic. As revealed by the shaded DEM, the subsiding area is clearly limited to the north by a topographical scarp (white arrows). We identified this scarp, in the field, as a 10 km long, south dipping, normal fault. A second fault, also normal and south dipping, is visible 3 km to the north of the first one (white arrows). These observations are in favour of a tectonic origin for the subsidence. The tectonic origin is also supported by a 5.3 earthquake, occurred in the area the 12 of December 2002, whose retrieved source mechanism is compatible both with the faults orientation and with an extensional displacement. These interferometric data provide here a clear localisation of an active extensional displacement in the Central Andean Cordillera, principally known to be a place of intensive compressive deformation.

Figure 3 : ASAR interferogram NW of Hualca Hualca volcanic complex (Peru)
and source parameters for Mw 5.3 earthquake (13/12/2002)



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