MONITORING ACTIVES VOLCANOES BY USING OF ENVISAT AND ERS DATA: FIRST RESULTS OF THE EURORISK-PREVIEW PROJECT

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ABSTRACT

In the framework of the Eurorisk-Preview project, funded by the European Union, a task is dedicated to the assessment, prevention and management of volcanic risk. We are developing a multidisciplinary approach, integrating the geophysical prospecting at local scale and large scale remote sensing data. To achieve this task, two volcanic test sites have been identified: Mt. Etna, in Sicily (Italy), and Tenerife, in Canary Islands (Spain). We investigate the surface deformation and the volcanic emission in the atmosphere by using SAR series and multispectral data, requested in the ESA Category 1 (n. 3560). For Mt. Etna data from historical to recent eruptions (1992 – 2006) has been analysed while for Tenerife archived SAR data from 1992 to 2005 has been analysed, individuating anomaly ground deformations in Pico de Teide and surrounding areas as suggested by GPS campaigns.

1. INTRODUCTION

The European Union EURORISK-PREVIEW project for the earthquakes and volcanoes platform is addressed to the European Civil Protections and proposes to develop, at the European scale, new information services to support the management of risks, of significant added value, making the best use of the most advanced research and technology outcomes and validated under pre-operational conditions. In order to study the ground deformation two volcanological test site has been chosen: Mt. Etna in Sicily which is the most active volcano in Europe with frequent eruptions and Tenerife in Canary Islands that is potentially dangerous due to its explosive characteristics and the high density population of the islands.

The Canarian archipelago, of which Tenerife is the largest island, is the one the world's major oceanic volcanic group. Along with the neighbouring island complexes of Madeira and Cape Verde, the Canaries occupy singular geodynamic position, distant from any plate margin but in a zone of transition from oceanic to continental crust. Teide (28.3N, 16.6W) is the third largest volcano on Earth. It is a shield volcano with an elevation at the summit of 3715 m a.s.l.. The age of the main subaerial shield phase for Tenerife is about 5 million years. The Las Cañadas depression is formed by a combination of explosive emptying of a high-level magma chamber and collapse and lateral movement of the summit. The most recent eruption was on the northwest flank of the volcano in 1909.

In the last 20 years seismicity in the Canary Islands was concentrated in a seismic zone located between the island of Tenerife and Gran Canaria, and where a magnitude 5.2 earthquake shook the area in 1989. Almendros et al. [1] pointed out that an horizontal compressional stress regime in NW-SE direction is present in the region, which is compatible with the tectonics in the northwestern part of the African continent. In Tenerife anomalous seismicity has been recorded since 2001 and more patently marked up to April 2004, when the first seismic swarm has been indicated a possible magma movement at depth.

A series of GPS campaigns observation has been done and a deformation in several areas in the island has been detected, sometime with changes from subsidence to elevation or vice versa [2], [3]. Simultaneous small displacements, including slow temporal evolution and fast short period variations, were detected with the ITER Permanent GPS network in Tenerife [4], [5], [6], which look to be connected with the seismic activity.

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Mt. Etna, in Sicily, is a large strato-volcano producing alkaline and basaltic lava during summit and flank eruptions. Etna is one of the world's most actively degassing volcanoes; an important feature of its activity is the continuous and abundant degassing from the summit craters. This degassing process produces a plume rich in gases, ash and aerosols. In the last eruption (2002 - 2003) a large amount of gas and particulates such as ash and aerosols have been emitted in troposphere producing high risk for aviation safety in the central Mediterranean area combined with risk for population health and for building security. Deformations characterize the dynamics of this volcano both before and during the eruptions. For example, the flank eruptions occurred on Mt. Etna during the last years (2001, 2002-03 and 2004) were preceded and/or produced deformation up to 1.5 m even at distance of 10 km from active vents [7]. The complex monitoring system implemented during the last decades, which include terrestrial and spatial geodetic techniques, provide fundamental data to asses the geometric and dynamic characteristic of the volcano plumbing system and structural framework and to forecast a few recent volcanic events.

In order to detect and measure structure deformation the SAR Interferometry (DIFSAR) remote sensing technique has been applied without any impact on the environment of the investigated areas. In particular, DIFSAR time series analysis has been reconstruct applying the procedure proposed by Berardino et al. [8], to reconstruct the temporal evolution of surface deformations. A this purpose ERS and ENVISAT data have been analyzed at Mt. Etna and Tenerife and combined with the existing and available ground data (e.g., GPS, micro-gravity) for a preliminary interpretation.

2. THE SMALL BASELINE APPROACH

Surface displacements are investigated by generating differential SAR interferograms as well as deformation time series, the latter obtained by applying the Small BAseline Subset (SBAS) technique [8]. The SBAS technique relies on the use of multiple small baseline acquisition subsets via an easy and effective combination of all the available interferograms. This combination is based on a minimum norm criterion of the velocity deformation, easily achieved via the application of the Singular Value Decomposition (SVD) method. This technique satisfies two key requirements: to increase the "temporal sampling rate" by using all the acquisitions included in the different small baseline subsets and to preserve the capabilities of the system to provide spatially dense deformation maps, which is a key issue of conventional DIFSAR interferometry. Clearly, the latter requirement is related to the use of small baseline interferograms, which limit the baseline decorrelation phenomena.
The proposed combination technique relies on the use of unwrapped interferograms, with the unwrapping operation based on the minimum cost flow algorithm, integrated with a region growing procedure to improve the performances in areas with low SNR. Moreover, in spite of the limited influence of possible topographic artifacts in the used DEM (due to the baseline limitation) an estimate of the topography errors is also included in order to increase the algorithm robustness. Additionally, in order to mitigate the effect of possible atmospheric artifacts, a filtering operation is performed. This step is based on the observation that the atmospheric signal phase component is highly correlated in space but poorly in time. Accordingly, the undesired atmospheric phase signal is estimated as follows: first of all, we remove the temporal low pass component of the deformation signal; then the cascade of a lowpass filtering step in the two-dimensional spatial domain and a temporal highpass filtering operation is performed.
In summary, the SBAS approach permits to detect and follow the temporal evolution of surface deformations with high degree of spatial coverage, due to the use of small baseline interferograms only.

3. RESULTS

The approach of SBAS has been applied to Tenerife ERS descending data set, and Mt. Etna ERS and ENVISAT descending data, acquired by the ESA Category 1 n.3560.
In the case of Tenerife test site 70 ERS SAR (1992-2005) data have been received and focused:
13 data have been discarded due to bad Doppler centroid; 1 data has been discarded due to missing lines; 1 data has been discarded due to big Spatial Baseline; 55 data have been successfully processed.
Via SBAS technique 182 differential interferogram have been performed and combined with a B_{perp} max of 400m and B_{temp} max of 600 days.
From the obtained mean velocity deformation map (Fig. 1) three different subsidence areas has been identified, as were showed in previous works [3], [4]. The very high coherence of the central part of the island can be attributed at the complex volcanic lavas that form the structure of volcano edifice. The performed mean velocity map relevant to the coherent pixels of the island shows a significantly subsidence deformation pattern localized on the Pico de Teide and in the surrounding caldera region. In particular, we have observed a good spatial fit between the geometry of the deformation and the main volcano structures of the island (i.e. horseshoe shaped caldera).
In the case of Mt. Etna test site, 107 ERS and ENVISAT SAR (1992-2005) data have focused:
10 ERS data have been discarded due to bad Doppler centroid; 1 ERS data has been discarded due to missing lines; 9 (6 ERS + 3 ENV) data have been discarded due to low coherence; 87 data have been successfully processed.
Via SBAS technique 242 differential interferograms have been performed and combined (204 ERS, 38 ENV) with a B_{perp} max of 400m and B_{temp} max of 1500 days.

The preliminary results show two remarkable features in the LOS velocity map (Fig. 2). The first is on the western flank where the jump occurred during the 2001 eruption produce an average negative LOS velocity, while the trend before and after the 2001 event is roughly positive. The second feature is the general positive LOS velocity observed on the eastern flank, according to the structural framework of this area. The velocity measured on this flank is not constant but is related to the local tectonic and volcanic structures (recent lava flows, Pernicana fault and Timpe Fault system.

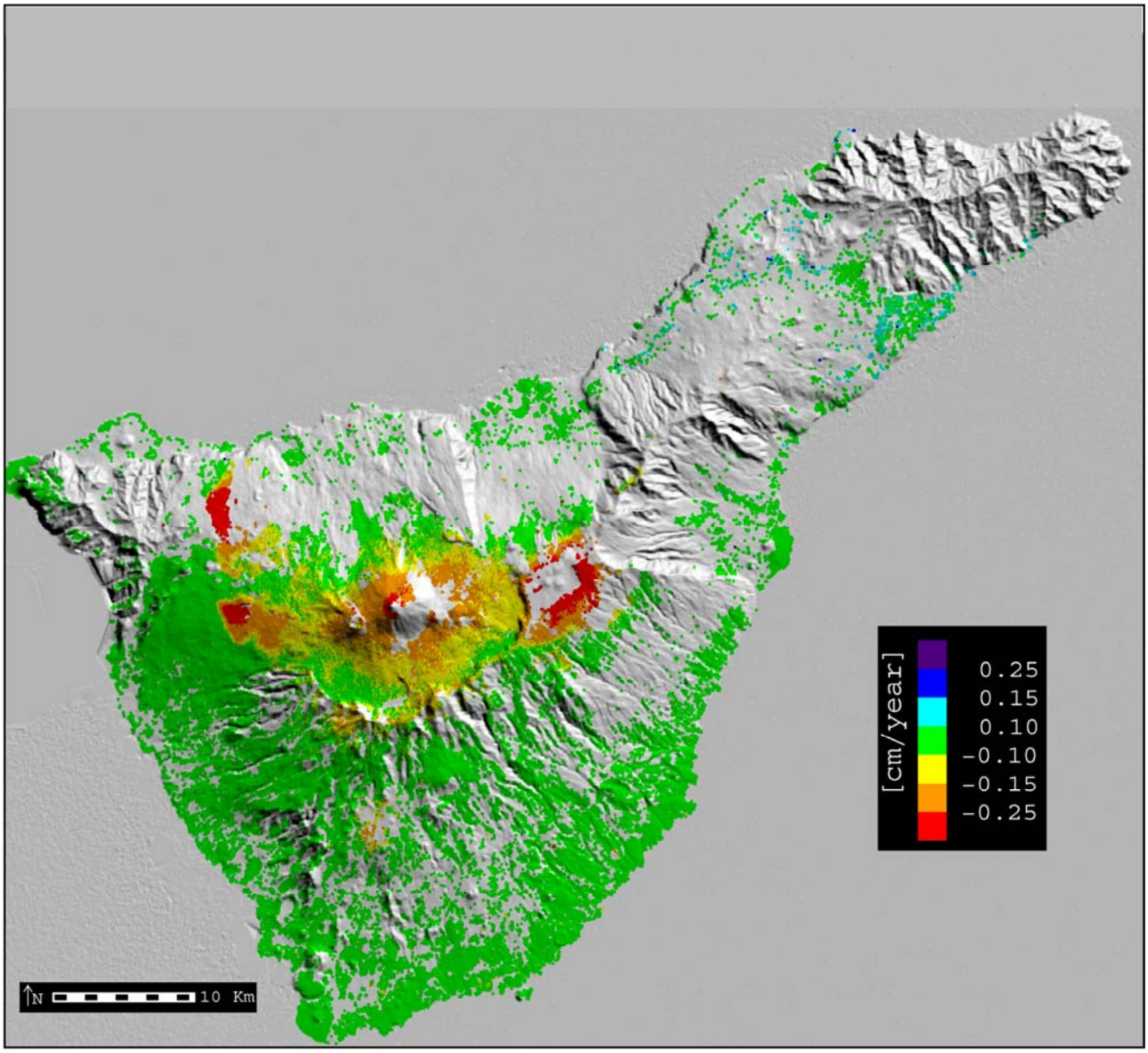

Figure 1. Mean deformations velocity map in LOS for Tenerife Island (1992-2005) computed using ERS data (descending orbit) superimposed to multilook image of the island.

4. TENERIFE RESULTS INTEGRATION AND PRELIMINARY INTERPRETATION

Using InSAR, we have also detected displacement at the same areas and showing similar variations. Many of the epicenters of located seismicity are situated in, or very close to, the deformation zones detected previously by InSAR [9]. Using 3D displacement data obtained from comparison of the GPS campaigns an interpretation has been done using different inversion techniques (Genetic Algorithm; Randon Search, [10]).

The inversions give as results sources of deformation changing with time their horizontal position, depth, radius, pressure and mass values. Some of the sources are very shallow, having a depth of only a few hundred meters. Considering geodetic data and their inversion results, seismic activity (www.ign.es), geochemical anomalies [11], we can suggest, in a preliminary interpretation, that some magma intrusion at depth and maybe some interaction with or migration of hydrothermal fluids could be the origin of the detected anomalies in Tenerife. This preliminary interpretation is consistent with the interpretation given by Gottsmann [12]. A more detailed study, using deformation data obtained from combination of GPS campaigns and InSAR results [13] and interpretation using different inversion techniques, is starting.

Another study, using the same deformation data (GPS campaigns and InSAR) combined with existing and new micro-gravity data will be done.

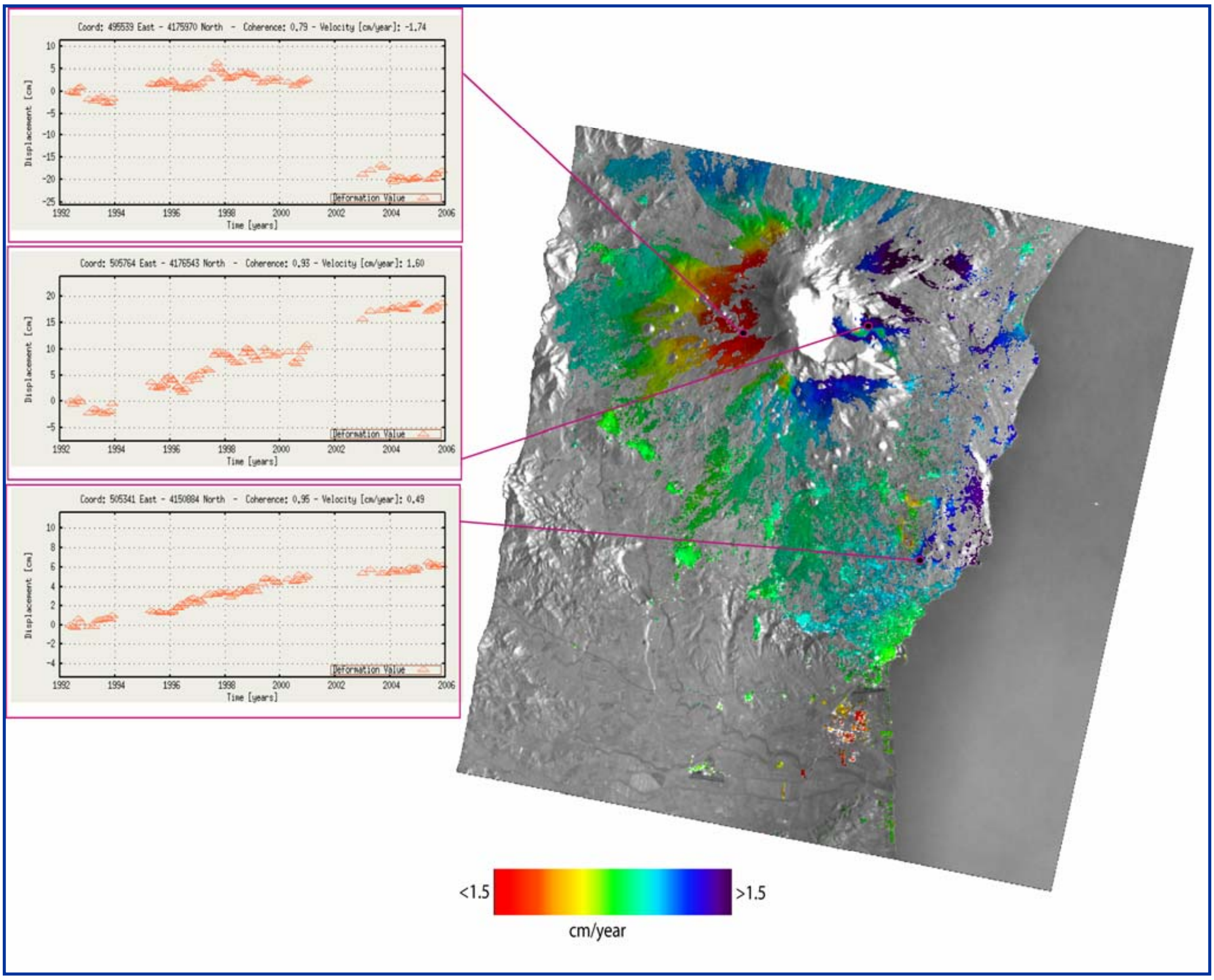

Figure 2. Mean deformations velocity map in LOS of Mt. Etna (1992-2006) computed using ERS/ENVISAT data (descending orbit) superimposed to multilook image of the area. On the left part of the figure are reported the displacement time series, from up to down: the first plot referred to western flank, the second referred to the recent lava flow (1986-1987, 1989) and the third plot referred to Timpe Fault system.

5. CONCLUSIONS

Concerning the Tenerife volcano from GPS, SAR images, gravity, gas emission, seismicity and cortical structure determined via solution of the inverse gravimetric problem solution, analyzed and interpreted we can make the following considerations:

- Some volcanic reactivation can be going on in Tenerife Island;
- Displacement and gravity changes have been detected with study of their evolution in time;
- Availability of terrestrial and space data is a key tool for volcano monitoring;
- Some integration of data has been done, but more will be done in the near future with technical improvements.

For what concern the deformation field retrieved on Mt. Etna it is explained in term of eastern flank spreading of the volcano, according to the structural framework of this area [14], [15], [16].

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