DEFORMATION TIME SERIES MONITORING OF NISYROS VOLCANO (GREECE) DURING UNREST AND REST PERIOD

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ABSTRACT

Nisyros Volcano (SW Greece) shows an unrest phase during 1996-97 accompanied by intensive seismic activity in the broader area at the beginning of 1996 and lasted through the end of 1997 and returned to the background level at the beginning of 1998.

SAR interferometry has already shown its ability in mapping ground deformation, like co-seismic deformation, as well as long-term movements as is the ground deformation in volcanoes, landslides and subsidence. Ground deformation monitoring is one of the main parameters that should be considered to assess volcanic hazard.

In the current study the multi-reference synthetic aperture radar (SAR) interferometric technique was applied in order to study the evolution of ground deformation during the unrest period 1996-1997 and the post period of 2003-2010. Two different data sets of common acquisition geometry of radar scenes covering the mention periods were used.

1. INTRODUCTION

Volcanic monitoring involves a variety of measurements and observations in order to detect changes at the surface of the volcano that reflect increasing pressure and stresses caused by the movement of magma within all beneath it. There are three main sources of crustal deformation in a volcanic environment: I) pressure changes in high-level magma storage areas and conduits ii) magmatic intrusions and iii) earthquakes.. There is a number of different geodetic techniques to monitor crustal deformation with different level of accuracy and operational capabilities the most important of which are: leveling, Global position system (GPS) and SAR interferometric teqniques.

A huge number of applications already done to monitor volcanoes with excellent results and capabilities [1-4].
In the present study the multi-reference synthetic aperture radar (SAR) interferometric technique was applied in order to study the evolution of ground deformation during the unrest period (1996-1997) and the post period of 2003-2010 at Nisyros island (Dodekanese, SE Greece). For that purposed two data sets of common acquisition geometry of radar scenes from ERS-1/2 and Envisat satellites covering the mention periods were used.

Due to the inability to find sufficient number of point-targets, natural or man-made, Persistent Scatterers Interferometry (PSI) technique failed to deliver results and for that reason Singular value Decomposition (SVD) was applied allowing to measure ground deformation time series in pixel basis.

Figure 1: Location of study area

2. GEOLOGICAL SETTING OF NISYROS VOLCANO

Nisyros is a strato-volcano at south-eastern (Fig.1) end of Hellenic Volcanic Arc (HVA) [5,6]. The HVA is related to the northward subduction of the African plate beneath the Aegean micro-plate. Most of the Nisyros island is made hyaloclastatite, lava flows and breccias, mainly of undesite composition. Pyroclastic deposits and volcanic doms of Dacite composition overlay these rocks.

According to [6,7] five main fracture zones dissecting the volcano in triangular segments are identified (Fig. 2) : i) The NE-SW fault system which is part of the large horst-graben system between the islands of Kondeliousa, Kos and the Datca Peninsula. ii) The NW-SE fault system which is more or less perpendicular to the above

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fault system and has steep inclinations of 70 to 80 degrees at the surface but with dips changing between NE and NW. iii) The E-W fault system might be the result of the deep reaching conjugate of the two mentioned faults. iv) The N-S fault system can be locally identified in the volcanic edifice of Nisyros island along the northwestern coast between the dacitic domes of Karaviotis and Trapezina and at Cape Akrotiri. v) The ESE-WNW fault system is observed in the older volcanic series, as well as in the youngest volcanic intrusives inside the caldera, and must be related to a regional fault system along which down-faulting of major block in Kos took place.

In 1996, an earthquake activity started with earthquake magnitudes between M=4 and M=5 and continued up to May 1998 [8].

The scientific interest related to volcano ground deformation monitoring during this period was great either by the establishment of GPS network or by applying SAR interferometry [9-14].

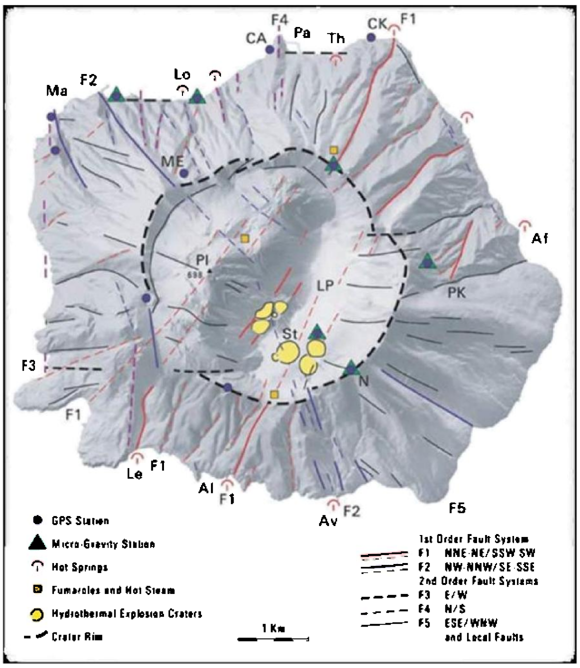

Figure 2: Tectonic map of Nisyros Island (GEOWARN Project)

3. DATA AND METHODOLOGY

In this study 63 SAR and 50 Advanced SAR (ASAR) scenes were acquired, within an ESA's CAT-1 project, which consist of the entire archive of ERS-1/2 and ENVISAT, respectively, for the area under investigation. With a total time span of 18 years (1992-2010) the scenes are both in ascending and descending orbit with VV polarization operating in C- band. Regarding the ERS scenes 18 are in ascending (track: 286) and 45 in descending (track: 107). Regarding Envisat scenes 27 are in ascending and 23 in descending in the same track, respectively. In addition, a Digital Elevation Model provided by Shuttle Radar Topography Mission (SRTM) with spatial resolution of 90 meters was used to simulate and subtract the topographic phase contributions. Precise orbit position data was obtained from Delft Institute for Earth-Oriented Space Research (DEOS) [15] for the ERS scenes and from Doppler Orbitography and Radio-positioning Intergrated by Satellite (DORIS) for Envisat ones, in order to improve the accuracy of the satellite orbit. SAR data processing which was performed using the GAMMA interferometric software was separated in two sessions, one for each period. The small island of Nisyros was not regularly imaged and as a result the archived scenes do not allow us to obtain inteferograms in consecutive time intervals. Moreover baseline limitations occurred.

Therefore the approach that was adopted to overcome these problems in this study and reveal the time dependent deformation pattern ,in both linear and also pixel basis, was the Singular Value Decomposition (SVD). The SVD solution is assumed correct only when the set of interferograms are completely linked [16] meaning that temporal gaps have to be avoided. In our case in order to avoid temporal gaps the solution was applied only when there is sufficient number of interferometric deformation images for the desired periods. Specifically the set of scenes that were used regarding the unrest period of the volcano are 14 in descending orbit of the ERS satellite covering the period 1995-1997 and for the rest period 19 Envisat ones in ascending orbit for the period 2004-2010.

According to [16] SVD offers in principal, a way to find approximate mathematical solution to a singular problem, based on a minimum-norm criterion of the deformation rate to derive time series. By using minimum norm velocity constraints reliable solution can be obtained. A key point of a multi temporal approach is that critical selection of interferometric pairs allows the minimization of the spatial baselines, thus the mitigation of decorrelation phenomena and topographic inaccuracies.

It is assumed that some common processing steps have been implemented in advance in order to produce the interferometric information that is going to be used as input in the proposed solution of SVD which is rather an independent interferometric processing. These steps consist of carefully unwrapping all the inteferograms, subtracting the topographic component of the signal and referring the unwrapped phase values to the same zero deformation point.

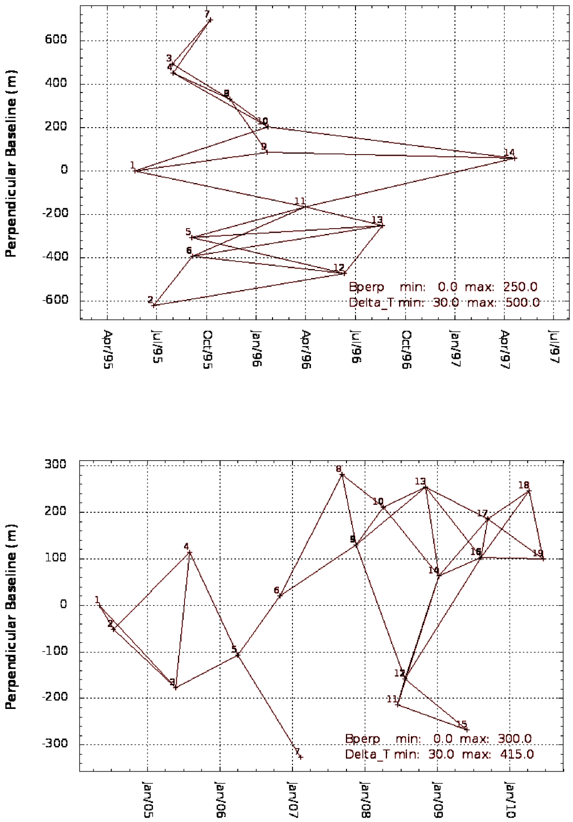

Figure 3: ERS scenes (Upper) and ENVISAT scenes (Down) networks.

4. PROCESSING

As already mentioned two separate processing procedures were carried out corresponding to the two phases of the volcano activity. Starting from preprocessing, co-registering all the scenes to the same geometry is required allowing us to match the resulting inteferograms in the upcoming steps in sub-pixel accuracy. Because of the relatively great appearance of sea in the scenes, problems occurred and a slightly adapted procedure was applied in order to achieve satisfactory results. In addition, the available DEM was geocoded in order to be converted into the SLC scene geometry. After subtracting the topographic component the next step consists of producing the initial interferograms. For the unrest period perpendicular baselines up to 250m and time interval up to 500 days were accepted in order to form a sufficient network. On the other hand for the rest period baselines up to 300 meters along with 415 days of temporal separation for each acquisition to form interferograms were selected (Fig.3). The interferograms were further analyzed and filtered using adaptive filtering. The goal of the adaptive filtering step is to reduce phase noise thereby reducing the number of the phase residues. The next step is related with unwrapping the inteferograms using the minimum cost-flow algorithm. The reference point for each was carefully selected in order to avoid biases which can lead to shifts in the deformation patterns. The two reference points were selected very close to the volcano's ring within 1.0 km of each other. This procedure was repeated using precision baselines in order to decide which interferograms are going to be selected as input to the SVD solution.

After producing multi-temporal reference stacks for both datasets of unwrapped phases, generation of time-series of unwrapped deformation phase takes place. The estimation of deformation phase time series is calculated by using a weighted least-squares algorithm that minimizes the sum of squared weighted residual phases. The total deformation phase at time t_n is the sum of deformation from the first (t_0 to t_1 and t_1 to t_2 etc). Therefore the total deformation phase at some time t_n can be expressed as a linear combination of measurements in the input data referenced to the time of the earliest scene in the series assuming that the deformation is 0 at the initial epoch for the series. Due to temporal decorelation of the acquisitions decorelation noise didn’t allow us to retrieve any dense inteferometric information in the North and North-East part of the island, as well as within the caldera due to layover and foreshortening phenomena. In order to visualize the values of the deformation patterns derived from the SVD solution they were geocoded back from the Range Doppler Coordinates to Universal Transverse Mercator (UTM) coordinates and plotted to the DEM of the island.

5. RESULTS

It is evident from this work that the method showed excellent results especially regarding the spatial extent of information concerning cumulative deformation covering from 60% to 85% of the island’s territory in an environment where persistent scatterers interferometry failed to give satisfactory results mainly due to the characteristics of the island (lack of build-up areas).

For the unrest period maximum uplift is observed within the caldera of about 5 cm, also uplift is observed in the area of Mandraki village (Fig. 4-5). Contrary the rest period shows downlift within the caldera with locally values up to 6 cm. The subsided area is extended from the southern coast of the island covering the caldera and follows the NNW trend to Mandraki village. (Fig. 6-7). In order to further investigate the evolution of the volcano’s activity the inteferometric results are going to be calibrated with GPS measurements and also combined with DEM-derived spatial models such as exposure of the island aiming to contribute to risk asses-

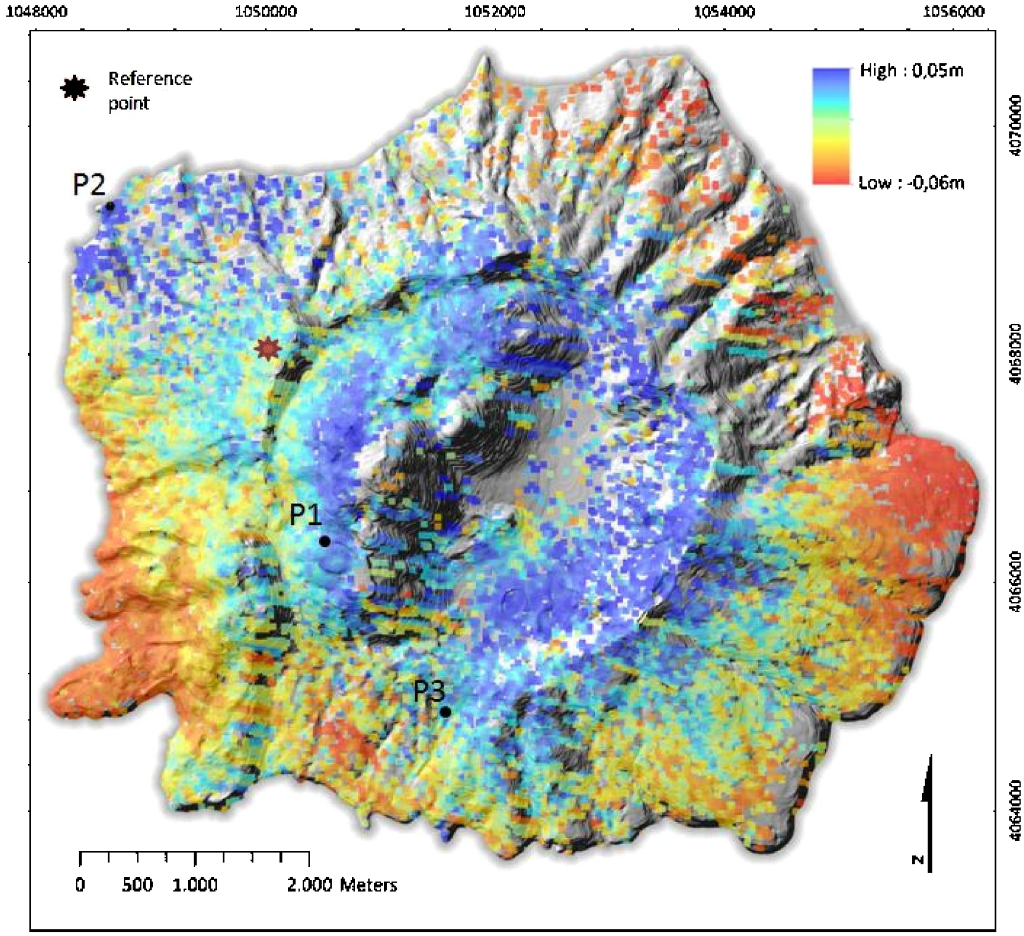

Figure 4: Cumulative deformation in the time interval 1995-1997 superimposed to the shaded-relief.

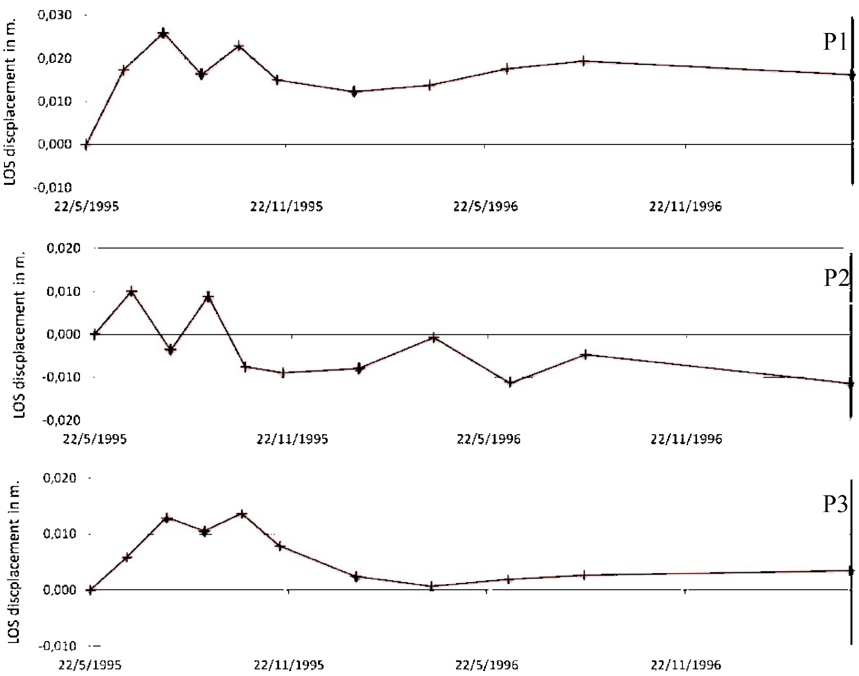

Figure 5: Time series deformation measures for points P1, P2, P3.

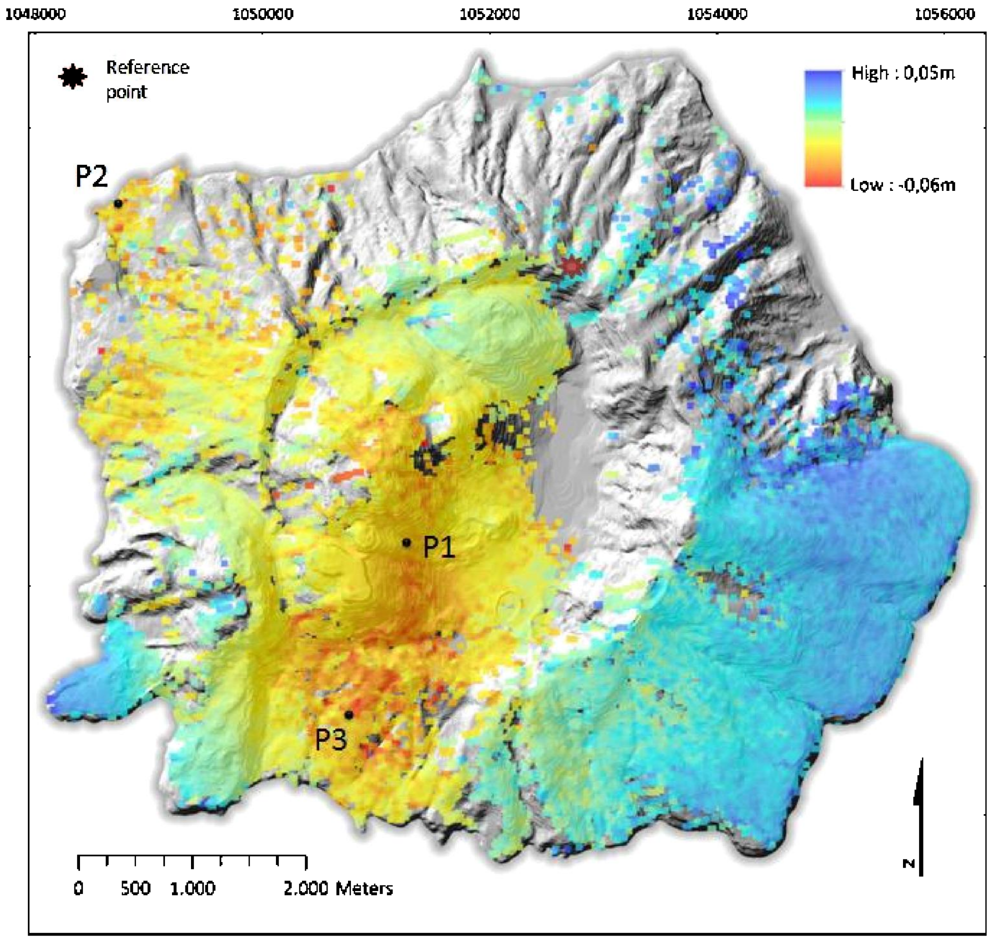

Figure 6: Cumulative deformation in the time interval 2004-2010 superimposed to the shaded-relief.

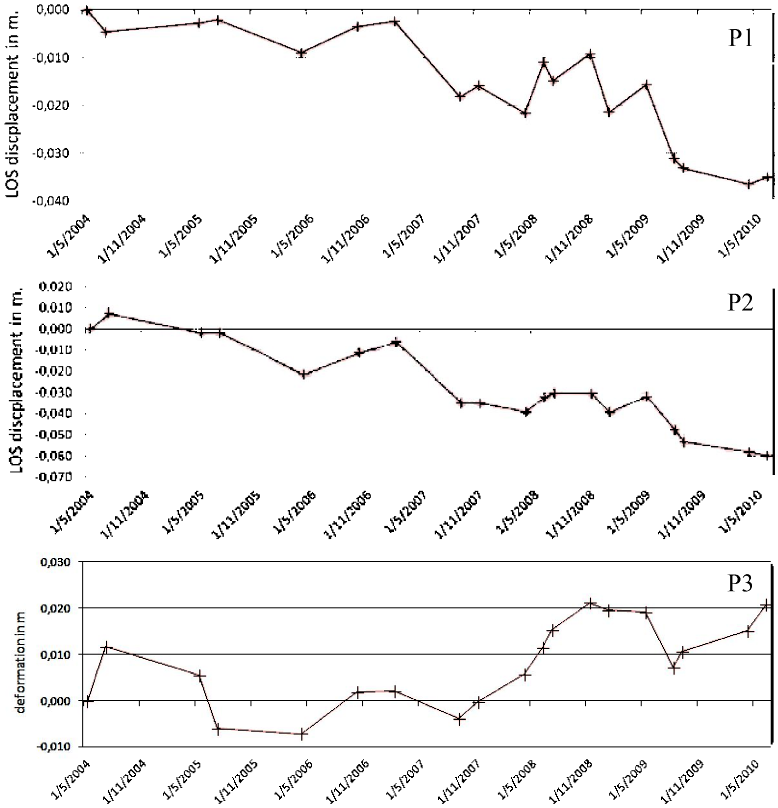

Figure 7: Time series deformation measures for points P1, P2, P3.

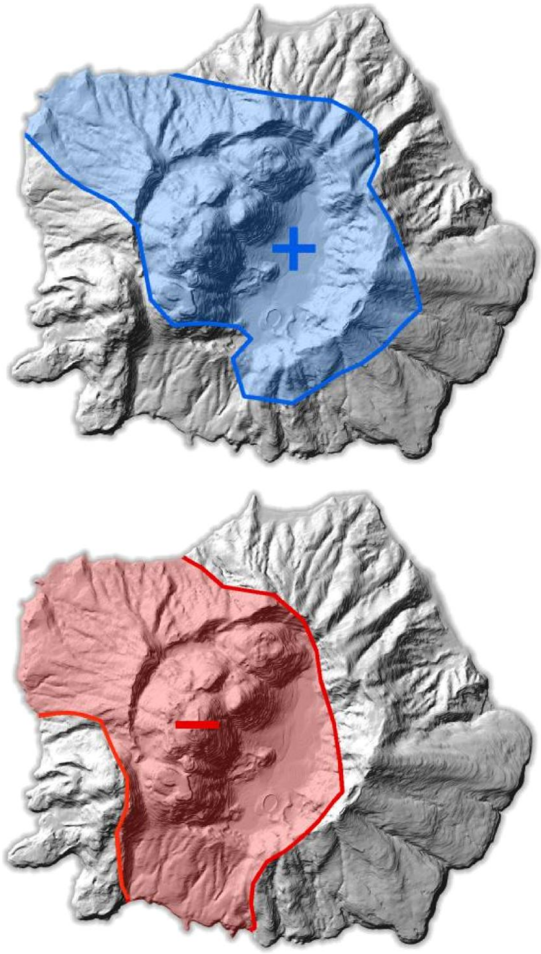

Figure 8: Spatial distribution of surface deformation during unrest phase (Upper) and rest phase (Down)

-ment. In order to achieve a complete knowledge about the volcano's behavior it is necessary to investigate the surface deformation of the rest periods before and after unrest and compare them in qualitative and quantitative terms.

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