COMBINED SQUEE-SAR™ AND GPS GROUND DEFORMATION STUDY OF NISYROS-YALI VOLCANIC FIELD (GREECE) FOR PERIOD 2002-2012

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ABSTRACT

This study presents the spatial and temporal ground-deformation pattern of the Nisyros-Yali volcanic field after the period of the seismic crisis (1996-1998) based on the local GPS network remeasurement and the analysis of Interferometric data (2003-2010) applying the SqueeSAR™ technique. The GPS results indicated intense subsidence in the northern and central parts of Nisyros that caused the western and eastern flanks of the island to "collapse" towards its center. The observed LOS velocity field of the SqueeSAR™ analysis revealed a nearly linear type of ground deformation, exhibiting values ranging between -3 to +3mm/yr with small standard deviations. The interferometric results have also shown subsidence along the northern and central parts of the island, and an inherent eastward horizontal component at its southeastern part. The overall pattern of the observed subsidence in the area after 2000 is consistent with decrease of pressure in the associated magma chambers and hydrothermal system.

Index Terms **—** Radar Interferometry, Geophysical measurements, Geodesy

1. INTRODUCTION

The Hellenic Volcanic Arc (HVA) in the Aegean Sea extends over a distance of approximately 600 km from NW to the islands of Kos and Nisyros on the SE. The HVA is regarded as a magmatic expression of the still-active north-eastward-directed subduction of the African Plate beneath the Aegean micro-plate. 160,000 years ago, several hundreds of km^3 of magma were emplaced in the region of the NE striking "Kos horst-graben system" from the upper mantle into low crustal levels, which led to the largest eruption in the Eastern Mediterranean emitting more than 100 km^3 of pyroclastic material, constituting the Kos Plateau Tuff [1]. The centre of this catastrophic eruption was probably located N to NE of Nisyros Island.

Nisyros Island is part of the Kos-Yali-Nisyros Volcanic Field (Fig. 1), and it has an average width of about 8 km and covers an area of about 42 km^2. Five major fault systems have been identified in the broader area [2]. The F1 NE-SW trending fault system cross-cuts the entire island of Nisyros. The F2 (NW-SE) fault system runs more or less perpendicular to the F1. The localized F3 fault system is oriented E-W and might be the result of the deep reaching conjugate F1 and F2 fault systems. A subordinate N-S trending fault system, F4, can be locally identified in the volcanic edifice of Nisyros. The F5 (ESE-WNW) fault system is observed in the older volcanic series. Finally, the caldera rim and its accompanying cone-shaped local faults are entirely volcanic structures, which are the result of the caldera collapse after the last Plinian eruptions.

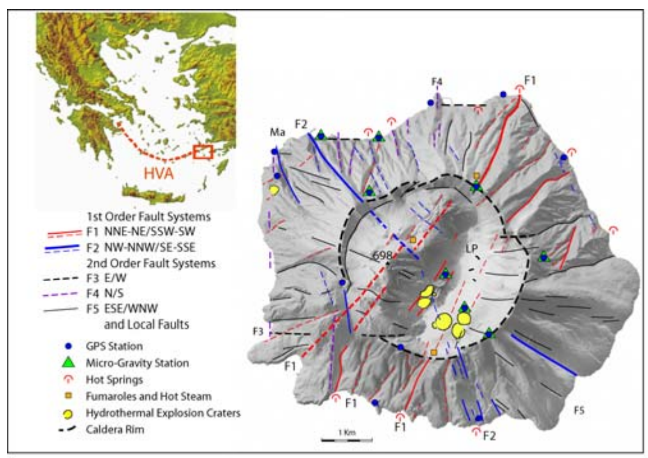

Fig.1. Fault pattern, location of hydrothermal explosion craters and hot springs superimposed on a digital elevation model (DEM) of Nisyros Island. Abbreviations of locations: LP: Lakki Plain, Ma: Mandraki, F1, F2, F3, F4 & F5 mark the five major and minor fault systems that have been identified in the area.

Earthquakes have been described throughout historical times. Their origin may be a result of regional tectonic processes, magma ascent, degassing phenomena of deep crustal magma, and steam explosions within the hydrothermal system as recognized by "hydrothermal noise". The last intense seismic activity started in the broader area of Nisyros at the beginning of 1996 and lasted through the end of 1998. That activity was accompanied with strong ground deformation, expressed as intense uplift, mainly in the central and northwestern part of the island. Source modelling assigned the observed deformation due to two magma sources: one located at almost the center of Nisyros, and another one offshore, between Nisyros and Yali islet to the North [3]. Since 2000, the area appears to be relatively quiet without any significant seismic, volcanic or deformational activity.

2. DEFORMATION OF NISYROS-YALI ISLANDS

The SqueeSAR™ [4] is a second generation of the Permanent Scatterer Interferometric (PSI) technique, and involves searching targets from a radar imaging dataset in order to identify both consistent Permanent Scatterers (PS) and homogeneous spatially distributed **s**catterers (DS). PS usually correspond to man-made objects (e.g. buildings and linear structures), while DS are typically associated with homogeneous ground surfaces, uncultivated, desert or debris covered areas, and scattered outcrops. All identified PS and DS are then jointly processed (taking into account their different statistical behaviors) by applying the SqueeSAR algorithm. Because of the higher density of identified measurement points (scatterers), and their wider spatial coverage, millimeter accuracy of ground displacement is achievable, together with reduced standard deviations.

A total of 26 ascending and 22 descending orbital geometry ASAR scenes acquired by ENVISAT satellites were processed covering the period February 2003 to June 2010. More than 3,400 and 2,200 PS/DS in ascending (Line of Sight (LOS) angle 24.62°) and descending (LOS angle 24.24°) geometry, respectively, were identified within an area of about 52 km^2 (Fig. 2). Since the vertical component of ground deformation is about 93% of LOS, this technique is more sensitive to the vertical deformation. The reference point for the interferometric analysis is located at the southern part of the island near GPS station No. 53 of the local network that has been remeasured periodically. The latter GPS point has a horizontal motion of SSE direction with respect to ITRF2008, while its vertical component indicates subsidence (V_{Up}= -6.1±3.1 mm/yr) for the period 2002-2012.

Ascending data (Fig. 2) show a clear pattern of negative LOS velocity values (<1.8 mm/yr) in the central part of Nisyros, in the flat Lakki Plain (LP), as well as in the north-western part. Smaller negative LOS velocity values are also observed in the south-eastern part of Nisyros. Since the LOS angle is quite small, the largest component of the velocity vector may represent vertical motion, and therefore subsidence seems to take place in this area. The highest LOS velocity values (>1.8 mm/yr) are observed at the south-western part of Nisyros, while small negative LOS values are observed in the south-eastern part.

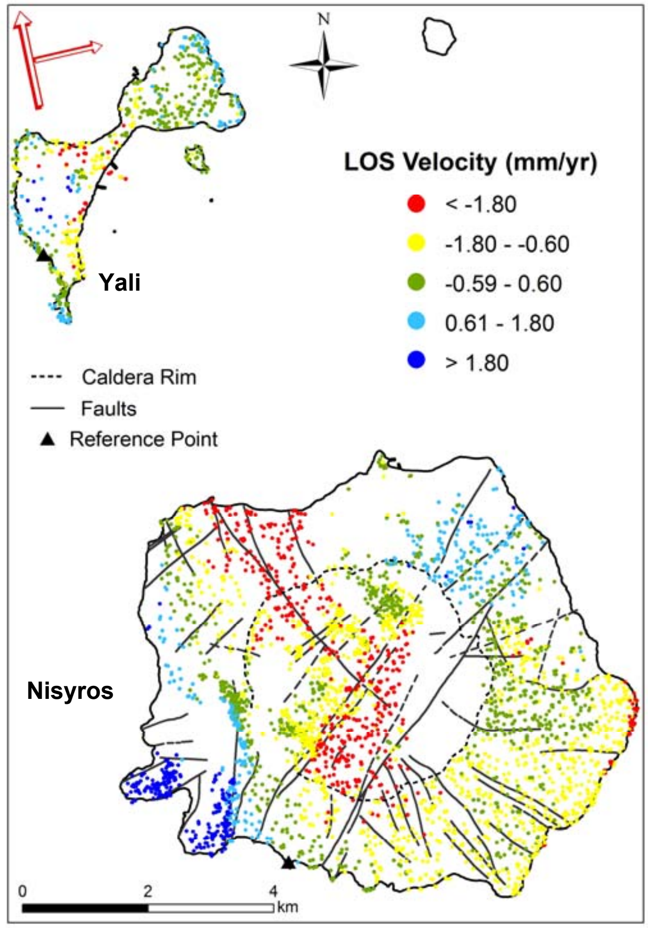

Fig. 2. Ground Deformation of Nisyros-Yali islands deduced by SqueeSAR™ Ascending orbital acquisition geometry (Red arrow) for the period 2003-2010.

Descending data (Fig. 3) are lacking resolution in the central Lakki Plain. Positive LOS velocity values in the south-eastern part indicate motion towards the satellite. When combined with the negative values shown in the ascending orbital geometry (motion away from the satellite), it indicates that a significant eastward horizontal component is inherent in this part of the island. Similarly, the small negative and positive (-0.6 to +1.8 mm/yr) LOS velocity values at the south-western part, on the descending orbital acquisition geometry, combined with the increased positive values of the ascending geometry in the same area, designate that uplift is taking place. Both acquisition geometries clearly identify that the observed deformation is controlled by the two major faulting systems (F1 & F2) that cross-cut the island, together with small local faults that belong to the caldera rim. Small patches of PS/DS showing irregular pattern are attributed to local morphological (steep slopes), tectonic and geothermal features that are scattered around the island.

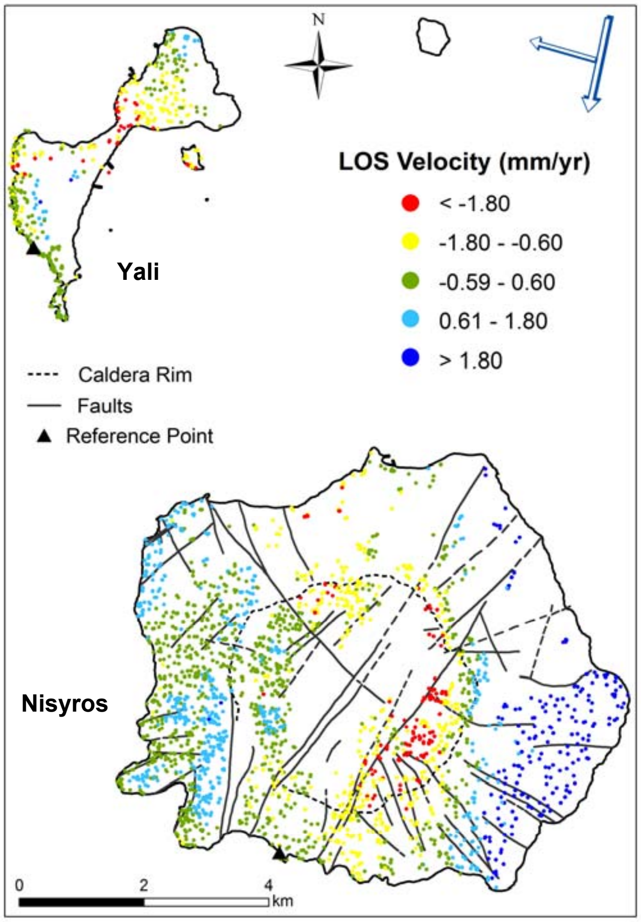

Fig. 3. Ground Deformation of Nisyros-Yali islands deduced by SqueeSAR^{TM} Descending orbital acquisition geometry (Blue arrow) for the period 2003-2010.

The deformation image of the Yali islet that is located just NNW of Nisyros does not exhibit a consistent pattern on both acquisition geometries, mainly due to the limited number of PS/DS points (~500). An overall differential motion is observed only between the north-eastern and south-western part of the island (in both geometries), but it is still not clearly depicted, and may be attributed to the different geological units of the two parts: obsidian on the NE, pumices on the SW.

The *standard deviation* of the velocity field was also computed for both the ascending and descending images (Fig. 4) presenting values quite smaller than 0.8mm/yr. Two parameters are generally affecting the calculation of the standard deviation: (i) *The distance of each PS/DS point from the reference point*. In fact, the displacement model is estimated on the phase-difference between the point under analysis and the reference point, in order to mitigate the effect of the atmospheric noise, which is strongly spatially correlated. The standard deviation of velocity increases moving away from the reference point. (ii) *The deviation of motion from the linear model.* Since the standard deviation is associated with the average rate of deformation, if a PS/DS point exhibits a strong non-linear motion then it would result in a large residual with respect to the linear model, and thus in a high standard deviation value.

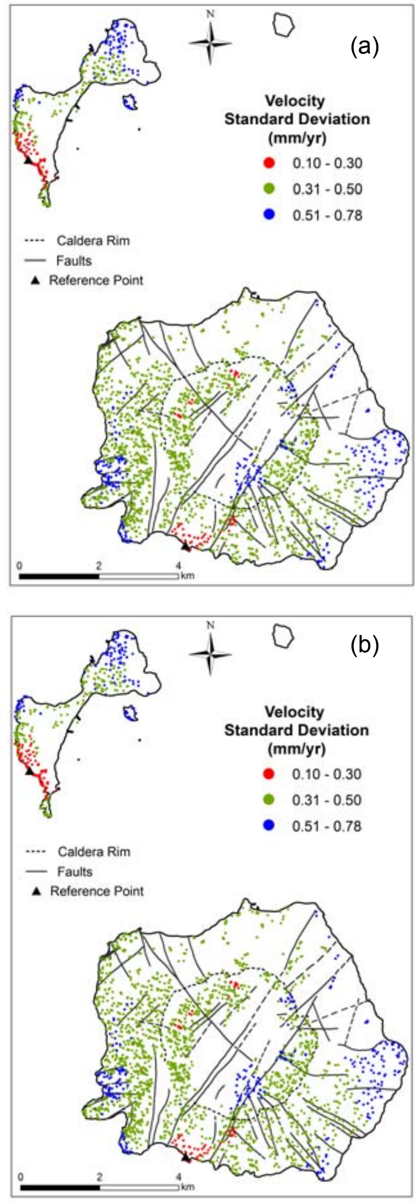

Fig. 4. Standard Deviation of PS/DS velocity deformation field deduced from **(a)** Ascending, and **(b)** Descending radar imaging.

The standard deviation of velocity for the descending data (Fig. 4b) has slightly higher values than the ascending data (Fig. 4a). The smallest values occur near the reference point as expected, and at the north-eastern part (Fig. 4a). Low moderate values of standard deviation (~0.4mm/yr) are observed for the rest of both islands (Nisyros and Yali). These overall low values suggest an almost *linear* type of ground deformation throughout the observational period.

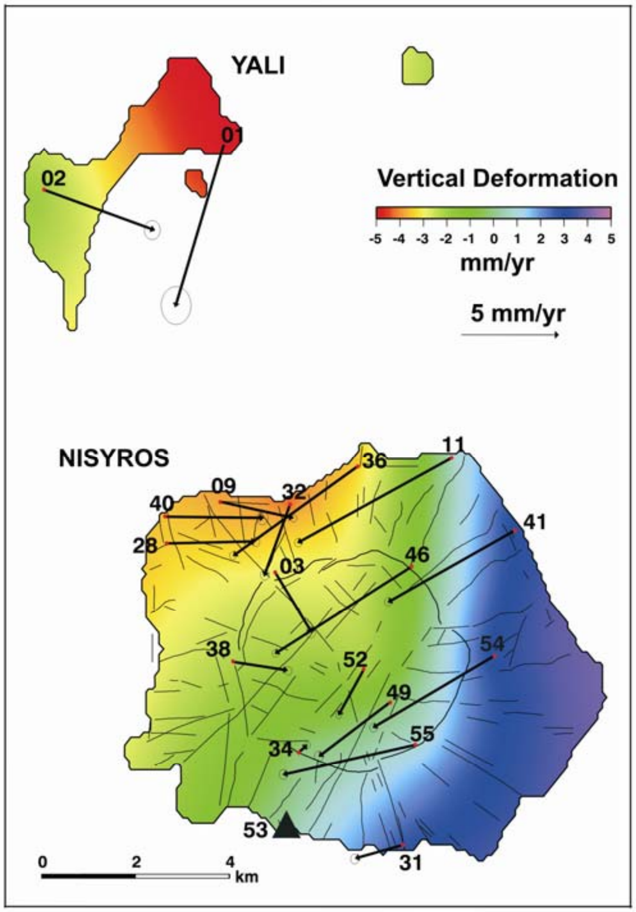

Fig. 5. Horizontal and vertical deformation on Yali-Nisyros deduced by GPS measurements relative to station 53 (black triangle) for the period 2002-2012.

The measurement of the GPS local network for the period 2002-2012, which has the same reference point as the results of the SqueeSAR analysis (GPS No. 53), revealed a significant subsidence in the northern part of the island. The horizontal component of the GPS deformation vector emphasizes this subsiding pattern, showing opposite horizontal motion of the stations located across this zone. The uplifted pattern of the south-eastern part, although is extrapolated from only two GPS stations located close to the caldera rim, coincides with the pattern of motion deduced by the descending data set. Deformation vectors on Yali also exhibit significant subsidence (up to 4 mm/yr) with the horizontal component pointing towards an area offshore, where the second offshore Mogi source was modelled [3].

3. DISCUSION - CONCLUSION

Reactivation of magmatic and volcanic activity in quiescent volcanic areas, as the broader area of Nisyros, is characterized by an increase of the geodynamic activity, as it has been expressed through earthquake activity and ground deformation in the broader area of Nisyros during the period 1996-2000. In this respect, the Nisyros-Yali volcanic field requires continuous monitoring of surface deformation.

The SqueeSAR^{TM} velocity map of Nisyros for the period 2003-2010, using ascending and descending ENVISAT radar images, reveals an overall small rate of deformation (-2 to +2 mm/yr), but a significant subsiding pattern along the central and north-western part of the island. The same pattern is apparent on the GPS measurements of the local network. The area that appears to subside coincides with the area that a Mogi point source was envisaged and assigned to model the observed strong uplift that occurred during the previous active period 1997-2000 [3]. Absence of any significant seismic activity during the last decade (2002-2012) in the broader area, supports the idea of the local aseismic character of the observed deformation, probably due to the decrease of the pressure in the possible magma chambers beneath and offshore of Nisyros Island. Discrepancies on the type of motion (indicating uplift or subsidence) between the ascending and descending radar data-set could be justified by an inherent E-W component on vector motion.

4. REFERENCES

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