GROUND DEFORMATION IN THE BROADER AREA OF THE ATALANTI FAULT ZONE (CENTRAL GREECE) BASED ON GPS & PSI-WAP

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ABSTRACT

The Persistent Scatterer Interferometry Wide Area Product (PSI-WAP) based on ERS1 & ERS2 radar data has been used in the seismic active area of Atalanti Faulting Zone (Central Greece) to spatially and temporally study the ground deformation for the period 1992-2003. The observed LOS velocity field, with values ranging between -0.5 to -5.0 mm/yr, combined with small standard deviation velocity values reveals an almost linear type of ground deformation. The most intense subsidence was associated to alluvia deposits and man made activities (intense water pumping). Differential motions along the main faulting zones have also been clearly identified. GPS results reflected a similar pattern of motions (subsidence) with the identified interferometric image. The recorded seismicity in the area is not significant for the PSI-WAP period. The micro-seismic activity (M<3) is mainly confined peripherally and does not seem to confidently affect the observed ground deformation.

Index Terms— Ground Deformation, PSI-WAP technique, GPS, Atalanti Faulting Zone.

1. INTRODUCTION

The Evoikos Gulf is a NW-SE trending graben that separates Evoia Island from Central Greece. Destructive earthquakes have occurred in the vicinity of that gulf since antiquity. It is the western border of the gulf that is of interest, which is defined by the broader area of the Atalanti Fault Zone (AFZ). The AFZ is controlled by six main faulting zones that are capable of generating large magnitude earthquakes (Fig.1). The last large and destructive sequence of earthquakes occurred in 1894, with two main shocks on April 20 and 27 (M=6.7 & M=7.0, respectively) [1]. The first shock produced small ruptures, cracks and landslides mainly in Malessina Peninsula along the coast. More serious effects resulted from the second shock, with most ruptures occurring along or close to the AFZ. Although no intense seismicity has occurred in the area during the last few years, the AFZ is considered to pose high seismic risk. As such since 1980, ground deformation of the broader area has been investigated by using ground geophysical work [2] to [6] and since 2001 space techniques. Long-term ground deformation monitoring using the Persistent Scatterer Interferometry Wide Area Product combined with Differential GPS (DGPS) measurements and seismicity analysis have provided useful information and new insights on the geotectonic regime of this complex region in Central Greece.

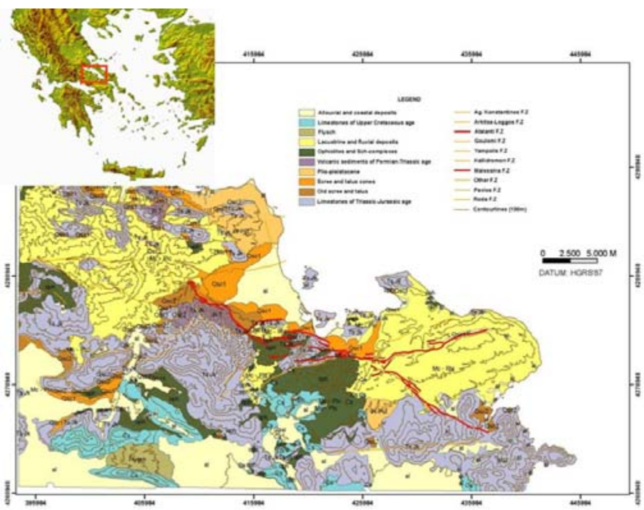

Fig. 1. Geological-Geotectonic Map of the broader area of Atalanti (Central Greece) - IGME [7].

Since 1992, several temporary seismological networks were installed in the broader area to study the local seismicity and evaluate the seismic risk. The seismic results for the WAP period 1993-2003 show low level of seismicity (M<3) along the Atalanti Faulting Zone, while the constrained focal mechanisms reveal normal faulting. Enhanced seismicity is observed more to the south, at the northern part of Evoia Island located to the east and within Evoikos Gulf. However, since 2008 more intense and of higher magnitude (M>3.5) seismicity has been observed in the area with several relatively strong events (5<M<5.5) taking place east, south and west of the Atalanti Faulting Zone, indicating the potential of the area to generate destructive earthquakes in the near future affecting the nearby large urban centers (i.e. Lamia) or even Athens (~100 km to the SSE).

2. THE PSI WIDE AREA PRODUCT (WAP)

The Wide Area Product (WAP) was developed by the German Aerospace Center (DLR) based on a modified PSI processing technique that accounts for a larger area (100km x100km) [8]. The aim is to map ground deformation at a millimeter accuracy on the scale of countries and even continents. In the course of ESA's ***Terrafirma*** project [9], the PSI-WAP mapping was applied in Greece. Seventy one SAR scenes that were acquired by ERS1 & ERS2 satellites on descending geometry were used to compile the PSI-WAP for the broader area of Atalanti for the period November 1992 to October 2003. Initially, a local reference point was selected for the analysis and several distinctive clusters were processed. On a second processing attempt, the PSI-WAP was calibrated using GPS results [8] from available stations in the broader area, and the absolute velocity field was obtained.

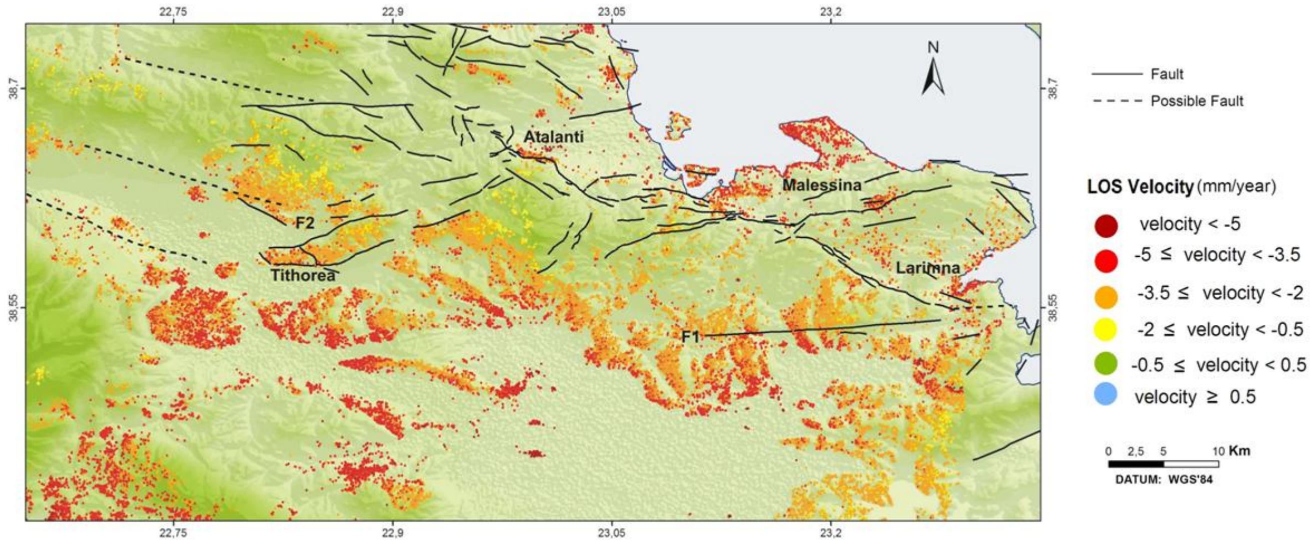

Fig. 2. PSI-WAP image in the broader area of Atalanti (Central Greece) for the period November 1992 to October 2003.

The possibility to interface and merge the PS results with additional measurements is a key point in the developing of an operational processor. Results provided by other sensors/instruments (in our case available GPS velocities from published data [10]) were used in order to overcome the limitations of the PSI that measures the ground deformation with respect to a reference point and not in an absolute manner. Therefore the displacements measured from available GPS stations that were carried out in the same time span period with the SAR acquisitions were taken into consideration. A map was generated as the reference on which the PSI results were calibrated. The input GPS data have been interpolated over the PSI processing areas. Subsequently, the PSI results have been adjusted in order to compensate the offset with the reference GPS measures and eventual trends due to residual orbital errors [8]. More than 170,000 PS points were identified within an area of about 111km x 118km to yield an average density of 17.3 PS/km^2 (Fig. 2). A significantly large number of PS points have been identified that are associated not only with urban regions, but also with outcropping limestone formations.

The AFZ consists of a series of small faults extending from NW to SE for about 50 km. The velocity (rate) of the ground deformation ranges from -0.5 mm/yr to -5.0 mm/yr (subsidence). However, there are some PS points with larger negative values that are located on alluvia deposits, and in most cases are associated with localized excessive pumping of the water table for irrigation, reaching values up to -7.0 mm/yr. The northwestern part of the AFZ is covered by dense vegetation and, together with the existence of alluvia, the number of possible PS points is severely limited. Most of the PS points are located at the southeastern part of the AFZ, namely along the Malessina and Larimna branches (Fig. 2). A significant velocity of subsiding character is observed at this part of the AFZ (up to -5 mm/yr), where lacustrine and terrestrial deposits prevail, while a relatively smaller rate (-3 mm/yr) is observed in areas of limestone outcrops.

Another interesting tectonic feature that plays an important role in the ground deformation of the southeastern part of the study area is the linear F1 faulting feature, which trends E to W and marks the boundary between the Jurassic limestone formations (on the North) and the alluvia deposits (on the South). The alluvia on its downthrown side is subsiding (up to -5 mm/yr), while the limestone outcrops across are subsiding at a lower rate (-3 mm/yr). Similarly and with respect to the mountains of Tithorea, the F2 fault system comprises the most interesting feature associated with ground deformation, where differentiated motions are clearly observed across the segments of this faulting system.

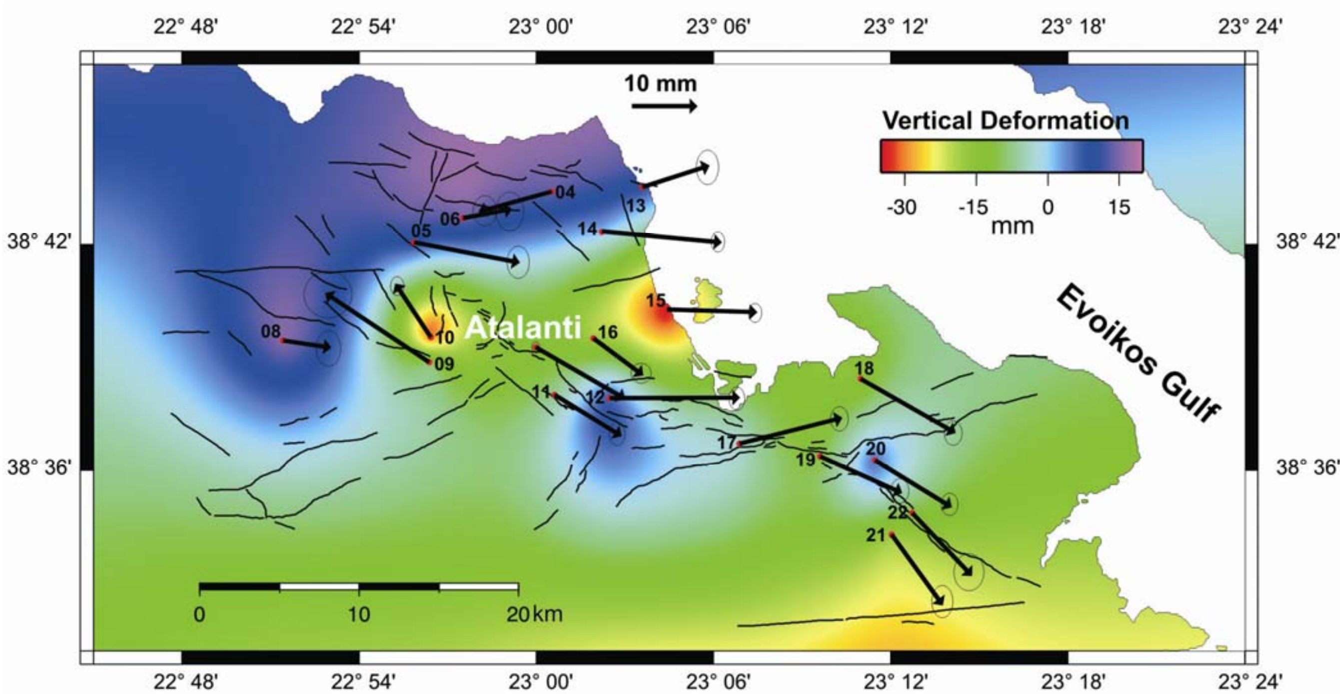

Fig. 3. Horizontal and vertical displacements as determined by the Atalanti GPS Network for the period 2001-2002 with respect to ITRF 2000.

3. THE DGPS MEASUREMENTS

A GPS network consisting of twenty stations covering the broader area of the AFZ was installed and remeasured during the period 2001-2002 [11]. The average spacing between the stations was about 5-8 km, and the network has been referenced to the Dionysos permanent station which is located in the Athens area (about 100 km SSE). Additionally, a station located at the center of the network in Atalanti town was chosen as a local reference in order to determine ground deformation relative to that station.

Figure 3 depicts the horizontal and vertical displacements in the broader Atalanti area with reference to the central station. The area can be divided into three zones of deformation according to the character of the ground deformational vector:

- The northern zone, where the horizontal vector is of large magnitude between 10-12 mm of NNW direction. This area shows significant uplift of about 15mm. The ground displacement values observed within this zone are associated with the generally increased prevailing seismic activity that is taking place in the vicinity. However, the PSI-WAP do not revealed a similar type of deformation (uplift) in that area, maybe due to the GPS calibration procedure that introduces a significant westward component to the LOS direction, causing motion away from the descending satellite (subsidence).

- The zone around Atalanti town, where the magnitude of the horizontal vector decreases to 7-8 mm, but of similar direction to the northern zone. The vertical displacements reveal subsidence of about 15mm that appears to be controlled by the surrounding faulting zones, as well as by intense water pumping for irrigation especially in the valley between Atalanti town and the coastline. This area is separated from the northern zone by a series of NE to SW oriented faults. This behavior is also deduced by the PSI-WAP emphasizing the intense subsidence that is taking place in this extensively cultivated area covered with alluvia.

- The southern zone, where the horizontal vector is within the estimated measurement error, and with vertical displacements of about +8mm, attributed to the stress field prevailing along the borders of the neotectonic units in the area. In this zone, the Malessina Faulting Zone is the main tectonic feature that controls these motions. The PS cover is not sufficient in this area, so no direct comparison between GPS results and the PSI-WAP could be made. Nevertheless, even in the PSI-WAP is evident that the different segments of the local faulting zone are strongly affect the pattern and the type of the differential ground deformation.

Summarizing, the DGPS results for the period 2001-2002 show that the deformation along the AFZ has a complex form, showing subsidence mainly along its downthrown side of its central part.

4. DISCUSION

The PSI-WAP for the Atalanti area revealed larger velocity of subsidence (up to -5 mm/yr) at regions of alluvia and marine sediments, as compared to smaller rates (about -2 mm/yr) for limestones and flysch formations as expected.

Higher velocities have also been noticed along the downthrown side of known active faulting segments. Nevertheless, human activity (water pumping for irrigation purposes) should have contributed to the observed subsidence. The overall subsiding image that the PSI-WAP revealed may also be attributed to the GPS data used to calibrate the PSI data. Regional GPS data used for this calibration exhibit a horizontal southwestern motion; this may introduce a motion away from the ERS descending satellite orbit, causing the PS points on the final image to attain a strong negative velocity component.

The remeasurement results (2001-2002) of the existing GPS network generally reflect subsidence in the central part of Atalanti area, consistent with the pattern that the identified PS points revealed. This area is covered mainly by alluvia, and extensive water pumping is taking place.

The seismicity in the broader region of Atalanti is not significant for the period of the PSI-WAP; only irregular micro-seismicity has been recorded (M<3), mainly confined peripherally, and does not seem to have affected the observed ground deformation. Therefore the AFZ, even though capable of large magnitude earthquakes, seems to be inactive nowadays, not only for the period of the WAP (1992-2003), but also after that period till the recent present (early 2013). However, in the summer of 2013 there was an outbreak of seismic activity in the region to the NW of the AFZ, which caused some damage, and also continued in 2014 with some more events of larger magnitude (M~5.1), but located peripherally from the AFZ emphasizing the need of continuous monitoring of this complex active area.

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