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Active deformation pattern of the Peloponnese region, based on geostatistical analysis of primary geodetic data

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Peloponnese area is in the broader South Aegean region, one of the most tectonically active regions in eastern Mediterranean. Peloponnese exhibits a profound extensional regime, which caused crustal thinning and the evolution of multiple tectonic windows. This extension has been ongoing in the neotectonic period as well (Papanikolaou et al., 1988), forming three major NNW – SSE trending normal fault zones at its southern part (largely controlling Messiniakos, Lakonikos and Argolikos Gulfs), while its northern part is deformed by primarily NW-SE and E – W trending normal fault zones, associated mainly to the tectonic activity of the Corinth Gulf. The area undergoes active deformation, as documented by several seismic events, such as Alkyonides (1981, M_w 6.7), Kalamata (1986, M_w 5.9), Aigion (1995 M_w 6.4) in 1995 and Andravida (2008, M_w 6.4) earthquakes (Jackson et al., 1982; Papanikolaou et al., 1988; Roumelioti 2004; Koukouvelas et al., 2010; GreDaSS Pavlides et al., 2010).

One of the most reliable ways of estimating the level of active deformation of an area is Satellite Geodesy, based on permanently installed GPS/GNSS stations and collecting geodetic data (specifically East and North velocity components of the station). Data processing is then implemented by dedicated software packages (UNAVCO), leading to the quantitative and qualitative determination of the uppermost crustal deformation of the study area. Primary data from 59 GPS/GNSS stations were used for extrapolating the deformation pattern of the broader Peloponnese area. They consist of timeseries for seven consecutive years (2008 – 2014), while the data analysis was carried out using 30-sec daily GPS observations. The reference frame of the geodetic data is the European Terrestrial Reference Frame 2000 (ETRF2000), which is coincident with the stable part of the Eurasian plate.

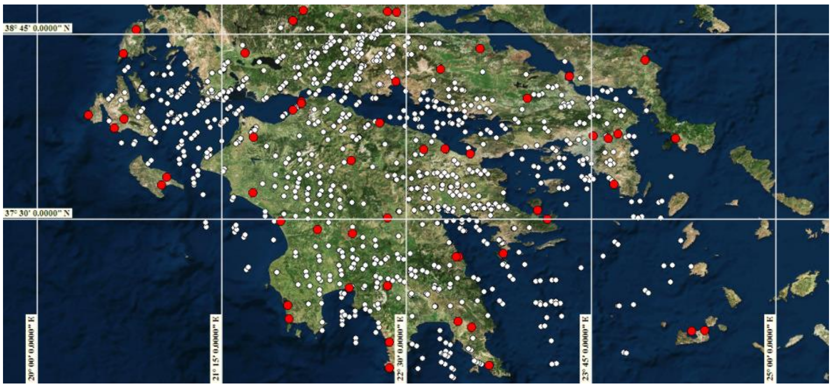

Figure 1. Location of the 59 permanently installed GPS/GNSS stations (red dots) and the 932 triangular centroids (white dots) within the study area.

Two main sets of methodologies were applied on the collected datasets. The first method is based on a triangulation process, taking into account the data of three different stations, which form a different each time triangle. Each station is located on a triangle vertex and is characterized by a specific velocity value, recorded for the aforementioned time. The intersection of the triangle medians defines the triangle centroid, which is then used as the centre of an inner, inscribed circle, expressing the initial and undeformed triangle. Taking into consideration the motion of the GPS/GNSS stations, which is imprinted on the corresponding velocity vectors of each station, the inner circle is morphed into an ellipse. By using equations, combining the major and minor axes of the inner circle and the ellipse, respectively, a series of parameters related to strain assessment can be calculated. The estimated parameters are: a) maximum and minimum horizontal extension, b) total velocity, c) maximum shear strain, d) area strain and e) rotation. In the frame of this study, 932 different triangles were taken into account, using the 59 permanently installed GPS/GNSS stations (Fig. 1).

Using the parameters from the first stage a second set of methodologies is implemented, leading to interpolation of missing or incomplete data. Interpolation is a reliable way of geostatistical process, as the distribution of each parameter throughout the study area is calculated with an acceptable confidence range. The geostatistically extracted parameters provide information leading to the interpretation of the neotectonic and the geodynamic setting of the study area.

The maximum and minimum horizontal extension parameters are identifying indicators of the extensional and compressional regime in a study area, respectively. The interpolated results show maximum horizontal extension values concentrated at the broader area of Corinth Gulf, as well as the northwestern part of Peloponnese, effectively the meisoseismal area of the 2008 Andravida earthquake sequence, which is contained in the recoding period. Furthermore, high maximum horizontal extension values are observed at the southwestern part of Peloponnese, probably related to offshore faults, located further to the West. Nevertheless, the maximum extension values of the study area, with the exception of the aforementioned areas, are generally low, indicating a rather tectonically quiescent area (Figure 2). Similarly, the main concentration of minimum extension values (i.e. associated with compression) is again located near the epicentral area of the Andravida earthquake. The concurrent maximum extension and maximum compression values are in good agreement with the focal mechanisms of the main event, which attribute it to the reactivation of a deep strike-slip fault.

The total velocity is associated to the motion and therefore the geodynamic evolution of the study area. The statistically processed results show an increase of total velocity values from the north-northeastern part to the south-southwestern part of Peloponnese area. These results are comparable and compatible with the general geodynamic setting of the area, as the south-southwestern part of Peloponnese is closer to the subduction zone, extended southwestwards into the offshore area, where African plate is subducted beneath the Eurasian one; it is therefore expected that it is deformed at a higher rate.

The maximum shear strain is associated to the deformation of the upper crust, caused by seismic, landslide or creeping phenomena. The areas where the highest values of maximum shear strain are observed are the same with the ones where maximum horizontal extension is observed.

The area strain expresses the dilatation and the compaction of the area, associated to extension and compression, respectively. Based on this parameter, a general extensional regime can be identified, while compressional effects are limited and located at the western part of the study area, where the transition from an extensional to a compressional regime is evident from other indicators (geological, structural, seismic, etc.). In general, the low to medium area strain values are compatible with a low activity character of the mainland Peloponnese area.

Finally, estimation of the areal rotation can indirectly contribute to the knowledge of the recent geodynamic evolution of area. To this end, the rotation pattern was modelled for three periods (1, 5 and 10 Myr BP), showing a dominant clockwise rotation of the study area. The results of the rotation analysis are preliminary in adequately good agreement with palaeomagnetic data for the broader area (Lazos et al., 2018).

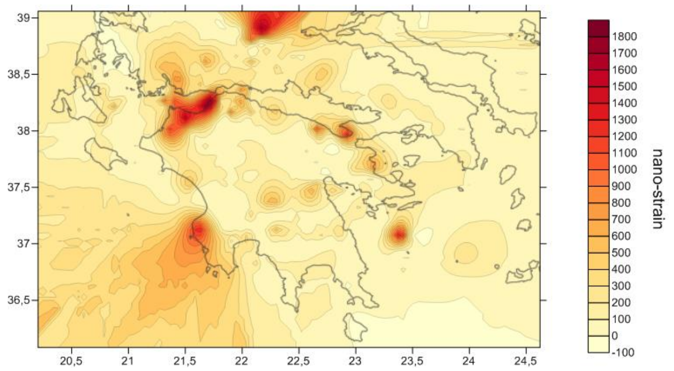

Figure 2. Interpolation of the maximum horizontal extension values of the study area. The highest values are concentrated at the northwestern part, where the epicentral area of the Andravida, 2008 earthquake is. Although this event did not produce significant ground deformation, its predominantly strike-slip regime was marked by performing parametric analyses on the primary data of the permanently installed GPS/GNSS network.

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