National Report of Greece to EUREF 2017

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1. Introduction

During the last months the main activities of the National Cadastre and Mapping Agency of Greece (NCMA SA) related to EUREF focused on geological phenomena that caused permanent displacements and/or changes of the tectonic velocities of HEPOS (Hellenic Positioning System) reference stations. The most representative studies are presented in this national report:

- Assessment of crustal deformations associated with the 2011-2012 unrest of the Santorini volcano.
- Estimation of the changes of station's velocities caused by the 2014 North Aegean Sea earthquake.

2. Crustal deformations due to the 2011-2012 unrest of the Santorini Volcano

After about six decades of seismic quiescence within Santorini caldera, in January 2011 the volcano reawakened with a significant seismic swarm and rapidly expanding radial deformation (Newman, 2012). This activity lasted until about April 2012 (Parks et al. 2015) without leading to eruption. The latest eruptions in the 20th century took place in 1950, 1939-1941 and 1925 (Parks et al. 2012).

From a geodetic point of view the 2011-2012 unrest of the volcano is important due to the induced changes in the coordinates of any point on Santorini, including the HEPOS station 048A, which is situated on the island. To investigate the magnitude and the geographic distribution of the displacements we used two datasets of GPS measurements conducted before and after the event on eleven benchmarks of the national trigonometric network. The first dataset consists of measurements conducted in 2007 as part of the HEPOS project for the development of the official transformation model between the reference frame of HEPOS (HTRS07: Hellenic Terrestrial Reference Frame 2007) and the national coordinate reference system GGRS87 (Greek Geodetic Reference System 1987) (Katsampalos et al. 2010). The second dataset consists of GPS measurements conducted by the Technological Educational Institute of Athens on the same benchmarks in 2017. In both datasets dual frequency receivers were used and the HEPOS station 048A was used as a base station for the formation of the GPS baselines. The occupation time was 60 min and 90 min for the first and the second dataset, respectively. The measured benchmarks and the corresponding baselines are shown in Fig. 1.

The first processing step was to solve the new measurements in order to compute the new coordinates. For this purpose the Trimble Business Center ver. 3.81 software was used. Keeping in mind that in both datasets the HEPOS station 048A was used as reference station, a direct comparison of the 2007 and 2017 coordinates would yield relative displacements with respect to station 048A. In order to obtain absolute displacements the dislocation of the HEPOS station due to the inflation had to be estimated. This was done by using the coordinate time-series of the station over the past years. More precisely, coordinates estimated by means of PPP (Precise Point Positioning) spanning from 2008.0 to 2015.5 were used. Fig. 2 and 3 show the time-series for the Easting and Northing, respectively. Clearly, the velocity of the station changed during the volcano

Fig. 1 The locations of the 11 benchmarks and the measured baselines.

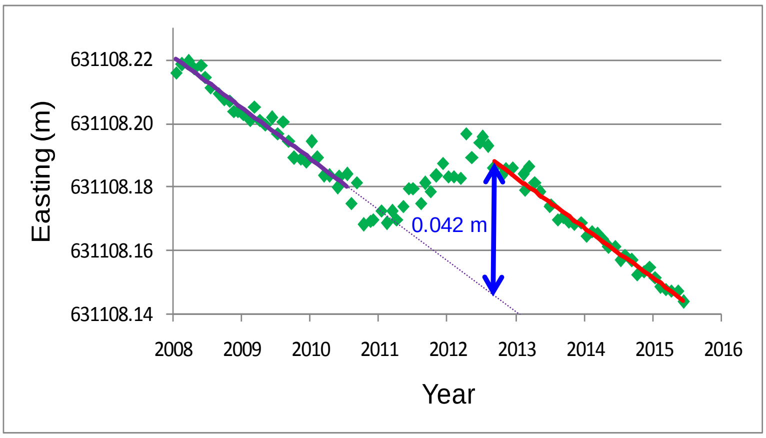

Fig. 2 Time-series of Easting of station 048A and its displacements due to the volcano inflation.

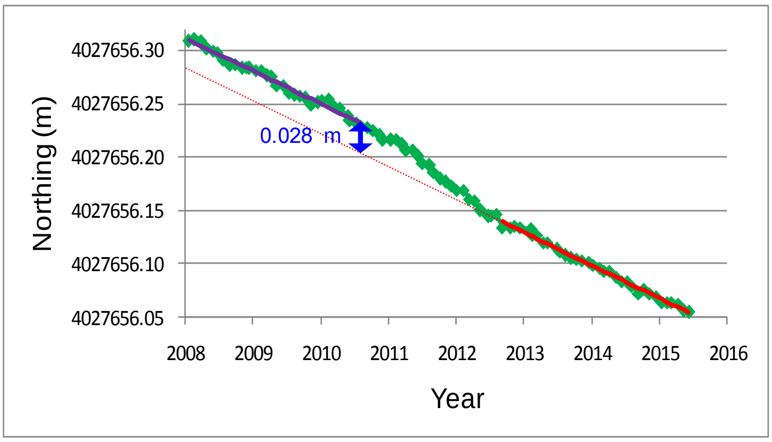

Fig. 3 Time-series of Northing of station 048A and its displacements due to the volcano inflation.

inflation. However, after the unrest period the velocity was stabilized at the same value as before the event. For more details the reader is referred to *Gianniou and Stavropoulou* (2016). Using the estimated velocities before and after the event, the displacement of station 048A was found to be 0.042 m to the East and 0.028 m to the South. These values were added to the coordinate differences between 2007 and 2017 in order to obtain absolute displacements of all points. Fig. 4 depicts the obtained dislocation vectors for the benchmarks as well as for the station 048A. With the exception of two points, these results agree quite well with the radial expansion pattern of the geological models published by other researchers (Saltogianni, et al., 2014; Papoutsis et al., 2013). The first point (with code 248016, located close to station 048A) is showing a displacement vector of correct magnitude but at a wrong direction. The second point (with code 248010 at the SW side of the island) is showing a vector pointing to the expected direction but its magnitude is unfittingly high. These two deviating vectors are caused by instabilities of the pillars, which are not anymore vertical (see Fig. 5), as it was the case in 2007. After excluding the two points with the proble-

Fig. 4 Displacement vectors (initial results).

Fig. 5 The pillars of the benchmarks 248016 (left) and 248010 (right).

matic pillars, we obtained our final results, shown in Fig. 6. The estimated displacements range from 0.040 m (point 248012) to 0.116 m (point 248033).

In closing, we should mention that the interpretation of the obtained displacements as a result of the 2011-2012 unrest episode presumes that no other significant activity took place between 2007 and 2017, which seems to be the case based on the available geological and seismological data.

Fig. 6 The displacement vectors (final results after excluding problematic points).

3. Change of tectonic velocities as a result of the 2014 North Aegean Sea earthquake

On May 24, 2014 a strong earthquake (Mw=6.9) stroke along the North Aegean Trough (NAT; see Fig. 7). Significant static horizontal displacements in the order of 10 cm were detected for the HEPOS station 018B in the nearby island of Samothrace (Gianniou et al., 2015), whereas displacements on the 1 cm level were identified on HEPOS stations at distances up to 120 km from the epicenter (Saltogianni et al., 2015).

Furthermore, examination of coordinate time-series spanning from 2008.0 to 2015.5 indicated that the earthquake caused changes in the tectonic velocities of the nearby HEPOS station 089A on the island of Lemnos. These coordinate time-series were produced using the Precise Point Positioning technique (Zumberge et al., 1997; Héroux and Kouba, 2001) in static mode and the CSRS (Canadian Spatial Reference System) PPP software. Instead of processing each day of the available data one daily solution was computed for each month. More details about the data and the processing can be found in *Gianniou and Stavropoulou* (2016). In order to get more accurate results, the time-series was extended from 2015.5 to 2017.3 by computing two daily solutions per month for this time period. The obtained coordinates as well as the estimated velocities for Easting and Northing before and after the earthquake are shown in Fig. 8. Clearly, after the earthquake

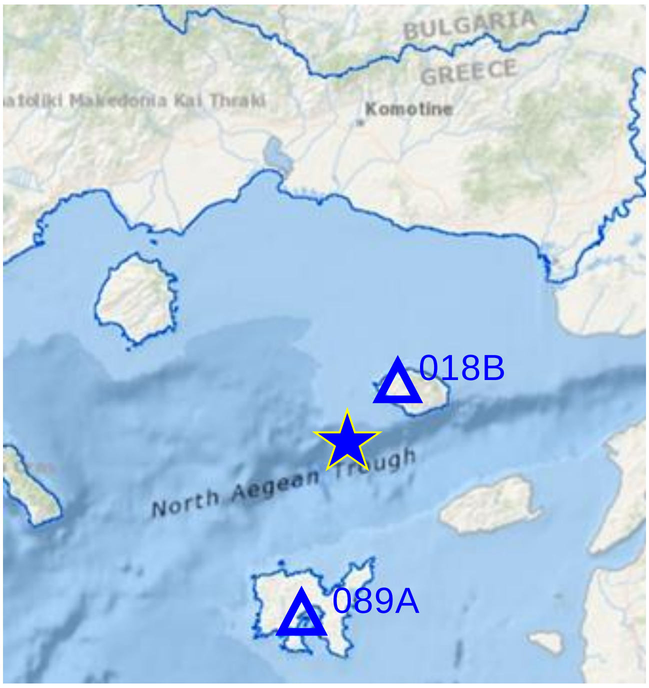

Fig. 7 Epicentre of the May 24, 2014 earthquake (blue star) and the nearby HEPOS stations 089A and 018B.

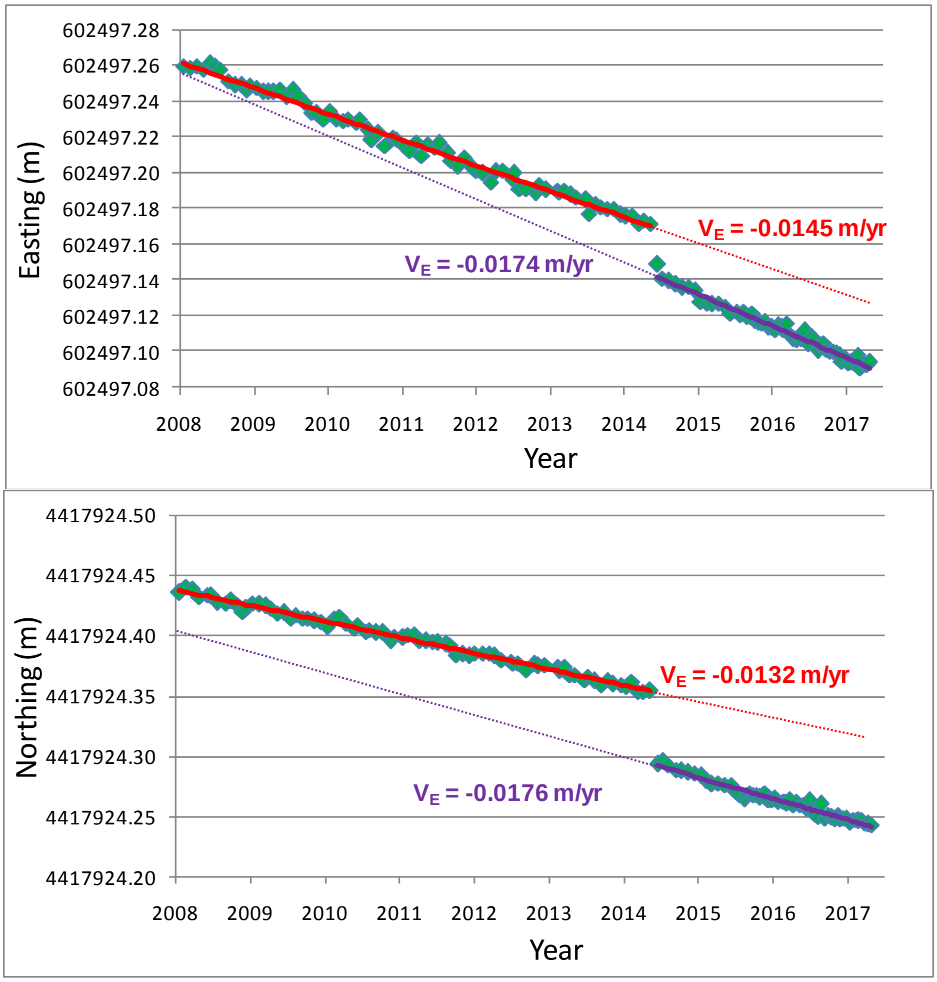

Fig. 8 Coordinate time-series for station 089A and estimated velocities before (in red) and after the earthquake (in purple).

a significant increase in the station's velocity is observed. Table 1 gives the velocities before and after the event as well as the relative changes.

Table 1. Tectonic velocity (m/yr) before and after the earthquake

	Before the earthquake	**After the earthquake**	**Change**
Easting	-0.0145	-0.0174	+20%
Northing	-0.0132	-0.0176	+33%

This velocity change was observed only for station 089A on Lemnos island, not for station 018B on Samothrace island although it is closer to the epicentre. This could be explained by the faulting mechanism (strike-slip) and the fact that the NAT consists the northern border of the Aegean plate which is moving southwest with respect to Eurasia (Papazachos et al., 2000). In any case such changes in the tectonic velocities are critical when velocities fields are being computed and/or are in use like e.g. in the case of a dynamic or semi-dynamic datum.

Acknowledgments

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