National Report of Greece to EUREF 2016

M.Gianniou, E. Mitropoulou, D. Mastoris
National Cadastre and Mapping Agency S.A.
Mesogion Ave. 288, 15562 Athens, Greece

1. Introduction

During the last months the main activities of the National Cadastre and Mapping Agency of Greece (NCMA S.A.) related to EUREF include:

- Estimation of velocities of the stations of HEPOS (Hellenic Positioning System) based on 7.5 years of observations
- Monitoring of the ionospheric activity over Greece
- Study of reference station displacements as a result of the 2015 Lefkada, Ionian Sea earthquake.

This national report describes the aforementioned activities.

2. Estimation of velocities of HEPOS stations

Greece lies in the boundary region between the Eurasian and the African plate. Moreover, the southern part of the country lies on the Aegean plate, a smaller plate which is moving southwest (Papazachos et al., 2000). This situation leads to an inhomogeneous velocity field which plays a critical role in the operation of HEPOS. The problem of maintaining a reference frame in seismo-tectonically active areas is being studied at international level. In this context the EUREF Technical Working Group has set up two initiatives: the EPN densification project and the EUREF Working Group on Deformation Models (Bruyninx et al., 2015).

The changes in the geometry of the HEPOS network as a result of the different station velocities have been studied already during the first years of operation of the network (Gianniou, 2010). In order to study in detail the velocity field in Greece NCMA S.A. analysed 7.5 years of HEPOS data and estimated precise velocities for the network stations. The processing of the GPS data was performed using the Precise Point Positioning technique (Zumberge et al., 1997; Héroux and Kouba, 2001) in static mode and using the CSRS (Canadian Spatial Reference System) PPP software. IGS final precise orbits and clocks were used, the elevation mask was set to 10^o and the processing interval was 30s. Instead of processing each day of the available data (7.5 years spanning from 2008.0 to 2015.5) one solution was computed for each month. Thus, a time-series of 90 solutions was produced for each station. The horizontal velocities were computed in ERTF2000. In order to make an evaluation of the reliability of the results the six Greek EPN stations were included in the computations and the estimated velocities were compared to the velocities published by EURF (EPN cumulative solutions). The comparison showed an agreement in the order of 10^{-4} m/yr. For a detailed description of the data analysis schema, the intermediate results and special considerations for earthquake-induced discontinuities the reader is referred to *Gianniou and Stavropoulou (2016)*.

Fig. 1 and Fig. 2 give two representative results of the produced time-series. Fig. 1 depicts the time-series for a station of relatively small horizontal velocity (0.0073 m/yr) while Fig. 2 shows the time-series for the fastest moving station within HEPOS (0.0363 m/yr). The red lines in Fig. 1-2 represent the linear trend calculated by means of least squares. Fig. 3 shows the estimated horizontal velocities for all stations. The obtained velocity field is consistent with previously published results (Nyst and Thatcher, 2004; Chatzinikos et al, 2013) and has the advantage of being based on homogeneous data set, i.e. uniform distribution of stations and long time-series (90 monthly solutions spread over 7.5 years).

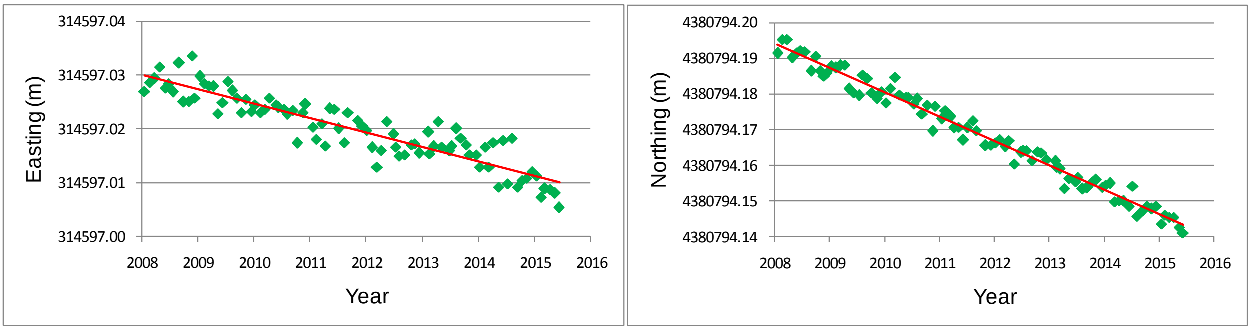

Fig. 1 Time-series for Easting (left) and Northing (right) of HEPOS station 071A in Thessaly.

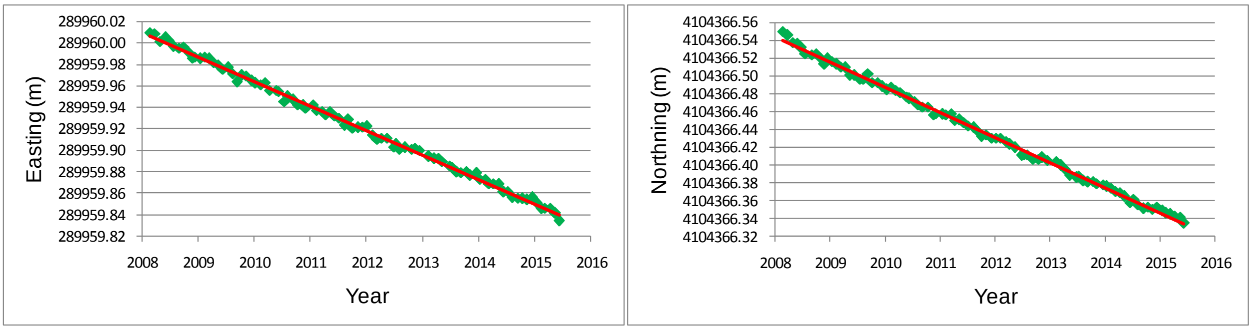

Fig. 2 Time-series for Easting (left) and Northing (right) of HEPOS station 063A in Peloponnese.

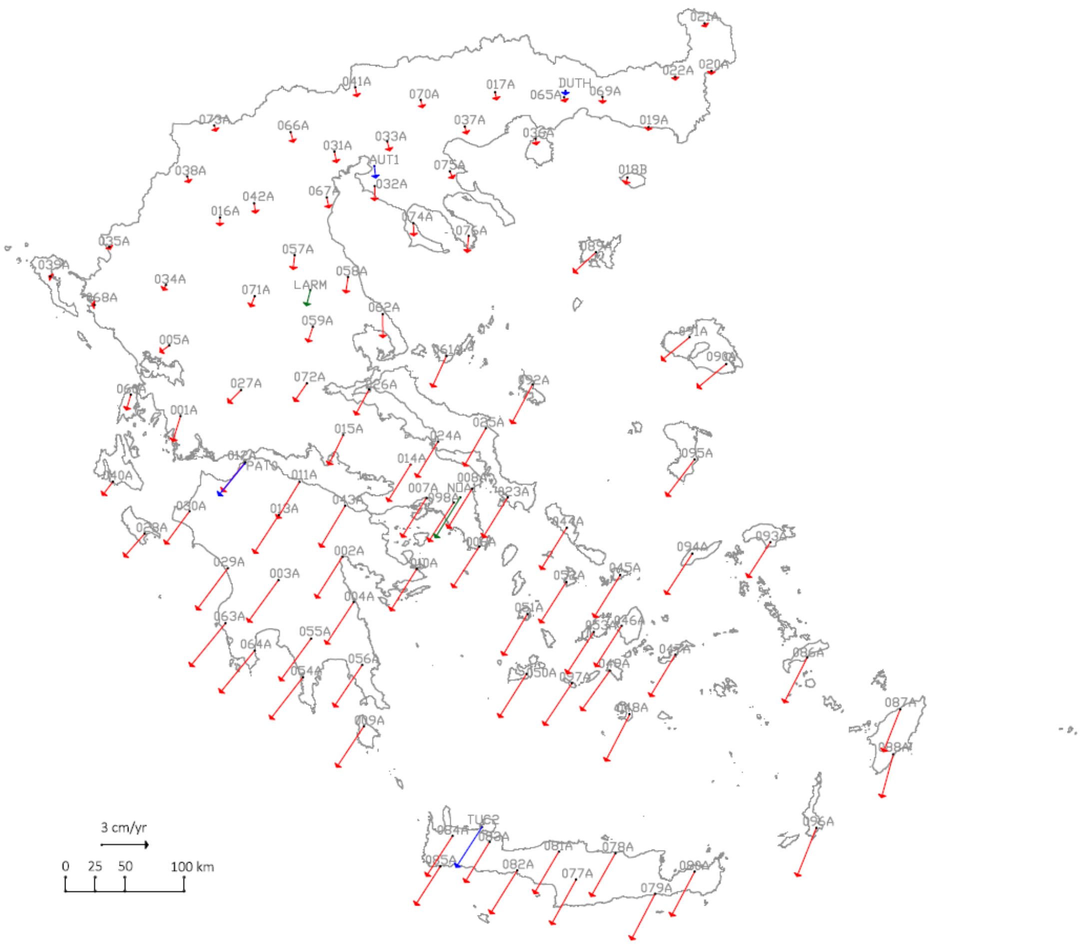

Fig. 3 Estimated horizontal velocities in ETRF2000 for HEPOS stations (red arrows) and EPN Class B stations (green arrows). For comparison reasons the velocities published by EUREF for the EPN Class A stations are also shown (blue arrows).

3. Monitoring of the ionospheric activity over Greece

During 2011 and 2012 intense ionospheric activity seriously affected the performance of RTK measurements in Greece, mainly in the southern part of the country. RTK-users had often needed longer times to obtain fixed solution than in the years before. Sometimes, initialization could hardly be achieved (Gianniou and Mitropoulou, 2012). On this occasion and knowing that the maximum of the 24th Solar Cycle was about to come, NCMA S.A. started in 2012 to monitor the ionospheric index I95 (Wanninger, 1999) in order to support the HEPOS users in the most efficient way (Gianniou and Mastoris, 2013). The time-series of I95 of HEPOS describes quite well the ionospheric activity over Greece in the years around the maximum of the 24th Solar Cycle. Fig. 4 shows the daily maximum of I95 for Crete and for the rest of the HEPOS network (mainland and islands) for the time period January 2010 to April 2016. As it can be seen, the maximum of the 24th Solar Cycle did not take place in 2003 as it was initially expected. Actually, the 24th Solar Cycle proved to be double-peaked. Furthermore, the second peak was higher than the first one. These facts had already been observed in 2014 examining the time-series from January 2010 to May 2014 (Gianniou et al., 2014). Since the last months the ionospheric activity is at moderate levels and RTK operations in Greece are not seriously affected by the ionosphere. Thus, the extension of the time-series to April 2016 describes better the ionospheric activity during the maximum of the 24th Solar Cycle.

A more representative overview of the ionospheric activity can be obtained using mean daily I95 values, instead of daily maximum values. So, starting from 1.1.2010 a mean I95 value (mean daily) was computed for each day from the 24 hourly values that are computed in HEPOS on a daily basis. Fig. 5 shows the mean daily I95 values (smoothed using a moving average filter with a span of 7 days). The two peaks of the 24th Solar Cycle (around November 2011 and March 2014) can clearly be seen, with the second one being higher.

In order to compare the I95 index (mean daily values) with other measures of the ionospheric/solar activity the time-series of the sunspot number was examined. Fig. 6 shows the time-series of the sunspot number which clearly indicates that the second peak of the solar activity was higher than the first one.

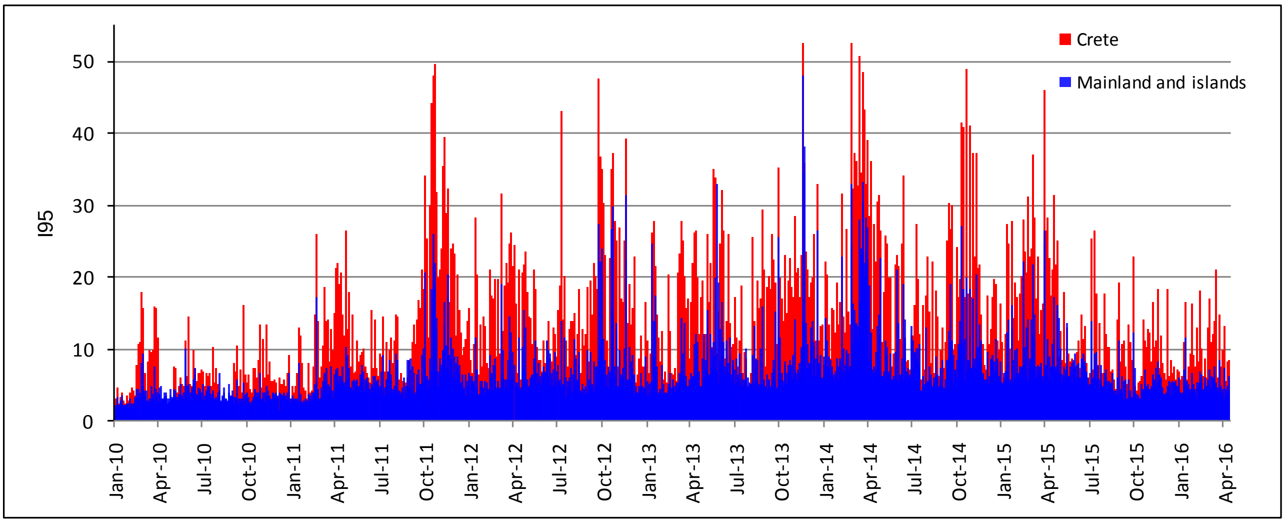

Fig. 4 Maximum daily I95 index estimated from HEPOS.

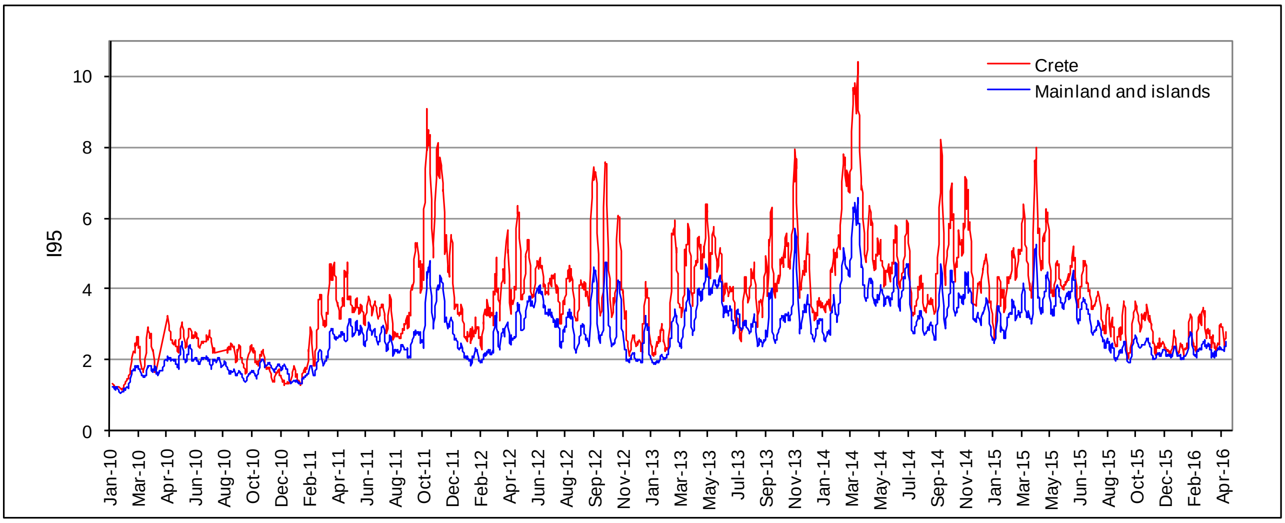

Fig. 5 Mean daily I95 index estimated from HEPOS (values are smoothed using moving average filtering).

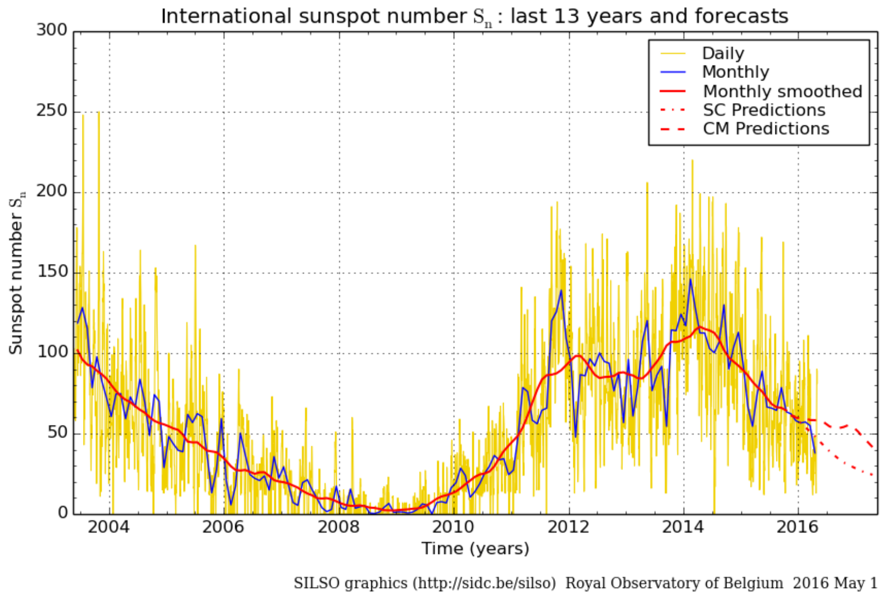

Fig. 6 Sunspot number for the last 13 years (source: Royal Observatory of Belgium)

4. Displacements caused by the 2015 Lefkada, Ionian Sea earthquake

On 17.11.2015 a strong Mw6.5 earthquake occurred on Lefkada Island in the Ionian Sea along a strike-slip fault. The earthquake triggered severe environmental effects like rock falls and landslides, mainly in the south-western part of the island. Moreover, the event caused significant horizontal coseismic deformations in the order of tens of centimeters (Ganas et al., 2016). These permanent displacements are of particular importance from a geodetic point of view. In order to investigate the impact of the earthquake on the reference stations of HEPOS we processed the data from the HEPOS stations that are located in the wider area of the earthquake, i.e. to distances between 14 and 66 km. In addition, we processed data from station PONT that belongs to NOANET, the GNSS network of the National Observatory of Athens (http://www.gein.noa.gr/services/GPS/noa_gps.html). This station is very important for the study of the deformations because it is located very close to the epicenter (about 5 km) and, moreover, it is located south of the epicenter, i.e. in the part of the island where the maximum displacements took place.

Fig. 7 Epicentre of the November 17, 2015 earthquake (yellow star).

The processing of the data was done using the Precise Point Positioning (PPP) method (Zumberge et al. 1997; Héroux and Kouba, 2001). We chose to use this approach rather than geodetic relative positioning, in order to avoid biased displacement estimation as a result of eventual displacements of the nearby stations that would be used as reference in the formation of the baselines. The PPP computations were made using the CSRS-PPP software. Dual frequency phase observations were used together with IGS final precise orbits (sp3 files) and clocks (clk files) (Kouba, 2003). The processing interval was 15s and the elevation mask 10^o.

Daily solutions were computed by processing 24-hour long observation files in PPP static mode. For each station the time period 1-30 November, 2015 was processed, which corresponds to 16 days before the event and 13 days after the event. Fig. 8-9 give the time-series of the estimated Easting and Northing coordinates of station 060A located on the island of Lefkada. The changes in

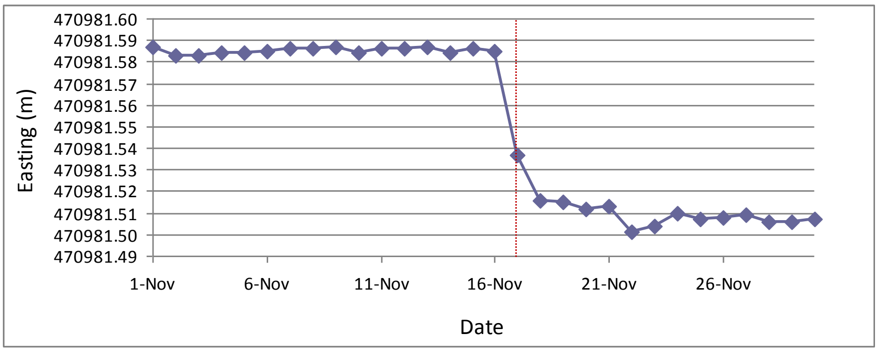

Fig. 8 Time-series of Easting of station 060A (the vertical dashed line indicates the day of the earthquake).

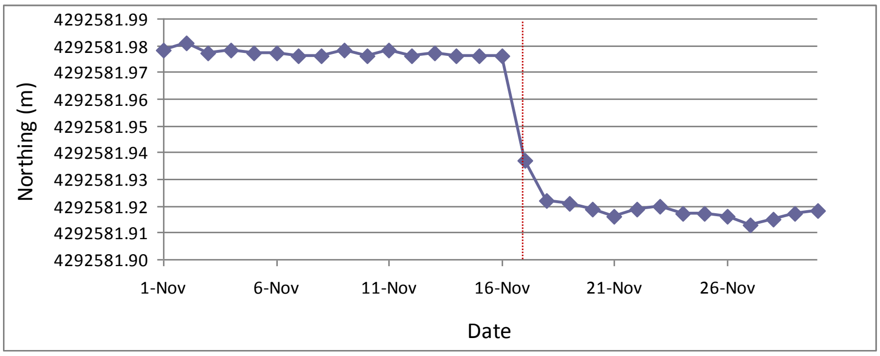

Fig. 9 Time-series of Northing of station 060A (the vertical dashed line indicates the day of the earthquake).

Easting and Northing are obvious and amount -76 mm and -59 mm, respectively. These coordinate changes correspond to a horizontal displacement of 9.6 cm at an azimuth of 232°. The slip vectors estimated for all stations under investigation are depicted in Fig. 10. As can be seen the longest slip vector was obtained for the station PONT and is in the order of 40 cm.

To conclude, deformations of this magnitude consist a major challenge for the maintenance of the reference frame. In order to handle efficiently such displacements a detailed deformation model should be available as soon as possible after the earthquake. However, for a complicated event like the 2015 Lefkada earthquake it usually takes some time until detailed deformation models are computed and published.

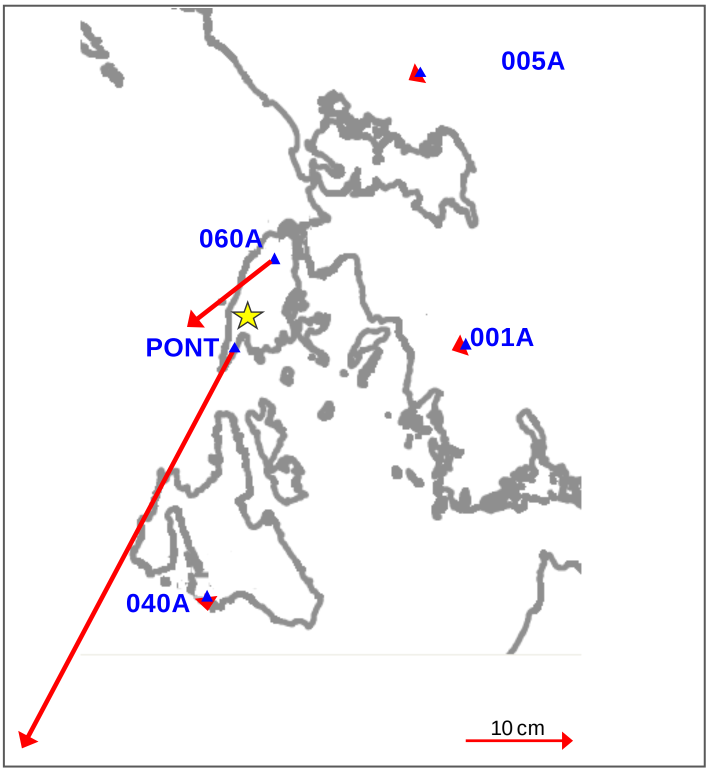

Fig. 10 Estimated static horizontal displacements at five reference stations. The epicentre of the earthquake is marked by yellow star.

Acknowledgments

The GPS data of station PONT were retrieved from the NOANET website (http://www.gein.noa.gr/services/GPS/NOA_GPS/noa_gps_files/data.html). The HEPOS project was co-funded by the European Regional Development Fund in the framework of the Operational Program "Information Society". Mrs. Vasiliki Kalantzi assisted the processing of the ionospheric data.

References

Bruyninx, C., Z. Altamimi, E. Brockmann, A. Caporali, R. Dach, J. Dousa, R. Fernandes, M. Gianniou, H. Habrich, J. Ihde, L. Jivall, A. Kenyeres, M. Lidberg, R. Pacione, M. Poutanen, K. Szafranek, W. Söhne, G. Stangl, J. Torres and C. Völksen (2015), Implementation of the ETRS89 in Europe: Current Status and Challenges, *International Association of Geodesy Symposia,* DOI 10.1007/1345_2015_130, Springer Verlag, pp. 1-11.

Chatzinikos, M., A. Fotiou, C. Pikridas and D. Rossikopoulos (2013), New results of the velocity field in Greece by an automatic process of a permanent GPS network. *EUREF 2013 Symposium*, Budapest, Hungary, May 29-31 2013.

Ganas, A., D. Melgar, P. Briole, J. Geng, G. Papathanassiou, G. Bozionelos, A. Avallone, S. Valkaniotis, E. Mendonidis, P. Argyrakis, A. Moshou and P. Elias (2016), Coseismic deformation and slip model of the 17 November 2015 M = 6.5 earthquake, Lefkada Island, Greece. *Geophys. Res. Abstr.* 18 (EGU2016–12041, EGU General Assembly 2016).

Gianniou, M. (2010), Tectonic deformations in Greece and the operation of HEPOS, *EUREF 2010 Symposium*, Gävle, Sweden, June 2-4 2010.

Gianniou M. and E. Mitropoulou (2012), Impact of high ionospheric activity on GPS surveying: Experiences from the Hellenic RTK-network during 2011-12, *EUREF 2012 Symposium*, Saint Mandé, France, June 6-8 2012.

Gianniou M. and I. Stavropoulou (2016), Estimation of tectonic velocities using GPS Precise Point Positioning: The case of Hellenic RTK network HEPOS, *EUREF 2016 Symposium*, San Sebastian, Spain, May25-27 2016.

Gianniou, M. and D. Mastoris (2013), National Report of Greece to EUREF 2013, *EUREF 2013 Symposium*, May 29-31 2013, Budapest, Hungary.

Héroux, P. and J. Kouba (2001), GPS precise point positioning using IGS orbit products, *Phys. Chem. Earth* Part A, 26(6–8), 573–578, doi:10.1016/S1464-1895(01)00103-X.

Kouba, J. (2003), Measuring seismic waves induced by large earthquakes with GPS, *Stud. Geophys. Geod*. 47(4), 741–755.

Nyst, M. and W. Thatcher (2004), New constraints on the active tectonic deformation of the Aegean, *J. Geophys. Res*., Vol. 109.

Papazachos, B., G., Karakaisis, C. Papazachos and E. Scordilis (2000), Earthquake triggering in the North and East Aegean Plate Boundaries due to the Anatolia Westward Motion, *Geophysical Research Letters, Vol. 27,* No. 23, pp. 3957-3960.

Wanninger, L. (1999), The Performance of Virtual Reference Stations in Active Geodetic GPS-Networks under Solar Maximum Conditions. *Proceedings of the 12th International Technical Meeting of the Satellite Division of The Institute of Navigation (ION GPS 99),* Nashville TN, 1419-1427.

Zumberge, J. F., M. B. Heflin, D. C. Jefferson, M. M. Watkins and F. H. Webb (1997), Precise point positioning for the efficient and robust analysis of GPS data from large networks, *J. Geophys. Res*., 102(B3), 5005–5017, doi:10.1029/96JB03860.