National Report of Greece to EUREF 2012

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1 Introduction

KTIMATOLOGIO S.A is a state-owned company responsible for the establishment and operation of the Hellenic Cadastre. The company has established and operates the HEPOS network. The underlying geodetic reference system of HEPOS (HTRS07: Hellenic Terrestrial Reference System 2007) is a realization of ETRS89. During the last months the main geodetic activities undertaken in Greece related to EUREF include:

- evaluation of the transformation model between the Hellenic realization of ETRS89 (HTRS07) and the national geodetic reference system GGRS87 (Greek Geodetic Reference System 1987)
- evaluation of the HEPOS geoid model that was developed by KTIMATOLOGIO SA in 2011
- investigation of the impact of ionospheric activity on GPS surveying using HEPOS.

This national report describes the aforementioned activities and also presents the growth of the usage of HEPOS.

2 Evaluation of the HEPOS transformation model

The coordinates of the HEPOS stations have been computed in HTRS07, which is a realization of ETRS89 in Greece (Katsampalos et al., 2010; Gianniou, 2010). The transformation between ETRS89 (HTRS07) and the national reference system (GGRS87) is being done using the official coordinate transformation model, which was issued for usage with HEPOS (Katsampalos et al., 2010). A first evaluation of the transformation model was done in 2008, at the stage of developing the model, by means of 231 test points uniformly distributed throughout Greece (Katsampalos et al., 2010). As the usage of HEPOS is steadily increasing a great number of data becomes available. Taking advantage of these data KTIMATOLOGIO S.A. started an in-house project for the evaluation of the transformation model between HTRS07 and GGRS87. In the framework of this project GPS measurements conducted on benchmarks of the national trigonometric network are being processed using HEPOS stations. The obtained HTRS07 coordinates are transformed to GGRS87 using HEPOS transformation model and then compared to the official coordinates of the benchmarks. To ensure accurate results, observations of at least one-hour duration are being used. Only in a limited number of cases (small baselines) observations of shorter duration (20-60 min) are used.

Up to now, a total of 594 benchmarks were used. Their locations are depicted in Figure 1. The horizontal error dS for each point was computed based on the differences between the official coordinates of the benchmark ($E_{off.}$, $N_{off.}$) and the coordinates estimated by means of HEPOS ($E_{estim.}$, $N_{estim.}$), i.e.:

$$\boldsymbol{dS} = \sqrt{\left(E_{off.} - E_{estim.}\right)^2 + \left(N_{off.} - N_{estim.}\right)^2} \quad (1)$$

The obtained horizontal errors are graphically represented in Figure 2. As can been seen, for the

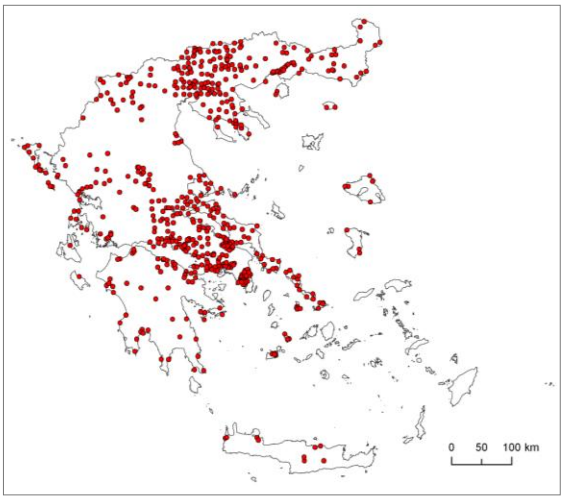

Fig. 1 The locations of the 594 benchmarks used for the evaluation of the transformation model.

majority of the points the horizontal error is below 5 cm. For a limited number of points (17 points corresponding to less than 3% of the sample) the error exceeds 15 cm, which error is considered high. In order to investigate such cases, local 7-parameter similarity transformations were computed for the areas of the points with high errors. As a first step, a local transformation was computed for the area of the benchmark with the highest error (0.242 m; point 169 in Figure 2 corresponding to benchmark code 107035). Figure 3 shows the six trigonometric benchmarks used for the computation of the local transformation as well as the horizontal residuals of the transformation. Clearly, point 107035 shows the largest horizontal residual (0.173 m). Moreover, the direction of its residual vector is opposite (S-SE) compared to the direction of the residuals of its closest points (mostly N-NW). This proves that point 107035 is a problematic benchmark, inherently inconsistent to its neighboring ones. Thus, it is justified that the horizontal error of the official transformation HTRS07-GGRS87 is high on this point.

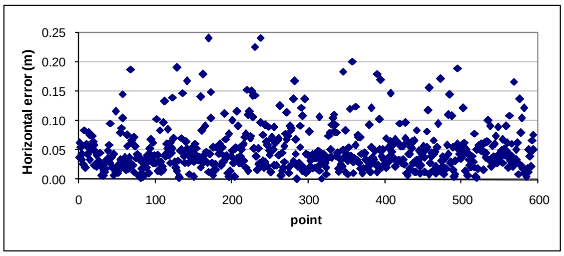

Fig. 2 Horizontal errors for the 594 benchmarks used for the evaluation of the HEPOS transformation model.

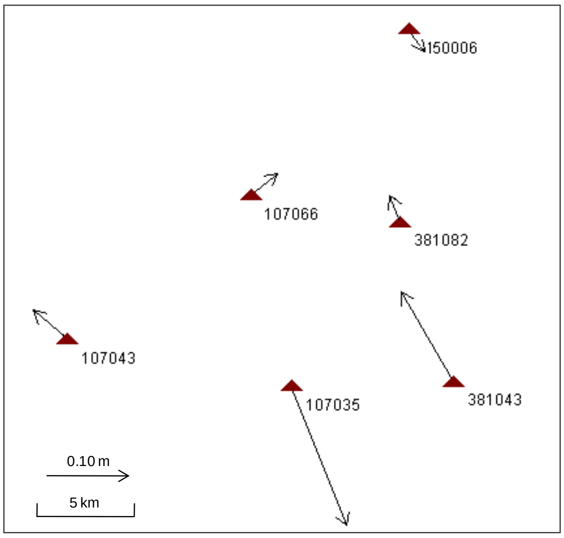

Fig. 3 Horizontal residuals of a local similarity transformation in the area of benchmark 107035.

Actually, it is wished that the transformation shows high errors on problematic benchmarks, in order to avoid unnecessary distortions in the representation of the reference frame. As in the case of point 107035, most of the points that are showing high transformation errors in Figure 2 were found to be problematic benchmarks.

In order to quantify the performance of the transformation HTRS07-GGRS87, statistics over the entire sample of the 594 benchmarks were computed. Table 1 summarizes the results.

Table 1 Statistics of the horizontal errors (m) of the 594 points used for the evaluation of the transformation HTRS07-GGRS87.

Min	Max	Percentiles			
		50th	90th	95th	99th
0.001	0.242	0.040	0.097	0.133	0.188

3 Evaluation of the HEPOS geoid model

In 2011, KTIMATOLOGIO S.A. developed a geoid model that allows the transformation of the ellipsoidal HTRS07 heights obtained from HEPOS to orthometric heights (Gianniou, 2011). Taking advantage of available GPS data KTIMATOLOGIO S.A. started an in-house project for the evaluation of the HEPOS geoid model. The data that were used as well as the processing schema are described in Section 2. However, not all of the 594 points used for the evaluation of the transformation model were used for the evaluation of the geoid model. Many of these points had been used for the development of the geoid model, so it was decided not to use these points for its evaluation to ensure unbiased results. For the evaluation of the geoid model a total of 254 benchmarks have been used. Their locations are shown in Figure 4. The height error *dH* for each point was computed by subtracting the orthometric height estimated using HEPOS geoid model from the official orthometric height of the benchmark. The obtained height errors are graphically represented in Figure 5. Table 2 summarizes the statistics of the errors. As can be seen, the height errors for the vast majority of the points (90%) are below 0.176 m, while only 1% of the points have errors exceeding 0.455 m. These error values constitute a good performance of the geoid model, particularly if we take into account that the official heights of the trigonometric benchmarks have been mainly estimated by means of trigonometric leveling, not spirit leveling. Thus, their accuracy is rather in the dm level than in the cm level. Moreover, the official heights of the trigonometric benchmarks have been estimated before approximately four decades. Consequently, differences between the official heights and newly estimated heights are expected in geologically active areas. Typical examples are the subsiding areas of Thessaloniki plain (Stiros, 2001; Psimoulis et al., 2007) and of Messara Valley in Crete (Mertikas et al., 2010).

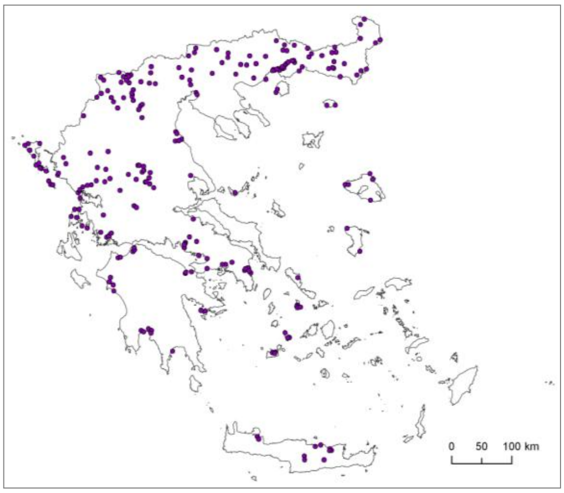

Fig. 4 The locations of the 254 benchmarks used for the evaluation of the HEPOS geoid model.

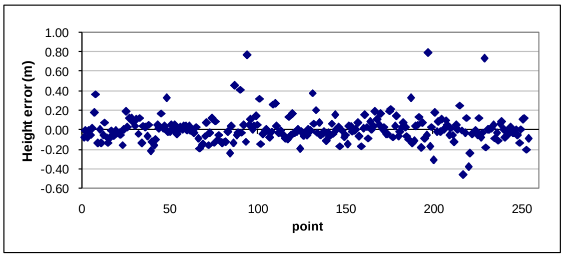

Fig. 5 Height errors for the 254 benchmarks used for the evaluation of the HEPOS geoid model.

Table 2 Statistics of the height errors (m) of the 254 points used for the evaluation of the HEPOS geoid model.

Min	Max	Percentiles			
		50th	90th	95th	99th
0.000	0.793	0.056	0.176	0.260	0.455

4 Assessment of ionospheric influence on network-RTK

Since 2011, RTK users of HEPOS often need longer initialization times than in the previous years. Sometimes, initialization cannot be achieved at all. Such difficulties were expected as we are approaching the maximum of the 24th solar cycle.

The intensity of the ionospheric activity can be assessed by means of the hourly I_{95} values computed in HEPOS. I_{95} is an index computed in RTK networks and it is based on the ionoshperic gradients in the south-north and east-west directions (Wanninger, 2004). Figure 6 shows an example of high ionospheric activity (March 21, 2012) reflected in high I_{95} values observed in HEPOS.

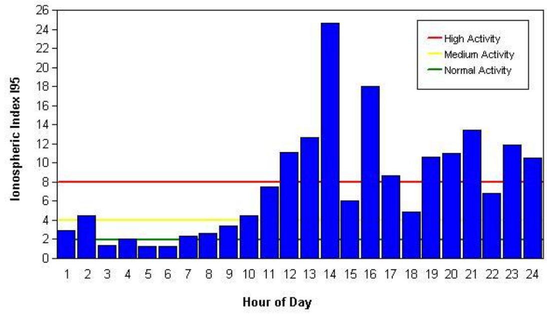

Fig. 6 I_{95} values for Crete on March 21, 2012.

In order to assess the impact of high ionospheric activity on the performance of GNSS geodetic positioning, we analyzed RTK and static measurements. The initialization time was examined with respect to the intensity of ionospheric refraction. Our tests demonstrated that during times of high ionospheric activity the initialization takes longer, whereas in certain cases it cannot be achieved at all. A detailed description of the tests that have been made and the results obtained can be found in *Gianniou and Mitropoulou* (2012).

5 Observation of co-seismic dynamic displacements

Coordinate stability is crucial for every GPS RTK network. Greece is characterized by an inhomogeneous tectonic velocity field (Nyst and Thatcher, 2004; Hollenstein et al., 2006). Moreover, Greece is the most seismically active area in Europe. For these reasons, in the framework of operating HEPOS, GPS data are being analyzed to estimate tectonic movements (Gianniou, 2010) as well as permanent displacements caused by strong earthquakes (Gianniou, 2011). In order to investigate further the impact of earthquakes on HEPOS stations, 1Hz data were processed in kinematic mode to estimate co-seismic dynamic displacements. The strong earthquake (Mw=6.4) which occurred in Achaia-Ilia (NW Peloponnese, Greece, near the town of Andravida) on June 8, 2008 (Margaris et al., 2008) was used as a case study. Coordinate time-series at a rate of 1 Hz were created for HEPOS stations 030A and 012A using GAMIT/TRACK software (Herring et al., 2010). Station 001A was used as base station. As can be seen in Figure 7, station 001A is located in central Greece at a distance of 80 km from the epicentre. Station 001A was chosen as base station because (due to its location) it is considered to be practically unaffected by the event, while -at the same time- its distance from stations 030A and 012A is adequate to ensure precise baseline solutions.

Fig. 7 The epicentre of the Andravida 2008 earthquake (red star) and the surrounding HEPOS stations (triangles). The two baselines indicate the stations processed for the investigation of co-seismic dynamic displacements.

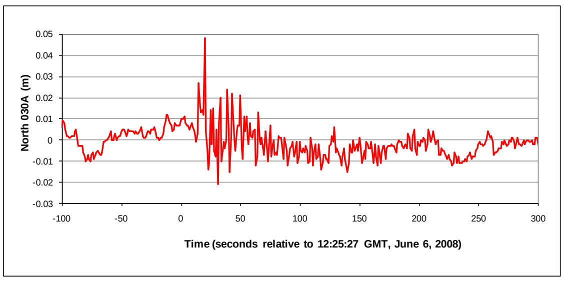

Fig. 8 Co-seismic dynamic displacements at HEPOS station 030A (east coordinate) caused by the Andravida 2008 earthquake.

Figures 8 and 9 show the time-series for the east coordinates of stations 030A and 012A, respectively. Coordinate variations exceeding 4 cm are obvious. For seismological research one should keep in mind that the data used were sampled at 1 sec, which is not sufficient to provide “alias-free” solutions of co-seismic dynamic displacements (Avallone et al., 2011).

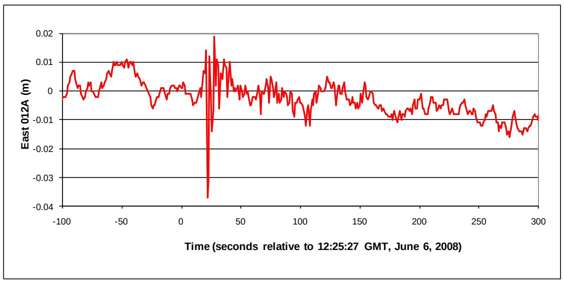

Fig. 9 Co-seismic dynamic displacements at HEPOS station 012A (east coordinate) caused by the Andravida 2008 earthquake.

The results described in Figures 8-9 are preliminary. We intend to extend our research by examining more HEPOS stations around the epicenter and by processing the data with other techniques like PPP (Precise Point Positioning).

6 Usage of HEPOS

HEPOS is progressively being used by an increasing number of professional geoscientists. Within the last year, the number of the issued user licenses increased from 680 (Gianniou, 2011) to 1074, which corresponds to an increment of 58%. These numbers fully meet our expectations. Figure 10 depicts the increment in the number of the issued HEPOS user licenses.

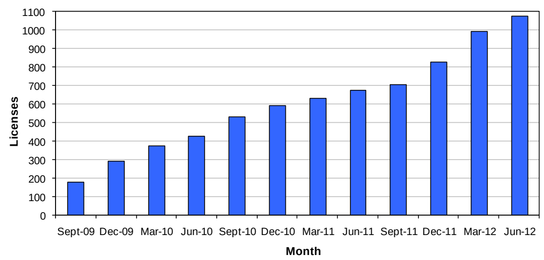

Fig. 10 HEPOS user licenses issued (cumulative) until June, 2012.

Acknowledgments

For the evaluation of the HEPOS transformation model and geoid model measurements on 621 benchmarks of the national triangulation network were used: 436 originate from KTIMATOLOGIO S.A. projects and 185 from academic institutions that collaborate with KTIMATOLOGIO S.A., namely AUTH (Aristotle University of Thessaloniki), NTUA (National Technical University of Athens), TEI of Athens (Technological Educational Institute of Athens) and TUC (Technical University of Crete).

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