National Report of Greece to EUREF 2021

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1. Introduction

During the last months the main activities of the Hellenic Cadastre related to EUREF focused on the upgrade of the HEllenic POsitioning System (HEPOS) and the estimation of permanent displacements caused by two strong earthquakes. This report describes the details of upgrading HEPOS to full GNSS (Global Navigation Satellite Systems) and the displacements of HEPOS stations induced by:
- The 2020 Samos, east Aegean Sea earthquake
- The 2021 Elassona, Thessaly, central Greece earthquake.

2. Upgrade of HEPOS to full GNSS

2.1 Preface

The HEllenic POsitioning System was established in 2007 as part of the project "Information Society" co-funded by the European Regional Development Fund. In 2008 it started its initial operation and was used by cadastral contractors, whereas in 2009 it was made available to the community. It consists of 98 reference stations, and supports network-RTK (VRS, MAC, FKP) and post-processing services (RINEX & VRINEX) (Gianniou, 2009). HEPOS is the official system for the cadastral surveys in Greece. The coordinates of its stations are expressed in the European Terrestrial Reference System 1989 (ETRS89) and constitute the official realization of ETRS89 in Greece approved by EUREF (EUREF, 2010). HEPOS is at the time of writing serving more than 1200 users (more than 1700 user licences). In 2020, using national funds, HEPOS was upgraded to full GNSS as described in the following.

2.2 Project details

The project started in 2019 and has two main components: a) the upgrade of the network to full GNSS and b) the maintenance of the network for 3.5 years. The upgrade has been concluded in 2020. The maintenance is being supplied from the beginning of the project and will last until the end of the project to ensure unproblematic completion of the extensive cadastral survey projects that are under deployment in Greece. Other parts of the project include testing of the upgraded system, training of the personnel and technical support, as described in the following sections. The contractual price for the complete project was 2 M€.

2.3 System upgrade

At the time of designing and establishing HEPOS the vast majority of the European RTK-networks were supporting solely GPS. The next evolution step was the combined use of GPS and GLONASS. In the latest years there was a significant progress in the deployment of the constellations of Galileo and BEIDOU. Thus, HEPOS has been upgraded, in order to support all four GNSS, i.e. GPS, GLONASS, Galileo and BEIDOU as well as SBAS (Satellite Based Augmentation Systems). The previously installed Trimble NetRS receivers were replaced by

Trimble Alloy receivers as shown in Table 1. The new receivers are capable of tracking all signals transmitted by the GNSS satellites (Table 2).

Table 1. Upgrade of HEPOS receivers and antennae

	Initial network	After Upgrade
Receivers	Trimble NetRS	Trimble Alloy
Antennae	Trimble Zephyr geodetic with dome *IGS code: TRM41249.00 TZGD*	Trimble Zephyr geodetic model 3 with dome *IGS code: TRM115000.00 TZGD*

Table 2. GNNS signal tracked by the upgraded HEPOS receivers

Satellite system	Signals tracked
GPS	L1, L2, L2C, L5, L1C
GLONASS	G1, G2, G3
Galileo	E1, E5a, E5b, E5alt-BOC, E6
BEIDOU	B1, B2, B3
EGNOS-WAAS-GAGAN	L1C/A, L5

Besides the upgrade of the GNSS equipment at the reference stations, the software in the Control Centre was also upgraded to support full GNSS operation. The old software Trimble GPSNet was replaced by Trimble PIVOT Platform. Selected features of the software are outlined in Table 3. The new software is hosted in powerful rack servers (Dell PowerEdge 540). Redundant servers are used, in order to minimize the impact of a possible hardware failure.

Table 3. Selected features of the new software in the Control Centre of HEPOS

Item	Software capabilities
Full GNSS	RTCM 3.2 and MSM 3-7 are supported for full GNSS RTK.
Modelling	Individual station velocities are supported.
Access plans	Access (contract) plans are customizable.
GDPR	The software supports the necessary tools to comply with GDPR (web site, passwords management etc.).
User accounts	Users are able to change personal data, reset password, view subscription information and usage details.

2.4 New services

Besides the full GNSS capability, the upgrade of HEPOS offers also new functionalities that registered users can benefit. Now, users have access to their personal and contract details. They can change personal data, reset their password and get information regarding their subscriptions (start and expiration dates, used and remaining time of the service etc.). Further to that, the users can retrieve detailed information of the usage they make, in terms of connection times, used services, duration etc. Also, the users, by logging into the system can have various information, like station status, ionospheric index I95, quality indexes IRIM/GRIM and notices issued by the system operators.

2.5 Other project components

After the completion of the upgrade, a testing phase took place. During the testing phase, extensive checks were performed to verify the satisfaction of all the technical specifications of the complete system as well as the backwards compatibility of the coordinates.

Another important project component was the training of the network operators on elements of the operation and administration of the upgraded system. The training program was provided in two phases. The aim of the first part of training was for the employees to acquire the necessary basic knowledge in order to be able to perform the basic management and operation of the system. The second part of the training was provided after the completion of the upgrade and was focused on more specialized topics of the fully operating upgraded system.

It is important to mention that apart from the upgrade of the HEPOS, the project includes also the maintenance and technical support for the whole system for 3.5 years.

2.6 Challenges faced

The upgrade of HEPOS was conducted in the presence of several challenges both technical and practical. The duration of the upgrade was limited to nine months which is considered short taking into account the perplexity of the venture and the dispersion of the localities to visit. Another challenging parameter of the project was the necessity to run in absolute synchronization with the renewal of the telecommunication network - a separate project that entirely changed the telecommunication infrastructure of the system. Perhaps, the greatest challenge was that the upgrade procedure had to take place in a way that wouldn’t interfere with the operation of the system itself. The achieved downtime was practically very close to zero in almost all cases, thus making the whole venture unseen to the users and allowing all works, cadastral projects included, to run uninterrupted. Another great challenge was that during upgrade strict measures due to Covid-19 conditions took place. All inter-prefectural transportations were practically prohibited so the deployment of the project suddenly halted. Special permission from the Hellenic State was needed in order to continue. Next to the above challenges, there also was the requirement to keep the coordinates that would be provided by the upgraded system backward compatible with the ones provided before the upgrade.

3. Displacements due to Earthquakes

In the framework of operating HEPOS and maintaining the reference frame, geological phenomena that lead to coordinate changes are being investigated. In this context the effects of two strong earthquakes that occurred during the last months have been studied. In the following the estimated permanent displacements caused by the 2020 Samos, east Aegean Sea earthquake and the 2021 Elassona, Central Greece earthquake are presented.

3.1 The 2020 Samos, east Aegean Sea earthquake

On October 30, 2020 a strong earthquake occurred in the northern offshore area of Samos Island, Greece. Estimations for the moment Magnitude Mw and the focal depth range from 6.9 to 7.0 and from 6 km to 21 km, respectively. The event triggered a powerful tsunami with 2 m recorded inundation in the northern part of the Island (Triantafyllou et al., 2021; Papadimitriou et el., 2020). Moreover, the event caused significant horizontal co-seismic deformations in the order of tens of centimeters mainly in the northern part of Samos. In order to investigate the impact of the earthquake on the reference stations of HEPOS we processed the data from three HEPOS stations located at distances between 25 and 75 km from the epicenter of the earthquake. Their locations as well as the epicenter of the earthquake are depicted in Fig. 1.

The data processing 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 final precise orbits (sp3 files) and clocks (clk files) (Kouba, 2003). The processing interval was 30s and the elevation mask 7.5^o.

Daily solutions were computed by processing the observations in PPP static mode. For each station the time period from October 16 to November 13, 2020 was processed, which corresponds to 14 days before the event and 14 days after the event. Fig. 2-4 give the time-series of the estimated Easting and Northing coordinates and the height of station 093A located on the island of Samos. The shifts in both coordinates are obvious and in the local ENU frame amount 2.0 cm in East and -15.4 cm in North. Moreover, an uplift of the station is clear which amounts 2.3 cm. The estimated slip vectors for stations 093A, 095A and 094A are depicted in Fig. 5 and correspond to horizontal displacements of 15.5 cm, 2.6 cm and 1.9 cm, respectively.

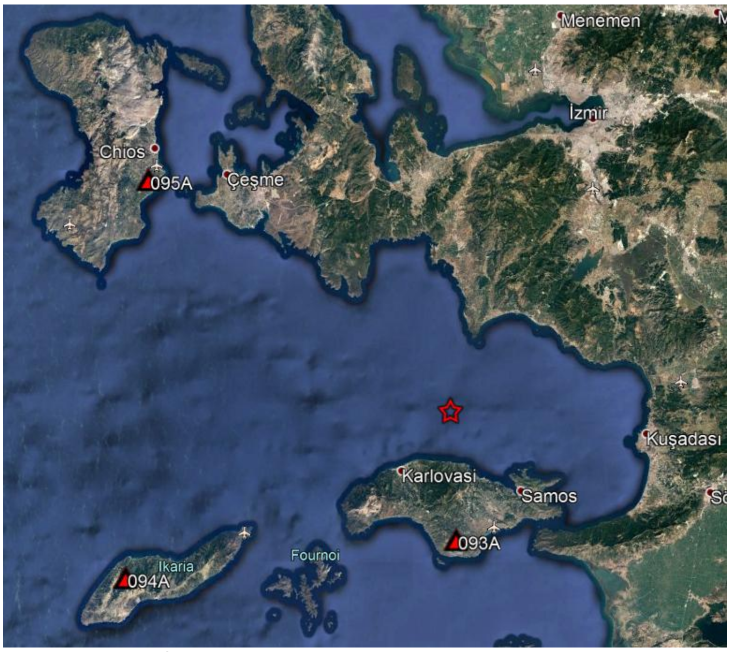

Fig. 1 Epicenter of the 2020 Samos earthquake (red star) and locations of the three nearby HEPOS stations (red triangles).

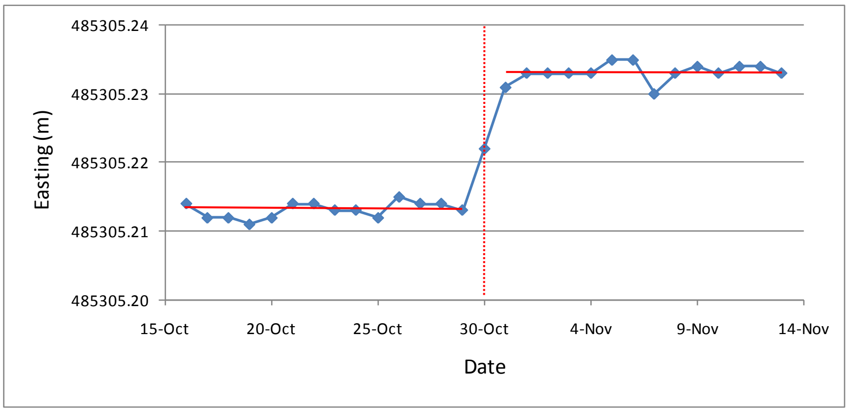

Fig. 2 Time-series of Easting of station 093A (the vertical dashed line indicates the day of the earthquake).

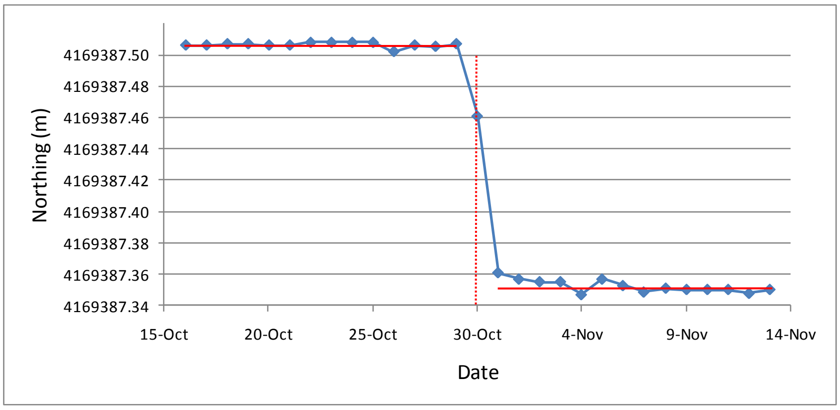

Fig. 3 Time-series of Northing of station 093A (the vertical dashed line indicates the day of the earthquake).

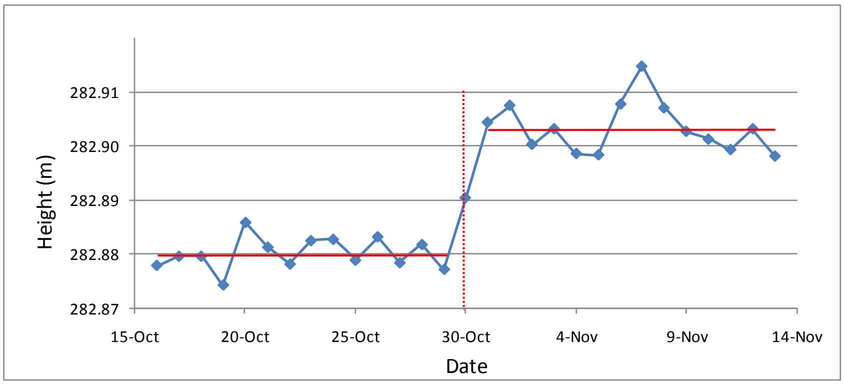

Fig. 4 Time-series of height of station 093A (the vertical dashed line indicates the day of the earthquake).

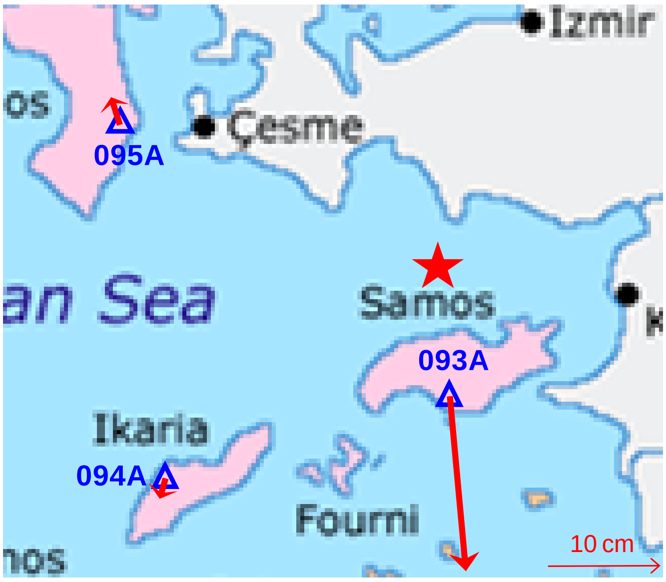

Fig. 5 Estimated static horizontal displacements at nearby HEPOS reference stations. The epicenter of the earthquake is marked by red star.

In the northern part of the Island of Samos displacements of ~37 cm were reported. 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 complicated events like the 2020 Samos earthquake it usually takes some time until detailed and reliable deformation models are computed and published.

3.2 The 2021 Elassona, Thessaly, central Greece earthquake

On March 3 and 4, 2021 two strong earthquakes stroke in Thessaly, central Greece, close to the town of Elassona. The events had moment Magnitudes Mw=6.3 and Mw=6.1 and their estimated focal depths vary from 4 to 19 km and from 7 to 17 km, respectively (Lekkas et al., 2021). The events caused severe damages and noticeable horizontal deformations. In order to investigate the impact of the earthquakes on the reference stations of HEPOS we processed the data from two HEPOS stations located at distances of 13 and 38 km from the epicenter of the first event (Fig. 6).

Fig. 6 Epicentral area of the March 3 & 4, 2021 earthquakes (red star) and nearby HEPOS stations (blue triangles).

The data processing was done using PPP following the data processing strategy described in section 3.1. Daily solutions were computed for each station for the time period February 17 to March 17, 2021, which corresponds to 14 days before the events and 14 days after the events. Fig. 7-9 give the time-series of the estimated Easting and Northing coordinates and the height of station 057A. The shifts in both coordinates are obvious and in the local ENU frame amount 2.8 cm in the East and 4.7 cm in the North. Moreover, an uplift of the station is clear which amounts 2.0 cm. The slip vectors estimated for stations 057A and 071A (Fig. 10) correspond to horizontal displacements of 5.5 and 2.1 cm respectively.

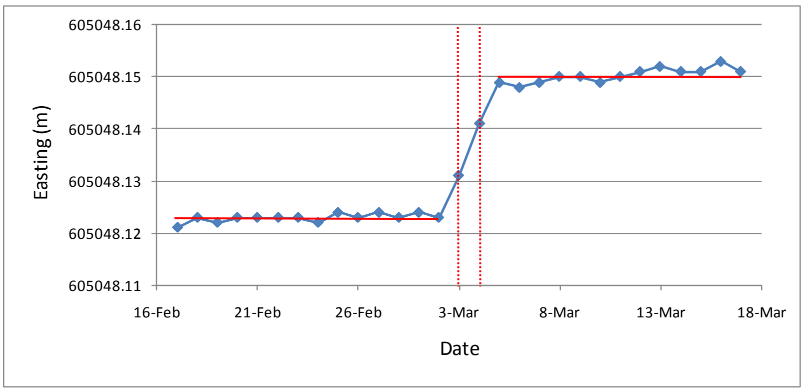

Fig. 7 Time-series of Easting of station 057A (the vertical dashed lines indicate the days of the earthquakes).

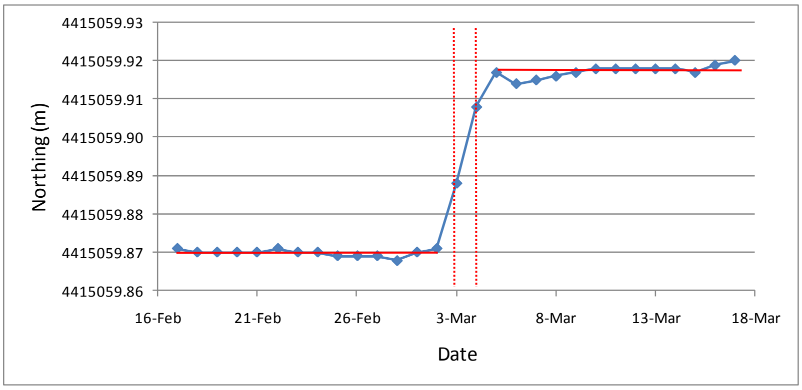

Fig. 8 Time-series of Northing of station 057A (the vertical dashed lines indicate the days of the earthquakes).

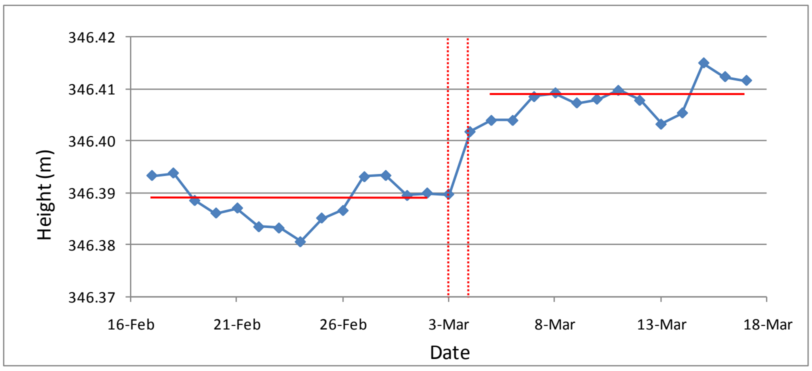

Fig. 9 Time-series of height of station 057A (the vertical dashed lines indicate the days of the earthquakes).

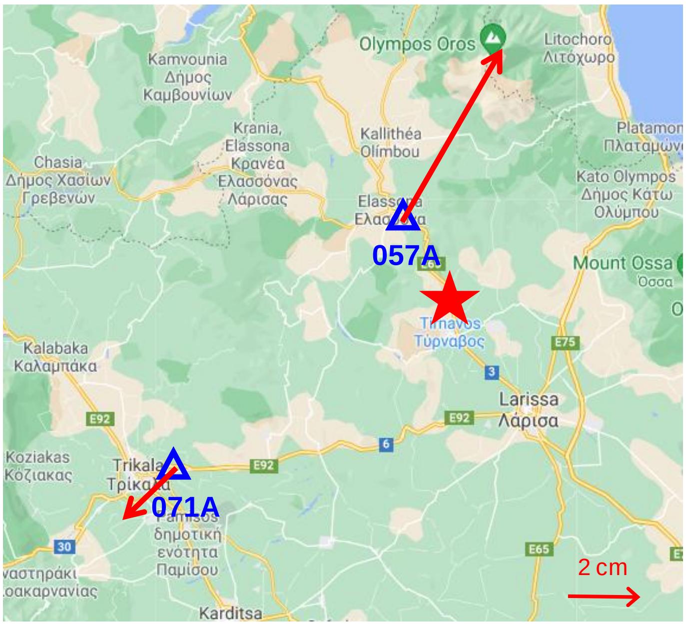

Fig. 10 Estimated static horizontal displacements at nearby HEPOS reference stations. The epicentral area of the earthquakes is marked by red star.

Acknowledgments

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