Dealing with significant differential tectonic plate velocities within an RTK-network: The case of HEPOS

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Abstract

Nowadays, national Geodetic Reference Systems (GRS) are realized by means of permanent reference stations. For surveying applications the spatial separation of the reference stations is usually bridged by means of network-based techniques like VRS (Virtual Reference Station). These techniques model the error sources in order to eliminate the distance-dependent errors in relative GNSS geodetic positioning. In order to effectively model the error sources, the coordinates of the reference stations must be known with very high accuracy in a well defined GRS, which for Europe is the European Terrestrial Reference System 1989 (ETRS89). Plate tectonics should be considered in order to maintain consistency between the local geodetic datum (e.g. ETRS89 for Europe) and ITRS in which the precise orbits are expressed.

Unlike the majority of European countries, Greece is characterized by intense tectonic activity. Moreover, the velocity field is not homogeneous throughout the country. This constitutes a major challenge both for the maintenance of the ETRS89 coordinates in Greece and the operation of HEPOS, the Hellenic Positioning System. The HEPOS network in being processed on a regular basis. The resulting differential motions between the stations reveal the boundaries of a major deformation zone that divides the country in two main parts with different tectonic characteristics. In order to deal with this situation, a certain approach has been developed.

This paper presents the velocity field resulted from the periodic adjustments of the HEPOS network. The differential velocities between adjacent stations are outlined and discussed. Furthermore, the developed approach is being described and first results of its implementation into HEPOS are presented.

Keywords: *Tectonic plate velocities; ETRS89 maintenance; HEPOS.*

1. Introduction

Coordinate stability is crucial for every GNSS-RTK network that supports network-based techniques. Network-based techniques like VRS and MAC (Master-Auxiliary Concept) eliminate the distance-dependent errors in relative GNSS geodetic positioning by estimating error models for the main error sources. The effective modelling of the error sources requires highly accurate coordinates of the reference stations. Tectonic movements should be considered, as they can lead to changes in the stations' coordinates with respect to the coordinate reference frame in which they are expressed. Most of the European countries are using ETRS89 as the GRS for their GNSS networks. ETRS89 is defined in a way that the coordinates in the stable part of the Eurasian plate remain practically unchanged in time. However, Greece does not lie in the stable part of the Eurasian plate. Greece is situated on the boundaries between the Eurasian and the African plates and has totally different tectonic characteristics compared to the majority of European countries. Tectonic velocities in Greece are up to two orders of magnitude higher than in central Europe. Moreover, tectonic velocities are not the same throughout the country. The southern part of Greece lies on the Aegean plate, a smaller plate which is moving southwest (Papazachos et al. 2000). The ETRS89 velocities in the southern part of the country reach 3cm/y, while in the northern part they are in the order of 1cm/y (Gianniou, 2010). This inhomogeneous velocity field requires special attention for the operation of the national RTK network HEPOS and the maintenance of the geodetic reference frame in Greece.

2. Eurasian intra-plate velocities

The Eurasian plate is characterized by a certain motion due to the continental drift. However, the tectonic velocities are not the same throughout Eurasia. Like in most tectonic plates, areas close to the plate boundaries are often showing different kinematics than the central area of the plate. This can be seen in Fig.1 (left), which shows horizontal ETRF2000 velocities of class A stations of the EUREF Permanent Network (EPN), as given by Caporali et al. (2011). A more representative description of this situation is shown in Fig. 1 (right), which gives an average velocity for each country. From Fig. 1 it becomes obvious that Iceland in the north and Greece, Cyprus, Turkey and Italy in the south clearly show different kinematics than the central Europe. For details concerning the vertical motions the reader is referred to Caporali et al. (2011) and Lidberg et al. (2011).

By definition, ETRS89 is tight to the stable part of the Eurasian plate. Thus, the maintenance of ETRS89 coordinates in countries showing different motions than central Europe can consist a major challenge. To describe this fact, Caporali et al. (2011) adopted a limit of 3 cm between the national ETRS89 realizations and the current ETRF2000 coordinates and estimated for each national ETRS89 realization the year after which the aforementioned limit will be exceeded. In this way the "lifetime" of each national ETRS89 realization was computed. The obtained values for the horizontal coordinates range from 50 years (e.g. Nordic countries) to 1 year in the case of Greece. Specifically for Greece, the maintenance of ETRS89 coordinates becomes more complicated due to the inhomogeneous velocity field of the country, as described in more detail in section 3.

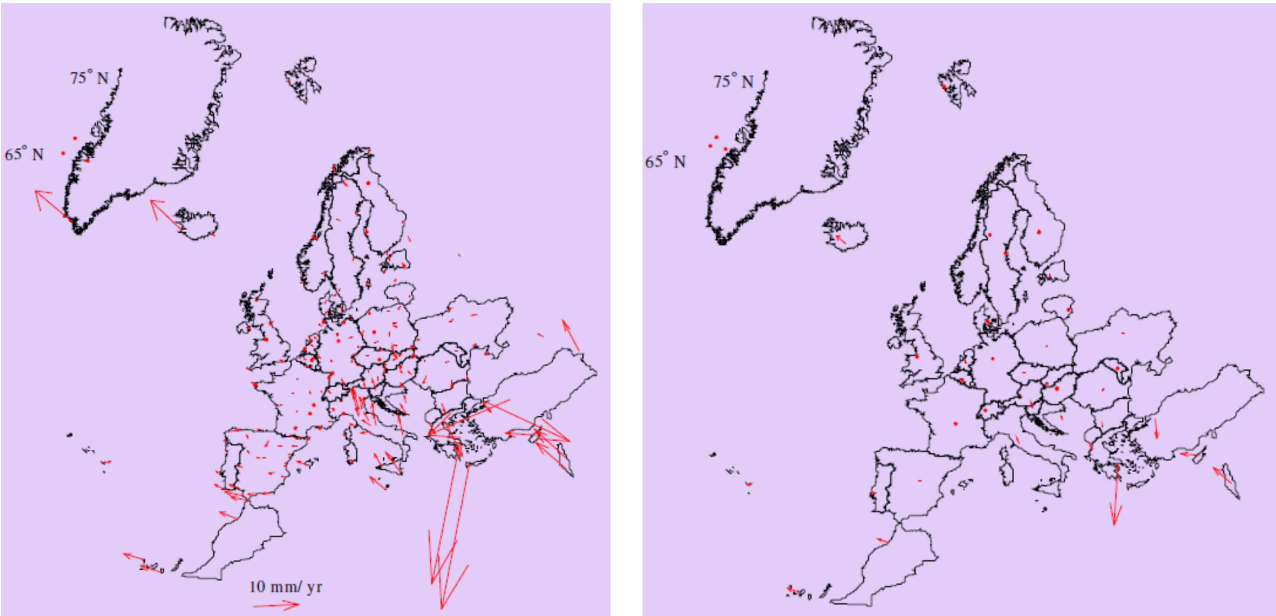

Fig. 1. Horizontal velocities of class A EPN stations (left) and average horizontal velocities (right) *(Caporali et el. 2011)*.

3. Differential tectonic plate velocities in Greece

The velocity field in Greece is greatly influenced by the Aegean plate, a smaller plate which extends from the Hellenic subduction zone in the south to the Ionian islands-central Greece-

Northern Aegean Through-Marmara Sea in the north (Fig. 2). The Aegean plate is moving southwest with respect to Eurasia (Papazachos et al., 2000). This southwestward motion has been well documented by several researchers who analyzed GPS measurements (Nyst and Thatcher, 2004; McClusky et al., 2000). The results of these studies were based mainly on episodic GPS campaigns on certain benchmarks in central and southern Greece. The establishment of the HEPOS network offered the possibility to estimate a detailed and accurate deformation field over the entire country based on continuous observations from permanent reference stations (Gianniou, 2010). Fig. 3 depicts a first estimation of the deformation field in Greece obtained by analyzing GPS data from

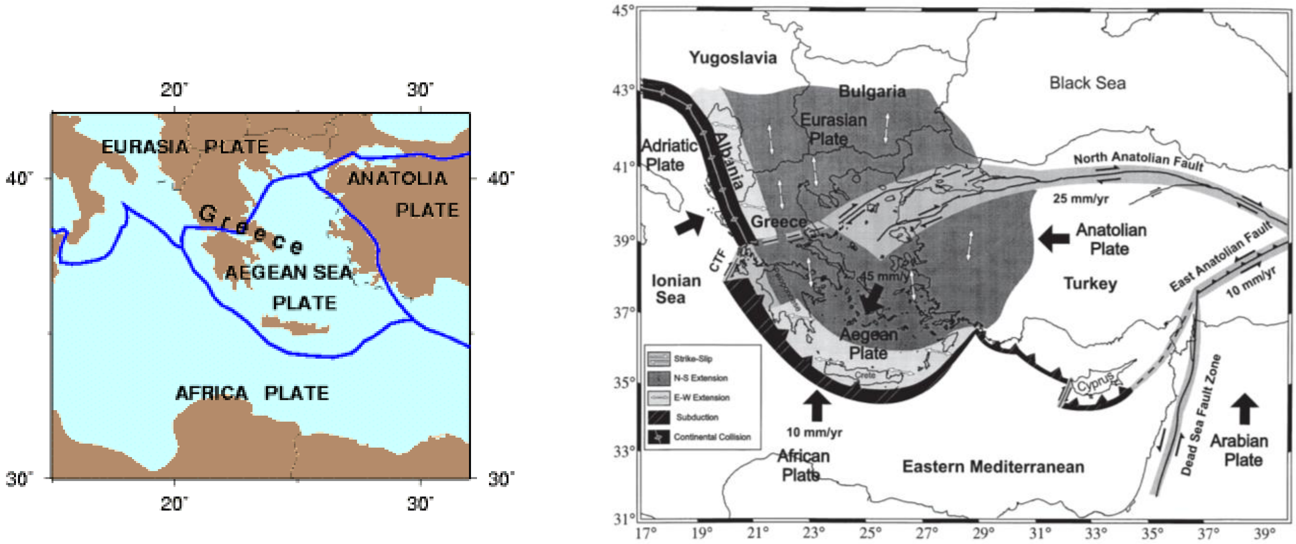

Fig. 2. The Aegean plate (left; *source: USGS*) and its southwestward motion (right; *source: Papazachos et al. 1998*).

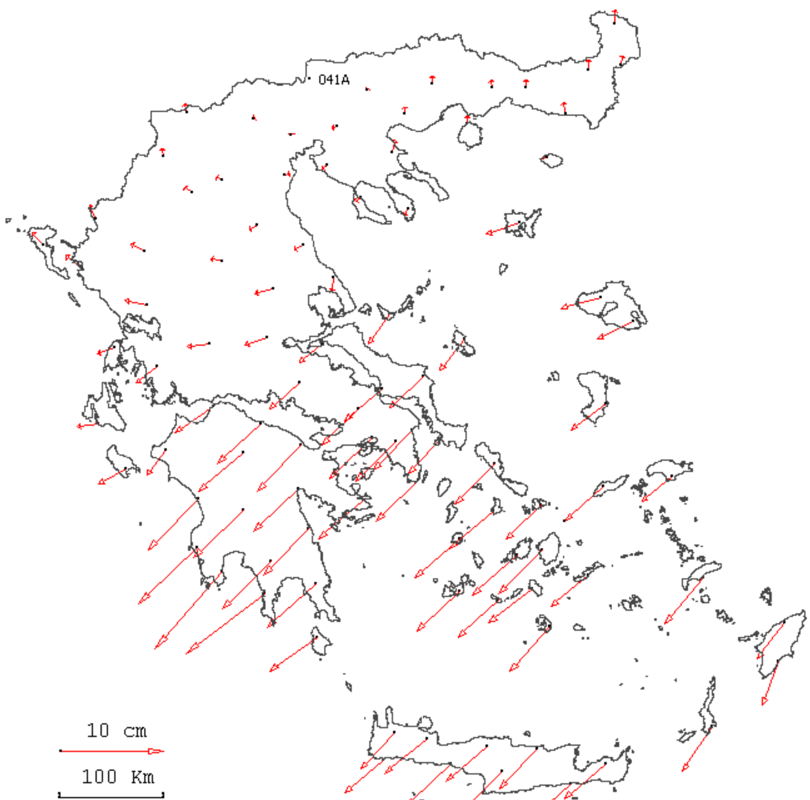

Fig. 3. Horizontal displacements of the HEPOS stations (relative to station 041A in the north) within the first 2 years of network operation *(Gianniou, 2010)*.

the 98 HEPOS stations gathered during the first two years of the operation of the network. The significant impact of the southwestward motion of the Aegean plate is clearly reflected in the large displacement vectors of the stations lying on this plate.

4. Approach currently followed in HEPOS

As demonstrated in the previous section the Aegean plate divides, from a kinematic point of view, the country in two main parts with different characteristics. The stations lying on the Aegean plate show totally different tectonic motions than the stations in the northern part of the country.

Differential velocities between the stations gradually distort the geometry of the network. This consists a serious challenge for the operation of any RTK network as the computation of network-based solutions presumes that the coordinates of the reference stations represent the shape of the network with high precision. From a theoretical point of view, the solution to this problem would be the regular update (e.g. every 1-2 years) of the stations coordinates. This would lead to a dynamic datum or to a semi-dynamic datum. In a dynamic datum time-dependencies like station velocities are inherent in its definition. On the contrary a semi-dynamic datum does not include any time-dependencies in its definition and it is 'frozen' at a certain epoch (Grant and Blick, 1998). A typical example of a semi-dynamic datum is NZGD2000, which is in use in New Zeeland (Blick et al., 2005). The implementation of NZGD2000 is based on a deformation model which allows to compute coordinates referring to the reference epoch of the datum (2000.0) from observations made at any other epoch. Under the assumption that a detailed and accurate deformation model can be estimated and maintained, the use of a semi-dynamic datum can efficiently face the problems of datum distortions as a result of earth deformation. The price to pay is increased complexity in the management of the cadastral and topographic databases as well as in the daily surveying practice (Blick et al., 2009).

To avoid the above mentioned implications of a semi-dynamic datum an alternative strategy was implemented in HEPOS and is currently under evaluation. Based on the kinematic characteristics of the HEPOS stations two sub-networks have been defined. Each sub-network contains stations that have similar tectonic velocities, so that within each sub-network the distortions are relatively small. Each sub-network is processed by a different VRS-network processor. To ensure smooth transition between the two sub-networks an overlap zone is being used. Users in the overlap zone are served by the network processor with the smallest modelling residuals. Fig. 4 depicts the two sub-networks as well as the overlap zone. As can be seen Crete does not belong to any sub-network. This is because Crete, due to the long distances to the other stations, has always been handled by a dedicated network processor.

As long as the tectonic velocities of the stations within each sub-network are similar, the geometry of the network is not distorted with time. Thus, the coordinates of the stations can be used for longer time. Of course, the administrator of the network should ensure that the transformation between the reference frame of the station's coordinates and the reference frame of the precise orbits is always well established in the networking software. In HEPOS, as the time passes, the actual coordinates of the stations deviate from the initial coordinates (referred in ETRS89 at epoch 2007.5) with rates of approximately 1 cm/y (northern part) and 3cm/y (Aegean plate). To account for these changes a user-defined transformation was computed and set-up for each sub-network in the networking software (Trimble GPSNet) ensuring accurate transformation between the two reference frames. The whole procedure is completely transparent to the users, who can work using unchanged coordinates for the stations.

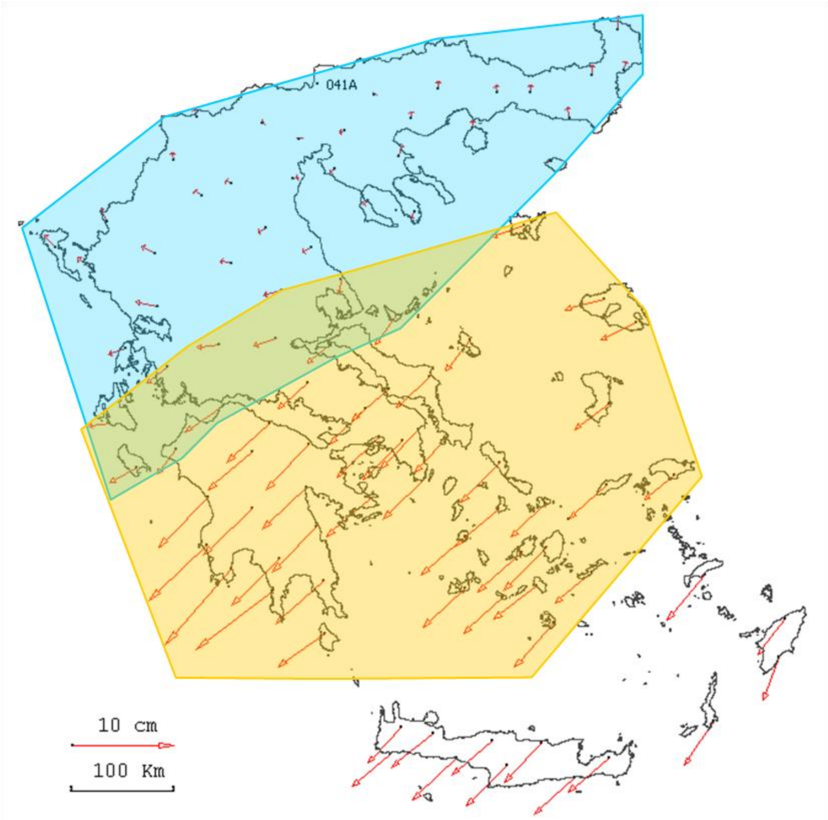

Fig. 4. The two sub-networks considered in HEPOS in order to cope with the problem of different tectonic velocities within the network.

5. Evaluation of the approach currently followed in HEPOS

The approach described in the previous section is being used in HEPOS for the last eight months. This section presents the first results of the evaluation of the approach. The evaluation is based on four criteria related to the performance of the network processors:

- network initialization time
- effectiveness of the error modelling
- precision of the network-based solutions
- stability in time of the network-based solutions.

5.1 Network initialization time

Each time a network processor is started (or initialized) a certain time period is required in order for the processor to solve the integer carrier-phase ambiguities at the reference stations. Generally speaking, the time needed depends on several factors like the size of the network, the atmospheric conditions, the accuracy of the stations' coordinates etc. The ambiguities are solved gradualy and network-based solutions can by supported when the ambiguities are solved to at least 5 satellites. When HEPOS started operation in late 2007 all stations of the two sub-networks shown in Fig. 4 were handled by one network processor and the initialization time was about 10 minutes. As the years were passing the initialization time was increasing. After the third year of operation of HEPOS the time needed by the network processor to initialize became considerably longer. This fact was attributed to the intense and inhomogeneous velocity field in Greece (see sections 2 and 3).

Indeed, after the implementation of the two sub-networks the initialization time decreased to the typical levels.

5.2 Effectiveness of the error modelling

As mentioned in section 5.1 the initialization time of the network processor depends on many factors. Similarly, the quality of the error modelling within the network processor and, in turn, the quality of the network-solutions depend on the same factors. The networking software used in HEPOS offers two indicators to describe the effectiveness of the error modelling: the predicted Ionospheric Residual Integrity Monitoring IRIM and the predicted Geometric Residual Integrity Monitoring GRIM (Chen et al., 2003). These indicators are computed omitting one reference station from the interpolation and then comparing the interpolation results at that station with the real measurements (Trimble, 2008). The monitoring of the GRIM values confirms the positive impact of the realization of the two sub-networks on the quality of error modelling in HEPOS.

5.3 Precision and stability of network-based solutions

The quality of the HEPOS network-based solutions is being evaluated on a regular basis. VRS data are periodically being created at different locations of the country. The data are being post-processed and the obtained time-series are analyzed. To check if the implementation of two sub-networks had an impact on the quality of the network-based solutions, VRS data were created for a location in the overlap zone and analyzed. The location of the VRS was selected in the middle of the distance between stations 059A and 062A as shown in Fig. 5. The exact coordinates of the virtual reference station are: $\varphi = 39^{o}$ 22’ 00.0”, $\lambda = 22^{o}$ 44’ 00.0” and h = 200m. For every day in the time period from 16/6/2012 to 31/12/2012 a VRS RINEX file (VRINEX) was created and processed using station 059A as reference. The length of the baseline 059A-VRS is in the order of 27 km. The VRINEX file was of one-hour duration, namely from 03:00 to 04:00 am. The observation session was intentionally chosen to be in the night time rather than in the day time in order to avoid intense ionospheric activity that is being observed in the years around the maximum of the 24th Solar Cycle (Gianniou and Mitropoulou, 2012). The Easting and Northing values obtained for the virtual station by the baseline solutions are shown in Fig. 6 and 7, respectively. As can be seen, the introduction of the two sub-networks in HEPOS has practically no impact on the stability of the VRS solutions. Furthermore, the time-series depicted in Fig. 6 and 7 offer a good possibility to assess the stability and precision of the VRS solutions of HEPOS in general. For this purpose the standard deviation was used, which found to be ±0.0046 m for the Easting values and ±0.0048 m for the Northing.

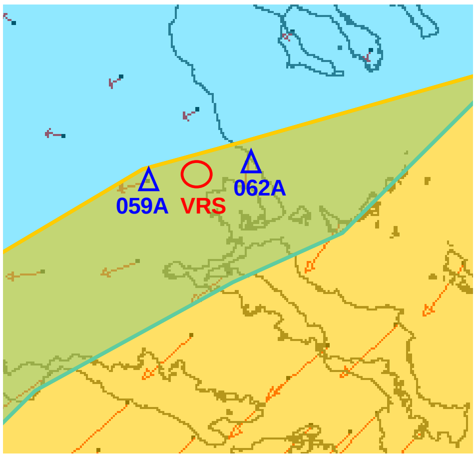

Fig. 5. The locations of the VRS and the HEPOS stations used for assessing the quality of the network-based solutions.

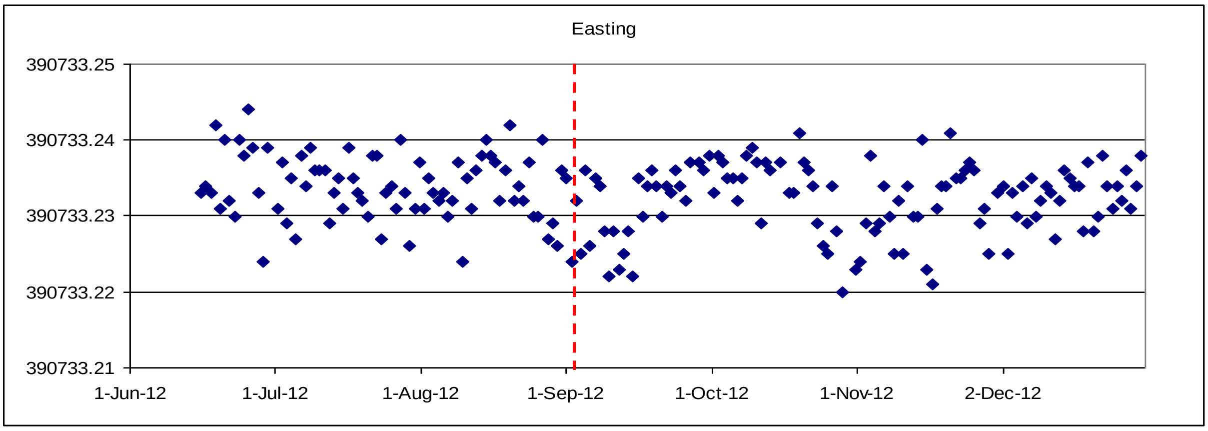

Fig. 6. Time-series (Easting) of estimated VRS coordinates (the vertical dashed line denotes the day of the implementation of the two sub-networks).

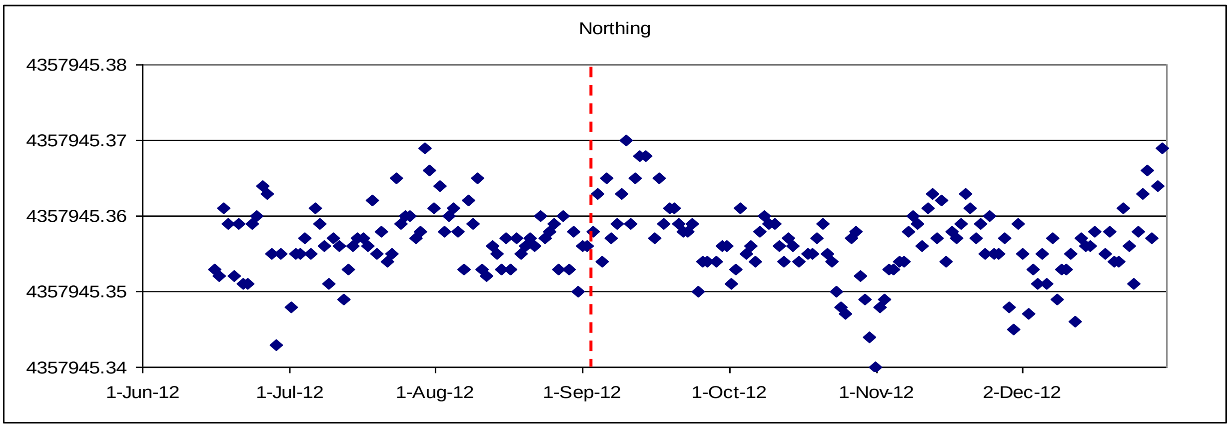

Fig. 7. Time-series (Northing) of estimated VRS coordinates (the vertical dashed line denotes the day of the implementation of the two sub-networks).

6. Conclusions

The intense and inhomogeneous tectonic velocity field in Greece consists a major challenge for the maintenance of ETRS89 coordinates and the operation of HEPOS. To cope with the differential velocities within the HEPOS network, two sub-networks have been recently defined; one for the northern part of country and one for the southern part (Aegean plate) which is characterized by an intense motion to the southwest. The sub-networks are defined in a way that within each network the tectonic velocities are as uniform as possible. This approach was proven to yield good results in terms of network operation and quality of services. Thus, the adoption of complicated strategies (e.g. implementation of a semi-dynamic datum) has been avoided for the moment. Methods are being considered to treat more challenging issues like the remaining deformations within each sub-network (mainly in the overlap zone) and abrupt coordinate changes due to earthquakes.

Acknowledgments

The HEPOS project was co-funded by the European Regional Development Fund in the framework of the Operational Program “Information Society”.

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