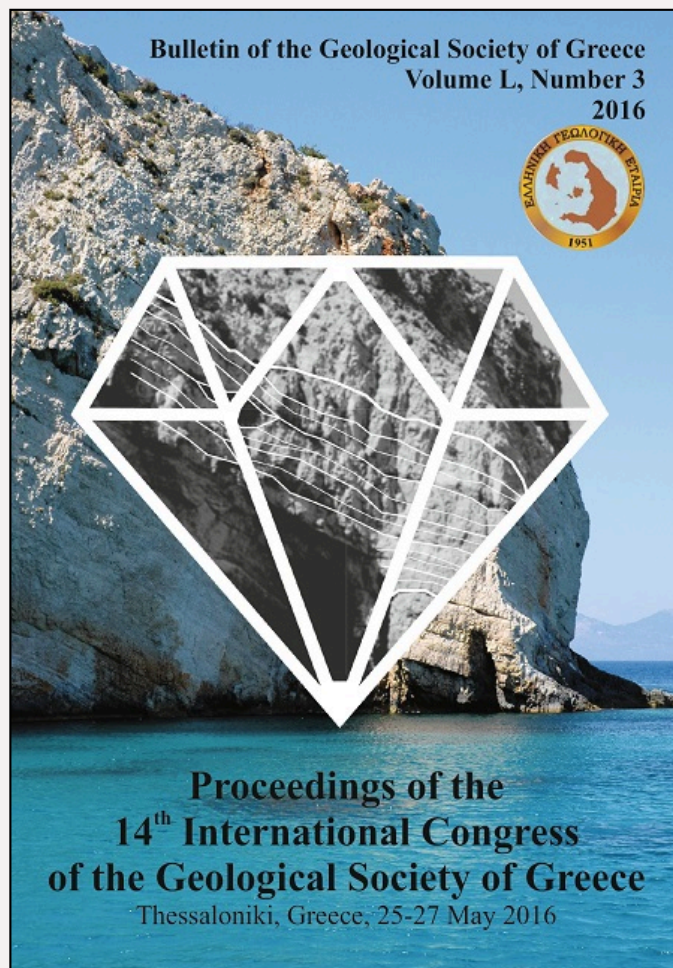


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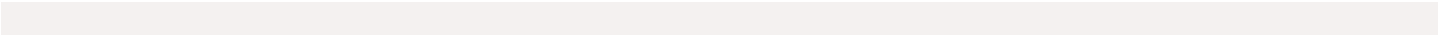
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THE SAMOTHRACE EARTHQUAKE OF MAY 2014 AND THE DISPLACEMENTS ESTIMATIONS USING PERMANENT GPS STATIONS DATA

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Abstract

The contribution of GPS networks in monitoring seismic events is important because they can provide a direct geometrical information on the Earth's crust using satellite observations. In this study position displacements of permanent GPS stations are determined due to intense seismic events in the North Aegean area after the strong earthquake on May 24, 2014. The horizontal coseismic displacements for the Samothrace Island were estimated at 9.4 cm and for Lemnos Island at 5.2 cm respectively. A study period of seven days was enough to show that the deformation evolved into two days.

Keywords: North Aegean, earthquake monitoring, coseismic displacements.

Περίληψη

Η συμβολή των δικτύων GPS στην παρακολούθηση σεισμικών φαινομένων είναι σημαντική καθώς παρέχει άμεση γεωμετρική πληροφορία στο γήινο φλοιό χρησιμοποιώντας δορυφορικές παρατηρήσεις. Στη παρούσα μελέτη εξετάζονται οι μετακινήσεις στη θέση των μόνιμων σταθμών GPS, που προέρχονται από έντονα σεισμικά φαινόμενα στη περιοχή του Β. Αιγαίου μετά τον έντονο σεισμό στις 24 Μαΐου του 2014. Οι μετακινήσεις στο οριζόντιο επίπεδο μετά το σεισμό για το νησί της Σαμοθράκης εκτιμήθηκαν σε 9.4 cm και για το νησί της Λήμνου σε 5.2 cm αντιστοίχως. Διάστημα μελέτης επτά ημερών ήταν ικανό για να φανεί ότι η παραμόρφωση εξελίχθηκε σταδιακά σε διάστημα δύο ημερών.

Λέξεις κλειδιά: Βόρειο Αιγαίο, παρακολούθηση σεισμών, μετασεισμικές μετακινήσεις.

1. Introduction

On May 24, 2014 at 09:25 UTC a strong earthquake (EQ) of Mw6.8 occurred with epicentre between Samothrace and Limnos islands and a focal depth of 14 km. This research focused on the estimation of crustal earth displacements at the northeast Aegean Sea using GPS observations for a few days period, before and after the seismic event. The contribution of GNSS permanent networks is very important because these networks can provide continuous and accurate satellite observations, giving the opportunity to monitor the sites location and their temporal variation as well. Except the ability to accurately detect tiny ground movements they can offer near-real time evidence of slow slip activity that seismometers do not necessarily capture. The used GNSS network of 21 permanent

stations, where 9 of them belongs to the IGS (International GNSS Service) network, 3 to the EPN (Euref Permanent Network), 6 to the SmartNet Greece (<http://www.metricanet.gr>), 2 to the NOA-Net (Ganas *et al.*, 2011) and 1 of them to the HEPOS network (<http://www.hepos.gr/>). The GNSS network with the focal mechanism of Samothrace EQ are illustrated in Figure 1.

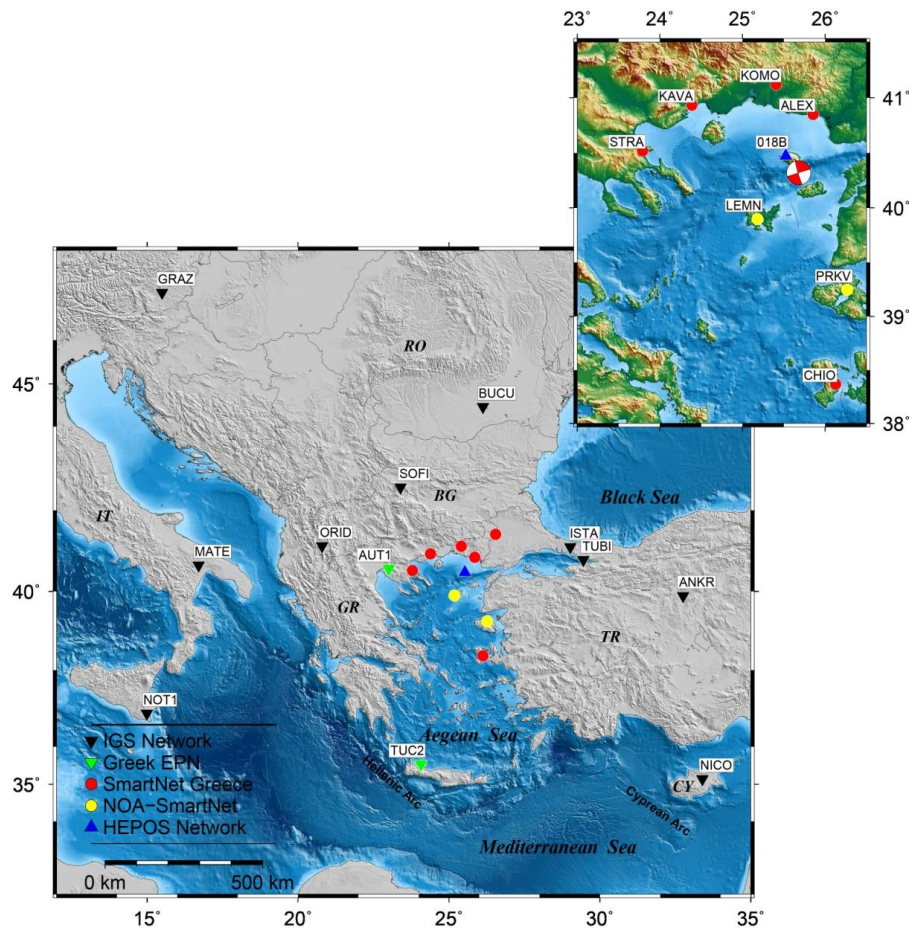


Figure 1 - The GNSS network of permanent stations and the focal mechanism of the Samothrace earthquake on May 24, 2014.

The focal mechanism is a product from the Global Centroid Moment Tensor (GCMT) project based on the methodology given by Dziewonski *et al.* (1981).

2. Process of GPS data

The satellite geodetic methods such as GPS are valuable for the analysis and estimations of displacements due to earthquake events. In order to study the influence of May 24, 2014 EQ on site displacements a time period of seven days was selected, from May 20, 2014 to May 26, 2014. Specifically data for four days before and three days after the event were processed. Data analysis was based on 30-sec daily GPS observations and elevation cut-off angle 10°. The process was held

on the current reference frame ITRF2008 (Altamimi *et al.*, 2011) using the scientific package GAMIT/GLOBK (Herring *et al.*, 2010). Firstly the phase code data were processed in order to estimate the 3-D relative positions of ground stations. IGS final orbits were used and atmospheric zenith delays estimated every two hours interval by means of the VMF1 mapping function (Boehm *et al.*, 2006) based on numerical weather models. Phase ambiguity resolution is very important for high precision geodetic applications. In the present work the resolved ambiguities were at the level of 92% for the narrow lane linear combination, a good enough percentage for our study (e.g., Fotiou and Pikridas, 2012). The reference frame for the daily solutions was defined by fixing seven IGS sites (GRAZ, BUCU, SOFI, ORID, MATE, NOT1, NICO) selected far from the EQ epicentre remaining unaffected by the seismic event. In the remaining stations of the surrounding study area we investigated the effect of EQ on the daily site coordinates.

3. Results

The results analysis is basically focused on daily time series coordinate estimations and on the total displacement from the first up to the last day of GPS data process.

3.1. Time series daily displacements

The position time series is a very useful tool to monitor the daily variation of site coordinates. A strong EQ have an effect on the time series analysis causing some discontinuities as offsets, which may lead to an unrealistic estimation of geodetic velocities (Bitharis *et al.*, 2015). More generally (Tregoning *et al.*, 2013) showed that large EQs can induce linear velocity errors of up to 0.4 mm/yr at sites over 1000 km from the earthquake locations. In Figure 2, daily displacements expressed in the topocentric (North, East, Up) system are presented for 018B (Samothrace Island) and LEMN (Lemnos Island) stations, which are the two nearest to the EQ epicentre. At these stations the displacements are more intense compared with the other surrounding stations. In addition the station ALEX at Alexandroupolis, in a longer distance from the epicentre, has also a notable but smaller displacement than the two nearest stations.

The estimated displacements from the GNSS time series analysis for Samothrace and Lemnos sites show a reverse motion as expected from the nature and location of the causative fault (Sboras *et al.*, 2015). Moreover the vertical offset is smoother than the horizontal one as happens in a strike-slip fault. The deformation evolved in two days as it is illustrated in Figure 2, where with respect to the North and East components the daily coordinate variations are evident. Concerning the vertical component (Up) is not shown any remarkable variation.

A more clear view is presented in Figure 3 where the differences of the 2-D position between successive days have been accounted for the above three most affected sites. In more detail the horizontal position difference for station 018B at Samothrace Island is 4.76 cm between the day of seismic event and the previous day. As far the stations at Lemnos and Alexandroupolis the displacements are determined to 2.74 cm and 1.29 cm respectively.

It is remarkable in Figure 3 that the direction and the magnitude of the displacements are almost equal for the two pairs of successive days, i.e. between (May 24-23, May 25-24), where the phenomenon has evolved. According to the results the last time span of May 25 to May 26 any additional deformation is not noticed as the relative position difference is smaller than 0.2 cm. A data analysis of a longer time span would give a better insight of post seismic relaxation.

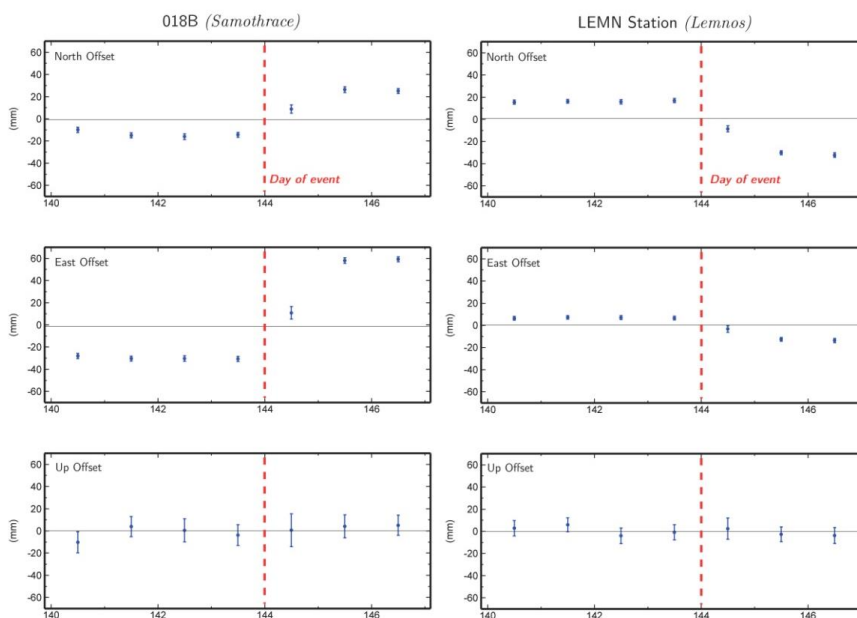


Figure 2 - Time-series position for 018B (left) and LEMN (right) stations from May 20 to May 26, 2014 with respect to the (North, East, Up) topocentric system.

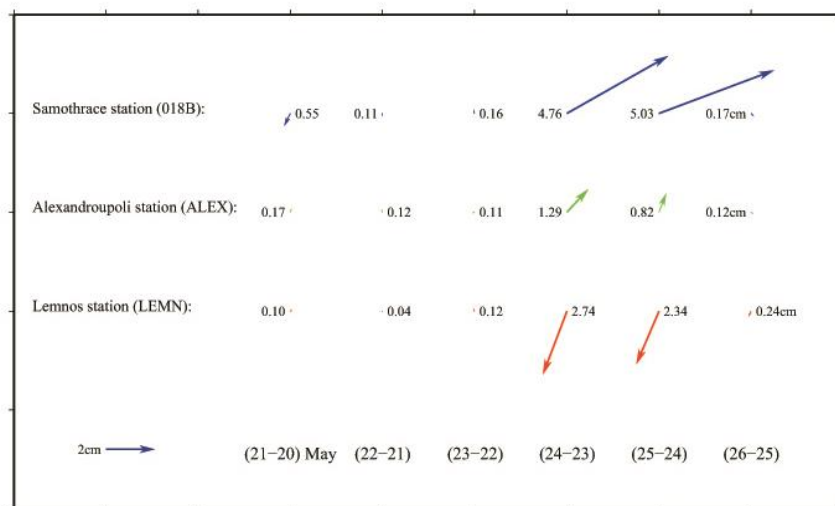


Figure 3 - Daily 2-D displacements for the three nearest to the EQ epicentre GNSS stations.

3.2. Total seismic displacements

In order to estimate the 2-D displacement field due the strong Samothrace EQ, we have taken the position difference between the first and the last day (May 20 to May 26) including some days before

and after the seismic event. As it is shown in Figure 4 and Table 1, the direction of 018B station displacement is ENE (East-Northeast) while its displacement is 9.4 cm. For the LEMN station the direction of its displacement is SSW (South - Southwest) with a magnitude of 5.2 cm. As far the Alex station the corresponding direction is NNE approaching that of 018B (Samothrace) with a magnitude of 2.2 cm. The determined directions of the displacement vectors are compatible to the focal mechanism given by Dziewonski *et al.* (1981), Sboras *et al.* (2015).

The tectonic setting of the affected areas consists of the eastern segment of the North Aegean Trough (NAT), which is the extension of the northern splay of the North Anatolian Fault (NAF) in the Aegean. It forms an elongated dextral transtensional basin which is frequently associated with moderate to large earthquakes (see Chatzipetros *et al.*, 2013 and Sboras *et al.*, *subm.*, and references therein). Among others, the seismic history of the broader area that can be directly or indirectly associated to NAT includes strong events such as the ones of 1905 (M 7.3), 1912 (M 7.4), 1982 (M 6.6) and 1983 (M 6.8), although several older large earthquakes are reported in written sources (June 1, 1366; November 12, 1456; 1471; August 12, 1564; April 12, 1572; June 28, 1585; December 5, 1776; July 23, 1719; February 3, 1779; August 6, 1860). The epicentres and exact seismotectonic parameters of those events is however uncertain and in many cases problematic (Papazachos and Papazachou, 1997, 2003; Ambraseys, 2009; Guidoboni and Comastri, 2005).

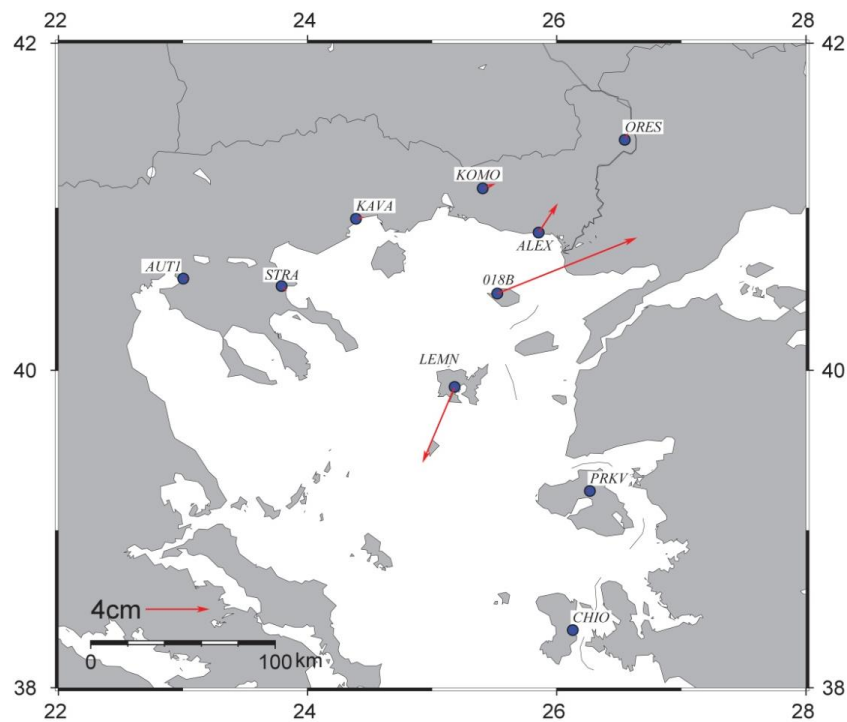


Figure 4 - Total horizontal seismic displacements in the area of North Aegean Sea for the period of May 20 to May 26, 2014.

Table 1 - Total displacements for 13 GNSS stations due to the Samothrace Earthquake of May 24, 2014: (δN , δE , δU), 2-D and 3-D vectors.

Site	Location	Approximate Position (dec. deg)		Horizontal & Vertical Displacement (mm)			Vector Norm (mm)		Azimuth (dec. deg)
		Long.	Lat.	δN	δE	δU	2-D	3-D	
AUT1	Thessaloniki, GR	23.00	40.57	-0.1	3.0	-9.8	3.0	10.2	99.909
STRA	Chalkidiki, GR	23.79	40.52	-3.4	3.4	6.0	4.8	7.7	135.000
TUC2	Chania, GR	24.07	35.53	0.8	0.5	1.8	0.9	2.0	32.005
KAVA	Kavala, GR	24.39	40.93	1.1	5.2	-10.4	5.3	11.7	78.056
LEMN	Lemnos, GR	25.18	39.90	-47.8	-20.1	-6.6	51.8	52.3	202.807
KOMO	Komotini, GR	25.41	41.12	3.1	8.2	8.9	8.8	12.5	69.291
018B	Samothace, GR	25.52	40.47	35	87.1	15.3	93.9	95.1	68.108
ALEX	Alexandroupolis, GR	25.85	40.85	18.4	12.0	-2.0	22.0	22.1	33.111
CHIO	Chios, GR	26.13	38.37	-0.9	-0.3	-3.2	0.9	3.3	198.435
PRKV	Lesvos, GR	26.27	39.25	0.2	-2.3	0.9	2.3	2.5	274.970
ORES	Orestiada, GR	26.55	41.41	4.7	2.2	1.6	5.2	5.4	25.084
ISTA	Istanbul, TR	29.02	41.10	-1.6	0.7	0.7	1.8	1.9	156.371
TUBI	Gebze, TR	29.45	40.79	-0.6	0.6	0.0	0.8	0.8	135.000

4. Conclusions

Displacement estimations have been estimated at the North Aegean Sea due to a strong earthquake occurred on May 24, 2014 between Samothrace and Limnos islands. Continuous GPS data from 21 permanent GNSS stations have been rigorously analysed and processed for a period of a week giving a daily time series position variation. The seismic effect caused some significant discontinuities on the 2-D position of the three nearest surrounding stations varying from 2.2 to 9.4 cm within a distance of about 70 km and being compatible in orientation with existed focal mechanisms. It is interesting to note that the deformation of the affected earth's crust evolved into two days, from May 23 to May 25. Position discontinuities from strong seismic events have to be taken into account for a realistic geodetic velocity field estimation, featured this way the permanent GNSS networks as valuable tools for accurate position and displacement estimation.

5. Acknowledgments

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