Geodynamic application of the PPP method using 1-s stream from NOANET stations, Greece

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1. INTRODUCTION

NOA operates a National GNSS network of thirteen (13) stations transmitting real-time 1-s data to the control centre in Athens (Fig.1). The PPP (Precise Point Positioning) processing technique is used to detect offsets in XYZ positions of GNSS stations in the Ionian Sea and Santorini Island, where tsunami hazard is high. PPP works on a single station, double-frequency, basis, continuously using the real-time RTCM v3.0 stream. PPP is a method to determine the exact coordinates of a single point using code or phase measurements with precise clocks and orbits. The use of dual frequency measurements eliminates the ionosphere effects. All the precise data (clocks and satellite orbits) are provided from IGS (International GNSS Service). The main mathematical model underlying dual frequency PPP is defined by the desired ionosphere free combination of code pseudorange.

$$\frac{R_1 f_1^2}{f_1^2 - f_2^2} - \frac{R_2 f_2^2}{f_1^2 - f_2^2} = \rho + cdt_r + \Delta_{trp}$$

and carrier phases

$$\frac{\lambda_1 \Phi_1 f_1^2}{f_1^2 - f_2^2} - \frac{\lambda_2 \Phi_2 f_2^2}{f_1^2 - f_2^2} = \rho + cdt_r + \Delta_{trp} + \frac{\lambda_1 N_1 f_1^2}{f_1^2 - f_2^2} - \frac{\lambda_2 N_2 f_2^2}{f_1^2 - f_2^2} .$$

The unknown parameters to be determined are: the point position constraint in range *ρ*, the receiver clock *dtr* ,the tropospheric delay *Δtrp* and the ambiguities *N.*

The BKG/BNC v2.6 processing engine was used. Our results show a N/E/U RMS error of 1-6 cm for all stations (Fig.2). This information is operationally useful for the Tsunami Warning Centre of Greece.

Fig 1. Map of NOANET stations

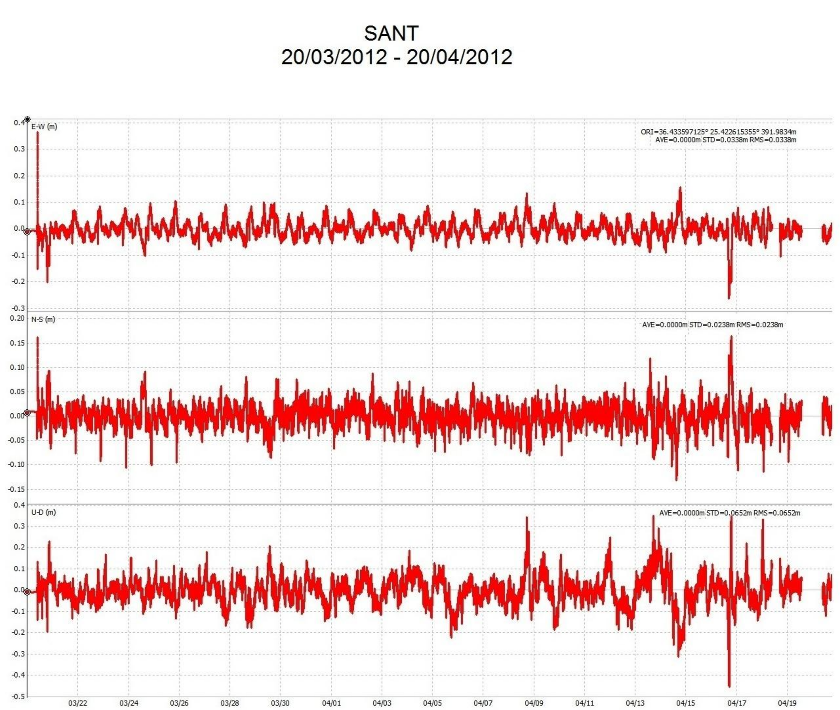

Fig 2. Graph of N/E/Up component of station SANT

2. NOANET PPP SCHEMATIC DIAGRAM AND INFRASTRUCTURE

The main infrastructure consists of GPS receivers and the telemetric system. The GPS receiver send the RTCM stream via ADSL/VPN modem/router to the main router of Geodynamic Institute through a firewall for intrusion protection. The Leica Spider software creates RINEX files of the 13 stations and makes them available through the webpage http://www.gein.noa.gr/gps.html. Also with the Leica QC software we check automatically the quality of these RINEX files daily. Moreover, with NTRIPserver we deliver the RTCM streams to the NOANET caster which provides the real-time data to the analysis software (BNC, CNES and other packages) for PPP. The orbit and clock corrections are also available through IGS caster which also connects to PC at NOA that run the Real time PPP.

Fig. 3. Infrastructure of Real time PPP

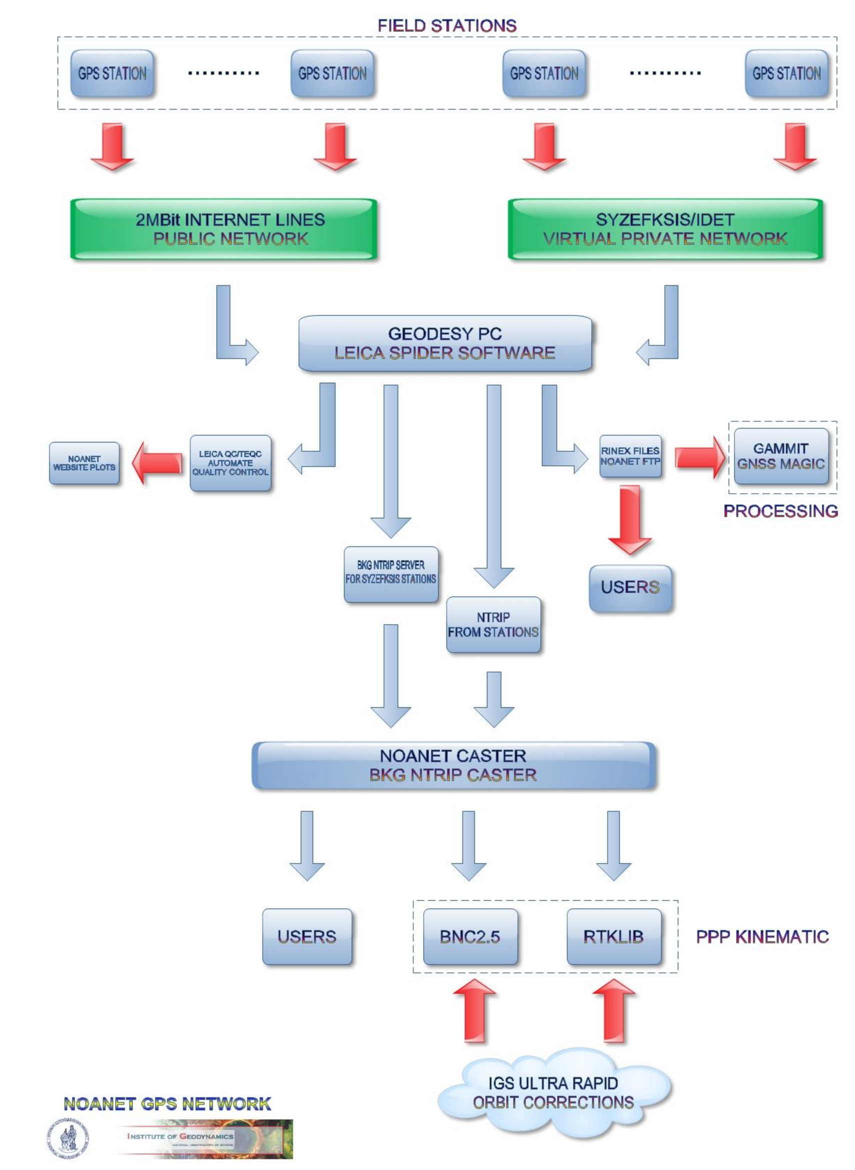

Fig 4. Schematic diagram of Noanet PPP

3. CHECKING MULTIPATH OF GPS STATIONS

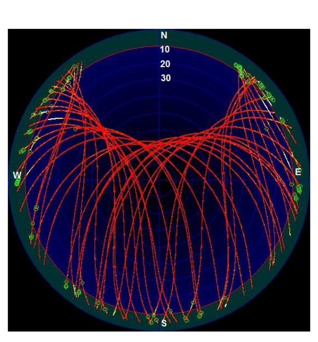

Fig. 5. MP1 polar diagram NOA1

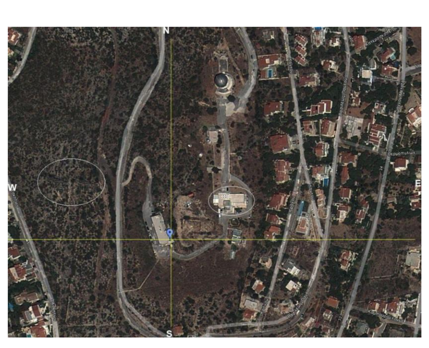

Fig. 7. Tracking Multipath from polar diagram

To improve our station quality and to further reduce common GPS errors we are doing quality control in the field. After installation a RINEX file is created in the acquisition server and is undergoing quality control with TEQC, thus producing reports and station plots. We check all quality parameters such as Multipath L1 and L2 (mp1 & mp2), SNR in both frequencies etc., we produce polar diagrams (Fig. 5-6) of the Multipath and we estimate the possible sources. We can identify both azimuth and elevation of the source and with Google map we track the source (Fig.7). In the following figures we see the method and the tracking of the possible Multipath source for station NOA1. We process daily files from DOY 127 for years 2008, 2009, 2010 and 2011 and we show (Fig. 8 & 9) the quality plots. Bruyninx et al. (2003) report that 75% of the European EUREF stations have values mp1 < 0.57 m and mp2 < 1 m. Moreover, 50% of IGS stations around the world have RMS mp1 values < 0.4m and 75% < 0.5m and corresponding RMS mp2 50% of values < 0.6 m and 75% < 0.75 m. It is seen that NOA1 and the rest of NOA stations fully meet the quality standards of the European EUREF stations and data is reliable for real-time applications but also for post-processing. Our data is ideal for study and research of geological and geodynamic applications. In Figure 8 & 9 add horizontal lines of EUREF mp1 and mp2 and IGS mp1 & mp2 to show NOANET performance.

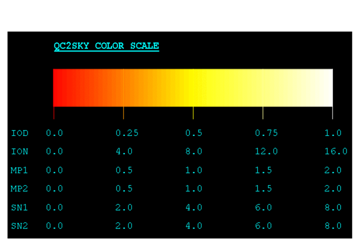

Fig. 6. Colour scale of polar diagram

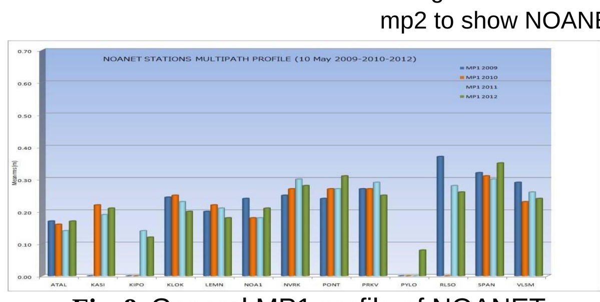

Fig. 8. General MP1 profile of NOANET

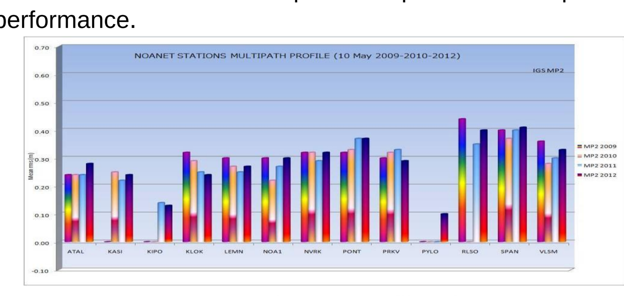

Fig. 9. General MP2 profile of NOANET

4. NOANET PPP ANALYSIS AND PPP WEBPAGE

We use several open source software packages to monitor the deformation of the NOA stations, like BKG BNC, Rtklib, and in cooperation with GFZ their online PPP interface. Using BNC we combine 1-s stream from our caster and the CLK stream from IGS in order to do real-time PPP processing. The results are saved in NMEA format for further processing. Using rtklib we are able to see the 2D deformation of the station (Fig. 10). Also in page http://kg6-dmz.gfz-potsdam.de/rtgnss we provide several streams from our caster for the online PPP of the GFZ (Fig. 11). We develop a special interface into the main NOANET GPS webpage http://www.gein.noa.gr/gps.html with ArcGIS map of Ionian stations and an interface to see the communication status of our stations to increase the reliability of our network.

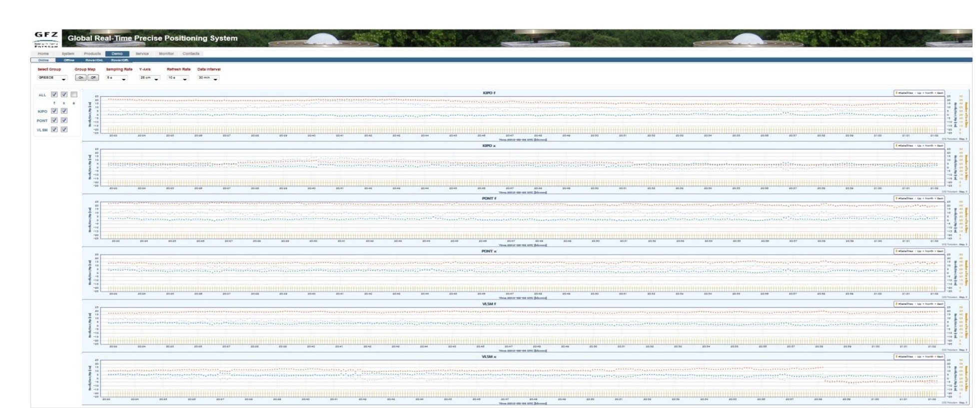

Fig. 11 PPP in cooperation with GFZ

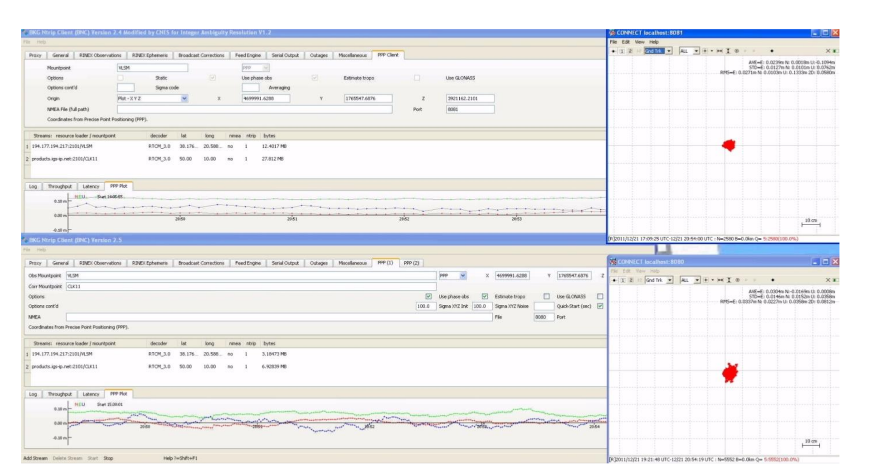

Fig. 10 BNC 2.5 and CNES analysis software

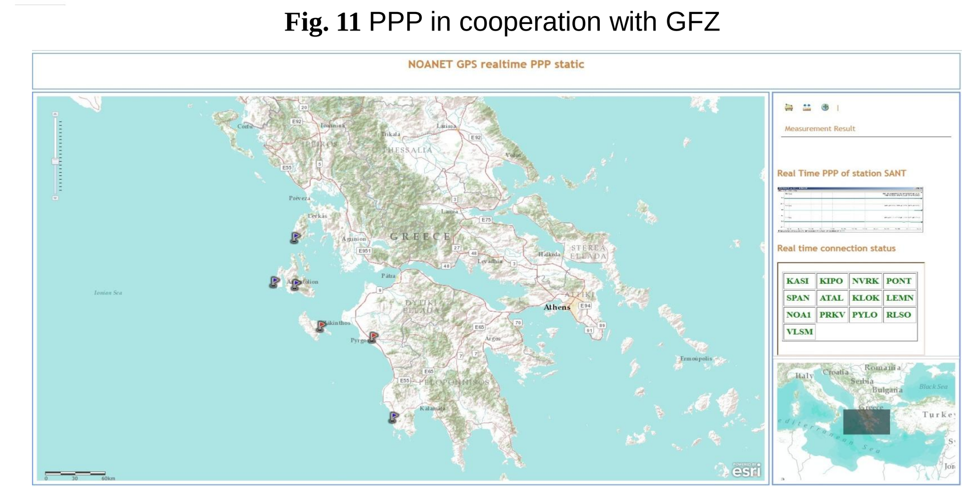

Fig. 12.PPP Webpage with station status

5. EARTHQUAKE MECHANISM WHICH CAN CAUSE MOVEMENT OF NOA STATIONS

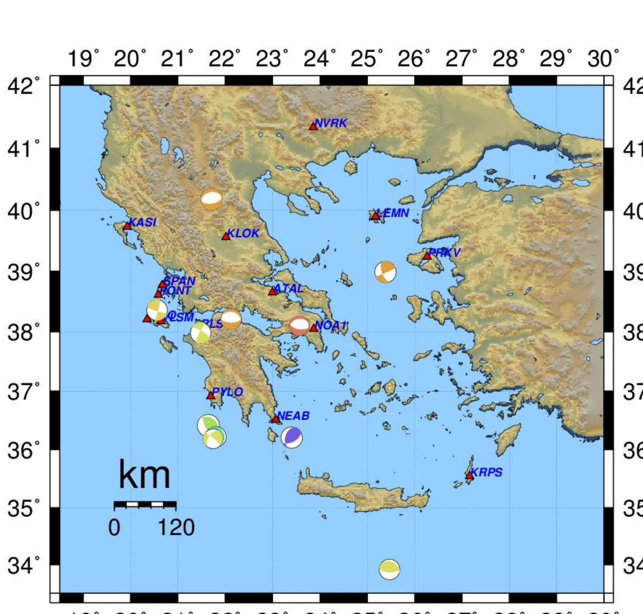

Fig. 13. Map of NOA GPS permanent network and focal mechanisms of the largest earthquakes which can cause movements

Greece is one of the most tectonically active regions of Earth. The country is located at the front of the collision between two tectonic plates, the Eurasian and the African, while the Arabian plate approaches the Eurasian plate in a northwestern-ward motion. The Hellenic subduction zone is a key element in the active tectonics of the Eastern Mediterranean. The study of Chaumillon and Mascle (1995) indicates that the Mediterranean seafloor, of probable Mesozoic age subducts nortwards beneath Crete at a rate 35 mm/yr, that greatly exceeds the convergence between Africa and Eurasia (5 mm/yr) because of the rapid SW motion of the southern Aegean relative to Eurasia (McKenzie, 1972; Reilinger etal., 2006).

The most seismically active regions in the Mediterranean is the Ionian Sea islands (Chephalonia and Lefkada, Makropoulos and Burton, 1984). The offshore area along Lefkada and Kefallinia is dominated by the Kefallinia dextral transform fault. Seismological data indicate right – lateral strike slip focal mechanims (Anderson and Jackson 1987; Jackson and McKenzie, 1988; Papadimitriou etal., 2006) in agreement with geodetic data that clearly show that the slip motion has a NNE – SSW direction (Cocard etal., 1999; Jenny etal., 2004). The Kefallinia transform fault exhibits dextral strike slip motion at a rate of 2 – 3 cm/yr (Kahle etal., 1996).

To study crustal deformation due to earthquakes NOA has began installing permanent GPS stations from 2006 (Ganas etal., 2008). Nowadays, there are 15 continuous GPS – stations, around Greece. Figure 6, represents the geographical positions of these stations. The characteristics of these stations are presented at the table 1.

Our stations are located close to major fault zones of Greece. Some stations such as KLOK (Thessaly) are located in "aseismic" or low earthquake frequency areas. For example, the Kozani earthquake of 13 May 1995, is the strongest event of the last decade in Greece. The Grevena area, is previously thought as aseismic region. The study of Rontogianni S. (2010) indicates to extend in a NNW – SSE direction (~ 0.07 ± 0.02 ppm/yr). In central Greece, the Gulf of Korinth was characterized as one of the most active rifts in the Aegean (Papazachos and Papazachou, 2002; Ambraseys 1990). The study of Billiris etal (1991) indicates a 1 cm/yr extension in the N-S direction.

No	Site	Location	Date	Longitude	Latitude	Elevation	Receiver S/N	Receiver Type	Antenna Type
1	VLSM	Valsamata Kephalonia	14/02/2006	38.1701	20.6331	437.857	462019	LEICA GRX1200PRO	AX1202 GG
2	NOA1	Pendeli Attica	13/03/2006	38.0437	23.8640	537.812	462590	LEICA GRX1200PRO	AT504LEIS
3	RLS	Riolos Achaia	29/07/2006	38.0637	21.4647	132.896	452163	LEICA GRX1200PRO	AX1202 GG
4	PONT	Ponti Lefkada	15/02/2007	38.6123	20.5818	48.527	462661	LEICA GRX1200PRO	AX1202 GG
5	KASI	Kassiopi Corfu	01/04/2007	39.7323	19.9322	103.851	465462	LEICA GRX1200PRO	AX1202 GG
6	SPAN	Spanohori Lefkas	22/05/2007	38.7746	20.6669	447.857	465460	LEICA GRX1200PRO	AX1202 GG
7	LEMN	Lemnos Agariones	16/06/2007	39.8938	25.1739	104.555	351610	LEICA GRX1200PRO	AX1202 GG
8	PRKV	Agia Paraskevi (Lesvos)	30/06/2007	39.2423	26.2651	169.346	465459	LEICA GRX1200PRO	AX1202 GG
9	NVRK	Nevrokopion (Drama)	12/07/2007	41.3335	23.8631	579.000	351602	LEICA GRX1200PRO	AX1202 GG
10	KLOK	Klokotos (Thessaly)	17/07/2008	39.5647	22.0143	137.457	463363	LEICA GRX1200PRO	AT504 LEIS
11	ATAL	Atalanti (Fthiotis)	27/03/2009	38.6530	22.9960	135.130	IR1200304026	ASHTECH UZ-12	NOV533
12	KIPO	Kipouria (Cephalonia)	31/08/2010	38.2031	20.3450	128.197	120160	GMX902 GG	AX1203 +GNSS
13	PYLO	Pylos (Messinia)	24/08/2011	36.9141	21.6919	39.114	1700407	GR 10	AS10
14	NEAB	Neapoli Voion	27/06/2012	36.5092	23.0603	-	-	-	AR 10
15	KRPS	Karpathos	25/07/2012	35.5471	27.1610	524	-	-	-

Table 1. NOA GPS permanent network: Description of each station as of 25 July 2012

6. CONCLUSIONS

NOA has developed a national GNSS network of 15 CORS stations with 1-s data streams to Athens. Primarily we installed the stations in order to study tectonic strain in Greece. Recently, we have upgraded telemetry and software so we can use the 1-s for operational requirements of NOA. Our current goal is to construct an online real-time platform for monitoring deformation. The platform will be capable to issue warnings for a tsunami after a large earthquake (M>7) near the Greek coasts .In addition we test several tools for making better GPS site installations. We cooperate with several institutions in order to to cross check the results of the RT-PPP for geodynamic applications by use of the open source software packages.

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7. ACKNOWLEDGEMENTS

This research was funded by EU project PREVIEW, EPOS, EU Structural funds, ESA GMES project TERRAFIRMA and the Greek Government (GSRT and EPPO). We are indebted to V. Karastathis, E. Lagios, C. Pikridas, Maorong Ge, Bob King, Ivan Georgiev, Marco Anzidei, Philip England, D. Paradissis, P. Briole,. K. Chousianitis, P. Grigorakakis, A. Antonakakis, E. Skassis, M. Papanikolaou, S. Rondogianni, C. Tsimi, and K. Boukouras for comments and suggestions. We thank Prof. Zerefos, Dr. G. Stavrakakis, and Prof. Makropoulos for their support.