CRUSTAL DEFORMATION STUDIES IN THE SEISMICALLY ACTIVE AREA OF PATRAS GULF (GREECE)

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ABSTRACT

A ten-station GPS network extending in the broader area of Patras Gulf was established in 1994 to study the local and regional ground deformation of the area. The network has been fully occupied in three periods: August 1994, October 1996 and January 2006. A smaller scale GPS network being consisted of seven stations was installed in July 2008 across the Rio-Antirrio strait (eastern part of Patras Gulf) and was remeasured in March 2009.

Differential GPS data analysis of both networks was performed revealing an extension of Patras Gulf at a rate of ≈10 mm/yr. Uplift of the southern part with respect to the subsided northern part of the gulf was observed.

A continuously recording GPS station (at a frequency of 1 Hz) has been operating at Riolos (RLSO) since August 2006. Automatic data processing applying the Bernese Processing Engine (v.5.0) resulted in the estimation of its horizontal and vertical deformation through the period 2006-2011, in which the co-seismic effect of the 2008 Andravida Earthquake (M_w = 6.4) is evident.

Index Terms— Differential GPS, Real Time GPS Measurements, Ground Deformation, Automatic GPS Processing, Patras Gulf

1. INTRODUCTION

The Eastern Mediterranean is one of the most tectonically active areas [10], resulting from the convergence between the Eurasian and the African continental plates.

The majority of the seismic activity of the Eastern Mediterranean is located in the Hellenic territory along the Hellenic Arc, the subduction zone of the African plate beneath the Aegean microplate, with the highest activity being observed on the western part of the arc that includes the Central Ionian islands [6]. Due to the compressing forces applied in the Aegean lithosphere, resulting in a southwestward (relative to Eurasia) movement of the plate [11], the Aegean domain undergoes crustal extension in a marginal basin environment behind the active subduction system of the Hellenic outer arc. This extensional stress field is concentrated in several zones of graben development, both in front and behind the active volcanic inner arc of the Aegean. The Gulf of Patras, along with the Gulf of Corinth, consists of an asymmetric system of grabens formed under the near N-S extensional regime.

The Patras Gulf (Fig. 1) is an asymmetric rift being consisted of WNW-ESE trending normal faults of listric shape as a result of the tensional stress regime. The Patras-Corinth rifts form the active tectonics in Central Greece and link the North Aegean Fault with the Cephalonia Transform Fault on the western front of the Hellenic Arc.

During historical times, the broader area of Patras Gulf was characterized by high shallow seismicity [13]. Large magnitude seismic events occurred though after 1900 in the broader area, as the 1993 Patras earthquake (M_w= 5.4) [15], the 1995 Aegion earthquake (M_s=6.2) [1] and most recently the 2008 Andravida earthquake (M_w= 6.4) [12].

2. GPS MEASUREMENTS

A GPS network (Fig. 1) was established in the broader area of Patras Gulf in August 1994, by personnel of the Department of Geophysics & Geothermics of the National and Kapodistrian University of Athens to study the crustal deformation as well as the tectonic settings and motions on this area, in both local and regional scale. The network was consisted of ten (10) stations equally distributed on both sides of the gulf (5 stations on the northern side and 5 stations on the southern side).

Additionally, a local GPS network (Fig. 1) consisted of seven stations was established in July 2008 along both sides of the Rio-Antirrio Bridge (eastern part of Patras Gulf) at an attempt to monitor its deformation in that very active tectonically area.

2.1. DIFFERENTIAL GPS

2.1.1. Campaign Data

The Patras Network was first measured on its installation and has been remeasured twice, that is in October 1996, and in January 2006. The GPS station at Riza (No. 50) (northern side of Patras Gulf) was selected as the reference station in all campaign periods.

The smaller scale GPS network of Rio-Antirrio has been occupied twice since its installation, that is in July 2008 and March 2009 [14].

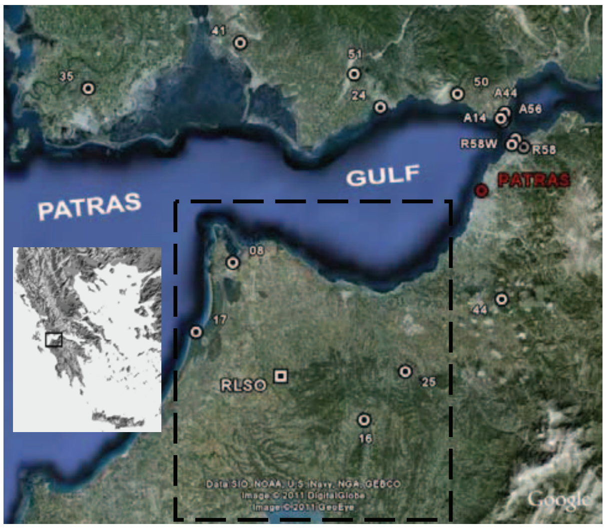
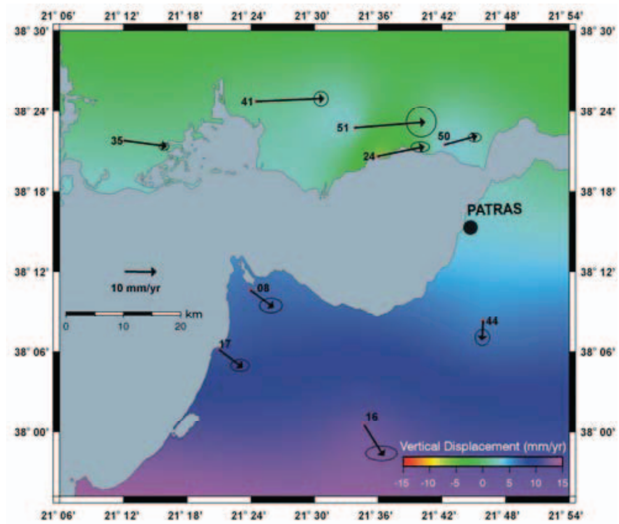


Fig. 1. Distribution of GPS Stations (circles) across the Patras Gulf and in the area of Rio-Antirrio. Square represents the continuously recording station at Riolos (RLSO). Rectangular indicates the area of Figure 4.

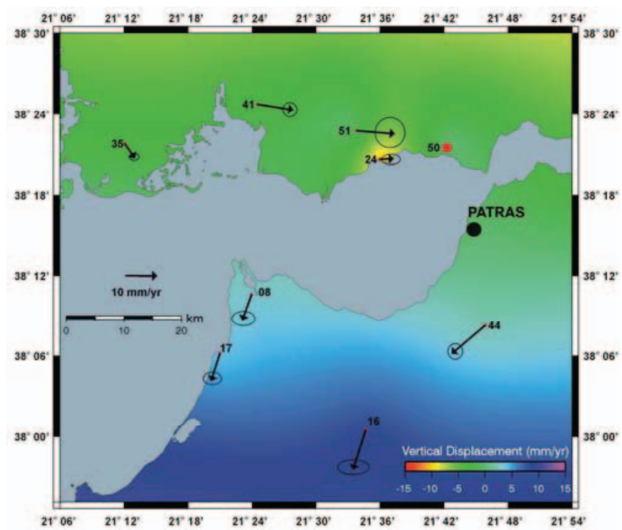
2.1.2. Data Analysis

The Bernese software v5.0 [4] was used for the post-processing of the GPS observations from both networks. A ground deformation having direction of ENE to NE was observed with a rate of 10.6 - 22.2 mm/yr at the northern part of the gulf with respect to the International Reference Frame (ITRF2000). The southern part exhibited an ESE to SE oriented displacement of 6.3-11.6 mm/yr. Concerning the vertical component, an uplift was generally observed. The uplift rate was about 3 mm/yr in the northern part of Patras Gulf, while in the southern part the uplift was higher ranging from 5.9-12.1 mm/yr (Fig. 2a). In local scale with respect to station No. 50, the ground deformation vectors revealed an extension of the Patras Gulf: The southern part seems to be extending towards the SSW direction with amplitudes of 8.7-13 mm/yr (Fig. 2b). Subsidence of the northern part and uplift of the southern part of the gulf was also observed.

Data processing of the Rio-Antirrio GPS Network revealed a horizontal deformation ranging from 10-18 mm for the period 2008-2009. The northern area (Antirrio) appears to uniformly deform along a NNE direction with amplitudes of 10-16 mm, while the southern area (Rio) exhibits similar amplitudes of horizontal displacements along the same general direction.



(a)



(b)

Fig. 2. Horizontal and Vertical deformation of the broader area of Patras Gulf for the measuring periods 1994 - 2006 relative to: (a) ITRF2000 and (b) Riza station (No. 50).

2.2. CONTINUOUS GPS

A continuously recording (at a frequency of 1 Hz) GPS station was established at Riolos (RLSO) in August 2006 (Fig. 1). The data of that station were processed automatically using the Bernese Software v5.0 Processing Engine [4] to calculate its displacement in both vertical and horizontal components. The data analysis (Fig. 3) confirmed the anticipated motion of the southern part of Patras Gulf that was resulted from the campaign data analysis relative to ITRF2000, as well as previous works [7]. The horizontal vector exhibited a SE displacement of the station. A relatively strong uplift of about 6 mm/yr was observed in the vertical scale.

The 2008 Andravida earthquake occurred in the vicinity of the RLSO station. It was noticed that only its northern component was basically affected. The focal mechanism of the mainshock (Fig. 4) showed a right lateral strike-slip fault motion. This movement is consistent with the GPS time series results (Fig. 3).

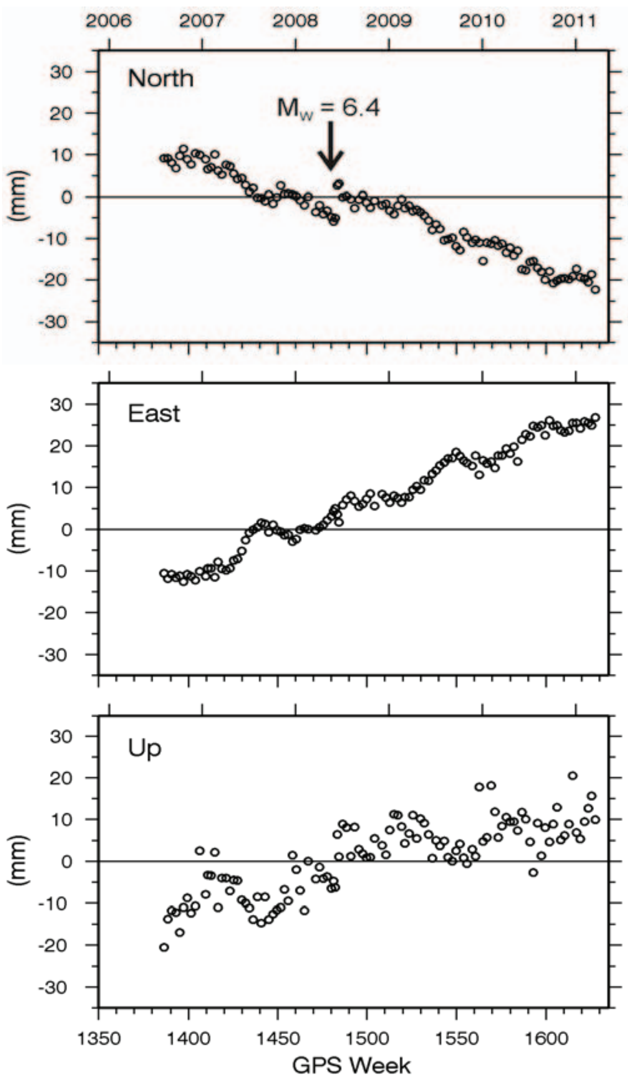


Fig. 3. Displacements of the real-time (1 Hz) GPS station at Riolos (RLSO) with respect to ITRF2000.

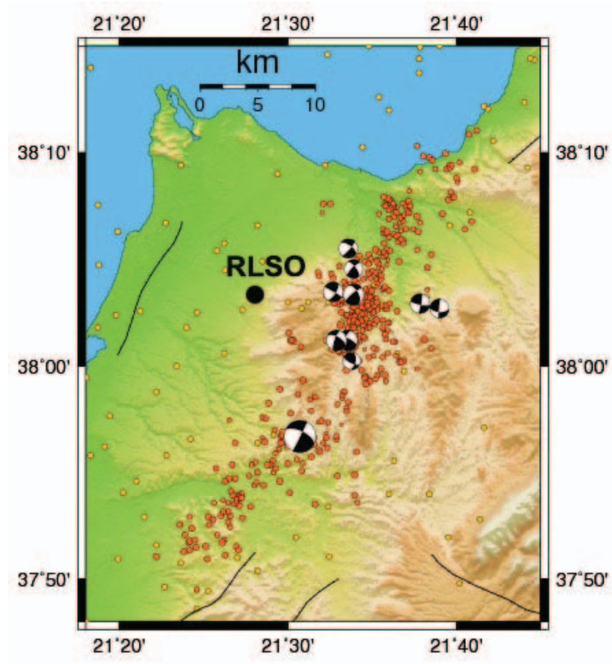


Fig. 4. Spatial distribution of epicentres together with the fault plane solutions of the Andravida earthquake sequence indicating a NNE-SSW activated area [12].

4. CONCLUSIONS

DGPS results from a local network in Patras Gulf, over a period of 12 years, showed an opening up of Patras Gulf at an almost N-S direction and at a rate of about 8-13 mm/yr, while the southern part seems to be uplifted with respect to the northern part with a rate of about 5 mm/yr. These results are consistent with geological [16], tectonic [5],[8], seismological [1] and other GPS studies [2] in the area. The extension of the Patras Gulf is consisted with previous research and it should be attributed to the counter-clockwise rotation of the Peloponnese relative to the mainland of Greece, around a pole located in the Saronic Gulf [9] south of the broader area of Athens.

Automated processing of RLSO continuously recording GPS station in the southern part of Patras Gulf revealed (i) a SE horizontal motion with respect to ITRF2000 that is consistent with the known kinematics of the region and (ii) moderate uplift consistent with the known tectonism of the area. The co-seismic effect of the 2008 Andravida earthquake (M_w=6.4) was clearly depicted in the neighboring RLSO station. The northward offset of about 10 mm observed in the northern component of the displacement vector is consistent with the right-lateral movement of the activated fault. The latter is in agreement with the estimated focal mechanism of the earthquake, as well as with the known tectonism of the area.

5. ACKNOWLEDGMENTS

GMT software (Wessel and Smith, 1995) was used to generate some figures (http://gmt.soest.hawaii.edu/).

6. REFERENCES

[1] P. Bernard, P. Briole, B. Meyer, H. Lyon-Caen, J. M. Gomez, C. Tiberi, C. Berge, R. Cattin, D. Hatzfeld, C. Lachet, B. Lebrun, A. Deschamps, F. Courboulex, C. Larroque, A. Rigo, D. Massonnet, P. Papadimitriou, J. Kassaras, D. Diagourtas, and K. Makropoulos, "The Ms=6.2, June 15, 1995 Aegion earthquake (Greece): evidence for low angle normal faulting in the Corinth rift," *J. Seismol.*, 1, pp. 131-150, 1997.

[2] P. J. Clarke, R. R. Davies, P. C. England, B. Parsons, H. Billiris, D. Paradissis, G. Veis, P. A. Cross, P. H. Denys, V. Ashkenazi, R. Bingley, H.-G. Kahle, M.-V. Muller, and P. Briole, "Crustal strain in central Greece from repeated GPS measurements in the interval 1989-1997," *Geophys. J. Int.*, 135, pp. 195-214, 1998.

[3] M. Cocard, H.-G. Kahle, Y. Peter, A. Geiger, G. Veis, S. Felekis, D. Paradissis, and H. Billiris, "New constraints on therapid crustal motion of the Aegean region: recent results inferred from GPS measurements (1993-1998) across the West Hellenic Arc, Greece," *Earth Planet. Sci. Lett.*, Elsevier Science B. V., 172 (1-2), pp. 39-47, 1999.

[4] Dach, R., U. Hugentobler, P. Fridez, and M. Meindl, *Bernese GPS Software Version 5.0*, Astronomical Institute, University of Bern, 2007.

[5] N. Flotté, D. Sorel, C. Muller, and J. Tensi, "Along strike changes in the structural evolution over a brittle detachment fault: Example of the Pleistocene Corinth-Patras rift (Greece)," *Tectonophysics*, Elsevier Science B. V., 403, pp. 77-94, 2005.

[6] A. Galanopoulos, "Plate tectonics in the area of Greece as reflected in the deep focus seismicity," *Bull. Geol. Soc. Greece*, IX/2, pp. 266-285, 1972.

[7] Ch. Hollenstein, M.D. Müller, A. Geiger, H.-G. Kahle, " Crustal motion and deformation in Greece from a decade of GPS measurements, 1993–2003'', *Tectonophysics*, 449, pp. 17-40, 2008

[8] J. A. Jackson, J. Gagnepain, G. Houseman, G. C. P. King, P. Papadimitriou, C. Soufleris, and J. Virieux, "Seismicity, normal faulting, and the geomorphological development of the Gulf of Corinth (Greece): the Corinth earthquakes of February and March 1981," *Earth Planet. Sci. Lett.*, 57 (2), pp. 377-397, 1982.

[9] X. Le Pichon, N. Chamot Rooke, S. Lallemant, R. Noomen, and G. Veis, "Geodetic determination of the kinematics of central Greece with respect to Europe: implications for eastern Mediterranean tectonics," *J. Geophys. Res.*, 100 (B7), pp. 12675-12690, 1995.

[10] D. McKenzie, "Active tectonics of the Mediterranean region," *Geophys.J. R. astr. Soc.*, 30, pp. 109-185, 1972.

[11] D. McKenzie, "Active tectonics of the Alpine-Himalayan belt: the Aegean Sea and surrounding regions," *Geophys. J. R. astr. Soc.*, 55, pp.217-254, 1978.

[12] P. Papadimitriou, A. Agalos, A. Moshou, V. Kapetanidis, A. Karakonstantis, G. Kaviris, I. Kassaras, N. Voulgaris, and K. Makropoulos, "An important number of recent significant earthquakes in Greece," 32nd General Assembly of the ESC 2010, 2010.

[13] Papazachos, B. C., and C. Papazachou, *The Earthquakes of Greece*, Ziti Editions, Thessaloniki, 1997.

[14] I. Parcharidis, M. Foumelis, P. Kourkouli, U. Wegmuller, E. Lagios, and V. Sakkas, "Continuous risk assessment of structures in areas of ground deformation susceptibility by Persistent Scatterers InSAR (PSInSAR): Preliminary Results of the Rio-Antirrio Bridge (Greece)", European Space Agency (Sp. Public.), ESA SP (649 SP), 5p (CD), 2008.

[15] V. Plicka, E. Sokos, G.-A. Tselentis, and J. Zahradnik, "The Patras earthquake (14 July 1993): relative roles of source, path and site effects," *Journal of Seismology*, Kluwer Academic Publishers, Netherlands, 2, pp. 337-349, 1998.

[16] M. Sébrier, "Tectonique récente d 'une transversale a l'arc égéen. Le golfe de Corinthe et ses régions périphériques. Thèse de 3eme cycle," Univ. Paris XI – Orsay, France, pp. 137, 1977.