IAG REPORT

GEODETIC RESEARCH ACTIVITIES IN GREECE

FOR THE PERIOD 2011-2015

Edited by

I.N. Tziavos
IAG National Correspondent

Contributions by:

Hellenic Military Geographical Service (HMGS)
National Cadastre and Mapping Agency SA (NCMA SA)

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FOREWORD

This report was prepared for the International Association of Geodesy (IAG) after an invitation of its Secretary General Dr. Hermann Drewes to the IAG National Correspondents, on the occasion of the 26th General Assembly of the International Union of Geodesy and Geophysics (IUGG) in Prague, June 22 – July 2, 2015.

The report aims primarily at the concise presentation of the geodetic activities and the progress achieved in Geodesy by research agencies and academic institutions. These refer to (a) Hellenic National Agencies and Governmental Institutions and (b) Hellenic University Departments, Institutions and Laboratories for the period 2011-2015. It provides a summary of the activities, as well as relevant publications, received by the contributors listed in the cover page, following a general response request to the Hellenic geodetic community. They are presented following the current structure of IAG in four main Commissions as outlined below:

- Commission 1: Reference Frames
- Commission 2: Gravity Field
- Commission 3: Earth Rotation and Geodynamics
- Commission 4: Positioning and Applications

Each of the aforementioned Commissions plays a leading and coordinating role to the specific scientific area and several *Commission Projects*, *Study Groups* and *Working Groups* are established and focused on particular scientific disciplines within the field of the respective Commission and under its responsibility.

The content of the report is divided in four main sections and each section is titled with the name of the corresponding Commission. For the respective scientific area the contribution of each Agency or individual scientist from a University, research institution or national agency is reported based on the material they provided along with the respective list of literature. An attempt was made to slightly homogenize the heterogeneous material provided by the contributors, but further and significant effort is needed to this direction in the future aiming to an updated and homogeneous version of the report to be produced. Therefore, the text and, in general, the style of each sub-report provided, have been maintained in the subsequent sections.

As it is expected, research work does not necessarily lays within the aims and goals of one Commission only, but covers broader and combined subjects. Moreover, given that nowadays Geodesy, both in terms of theoretical developments as well as practical applications, is cooperating widely with other geosciences, it is evident that in many cases the research results presented may not be strictly geodetic. This is in the sense that Geodesy offers the fundamental and basic breadboard, so that its products can then be used in other

scientific applications and/or through other data/services/product manipulation and processing tools. Such examples are the use of GNSS products in GIS-based, remote sensing and photogrammetric applications, the implementation of geoid models within oceanographic, hydrological, engineering and geodynamic studies and the exploitation of geodetic methods and databases in the prevention and mitigation of natural hazards. Therefore, interdisciplinary research results focusing on some of the aforementioned scientific areas are reported in section 4.

The IAG national report for Greece including all the above mentioned activities for the period 2011-2015 will be available in pdf format at the website of IAG (http://www.iag-aig.org/) after the 26th IUGG General Assembly.

The editor of this report would like to express his sincere thanks to all National Agencies and colleagues working at University and Research Institutions for their contributions, extensive lists of publications and other relevant material provided for the compilation of this report under strict time conditions.

Thessaloniki, June 2015

Prof. I.N. Tziavos
Aristotle University of Thessaloniki

1. Commission 1: Reference Frames

For this section material has been provided by:

(a) Hellenic Military Geographical Service (HMGS),
(b) National Cadastre and Mapping Agency SA (NCMA SA),
(c) School of Rural and Surveying Engineering, Department of Geodesy and Surveying, Aristotle University of Thessaloniki

1.1 Hellenic Military Geographical Service (HMGS)

Reference Systems

a. Implementation of GGRS in remote islands

HMGS connected the triangulation network of the islands Megisti, Ro and Stroggyli, to the IGS network. These islands are far away from Greece' s mainland and their triangulation network was connected to the rest national network through Doppler measurements in 1985. The above mentioned re-connection was necessary in order to assure the absolute position in a global reference system and increase the accuracy of the appropriate transformations.

Five points were measured with GNSS receivers and they were referenced to the IGS network through twelve IGS stations. In order to assist data processing eight more EPN stations were used. Also, additional observations were used, collected by two more GPS receivers positioned on network stations in Rhodes and Crete islands. Furthermore, GPS observations from other six points of the HEPOS (Hellenic Positioning System) network were used too. The reference frame employed was ITRF2008, as it was implemented from the IGS stations.

Based on the processing of the above data, a 3 parameter translation was computed giving low accuracy, suitable for cartographic and navigation purposes. In order to achieve better accuracy a Helmert 7-parameter transformation was computed between the reference systems of ITRF2008 and GGRS87 as it is implemented in the three islands. GNSS observations were held in 2014 and computations in 2015.

Publications:

1. HMGS internal report.

2. Formal announcement of the above local adjustment among HMGS, National Cadastre & Mapping Agency and National Technical University of Athens is under elaboration.

Fig. 1. GNSS stations network for materialization of GGRS in Megisti, Ro and Stroggyli

b. <u>Establishment of local frame network near the Greek/Turkish borderline for the construction of bilateral bridge.</u>

HMGS in cooperation with the Turkish General Command of Mapping established a small network consisting of six points, three on Greek territory and three on Turkish territory very close to the borderline in order to implement a common reference frame for the assistance in constructing a new bridge over Evros river.

The main purpose was the exact location of the new bridge and there were datum inconsistencies between the two countries. Therefore, ETRF2000 was adopted as the reference frame for that project only. The six-point local network which implemented ETRF2000, was referenced from two EUREF's EPN stations. The closer EPN stations were DUTH (Greece) and ISTA (Turkey) which were used.

Publications: Protocol between the Government of the Hellenic Republic and the Government of the Republic of Turkey concerning the location of and the border line on the second border crossing road bridge between the two countries in the area of the Kipi/Ipsala border crossing, signed on April 4, 2014 in Thessaloniki.

1.2 National Cadastre and Mapping Agency SA (NCMA SA)

Activities

National Cadastre and Mapping Agency SA (former KTIMATOLOGIO S.A.) operates the Hellenic Positioning System (HEPOS) since 2007. In this framework the main activities of NCMA SA in the period 2011-2015 have been:

- Development of a local geoid model to support the determination of orthometric heights by means of HEPOS.
- Realization of ETRS89 in Greece by means of the coordinates of HEPOS stations.
- Evaluation of the national trigonometric network, the HEPOS coordinate transformation and geoid model.
- Cooperation with EUREF towards a solution for maintaining ETRS89 in presence of strong tectonic activity.
- Participation in the EUREF project "Deformation Models" for the determination of a dense European tectonic velocity field and the consideration of a deformation model in the maintenance and use of national realizations of the ETRS89.
- Monitoring of the ionospheric activity over Greece (I95 index estimated in HEPOS).

Publications

Gianniou, M, I. Stavropoulou, D. Mastoris (2014): " EGSA87 and its realization through the Hellenic Positioning System HEPOS ", *13th National Cartographic Conference*, Patra, 22-24 October 2014 (in Greek).

Gianniou, M., D. Mastoris, E. Mitropooulou (2014): "National Report of Greece to EUREF 2014", *EUREF 2014 Symposium*, June 3-7 2014, Vilnius, Lithuania.

Gianniou, M. (2014): "Observing co-seismic displacements using 1-Hz data from a network of reference stations: a comparison of different data processing methods", *EUREF 2014 Symposium*, June 3-7 2014, Vilnius, Lithuania.

Gianniou, M., D. Mastoris (2013): "National Report of Greece to EUREF 2013", *EUREF 2013 Symposium*, May 29-31 2013, Budapest, Hungary.

Gianniou, M., E. Mitropoulou, I. Stavropoulou (2013): "Dealing with significant differential tectonic plate velocities within an RTK-network: The case of HEPOS, *EUREF 2013 Symposium* May 29-31 2013, Budapest, Hungary.

Gianniou, M., D. Mastoris, I. Stavropoulou (2012): "National Report of Greece to EUREF 2012", *EUREF 2012 Symposium*, June 6-8 2012, Saint Mandé, France.

Gianniou, M., E. Mitropoulou (2012): "Impact of high ionospheric activity on GPS surveying: Experiences from the Hellenic RTK-network during 2011-12", EUREF 2012 Symposium, June 6-8 2012, Saint Mandé, France.

Gianniou, M., (2011): "National Report of Greece to EUREF 2011", *EUREF 2011 Symposium*, May 25-28 2011, Chisinau, Moldova.

Gianniou, M., (2011): "Detecting permanent displacements caused by earthquakes using data from the HEPOS network", *EUREF 2011 Symposium*, May 25-28 2011, Chisinau, Moldova.

1.3 School of Rural and Surveying Engineering, Department of Geodesy and Surveying, Aristotle University of Thessaloniki

Prof. A. Dermanis

The research activity of Prof. Dermanis for the reporting period focuses mainly on the scientific area of Reference Frames. His research results have been published in the following papers.

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Dermanis, A. (2011): Fundamentals of surface deformation and application to construction monitoring. Journal of Applied Geomatics, Vol. 3, Nr. 1, pp. 9-22.

Altamimi, Z. & A. Dermanis (2011): Theoretical foundations of ITRF determination. The algebraic and the kinematic approach. Volume in honor of Prof. D. Vlachos, pp. 331-359. Publication of the School of Rural & Surveying Engineering, Aristotle University of Thessaloniki.

Altamimi, Z. & A. Dermanis (2012): The Choice of Reference System in ITRF Formulation. In: Sneeuw N, Novàk P, Crespi M, Sansò F (eds) VII Hotine-Marussi Symposium on Mathematical Geodesy. International Association of Geodesy Symposia, vol. 137, 329-334, Springer, Berlin.

Dermanis, A. (2013): On the computation of strain rate parameters – or – The rigorous character of some classical approximate formulas for strain rates. In: Arabelos D, Kaltsikis C, Spatalas S, Tziavos IN (eds.) Thales. Volume in honor of Prof. M. Kontadakis, pp 150-158. Publication of the School of Rural & Surveying Engineering, Aristotle University of Thessaloniki.

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Collilieux X, Altamimi Z, Argus DF, Boucher C, Dermanis A, Haines BJ, Herring TA, Kreemer CW, Lemoine FG, Ma C, MacMillan DS, Mäkinnen J, Métivier L, Ries J, Teferle FN, Wu X (2014). External Evaluation of the Terrestrial Reference Frame: Report of the Task Force of the IAG Sub-commission 1.2. IAG General Assembly, Melbourne, Australia, June 28 - July 2, 2011. In: C. Rizos, P. Willis (eds.) 2014. *Earth on the Edge. Science for a Sustainable Planet*, International Association of Geodesy Symposia 139, pp 197-202, Springer-Verlag, Berlin - Heidelberg.

Dermanis, A. (2015): Geodetic Calculations. History of Cartography, Volume Six (in print)

Chatzinikos M, Dermanis A (2015): A study of the role of the choice of reference system in the analysis of GNSS coordinate time series. In: van Dam T (ed.) 2015, Reference Frames for Applications in Geosciences (REFAG2014). IAG Symposia 146 (in print).

Dermanis, A. (2015): Global Reference Systems: theory and open questions. Invited paper at the Academia dei Lincei Session, VIII Hotine-Marussi Symposium, Rome, Italy, 17-21 June 2013. In: Sneeuw N, Novàk P, Crespi M, Sansò F (eds). VIII Hotine-Marussi Symposium on Mathematical Geodesy. IAG Symposia Volume 142 (in print).

Prof. K. Katsambalos

The research activity of Prof. Katsambalos for the reporting period focused on reference frames as well as on gravity field and positioning applications and has been published in the

following papers.

References

Ampatzidis D., Kotsakis C., Katsambalos K. (2011) The need of a local reference frame in Greece: the deficiency of ETRS89 and a new proposed strategy. e-Proceedings of the *Annual Symposium of the IAG Reference Frame Sub-Commission for Europe (EUREF2011)*, Chisinau, Moldavia, May 25-28, 2011.

Kotsakis C., Katsambalos K., Ampatzidis D. (2012) Estimation of the zero-height geopotential level in a local vertical datum from inversion of co-located GPS, leveling and geoid heights: a case study in the Hellenic islands. *Journal of Geodesy*, vol. 86, no. 6, pp. 423-439.

Ampatzidis D.. Kalamakis N., Katsambalos K (2014) Use of RTK baselines for positioning in old low-accuracy classical datums: A case study for the old Greek Datums South. Eastern European Journal of Earth Observation and Geomatics. Vo3, 2014.

Prof. C. Kotsakis

The primary focus of C. Kotsakis' research activity during the last four years was directed on the theoretical and practical aspects of geodetic reference frames and their impact in geodetic network analysis and Earth monitoring applications. The major highlight of his work was the study of the optimal weighting for the reference stations participating in the datum definition of a local, regional or global geodetic network, which has been a well-known unsolved and long-lasting problem under the scientific objectives covered by Commission 1 of the IAG. The work of C. Kotsakis on this topic resulted in the development of new methodological tools for optimal frame realization and it introduced the so-called optimally weighted minimum constraints into the arsenal of current approaches for the alignment of GNSS networks to the International Terrestrial Reference Frame (Kotsakis 2013a, 2014a, 2015; Chatzinikos and Kotsakis 2015). His research work on reference frames included also the optimal revision of the classic Helmert transformation approach for integrating a geodetic network solution (or a series of network solutions) into a global frame by considering both the intra-frame and inter-frame covariances during the transformation procedure (Kotsakis et al. 2014, 2015; Vatalis et al. 2014). A sample of results obtained by his revised frame transformation approach is given in Figure 1, which depicts the ITRF2008 coordinate differences between the classic and the optimal implementations of the Helmert transformation, with respect to a directly constrained solution, using the same set of reference stations.

Dr. Kotsakis has also worked on various other important geodetic topics, including the study of the frame stability and the nonlinear distortion in minimally constrained networks (Kotsakis 2012a), the consistent combination of heterogeneous height data both for static and time-dependent cases (Kotsakis 2012b, 2013b; Kotsakis and Tsalis 2014; Tsalis et al. 2014), the estimation of the zero-height level of Greece using EGM08 and GPS/leveling data (Kotsakis et al. 2012; Grigoriadis et al. 2014), the external evaluation of the latest GRACE and GOCE geopotential models over the Hellenic area (Vergos et al. 2014), the quality assessment of the Hellenic Geodetic Reference System 1987 and the design considerations

of a new dynamic reference frame for Greece (Ampatzidis et al. 2011, 2012; Chatzinikos and Kotsakis 2014; Kotsakis 2014b), the comparison of geo-referencing procedures for old land demarcation maps using GNSS data (Aslanidis and Kotsakis 2014), and the development of a new software package for the adjustment and the statistical analysis of geodetic and surveying networks (Mikrou et al. 2014).

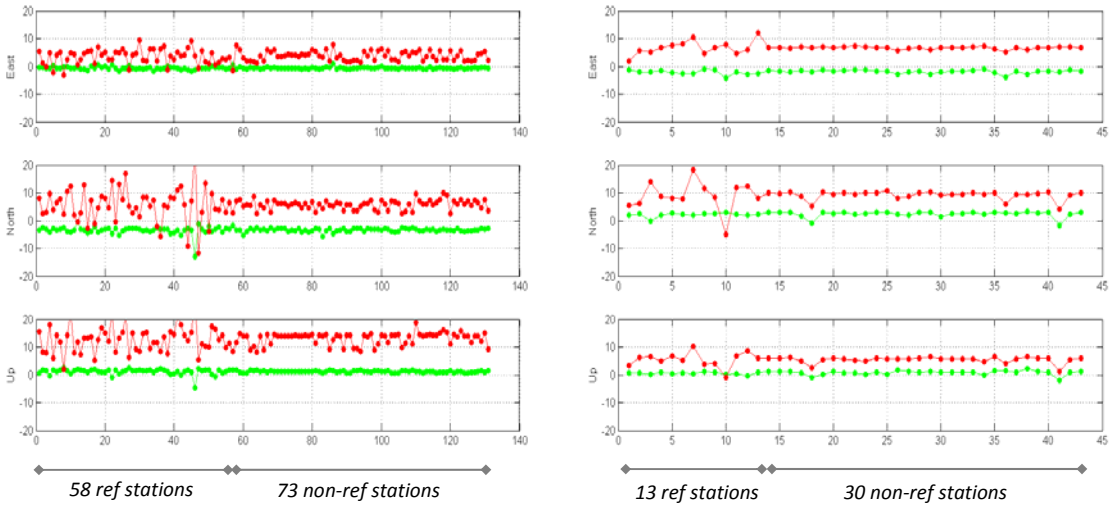

Fig. 1 Differences (in mm) of the ITRF2008 coordinates obtained by the directly constrained solution vs. the optimal HT solution (green line) and the standard HT solution (red line). The used sinex files refer to the sixth day of GPS week 1809 from the MUT and SUT (left and right plots respectively) local analysis centers of the EPN network.

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Ampatzidis D., Kotsakis C., Katsambalos K. (2011) The need of a local reference frame in Greece: the deficiency of ETRS89 and a new proposed strategy. e-Proceedings of the *Annual Symposium of the IAG Reference Frame Sub-Commission for Europe (EUREF2011)*, Chisinau, Moldavia, May 25-28, 2011.

Ampatzidis D., Kotsakis C., Katsambalos K. (2012) Realization of an optimal geodetic reference frame in the Hellenic area: open problems and proposals (in Greek). Presented at the *Workshop on Tectonic Geodesy*, Athens, January 25, 2012.

Aslanidis N., Kotsakis C. (2014) Geo-referencing procedures for old land devision maps in the Hellenic Geodetic Reference System 1987 using GNSS observations: a case study in Dasochori, Serres (in Greek). e-Proceedings of the *Fourth Scientific Conference of the Hellenic Association of Rural and Surveying Engineers*, Thessaloniki, September 26-28, 2014.

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Grigoriadis V.N., Kotsakis C., Tziavos I.N., Vergos G.S. (2014) Estimation of the reference geopotential value for the local vertical datum of continental Greece using EGM08 and GPS/leveling data. *IAG Symposia Series*, vol. 141, pp. 249-255. Proceedings of the *IAG International Symposium on Gravity, Geoid and Height Systems*, Venice, Italy, October 9-12, 2012.

Kotsakis C. (2012a) Reference frame stability and nonlinear distortion in minimum-constrained network adjustment. *Journal of Geodesy*, vol. 86, no. 9, pp. 755-774.

Kotsakis C. (2012b) A conventional approach for comparing vertical reference frames. *Journal of Geodetic Science*, vol. 2, no. 4, pp. 319-324.

Kotsakis C. (2013a) Generalized inner constraints for geodetic network densification problems. *Journal of Geodesy*, vol. 87, no. 7, pp. 661-673.

Kotsakis C. (2013b) The role of a conventional transformation scheme for vertical reference frames. *IAG Symposia Series*, vol. 138, pp. 201-206. Proceedings of the *IAG International Symposium on Reference Frames for Applications in Geosciences*, Marne-La-Vallee, France, October 4-8, 2010.

Kotsakis C. (2014a) Solving the reference station weighting problem in minimally constrained networks. Presented at the *Annual EUREF Symposium of the IAG Reference Frame Sub-Commission for Europe*, Vilnius, Lithuania, June 4-6, 2014.

Kotsakis C. (2014b) Design, realization and operational aspects of a time-dependent high-accuracy geodetic reference frame for the Hellenic region (in Greek). Presented at the *Fourth Scientific Conference of the Hellenic Association of Rural and Surveying Engineers*, Thessaloniki, September 26-28, 2014.

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Kotsakis C., Katsambalos K., Ampatzidis D. (2012) Estimation of the zero-height geopotential level in a local vertical datum from inversion of co-located GPS, leveling and geoid heights: a case study in the Hellenic islands. *Journal of Geodesy*, vol. 86, no. 6, pp. 423-439.

Kotsakis C., Vatalis A., Sanso F. (2014) On the importance of intra-frame and inter-frame covariances in frame transformation theory. *Journal of Geodesy*, vol. 88, no. 12, pp. 1187-1201.

Kotsakis C., Tsalis I. (2014) Combination of geometric and orthometric heights in the presence of geoid and quasi-geoid models. *IAG Symposia Series*, vol. 141, pp. 235-239. Proceedings of the *IAG International Symposium on Gravity, Geoid and Height Systems*, Venice, Italy, October 9-12, 2012.

Kotsakis C., Vatalis A., Sanso F. (2015) The Helmert transformation approach in network densification revisited. *IAG Symposia Series*, under review. Proceedings of the *IAG International Symposium on Reference Frames for Applications in Geosciences*, Kirchberg, Luxemburg, October 13-17, 2014.

Mikrou T., Ouzounoudis G., Kotsakis C. (2014) NETIST: A new software package for the adjustment and statistical analysis of geodetic and surveying networks (in Greek). e-Proceedings of the *Fourth Scientific Conference of the Hellenic Association of Rural and Surveying Engineers*, Thessaloniki, September 26-28, 2014.

2. Commission 2: Gravity Field

For this section material has been provided by:

(a) Hellenic Military Geographical Service (HMGS),
(b) School of Rural and Surveying Engineering, Department of Geodesy and Surveying, Aristotle University of Thessaloniki,
(c) School of Rural and Surveying Engineering, Department of Topography, National Technical University of Athens

2.1 Hellenic Military Geographical Service (HMGS)

a. Gravity Measurements

HMSG started a project of gravity measurements on triangulation pillars where GPS observations exist, in order to compute a more accurate geoid model over the Hellenic territory.

During 2013 – 2014, 250 pillars were measured in the regions of Macedonia and Epirus. Gravity measurements were held with Scintrex CG-5 and LaCoste & Romberg (model D-107) gravity meters and they were referenced to the National Gravimetric Network.

Data processing was made through software modules developed by HMGS. GRAVcalib was used to compute a calibration constant for L & R gravity meter, derived from measurements in Mount Parnitha calibration loop. Also, GRAVloop software was used to compute absolute gravity in each point, taking into account earth tide effects, calibration constant and meter's drift.

HMGS schedules to continue gravity measurements in 2015 in the region of Thrace and Northern Aegean Sea islands.

Publication:

HMGS internal report

b. Data Analysis

Using gravity data and simultaneous GPS observations from the period 2004-2007 on 660 triangulation pillars in central Greece and gravity data from 8998 points of HMGS's database all over Greece, a study has been conducted, including evaluation and numerical investigation in gravity field functionals between the above datasets and various geopotential models derived from GRACE and GOCE missions and the ultra-high degree models EGM2008 and EIGEN-6C3stat.

The numerical investigation was carried out by spherical harmonic synthesis using GRAVSynth a software developed by HMGS. Furthermore a degree-wise cumulative analysis

was held between gravity data derived from the 660 points in central Greece and selected satellite gravity models as well as the EGM2008 and EIGEN-6C3stat combined models.

Publications:

1. HMGS internal report.

2. Papanikolaou T.D., Papadopoulos N., High frequency analysis of the Earth gravity field based on terrestrial gravity data and GPS/leveling data: a case study in Greece, Journal of Geodetic Science, in press, De Gruyter

Fig. 1. Simultaneous GPS observations and gravity measurements network in central Greece

2.2 School of Rural and Surveying Engineering, Department of Geodesy and Surveying, Aristotle University of Thessaloniki

Prof. D. Arabelos

Prof. Arabelos scientific work in gravity field modeling and satellite altimetry for the reporting period has been published in the following research papers.

References

Tscherning, C.C., Arabelos, D.N.: Gravity anomaly and gradient recovery from GOCE gradient data using LSC and comparisons with known ground data. Proc. of '4th International GOCE User Workshop', Munich, Germany 31 March - April 1, 2011, ESA Publications Division, (ESA SP-696, 2011), Nordwijk, The Nederlands.

Arabelos, D.N. and Tsoulis, D. The exploitation of state of the art digital terrain databases and combined or satellite-only Earth gravity models for the estimation of the crust-mantle interface over oceanic regions. Geophys. J. Int. (June, 2013): 1343-1352 doi: 10.1093/gji/ggt081.

Arabelos, D.N., An assessment of satellite-only Earth gravitational models based on comparisons with gravity anomalies and combined gravitational models. In volume dedicated to Professor Emeritus D. Vlachos, Ziti Publishing, April 2013, pp. 276-307.

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Arabelos, D.N., D.Z. Papazachariou, M.E. Contadakis and S.D. Spatalas: A new tide model for the Mediterranean Sea based on altimetry and tide gauge assimilation. Ocean Sci., 7, 429-444, 2011 www.ocean-sci.net/7/429/2011/ doi:10.5194/os-7-429-2011.

Arabelos, D.N., and D.Z. Papazachariou: Assessment of PISTACH data in monitoring temporal level variations over non-oceanic areas in Greece. International Journal of Lakes and Rivers, ISSN 0973-4570 Volume 7, Number 1, 63-75, 2014.

Prof. D. Tsoulis

Research activities in the area of gravity field modeling and interpretation during the 2011-2015 period include work related to the analysis and validation of currently available as well published during this period satellite-only and combined Earth gravity models. Spectral and spatial properties of these models have been demonstrated in the frame of thorough degree-wise and band-limited validation studies (Tsoulis and Patlakis 2013a,b; Patlakis and Tsoulis 2015). A special aspect in the frame of these investigations has been documented in studies focusing on the role of isostatic gravity models in understanding the medium to high frequency part of the observed gravity field (Tsoulis 2013; Tsoulis and Patlakis 2014). A different procedure, which permits a degree-wise cumulative analysis of the different models at satellite altitude in terms of geometric contributions to the observed and estimated orbit of Low Earth Orbiters has been presented by Tsoulis and Papanikolaou (2012, 2013), Papanikolaou and Tsoulis (2014). The role of state of the art global digital terrain and crustal databases for gravity field related studies has also attracted research efforts during this period (Arabelos and Tsoulis 2013; Tenzer et al. 2014). Finally, a closed analytical formulation for the complete gravity tensor of an arbitrarily shaped polyhedral source has been published (Tsoulis 2012) as well as its implications on local and regional applications (Tsoulis et al. 2012).

References

Tsoulis D (2012) Analytical computation of the full gravity tensor of a homogeneous arbitrarily shaped polyhedral source using line integrals, *Geophysics*, 77 (2), pp F1-F11

Tsoulis D, Papanikolaou T, Vassiliadis I, Venesis C (2012) On the computation of crustal induced gravity signal at a typical low Earth orbiter altitude, *Journal of Geodetic Science*, 2**(3)**, pp 240-246

Tsoulis D, Papanikolaou TD (2012) Numerical investigation of different gravity models in orbit propagation of two short CHAMP and GRACE-A arcs, In: *VII Hotine-Marussi Symposium on Mathematical Geodesy* (Eds: N Sneeuw et al), IAG Symposia Series, Volume 137, 279-284 pp, Springer

Tsoulis D, Patlakis K (2013) Band-limited analysis of current Satellite-to-Satellite Tracking, Gradiometry and combined Earth Gravity Models, *Surveys in Geophysics*, 34 (4), pp 375-394

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Tsoulis D (2013) Geodetic use of global digital terrain and crustal databases in gravity field modeling and interpretation, *Journal of Geodetic Science*, 3 (1), pp 1-6

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Tenzer R, Chen W, Tsoulis D, Bagherbandi M, Sjoberg L, Novak P, Jin S (2014) Analysis of the refined CRUST 1.0 crustal model and its gravity field, *Surveys in Geophysics*, doi 10.1007/s10712-014-9299-6

Papanikolaou T, Tsoulis D (2014) Dynamic orbit parameterization and assessment in the frame of current GOCE gravity models, *Physics of the Earth and Planetary Interiors*, doi: http://dx.doi.org/10.1016/j/pepi.2014.08.003

Patlakis K, Tsoulis D (2015) Assessment of the recently released GOCE-based models in terms of spectral and spatial resolution, IAG Symposia Series, Volume 143, Springer, in press

Prof. I.N. Tziavos, Ass. Prof. G.S. Vergos, Lecturer V.N. Grigoriadis – GeoGrav group

During the last four years the main research activities of the GeoGrav group have been driven, naturally, by the realization of the GOCE mission and the contributions brought to gravity field approximation by its observables. The work performed was mainly directed to GOCE validation and GOCE use, the first one referring to the spectral validation and comparison with external data of the released GOCE, GOCE/GRACE and combined GGMs. The second refers to the use of GOCE products for geoid and gravity related work, i.e., for the determination of the zero-level geopotential value of Greece, calibration/validation of altimetric satellites, mean dynamic ocean topography modeling and regional geoid improvement. With the aforementioned in mind, the report contains material related to the validation of GOCE data and their use in practical geoid-related and geoid-based studies.

GOCE model validation (spectral)

A significant portion of the work performed during the last four years was directed to the spectral evaluation of GOCE and GOCE/GRACE Global Geopotential Models (GGMs). This was performed in terms of their signal and error degree variances (both by-degree and cumulatively), the signal-to-noise ratio (SNR) and gain relative to EGM2008. The signal and error degree variances reveal the spectral content of the GGMs for the various d/o

investigated as well as the cumulative signal spectrum and signal error. The SNR provides useful information for the relative signal strength given the signal error, while the gain, relative to EGM2008, provides an indicative measure of the improvement brought by the GOCE/GRACE GGMs w.r.t. the reference GGM used.
From this analysis, an improved representation of the geoid height error spectrum was evident as more GOCE data were included (TIM-R4 and DIR-R4 compared to GOCO03S), along with the improved error spectrum due to the use of GRACE data (DIR-R4 compared to TIM-R4).

GOCE model validation (external)

For the external evaluation of the GOCE/GRACE GGMs, comparisons with collocated GPS/Levelling benchmarks (BMs) and point free-air gravity anomalies covering the entire part of continental Greece, have been performed. As far as geoid heights and gravity anomalies are concerned, the differences between the GOCE/GRACE GGMs with the local data have been formed using the spectral enhancement approach, i.e., by filling-in the missing spectra with EGM2008 contribution and RTM effects for the ultra-high frequencies (above d/o 2190).

GOCE model for Wo determination

The GeoGrav group has been also involved in the use of GOCE GGMs for the estimation of the zero-level geopotential value over Greece. The methodology followed was based on a combination, through Least-Squares (LS), of available Helmert orthometric heights, surface gravity data and geopotential values on trigonometric BMs, where the latter two estimated from the available GOCE GGMs.

GOCE MRA with wavelets for local geoid improvement

The GeoGrav group employed wavelet (WL) based Multi-resolution analysis (MRA) for the decomposition and regional improvement of the geoid and gravity field from GOCE-based GGMs as well as from the original GOCE SGG data. We have specifically focused on the spectral analysis of GOCE, GOCE/GRACE and combined Global Geopotential Models (GGMs) through wavelet decomposition, filtering and reconstruction in order to improve their performance as to their spectral content in the higher bands of the spectrum.

Moreover, a regional improvement of the gravity field and geoid was performed by combining GOCE SGG data at mean orbit with surface gravity anomalies. This was done through the application of a Monte-Carlo method (Simulated Annealing). Through SA the inverse problem of downward continuation of SGGs from mean orbit to the Earth's surface using an iterative Monte Carlo procedure based on a quasi-random generator was carried out.

Geoid determination in regional scales

The GeoGrav group has continued its work within geoid-determination activities either at regional scales or local ones. The latter refers to the development of geoid models for the

calibration/validation of altimetric satellites (Jason1, Jason2, Envisat, HY2, Saral) in the dedicated facility of Gavdos. Within these studies, the well-known remove-compute-restore (RCR) method has been used along with least-squares collocation (LSC) and FFT-based spectral methods.

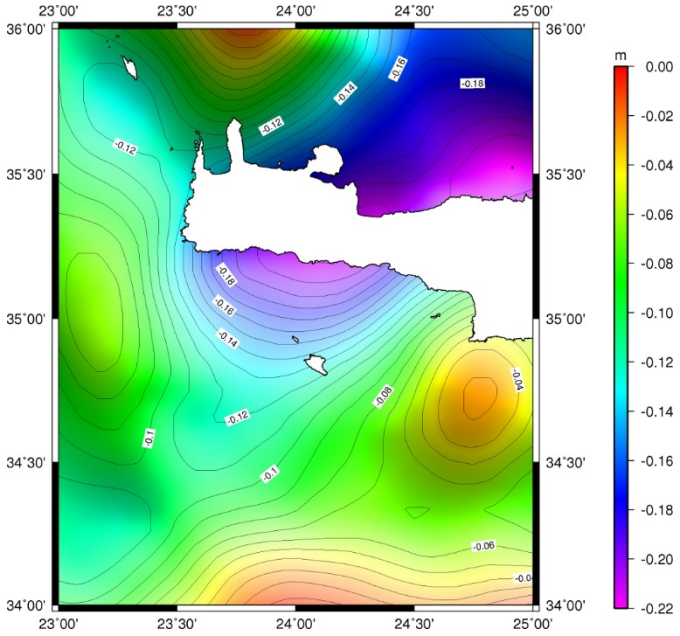

Figure 1: A GOCE geoid employing the RCR method and LSC for the cal/val of altimetric satellites.

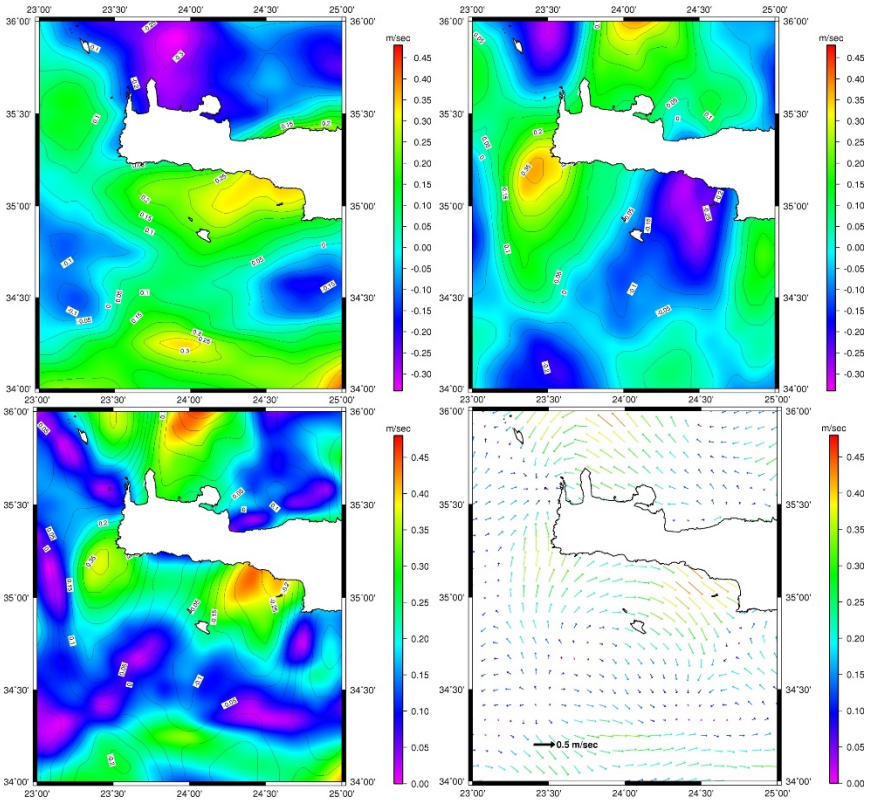

Figure 2: A GOCE-based MDOT over Gavdos (upper left), with its NS (upper-right) WE (lower left) constituents and the resulting circulation.

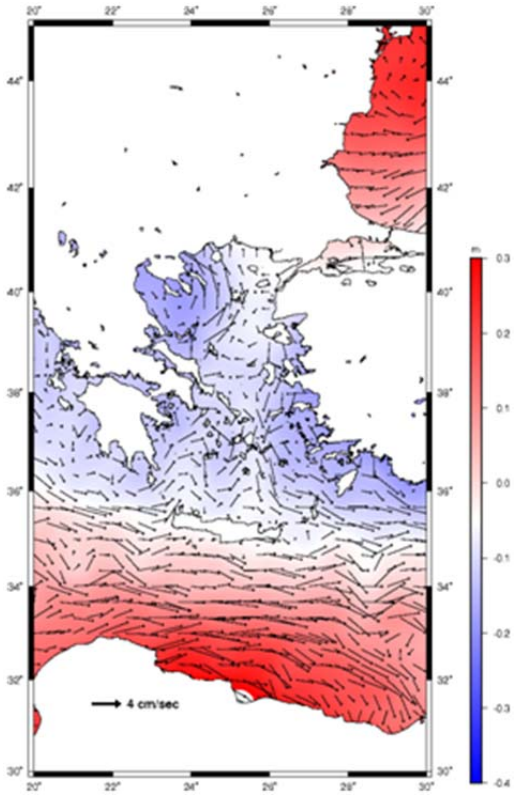

Figure 3: A GOCE-based MDOT in the eastern Mediterranean Sea.

Mean-dynamic Ocean topography

The determination of MDOT models was the focus of our work as well, employing satellite altimetry (mono- and multi-mission data) and local geoid models either from the GOCE GGMs or gravimetric ones. This resulted in MDOT and ocean circulation models for the Mediterranean Sea and the area surrounding Gavdos.

Geophysical interpretation and Moho-depth modelling

Another research area of the GeoGrav group was the study of geological and geotectonic settings of the crust and upper mantle. In this frame, new gravity databases containing Bouguer anomalies were compiled for the wider Hellenic area and the Adriatic Sea, following a detailed validation and evaluation procedure for the used source data. These databases were then utilized in the determination of the Mohorovičić discontinuity by gravity inversion, as well as in density modeling in order to study the lower-crustal/upper-mantle depth range and constrain the 2D geometry of shallow geological units.

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2.3 School of Rural and Surveying Engineering, Department of Topography, National Technical University of Athens

Assoc. Prof. D. Delikaraoglou and his scientific group

For the period 2011-2015, our geodetic research activities focused on two main areas:

- Various theoretical and practical aspects relating to applications in high precision global and regional gravity field modelling based mainly on the combination of altimetry data, terrestrial gravity data, digital elevation and GPS/levelling measurements. Emphasis was given to in-depth studies of the various types of Geodetic Boundary Value Problems (GBVPs) in Ellipsoidal Geometry.

- Algorithms and methods for improving the performance of network-based RTK and PPP techniques, as well as integrity monitoring techniques and navigation performance, including the usage of new software GNSS toolkits. The foreseeable advantages arising from the combination of GPS with other GNSS systems like GLONASS, Galileo, Beidou etc. were studied through detailed analyses of simulated and actual data showing that users can benefit already now especially in the urban areas.

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3. Commission 3: Earth Rotation and Geodynamics

For this section material has been provided by:

(a) School of Rural and Surveying Engineering, Department of Geodesy and Surveying, Aristotle University of Thessaloniki,
(b) Laboratory of Geodesy and Geomatics Engineering, Technical University of Crete,
(c) The GNSS National Network (NOANET) of the Institute of Geodynamics, National Observatory of Athens (scientific responsible: Dr. A. Ganas)

3.1 School of Rural and Surveying Engineering, Department of Geodesy and Surveying, Aristotle University of Thessaloniki

The research reported here focuses both to Geodynamics as well as to other disciplines and applications of geosciences.

Prof. D. Arabelos

Total Electron Content

It is broadly accepted in the scientific community that the tectonic activity resulting in earthquakes can induce variations in the ionosphere through the so-called lithosphere-atmosphere-ionosphere coupling (LAIC) mechanism. Based on this principle, Total Electron Data over broad area of several hundred kilometers from earthquake are analyzed in order to investigate the TEC variations in the month before the earthquake.

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M.E. Contadakis, D.N. Arabelos, G. Vergos, S.D. Spatalas, M. Skordilis, TEC variations over the Mediterranean before and during the strong earthquake (M = 6.5) of 12th October 2013 in Crete, Greece, Physics and Chemstry of the Earth, 2011, doi:10.1016/j.pce.2015.03.010.

Tidal triggering

Although the stress drop in an earthquake event is two or three orders higher than the amplitude of the tidal stress variations, the tidal stress rate is comparable or much higher that the tectonic stress accumulation in a fault. Thus, unless the earthquake event to be the result of sudden stress accumulation on a fault, the Earth tides can act as a triggering mechanism for a mature fault for rapture occurrence. In this principle I s based the investigation in the relevant papers.

List of Publications

Michael E. Contadakis, Dimitrios N. Arabelos, Spyrous D. Spatalas Evidence for tidal triggering for the earthquakes of the Ionian geological zone, Greece. Annals of Geophysics, 55,1 2012; doi:10.4401/ag-5314.

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European Radio Network

The propagation of the VLF and LF radio signals is affected by different factors such as the meteorological conditions, the solar activity and the geomagnetic activity. At the same time, variations of some parameters in the ground, in the atmosphere and in the ionosphere occurring during the preparatory phase of earthquakes can produce disturbances in the above mentioned signals. In this way, the analysis of the VLF and LF radio signals can give information on the preparatory phase of earthquakes.

List of Publications

C. Skeberis, Z.D. Zaharis, T.D. Xenos, S. Spatalas, D.N. Arabelos, M.E. Contadakis, Time frequency analysis of VLF for seismic-ionospheric precursor detection: Evaluation of Zhao-Atlas-Marks and Hilbert-Huang Transforms, Physics and Chemstry of the Earth, 2011, doi:10.1016/j.pce.2015.02.006

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Christos Skeberis, Dimitrios T. Xenos, Thomas D. Xenos, Michael E. Contadakis, Dimitrios Arabelos, Georgia Chatzopoulou, Application of empirical mode decomposition to very low frequency signals for identification of seismic-ionospheric precursor phenomena. Annals of Geophysics, 55, 1 2012; doi:10.4401/ag-5312.

Skeberis, C.; Xenos, T. D.; Arabelos, D. N.; Spatalas, S., Evaluation of the Hilbert-Huang transform application for the recognition of seismic precursory phenomena by the analysis of VLF transmission signals of the European Network. Thales, in honor of Prof. Emeritus Michael E. Contadakis, ISBN 978-960-89704-1-0, 2013, p 288-303.

Righetti, F., Biagi, P.F., Maggipitinto, T., Schiavulli, L., Ermini, A., Moldovan, I.D., Moldovan, A.S., Buyuksarac, A., Silva, H.G., Bezzeghoud, M., Contadakis, M.E., Arabelos, D.N., Xenos, T.D.: Wavelet analysis of the LF radio signals collected by the European VLF/LF network from July 2009 to april 2011. Annals of Geophysics, 55, 1 2012; doi:10.4401/ag-5188.

Skeberis, Ch., Xenos, T.D., Contadakis, M.E., Arabelos, D.N., Chatzopoulou, G.: Application of empirical mode decomposition to very low frequency signals for identification of seismic-ionospheric precursors phenomena. Annals of Geophysics, 55, 1 2012; doi:10.4401/ag-5312.

P.F. Biagi, F. Righetti, T. Maggipinto, L. Schiavulli, T. Ligonzo, A. Ermini, I.A. Moldovan, A.S. Moldovan, H.G. Silva, M. Bezzeghoud, M.E. Contadakis, D.N. Arabelos, T.D. Xenos, A. Buyuksaraca: Anomalies observed in VLF and LF radio signals on the occasion of the western Turkey earthquake (Mw=5.7) at May 19, 2011, International Journal of Geosciences, 2012,3,856-865 doi:10.4236/ijg.2012.324086.

Skeberis, Ch., Xenos, T.D., Arabelos, D.N., Sparalas, S.D.: Evaluation of the inplementation of Hilbert-Huang transformation in the identification of precursor seismic phenomena by analyzing signals of the European VLF radio network. "Thales" volume dedicated to Professor Emeritus M.E. Contadakis, Ziti Publishing, pp 288-303, 2013 (in Greek).

3.2 Laboratory of Geodesy and Geomatics Engineering, Technical University of Crete

The research reported here focuses both on Geodynamics as well as on other disciplines and applications of geosciences, e.g., gravity field, satellite altimetry, GNSS-based applications, geophysical interpretation.

Prof. Mertikas and his scientific group (http://www.geomatlab.tuc.gr**)**

In the world, there exist four permanent Cal/Val facilities mainly for the satellite altimetry calibration. Two of those sites are located in Europe (Gavdos in Greece operated by the Geodesy & Geomatics Engineering Lab (GeoMatLab), Technical University of Crete; Corsica in France operated by Centre National d'Etudes Spatiales), one in the USA (Harvest Oil Platform, California, operated by the Jet Propulsion Lab/NASA) and one in Australia (Bass Strait, operated by the University of Tasmania).

The Gavdos-Crete Cal/Val infrastructure is the only permanent facility in the world to provide but also to cross-compare calibration values for various satellite altimeters with two independent techniques (sea-surface calibration + transponder on land). It is a research infrastructure, in the center of East Mediterranean, which is of strategic importance and constitutes an indispensable element for proper altimeter operations and measurements in current and future satellite missions. American, French, Indian, Chinese, NASA, and the European Space Agency missions have officially included this Gavdos/Crete infrastructure in their ground-support infrastructure for their satellite altimetry operations.

Significant investments had taken place in the past to reach this scientific and technological excellence of the Gavdos-Crete Cal/Val facility. These investments were mainly supported through European Research & Innovation and Structural Funds, ESA, NASA and the EU.

In support of the Gavdos Cal/Val, a network of 13 continuously operating GNSS (Global Navigation Satellite Systems) reference stations has also been established in western Crete and Gavdos. Most of these dedicated stations are collocated with tide gauges, meteorological sensors, etc. In 2012, GeoMatLab has also installed the first EGNOS (European Geostationary Navigation Overlay System) station in Greece in the University Campus. This has been officially included into the EGNOS Data Collection Network (EDCN) as of January 2013. Also, a Satellite Laser Ranging (SLR) facility was established on campus, and operated in 2003 by mobile French laser units, to determine accurate orbits for the

overflying satellites. Finally, next to the EGNOS station, a Chinese BeiDou satellite receiver, the first one in Greece and one of the very few in Europe, has been set up in May 2012.

This Cal/Val infrastructure in Gavdos & Crete is important not only for the satellite altimetry mission stakeholders (i.e., ESA-Europe, NASA-USA, Indian Space Research Organization, Chinese State Oceanic Administration), but also for the national research community and economy. This is because satellite altimetry applications range from geodesy/geophysics (i.e., bathymetry, marine geoid), to oceanography, ocean engineering (ocean circulation, mean dynamic topography, wave heights, sea state, tides), hydrology and water resources discovery, and biology. All these scientific fields benefit from altimetric reliable data of high accuracy provided by the international satellite altimetry community. Data from the scientific research instrumentation installed at the Gavdos-Crete Cal/Val facilities are valuable for the national scientific community because it provides long-term and unequivocal monitoring of several environmental variables, like sea surface height, sea level change, atmospheric delays, tectonic deformation, etc.

Additionally, changes in the Earth's gravity field as monitored by satellite altimeters, in conjunction with other geodetic/geophysical techniques, provide an essential tool for locating offshore sedimentary basins and resources.

Publications

The co-authored publications of Prof. Mertikas focused on geodynamic, satellite altimetry, gravity field and its geophysical applications are listed in section 2.2.

Some of the activities at the Gavdos calibration site are shown in the following figures.

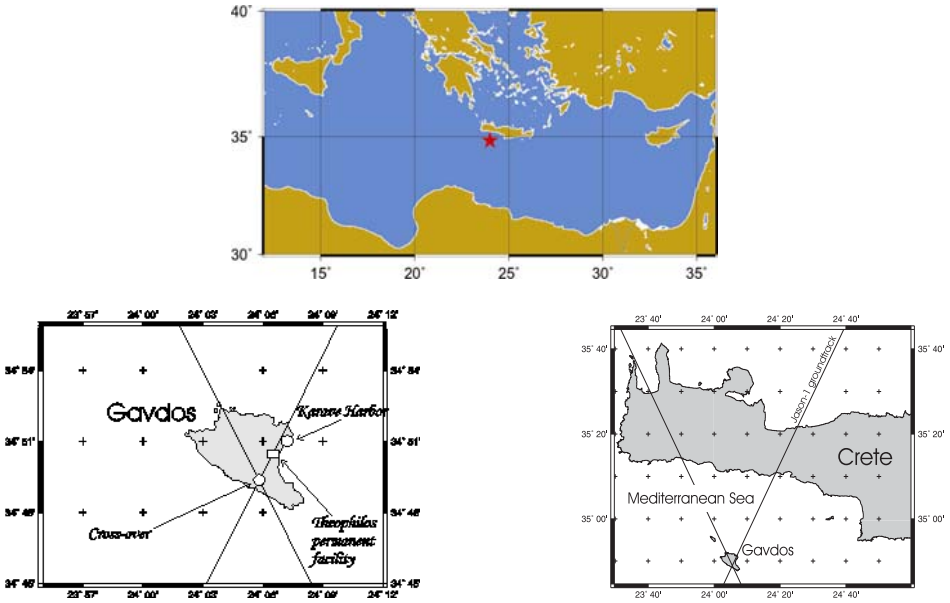


Figure 1: Gavdos permanent facility, Greece

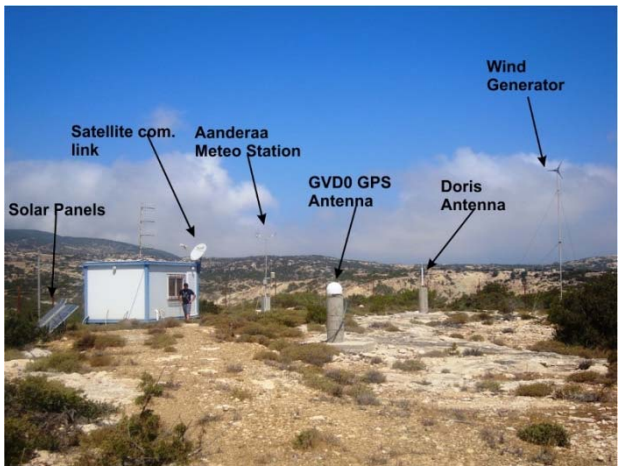
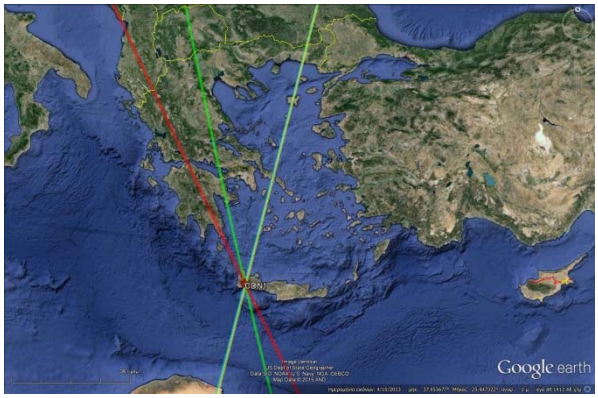


Figure 2: Gavdos and west Crete facilities



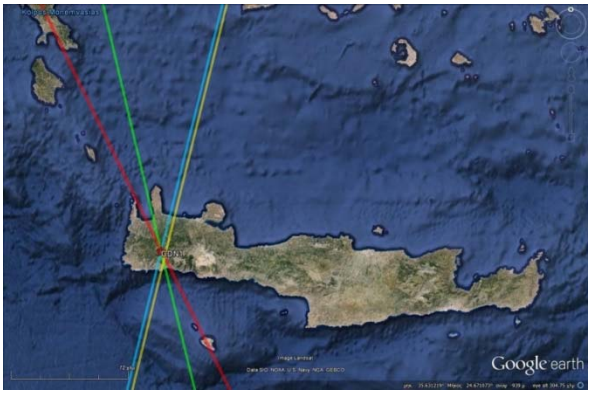


Figure 3: ESA permanent altimeter calibration site in Crete, Greece

3.3 The GNSS National Network (NOANET) of the Institute of Geodynamics, National Observatory of Athens www.gein.noa.gr/gps.html

Scientific responsible: Dr. Athanassios Ganas, Research Director, aganas@noa.gr

Dr. George Drakatos, Research Director, g.drakat@noa.gr

Dr Kostas Chousianitis, Assistant Researcher, chousianitis@noa.gr

GNSS group: Dr Alexandra Moshou, Mr. Marios Papanikolaou, MSc, Mr. Panagiotis Argyrakis, MSc, Ms Christina Tsimi, MSc, Mr. Evangelos Mendonidis, MSc, Mr. Vasilios Pikoulis, Msc, Mr. Kostas Exarchos.

1. Permanent and Campaign Stations

The NOANET network has been operating since 2006 following the EUREF (Regional Reference Frame Sub-Commission for Europe; www.epncb.oma.be) Permanent Network standards. The mission of NOANET is to monitor and quantify crustal deformation in Greece, so the location of each permanent station was carefully selected in order that both geological and seismotectonic criteria are fulfilled. The initial aim of NOANET was to investigate the contemporary motions of Western Greece over the time span of ten years (2006-2016). Progressively, the network expanded to other regions on mainland Greece as well as in Rhodes and Santorini islands. The stability of points was an important issue during the network design. All station antennas are installed on bedrock either directly with pillars or indirectly with steel masts on building roofs. The number of operating stations as of 31/12/2014 is twenty two (**22**) of which 16 stations belong to NOA, 3 stations are operating with METRICA SA geodetic equipment (Fig.1; NEAB, KRPS, SKYR), 1 station belongs to MIT (Fig.1; KATC), and 2 stations with NTUA equipment (Fig.1; ATAL, STEF). The station location is shown in Figure 1. Coordinates of some permanent stations are reported in Table 1.

Table 1. List of selected NOANET stations with their ITRF 2008 coordinates. This is a GAMIT double-difference solution provided by Dr. K. Chousianitis on Dec. 7, 2012.

Site	x	y	z	Epoch
PRKV	4435581.3031	2188830.5049	4013585.9138	2011.999
LEMN	4434466.0752	2084864.3964	4069305.4695	2011.999
NVRK	4386262.8269	1940952.5414	4190906.9445	2011.189
NOA1	4599641.9560	2034827.3829	3909890.5811	2011.999
ATAL	4591113.8306	1948751.1777	3962396.6818	2010.818
RLSO	4564747.0039	1845610.7931	4040935.1211	2010.836
SPAN	4744074.1442	1887446.2490	3809805.6462	2011.842
VLSM	4679938.9903	1840151.1631	3910407.7030	2010.798
KLOK	4658312.2222	1757780.7028	3973702.5974	2011.241
PONT	4699991.5930	1765547.7434	3921162.2237	2011.999
PYLO	4671272.6340	1754437.1000	3959389.4112	2011.210
KIPO	4705431.0408	1745107.4454	3923270.9305	2011.457
KASI	4616572.5484	1674415.5976	4056441.3233	2011.999

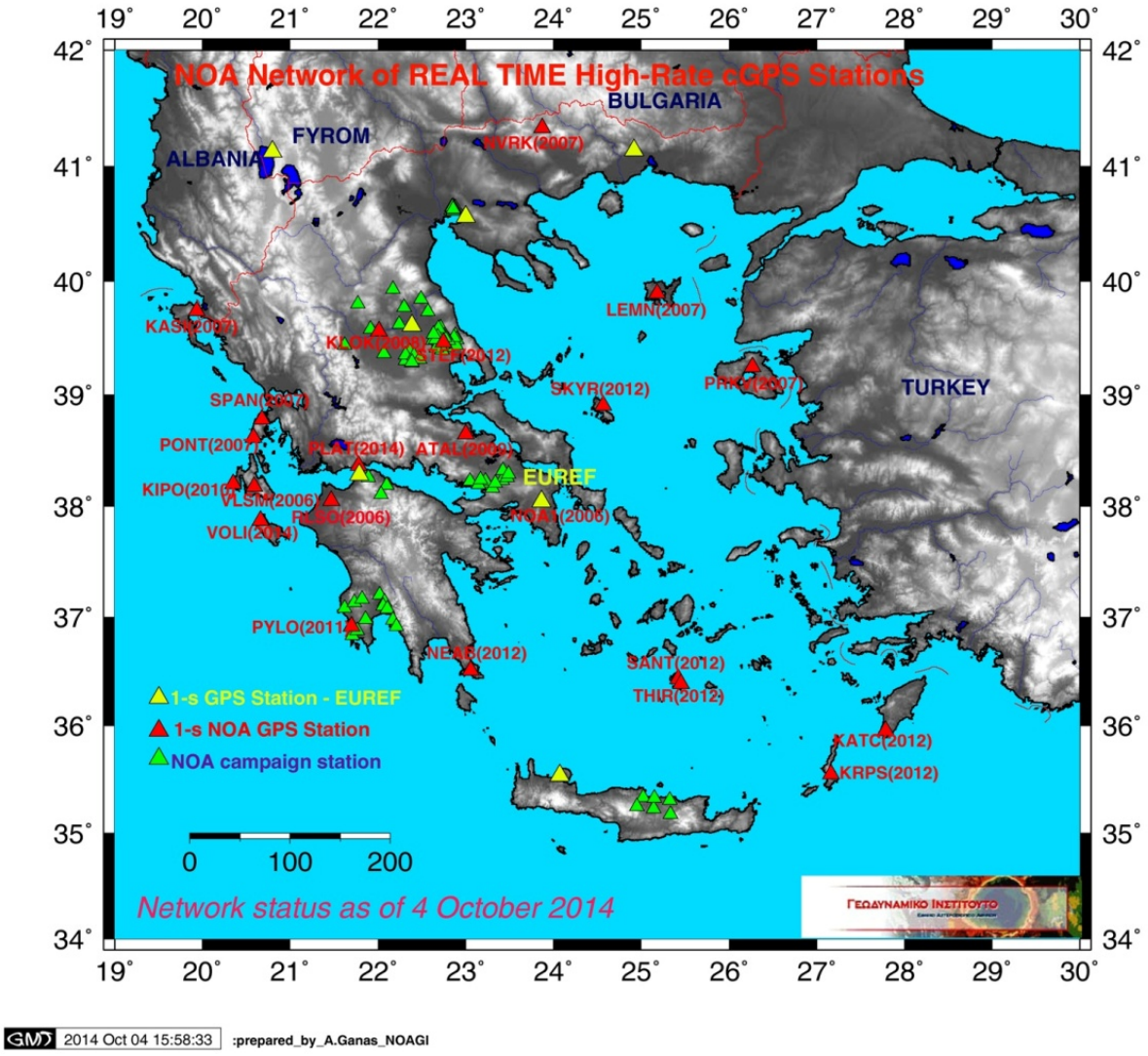


Figure 1: Relief map of Greece with locations of NOANET stations (permanent and campaign), as well as, other stations belonging to EPN/EUREF.

2. Hardware and software

NOA operates a mixed pool of receivers (***LEICA, ASTECH, TRIMBLE, TOPCON***) and antennas for permanent GPS/GNSS observations (see Table **2** for details of geodetic equipment). The data acquisition software is ***LEICA SPIDER*** (see attached screenshot in Fig. 2). We currently use a real-time quality processing of four reference stations using the **LEICA SpiderQC v.4.1** software. The **PPP** (Precise Point Positioning) processing technique is also used to detect offsets in XYZ positions of GNSS stations in the Ionian Sea and Santorini Island, where tsunami hazard is high (Argyrakis et al., 2014). The GNSS data are distributed via the Internet in the form of daily files, sub-sampled at 30-s. Following a successful collaboration with UNAVCO http://www.unavco.org/ the **GSAC** Web Service was implemented. The GSAC is UNAVCO's Geodesy Seamless Archive Centers software system, which powers geodesy data repositories with a web service. NOA expresses special thanks to Dr. Stuart Wier, GNSS

software developer, UNAVCO. The NOA GSAC was created 24 September 2013 and it is available at http://194.177.194.238:8080/noanetgsac

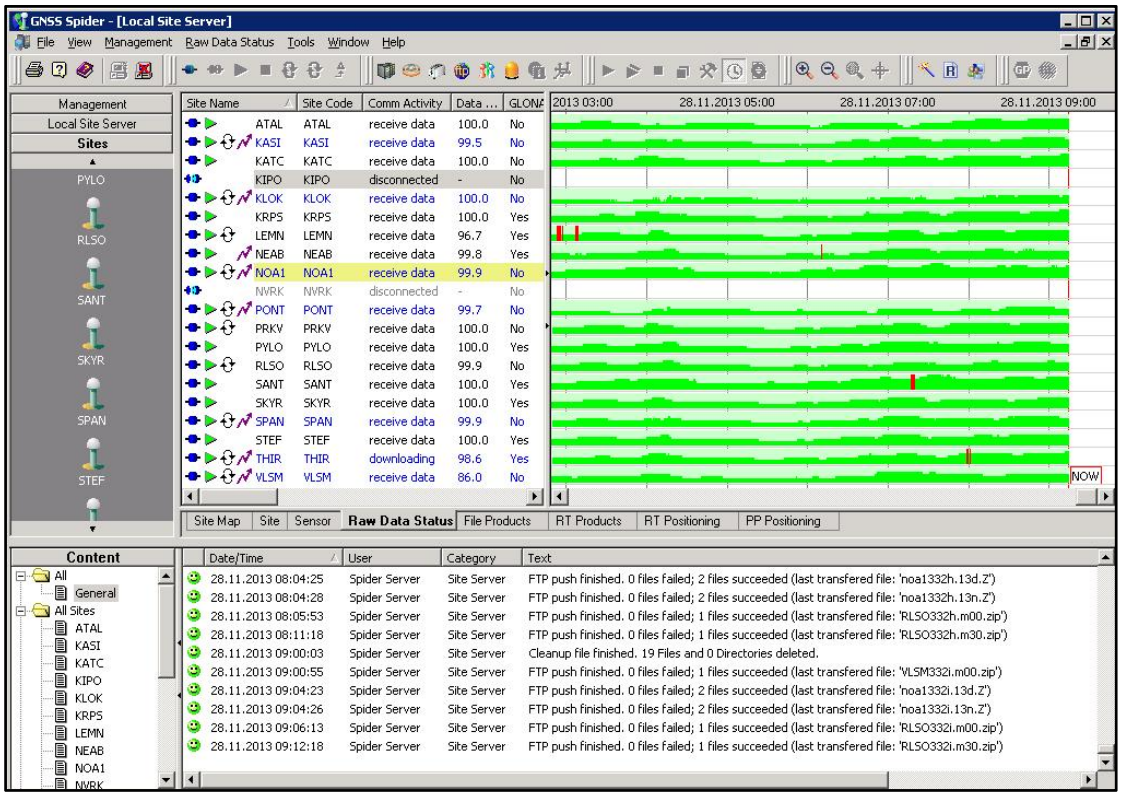


Figure 2: NOANET real-time acquisition software (screenshot 12/2/2013)

NOA-IG personnel have processed 30-s GPS data from permanent GNSS stations in Greece, using the **GAMIT/GLOBK** software, in order to map tectonic strain (see papers by *Ganas et al., 2013b, Chousianitis et al., 2013, 2015*). All data were processed in 24-h sessions in a three step distributed approach, which is based on the "quasi-observation" theory and the reference frame was not defined until the last step of the analysis. We also processed many IGS stations together with the NOANET stations in order to optimize the network internal constraints. The final products were time series along with horizontal and vertical velocities. To ensure reliable velocity results we performed outlier editing and modeling of the first-order features of the time series, while temporally correlated noise has been taken into account. The station distribution allowed to draw velocity profiles and to calculate rates of baseline length change (1-D strain) and 2-D strain as well as strain rates (dilatation, shear, rotational). In central Greece, the coherent picture of the velocity pattern for Attica and north-eastern Peloponnese (Corinth) stations (effectively a velocity "plateau" at 30 mm/yr) indicates that these areas belong to the same crustal block, although some internal strain is present within Attica's crust, as well as across the Saronic Gulf. The strain estimates are in general agreement with geological data (fault slip rates) in central Greece, implying accommodation of this crustal extension along E-W striking active normal faults. Following the 2008 M=6.4 earthquake in western Greece, a second earthquake (18/1/2010) was

recorded at the CRL station EYPA and it was analysed in the paper by *Ganas et al., (2013a)*. Two earthquakes were recorded during the 2014 Cephalonia sequence and the results were published in *Ganas et al., (2015*). A fifth earthquake was recorded on May 24, 2014 along one of the branches of the North Anatolian fault in the North Aegean Sea.

Table 2. List of NOANET stations with geodetic equipment used. Column Date refers to date of first station operation. Column COMM refers to mode of data telemetry.

CODE	LAT	LONG	H	DATE	COMM	Antenna type	Receiver Type
VLSM	38.176	20.588	437	14/02/2006	DSL	LEIAS10 NONE	LEICA GR10
NOA1	38.047	23.864	537	13/03/2006	DSL	AT504 LEIS	LEICA GRX1200PRO
RLSO	38.055	21.464	132	29/07/2006	DSL	LEIAX1203+GNSS	LEICA GMX902GG
PONT	38.618	20.585	48	15/02/2007	DSL	AX 1202 GG	LEICA GRX1200PRO
KASI	39.746	19.935	103	01/04/2007	DSL	AX 1202 GG	LEICA GRX1200PRO
SPAN	38.781	20.673	447	22/05/2007	DSL	AX 1202 GG	LEICA GRX1200PRO
LEMN	39.897	25.180	104	16/06/2007	DSL	AX 1202 GG	LEICA GRX1200PRO
PRKV	39.245	26.265	169	30/06/2007	DSL	AX 1202 GG	LEICA GRX1200PRO
NVRK	41.336	23.869	579	12/07/2007	DSL	AX 1202 GG	LEICA GRX1200PRO
KLOK	39.564	22.014	137	17/07/2008	DSL	AT504 LEIS	LEICA GRX1200PRO
ATAL	38.653	22.999	135	27/03/2009	DSL	NOV533	ASHTECH UZ-12
KIPO	38.203	20.348	128	31/08/2010	DSL	LEIAX1202GG	LEICA GRX1200PRO
PYLO	36.914	21.695	39	24/08/2011	DSL	AS10	LEICA GR10
NEAB	36.509	23.060	39	27/06/2012	DSL	AR10	LEICA GRX1200PROGG
KPRS	35.547	27.161	554	14/08/2012	DSL	AR10	LEICA GR10
SANT	36.433	25.422	392	17/08/2012	DSL	AR10	LEICA GR10
KATC	35.951	27.780	75	31/08/2012	Mobile	ZEPHYR TRM 41249.00 NONE	TRIMBLE NetRS
STEF	39.464	22.742	98	07/09/2012	DSL	ASHTECH ASH 111661	ASHTECH PF500
SKYR	38.904	24.564	117	28/11/2012	DSL	LEIAR10 NONE	LEICA GR10
THIR	36.384	25.452	355	27/12/2012	Wi-Fi DSL	LEIAX1202GG	LEICA GRX1200GGPRO
PLAT	38.370	21.781	39	19/03/2014	DSL	TPSCR.G5 TPSH	TPS NETG3A
VOLI	37.876	20.662	454	21/03/2014	DSL	TPSCR.G5 TPSH	TPS NETG3A

3. Data Sampling and Telemetry

The current plan is to download 1-second sampled data (1 Hz) through the Internet on a daily basis, to maintain a 5-20 Hz data in the ring buffer, although there are also plans to collect data sampled 50 times per second (50 Hz) in a rotating buffer in advanced receivers (such as GR10 in PYLO), and to retrieve the high rate data after a large earthquake to support GPS seismology. The high rate (1 Hz - one sample per second) operations are also useful for the purpose of seismic early warning, damage mitigation, and to increase sensitivity to transient motions. The network server in Athens is collecting data in automatic mode. The in-house software consists of the LEICA **SPIDER** software which is used to manage

check and control the reference stations as standalone stations and as a network. A daily file is created at midnight by sub-sampling the hourly observations every 30-s intervals. This file is converted to compact RINEX format and delivered to the NOA Web Server (www.gein.noa.gr/gps.html) where it is available for immediate download.

4. GNSS Data offered by NOANET

Type (e.g., time series, parametric,)

Raw GPS + GLONASS observations at 1-s intervals, Rinex at 30-s intervals, station velocities, 1-D and 2-D strain

Format: (international standard, in-house developed,)

Formats include streams in RTCM v3.X, also MDB, Rinex, Compact Rinex, .zip, .Z

Type of data transmission

Internet (leased lines from Greek Telecom – OTE), 3G (mobile telephony)

5. Network Funding

NOA has obtained funding for GPS/GNSS observations through the EU projects PREVIEW (www.preview-risk.com), RASOR http://www.rasor-project.eu/ EPOS http://www.epos-eu.org/, from ESA-TERRAFIRMA http://www.terrafirma.eu.com/ , and from several national research programmes (such as INDES-MUSA http://www.indes-musa.gr/ - ASPIDA http://aspida.gein.noa.gr/?page_id=2360), as well as services to third parties.

6. References (2011-2015)

The GNSS group of NOA published **19** papers during the period 2011-2015, of which **6** in peer-reviewed journals. The full paper titles etc, are reported below.

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Africa-Eurasia GPS Velocity Field (1994-2014) and E Mediterranean Block Model: Implications for Continental Deformation in a Zone of Active Plate Interaction;, AGU 2014 Fall Meeting, 15-19 December 2014, San Francisco, CA, USA (abstract).

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7. Fernandes Rui, Luisa Bastos, Carine Bruyninx, Nicola D'Agostino, Jan Dousa, Athanassios Ganas, Martin Lidberg, and Jean-Mathieu Nocquet, 2014. Current status of the EPOS WG4 – GNSS and Other Geodetic Data. Geophysical Research Abstracts, Vol. 16, EGU2014-7064, 2014, EGU General Assembly 2014, © Author(s) 2014. CC Attribution 3.0 License.
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   http://www.sciencedirect.com/science/article/pii/S026437071300094X
10. Ganas Athanassios, Chousianitis Kostas, Batsi Evaggelia, Kolligri Maria, Agalos Apostolos, Chouliaras Gerassimos, Makropoulos Kostas, 2013a. The January 2010 Efpalion earthquakes (Gulf of Corinth, Central Greece): earthquake interactions and blind normal faulting. Journal of Seismology, 17 (2), 465-484, http://dx.doi.org/10.1007/s10950-012-9331-6
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    http://www.geosociety.gr/images/news_files/EGE_XLVII/Vol_2/508_Chousianitis.pdf
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4. Commission 4: Positioning and Applications

For this section material has been provided by:

(a) Hellenic Military Geographical Service (HMGS),
(b) School of Rural and Surveying Engineering, Department of Geodesy and Surveying, Aristotle University of Thessaloniki,
(c) School of Rural and Surveying Engineering, Department of Topography, National Technical University of Athens,
(d) Laboratory of Geodesy and Geomatics, Department of Civil Engineering, Aristotle University of Thessaloniki,
(e) Laboratory of Geodesy and Geodetic Applications, Department of Civil Engineering, University of Patras,
(f) Department of Civil Engineering and Surveying and Geoinformatics Engineering, Technological and Educational Institute of Athens (T.E.I. Athens)

4.1 Hellenic Military Geographical Service (HMGS)

During the period 2011 – 2014, HMGS has collected about 400 high accuracy GCPs all over Greece. These GCPs were used for special HMGS's responsibility projects. They were located in remote mountainous areas or small islets.

Double frequency GPS receivers were used in order to achieve the best accuracy and prepare high quality products. The reference system in use was GGRS87 and it was materialized by differential positioning from the National Triangulation Network.

In 2015, HMGS plans to collect about 80 more GCPs in order to have the ability to provide high quality products in remote and difficult to approach areas.

Publication:

HMGS internal report

4.2 School of Rural and Surveying Engineering, Department of Geodesy and Surveying, Aristotle University of Thessaloniki

Prof. M.E. Contadakis

- Member of the Editorial Board of the International Journal "Earth System Science Data" of Copernicus Organization (2009-today)
- In these years I was engaged with the study of the variations of different physical parameters of the Geosphere in relation to the seismic activity, in order to identify

earthquake's pre-cursory phenomena. In particular the variations of the lower Ionosphere around the time of intensive tectonic activity was of our merit in order to approve the internationally suggested L(ithospher)A(tmosphere)I(onosphere)C(upling) mechanism. We approach the charting of the variations of the lower Ionosphere around the time of intensive tectonic activity by two methods committing two research programs.

1) Direct estimation of the lower Ionosphere variations analyzing the T(otal)E(lectron)C(ontent) estimations of GLONASS and GPS networks.
Collaborators: Professors D. Arabelos, S. Spatalas, Drs. G. Vergos, occasionally C. Pikridas

2) Indirect estimation of the lower Ionosphere variations by analyzing the disturbances on the LF/VLF electromagnetic wave transmission induced by the disturbed lower Ionosphere. To this purpose we contact the research of the international network I(nternational)N(etwork) for F(rondier)R(esearch) for E(arthquake)P(recursors). In this network apart of our group and Prof. T.D.Xenos and Mr. C. Skeberis from the Department of Telecommunication of Aristotle University Thessaloniki, contribute researchers from : University of Bari, Italy (Prof. P.F.Biagi, leader of the network); Department of Engineering of Enterprise, University of Tor Vergata, Italy; National Institute of Earth's Physics, Seismological Department, Bucharest, Romania; Austrian Academy of Sciences, Austria; Canakkale Onsekiz Mart University, Department of Geophysics, Turkey; Institute of Physics of the Earth, National Academy of Sciences, Moscow, Russia.

3) Finally our group is engaged systematically with the problem of tidal triggering effect on earthquakes.

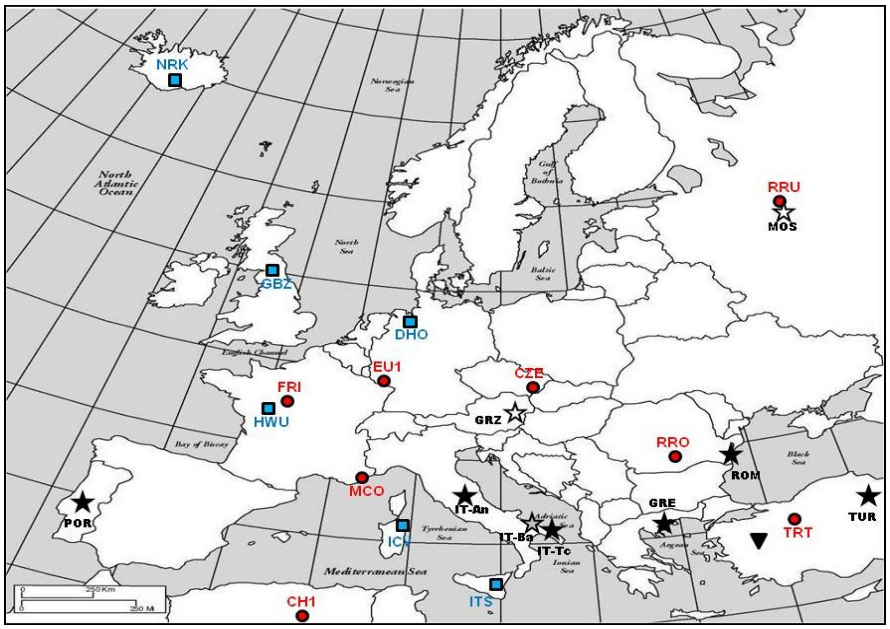

Figure: Map showing the different receivers of INFREP network and the VLF and LF transmitters of the European Radio Network. The stars show the location of the receivers (black≡Elettronika, white≡MSK, grey≡OmniPal); the squares indicate the VLF transmitters and the circles the LF transmitters, the signals of which are collected by the different receivers. The triangle indicates the epicentre of the western Turkey earthquake (M = 5.7) occurred on May 19, 2011.

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Prof. C. Pikridas, Prof. A. Fotiou, Prof. D. Rossikopoulos

On January 2011 a new GNSS permanent station was included in EPN network. The new station is established in the city of Larisa at Province of Thessaly. The station provides hourly and daily rinex data, to the EPN Analysis Centers, contains measurements of GPS and Glonass satellite systems and is also ready for tracking Galileo signals (more info available at: http://www.epncb.oma.be/_networkdata/siteinfo4onestation.php?station=LARM).

The following figure (1.) depicts the receiver and choke ring antenna (Leica AR25) installation at LARM EPN station.

Fig. 1: The receiver and antenna installation at LARM EPN station.

The station also participates to the HermesNet (managed by the Dept. of Geodesy and Surveying-AUTh) and provides its RTCM stream via the (local) Hermes NtripCaster for RTK positioning services (more info available at: http://users.auth.gr/cpik, www.ntrip.org).

Due to Greece is characterized by complex and intense geodynamics, between the 2001 and 2015, several GNSS campaigns have been carried out using dual frequency geodetic receivers for main purpose to create and validate a modern and improved geodetic velocity field for Greece using GNSS observations from continuously permanent reference stations and various campaigns. Recently, a new set of geodetic velocities is derived from the process of seven years (2008-2014) daily GPS data, using 150 stations distributed in the broader Greek territory and presented at the IUGG 2015 General assembly by the GNSS-QC research team.

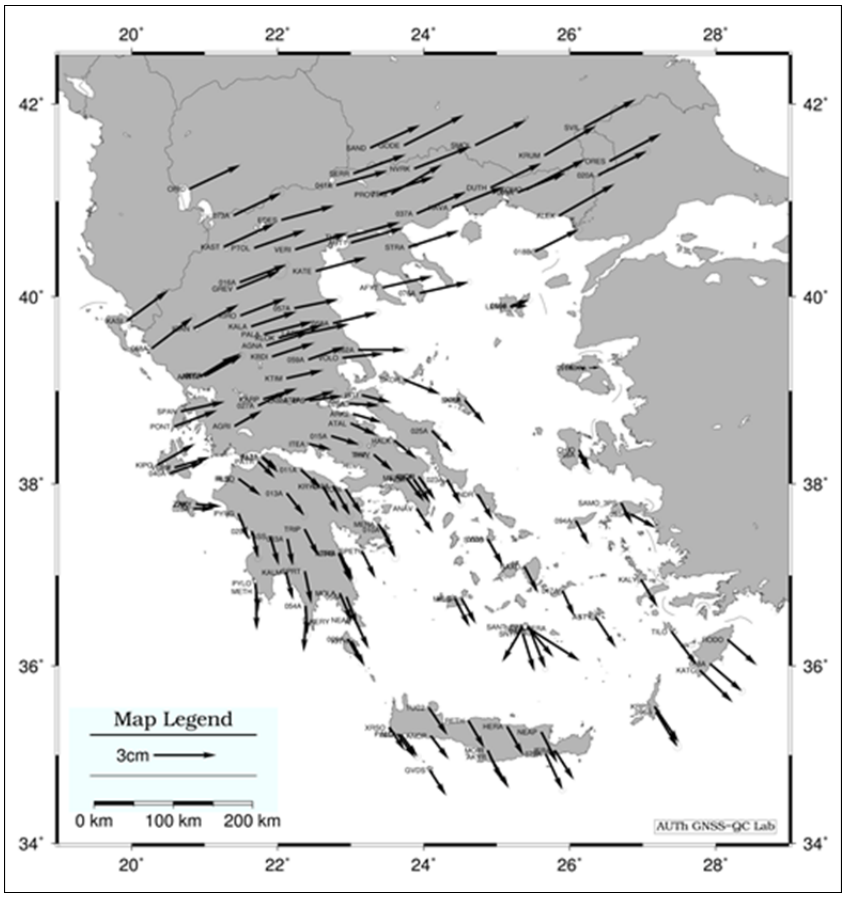

Fig. 2: The estimated velocities on IGS08 reference frame for the Greek area.

From October 2014 a new GNSS Analysis Center using the Bernese software v5.2 was established at department of Geodesy and Surveying for near real time estimation of Zenith tropospheric delay (http://egvap.dmi.dk/) for the Hellenic area. Also, the contribution to E-GVAP program was started. E-GVAP was set up, in April 2005, to provide its EUMETNET members with European GNSS delay and water vapour estimates for operational meteorology in near real-time. The core of E-GVAP is a close collaboration between geodesy and meteorology. E-GVAP contributes meteorological data, that can be used to validation GNSS delay estimation, and to improve GNSS positioning in the future. On figure 3 the clustering definition during process of (mainly) the permanent GNSS stations (of SmartNet) is shown. SmartNet-Greece includes stations from NoaNet and HermesNet on a contractual basis.

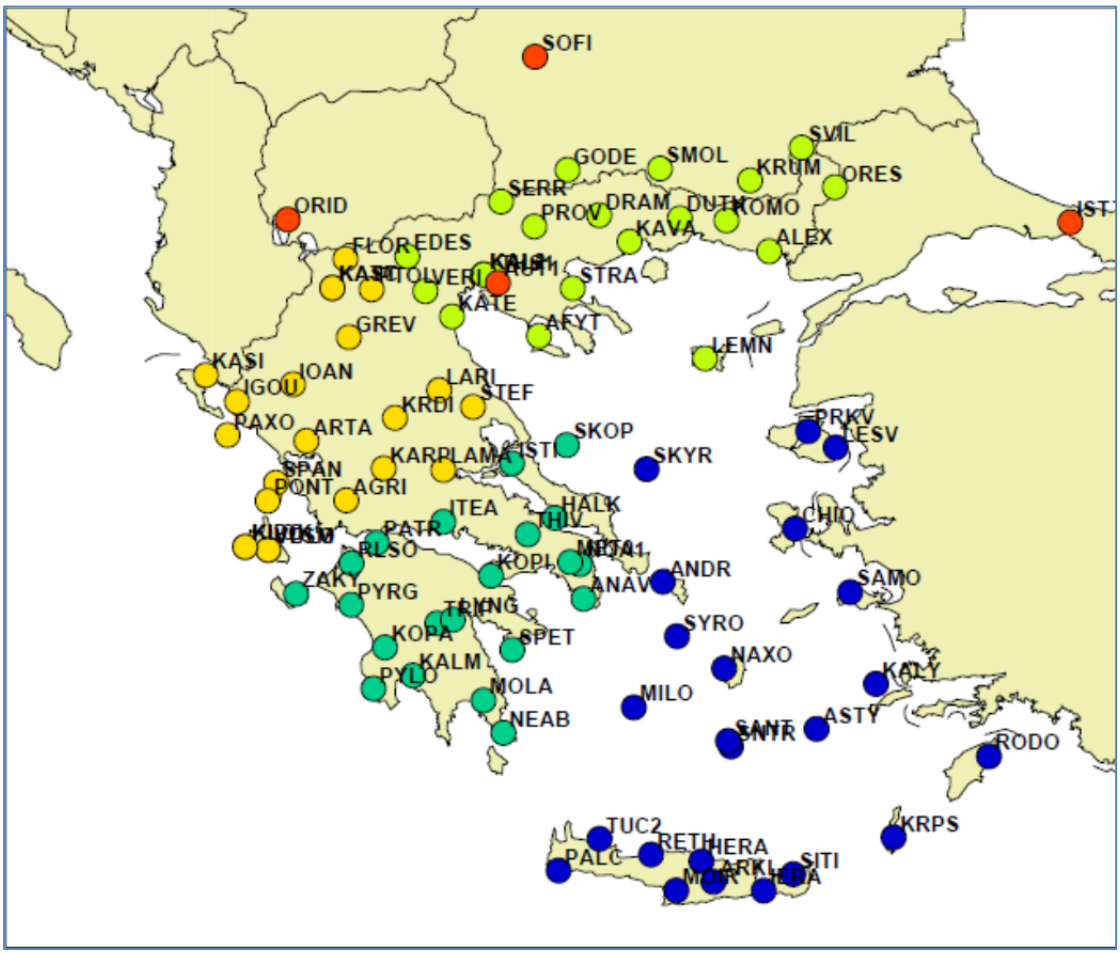

Fig. 3: Cluster definition of Greek permanent stations during processing at AUTh Analysis Center.

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4.3 School of Rural and Surveying Engineering, Department of Topography, National Technical University of Athens

Dr. Vassilis Gikas, ASSOC. PROF., NATIONAL TECHNICAL UNIVERSITY OF ATHENS, GREECE

IAG SC4.1 Vice-Chair

*** *This summary report relates only to IAG thematic areas for the period Aug. 2011–today.* ***

Papers based on IAG 4.1.1 / FIG 5.5 collaboration
"*Ubiquitous Positioning*" *https://ubpos.net*

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Papers based on SaPPART project
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Gikas V., Daskalakis S. (2011) "Radar-based Measurements of the Oscillation Parameters of Large Civil Engineering Structures", 14th FIG Symp. on Deformation Monitoring and Analysis & 5th IAG Symp. on Geodesy for Geotechnical and Structural Engineering, Hong Kong, China, Nov. 2–4, 2011

Papers based on independent research

Yigit C. O., Gikas V., Alcay S., Ceylan A. (2014) "*Performance Evaluation of Short to Long Term GPS, GLONASS and GPS/GLONASS Post-Processed PPP*", Survey Review, Vol. 46(336), pp 155–166

Danezis C., Gikas V. (2013) "*An Iterative LiDAR DEM-Aided Algorithm for GNSS Positioning in Obstructed / Rapidly Undulating Environments*", Advances in Space Research, Vol. 52(5), pp 865 – 878

Paradissis D., Gikas V. (2013) "*GNSS for Sea Trials: Measuring Ship Controllability*", GIM International, Vol. 37(2), pp 31–35

Gikas V., Mpimis A., Androulaki A. (2013) "*Proposal for Geoid Model Evaluation from GNSS/INS-Leveling Data: Case Study along a Railway Line in Greece*", Journal of Surveying Engineering, Vol. 139(2), pp 95–104

Gikas V., Stratakos J. (2012) "*A Novel Geodetic Engineering Method for the Extraction of Road/Railway Alignments Based on the Bearing Diagram and Fractal Behavior*", Transactions of Intelligent Transportation Systems, IEEE, Vol. 13(1), pp 115–126

Danezis C., Gikas V. (2012) "*Performance Evaluation of A Novel Terrain-Aiding Algorithm for GNSS Navigation in Forested Environments*", ION/GNSS, Nashville, Tennessee, USA, Sept. 17–21

Assoc. Prof. E. Lambrou

My **Research interests** focused on:

- Development of methodology for the determination of astronomical coordinates
- Precise determination of undulation N of Geoid
- Interconnected systems, e - Geodesy, observations via Internet
- Check and calibration of geodetic instruments (Geodetic Metrology)
- Development of methodologies for precise measurements
- Geometric documentation of technical and natural structures

I have the following published papers from 2011 – today, in the above scientific areas

E.G. Alevizakou, E. Lambrou "Fast and Convenient Determination of Geoid Undulation N in an Urban Area". Proceedings of "FIG Working Week 2011, Bridging the Gap between Cultures", Marrakech, Morocco, May 2011.

Evangelia Lambrou, Konstantinos Nikolitsas, George Pantazis " Special marking of 3d networks' points for the monitoring of modern constructions ". Journal of Civil engineering and Architecture (ISSN 1934-7359), July 2011, Volume 5, Number 7, Serial No 44, pp 643-649.

E. Lambrou, G. Pantazis, "Geodetic monitoring of bridge oscillations". Proceedings of International conference "Innovations on Bridges and Soil-Bridge Interaction", Athens, October 2011. pp 455 – 462.

G. Pantazis, E. Lambrou, S.Polydoras and V. Gotsis "3D Digital Terrestrial Model Creation Using Image Assisted Total Station and Rapid Prototyping Technology " International Journal of Heritage in the Digital Era, vol. 2, No 2, pp 245-262, September 2013

Evangelia Lambrou, "Analysis of the errors of the antenna's set up at the GNSS measurements". Journal of Civil engineering and Architecture (ISSN 1934-7359) Volume 7, No. 10 (Serial No. 71), pp. 1279-1286, October 2013.

Evangelia Lambrou, "Accurate Geoid height differences computation from GNSS data and modern astrogeodetic observations". Proc. of the International Symposium on Gravity, Geoid and Height Systems (GGHS2012), U Marti (Ed.), IAG Symp. 141, 2015

Evangelia Lambrou,"Remote Survey. An Alternative Method for Capturing Data". Journal of Surveying Engineering, Volume 140, Issue 1, pp 60-64, February 2014
http://dx.doi.org/10.1061/(ASCE)SU.1943-5428.0000115

Evangelia Lambrou, Konstantinos Nikolitsas. "A new method to check the angle precision of total stations", Proceedings of ″FIG Working Week 2015, From the Wisdom of the Ages to the Challenges of the Modern World, Sofia, Bulgaria, 17–21 May 2015.

Evangelia Lambrou, Antonios Antonakakis, "Estimation of the gauging and the calibration time interval for the modern total stations". For publication in Journal of Civil engineering and Architecture, 2015

Assoc. Prof. G. Pantazis

My **Research interests** focused on:

- Development of a methodology for investigating the orientation of monuments
- Determination of astronomical azimuth
- Prediction of movements of structures during monitoring
- Observation analysis of geodetic networks
- Geometric documentation of technical and natural structures
- Check and calibration of geodetic instruments (Geodetic Metrology)
- Development of methodologies for precise measurements

I have the following published papers from 2011 – today in the above scientific areas

Evangelia Lambrou, Konstantinos Nikolitsas, George Pantazis " Special marking of 3d networks' points for the monitoring of modern constructions ". Journal of Civil engineering and Architecture (ISSN 1934-7359), July 2011, Volume 5, Number 7, Serial No 44, pp 643-649.

G. Pantazis, K. Nikolitsas, "Assessing the use of ″light″ laser scanners and the Monte Carlo technique for the documentation of geometric surfaces". Proceedings of ″FIG Working Week 2011, Bridging the Gap between Cultures", Marrakech, Morocco, May 2011.

E.Lambrou, G. Pantazis, "Geodetic monitoring of bridge oscillations". Proceedings of International conference "Innovations on Bridges and Soil-Bridge Interaction", Athens, October 2011. pp 455 – 462.

G. Pantazis, "Preserving monuments' astronomical orientation by using different databases". Proceedings of 4th International Euro-Mediterranean Conference (EuroMed 2012), Limassol, Cyprus, November 2012. pp. 701–709

George Pantazis Eleni-Georgia Alevizakou "The Use of Artificial Neural Networks in Predicting Vertical Displacement of Structures". International Journal of Applied Science and Technology, Vol. 3 No. 5; May 2013

G. Pantazis, E. Lambrou, S. Polydoras and V. Gotsis "3D Digital Terrestrial Model Creation Using Image Assisted Total Station and Rapid Prototyping Technology " International Journal of Heritage in the Digital Era, volume 2, number 2, 2013

George Pantazis, A complete processing methodology for 3D monitoring using GNSS receivers, Proceedings of ″FIG Working Week 2015, From the Wisdom of the Ages to the Challenges of the Modern World, Sofia, Bulgaria, 17–21 May 2015.

4.4 Laboratory of Geodesy and Geomatics, Department of Civil Engineering, Aristotle University of Thessaloniki

Prof. P. Savvaidis

Research work in the Laboratory of Geodesy and Geomatics, Department of Civil Engineering, Aristotle University of Thessaloniki

The Laboratory of Geodesy and Geomatics has been doing research in the field of GNSS positioning in combination with GIS and webSIS systems mainly for traffic prediction in urban areas as well as the management of natural disasters, especially evaluating the vulnerability of structures susceptible to earthquake and flooding hazards.

Concerning traffic prediction in urban areas, a mobile low-cost dual-DGPS system for the fast tracing of the basic road design elements (horizontal plan, long section and cross sections) was designed based on the use of GPS/GNSS technology. The system consists of a moving vehicle equipped with GPS receivers and the necessary software algorithms. It was tested on a road segment that was accurately surveyed right after its construction (as-built) with classical surveying methods in order to verify its results. The performance of the system was evaluated on a mapping generalization base, more concerning the geometrically generalized road surface reliability and less the point mapping accuracy. Also, the effectiveness of a combination of a map-matching process and a prediction method aiming at the development of a traffic prediction system was investigated. The system can be described as a smart urban navigation system, but also as an expert tool which learns everyday and supports the decision makers about traffic congestion, emergency response, optimum business location or unexpectedly traffic events.

Lakakis K., Savvaidis P., and Wunderlich T.: Evaluation of a low-cost mobile mapping and inspection system for road safety classification, *American Journal of Geographic Information Systems*, p-ISSN: 2163-1131, vol. 2(1), pp. 6-14, 2013.

Lakakis K., Kyriakou K., and Savvaidis P.:Traffic Prediction System in the Urban Area of Thessaloniki City, *American Journal of Geographic Information System*s, vol. 3/2, pp. 98-107, 2014.

Concerning the management of natural disasters, GNSS positioning, Remote Sensing and webGIS techniques were investigated in order to contribute to the systematic, standardized evaluation of areas that are more susceptible to earthquake ground motions, to earthquake-related secondary effects and to tsunami-waves. Knowing areas with aggregated occurrence of causal ("negative") factors influencing earthquake shock and, thus, the damage intensity, this knowledge can be integrated into disaster preparedness and mitigation measurements. The evaluation of satellite imageries, digital topographic data and open source geodata can contribute to the acquisition of the specific tectonic, geomorphologic/topographic settings influencing local site conditions in an area and, thus, estimate possible damage to be suffered. Also, this knowledge can be integrated into disaster preparedness and mitigation measures. Combined with real time positioning data, this information assists the decision on priority either for pre-seismic control (during preparedness phase of civil protection) and / or after an earthquake disaster (during response and recovery phases of civil protection). Two webGIS systems were developed and tested in several cities in Northern Greece (the SEISIMPACT and the SYNARMA projects).

Papadopoulou, I. D., Savvaidis P. and Tziavos I. N.: Using the SyNaRMa system as a disaster management tool, Natural Hazards, Volume 57, Issue 2, pp. 453-464, 2011.

Theilen-Willige B., Papadopoulou I.D., Savvaidis P., and Tziavos I.N.: Use of Remote Sensing and GIS methods for mitigating the impact of earthquakes in cities, Proc. Inter. Congress "Natural Cataclysms and Global Problems of the Modern Civilization – GeoCataclysm 2011, Istanbul, Turkey, 2011.

Savvaidis P., Theilen-Willige B., Tziavos I. N., Grigoriadis V. N., and Papadopoulou I.D.: Detection of earthquake vulnerable areas in the Grevena region/Northern Greece using Remote Sensing and WebGIS methods, in Proc. "Modern technologies, education and professional practice in geodesy and related fields", 19th International Symposium, 08 - 09 November, Sofia, 2012.

Theilen-Willige B., Savvaidis P., Tziavos I.N., Papadopoulou I. Remote Sensing and Geographic Information Systems (GIS) Contribution to the Inventory of Infrastructure Susceptible to Earthquake and Flooding Hazards in North-Eastern Greece. *Geosciences, vol.* 2(4), pp. 203-220, 2012.

Dr. Eng. **Ioannis (John) D. Doukas**
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Activity (2011-2015)

Basic research activities during this time-period, were focused on the following fields:

- GIS/Web-GIS applications for the management of natural and/or human-made disasters
- Geosensorics - Sensor fusion
- Machine Guidance
- Metrology of geodetic/surveying instruments (testing, calibration)
- Industrial Geodesy, Engineering Geodesy (Geodetic Engineering), Engineering Surveying (Surveying Engineering), Geodetic Metrology, Technical Geodesy, 3D-Metrology, Industrial Metrology, Large Volume Metrology, Large Scale Metrology

Active Memberships:

2011-2015: *Member of the Working Group WG 4.2.5:* "Application of Artificial Intelligence in Engineering Geodesy". International Association of Geodesy (IAG), Sub-Commission 4.2: «Applications of Geodesy in Engineering»

http://www.geo.bgu.tum.de/index.php?id=27&L=1

2011-2015: *Chair of the IAG/GGOS (Global Geodetic Observing System (GGOS)) Working Group 0.2.1:* "New Technologies for Disaster Monitoring and Management". International Association of Geodesy (IAG), Commission 4: «Positioning and Applications»

http://doukas.civil.auth.gr/iag_sc41_sg41/

Financed Research programs/projects:

2010-2012: Leveling, Monitoring and Investigation of Ground Subsidence in Regions of Municipality of Echedoros, Northern Greece (Research Committee AUTh, Project No. 85725, 2010-2012)

2011-2013: Eco-Satellite: Development of a Common Intra-regional Monitoring System for the Environment Protection and Preservation of the Black Sea – (European Union Black Sea Cross Border Cooperation, Project 1.2.1.67652.36, Research Committee AUTh, Project No. 84886, 2011-2013)

2012-2014: Enhancement of Research, Education and Cultural Activities of the Division of Geotechnical Engineering (Research Committee AUTh, Project No. 88363, 2012-2014)

2014: Specialized teaching

Jointly tutoring concerning the ***'Continuing Education Programme for updating Knowledge of University Graduates'***: **"Modern Development in Offshore Structures"**. Dedicated lectures on:

- Sub-session 1.8: *Setting out of offshore structures*
- Sub-session 2.3: *Hydrographic/bathymetric mapping of seabed*
- Sub-session 2.5: *Setting out and designation of continental shelf (geology, geodesy)*

2014: *Invited Expert Talk & Session Chair:* "Sensors, Geosensors and their Wireless Networks. New Horizons and Possibilities in Geomatics, Civil/Construction and Environmental Engineering". 2nd International Conference on Advances in Civil, Structural and Environmental Engineering - ACSEE 2014, 25-26 October, Zurich, Switzerland

Papers (2011-2015)

Doukas, I.D. and Retscher, G.: Whereto with Earthquake Risk Management: The Resultant of Sensor-Web and Web-GIS Could Show the Way. International Conference on Indoor Positioning and Indoor Navigation (IPIN), Guimarães, Portugal, 21-23 September 2011.

Doukas, I.D. and Retscher, G.: The Contribution of Contemporary Sensors to the Management of Natural and Manmade Disasters – The Present and the Future. Joint International Symposium on Deformation Monitoring (JISDM), Hong Kong, China, 2-4 November 2011.

Doukas, I.D. and Rossikopoulos, D.: Geodetic Control of Deformations. The Case of Monuments and Technical Works. 4th National Congress on Metrology "Metrologia 2012", National Technical University of Athens, Athens, 3 & 4 February 2012 (in Greek).

Doukas, I.D.: The Contribution of Geodetic Instruments and Methods to Construction Automation. 4th National Congress on Metrology "Metrologia 2012", National Technical University of Athens, Athens, 3 & 4 February 2012 (in Greek).

Demoula, S.D., Doukas, I.D. and Savvaidis, P.D.: Spatiotemporal Approach of the Distribution of Jews Professionals in Thessaloniki During the Years 1908-1915, with the Use of a Geo-information System. Interdisciplinary Symposium: "Thessaloniki on the Eve of 1912", History Centre of Thessaloniki, 21-23 September 2012 (in Greek).

Demoula, S.D., Doukas, I.D. and Savvaidis, P.D.: Spatiotemporal Study of the Accommodation and Entertainment in Thessaloniki During the Years 1908-1915, with the Use of a Geo-information System. Interdisciplinary Symposium: "Thessaloniki on the Eve of 1912", History Centre of Thessaloniki, 21-23 September 2012 (in Greek).

Voulgaroudis, A.X. and Doukas, I.D.: The Use of Mobile Devices with 3G/4G Networks and/or Wifi for Data Collection Related to Post-seismic Control of Buildings. Cooperation with a Geoinformation System. 3rd National Conference of Urban Planning and Regional Development, Volos, September 27-30, 2012 (in Greek).

Demoula, S.D. and Doukas, I.D.: On the Business Activities of Ethnicities on Venizelou Street in Thessaloniki: Studying their Temporal Variations (1908-1938) with the use of a Geographic Information System. International Conference: "Thessaloniki: A City in Transition, 1912-2012", Thessaloniki, 18-21 October, 2012 (in Greek).

Tziavos, I.N., Alexandridis, T.K., Alexandrov, B., Andrianopoulos, A., Cernisencu I., Dimova S., Doukas, I.D., Georgiadis, P., Grigoras, I., Grigoriadis, V.N., Karapetsas, N., Michailides, C., Papadopoulou, I.D., Repa, E., Savvaidis, P., Stancheva, M., Stergioudis, A., Stila, K., Teodorof, L., Vergos, G.S., Vorobyova, L. and Zalidis, G.C.: Development of a WebGIS-based Monitoring and Environmental Protection and Preservation System for the Black Sea: The ECO-Satellite project. EGU General Assembly, April 07-12 2013, Vienna, Austria.

Doukas, I.D.: On Sensors And Geosensors And On Their Wireless Networks. Applications In Geodesy - Geomatics. 5th National Congress on Metrology "Metrologia 2014", National Hellenic Research Foundation, Athens, 9 & 10 May 2014 (in Greek).

Doukas, I.D.: Geomatics and the Automatic Machine Guidance and Control, in Relation with the Construction Machinery. Modern Developments. 4th National Conference of Rural & Surveying Engineering, Thessaloniki, 26-28 September 2014 (in Greek).

Doukas, I.D. and Demoula, S.: Historical GIS (HGIS): An Amply Mature High-tech Tool, to the Decisive and Effective Help in the Historical Research. Honorary volume dedicated to Prof. Myron Myridis, Dept. Of Rural and Surveying Engineering, Faculty of Engineering, Aristotle Univ. Of Thessaloniki.

Doukas, I.D.: On the high-tech onrush of sensors, geosensors, sensor fusion and their networks. Their influence on geodesy and geomatics. Honorary volume dedicated to Prof. Christogeorgis Kaltsikis, Dept. Of Rural and Surveying Engineering, Faculty of Engineering, Aristotle Univ. Of Thessaloniki.

Doukas, I.D., Dassiou, K. and Papadopoulos, I.: Development of a specialized Web-Geoinformation System for the Study, Sustainability Documentation, Modernization and Promotion of Moving Livestock. 1st Conference of Geographic Information Systems and Spatial Analysis in Agriculture and the Environment, 28 - 29 May 2015, Athens (in Greek).

Doukas, I.D. and Ampatzidis, D.: The Validation of the Transformation between a Classical Datum and a Modern Reference Frame, by using External Space Techniques. 26th IUGG General Assembly, June 22-July 2, 2015, Prague.

Barbara Theilen-Willige and Doukas, I.D.: Remote Sensing and GIS Contribution to the Detection of Areas Susceptible to Earthquake Hazards. The Case Study of Northern Greece. 26th IUGG General Assembly, June 22-July 2, 2015, Prague.

Doukas, I.D.: Industrial Metrology (and 3D Metrology) vs Geodetic Metrology (and Engineering Geodesy). Common Ground and Topics. Honorary volume dedicated to the memory of Professor Ioannis Paraschakis, Dept. Of Rural and Surveying Engineering, Faculty of Engineering, Aristotle Univ. Of Thessaloniki.

Demoula, S.D. and Doukas, I.D.: Development of a GIS System for the Study of the Transition and Spatiotemporal Evolution of Old Ottoman Neighborhoods to the Nowadays Parishes of Thessaloniki. 4th National Conference of Urban Planning and Regional Development, 24 - 27 September 2015, Volos.

Assoc. Prof. K. Lakakis

Positioning and Applications – A Smart Urban Navigation System

The basic context of our research activities the last five years (2011-2015), which included in IAG research sectors and especially in fourth sector **(Positioning and Applications),** concerns the continuous development and optimization of a spatio-temporal urban navigation

system, which has as core technology the GPS/GNSS. Follows a relevant briefly report of our Smart Urban Navigation System:

An interesting application of GPS is the creation and development of a smart system that will predict the travel time for a destination in real time and navigate the drivers according this prediction. GPS receivers are widely used on vehicles for navigation. Nowadays, almost all taxi vehicles use GPS receivers to navigate in urban areas. While the taxi-vehicles travel along the road network following the general traffic flow they provide with a large amount of GPS data giving vehicle's ID, vehicle's coordinates, velocity, orientation, time and date. So receiving these data and implementing the following process it is possible to create a smart travel time predictions system using only GPS points. This system is a "closed" system and with the ability to stay always updating. The development stages of this system, as they are in today development phase, are the followings:

1. **Selection of data** for the area that is under study. Each street must be divided into segments starting and ending at nodes with traffic lights. The aim is to exclude the spent time at traffic lights in order to have higher accuracy at the prediction times. For those segments, it is possible to calculate the travel time through GPS data, knowing time and distance of segments. In addition, it must be selected from numerous GPS data the points that are assigned to streets that are under study giving a margin of 80 meters right and left of the road through ArcGIS. Another one excluding criterion is vehicle's orientation. Orientation criterion excludes vehicles that are not moving on a specific road but on other parallels or perpendicular roads. So a wide of values for orientation is defined and then points that don't follow this criterion are excluded.
2. **Map-matching process**. Data have to be referenced spatially, so a process of map-matching was necessary. This procedure is a crucial issue especially in urban areas with narrow roads, tall buildings and other signal degraded environments. Thus, it is challenging to identify the actual link on which the vehicle is travelling and to determine the vehicle location in that link. There are many proposed procedures for map matching varying from those using simple search techniques to those using more advanced techniques. Many of them have been used in urban and suburban areas and the percentage of correct links ranges between 86% and 93% and the 2-D horizontal accuracy range between 15m and 10.6m. At this case, it was selected one map-matching method that has been successfully accepted by the international community and it is based on the idea of using as spatial street network only the road segments which are measured by the system itself and not by external sources (i.e., electronic city maps produced by other surveying methods). The mathematical algorithms which have been used were the linear regression model and its prediction zone. The method has been tested in different confidence levels (95%, 97.5% and 99%) and in the case of standalone GPS observations gave map-matching accuracy range between 15m. and 21m. In the case of differential GPS observations the range was 1.5m to 2.0m. The general mathematic model of linear regression is the following:

$Y = \alpha + \beta X + \varepsilon$ (1)

And its confidence interval or prediction zone for every road:

$Y\hat{}\ 0 - t\ \alpha/2 \cdot s\ Y\hat{}\ 0 \leq Y0 \leq Y\hat{}\ 0 + t\ \alpha/2 \cdot s\ Y\hat{}\ 0$ (2)

Normally, the prediction zone is defined by two hyperbolic curves while the most close point is defined implementing the equation (2) for x mean. However, the difference between maximum and minimum points is so minor giving the possibility to assume the hyperbolic curve as a straight line. After implementing the method of linear regression a set of spatial models are revealed, each one for a segment and theirs prediction zones in meters. This means that any point of vehicle's route located within the zone, will be matched with the regression line.

3. **Travel time calculation** is implemented per road segment during all the day for every single day. The implementation requires numerous data and this constitutes a critical problem. So the whole process is performed through the mathematical software Matlab where specified code has been written to perform the following processes:

- Identification of TAXI's ID that is appeared among the road segment at least twice in order to be possible to calculate its travel time
- Points selection with same ID at the same period of day
- Calculation of travel time from point p to p+1
- Exclusion of travel times with more than some minutes depending on each segment's length. For instance a travel time more than 4 minutes for 200m indicates that the vehicle had a different route
- Calculation of travelled distance and a further calculation of time travel in relation with the segment's length.

4. **Definition of Time Periods**. At this phase, working days and weekends are separated into homogenous time zones. The criteria are the hours when land uses such as shopping, entertainment and use of offices and services predominate. Having time and date from GPS receivers it is possible to classify data to each time zone period. This step is also performed through Matlab software.

5. **Travel time predictions**. Having the travel times, travel times predictions are possible using various algorithms such as Kalman Filter. A method that is a set of mathematical equations that implement a predictor-corrector type estimator. The whole process is a loop consisted of two basics steps. The first step is "Measurement Update – Correction" and the second step is "Time update – Prediction". The procedure is repeated for each time step using the state of previous time as an initial value. Therefore the Kalman Filter is called a recursive filter. In order to implement this method Matlab code was written.

Another method that has been implemented is Artificial Neural Networks. Neural networks are statistical models of real world systems that are built defining a set of parameters. These parameters function as inputs that are associated to a set of values, the outputs. The process of tuning the weights to the correct values – training – is carried out by passing a set of examples of input-output pairs through the model and adjusting the weights in order to minimize the error between the answer the network gives and the desired output. Once the weights have been set, the model can produce answers for input values that were not

included in the training data. In order to build the optimum network for the case of Thessaloniki, 10 architectures were tested and with the criterion of Mean Square Error (MSE) and Mean Absolute Error (MAE) it was selected the fleet one. Weekdays, homogenous time zones and time period are used as parameters to optimize the model. Both methods have been implemented through Matlab software, providing with travel time predictions not only for every single day but also for every time period as they have been defined. Taking as criterion the MAE and MSE it is concluded that the performance of ANN is much better than Kalman's Filter.

Implementing the described stages it is possible to create a smart system to navigate the drivers according to theirs location to theirs destination avoiding crowded roads. Last but not least, this system can also contribute to air pollution by predicting and estimating the emissions and detecting the "greener" path using only GPS points again. This means that if a driver has a GPS receiver on vehicle can have the possibility to select the greener route using GPS data in real time. In addition, since it is real time, the system of emissions estimations can be ameliorated continuously by itself without human intervention. So it could be a choice on vehicle's GPS to navigate in the urban area of Thessaloniki selecting the greener routes and not the shortest. It should be noted that for the case of Thessaloniki if the same 100 vehicles had chosen the greener path 10% reduction of emissions production would be remarked.

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Lakakis K. and Kyriakou K. (2015) "Creating an intelligent transportation system for smart cities: Performance evaluation of spatial – temporal algorithms for traffic prediction"**,** 14th International Conference on Environmental Science and Technology(CEST), Rhodes island, Greece, 3-5 September 2015. (Accepted)

Lakakis K. and Kyriakou K. (2015) "Environmental impact analysis of an advanced navigation system for urban areas using GIS", 5th International Conference on Environmental Management, Engineering, Planning and Economics (CEMEPE) and SECOTOX Conference, Mykonos island, Greece, 14-18 June 2015. (Accepted)

Lakakis K., Kyriakou K. and Savvaidis P. (2014) "Traffic Prediction System in the Urban Area of Thessaloniki City". American Journal of Geographic Information System, 3(2),98-107.

Lakakis K., Kyriakou K. and Savvaidis P. (2014) "Investigation and prediction of traffic travel time for the road network of Thessaloniki through spatial temporal model". Fresenius Environmnental Bulletin 23 (11a) 2832-2839

4.5 Laboratory of Geodesy and Geodetic Applications, Department of Civil Engineering, University of Patras

Prof. S. Stiros

Research activities of Prof. Stiros and his scientific group focus on (a) Geodynamics including Seismotectonic Volcanology, (b) Instruments and Methodology and (c) Methods on networks adjustment. The scientific results of the group have been published in the following papers.

Publications

Saltogianni, V., Stiros, S., Newman, A., Flanagan, K., Moschas, F, Time-space modeling of the dynamics of Santorini volcano (Greece) during the 2011-2012 unrest, *J Geophys. Res. (Solid Earth)* 119, 8517–8537, doi:10.1002/2014JB011409, 2014

Mouslopoulou, V, Saltogianni, V., Gianniou, M., Stiros, S., Geodetic evidence for tectonic activity on the Strymon Fault System, northeast Greece, *Tectonophysics,* 633, 246-255, 2014

Stiros, S., Moschas, F., Feng, L. Newman, A., Long-term versus short-term deformation of the meizoseismal area of the 2008 Achaia-Elia (M_W 6.4) earthquake in NW Peloponnese, Greece: Evidence from historical triangulation and morphotectonic data., *Tectonophysics*, 592, 150–158, 2013

Newman, A. Stiros, S., Feng, L., Psimoulis, P., Moschas, F., Saltogianni, V., Jiang, Y., Papazachos, C., Panagiotopoulos, D., Karagianni, E., Vamvakaris, D., Recent Geodetic Unrest at Santorini Caldera, Greece, *Geophys. Res. Lett*., doi:10.1029/2012GL051286, 2012.

Saltogianni, V. and Stiros, S. Modeling of the Mogi magma source centre of the Santorini volcano (Thera), Aegean Sea, 1994-1999, based on a numerical-topological approach", *Stud. Geophys. Geod*., 56, 1037-1062, 2012.

Moschas, F., Stiros, S., PLL bandwidth and noise in 100Hz GPS measurements, *GPS Solutions, 18, 209-218,* 2014

Moschas, F., Avallone, A., Saltogianni, V., Stiros, Strong-motion displacement waveforms using 10Hz PPP-GPS: an assessment based on free oscillation experiments, *Earthquake Engineering and Structural Dynamics*, 43, 1853-1866, 2014

Moschas, F. and Stiros, S. Dynamic multipath in structural bridge monitoring: an experimental approach. *GPS Solutions,* 18(2), 209-218, 2014.

Moschas, F. and Stiros, S. Noise characteristics of high-frequency, short-duration GPS records from analysis of identical, collocated instruments, *Measurement,* 46, 1488-1506, 2013

Pytharouli, S. and Stiros, S. Analysis of short and discontinuous tidal data: a case study from the Aegean Sea. *Survey Review*, 44 (326), 239-246, 2012

Stiros, S., Levelling in antiquity: instrumentation, techniques and accuracies, *Survey Review*, 44 (32), 45-52, 2012

4.6 Laboratory of Geodesy and Surveying, Department of Civil Engineering and Surveying and Geoinformatics Engineering, Technological and Educational Institute of Athens (T.E.I. Athens)

Ass. Prof. V.D. Andritsanos, Ass. Prof. M. Gianniou, Assoc. Prof. V. Pagounis

The laboratory of Geodesy and Surveying of the Department of Civil Engineering and Surveying and Geoinformatics Engineering (Technological and Educational Institute of Athens) is equipped with recent geodetic instruments as total stations (robotics and image

stations), GPS geodetic receivers, a gravimeter of relative measurements, a TOF laser scanner and a single beam echo sounder. A permanent GPS station is working from 2010, with a recording rate of 15 sec., and provides accurate position data for educational and research purposes. In addition, two tide gauges are operational in Isthmos Canal (Peloponnesus – Central Greece) from 2014 and provide local sea surface measurements every 10 sec.

The research interests of the laboratory are Accurate Positioning and Applications, Gravimetry, Altimetry, Heterogeneous data combination in local and regional geoid modeling and deformation monitoring.

The current geodetic research projects of the laboratory of Geodesy and Surveying are:

Main coordinator – ELEVATION project: "EVALUATION OF THE HELLENIC VERTICAL NETWORK IN THE FRAME OF THE EUROPEAN SYSTEMS AND CONTROL NETWORKS INTERCONNECTION - APPLICATION IN THE AREAS OF ATTIKI AND THESSALONIKI" co-financed by the E.U. (European Social Fund) and national funds under the Operational Program "Education and Lifelong Learning 2007 – 2013" in the frame of the action "Archimedes III – Funding of research groups in T.E.I."

Partner - "State-of-the-art mapping technologies for Pubic Work Studies and Environmental Impact Assessment Studies". The Laboratory is responsible for GPS measurements, processing and evaluation of various transformation schemes between local reference system and satellite image reference system. For the Greek side SUM project is co-funded by the EU (European Regional Development Fund/ERDF) and the General Secretariat for Research and Technology (GSRT) under the framework of the Operational Programme "Competitiveness and Entrepreneurship", "Greece-Israel Bilateral R&T Cooperation 2013-2015".

A list of publications of the members of the Laboratory of Geodesy and Surveying for the period 2011 – 2015

Andritsanos V.D., M. Gianniou and V. Pagounis (2011) Vertical Datum Evaluation Based on Heterogeneous Data Combination over Attica, Greece. Presented at FIG Working Week 2011 *"Bridging the Gap between Cultures"*, Marrakech, Morocco, 18 – 22 May 2011.

Pagounis, V., M. Gianniou and V. D. Andritsanos (2011) The Permanent GPS station of the Laboratory of Geodesy and Surveying, Department of Surveying, T.E.I. Athens. Technologica Chronica, vol. 23, pp. 72-73, Internal publication of T.E.I. Athens.

I.N. Tziavos, G.S. Vergos, V.N. Grigoriadis and V.D. Andritsanos (2012) Adjustment of collocated GPS, geoid and orthometric height observations in Greece. Geoid or Orthometric Height Improvement? International Association of Geodesy Symposia 136 "Geodesy for Planet Earth", pp. 411 – 418. Springer.

Andritsanos, V.D. and I.N. Tziavos (2012) A Sensitivity Analysis in Spectral Gravity Field Modeling Using Systems Theory. International Association of Geodesy Symposia 136 "Geodesy for Planet Earth", pp. 411 – 418. Springer.

Pagounis V. and V. D. Andritsanos (2013) Local height control systems. Presented at the 15th Scientific Meeting of the Southeastern Attica. October, 17 – 20, 2013.

Andritsanos V. D., G. S. Vergos, V. N. Grigoriadis, V. Pagounis and I. N. Tziavos (2014) Spectral characteristics of the Hellenic vertical network – Validation over Central and Northern Greece using GOCE/GRACE global geopotential models. Presented at the European Geosciences Union General Assembly 2014, Session G4.2 Satellite Gravimetry: GRACE, GOCE and Future Gravity missions, Vienna, Austria, April, 27th to May, 2nd.

Vergos G. S., V. D. Andritsanos, V. N. Grigoriadis, V. Pagounis and I. N. Tziavos (2014) Evaluation of GOCE/GRACE Global Geopotential Models over Attica and Thessaloniki, Greece, and Wo determination for height system unification. Presented at the 3rd IGFS General Assembly (IGFS2014) "Geodesy for Planet Earth", Shanghai, China, June 30th – July 6th, 2014. To appear in the Proceedings.

Andritsanos, V. D., M. Gianniou and D. I. Vassilaki (2015) Effect of the transformation between Global and National Geodetic Reference Systems on GCPs and CPs accuracy. Presented at the 35th EARSeL Symposium – European Remote Sensing: Progress, Challenges and Opportunities, Stockholm, Sweden, June 15-18. To appear in the Proceedings.

Additional Research by the Hellenic Military Geographical Service (HMGS)

Geomagnetism

HMGS has collected magnetic declination data all over Greece. During 2010-2012 about 120 geomagentic stations were measured. Also, each destroyed station was reconstructed and remeasured to its new position. For every station there were at least two measurements during the past five years in order to compute the Mean Annual Change Rate of the magnetic declination for each station. All magnetic declination values were time corrected depending on the meridian of their location, referenced to the Magnetic Observatory of Penteli (Institute of Geology and Mineral Exploration) and computed for January the 1st of each year.

As soon as field works ended and all the appropriate computations took place, all stations' magnetic declination values referred to the 1/1/2011 using the Mean Annual Change Rate of each station. Based on the dataset of magnetic declination of 1/1/2011 and mean annual change rate two contour datasets were determined. The first depicts values of Magnetic Declination with 10' interval. The second contour dataset contains values of the Mean Annual Rate of magnetic declination with 0.5' interval which devides Greece into four zones. Finally, using the above datasets of contour lines a "Magnetic Declination Map of Greece" with its annual change rate was compiled referring to the 1/1/2011.

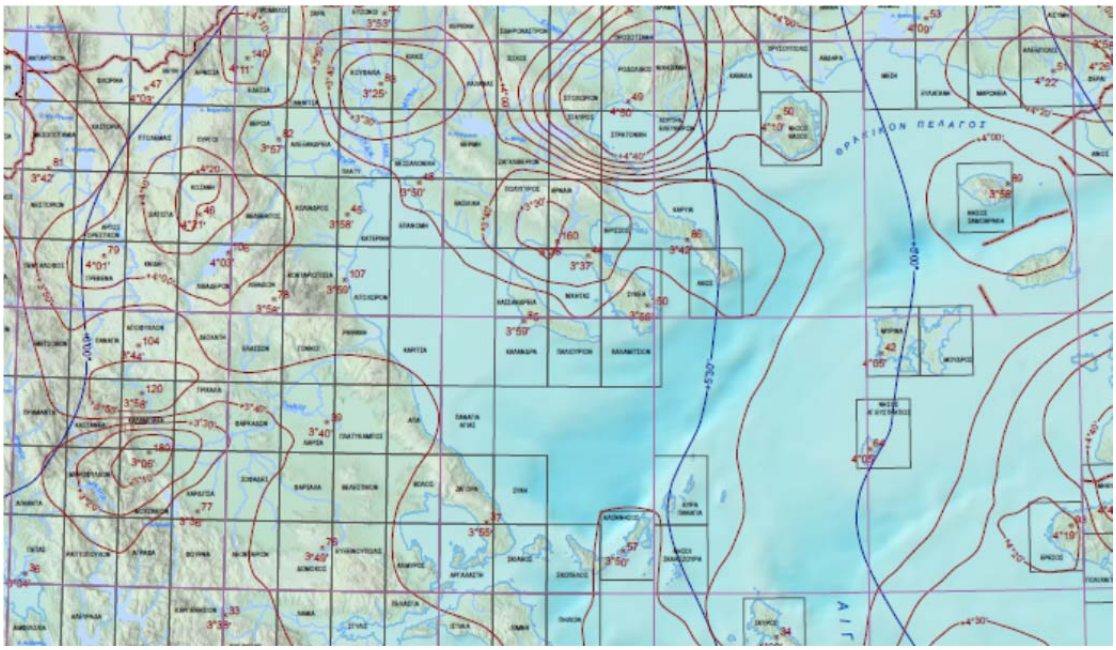

Figure: Subset of Magnetic Declination Map of Greece referred to 1/1/2011.

Publication:

Magnetic Declination Map, scale 1:1.000.000, HMGS, May 2013