GEODESY ACTIVITIES IN BULGARIA
NATIONAL REPORT 2007 – 2011

GEODESY, CARTOGRAPHY AND CADASTRE AGENCY

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GEODESY ACTIVITIES IN BULGARIA
NATIONAL REPORT
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Geodetic organizations, institutions and universities in Bulgaria

Professional organizations:

Assembly of Geodetic Engineers http://www.kig-bg.org
Association of the Geodetic Companies
Union of the Geodesists and Land Surveyors http://geodesy-fnts-bg.org
Assembly of the Engineers of Investment Design http://www.kiip.bg

Institutions:

Geodesy, Cartography and Cadastre Agency, Ministry of Regional Development and Public Works http://www.cadastre.bg/
Military Geographic Service at Bulgarian Army
Department of Geodesy, National Institute of Geophysics, Geodesy and Geography at Bulgarian Academy of Sciences, http://www.niggg.bas.bg; http://clg.cc.bas.bg

Universities:

University of Architecture, Civil Engineering and Geodesy, Geodetic Faculty, Sofia http://www.uacg.bg
University of Mining and Geology, Geological Faculty, Sofia http://www.mgu.bg
Shumen University, Faculty of Technical Sciences, Shumen http://shu-bg.net

The government documents and laws for regulation of the geodetic and cartographic works in Bulgaria are:

Decree of the Council of Ministers No 1 from January 18, 2005 about "Distribution of the geodetic and cartographic tasks of national importance", State Gazette No 6, 18. 01. 2005

Law for Geodesy and Cartography, State Gazette No 29, 07. 04. 2006

Decree of the Council of Ministers No 153 from July 29, 2010 about "Decree for establishment of the Bulgarian Geodetic System 2005", State Gazette N 60, 06. 08. 2010

Instruction No 2 from July 30, 2010 about "Defining realization and maintenance of the Bulgarian Geodetic System 2005", State Gazette N61, 10. 08. 2010

Instruction for transformation of the existing geodetic and cartographic materials into the Bulgarian Geodetic System 2005 (prepared and ready for acceptance)

Instruction for determination of geodetic points with GNSS (prepared and ready for acceptance)

Bulgaria is a member of the EuroGeographics and successfully participate in a number of projects – EuroBoundaryMap, EuroGlobalMap, EuroRegionalMap and EuroDEM.
Bulgaria participates in the activities and projects of the IAG sub-commission EUREF.
Geodetic organizations, institutions and universities in Bulgaria

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Foreword

The present report is composed by Assoc. Prof. D.Sc. Ivan Georgiev, IAG National Correspondent, on the basis of information and in close cooperation with the Geodesy, Cartography and Cadastre Agency, the Military Geographic Service and the Department of Geodesy of the National Institute of Geophysics, Geodesy and Geography, Bulgarian Academy of Sciences. Contributions are also made by the Geodetic Faculty of the University of Architecture, Civil Engineering and Geodesy and private companies.
The list of contributors is given in the appendix.
Since this is the first report for a number of years on the work in the field of geodesy in Bulgaria, the aspiration has been to cover the more important trends and activities and for this reason processes that have begun before the reported period, yielding results in the recent years, are also considered and discussed in this review!
Brief description of the main geodetic institutions in Bulgaria and their basic priorities and responsibilities:

Geodesy, Cartography and Cadastre Agency, Ministry of Regional Development and Public Works

The activities in the field of geodesy, cartography and cadastre in the Republic of Bulgaria have a more than 100-year history.
The beginning of topographic cartography in Bulgaria dates back to the end of the XIXth century. The systematic measurements on the creation of the state triangulation and leveling systems were started in the 20-ies of the XXth century and the first cadastral plans of the settlements were launched by the Cadastre Law in 1908.
The development of the activities in the field of geodesy, cartography and cadastre in Bulgaria is related with the enforcement of the Law for Geodesy and Cartography (2006) and the Law for Cadastre and Real Estate Registry (LCRER) (2001).
The Geodesy, Cartography and Cadastre Agency (Directorate of Geodesy and Cartography and Directorate of Cadastral and Specialized Maps), the national geodetic institutions – the Military Geographic Service of the Bulgarian Army, the Department of Geodesy of the National Institute of Geophysics, Geodesy and Geography of the Bulgarian Academy of Sciences and the private geodetic companies are the main institutions that are basically related to the geodetic activities in Bulgaria.
The Geodesy, Cartography and Cadastre Agency is an administrative body to the Minister of Regional Development and Public Works for realizing the cadastral activities in accordance with the Law for Cadastre and Estate Registry and the activities in the field of geodesy and cartography in accordance with the Law for Geodesy and Cartography (LGC).
The Directorate of Geodesy and Cartography organizes the performance of the basic geodetic and cartographic activities related with:

- the geodetic networks of local importance;
- the state leveling and mareographic networks;
- the large scale topographic map;
- the transcription and spelling of geographic denominations;
- the maintenance of the state geodetic, cartographic and cadastral fund (Geocartfund).

The Directorate of Cadastral and Specialized Maps organizes the activities on the systematic producing of cadastral maps and cadastral registries of territories with intensive turnover of real estates or high investment interest.

Military Geographic Service of the Bulgarian Army

The Military Geographic Service (MGS) is a specialized organ of the Ministry of Defense (MoD) for the formation of policies and carrying out all necessary activities for the development of geoinformation products (maps, schemes, terrain analyses, digital data for the localities and other geographic information) and ensuring the armed forces and state organs and structures with these products as well as rendering specialized technical assistance.

The main priorities of MGS are:

- meeting the obligations of the Republic of Bulgaria on the geographic support of the collective security system, including of the armed forces (AF) of the Republic of Bulgaria;
- meeting the obligations of the Ministry of Defense ensuing from the Law for Geodesy and Cartography – participation in the realization and maintenance of the unified geodetic data base of the Republic of Bulgaria by building and development of the state geodetic network, state gravimetric network and magnetic station network; establishment and maintenance of state topographic maps and orthophoto plans and topographic databases, including for ensuring the defense and security of the state, as well as for the purposes of navigation, aviation and shipping;
- organizing of cooperated production and exchange of geographic materials with the other geographic services of the other NATO countries;
- ensuring geoinformation materials and data to civil administrations and organizations in the Republic of Bulgaria;
- management of the activities on standardization and attainment of technical, technological and operative compatibility in the area of geographic provision.

Department of Geodesy, National Institute of Geophysics, Geodesy and Geography, Bulgarian Academy of Sciences

The Department of Geodesy (former Central Laboratory of Geodesy - CLG) is a department of the National Institute of Geophysics, Geodesy and Geography (NIGGG) of the Bulgarian Academy of Sciences. The Department of Geodesy has more than 60-year history and its main priorities are:

- participation in the international scientific integration for studying the shape and dimensions of the Earth as a planet, its orientation in space and its external gravitation field;
- carrying out fundamental and applied scientific research on introducing, updating and using the national reference and coordinate systems as part of the European and global ones with the view of the economic and social needs of the country;
- integration of the results from geodetic research and the results from other Earth sciences for the study of local, regional and global deformation processes and especially processes related to hazardous geodynamic phenomena (earthquakes, landslides, etc.);
- development of the geodetic aspects of the systems for monitoring and control of the natural and technogenic risks and protection of the environment;
- development of a concept for a national geodetic information database and elaboration of methods for its maintenance, renewal and integration with other national and international geoinformation systems;
- establishment of technologies, consulting and expert activities for supporting the competitive and sustainable development of society;
- training of specialists on General, Theoretical and Applied Geodesy.

According to the newly accepted Law for Geodesy and Cartography (2006), the responsibilities for the geodetic activities in the Republic of Bulgaria are distributed as follows: the Military

Geographic Service (MGS) of the Bulgarian Army is responsible for maintenance of the National GPS Network and maintenance of the main gravimetric and magnetic networks. The Geodesy, Cartography and Cadastre Agency is responsible for the maintenance of the local geodetic networks, the National Vertical Network and the the Tide Gauge Network and for the geodetic and cartographic data base. All these activities are performed in close cooperation and active participation of the Department of Geodesy of NIGGG and the Geodetic Faculty of the University of Architecture, Civil Engineering and Geodesy.

1. Reference frames and networks

1.1 National GPS Network. Realization of the European Terrestrial Reference Frame ETRS89 in Bulgaria

In the last several years the geodetic systems and networks in Bulgaria have been radically updated. This activity was launched by the design, construction, processing and analysis of the measurements of the new National GPS Network. The approval of the official documents for introducing the new geodetic network was completed in 2010.

The project of the (new) National GPS Network and the program for its measurement were developed in the Military Geographic Service of the Bulgarian Army. The National GPS Network was realized in performance of the Act of the Council of Ministers 140/04.06.2001, which defined the Bulgarian Geodetic System and served for the radical updating of the (old) National Geodetic Network of Republic of Bulgaria. The National GPS Network consists of two orders of points unified in Main and Secondary orders.

The Main order of the network is created to realize, distribute and maintain the European terrestrial reference system ETRS89 on the territory of the country with an accuracy of 5-10 mm in position and 10-15 mm in height using the GPS technology. The full realization of the Main and Secondary orders will provide the possibility of using their points as reference for the establishment of local geodetic networks for the needs of the practical applications and actually, for all geodetic applications.

The Main Order network

The Main order GPS network includes the following types of points: the EUREF points in Bulgaria officially accepted at the EUREF Symposium in Istanbul 1996, including the points of the European Unified Vertical Network (EUVN) – Burgas (BUTG) and Varna (VATG); points of the I, II, III and IV orders of the existing (old) National Geodetic Network (NGN); newly built points during the period 2002 – 2003 especially for the National GPS Network (Table 1).

The requirements towards the GPS points are given in the "National GPS Network – Project of the network and program for measurement", Ministry of Defense, Military Geographic Service, Sofia, May 2004. All points of the Main GPS Network are identified by number and name. All EUREF and NGN points have unique numbers. The names of the EUREF points, including of EUVN, are four-character abbreviations. The Main order points of the National GPS Network are shown in Fig. 1.

Reconnaissance of the points of the National GPS Network was performed in 2002 – 2003, as well as repair of existing and construction of new points - 219 existing points were repaired and 123 new points were built. The achieved coincidence between the points of the National GPS Network and the existing NGN points is about 70%. A final project and an observation program for the National GPS Network were developed and approved by a commission appointed by order of the Minister of Regional Development and Public Works.

The measurements of the Main order of the National GPS network were performed in July –

Table 1. Points from the Main GPS network

№	Type of the points	Number	Note
1	EUREF pointsnetwork	15	1 NGN II order points
2	Points from EUVN	2	
3	Points from NGN I and II order	25	
4	Points from NGN III and IV order	46	
5	New points	22	
6	Points with special statute	2	
	Total	**112**	

October 2004, GPS campaign BG 2004, by teams of the Military Geographic Service using geodetic receivers of the Trimble Company. The measurements of all Main order points were performed in sessions with duration of two days, from 0 h UTC, and additional two sessions with duration from 5 to 8 hours – before and after the two main sessions. All measurements were made with 15 seconds sampling rate and 10 degrees elevation mask. The measurements started July and ended September 2004.

The processing and analysis of the network were carried out in 2005 in the Department of Geodesy (Georgiev et al., 2006). The processing was done in the International Terrestrial Reference Frame 2000 (ITRF2000) realization of the International Terrestrial Reference Ssytem (ITRS), available at that time, by the Bernese 5.0 scientific research software - state-of-art software for GPS processing. The software has been created as a "tool for the highest accuracy in GPS processing

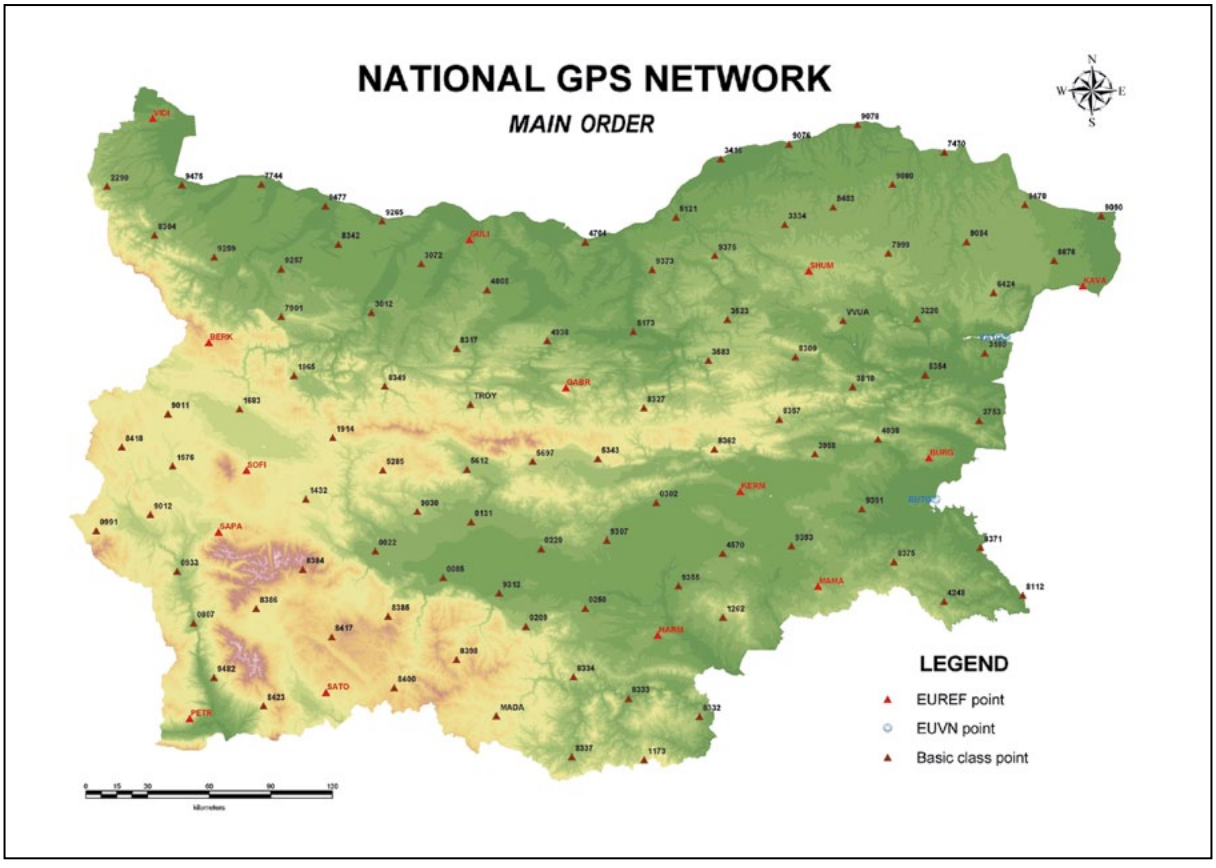

Fig.1. National GPS Network of Bulgaria – Main order. With red triangles the EUREF points and the two EUVN points – BUTG and VATG.

in various applications". Details of the processing can be found also in Georgiev et al., (2010). An example of the root mean square (rms) values in the position – north, east, up of the Helmert's transformations between ITRF2000 and some of the daily solutions are shown in Fig. 2 for the GPS week 1285.

New solution for the EUREF BG 1993 GPS campaign

According to the agreement between Bundesamtes fuer Kartographie und Geodesie (BKG, former IfAG) and the Military Geographic Service the GPS EUREF BG 93 campaign was performed in the period 12.10. – 16.10.1993. The 15 points were measured in four sessions with duration of 24 h with Trimble 4000SSE receivers. The campaign was performed with the purpose to determine 15 points on Bulgarian territory in the ETRS89.

The reprocessing of the measurements from the EUREF BG 93 GPS campaign was necessary

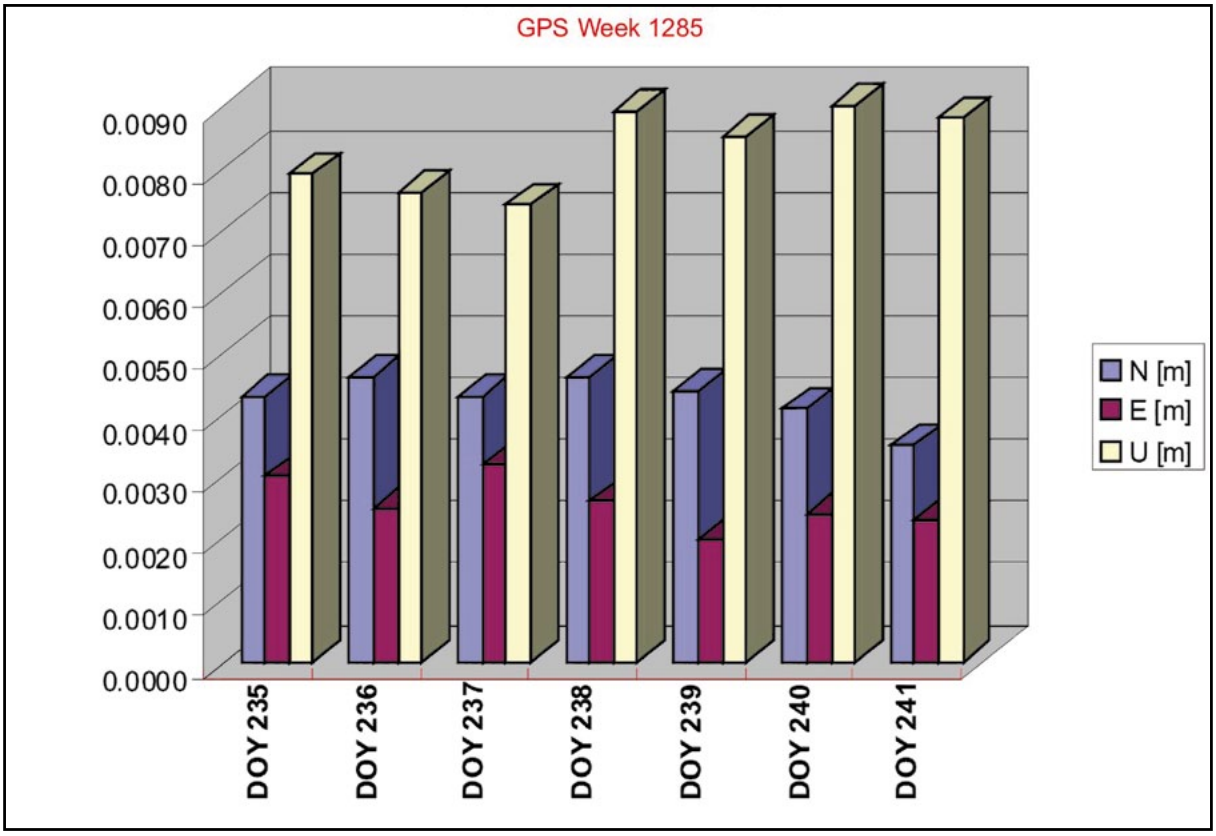

Fig. 2. Rms in north, east, up from the Helmert transformation between ITRF2000 and daily solutions for the GPS week 1285.

mainly because of two reasons: for control, comparison and analysis of the new solution and for obtaining the velocities of the EUREF points. The processing and analysis of the observations from the EUREF BG 93 campaign were performed according to the same strategy as the BG 2004 GPS campaign.

New realization of ETRS89 on the territory of Bulgaria

The results from the processing and analysis of the measurements of the Main order GPS network are accepted by an Expert Commission appointed by an order of the Minister of Defense of the Republic of Bulgaria RB-N-P-13/06.01.2006. The main conclusion drawn by the commission is: ***"The performed work and the obtained results in the development and processing of the Main order of the National GPS network are of fundamental importance for the state,***

comparable to that of the created in the 30-ies of the 20th century National Geodetic Network and correspond in their volume and accuracy to the regulating documents and to the advanced scientific achievements in this field".

The results are reported to the EUREF Technical Working Group at the annual international EUREF symposium in Riga, Latvia, 14-17 June, 2006. The results were accepted by the TWG in Resolution No 1 of the Symposium.

Due to the good quality of the obtained results new official realization of the ETRS89 on the territory of Bulgaria, consisting of 25 points (Fig. 3) and replacing the previous 15 from 1996, was also accepted at the meeting of the Technical Working Group.

The processing and analysis of the Main order of the National GPS network and the obtained precise coordinates made it possible for Bulgaria to have, at the moment of its accession to the European Union, a modern geodetic network, tied to the European Reference System and meeting the requirements of the advanced achievements in the field of GPS technology. The analysis of

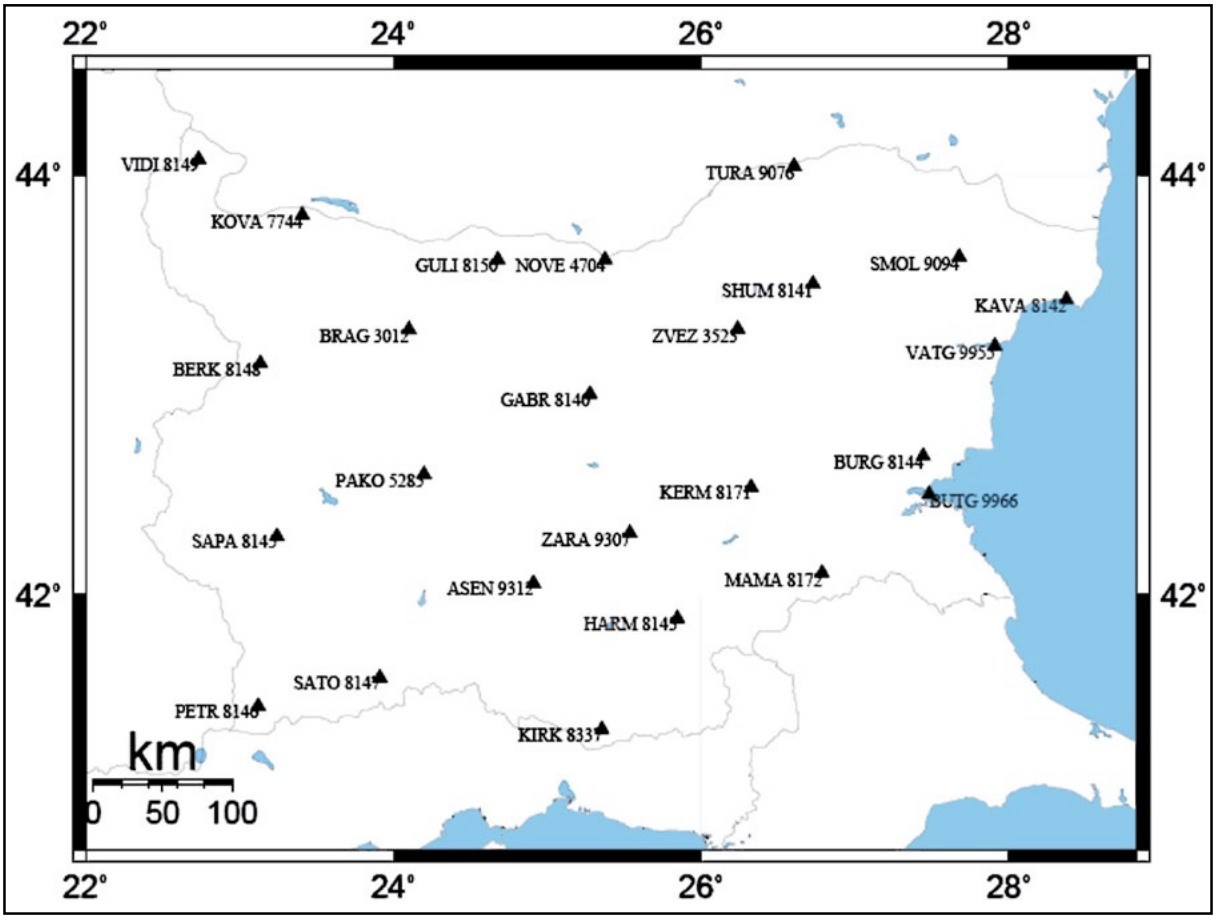

Fig. 3. New realization of the ETRS89 on the territory of Bulgaria (25 points) accepted by the EUREF TWG in Riga, 2006

the results show that the accuracy of the obtained coordinates is 5-10 mm in position and 10-15 mm in height. The network is very important for updating the national geodetic networks in the country. In fact, the points of the Main order of the National network represent a densification of EUREF on the territory of the country.

The velocities of the points from the new realization of the ETRS89 obtained from EUREF BG 93 and BG 2004 GPS campaigns are shown in Fig. 4.

Secondary Order GPS network

The Secondary order GPS network was developed with the objective of densification of the Main order to an average distance between the points of 10 – 15 km. The wholesome realization of the Main and Secondary order networks will lead to a density allowing the use of their points as reference for all practical applications in Bulgaria. All the requirements towards the Main order

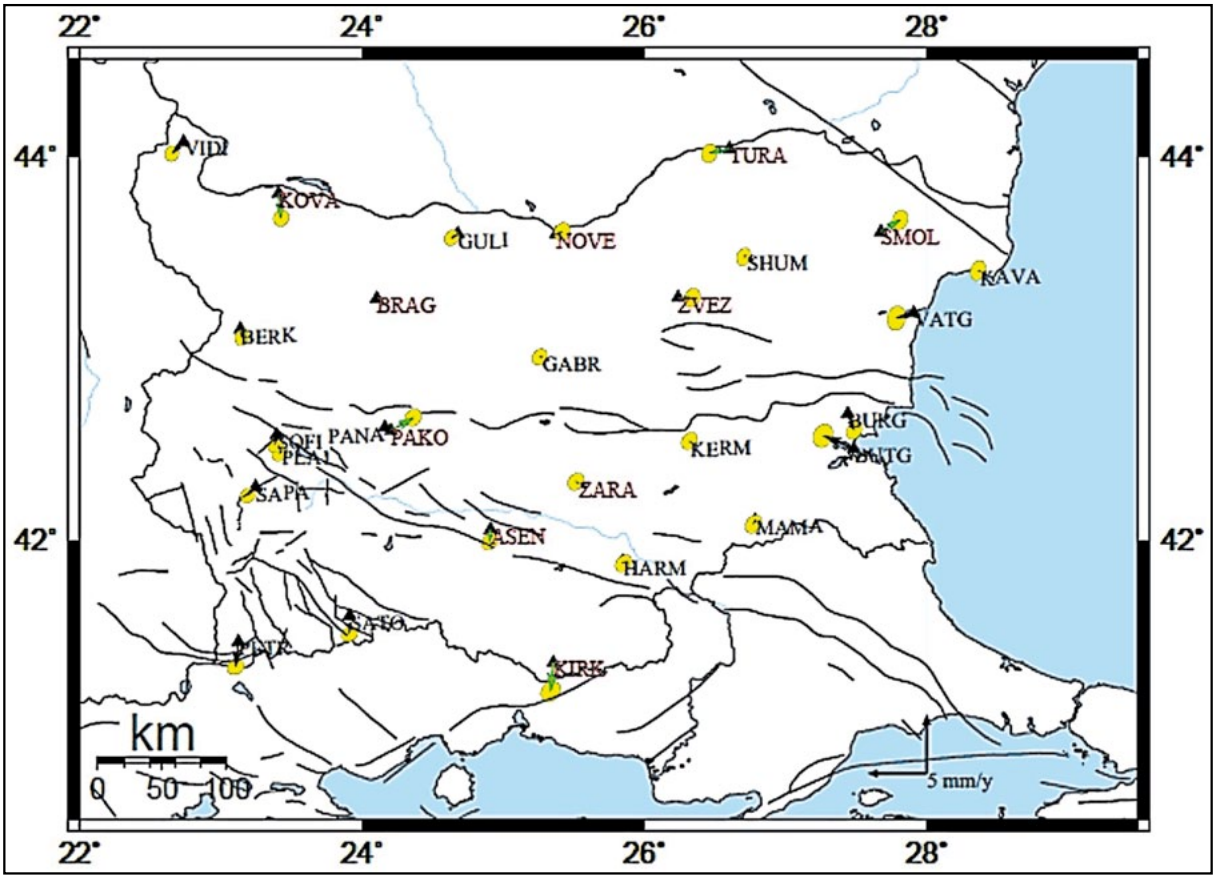

Fig. 4. Velocities of the points of the new ETRS89 realization on the territory of Bulgaria. The velocities of the new points are shown in green and their names are given in red

GPS network are applied to in the process of design and selection of points for the Secondary order GPS network.

The points of the Secondary order GPS network are shown in Fig. 5. The total number of the points of the Main and Secondary order is 457. The Secondary order network includes the following types of points (Table 2):

The measurements of the Secondary order network were realized in two GPS campaigns – in October 2004 and in July-October 2005, by teams of the Military Geographic Service with geodetic receivers of the Trimble Company in sessions with duration of 8 hours. The sessions were measured with meeting the following requirements: minimum three points of the Main GPS network participate in each session; each session was connected with the adjacent (neighboring) with minimum three additional common points. All measurements were carried out with sampling rate 15 seconds and elevation mask 10 degrees.

The processing and analysis of the network were realized in the Department of Geodesy (Georgiev et al., 2007).

Table 2. Points of the Second order GPS network Table 2. Points of the Second order GPS network

GPS points of the Second class network					Total
NGN I and II order	NGN III and IV order	Local networks	Gravimetric points	Newly built points	
25	226	3	1	89	
					345

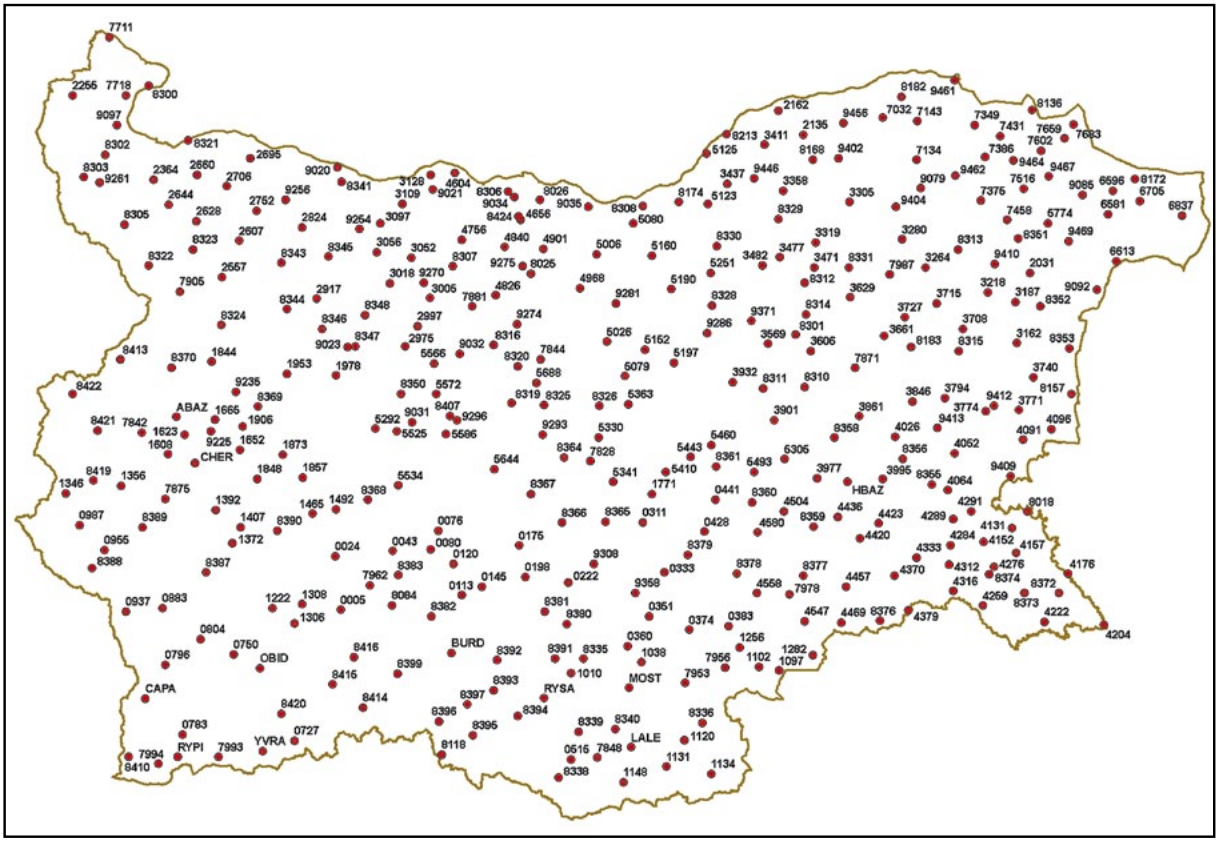

Fig. 5. National GPS network – Secondary order

The processing was performed by the Bernese 5.0 scientific software. The Main order points were used as referenced. Their coordinates obtained in the ITRS (ITRF2000) were extrapolated for the epoch of observation using the velocities: for the EUREF points – those obtained from the observations and for the rest of the points – those calculated according to the Eurasian rotation pole.

The two GPS campaigns from 2004/2005 were divided in daily (8-hour) sessions. Daily solutions were calculated for each session which (normal solutions) were then combined to obtain solutions for the campaigns. Each one of the GPS campaigns was processed individually and then the coordinates of all points were transformed to epoch 2005.0, the epoch of the coordinates of the Main order points.

The analysis of the Secondary order network solution show that the accuracy of the obtained coordinates is 10-15 mm in position and 15-20 mm in height. The results of the processing were reported at the annual EUREF symposium in London, 2007.

1.2 Permanent GNSS networks

Permanent network of the Department of Geodesy. Establishment of a national wide Permanent GNSS network

The first permanent GPS station in Bulgaria was installed in 1997 by the German Federal Service of Cartography and Geodesy in the observatory of the Military Geographic Service in the vicinity of Sofia (SOFI). The station is part of the EPN/IGS networks.

The Department of Geodesy initiated the establishment of a national wide Permanent GNSS Network. The basic requirements that are strictly followed in the network establishment are:

-stabilization of the points in a manner providing the possibility to avoid errors from centering. Usually these are reinforced concrete pillars with centering devices;

-free access to the data (30 second files), coordinates and velocities of the stations for all users;

-permanent processing of the GPS measurements, generation of time series of the coordinates and control on the stability of the points;

-using the results for the maintenance of the National GPS network and for all geodetic applications;

-using the results for various scientific applications – geodynamics, seismic hazard, GPS meteorology, etc.

The first permanent GNSS stations of the network were installed in May 2007 in Southwest Bulgaria within the framework of a project supported by the Science for Peace NATO program. At present the Department of Geodesy operates 16 permanent tracking GNSS sites.

Private Permanent GNSS networks in Bulgaria

At present 3 private companies operate commercial GNSS permanent networks in the country – NAVITEQ network (http://naviteq.net), GEONET network (http://www.geonet.bg) and BULiPOS SMARTNET network (http://www.bulipos.eu).

The Department of Geodesy has good cooperation with the private companies and supports their work with precise positioning, long term monitoring and time series analysis.

For example, the NAVITEQ in fact established the first commercial reference GPS network in Bulgaria. The first stations of the network were installed in the end of 2005 and today the company operates a network of 24 active stations (6 common with Department of Geodesy). According to the contract between the Department of Geodesy and NAVITEQ, the company submits the 30-second GPS data from all of its stations to the Department for processing and analysis and for various scientific applications. The Department of Geodesy realizes also the monitoring of the long-term stability of the NAVITEQ stations.

GNSS Analysis Center at the Department of Geodesy. Processing and analysis of the observation data from the permanent stations

A **Center for Analysis of GNSS Measurements** was established in the Department of Geodesy in connection with the obligations for the processing and analysis of the new State GPS Network and its long-term maintenance and the processing and analysis of the data from the permanent GNSS stations.

The Center for analysis has on its disposal modern software for processing and analysis of GPS/GNSS (and generally of satellite observations) – the Bernese scientific-research programs, GAMIT/GLOBK, QOCA, FONDA. The programs are based on the recent achievements in the GPS/GNSS technologies and satellite geodesy as a whole. As of the present moment data from the 28 permanent stations in Bulgaria, as well as from the regional permanent GPS stations in Romania, Turkey, Greece and Republic of Macedonia (about 70 in total), are received, archived, processed and analyzed in the Center for analysis – Fig. 6.

The Department of Geodesy uses the GAMIT/GLOBK scientific research software for processing

and analysis of the GPS measurements from permanent sites.
GAMIT/GLOBK is a scientific research software reflecting the state-of-art in satellite geodesy and GNSS technology in particular, developed in the Massachusetts Institute of Technology, the Harvard-Smithsonian center on Astrophysics and the Scripps Institute of Oceanography. The software is intended mainly for obtaining estimates of coordinates and velocities of stations, stochastic and functional representation of post-seismic deformations, models of the atmosphere, satellite orbits and Earth orientation parameters.
Time series with the coordinates of the stations, as well as their horizontal velocities are obtained on a regular basis. Fig. 7 shows raw time series of one of the permanent stations.
The maintenance and extension of the GNSS network, the processing and analysis of the measurements and the free access to them are important for the scientific investigations and

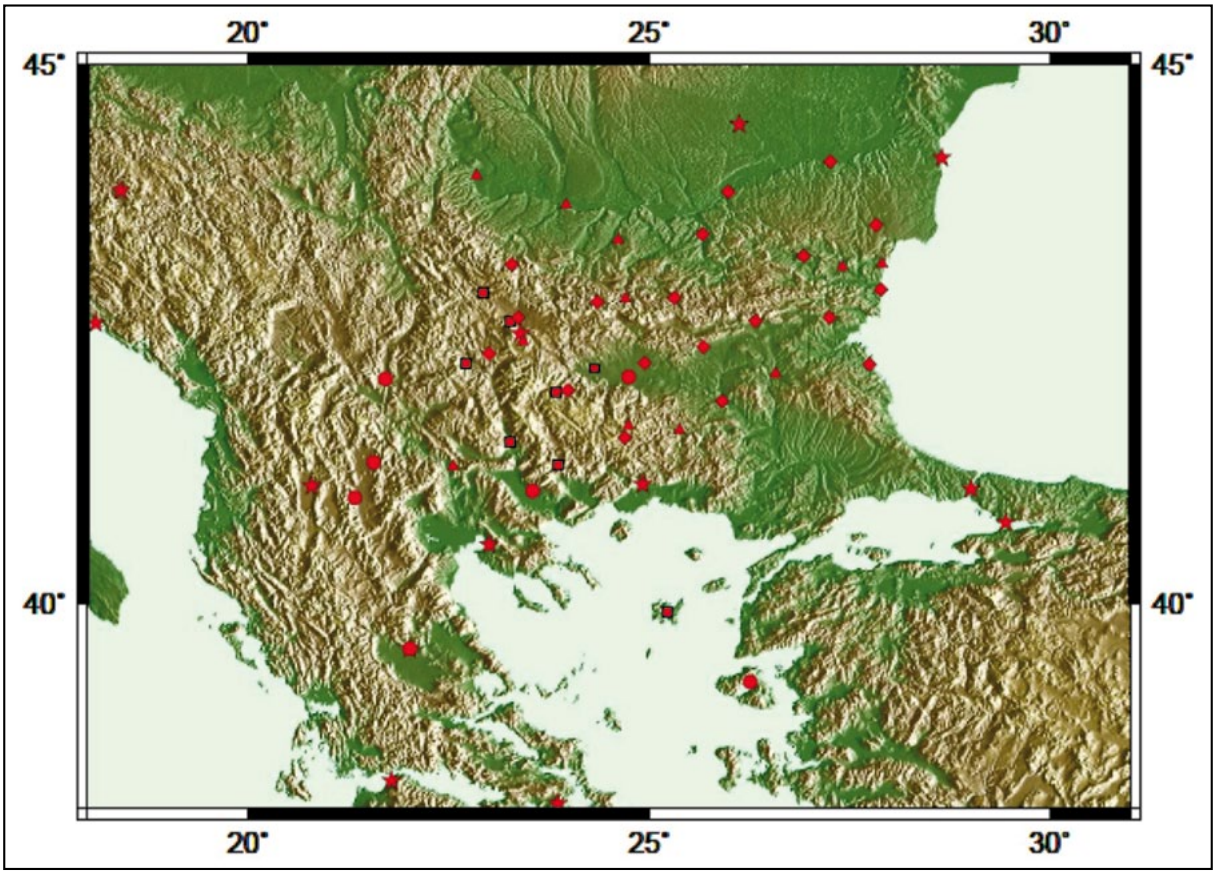

Fig. 6. Permanent GNSS sites which data are processed and analyzed in the Analysis Center in the Department of Geodesy. With squares and triangles are shown the Department of Geodesy sites, rhombs show NAVITEQ sites. With stars are marked EPN sites in the Balkans included in the processing.

geodetic practice in the country. The permanent GNSS stations may be used for both the maintenance of the new National GPS network in Bulgaria and with the appropriate legal regulations – of all geodetic GNSS applications. The analysis of the measurements will be used successfully for long-term monitoring of the recent crustal movements and for the seismic hazard assessment.

Local Geodetic networks

The local geodetic networks are created for densification of the National geodetic network in connection with the large scale mapping of the territory, the cadastre of settlements and other tasks.

About 35 000 local geodetic points established by classical technology are preserved on the territory of the country. The present period of the development of local networks is related with the finalization of the National GPS network adjustment. In the recent years, since the mass introduction of the GPS technology in the geodetic practice, the established local geodetic networks possess already more than 3400 points.

1.3 Leveling networks. Realization of the European Vertical Reference System EVRS in Bulgaria

Unified European leveling network UELN

The UELN Unified European leveling network, including the leveling networks of the states in

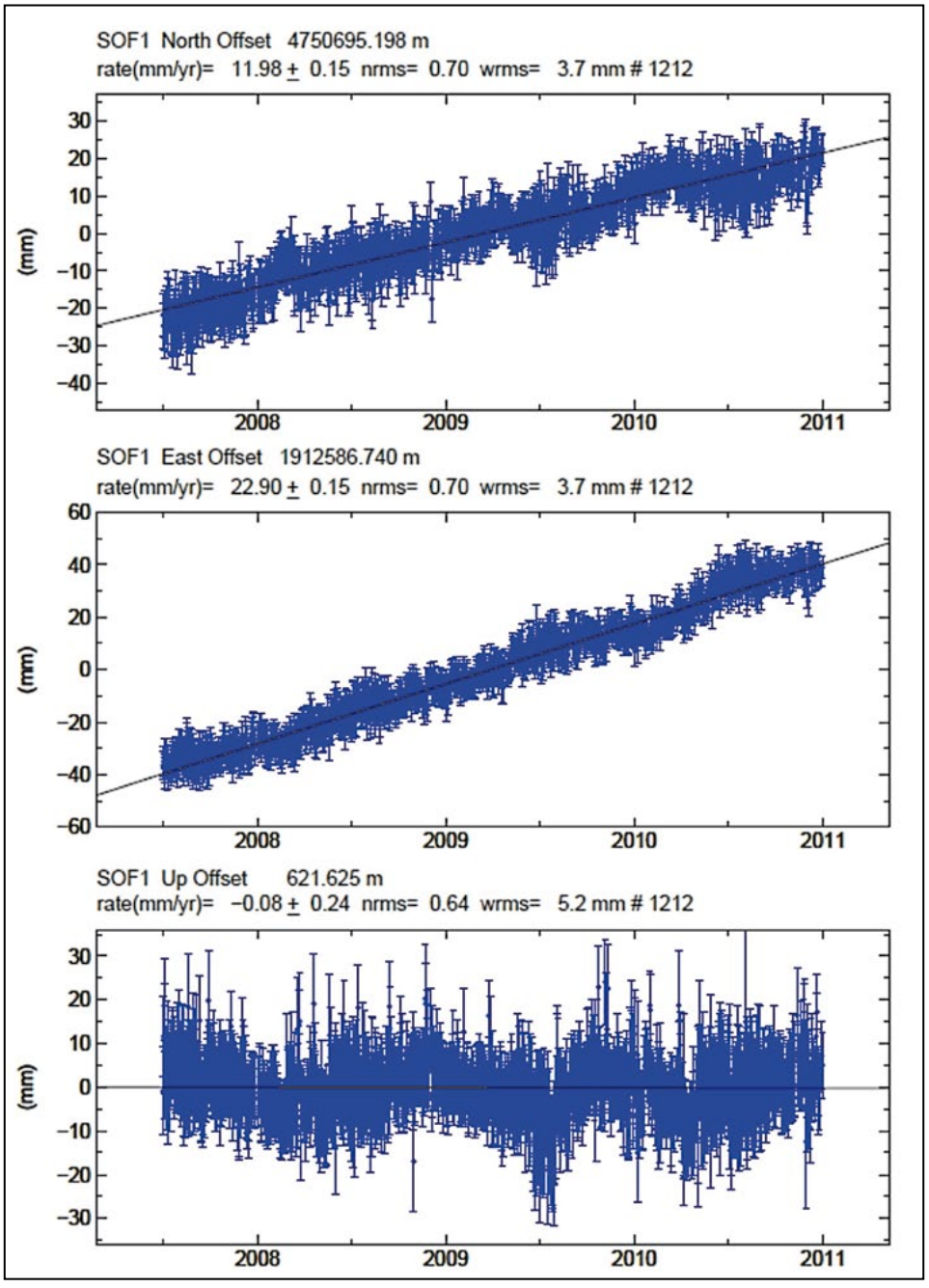

Fig. 7. Row time series of the SOF1 permanent site in Sofia.

West Europe, was established in 1973 (UELN73), the initial point of the height system being the tide gauge in Amsterdam. A decision was made at the EUREF symposium in Warsaw in 1994 for adhering of the leveling networks of the countries in East Europe to UELN by launching the UELN95/98 project. Bulgaria joined this project in 2003 and was the 26th European country that joined UELN.

European unified vertical network EUVN

In 1995 the EUREF Commission made the decision to launch a European project for establishing a European Unified Vertical Network (EUVN). The principal objective of EUVN is to develop a homogeneous and unified height network and system in continental Europe. The purpose of the network is also to ensure a reference system for kinematic investigations of the vertical movements.

The EUVN network consists of: permanent EPN stations; GPS stations, situated in the proximity of the tide gauge stations; GPS points, coinciding with the nodal benchmarks of the national leveling networks. The first GPS campaign was realized within the frame of the EUVN project in May 1997 and comprised 196 stations in 32 countries. All these points received three dimensional coordinates in ETRS89. The average accuracy of the determined heights in EUVN is about 0.5 cm. The further efforts of the GPS-based EUVN are aimed at its combination with the classical leveling and gravimetric data for the development of the unified EVRS European vertical reference system.

European vertical reference system EVRS

EVRS is a ***kinematic*** vertical reference system, its last realization EVRF2007 is based on the combination of three main elements: ***network (EUVN), vertical coordinate system (vertical datum) and its changes with time.***

The EVRF2000 realization. Including the Bulgarian First order National Leveling Network (NLN) to the European network

Bulgaria joined the UELN95/98 project in 2003 with its First order NLN, III cycle measurement in the period 1974-1984. The network measurement was realized at two stages. Five polygons, comprising the territory of the whole country, were measured in the period 1974-1980, which were made denser with new lines in 1981-1984. The base of this network is represented by the 300 fundamental underground (secular) I and II order benchmarks, built in the period 1962-1963, their number reaching now 330 (together with these constructed after this period), Fig. 8. The total length of the leveling lines is 5 630 km and the number of nodal benchmarks is 33.

The activities on the project were financially supported by EuroGeographics and were carried out in the German Federal Service on Cartography and Geodesy in Leipzig. The inclusion of the First order NLN in UELN was realized via the leveling network of Romania. The trans-border leveling connections, established between the two countries in 1974-1977 at Vidin-Kalafat, Nikopol-Turnu Magurele, Ruse-Gyurgevo, Silistra-Kalarash and Kardam-NegruVoda, were used for this purpose.

The performed adjustment of UELN95/98 to obtain EVRF2000, with the First order NLN of Bulgaria, has the following parameters: number of unknown values (benchmark heights) – 3653, number of observations (height differences between benchmarks) – 5131, initial benchmark of the network – No 000A2530/13600 (the Netherlands) with geopotential benchmark 0,70259 kgal.m, normal height 0,71599 m, g = 9,81277935 m/s2. The adjustment of UELN95/98 for the territory of Bulgaria includes 36 unknowns (the heights of nodal benchmarks, including these in the connections) and 63 height differences. The mean square error for the Bulgarian Leveling Network after the adjustment of the whole network is 1,18 mm/km, which a very good parameter when compared to other networks. The total mean error of UELN is 1,28 mm/km.

The differences between the adjusted heights and the old Baltic height system are in average 18 cm.

Realization EVRF2007

A new adjustment of UELN was made in 2008 using as initial ones 13 benchmarks in Austria, Belgium, Denmark, Italy, the Netherlands, Hungary, Poland and Slovakia, situated in the stable part of the Eurasian plate. This is the actual realization of EVRS - EVRF2007 on the territory of

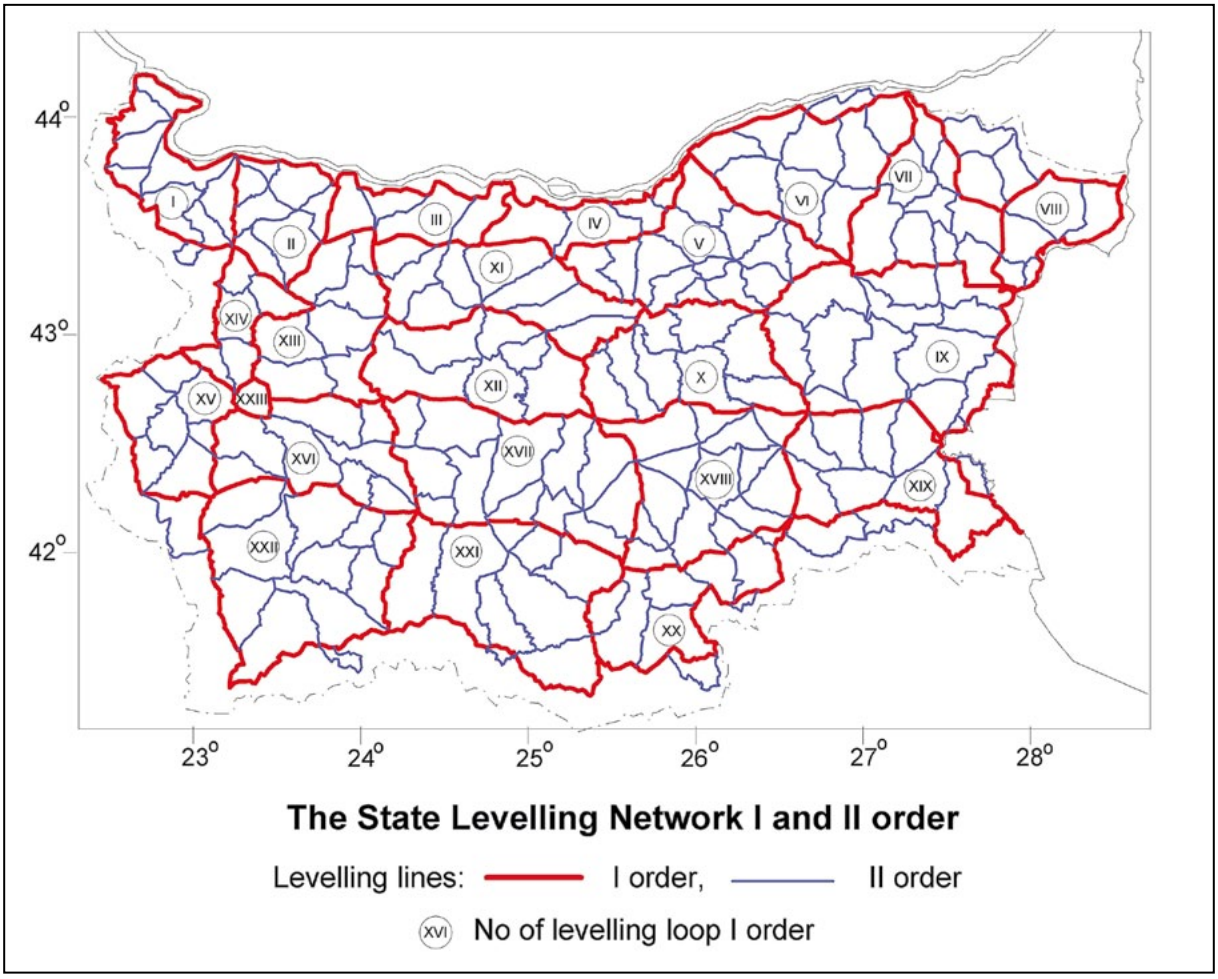

Fig.8. First and Second order leveling networks

Bulgaria. Except for the nodal benchmarks, participating in the EVRF2000, it includes additional densification points on the territory of the country, determined in the frames of the EUREF project EUVN-DA (European Unified Vertical Network Densification Action) – their number being 22 and the initial benchmarks for their determination – totally 44 (see below). The mean square error of the adjustment of UELN (EVRF20007) for the Bulgarian leveling network is 1,14 mm/km.

The transformation parameters between EVRS and the (old) National (Baltic) system are: EVRF2000 – - for the system of geopotential heights: UELN - BG = +179 kgal.mm and for the system of normal heights: UELN - BG = +182 mm. The difference between the Baltic height system and EVRF2007 is +228 mm for the normal height system. The difference of 46 mm between the two realizations from 2000 and 2007 is due to the inclusion of new benchmarks as initial ones, as well as due to the effect of tidal deformations in the solid Earth's crust. During the adjustment in 2008 the geopotential differences were established for Earth potential, corresponding to the zero-tide system, while for EVRF2000 they were calculated for average-

tide values.

The EUVN-DA project

In 2003 the Technical Working Group of EUREF launched the EUVN-DA project with the main objective – ***establishment of continental and homogeneous GPS/leveling network and databases compatible with ETRS89 and EVRS.***

The national (geodetic/cartographic) agencies of the European countries render broad support to the project, ensuring existing and/or new data. Till 2009 25 European countries participate in the project and the database contains more than 1400 GPS/leveling points. The EUVN-DA project was finalized in the end of 2009 but it is planned to continue and broaden the maintenance of the database within the frame of EVRS. The improvements will be published, when new data become available.

Bulgaria joined the EUVN-DA project with the points of the new realization of ETRS89 on its territory. The points meet the requirements of the above mentioned criteria and they have coordinates and velocities in the European Terrestrial Reference System. To meet all requirements of EUVN_DA, the points are affiliated to the I order State Leveling Network, i.e. to UELN, by precise leveling. Gravimetric measurements have been also realized for determining the gravity force values.

Leveling measurements for determining the heights of the EUVN_DA points

All heights of the 26 EUREF points, the new realization of the ETRS89 in Bulgaria, and height of the permanent station SOFI are also obtained by precise leveling. Precise leveling is performed between 23 of them and leveling nodal benchmarks from the National Leveling Network. As nodals are used: 13 points from the First order network, included to EULN in 2003; 8 points from Second order network, tied to EULN in 2007; 1 point from the Third order network; 1 point from the geodynamic network.

The heights of these benchmarks are determined at the last leveling of the National Networks: First order during 1974-1984 and Second order during 1987-1992 (one point is from the previous epoch 1947). The Third order point was determined in 1960. The rest three points – SOFI, VATG and BUTG, are determined within the frame of the EUVN project in 1997.

The heights of 19 EUREF points are measured from one nodal point, and those of four others – from two points. The measurements were completed in 2006 by the MGS, for 4 points measurements from 1996-1997 were used. The mean distance from the nodal points to the EUREF points is 5.3 km; the mean error for 1 km leveling distance is - 0.46 mm/km1/2.

Gravimetric measurements for determining the gravity force values of the EUVN_DA points

Gravimetric measurements were carried out in 2007 at the points and the initial leveling benchmarks for the calculation of the geopotential benchmarks and normal heights of the EUVN-DA points. Points of the Reference Gravimetric Network of Bulgaria are used as initial gravimetric points. The measurements were made by teams of CLG BAS and the MGS of BA using GAK-7T No 524 and GR/K2 No 1319 gravimeters. The average value of closure of the gravimetric polygons from the measured gravity force differences is 0,09 mGal.

The leveling data, the geopotential differences and normal heights are controlled and evaluated in the EUVN/UELN Center in Leipzig, Germany. The EUVN-DA points, affiliated to the UELN benchmarks, represent a part of the UELN network and are included in its adjustment.

Precise leveling of the National GPS Network Main order points

In 2006 the MGS started precise leveling of the points from the Main order of the National GPS Network in order to obtain their normal heights. The measurements were performed with two Topcon DL-101C digital levels and invar rods. A total of 483 km precise leveling was performed and normal heights of 58 Main order and 61 Secondary order poins were obtained (Fig.9). In

order to check the initial benchmarks, from which the point heights are determined, additional 411 km leveling was performed.

New measurements of the First order leveling network

In 2008 a new cycle of measurements of the First order National Leveling Network was started. Ten leveling lines of the I order leveling network, being in the process of re-measurement, were determined in 2008-2009. These lines are from polygons VI, VII, VIII, IX, XV and XIX. The total length of the measured lines is 1405 km, which represents 25% of the whole network.

The measurement was made with Leica DNA 03 and NA 3003, Topcon DL-101C, Zeiss DiNi 10 and Trimble DiNi 03 digital levels. Gravimetric measurements were performed at the leveling benchmarks to determine the corrections for non-parallel level-surfaces. The average value of the mean error per 1 km is ± 0,38 mm/km1/2.

1. 4 Gravimetric networks

The activities carried out with respect to the gravimetric networks are: the performed relative gravimetric measurements of points from the National GPS network, ETRS89 realization on the territory of the country (see above) and the reanalysis of the gravimetric data from the Bulgarian

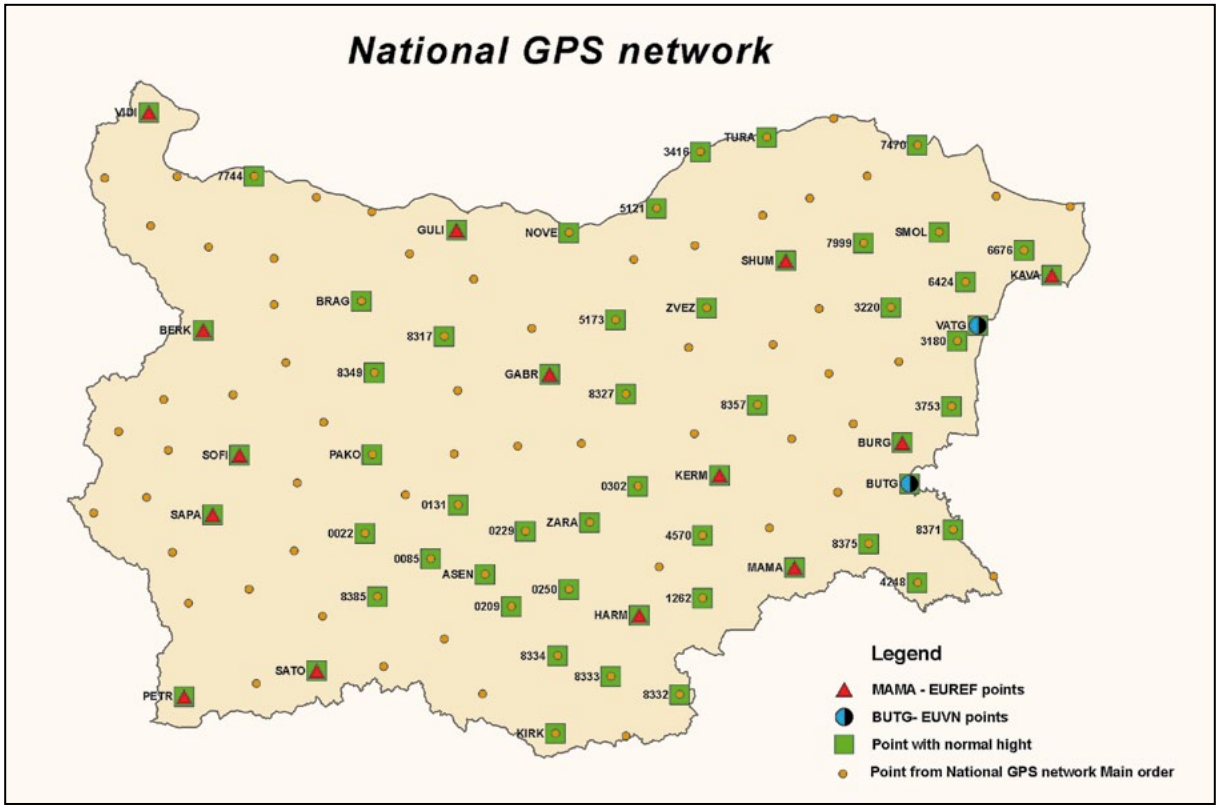

Fig. 9. Points from GPS network Main order with précis leveling.

Main (Etalon) gravimetric network (Fig. 10) and the Zero, First and Second order gravimetric networks – Fig. 11. The data are submitted and included into the newly developed European geoid model EGG08 (see below).

1. 5 Bulgarian Geodetic System 2005 (BGS2005)

The affiliation of the geodetic and leveling network of Bulgaria to ETRS89 and EVRS provided

the possibility of introducing the (new) Bulgarian Geodetic System 2005 based on the Decree of the Council of Ministers No 153 from 29.07.2010 and Act No 2 from 30.07.2010 for the definition, realization and maintenance of the Bulgarian Geodetic System 2005 (BGS 2005), in pursuance of Article 12, paragraph 2 of the Law for Geodesy and Cartography.
By definition BGS2005 includes:

- fundamental geodetic parameters according to the Geodetic Reference System 1980 (GRS80);
- the geodetic reference system ETRS89;
- the height system, realized by the leveling benchmarks of the State Leveling Network, included in the Unified European Leveling Network (UELN), and determined in the European

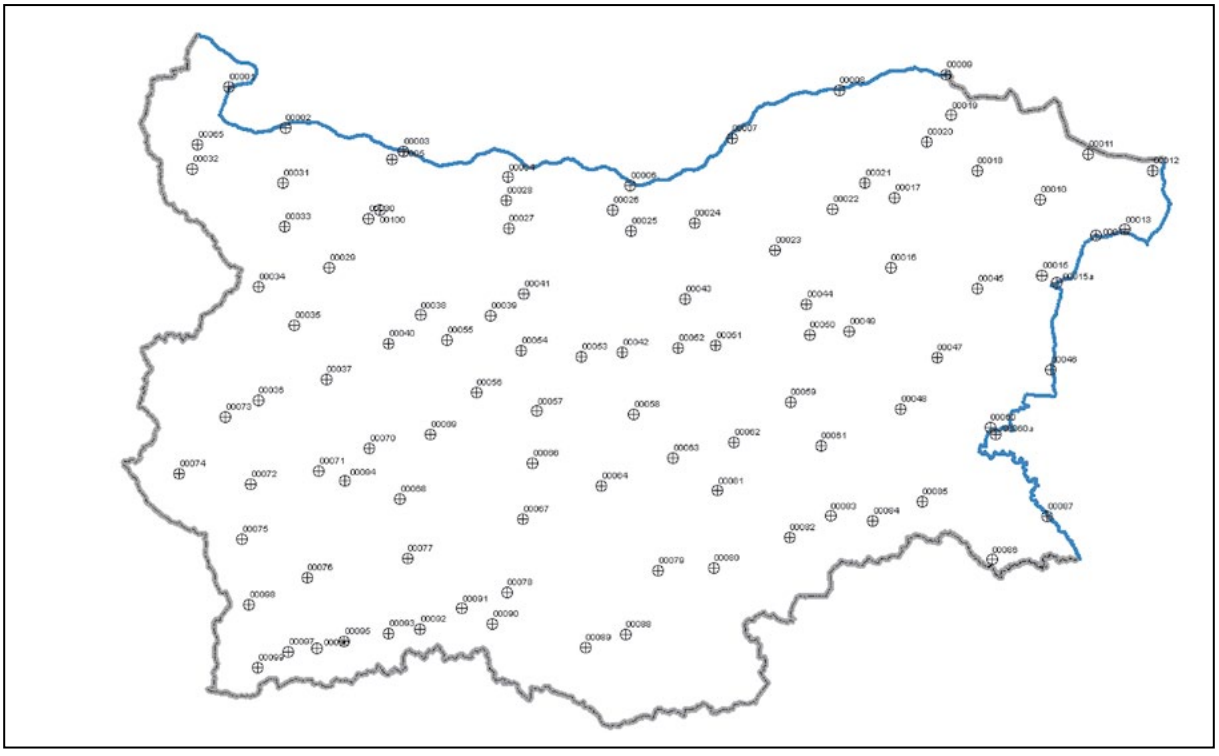

Fig. 10. Bulgarian Main (Etalon) gravimetric network

Vertical Reference System (EVRS) by means of gravity force data in the unified gravimetric system (IGSN 1971);

- the geodetic projection – Universal transversal cylindrical projection of Mercator (Universal Transverse Mercator – UTM), and the orthogonal plane coordinate system introduced by means of it;

The introduced BGS 2005 provides the possibility of implementing the GNSS technology and realizing a unified geodetic base, which ensures standardized and compatible geospatial materials and data. The transformation of the materials and data when introducing the new geodetic system represents a basic problem, since five coordinate systems exist in the country till the present moment – from 1930, 1942, 1942/83, 1950 and 1970.

1.6 Tide Gauge Network

Historically, the State leveling is related with four mareographic stations, situated along the Black Sea coast, the result of their activity being the records of the Black Sea level and its fluctuations in the course of more than 70 years. The Geodesy, Cartography and Cadastre Agency, together

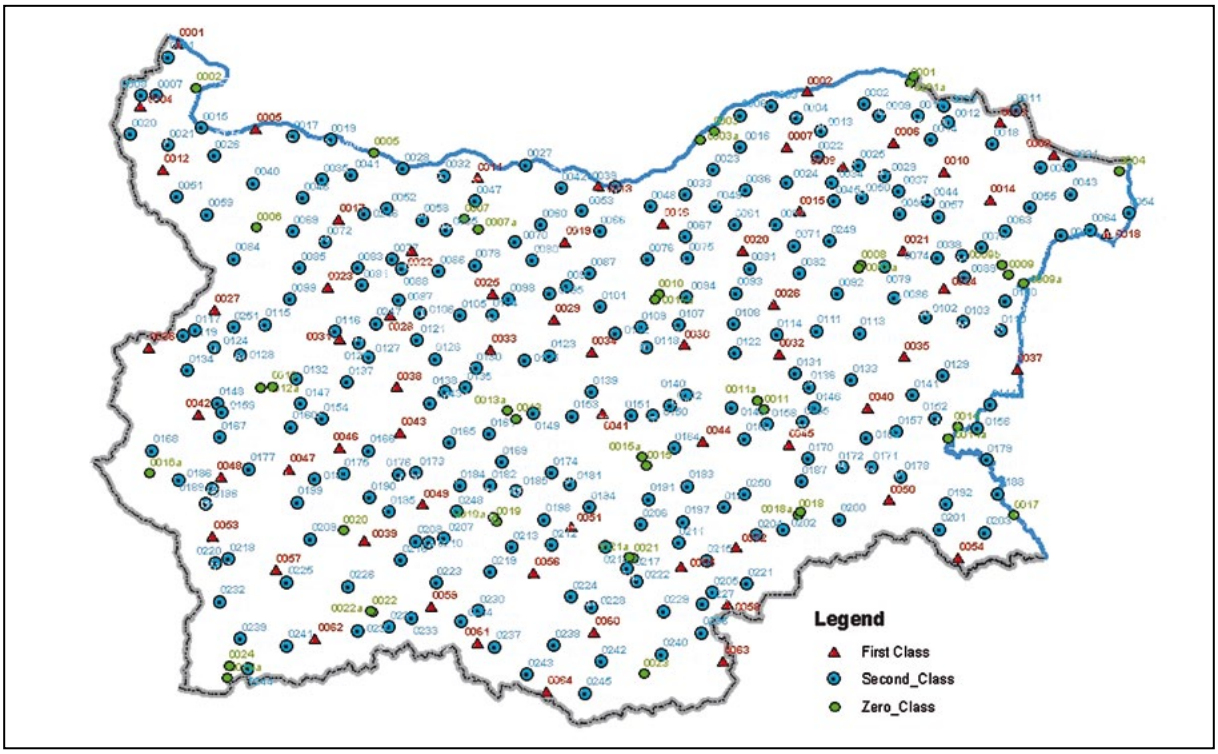

Fig. 11. Zero, First and Second order gravimetric networks

with the Department of Geodesy, operates four tide gauge stations: two in the towns of Burgas and Varna – functioning since 1928 and situated in the immediate proximity of the UELN points and two – in the town of Ahtopol and the Irakli locality (between the village of Obzor and the Emine cape) – in operational since 1971.

2. Determination of the Gravity Field

2.1 Contribution to the EGG08 development

Gravimetric data for Bulgaria in EGG08

The gravimetric data included in the territory of the country are from the State gravimetric networks of the Zero, First and Second order, from the Reference gravimetric measurements and from the last gravimetric measurements within the EUVN-DA project. All data are digitalized, analyzed and verified in cooperation with the computing center on the European Gravity and Geoid Project (EGGP) of IAG in Hanover. About 10 % of all gravimetric data are evaluated and excluded as low-quality. All other points are submitted and included in the EGG08 development. An estimation of the model accuracy for the territory of Bulgaria is made by its comparison with GPS/leveling data – about 350 regularly distributed points. The comparison proves that the differences do not exceed 10 cm for the greater part of the country. The zones, where higher differences are observed, are situated in the Southwest and Central part of Bulgaria (the mountainous regions) – of the order of 20-30 cm.

3. Geodynamic applications

3.1 Position of Bulgaria in the regional geodynamic settings

One of the important application of the Main order of the National GPS network, underlain during its design, is the possibility to use the results for solving scientific and applied tasks –

geokinematics and geodynamics, assessment of the recent geodynamic processes and seismic hazards. This is of special significance due to the fact that on the territory of Bulgaria the residual velocities, i.e. the velocities with respect to the stable part of the Eurasian plate are different from zero.

The area of the East Mediterranean is complicated tectonically and seismotectonically active region with significant, reaching up to 35 mm/y, horizontal movements (Fig. 12). The region of South Bulgaria, and especially Southwest Bulgaria and the Rhodopes, is the most active tectonic and seismotectonic area of the country with proved recent active tectonic structures and crustal movements. The strongest earthquake, with magnitude 7.8, in continental Europe in the last two centuries is occurred here, in the Krupnik-Kresna region;

Tectonic settings in the East Mediterranean The tectonic settings in the East Mediterranean are dominated by the collision of the Arabian and African plate with Eurasia. The models of plate movements show that the Arabian plate moves in north-northwest direction with respect to Eurasia with a velocity of about 18–25 mm/y. These models also show that the African plate moves in north direction with respect to Eurasia with a velocity of about 10 mm/y. The leading edge of the African plate is subducted along the Hellenic Arc under the Eurasian plate with higher rate than the relative movement in north direction of the African plate itself due to the slight effect of plate rotation. The known data support the regional extension with dominating north-south direction and all authors agree about the extensional regime in the north-northwest from the North Anatolian Fault (NAF).

Southwest Bulgaria – the most active tectonic and seismotectonic region in the country

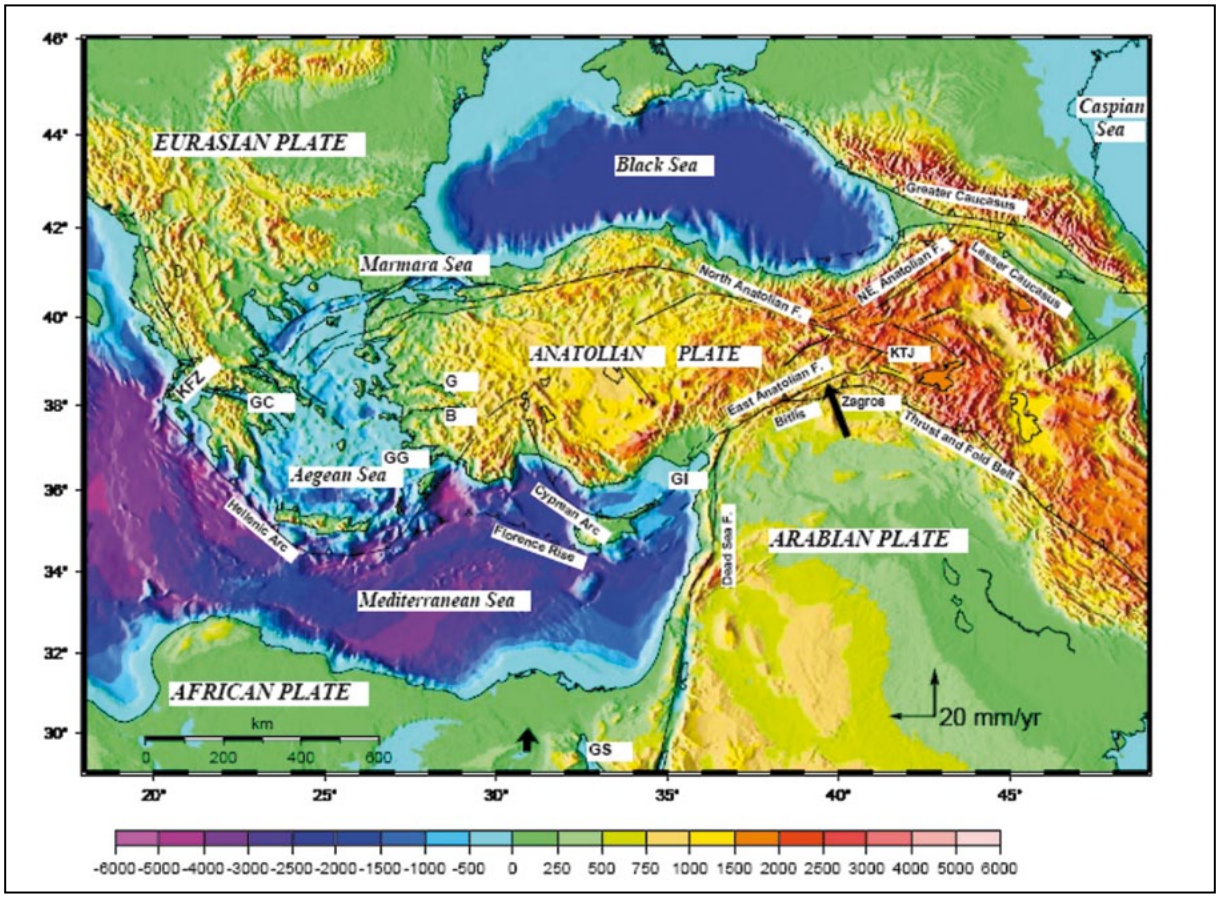

Fig. 12. Simplified tectonic map of the region of the East Mediterranean with displayed continental and micro- plates and main faults

The tectonic processes in South Bulgaria during the Neogene and the Quaternary are result from the destruction of the Late Alpine orogen, the extensional regime in the west and north parts of the Hellenic Arc and the complex interaction of the intensive vertical and horizontal movements in the region.

Southwest Bulgaria is the most active tectonic area of the country characterized also by high seismicity. The territory belongs to the southern part of the Central-Balkan neotectonic region – a zone with recent extension of the crust and with complex interaction between the horizontal and vertical movements of the tectonic structures. The geological and geophysical data confirm the recent activity of the fault structures formed during the Late Neogene and the Quaternary. The area is located in the northern part of the North Aegean region and is strongly affected by its tectonics and high seismicity (Fig. 13).

The recent seismicity recorded by the National Operation Telemetric System for Seismic Information (NOTSSI) of the NIGGG at BAS shows concentration of the events in the Krupnik-Kresna area and the Mesta River valley.

The recent crustal movements in SW Bulgaria are result from the continuous extensional movement in the internal part of the Aegean region. The complex effect of the southwestern movements of the Anatolian and North-Aegean plate along the North-Anatolian fault zone (NAFZ), in the Aegean Sea provoke the formation of the extensional zone to the north of the North-Aegean Trough (NAT). The region of SW Bulgaria is of key importance for the regional neotectonics and recent tectonics because it is located in the intersection points between several fault lineaments of high significance: the Struma (Kraishtide) lineament with NNW-SSE direction, the Maritsa lineament with WSW-E direction, and the northern-most fault branches of the North Anatolian fault zone NAFZ.

Geodynamic networks in Bulgaria

Scientific research GPS network in Southwest Bulgaria and the Rhodopes

A detailed geodetic study of the recent geodynamic processes in the region of Southwest Bulgaria and the Rhodopes has been initiated by Department of Geodesy and Geodetic Faculty of UACEG in the early 2000. Geodynamic GPS network in Southwest Bulgaria and the Rhodopes for long-term monitoring of recent crustal movements has been established. The network consists of 52 points, selected to cover the main tectonic structures (see Fig. 13 below). The choice of each point was made after geological and terrain investigation. The first GPS campaign for observing the geodynamic network was realized in 2001 – SWB 2001. Except this national scale geodynamic network another two local geidynamic networks are regularly measured – both in the regions of the strong earthquakes in 1904 in Krupnik and in 1928 in Chirpan-Plovdiv

A considerable number of GPS campaigns in the period 1993-2009 have been either performed by or submitted to Department of Geodesy. These are all the measurements of points from the Main and Secondary orders of the National GPS network, measurements of the geodynamic network in SW Bulgaria and the Rhodopes, the local geodynamic networks in the regions of Sofia, Krupnik-Kresna and Chirpan-Plovdiv: totally 33 GPS campaigns are processed and analyzed.

On the basis of the processing and analysis of 33 GPS campaigns during the period 1993 – 2007 the horizontal velocities of 89 GPS points have been obtained. They represent the velocity field in the country at the moment.

The recently active faults and fault structures are localized by the analysis of the horizontal velocities in the region of SW Bulgaria and the Rhodopes, vertical crustal movements, geological, tectonic and seismic data. The territory of SW Bulgaria is divided in five blocks with homogeneous recent movements and average velocity in south-southwest direction of 1.3 ± 0.3 mm/y with respect to stable Eurasia. This movement is in good agreement with the regional

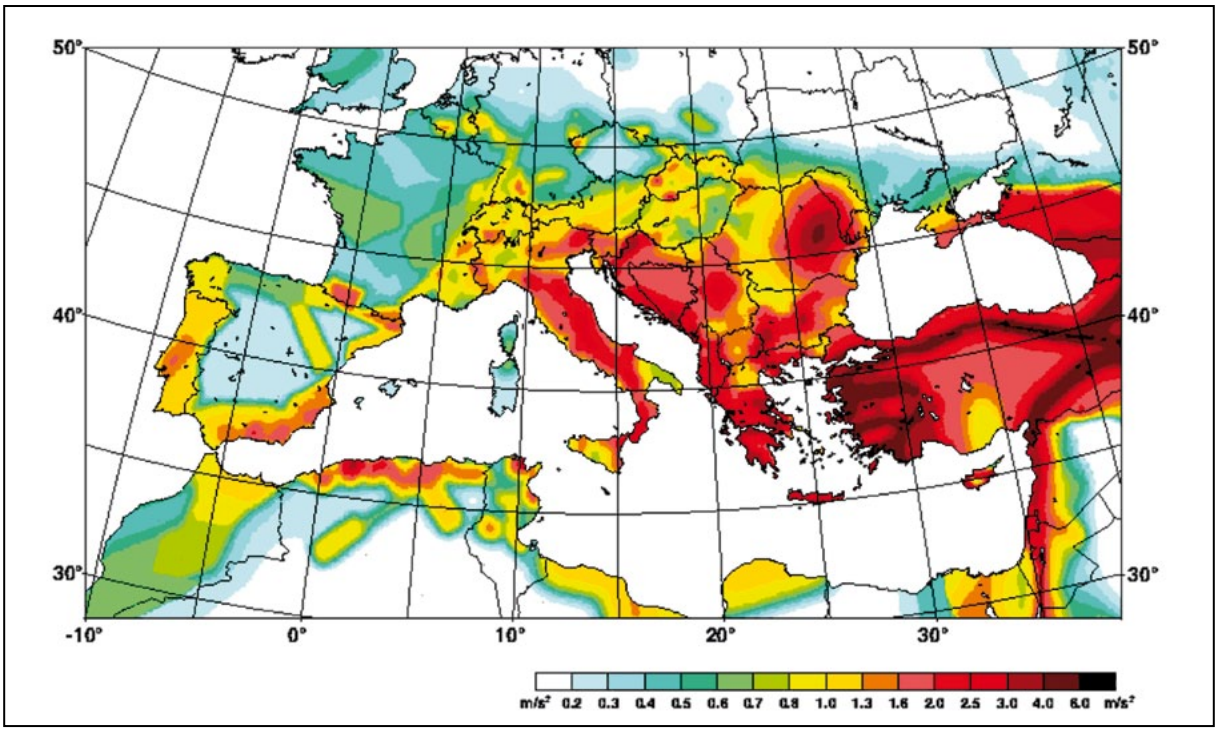

Fig. 13. Map of the seismic hazard according to the Global Seismic Hazard Assessment Program, a part of the International Lithosphere Program. The seismic hazard is expressed as peak ground acceleration with a 10% probability for expected event within 50 years

kinematics in the East Mediterranean.

The horizontal velocities of totally 89 points on the territory of Bulgaria are estimated. The velocities of the points in SW Bulgaria show movement in southern direction with respect to stable Eurasia. This movement is in good agreement with the right strike-slip movement along the western parts of the North Anatolian fault and the North Aegean extensional province. Having in mind that the movement of the Aegean plate is times more than the recent movements in Southwest Bulgaria it is obvious that the counter-clockwise rotation of the Anatolian plate and the movement of the Aegean plate to the south are accompanied by its detachment from stable Eurasia. The increasing horizontal movements from north to south explain also the north-south extensional regime in the North Aegean area (see below Fig. 15).

The established GPS geodynamic network in the region of Southwest Bulgaria and the Rhodopes for monitoring the recent crustal movements is important for the assessment of the recent geodynamic processes in this most active tectonic and seismotectonic region in Bulgaria, for assessment of the seismic hazard and for the seismic zoning.

Velocity field in Bulgaria and the Balkan Peninsula

A comprehensive GPS study of recent tectonics of Bulgaria, Albania and Northern Greece has been done in cooperation with French, Albanian, Republic of Macedonian and Greek colleagues in the frame of joint Bulgarian-French project.

A huge amount of GPS data collected between 1996 and 2009 is used. Except data from Bulgaria (National GPS Network and geodynamic networks) GPS data from Albania, Republic of Macedonia and Northern Greece are included – about 100 points.

The reoccupation networks included data from GPS campaigns on the territory of Albania, Northern Greece and Republic of Macedonia are:

Albania: dense GPS network has been installed to better localize areas undergoing current

deformation. Benchmarks allow direct centering of antennas to avoid centerings errors and bad determinations of antenna heights. Measurements of 34 GPS stations were analyzed in 4 campaigns in 2003, 2006, 2008, and 2009. The observation sessions are between 36 and 72 hours. The sampling rate of the observation is 30 s, with an elevation cut-off angle of 10 degrees.
Northern Greece: GPS data from 21 points are used to determine crustal displacements collected in 1999, 2000 and 2008. In 1999 and 2000 only short sessions (3-10 hours) were performed whereas in 2008, points measurements were between 48 and 72 hours.
Republic of Macedonia: measurements of 5 points are analyzed from three campaigns in 1996, 2000 and 2008. The data for 1996 are courtesy given by the Republic of Macedonian Agency of Cadastre. For that campaign measurement sessions for each GPS station were 72 hours. In the 2000 campaign the observation sessions were 24 hours. The observation session for each GPS station was 24 hours. The 2008 campaign was made in collaboration with Department of Geodesy, BAS and Faculty of Civil Engineering, Chair for Geodesy, University "St. St. Cyril and Methodius", Skopje, Republic of Macedonia, with observation session duration of 8 hours.
The velocity field in Bulgaria, Northern Greece and Albania is presented in Fig. 14. The figure shows also results of other author for the rest of the region.

Crustal deformation in the East Mediterranean by InSAR

Along with the University Pierre and Marie Curie – Paris VI, France, a comprehensive study on the crustal deformation in East Mediterranean was done using InSAR technology and seismotectonic data.
The principal objectives are to determine by radar interferometry the fields of deformations of the Earth's crust caused by several specific shallow seismic events which occurred in the East Mediterranean, to suggest dislocation models using the Okada formalism and to delineate some tectonic structures in the investigated region. Where additional data like GPS or others are available, comparisons and complex analyses are introduced.
Two of the studied events, namely the Konitsa sequence of shocks from July-August 1996 and Valandovo earthquake from May 2009 have small magnitudes between 5.0 and 5.3 and their detection by InSAR is a serious challenge. In the case of the Konitsa earthquake (in the border area between Greece and Albania) the crustal deformations are very clear on the processed interferogram and are revealed as two fringes, corresponding to at least 5.6 cm displacement (Fig. 16). In comparison, the Valandovo event (northward of the Dojran Lake) has similar magnitude and parameters to the previous one, but could not be detected by radar interferometry mainly because of the deeper location of the fault and probably due to the different geological structure of the area. No earthquake signal can be found also in the time series of the Valandovo permanent GNSS site.
On the other hand, the other examined shock, the Lefkada Island earthquake from 2003 occurred with bigger magnitude of 6.3. Regardless of the bigger size of this event, it has other specificities for which it rouse interest. The particular situation related with the Lefkada event is that the shock stroked in the sea, near the coast of the island, and the difficulty is to produce and interpret an interferogram for a small island surrounded by big areas with very low backscatter capabilities. The interferograms obtained are influenced by the specific conditions and contain vast decorrelated areas. Nevertheless, a surface deformation of about 5.6 cm has been detected (Fig. 17).
The new knowledge obtained for the fault structures in the region of Lefkada confirms the hypothesis for the existence of a separated tectonic structure – the Central Ionian Islands block, comprising the Northwest Peloponnesus, the area of Akarnania on the mainland part of Greece and the Central Ionian Islands.

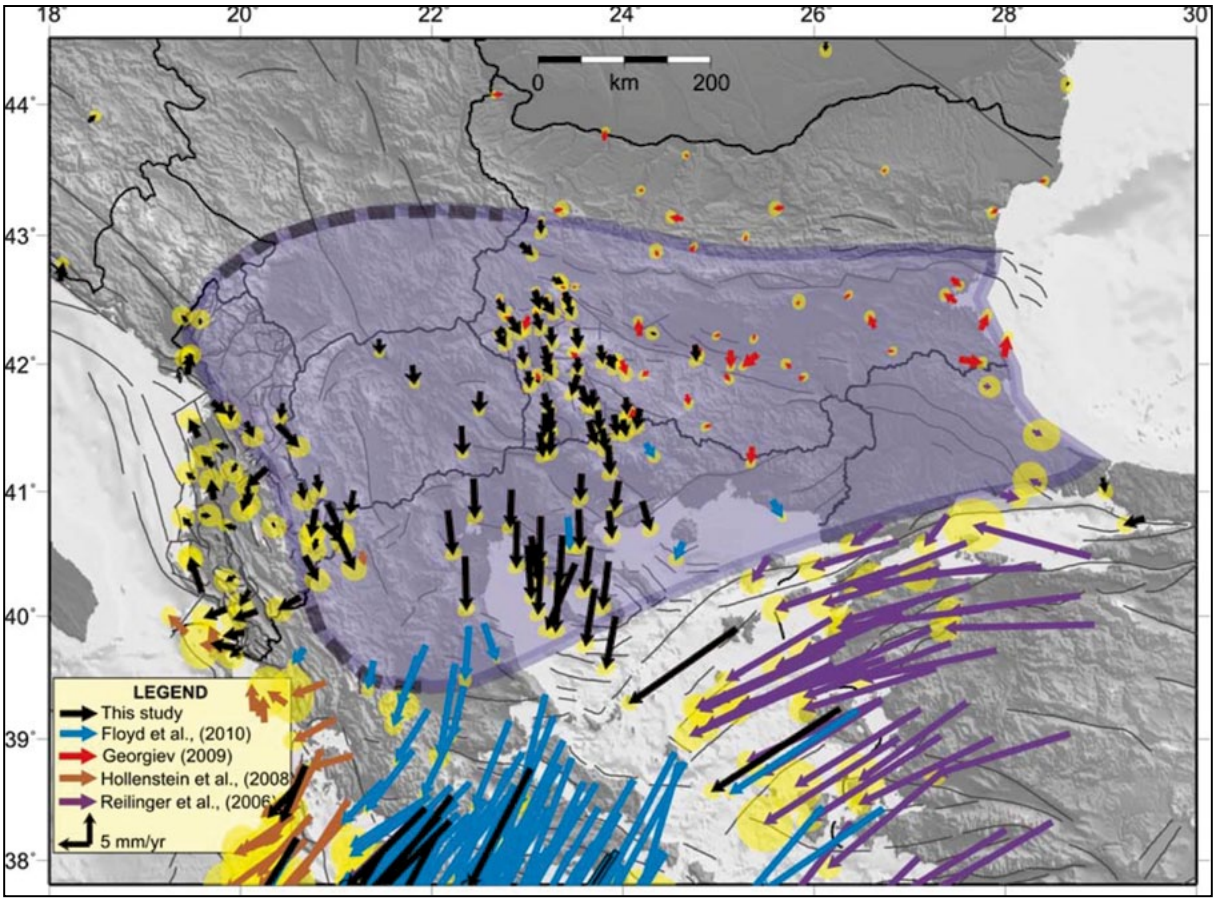

Fig. 14. Velocities in Bulgaria, Northern Greece and Albania obtained in the Department of Geodesy and other authors along with modified west boundary of South Balkan extension region. Velocities are expressed in Eurasia fixed reference frame.

4. Position and applications

Recently introduced instructions

Important instructions have recently been adopted for datum transformations and GNSS positioning for survey purposes. These documents are addressed at providing local survey and mapping works with standardized procedures for a smooth transition to the new BGS2005 datum introduced last year, for both existing and newly collected data and products.

The first document, Instructions for transformation of existing survey and mapping data into BGS2005, deals with the basic definitions related to BGS2005 and the legacy datum widely used through the years which still provide geodetic reference of most digital and paper products. Emphasized are the transformation procedures which are presented in details, down to simple computation steps, in the numerous appendices to the specification. Parts of them are published for the first time.

Since BGC2005 is an ITRS based reference system, important part of the Instructions are the IERS and EUREF adopted procedures providing the models and digital data necessary for transformations between the specific frames and observation epochs. For the sake of completeness, various numerical procedures relevant to datum transformations and conversions are also given.

The second document, Instructions for GNSS positioning, treats a wide range of practical surveying and mapping problems where GPS, GLONASS and other future systems are implemented. Being

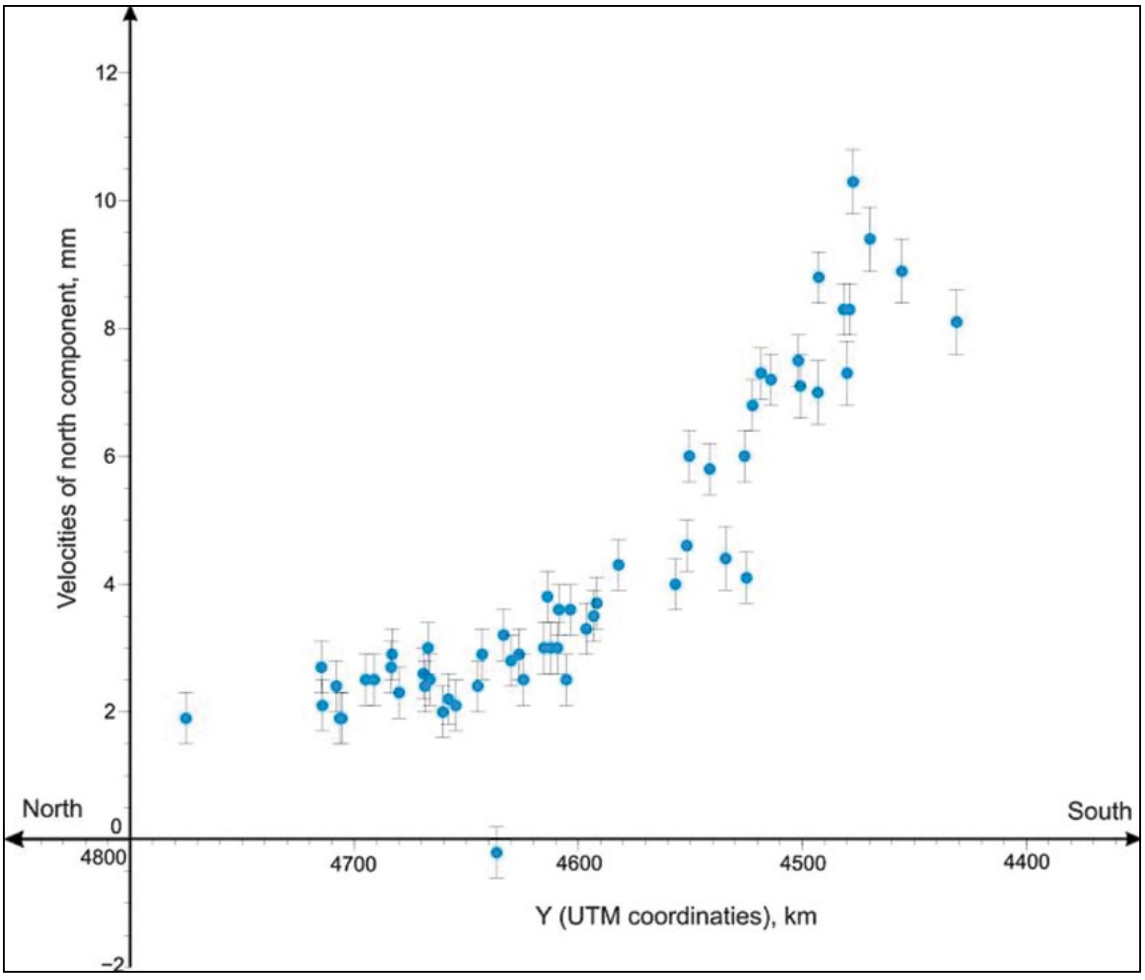

Fig. 15. Velocity gradient from central Bulgaria (Balkan Mountain) to Northern Greece (Halkidiki)

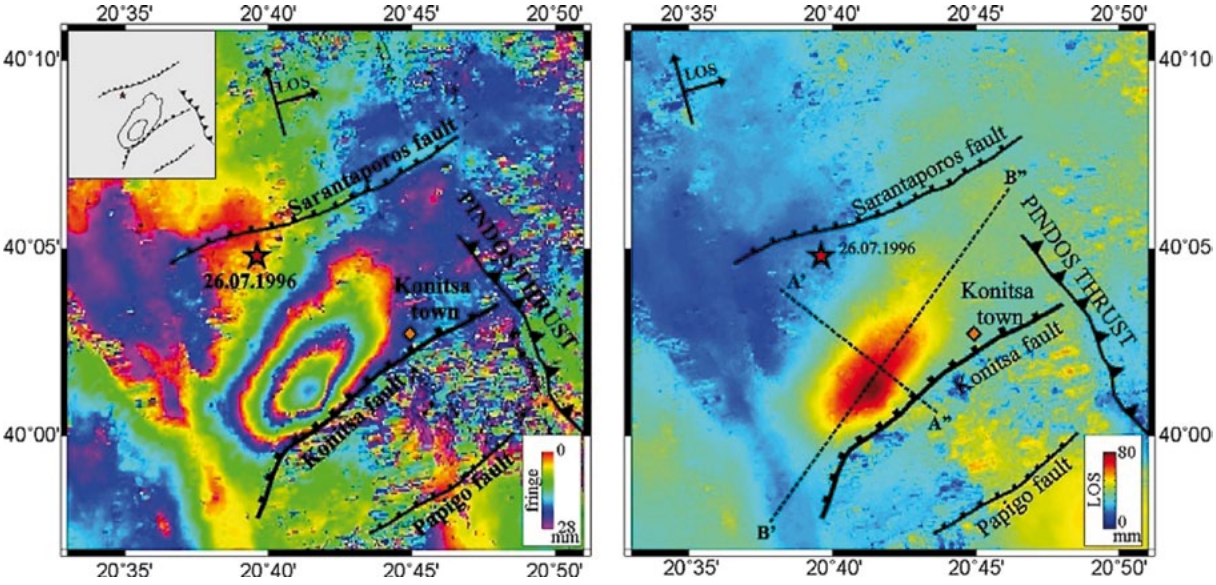

Fig. 16. Left: Ascending differential co-seismic interferogram – ifg8 (Bp 95m). The star shows the main shock from 26.07.1996; orange diamond – Town of Konitsa; the arrows – direction of ascending flight and side of looking of the satellite. Inset: the observed fringes used for the inverse modelling. Right: The same interferogram but unwrapped.

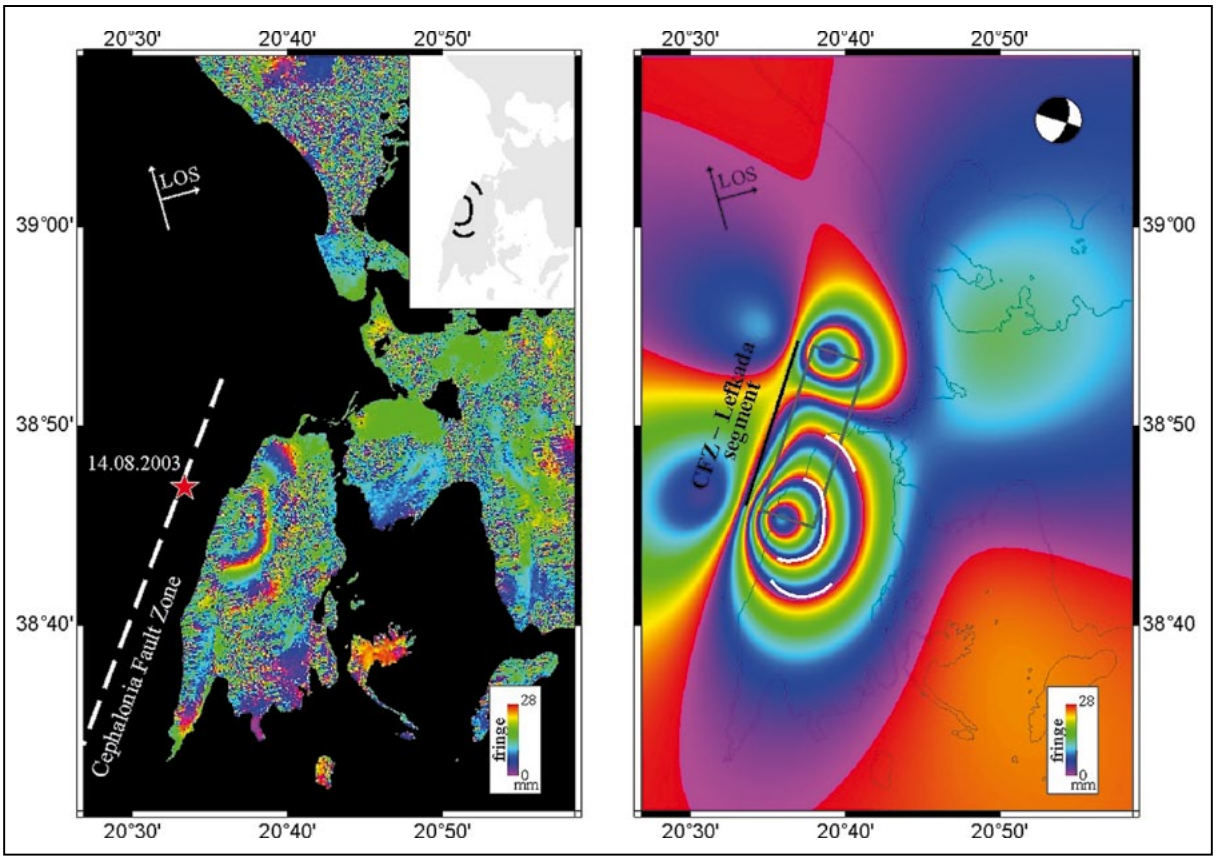

Fig. 17. SAR interferometry results for the Lefkada earthquake. (Left) Differential ascending interferogram – ifg5 (BL 88m). The star shows the main shock according to NOA; the arrows – direction of ascending flight and side of looking of the satellite. Inset: The observed fringes. (Right) Synthetic ascending interferogram obtained from inversion of the received observed fringes (left). The rectangle represents the approximate model of the fault segment.

the second Instructions of similar type, after the original one published in 1995, it is focused on the most actual aspects relevant to positioning of control points, detailed surveys and staking-out using the existing GNSS infrastructure, and referenced to the BGS2005 datum. Covered are first of all the precise relative carrier phase positioning technologies, both static and kinematic, post-processed and in real time. Regulations on simplified decimeter accuracy applications and differential sub-meter methods are also included.

For the first time, requirements for GNSS infrastructure operators are also articulated, along with certification rules aimed at their public identification and recognition. This is an initial attempt to establish control over the service quality available to users and the responsibilities of the service providers.

The public demand on both documents was realized long time ago, but they could emerge only after BGS2005, which provides the necessary technological and legal background, has been introduced.

Another instructions deal with "Ordinance for the planning, implementation, monitoring and acceptance of aerial imaging and the results of remote sensing methods for scanning and interpretation the earth surface" is also prepared. The Instructions specifies the planning, implementation, control and approving aerial imaging for civilian purposes and results of various remote sensing methods for scanning and interpreting surface.

5. International cooperation

In the recent years fruitful cooperation between geodetic institutions in Bulgaria and European and worldwide geodetic community is going on – EuroGeographics, IAG EUREF sub-commission, Royal Observatory of Belgium; Ecole Normale Superieure and CNRS, France, Astronomical Institute of the Czech Academy of Sciences; Center for Space Research of the Polish Academy of Sciences; Massachusetts Institute of Technology, USA.
Below are listed some of the international projects of the Department of Geodesy along with finance institutions:
Central European Geodynamic Project (CERGOP2), European commission, Directorate I "Protection of the ecosystem – protection of the environment";
Balkan Geodetic observing system (BALGEOS), Austrian Federal Ministry of Science and Investigations (BMWF), represented by the Center for social Innovations, Vienna, Austria;
Research on the seismotectonic manifestations of the earthquakes on 14 and 18 April 1928 in South Bulgaria, Royal Observatory of Belgium;
Investigation of the mechanisms of the Earth's crust deformations, Ministry of education and science, France;
Monitoring of the Earth's crust deformations in West Central Bulgaria and North Greece by means of the Global Positioning system GPS – HemusNET, NATO, Science for Peace program;
Investigation of the surface deformation mechanisms of the lithosphere, Bulgarian Science Foundation at the Ministry of education, youth and science and the Ministry of education and science, France;
An international school and work meeting for the state-of-art GNSS software GAMIT/GLOBK, developed in the Massachusetts Institute of Technology, was organized by the Department of Geodesy between November 30 and December 02 2007 in Sofia.

6. Contributors of the Report

Georgiev Ivan, Assoc. Prof. DSc., Department of Geodesy, NIGGG BAS, ivan@bas.bg;
Lazarov Aleksander, Dipl. Eng., Geodesy, Cartography and Cadastre Agency, Executive Director;
Koritarova Violeta, Dipl. Eng., Geodesy, Cartography and Cadastre Agency, Directorate "Geodesy and Cartography", Chief;
Bochev Toma, Dipl. Eng., Geodesy, Cartography and Cadastre Agency, Directorate "Geodesy and Cartography", State expert;
Gladkov Georgi, Dipl. Eng., Coll., Military Geographic Service, Chief;
Danchev Peter, Dipl. Eng., Coll., Military Geographic Service, Deputy Chief;
Belyashki Tassi, Assoc. Prof. Dr., Department of Geodesy, NIGGG BAS;
Dimitrov Dimitar, Assoc. Prof. DSc., Department of Geodesy, NIGGG BAS;
Minchev Momchil, Assoc. Prof. Dr., University of Mining and Geology, Geological Faculty;
Gospodinov Slaveiko, Assoc. Prof. Dr., University of Architecture, Civil Engineering and Geodesy, Dean of the Geodetic Faculty;
Elena Peneva, Assoc. Prof. Dr., University of Architecture, Civil Engineering and Geodesy, Geodetic Faculty;
Gabenski Plamen, Dipl. Eng., NAVITEQ GNSS network project manager;
Nikolov Marian, Dipl. Eng., Geomathics Ltd.

7. Selected publications

A few journals are related to geodesy and geodetic practice in Bulgaria: "Geodesy", the Department of Geodesy issue (in English); "Geodesy, Cartography and Land Surveying", issue of the Union of the Geodesists and Land Surveyors and "Geomedia", the Geomedia Ltd. issue.

Selected references for the period 2007 2010 are listed below:

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