GNSS and Gravity Projects in Europe and Bulgarian Participation

Georgi MILEV and Keranka VASSILEVA, Bulgaria

Key words: GNSS, EUREF, EUVN, CERGOP-1/2, UNIGRACE, EUPOS.

SUMMARY

Several projects are being developed on the territory of Europe that are related mainly to the reference systems and geodynamics. The EUREF, EUVN, CERGOP-1/2, UNIGRACE and EUPOS projects are especially important for Bulgaria and it participates actively in their realization. The main aspects of the Bulgarian participation in these projects, the solved problems, specific features, results and their future development are briefly considered.

ZUSAMMENFASSUNG

Es wurden verschiedene Projekte in Europa entwickelt, die hauptsächlich mit den Referenzsystemen und der Geodynamik im Zusammenhang stehen. Bulgarien nimmt aktiv an der Realisierung der Projekte EUREF, EUVN, CERGOP-1/2, UNIGRACE und EUPOS teil, welche für das Land besonders bedeutsam sind. Dargestellt werden die wesentlichen Aspekte der Projekte und der bulgarischen Teilnahme an diesen Projekten, die gelösten Probleme, spezielle Merkmale, Ergebnisse und die weitere Entwicklung.

RESUME

Pour la territoire européen sont élaborés divers projet, généralement lie aux system de références et la géodynamique. De l'importants particulier, concernant la Bulgarie sont le projets suivent - EUREF, EUVN, CERGOP-1/2, UNIGRACE et EUPOS et le pays prend un part active dans leur réalisation. On a donné ici les aspect prencipeaux des Projets, de la participation bulgare, des problèmes résolves les résultats obtenues et leur a développement proche.

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1. GENERAL

An active collaboration on a regional base has been also developed along with the specialized global international geodetic collaboration within the framework of international geodetic and other organizations and institutions, often on the interdisciplinary base. In this respect, the collaboration within the Europe is of specific importance. European projects related to the reference systems are mostly a matter of interest. Individual projects for different regions of Europe, some of them with potential possibility to be enlarged for the entire continent are being developed, too. The establishment of a unified coordinate, height and gravity system and network, and geoid is the main tendency [2]. The interest is also focused on the regional geodynamic interdisciplinary investigations.
Short description of European projects developed at present and Bulgarian participation has been outlined. It is emphasized on the solved problems, some particularities and their further concrete development.

2. MAIN PROJECT CHARACTERISTICS AND THEIR REALIZATION ON THE TERRITORY OF BULGARIA

2.1 EUREF, EUVN, EVRS and EUPOS Projects

2.1.1 European Reference Frame - EUREF

The European Reference Frame – EUREF has been established on the base and within the framework of the International Terrestrial Reference System - ITRS with the goal to become a base for resolving different international objectives related to:
United coordinate origin and datums
Transformation from national to European (international) systems and other transformations
Navigation on land, sea, air
Digital cartography
Realization of geodynamical projects
Modern cadastre etc.

The International Terrestrial Reference System is a conventional system, which supports millimeter accuracy. Many realizations of this system obtained for different years are known as ITRF-88, ITRF-89 etc. (International Terrestrial Reference Frame 1988, 1989). Moreover a World Geodetic System WGS 84 (World Geodetic System 1984) is especially important. The accuracy of WGS 84 is about 1 m and it is the same degree of difference from the ITRS. IAG recommends ITRS or continental systems to be used for precise applications [14].
EUREF is fixed by determination of the ITRS parameters for selected epoch, in this instance 1989, i.e. ITRF-89, the year of the first GPS (Global Positioning System) campaign. It is realized by the coordinates of fidutial geodetic observatories on the continent determined

from Very Long Baseline Interferometry (VLBI), Lunar Laser Ranging (LLR), Satellite Laser Ranging (SLR) and GPS and framed the EUREF network. The Central and Eastern European countries as well as other parts of Europe depending on their readiness and possibilities have been gradually included in the established system and network by new GPS campaigns. The EUREF activities are based on the respective resolutions of general Assemblies of IAG or symposia of its body, e.g. of subcommission for EUREF and in a collaboration with CERCO (now Eurogeographics).
Bulgaria participates with 15 stations (Fig.1)

Figure 1

Two campaigns were carried out in 1992 and 1993. The results obtained from data processing were submitted and accepted at the EUREF symposium in Ankara, 1996 and Bulgaria was officially included in EUREF with 7 of the 15 stations [1].
Since May 1997 a permanent GPS station has been operated in Sofia as a part of the EUREF network of permanent stations (Fig. 2). It is already a part of the IGS (International GPS System) network of permanent stations. EUREF is a base for establishment of the national GPS network and it is the core of the introduction of the Bulgarian Geodetic System 2000 (BGS 2000).

Figure 2

2.1.2 European Vertical Network – EUVN

Bulgaria has taken a participation in the subproject EUVN of EUREF [3], [12]. A specially established network and a series of GPS measurement campaigns on the territory of Europe represent the base of the project with the main aim to be achieved the following scientific and practical results:
Establishment an unified vertical system in Europe in short terms;
Connection with the European tide gauges to monitor the absolute sea level variations;
Fixing of control points to determine the European geoid;
Preparation for establishment of a European Vertical geodynamic Network.
EUVN consists of 195 stations, as 79 are EUREF stations (37 are with known coordinates in ITRF-96), 53 are nodes of the national levelling networks and 63 are tide gauges. The stations are stabilized with special observation pillars. An international GPS campaign with 24 hours sessions were carried out from May 21 to May 29, 1997. Respective levelling and gravity measurements and connections with the tide gauges were carried out simultaneously or subsequently. Data processing was accomplished in 8 Processing Centers and subsequently combined processing was done in two Processing Centers. The coordinates of the stations were determined in ITRF-96, epoch 1997,4.

Bulgaria has been included in EUVN with three stations. Two of them BG01 and BG04 are specially constructed pillars located at the Black Sea coast near the tide gauges in Varna and

Burgas (Fig. 1). Station BG03 is a pillar on which the antenna of the GPS permanent station near Sofia is installed. Bulgarian specialists have also participated in data processing. The values of the gravity at the three stations were determined during the measurements on the project UNIGRACE – Unification of the Gravity Systems of the Countries from Central and Eastern Europe on the COPERNICUS Program of EC (see 2.3). Their normal heights have been determined as at the Black Sea pillars a levelling connection with the benchmarks of the tide gauges has been realized The month values of the mean sea level for the period 1997-2000 have been also determined. They have been submitted to the EUVN Processing Center in France. The tide gauge data from 1928 to 1996 are available in PSMSL in England [9].

2.1.3 European Vertical Reference System – EVRS

The realization of the European Vertical Reference System (EVRS) on the territory of Bulgaria is determined by the successful including of the national levelling data along with an additional information into the database of the Unificated European Levelling Network (UELN) [2]. A preparation of the 1st order levelling data has been done for this purpose. Differences between the geopotential numbers of the levelling benchmarks, geographic latitude and longitude, and normal heights of the benchmarks in Baltic system have been calculated. For realization of the connection with the neighboring levelling networks and mostly with Romania a special preparation is also going for connection with UELN [9].

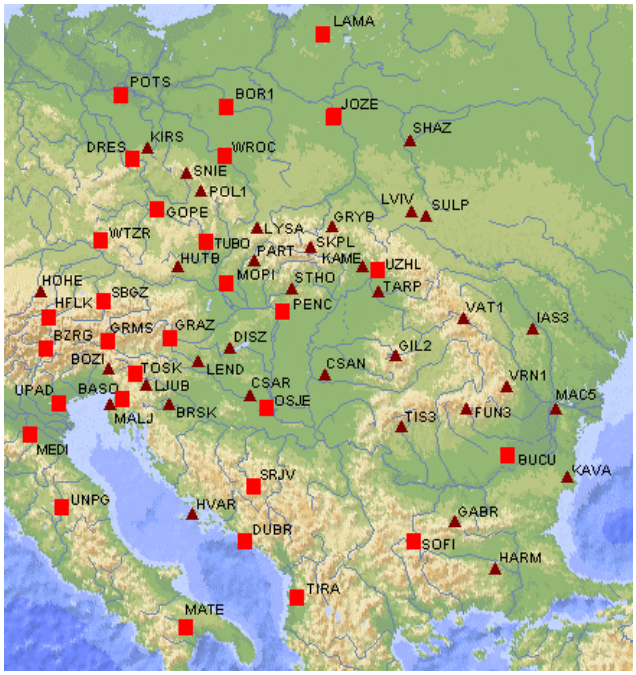
2.1.4 European Position Determination System – *EUPOS*®

A project *EUPOS*® was initiated with an active work on the Bulgarian part in 2002. It is a regional development of SAPOS® (Satellite Positioning Service) for Europe and it presents itself a European Satellite System and Service for Position Determination [13]. The project *EUPOS*® is an initiative for establishment of unified DGNSS basic infrastructure for Central and Eastern Europe. It is based on the already existing and operating DGNSS system of reference stations SAPOS® in Germany. The main goal of *EUPOS*® is a multifunctional regional application of DGNSS (15 Central and Eastern European countries involved). Networks of active reference stations will be established on the base of the common reference system ETRS89. They will provide position accuracy from 1-3 m up to 2 cm in real time and higher accuracy in post processing. The founded Steering Committee coordinates the project activities. A preliminary project of the Bulgarian network of permanent stations has been proposed. The final project of the *EUPOS*® reference stations in the 15th countries is in progress. *EUPOS*® was presented by Bulgarian delegates in the charge of the Steering Committee (during the Sofia meeting on November 5-6, 2002) at the International Meeting of Experts on the Use and Application of GNSS, organized by UN/USA in the UN Center in Vienna, Austria, November 11-15, 2002. Among the other projects proposed, the project *EUPOS*® was the most highly evaluated.

2.2 Central European Regional Geodynamics Project – CERGOP

Geodetic and Geodynamic programs of the Central European Initiative (CEI) and the Central European Regional Geodynamics Project – CERGOP 1&2 have been included within the

framework of the IAG Section V “Geodynamics”. The first phase of the CERGOP project started in 1993 and closed in 1998 [7].
The first objective of this proposal concerns the long term monitoring of the region of Central Europe by GPS methods which is realised by determining the time variations of coordinates and velocity vectors of more than 60 stations (Fig. 3) in a global reference system provided by IGS and EUREF (European Reference Frame) with an accuracy of better than 5 mm. For all permanently observing stations weekly solutions are computed and merged to coordinate time series, which presently have a length of up to 9 years. These continuously updated series are analysed for station specific influences, a spectral analysis of the cleared results gives information about secular and periodic coordinate changes and even velocity changes on the 1 mm/year level, the latter allowing for the estimation of possible energy transports and the derivation of force models.
Non-permanent stations are observed every 2 years for about one-week and aligned to the continuous time series results, giving a realisation of the CEGRN reference frame for the respective epoch. We expect to have eight monitoring campaigns realised in this project during the period 1994 to 2004, the derivation of geokinematic models will give insight view into the structure of this region and will be used as a basis for regional investigations of seismic active areas.



I. Fejes. April 2002

Permanent stations
Epoch stations

Figure 3

The first phase CERGOP-1 has already finished. During this period six monitoring GPS CEGRN campaigns were performed in 1994, 1995, 1996, 1997, 1999 and 2001. In the second phase – CERGOP-2 the following 14 countries participate: Albania, Austria, Bosnia&Herzegovina, Bulgaria, Croatia, the Czech Republic, Germany, Hungary, Italy,

Romania, Poland, Slovakia, Slovenia and Ukraine. Total number of stations of the CERGOP-2 is 63. About thirty CERGOP-2
points are permanent stations. Project CERGOP was an impulse for establishment of the CEGRN Consortium of institutes involved in realisation of the Project. The Consortium will also be a seedbed of new European projects and initiatives. A working group for Geotectonic analysis of the region of Central Europe has been founded in it. [4]. On the initiative of Bulgaria a special subgroup "Geodynamics of Balkan Peninsula" was established in 2000. On the EUREF base, including three stations of it, Bulgaria actively participates in this program and projects. Further GPS measurements are foreseen on the base of EUREF stations located in the central European region and the region of the Balkan Peninsula.

2.3. Project Unification of the Gravity Systems of Central and Eastern European Countries – UNIGRACE

By the unification of existing gravity systems in Central and Eastern European countries the differences between them are removed. In some cases these differences are considerable and have an effect on the definition of height systems and on the resolving of series of scientific and practical problems. To overcome these problems a network of absolute gravity stations has been established and each of them has been connected to the respective national network by precise relative gravity measurements.

Within the framework of the project INCO/COPERNICUS the efforts of scientific teams from the EC (Austria, Germany, Italy and France) and Central and Eastern European countries (Bulgaria, Poland, Romania, Slovak Republic, Slovenia, Hungary, Croatia and Czech Republic) have been integrated to be solved the following objectives [11]:
Establishment of a network of 17 absolute gravity stations collocated with the control geodetic stations situated in geologically stable regions and with tide gauges (Fig. 4);
Repeated measurements of the absolute gravity stations to assess the instrumental accuracy and geologic stability during the project realization – 01.01.1998 ÷ 31.12.2000;
Connection of the absolute gravity stations to the national gravity system and supplementation with a local gravity micro-networks for monitoring the terrain deformations and gravity changes caused by groundwater changes etc.

The absolute gravity measurements have been carried out with 5 ballistic gravimeters of different type provided by the EC and Poland participants. The achieved accuracy of the absolute gravity determinations is in order of 10^{-9}.
Three absolute gravity stations – Sofia, Plana (40 km south-east of the Sofia station) and Varna at the Black Sea coast near the Varna tide gauge, were established in 1998 on the project Unification of the Gravity Systems of Central and Eastern European Countries (UNIGRACE) jointly with the Federal Office of Metrology and Surveying (BEV), Austria (Fig. 1) [8]. An absolute gravimeter JILA 6 of BEV was used for the measurements in 1998.
A calibration line with two intermediate points has been established between the absolute stations Sofia and Plana (Fig. 1). Two more points have been included in the site of the national geodetic observatory.

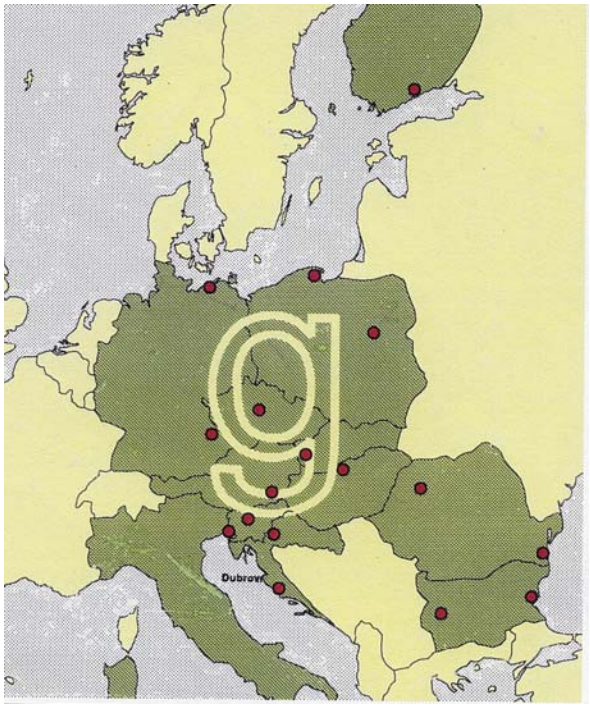


Figure 4

Relative measurements have been also carried out at the absolute station in Varna. The Black Sea tide gauges in Varna, Hirakli and Burgas as well as the GPS observation pillars near the gauges, which are stations of the EUVN levelling network of EUREF have been connected to this station. The measurements have been carried out with two relative gravimeters LCR-D51, owned by BEV and LCR-1095 – owned by the University of Architecture, Civil Engineering and Geodesy, Sofia.
The absolute stations in Sofia and Varna are also stations of the National Gravity Network.
A second set of measurements was carried out at the absolute stations Sofia and Plana using an absolute free-fall ZZG gravimeter. In the respective relative gravity nets additional measurements were done by LCR – G986 of the Geodetic and Astronomic Institute of the Warsaw Technology University, Poland, in 2001.
In order to study the influence of groundwater changes on the gravity values, hydrologic system has been established in the region around the Sofia station and the respective geodetic and hydrologic measurements, analyses and generalizations have been carried out.

3. RESULTS, SPECIFIC APPLICATIONS AND FURTHER DEVELOPMENT

A part of the results obtained within the scope of the international cooperation and projects has been used to solve the national problems of Bulgaria and its further integration in the European structures. The results are also a base for solving the common problems of Europe and especially this one related to the reference systems and regional geodynamics. Some specific applications included here are related to the introduction of EUREF in Bulgaria,

establishment of a national gravity system, geodynamic investigations of the territory of the country etc.

3.1 Introduction of EUREF in Bulgaria

The next steps in the development, regulation and introduction of EUREF in Bulgaria are related to the introduction of a new coordinate system for the territory of the country [9].

3.1.1 Standards

Introduction of EUREF in Bulgaria is regulated by an act of the Council of Ministers. In this respect a special government Decree, coordinated with ministries and country administrations (A Decree of Council of Ministers RB 140/4.06.2001 for defining of the Bulgarian Geodetic System 2000) has been issued. The Ministry of regional development and public works which belongs a civil national geodetic service – Department of geodesy and cartography to, has been delegated to implement this Decree [9].
The geodetic system of Bulgaria – called Bulgarian Geodetic System 2000 (BGS 2000) includes:

- Fundamental geodetic parameters determined in geodetic reference system 1980 (GRS80);
- Geodetic coordinate system ETRF-89 realized by the European geodetic network EUREF;
- Height system realized by the levelling benchmarks of national levelling which have been determined in the European Vertical Network (EUVN) as well as in the unified gravity system by gravity measurements;
- Systems of map coordinates based on ETRF-89 and conform conic projection (Lambert projection) with two standard parallels and one meridian used for all civil applications;
- International system for gridding and nomenclature of map sheets in scale up to 1:2 000 including.

A network of geodetic points realizes the Bulgarian Geodetic System. The cadastre map of Bulgaria is being created and maintained on the base of the Bulgarian Geodetic System .
The following activities have been accomplished in pursuance of the Decree:
The optimal parameters of Lambert conic projection have been determined.
The regulations for the introduction of BGS 2000 have been worked out. A provisional project of a National GPS Network has been designed on the base of these regulations.

3.1.2 National GPS Network

A provisional project of a National (State) GPS Network was designed in 2002 within the framework of the establishment of the Bulgarian cadastre with the support of the World Bank [9]. It is foreseen the network to be consisted of the 7th, respectively 15th EUREF stations on the territory of the country (BULREF). About 442 more GPS points are supplemented as 113 of them are points of the 1st order and 329 are of the 2nd order. The points will be located in

the best way so the sites to collocate GPS, national levelling and national levelling and gravity points. Requirements, reconnaissance, station monumentation, equipment and measurement of the network, data processing and analysis, transformation of point coordinates from the existing state network in point coordinates of the national GPS network have been present in the project.

3.1.3 DGPS Application

A project for an establishment of network of permanent reference stations in Bulgaria working on DGPS principles, analogue of the German national satellite system for position determination (SAPOS®) has been prepared. The concept, requirements and basic principles for establishment of such a system of stations have been specified. Different variants for the number of the network stations, their equipment and financing, qualification of the personal, stages of introduction of the system and concept for its multifunctionality have been outlined. The scope of application and the possibilities of this system have been specified. A pilot project for a multifunctional DGPS system for the Sofia region supported by the mayors of Sofia and Berlin has been developed. The DGPS works are based on the Bulgarian-German collaboration with colleagues from the Berlin Senate. In 2002 an *EUPOS*® project was proposed with the active work on Bulgarian part and the mentioned projects were transformed as parts of it.
A special monograph "European Reference System in Bulgaria" is prepared to be printed [6].

3.2. Results from the UNIGRACE Project

The obtained gravity values at the three absolute stations and the accuracy achieved from the final processing of two UNIGRACE measurements are shown in table 1.

Table 1: Results of final data processing

Station	Independent Measurements	g 10^{-8} [m.s^{-2}]	σ 10^{-8} [m.s^{-2}]
0BG Plana	10	980 074 440.0	3.0
		980 074 339.5	1.0
OBG Sofia	7	980 240 584.4	5.6
OBGVarna	5	980 470 768.3	6.0

These values are representative for the country and they will serve as a standard for Bulgaria. More detailed information and specific results for Bulgaria and the UNIGRACE project as a whole are presented in [8], [10]. The measurements and studies outlined are an absolutely necessary precondition for an establishment of a new high precision national gravity system corresponding to the European standards.

A project “National Gravity System” is being developed for solving the main problems of the national gravity system within the framework of the National Council “Scientific Investigations” (NC”SI”) of the Ministry of Education and Science (MES) of the Republic of Bulgaria. The next activities on the establishment of the National Gravity System are towards the unification of the reference gravity system and preparation, and realization of a new gravity network of the country.

3.3. Bulgarian contribution to CERGOP

It is related to the Bulgarian participation in GPS campaigns CEGRN’96’97’98’99’2001, their processing and analysis, and preparation of the Consortium CEGRN and the GERGOP project-2 within the 5th Framework Program of EC, to local investigations of the earthquake activity in selected seismic regions in the country including local interdisciplinary studies, preparation of monographs, papers and reports, carrying out conferences and symposia.
Bulgaria has been included in CERGOP a little bit later. It happened at the conference of the project in Warsaw in 1995. In accordance with the signed protocol, the territory of Bulgaria was associated with the project. With the assistance of BKG (former IfAG), Germany, Bulgaria participated with 4 (later only 2) stations in the GPS campaigns - CEGRN’96’97’98’99’2001. One of them is a permanent station. A Bulgarian specialist took part in the data processing of CEGRN’96 in 1997 in BKG- Leipzig. A participation in the other conferences of the project has been also realized Bulgaria participates in the project CERGOP-2 as a full member. Active interdisciplinary investigations within the framework of the project are carried out on the territory of the country which are presented at the relevant symposia [7].

On Bulgarian part, two collective monographs have been prepared and published in the international series Reports on Geodesy, Warsaw university of technology, Institute of geodesy and geodetic astronomy, 2000 with the general title "Geodynamic investigations on the territory of Bulgaria" [4], [5], namely:
No 3 (48), Investigations of the Chirpan-Plovdiv Region related to the 1928 Earthquake, 174;
No 4 (49), Investigations of the Krupnik-Kresna Region related to the 1904 Earthquake, 256.
These two publications do not only concern Bulgaria but the entire scientific program of CEI and especially of CERGOP, Working Group 5 ”Geotectonic Analysis of the Region of Central Europe”(CSG.5 - CERGOP Study Group 5.7). They are a part of the series of the Central European Initiative (CEI).

The monographs are devoted to the study of the geodynamics of Bulgaria and especially to the study of destructive earthquakes in Bulgaria – Kresna, 1904 (the strongest one in the last 250 years in Europe) and Chirpan, Plovdiv, 1928. The efforts of scientists working mainly on different fields of Earth sciences have been combined and presented in the monographs. They will help for better understanding and explanation of the earthquakes – the most dangerous and destructive phenomena occurred in the two most seismically active regions in Bulgaria. Their complex consideration by means of possibilities of the advanced science is being done along with a searching of methods and facilities for their understanding with a view to react in such situations. The monographs contribute to the study not only of geodynamics of the

Bulgarian territory but of the Balkans as their earthquake activity is the most striking phenomena.
The first activity of the group CWSG 5/7 "Geodynamics of Balkan Peninsula" within the CERGOP was the Special Symposium "Geodynamics of Balkan Peninsula" held during the 3rd Balkan Geophysical Congress, 24-28 June 2002, Sofia, Bulgaria. The works carried out within the framework of CEI and CERGOP have been presented in a special paper. The purpose, team, expected results and the working program on the project GERGOP-2 have been formulated

4. CONCLUSIONS

The presented projects and activities in Europe, Bulgarian participation and the obtained results are very important. On one hand it is important for the European unification and integration within the framework of the reference systems and regional geodynamics and on the other hand they contribute to the solution of the national problems of Bulgaria. The follow-up activities on these projects will promote the extension of development of the given directions and resolving of the problems.

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CONTACTS

Prof. Dr.-Ing. Georgi Milev
Präsident der Vereinigung der Vermessungsingenieure und Landmanager in Bulgarien;
Bulgarische Akademie der Wissenschaften
Zentrales Laboratorium für Höhere Geodäsie
Acad. G. Bonchev Str., Bl. 1
1113 Sofia
BULGARIA
E-Mail: milev@bas.bg

Dr.-Ing. Keranka Vassileva
Bulgarische Akademie der Wissenschaften
Zentrales Laboratorium für Höhere Geodäsie
Acad. G. Bonchev Str., Bl. 1
1113 Sofia
BULGARIA
E-Mail: ker@bas.bg, Kvassileva53@yahoo.com