

4.3.9. GEODETIC MEASUREMENTS AND INVESTIGATIONS ON THE TERRITORY OF BULGARIA WITHIN THE CERGOP PROJECT

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4.3.9.1. Introduction

The territory of Bulgaria is studied within the CERGOP project as a part of the Balkan Peninsula and as a specific geodynamic region by geodetic means from 1996 (Milev et al, 2002; Milev et al, 2003). EUREF and CERGOP stations were included in four GPS CEGRN campaigns - 1996, 1997, 2003 and 2005. In the second stage of the project – CERGOP-2 the country participates as a full contractor and it is responsible for the implementation of the Work Package 10.7 – Geodynamics of the Balkan Peninsula (Milev et al., 2004). GPS data from all campaigns were processed compared and analyzed and published. Two permanent GNSS stations have been established and operated on the territory of Bulgaria. The main results obtained – coordinates and velocities concerning the territory of Bulgaria are analyzed from geodynamic point of view and some conclusions and suggestions have been drawn. The activities accomplished with respect to the establishment of the National Gravity System presented in more detail in sections 4.3.10 and 4.3.11 are related to the implementation of CERGOP-2 project. Moreover an integration of CERGOP-2 activities with activities on other international projects on the territory of Bulgaria like EUREF, European Combined Geodetic Network (ECGN), Unified European Gravity Network 2002 (UEGN02) has been implemented.

4.3.9.2. Geodetic measurements

CEGRN 1996 and CEGRN 1997

First geodetic measurements on the project were carried out in 1996. Only two Bulgarian stations (SOFI, HARM) of the four planned stations (SOFI, HARM, GABR, KAVA) were involved in the CEGRN'96 and in the CEGRN'97 GPS campaigns (Fig. 4.3.9.1.). SOFI and HARM stations operated with Trimble 4000SSE receivers and 4000ST L1/L2 GEOD antennas in 1996. In 1997 HARM station operated with the same type of equipment as in 1996 and SOFI station became an EUREF permanent station and was equipped with Rogue SNR-8000 receiver and Dorne Margolin T antenna.

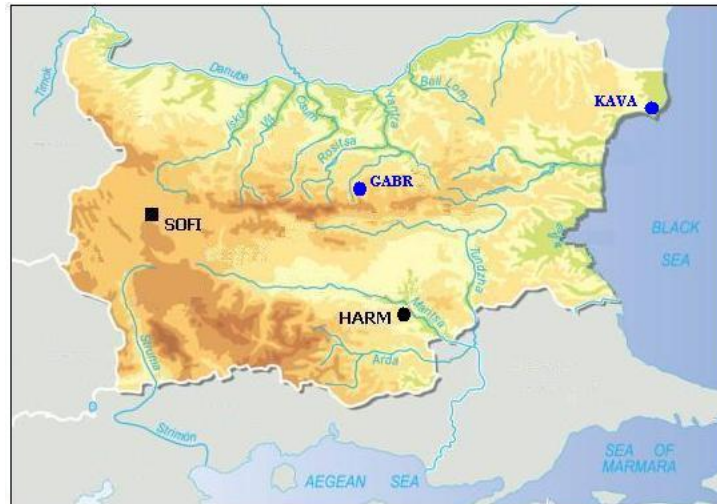


Fig. 4.3.9.1. Bulgarian CERGOP stations

CEGRN2003

In the second stage of the project during the CEGRN'03 GPS campaign Bulgaria participated with all 15 BULREF points as three of them were the CERGOP epoch stations - GABR, HARM, KAVA and one IGS/EPN permanent station - SOFI (Fig. 4.3.9.2.), (Milev et al., 2004).

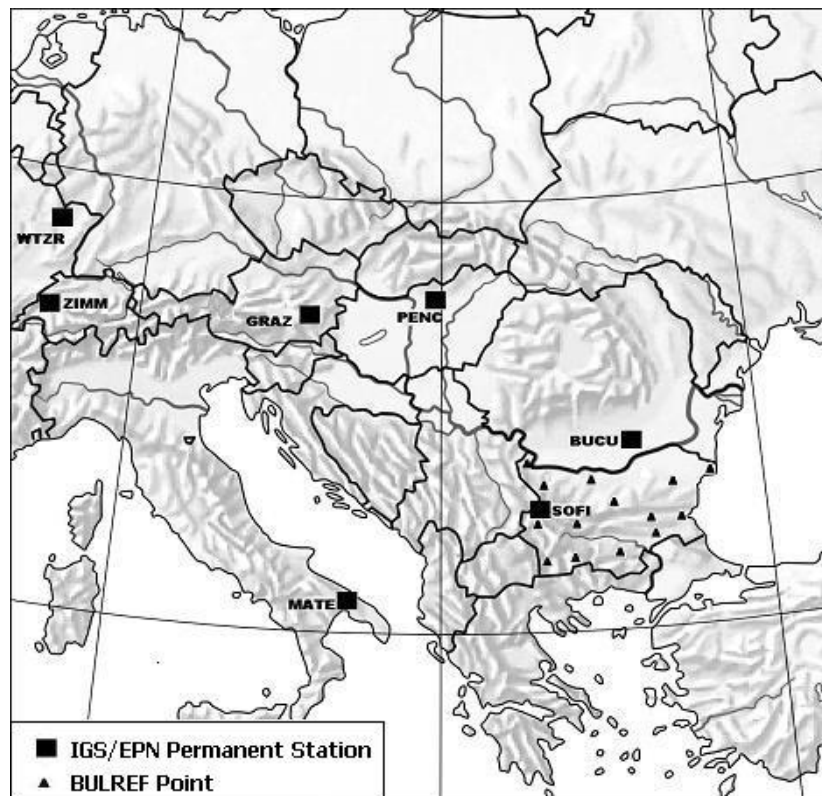


Fig. 4.3.9.2. Bulgarian stations participated in CEGRN03 campaign

The BULREF points were observed earlier in 1993 during the EUREF – BULREF GPS campaign and as a part of the WEGENER-MEDLAS geodynamic project. The CEGRN2003 GPS campaign was carried out according to the general requirements

of the CERGOP Data Centre. It started on 16.06.2003 at 12:00 (UT) and closed on 21.06.2003 at 12:00 (UT). Different types of receivers and antennas were used: Trimble 4000 SSI with compact L1/L2 G/P antenna, Trimble 5700 with Zephyr / Zephyr Geodetic antennas, Trimble 4000 SSE/4000 with SST/E L1/L2 GEOD antenna; Leica SR530 with LEIAT502 antenna; Sokkia Radian with SK502 antenna for the epoch and BULREF stations and AOA SNR-8000 ACT/AOAD/M_T antenna for the permanent station SOFI. During the measurements no interruptions occurred. Only short interruptions occurred for the stations SATO and HARM because of bad meteoconditions (strong lightning and thunders).

CEGRN2005

In the CEGRN'05 GPS campaign the country was involved with one EPN/IGS permanent station (SOFI), two newly established CERGOP permanent stations (VARN, ROZH) and the three epoch stations (Fig. 4.3.9.3). The CEGRN2005 GPS campaign was carried out according to the general rules of the CERGOP data centre. All permanent stations observed from 20. 06. 2005 (doy 171) 00.00 UT to 25. 06. 2005 (doy 176) 24.00 UT and all epoch stations operated from 20. 06. 2005 (doy 171) 12.00 UT to 25. 06. 2005 (doy 176) 12.00 UT. LEICA GX1230 receivers and LEIAX1202 antennas were used at the epoch stations. At the permanent stations were used: TPS E_GGD receiver and ACT/AOAD/M_T antenna for SOFI and TPS E_GGD receivers and TPSCR3_GGD CONE antennas for VARN and ROZH.

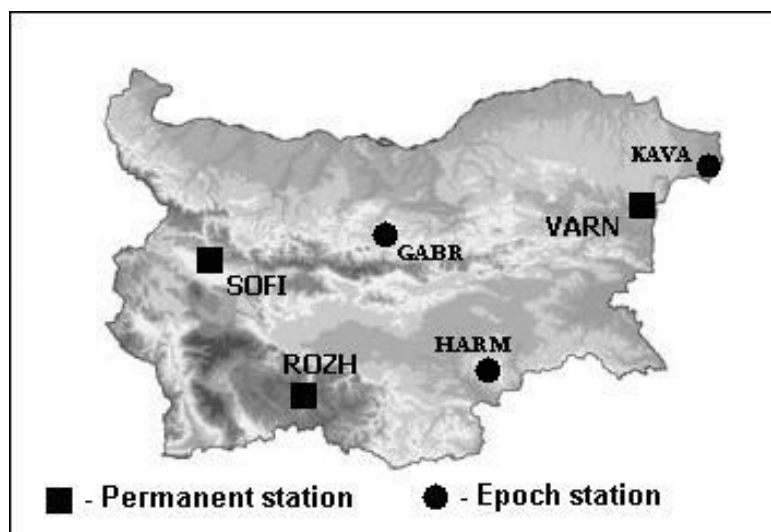


Fig. 4.3.9.3. Bulgarian stations participated in CEGRN05 campaign

4.3.9.3. Establishment of the CERGOP-2 Permanent Stations in Bulgaria

Two CERGOP permanent stations (PS) were selected in Bulgaria according to the standards for CEGRN permanent stations early in 2005. They were established at the Astronomical Observatory (AO) and Planetarium “Nicolas Copernicus” in Varna town (VARN) (Fig. 4.3.9.4., left) and at the National Astronomical Observatory (NAO) of the Bulgarian Academy of Sciences (BAS), located at the “Rozhen” peak of the Rhodops (ROZH) (Fig. 4.3.9.4., right). The antenna of VARN station was installed on the roof of the Planetarium (Fig. 4.3.9.5., left) and the antenna of ROZH station – on the roof of the main building (Fig. 4.3.9.5., right). VARN and ROZH stations are also collocated with absolute gravity stations and connected to the National Levelling Network and they are

included as an element of the project EUREF – ECGN (European Combined Geodetic Network) (Milev et al., 2004). The stations operate regularly and the data are transferred to the data centre in Graz. Only ROZH was out of operation for some period because of natural calamity.



VARN



ROZH

Fig. 4.3.9.4. Location of the Bulgarian CERGOP Permanent Stations



VARN



ROZH

Fig. 4.3.9.5. Antenna spots of VARN and ROZH permanent stations

4.3.9.4. Geodetic investigations and analysis

- **Data processing**

GPS data of all 15 BULREF stations are available for two campaigns - BULREF93 (Altiner et al. 1996) and CEGRN03/BULREF03 (Fig. 4.3.9.2.) and only of four of them for three campaigns (BULREF93, CEGRN03 and CEGRN05). The adjustment of the network of BULREF stations was performed with the Bernese GPS Software, version 4.2 (Milev et al., 2003, 2004, Vassileva, 2004) regarding the accepted processing CERGOP principles. The data in 1993 were reprocessed in ITRF2000 system as the precise ephemerides were transformed into ITRF2000. Final station coordinates in ITRF2000, at epoch 1993.8 and respectively at epoch 2003.46 and at epoch 2005.47 were obtained. Six and seven IGS stations (WTZR, ZIMM, GRAZ, MATE, SOFI, PENC, BUCU) were involved respectively in 1993, 2003 and in 2005.

The results from Helmert transformations in 1993 showed high values of residuals only for Matera and in 2003 higher values of residuals in Up component for station BERK in all sessions and for station MATE in North component only on 170 DoY were obtained. Probably the reason for the bad results of station BERK is the technical problem occurred during that campaign.

- **Comparison and analysis of the results**

A combined processing of BULREF'93 and BULREF'03 was accomplished by use of the program Addneq of the Bernese software version 4.2 and estimations of the ITRF2000 coordinates for the mean epoch and station velocities were computed. For obtaining the velocities of the BULREF stations the ITRF2000 coordinates and velocities of the IGS permanent stations - WTZR, ZIMM, GRAZ, MATE, SOFI and PENC were kept fixed (Milev, Vassileva, Becker, Kirchner, 2005). GPS velocity vectors (blue), calculated NNR-NUVEL1A velocity vectors (green) and the obtained relative velocity vectors (red) are presented in the Fig. 4.3.9.7.

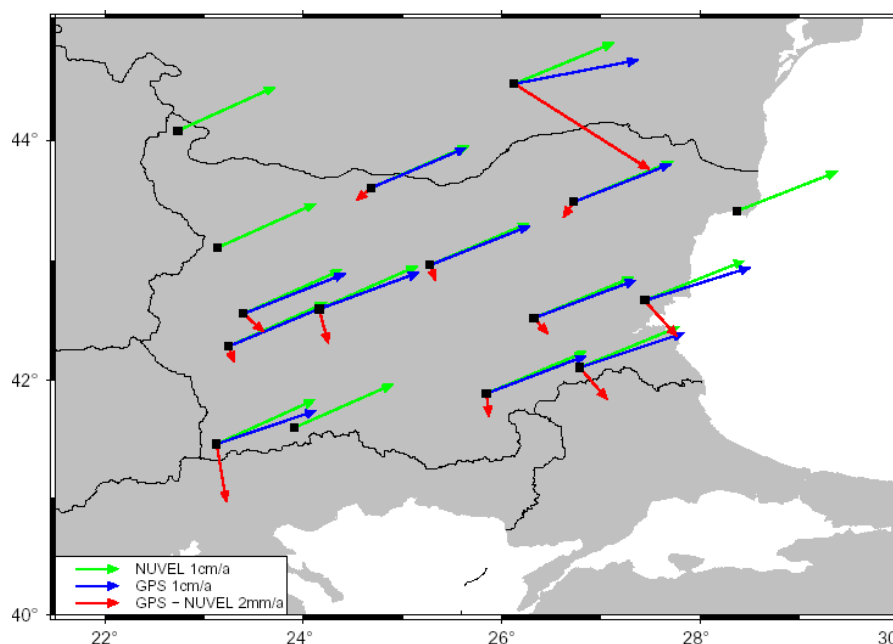


Fig. 4.3.9.2. GPS and NNR-NUVEL1A velocity vectors of BULREF stations

The velocity estimations obtained from the study show undisturbed behavior for all BULREF stations for the period of 10 years, period between two campaigns. The values of station velocities are very similar and differences vary with an amount of maximum up to 2 mm in north component and in east component. Also the deviations to the NUVEL model velocities are in a reasonable size. This indicates that no unexpected jumps or outliers occurred in the behavior of stations during that time.

For Bulgarian CERGOP stations (or part of them) participated in more than two measurement GPS campaigns another comparison and analysis of the results from the respective data processings has been done. It concerns BULREF'93, CEGRN'97, CEGRN'03 and CEGRN'05 (Milev et al., 2005). The participation of the respective Bulgarian stations in the mentioned GPS campaigns is shown in Table. 4.3.9.1.

Table 4.3.9.1. Participation of Bulgarian stations in CEGRN GPS campaigns

Station type	BULREF'93	CEGRN'97	CEGRN'03	CEGRN'05
SOFI EPN/IGS	Yes	Yes	Yes	Yes
GABR epoch	Yes	No	Yes	Yes
KAVA epoch	Yes	No	Yes	Yes
HARM epoch	Yes	Yes	Yes	Yes
VARN perm.	No	No	No	Yes
ROZH perm.	No	No	No	Yes

The ITRF2000 velocity estimations of the above stations obtained from different multicampaign solutions are shown in Table 4.3.9.2.

Table 4.3.9.2. ITRF2000 velocity estimations

Station	Velocity estimations in [mm/yr] from combined solutions					
	Axis	93-03	93-05	03-05	97-03	97-05
GABR	X	- 16.26	- 16.43	- 17.30	-	-
	Y	17.95	18.77	22.43	-	-
	Z	7.56	7.33	6.51	-	-
HARM	X	- 16.11	- 16.24	- 16.98	- 16.27	- 16.59
	Y	18.01	19.06	23.80	17.49	20.06
	Z	7.40	7.04	5.47	7.86	6.89
KAVA	X	-	-	- 15.25	-	-
	Y	-	-	16.96	-	-
	Z	-	-	5.66	-	-

The estimations in North component agree very well for all stations with a few exceptions. But it is only partly valid for estimations in East and Up components.

The results for the BULREF/CEGRN station HARM (93-03, 93-05, 97-03) are confirmed by the CEGRN analysis and confirm the velocity estimations obtained in this study through an independent observation epoch.

4.3.9.5. Generalization

The CERGOP activities, the measurements and investigations accomplished can be summarized in several aspects.

The comparison and analysis of the processing of BULREF'93, BULREF'03 and BULREF'05 campaigns show that the results from GPS campaigns are reliable. After the proper consideration of the discrepancies in MATE, WETT, BUCU and BERK in the respective campaigns, they can be used as a base for a combination and velocity estimation in the period from BULREF'93 up to now. The estimations obtained and the accuracy estimates give the reason to assume a homogeneous and consistent velocity field within Bulgaria. The coordinates of the BULREF stations can be used as basis for respective transformations and comparisons in the national reference system of Bulgaria with accuracy in the ITRF 2000 at or below the cm level.

The accomplished works in the country are of great importance for the integration of Bulgaria within the framework of European space and for the implementation of other European projects especially those ones related to the EUREF. That concerns also the region of the Balkan Peninsula which is the most active geodynamic region within the CERGOP-2. It is valid for the particular Earth sciences and their integration as well and not only in geodynamic aspect. It is of great importance for the establishment of the BULREF station stability and their further use.

4.3.9.6. Reference

- Altiner, Y., P. Gabenski, K. Habrich, G. Milev, M. Minchev, H. Seeger, K. Vassileva, 1996. EUREF Bulgaria GPS Campaigns. Final Results 1996. EUREF-Symposium, Ankara, Turkey, 22-25 May 1996, DGK. Muenchen. AGA. Heft 57, 86-97.
- Milev, G., K. Vassileva, 2003. Report on the Project Activities of Bulgaria Warsaw university of technology, Institute of geodesy and geodetic astronomy. Reports on Geodesy. 2003, No 3 (66), 129-138.
- Milev, G., K. Vassileva, 2004. The Project Cergop-2 and its Realization for the Balkan Peninsula. Report on the Serbian Geological Society. Belgrade, 3.03.2004, 13
- Milev, G., K. Vassileva, 2004. Geodynamics of the Balkan Peninsula within the Framework of CERGOP-2. Reports on Geodesy, Warsaw University of Technology, No 2(69), 97-104.
- Milev, G., J. Sledzinski, K. Vassileva, 2002. Geodynamic Investigations of the Balkan Region within the Framework of CEI-CERGOP2. 3rd Balkan Geophysical Congress and Exhibition. 24-28 June 2002. Sofia. Bulgaria. Book of Abstracts. 347, Report 13 p.
- Milev, G., Vassileva, K., Dimitrov, N. 2004. Sofia CERGOP-2 Progress Report of Bulgaria. Reports on Geodesy, Warsaw University of Technology, No 4(71), 201-207.
- Milev, G., K. Vassileva, N. Dimitrov, 2005. Sarajevo, CERGOP-2 project activities of Bulgaria. Reports on Geodesy, Warsaw University of Technology, No 4(75), 195-201.

- Milev, G., K. Vassileva, M. Becker, M. Kirchner, 2005. Analysis of the EUREF stations stability on the territory of Bulgaria. EUREF Symposium, Vienna, Austria, June 01-04, 2005. Mitteilungen des Bundesamtes fuer Kartographie und Geodaesie. Frankfurt am Main, EUREF Publikation, 10 p. (in press).**
- Vassileva, K., 2004. Results of the CEGRN'03/BULREF'03 GPS Campaign, Reports on Geodesy, Warsaw University of Technology, No 4(71), 208-217.**