Analysis of the Euref Stations Stability on the Territory of Bulgaria

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Abstract

Two GPS EUREF campaigns in 1992 and 1993 were carried out on the territory of Bulgaria and they were the basis for introduction of EUREF in Bulgaria (named BULREF). Within the framework of GPS campaigns of the CERGOP project the BULREF stations have been involved again. Data processing, comparison and analysis of the results from the respective campaigns have been accomplished. The BULREF stations stability has been assessed as well as their further effective use.

1. General

The European Reference Frame EUREF was introduced in Bulgaria in 1996 with a resolution of the EUREF symposium in Ankara [Altiner et al, 1996]). Out of the 15 EUREF stations observed within the 1993 GPS campaign 7 stations were officially approved as EUREF stations. Nevertheless, all 15 stations defined the National Bulgarian system BULREF and they were used later as basis for further realisation of EUREF in the country. The geodynamic conditions of the territory of Bulgaria were considered in the selection of the station location. Later on four of the EUREF stations were included in the CEGRN GPS measurement campaign of the Central European Geodynamics Project – CERGOP [BECKER et al., 2002]. In 2003 the consecutive GPS campaign of the second phase of the project – CERGOP-2 was carried out. All 15 BULREF stations were re-occupied in this campaign. Comparison of the results and assessment of the BULREF stations stability have been accomplished on the base of a new processing of both the BULREF'93 data and the CEGRN'03/ BULREF'03 data. The results of this analysis, assessment and interpretation are the subject of the present paper.

2. GPS BULREF campaigns in 1993 and 2003 and data processing

2.1. GPS campaigns

The EUREF GPS campaign for Bulgaria in 1993 was carried out from 12.10.1993 to 16.10.1993. All 15 BULREF stations (fig. 1) were equipped with Trimble 4000SSE receivers and antennas 4000ST L1/L2 GEOD were used in the campaign. The GPS measurements were carried out in five 24-hours sessions with sampling rate of 15 sec and elevation mask 15°. More information about the campaign, its processing and results can be found in [ALTINER, Y. et al, 1996].

The BULREF'03 GPS campaign was carried out within the framework of the CEGRN'03 GPS campaign of the EC Project CERGOP-2 and it is the second campaign for the BULREF network [Milev, Vassileva, 2003; 2004]. It was carried out according to the general requirements of the CERGOP data center. The measurements started on 16.06.2003 at 12:00 (UT) and closed on 21.06.2003 at 12:00 (UT). The four Bulgarian CEGRN/BULREF stations – SOFI, GABR, KAVA and HARM were measured in five 24-hours sessions. They have been carried out by teams of the Military Topographic Service and Boundary Police. The other stations (KERM, MAMA, BURG, BERK, GULI, SHUM, VIDI, PANA, SATO, SAPA, PETR, fig. 1), were measured in two 24-hours sessions because of insufficient number of receivers. They were carried out with the collaboration of Bulgarian private companies – "Geoprecise" and "Mapex". A data sampling rate of 30 sec and an elevation mask of 10° was used. Because of some problems with the controller used at station GABR the elevation mask used was 13°. Different types of receivers/ antenna pairs were used. They were Trimble 4000 SSI with compact L1/L2 GP antenna, Trimble 5700 with Zephyr / Zephyr Geodetic antenna, AOA SNR-8000 ACT/AOAD/ M_T antenna for the permanent station SOFI, Trimble 4000 SSE/4000 SST/E L1/L2 GEOD antenna; Leica SR530/ AT502 antenna and Sokkia Radian/SK 502 antenna.

During the measurements no interruptions occurred. Only for station HARM in the fourth session and for station SATO in the second session an interruption occurred because of bad meteo conditions (strong lightning and thunders).

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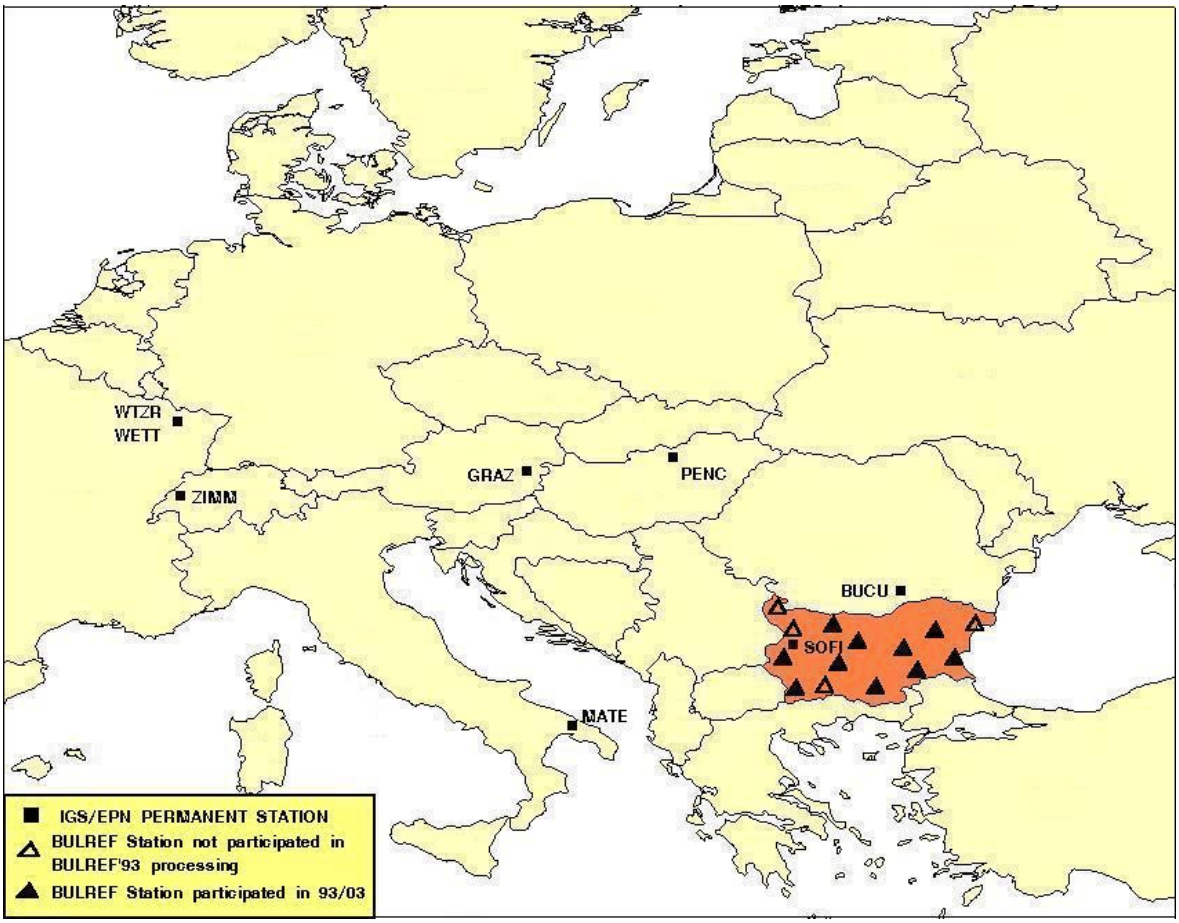

Fig. 1. BULREF stations and IGS stations involved in BULREF'93 and BULREF'03 campaigns

2.2. Data processing

2.2.1. BULREF'93 data processing

The original BULREF'93 GPS data were processed with the Bernese GPS software, version 3.5. Four IGS stations – WETT, MATE, GRAZ, ZIMM were involved. Precise CODE ephemerides in system ITRF91, Saastamoinen troposphere model and local ionosphere model were applied [ALTINER, Y. et al, 1996]. Station WETT was selected as reference station in the free network adjustment.

In 2004 the BULREF'93 GPS data were re-processed in the system ITRF2000, epoch 1993.8. The precise ephemerides were transformed into ITRF2000. "Dry Niell" troposphere model for estimation of station troposphere parameters and global ionosphere model were applied. In the free network adjustment IGS station GRAZ was selected as reference with a priori rms = ± 0.0001 m of the coordinates. As there were some problems with GPS data restoring of some stations (BERK, KAVA, SATO, VIDI) they did not participated in the processing. Final station coordinates in ITRF2000, 1993.8 were obtained. A 7-parameters Helmert transformation was accomplished for the analysis of the results.

Table 1. Residuals of Helmert transformation between coordinates of IGS sites from the BULREF'93 solution and official ITRF2000, 1993.8 coordinates

No	Site Name	Residuals in mm		
		N	E	U
1	GRAZ 11001M002	0.9	-3.8	-1.5
2	SOFI 11100M002	-1.9	0.2	1.8
3	MATE 12734M008	-0.7	2.4	-1.5
4	WETT 14201M009 A	0.2	-2.3	-1.0
5	ZIMM 14001M004	1.6	3.5	2.2
	RMS/Component	1.3	3.1	1.8
	RMS of transformation	2.7		

The results from the transformation between the final campaign solution BULREF'93 and official published ITRF2000 coordinates for the observation epoch 1993.8 of the IGS permanent stations are given in table 1 and they show a very good consistence. Transformations between station coordinates of final campaign solution and 285, 286 and 288 session solutions also show good consistence. For 287 session solution residuals become smaller after marking of station WETT. Some of residuals are shown in table 2.

Table 2. Residuals of Helmert transformation between BULREF'93 station coordinates of campaign solution and session solutions

No	Station Name	Campaign BULREF'93 solution – 286 session solution			Campaign BULREF'93 solution – 287 session solution			
		N [mm]	E [mm]	U [mm]	N [mm]	E [mm]	U [mm]	
1	GABR	-0.6	0.6	0.9	0.2	1.1	-2.1	
2	GULI	-0.1	0.3	2.6	0.0	0.3	2.4	
3	KERM	-0.1	-0.5	-1.6	0.9	0.4	-0.1	
4	GRAZ 11001M002	1.6	-0.5	8.3	0.5	4.8	-11.6	
5	SOFI 11101M002	-0.6	-1.3	-3.2	-0.4	-3.1	-8.6	
6	HARM	0.0	-0.5	-3.4	-1.3	0.9	10.1	
7	MAMA	-0.1	-0.1	-0.5	1.3	-0.6	-2.5	
8	MATE 12734M008	0.6	0.7	0.9	1.1	-1.7	-0.8	
9	BURG	0.2	0.4	-0.4	-0.8	-0.6	5.9	
10	PANA	0.0	0.9	1.8	0.7	0.3	-1.4	
11	SAPA	-0.4	1.1	1.4	-0.1	0.6	-1.7	
12	PETR	-0.6	0.3	-1.1	-0.5	-0.7	-3.0	
13	SHUM	-0.4	-1.5	1.1	0.3	1.0	3.9	
14	WETT 14201M009 A	2.7	-2.5	-5.3	2.1	5.0	21.9	M
15	ZIMM 14001M004	-2.2	2.7	-1.5	-1.9	-2.7	9.5	
	RMS/Component	1.1	1.2	3.2	0.9	1.9	6.1	
	RMSof transformation	2.2			3.9			

2.2.2. BULREF'03 data processing

The computations of the BULREF network was performed with the Bernese GPS Software, version 4.2 [Milev, Vassileva, 2003,2004; Vassileva, 2004]. Precise ephemerides from IGS final orbit computation in system IGS2000 were used. Seven IGS sites – WTZR, ZIMM, GRAZ, MATE, SOFI, PENC, BUCU were involved. Their coordinates were transformed to the observation epoch 2003.46 using their velocities in ITRF2000. Site GRAZ was selected as reference in the free network adjustment with a priori rms = ± 0.0001 m. Antenna elevation-dependent phase center offsets and variations (NGS relative values used), "Dry Niell" troposphere model for estimation of station troposphere parameters and global ionosphere model were applied. Final station coordinates in ITRF2000, 2003.46 were obtained. A set of final coordinates was compared to the coordinates of the reference IGS sites (table 3).

Table 3. Residuals of Helmert transformation between final IGS site coordinates from BULREF'03 solution and official ITRF2000, 2003.46 coordinates

No	Site Name	Residuals in mm		
		N	E	U
1	BUCU 11401M001	9.6	-16.7	-8.9
2	GRAZ 11001M002	-0.8	-1.2	15.8
3	SOFI 11100M002	-5.7	7.0	4.0
4	MATE 2734M008	-10.3	1.1	2.1
5	PENC 11206M006	0.9	5.5	-7.0
6	WTZR 14201M010	3.0	3.0	7.8
7	ZIMM 14001M004	3.3	1.3	-13.9
	RMS/Component	6.5	7.9	10.4
	RMS of transformation	9.6		

The results of the comparison show a good agreement of coordinates except the residuals in North and East component for site BUCU and in North component for site MATE. After marking site BUCU in the transformation process the obtained results have been improved (table 4).

Table 4. Residuals of Helmert transformation between final IGS site coordinates from BULREF'03 solution and official ITRF2000, 2003.46 coordinates. Site BUCU marked

No	Site Name	Residuals in mm		
		N	E	U
1	BUCU 11401M001	14.7	-27.1	-17.2 M
2	GRAZ 11001M002	-0.7	-3.8	14.1
3	SOFI 11100M002	1.2	-0.0	-2.1
4	MATE 2734M008	-3.4	0.0	2.2
5	PENC 11206M006	1.5	-0.5	-11.8
6	WTZR 14201M010	0.3	0.9	7.1
7	ZIMM 14001M004	1.0	-9.4	3.3
	RMS/Component	1.8	2.3	9.9
	RMS of transformation	7.0		

To be find some explanation of such a behaviour of BUCU site coordinate differences obtained for this site from different solutions at the observation epoch 2003.46 were formed (table 5).

A 7-parameter Helmert transformation was accomplished for IGS permanent stations as in table 4 but using coordinates of BUCU obtained from BKG – EUREF weekly 1223 solution. The results were similar (table 6). At present this behaviour of BUCU site could not be explained.

Table 5. Coordinate differences for BUCU site in ITRF2000, epoch 2003.46

Solutions	Coordinate differences in m		
	dX	dY	dZ
OLG EUREF – BULREF'03	72	96	47
BKG EUREF – BULREF'03	-20	-72	-20
OLG EUREF – BKG EUREF	92	-24	-27
OLG CEGRN'03 – BULREF'03	6	0	-17

Table 6. Residuals of Helmert transformation between final IGS site coordinates from BULREF'03 solution and official ITRF2000, 2003.46 coordinates. The coordinates of BUCU site used from BKG-EUREF weekly solution.

No	Station Name	Residuals in mm			Residuals in mm		
		N	E	U	N	E	U
1	BUCU 11401M001	-10.6	20.6	11.1	-16.1	33.4	21.4 M
2	GRAZ 11001M002	0.7	0.7	-16.3	0.7	3.8	-14.1
3	SOFI 11100M002	6.7	-8.9	-5.5	-1.2	0.0	2.1
4	MATE 2734M008	11.7	-1.7	-2.0	3.4	0.0	-2.2
5	PENC 11206M006	-1.1	-6.7	5.8	-1.5	0.5	11.8
6	WTZR 14201M010	-3.7	-3.3	-8.0	-0.3	-0.9	-7.1
7	ZIMM 14001M004	-3.7	-0.8	15.0	-1.0	-3.3	9.4
	RMS/Component	7.3	9.7	11.1	1.8	2.3	9.9
	RMS of transformation	10.8			7.0		

Using a seven-parameter Helmert transformation comparison between final network solution and session solutions was accomplished. The results from Helmert transformations show high values of residuals in Up component for station BERK in all sessions (from 22,7 mm up to 40,6 mm) and for station MATE in North component only on 170 doy. Probably the reason for the bad results of station BERK is the technical problem occurred during the campaign. After marking this station the residuals from the Helmert transformation are getting smaller (table 7).

Analysis of the results from data processing of BULREF'03 shows that the obtained final coordinates are reliable except those ones for IGS site BUCU and for BULREF station BERK.

Table 7. Residuals of Helmert transformation between BULREF'03 station coordinates of campaign solution and session solutions

No	Station Name	Campaign BULREF'03 solution – 170 session solution			Campaign BULREF'03 solution – 170 session solution			
		N [mm]	E [mm]	U [mm]	N [mm]	E [mm]	U [mm]	
1	BUCU 11401M001	-1.1	-0.4	-2.5	-1.2	-0.5	-3.9	
2	KAVA	1.4	-0.9	-4.7	1.4	-1.0	-6.3	
3	GABR	-0.5	-0.8	1.6	-0.6	-0.9	-0.2	
4	GRAZ 1001M002	0.4	-1.9	2.6	0.3	-2.0	1.8	
5	SOFI 11101M002	-0.4	0.7	-6.7	-0.5	0.6	-8.6	
6	HARM	-0.2	0.6	14.3	-0.2	0.5	12.3	
7	MATE 12734M008	11.4	2.4	-3.1	11.4	2.3	-5.3	
8	PENC 11206M006	1.6	1.4	8.1	1.3	1.5	7.4	
9	BERK	-0.4	-1.2	-22.7	-0.5	-1.3	-24.4	M
10	WTZR 14201M010	-2.2	-2.2	-3.3	-2.2	-2.3	-3.6	
11	ZIMM 14001M004	-0.8	-2.7	1.8	-0.8	-2.7	1.1	
12	VIDI	-3.5	2.2	1.5	-3.5	2.1	0.0	
17	SHUM	0.2	-1.9	-6.0	0.2	-2.0	-7.7	
00	MAMA	-1.5	1.5	8.6	-1.5	1.3	6.7	
00	PETR	-1.5	1.7	0.3	-1.5	1.6	-1.8	
00	SATO	-2.6	1.5	10.2	-2.6	1.4	8.2	
	RMS/Component	3.3	1.7	8.6	3.4	1.7	6.3	
	RMS of transformation	5.7			4.5			

3. Comparison and analysis of results from the campaigns BULREF'93 and BULREF'03

A multi campaign solution of BULREF'93 plus 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.

Table 8.Residuals of Helmert transformation between coordinates of IGS sites from BULREF'93-03 solution and official ITRF2000, 1993.8 coordinates. Sites WETT and MATE marked

No	Site Name	Residuals in mm			
		N	E	U	
1	GRAZ 11001M002	3.8	-1.0	0.5	
2	SOFI 11100M002	-1.8	-0.2	-0.3	
3	MATE 2734M008	25.5	5.2	-7.8	M
4	WETT 14201M009 A	-70.0	-114.3	14.8	M
5	ZIMM 14001M004	1.2	-2.0	-0.2	
	RMS/Component	3.3	1.1	0.5	
	RMS of transformation	3.5			

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. A 7-parameter Helmert transformation was accomplished for the analysis of the results. Residuals from transformation between the multi campaign solution BULREF'93-03 and official published ITRF2000 coordinates for the observation epoch 1993.8 of the IGS permanent stations were obtained with high values, especially in North and in East components. After marking the suspected bad stations – WETT and MATE the results were become very small (table 8).

Table 9. Residuals of Helmert transformation between coordinates of IGS sites from BULREF'93-03 solution and official ITRF2000, 2003.46 coordinates. Sites BUCU and MATE marked

No	Site Name	Residuals in mm			
		N	E	U	
1	BUCU 11401M001	81.6	81.3	-43.3	M
2	GRAZ 11001M002	-3.9	-2.5	7.5	
3	SOFI 11100M002	1.4	0.4	-0.5	
4	MATE 2734M008	-27.9	-6.9	4.9	M
5	PENC 11206M006	0.7	0.3	-4.7	
6	WTZR 14201M010	0.8	2.3	0.5	
7	ZIMM 14001M004	1.0	-0.6	-2.8	
	RMS/Component	2.2	1.7	4.7	
	RMS of transformation	3.9			

The same transformation was accomplished between the multi campaign solution BULREF'93-03 and official published ITRF2000 coordinates for the observation epoch 2003.46 of the IGS permanent stations. The results obtained are similar as above but for sites BUCU and MATE. After marking the suspected bad sites – BUCU and MATE the results have been significantly improved (table 9).

The results obtained from transformations show that there are some problems with IGS sites BUCU, WETT and MATE.

As BULREF station HARM participated in another CEGRN'97 campaign its ITRF velocities were estimated and compared from two multi campaign solutions (table 10). The results show very similar values and confirm the velocity estimations obtained.

The obtained velocity estimations from the multi campaign solution are given in table 11.

Table 10. Velocity estimations of BULREF/CEGRN station HARM

Station	Station velocities in mm/year concerning zero velocity					
	vx vn	rms rms	vy ve	rms rms	vz vu	rms rms
HARM	1993-2003 (this study)					
	-16.11	0.02	18.01	0.03	7.40	0.03
	9.95	0.03	23.23	0.03	-0.01	0.01
HARM	1997-2003 (Milev, Vassileva, Dimitrov, 2005)					
	-16.27	0.05	17.49	0.06	7.86	0.05
	10.54	0.07	22.84	0.06	0.02	0.02

The estimated velocities of the BULREF stations and the participating IGS stations were compared to the geophysical model NNR-NUVEL1A. The station velocity vectors obtained from the Bernese software adjustment (blue colour) and from the NNR-NUVEL1A model (green colour) are shown in the figures 2 and 3. Comparison of the results from two velocity models shows very small differences and respectively a very good agreement. Only for IGS station BUCU (it does not participate in the first measurement campaign in 1993) and for IGS station MATE differences are too large as it is shown above (table 9).

Table 11. ITRF2000 velocity estimations of BULREF stations from this study

Station velocities in mm/year concerning zero velocity field						
station	vx vn	rms rms	vy ve	rms rms	vz vu	rms rms
GABR	-16.26 10.33	0.02 0.03	17.95 23.18	0.03 0.02	7.56 -0.00	0.02 0.01
GULI	-15.96 2.23	0.03 0.03	17.13 -0.01	0.03 0.01	7.70 10.65	0.03 0.04
KERM	-16.57 10.03	0.02 0.03	18.25 23.71	0.03 0.03	7.42 0.04	0.03 0.01
GRAZ 11001M00	-17.58 14.44	0.01 0.01	18.14 22.17	0.01 0.01	8.19 -2.24	0.01 0.01
SOFI 11101M002	-16.49 10.57	0.01 0.01	18.72 23.73	0.01 0.01	7.28 -0.75	0.01 0.01
HARM	-16.11 0.03	0.02 -0.01	18.01 0.01	0.03 9.95	7.40 0.03	0.03 23.23
MAMA	-16.50 9.13	0.03 0.04	19.14 24.52	0.03 0.03	6.79 0.03	0.03 0.01
MATE 12734M008	-18.74 18.07	0.01 0.01	18.97 23.55	0.01 0.01	13.09 -0.95	0.01 0.01
BURG	-16.73 8.84	0.03 0.04	19.25 24.79	0.04 0.04	6.51 0.02	0.03 0.01
PANA	-15.52 9.66	0.03 0.04	18.53 23.26	0.03 0.03	7.08 -0.04	0.03 0.01
SAPA	-15.78 10.83	0.03 0.04	18.28 23.02	0.03 0.03	8.02 0.00	0.03 0.01
PETR	-14.53 8.84	0.03 0.04	19.12 23.29	0.03 0.03	6.62 -0.00	0.03 0.01
ZIMM 14001M004	-13.85 15.13	0.01 0.01	18.54 20.18	0.01 0.01	10.04 -0.42	0.01 0.01
SHUM 10.08	-16.40 10.08	0.03 0.04	17.13 22.68	0.03 0.03	7.30 -0.02	0.03 0.01
PENC 11206M006	-16.65 12.74	0.01 0.01	18.08 22.57	0.01 0.01	8.22 -0.46	0.01 0.01
WTZR 14201M010	-15.69 14.33	0.01 0.01	17.25 20.32	0.01 0.01	8.68 -0.93	0.01 0.01

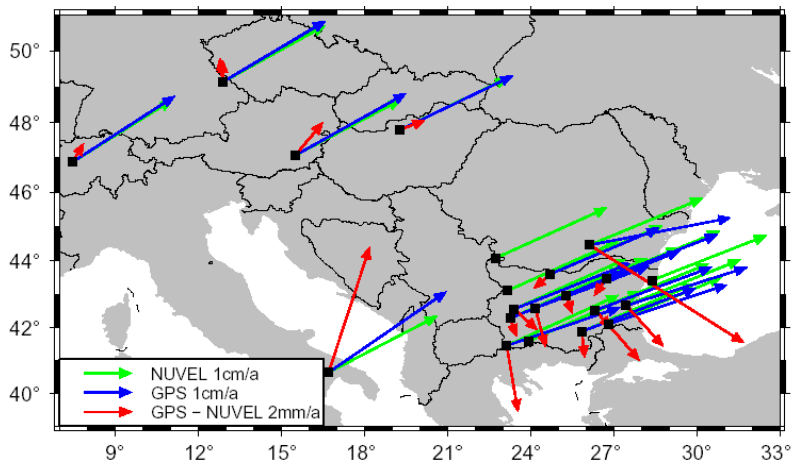

Fig. 2. GPS and NNR-NUVEL1A velocity vectors of BULREF and participated IGS stations

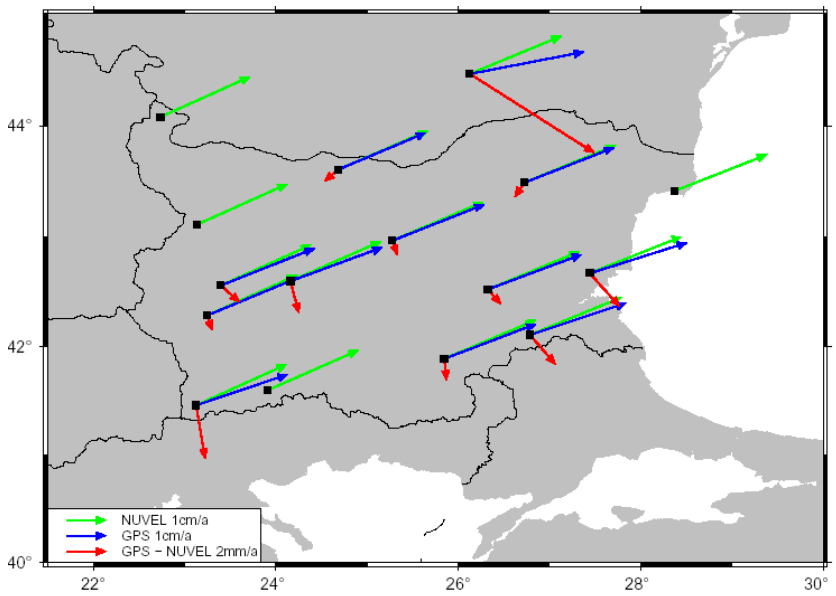

Fig. 2. GPS and NNR-NUVEL1A velocity vectors of BULREF stations

More reliable velocity estimations of the stations will be obtained after including and analyzing the results from the forthcoming CEGRN'05 campaign to be conducted in June 2005 and which will include BULREF/CEGRN stations once more.

4. Assessment of the BULREF stations stability

The velocity estimations obtained from this study show undisturbed behaviour 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 maximally up to 2 mm in north component and in east component (table. 11). Also the deviations to the NUVEL model velocities are in a reasonable size. This indicates that no unexpected jumps or outliers occurred in the behaviour of stations during that time. However, as only two epochs are involved in this study, no final conclusions on the deformations within Bulgaria can be drawn because no error estimates are available yet for the velocities to check the significance of the deviations to the model. The results for the BULREF/-CEGRN station HARM are confirmed by the CEGRN analysis and confirm the velocity estimations obtained in this study through an independent observation epoch.

5. Conclusions and suggestions

The comparison and analysis of the processing of two campaigns BULREF'93 and BULREF'03 show that the results from both GPS campaigns are reliable. After the proper consideration of the discrepancies in 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 to CEGRN'03/BULREF'03. 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 an accuracy in the ITRF 2000 at or below the cm level. Further campaigns, like the 2005 CEGRN campaign, have to be added in order to allow for a verification and a proper error estimation, also in order to detect possible variations in the CEGRN/EUREF site velocities over the territory of Bulgaria. This will allow for interpretation and improvement of the regional velocity field as well in view of improved geodynamical modeling.

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