5.2.1. GPS OBSERVATIONS IN BALKAN PENINSULA AND ADJACENT REGION WITHIN THE CERGOP-2/ ENVIRONMENT ACTIVITIES

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5.2.1.1. Introduction

The CERGOP activities in Central Europe, Adriatic and Balkan territory started in 1994 when the first epoch GPS campaign was realized. Further were seven epoch campaigns performed in the region. These campaigns because of their 11–year history and the relative dense coverage will serve as very important source of geokinematic information about the Balkan Peninsula. Later on, several permanent stations were established in the region. Some of them are part of EUREF Permanent Network (EPN), the others are built for special purposes and their data are available for scientific application. Part of the permanent stations in region is systematically analyzed since 2003 within the CERGOP-2/ENVIRONMENT Work Package 5 "GPS data analysis and the definition of reference frames". We will present here the outputs relating to site velocities estimation based on two types information – epoch observations from time span 1994.3 - 2005.4 and permanent observations in Central Europe region from period 2003.0 – 2006.4. Our results will be for some stations also compared with velocities from ITRF2000 and EPN analysis.

5.2.1.2. Epoch observations within CERGOP and CERGOP-2/ENVIRONMENT

The series of regularly repeated GPS campaigns occupying several days are frequently used for estimation of site velocities, in particular in regions where permanent sites are not available or the density of permanent stations is not sufficient. In Central Europe region such activities motivated in 1994 establishment of the Central Europe Regional Geodynamic Project (CERGOP, Fejes, Sledzinski, 1998) as the research collaboration of 11 countries. As the observational background for CERGOP serves the Central European GPS Geodynamic Network (CEGRN). From the Balkan states Slovenia, Croatia and Romania were participating CERGOP from its establishment, Bulgaria was an associate member of CERGOP. The continuation of these activities is realized in follow-up project CERGOP-2/Environment (Fejes, Pesec, 2003). In CERGOP-2 also Bosnia and Herzegovina is participating. The CEGRN which was originally consisting of 24 sites distributed in Central and south-east Europe was observed for the first time in May 1994. Since that time the CEGRN was significantly enlarged from originally observed sites to 92 network sites observed in 2005. The part of CEGRN stations in southern part of Central Europe, Adriatic region and Balkan is shown in Fig. 5.2.1.1. (status in 2005). However it is worth to mention that many stations in Romania were between the successive campaigns destroyed and then re-established without knowing their eccentricities.

The epoch-wise observing campaigns of CEGRN comprising of five 24-hour simultaneous sessions were performed in late spring annually in 1994, 1995, 1996, 1997, and than bi-annually in 1999, 2001, 2003 and 2005. The processing and analysis of all campaigns will be included in final report of CERGOP-2/Environment, Work-Package 7 (Hefty et al., 2006). Velocity estimation based on combined solutions from 3 to 6 analysis centres is expected. Here we will present results based on solutions from one analysis centre, namely Slovak University of Technology (SUT) in Bratislava. The mathematical background and processing strategy applied are described in (Hefty, Gerhátová, 2006).

Table 5.2.1.1. shows list of CEGRN epoch campaigns used for velocity estimation. Based on 8 epoch coordinate sets and their covariance matrices the estimates of 3-D velocities of more than 50 stations are obtained. The reference frame used for velocity estimation is the ITRF2000 realized by referencing the CEGRN to8 IGS European permanent stations (BOR1, GRAZ, KOSG. MATE, WTZR, ONSA and ZIMM). For obtaining the intraplate velocity field the ITRF velocities are reduced for Actual Plate Kinematic Model APKIM 2000 (Drewes, 1998). Finally the velocities in geocentric coordinate system are transformed to local horizontal system. The evaluated velocities for stations situated in Balkan region are listed in Tab. 5.2.1.2. We restricted our velocity estimation to sites where at least 3 epoch campaigns at identical monumentation were performed.

For better insight into the coordinate evolution at individual CEGRN sites we show in Figs. 5.2.1.2. and 5.2.1.3. some examples. Fig. 5.2.1.2. shows four sites in west Balkans territory where the north-wards oriented horizontal drift is observed. The ellipses indicate the mean error confidence ellipses of individual campaigns based on accuracy estimates from combination of all CEGRN campaigns performed. The vectors in left upper part of each plot indicate estimated movement of the site during 11 years of CEGRN observing campaigns. We may observe that for this region is visible drift over 20 mm per 11 years. Quite opposite is the direction of movements in east Balkan region shown in Fig. 5.2.1.3. The estimated movements in 11 years are from 20 to 50 mm but oriented dominantly to south.

The graphical representation of annual horizontal velocities is in Fig. 5.2.1.4. The error ellipses indicate 2σ confidences. Three main characteristic trends can be observed in the horizontal velocity plots:

- **North oriented movement of west Balkan with magnitude above 2 mm/yr.**
- **East oriented movement of southern part of Central Europe with magnitude up to 2 mm/ yr.**
- **South oriented movement of east Balkan region with magnitude generally exceeding 3 mm/yr.**

Table 5.2.1.1. Main characteristics of CEGRN epoch campaign solution obtained at the SUT Bratislava

Observing campaign	Epoch of observation	Number of sites included in the final solution	Residual RMS of the final solution
CEGRN'94	1994.34	27	0.0026 m
CEGRN'95	1995.31	36	0.0025 m
CEGRN'96	1996.45	37	0.0025 m
CEGRN'97	1997.43	45	0.0023 m

CEGRN'99	**1999.46**	**61**	**0.0025 m**
CEGRN'01	**2001.47**	**55**	**0.0027 m**
CEGRN'03	**2003.46**	**72**	**0.0030 m**
CEGRN'05	**2005.47**	**95**	**0.0031 m**

Fig. 5.2.1.1. GPS stations in southern part of Central Europe, Adriatic region and Balkan – status in CEGRN campaign 2005. o - permanent stations, □ - epoch stations, + - candidate stations

Table 5.2.1.2. Horizontal and vertical velocity estimates from epoch CEGRN campaigns. The intraplate velocities are obtained from ITRF2000 velocities reduced for APKIM 2000

Site	Number of campaigns	Time span of observations	v_n (mm/yr)	σ_{vn} (mm/yr)	v_e (mm/yr)	σ_{ve} (mm/yr)	v_h (mm/yr)	σ_{vh} (mm/yr)
LJUB	8	11	1.8	0.4	-0.1	0.4	-1.2	2.0
BUCA	6	10	-2.8	0.5	0.7	0.4	-0.7	2.5
HARM	4	9	-3.4	0.6	1.3	0.5	-3.3	3.0
SOFI	6	9	-2.4	0.6	1.0	0.5	-2.3	2.9
BRSK	8	11	1.6	0.4	1.0	0.3	-2.2	1.9
DISZ	8	11	-0.5	0.4	2.1	0.3	-2.5	1.9
IAS3	3	4	0.6	1.8	0.5	1.4	-1.0	10.5
MACI	3	3	-1.1	0.7	0.9	0.6	-4.5	3.9
TIS3	5	9	-2.5	0.6	0.7	0.5	-0.3	3.1
CSAR	8	11	0.2	0.4	0.4	0.3	-2.2	2.0
BOZI	4	6	2.9	0.8	-0.5	0.6	-2.9	4.0
BUCU	4	6	-2.3	0.8	-0.5	0.6	-0.5	4.0
CSAN	4	6	0.2	0.9	-0.0	0.9	-2.6	4.4

DUBR	3	4	2.9	1.2	-1.0	0.9	-5.2	5.6
FUN3	4	6	-2.7	0.8	-1.0	0.6	-0.6	4.1
HVAR	5	8	4.0	0.6	2.6	0.5	-7.0	3.0
MALJ	4	6	2.9	0.8	0.6	0.7	-4.4	4.2
SRJV	4	6	1.3	0.8	0.5	0.7	-2.8	4.2
VRN1	5	8	-2.7	0.9	-0.4	0.7	-11.9	4.6

Fig. 5.2.1.5. shows velocity field evaluated for regular grid obtained by interpolation of horizontal velocities. The interpolation procedure is based on least squares collocation respecting the covariance matrix of interpolated velocities.

The observed movements (Figs 5.2.1.4. and 5.2.1.5.) in the Balkan region can be generally described as clock-wise rotation with centre in Serbia. This interpretation is very approximate only and can be confirmed in the future, when more information will be available.

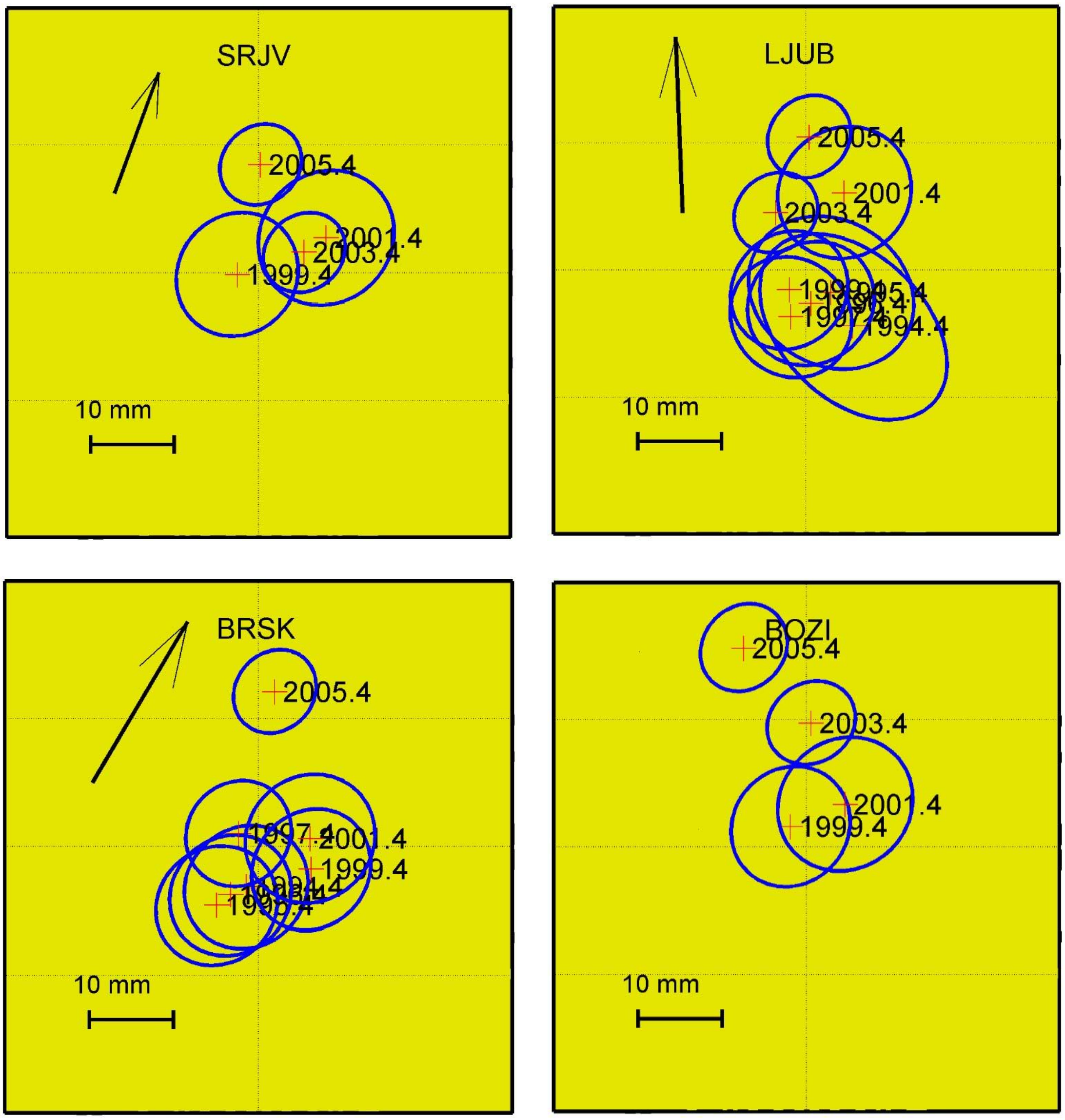


Fig. 5.2.1.2. Evolution of horizontal position of some CEGRN sites in western part of Balkan Peninsula. The vectors in upper left part indicate the observed motion during 11 years

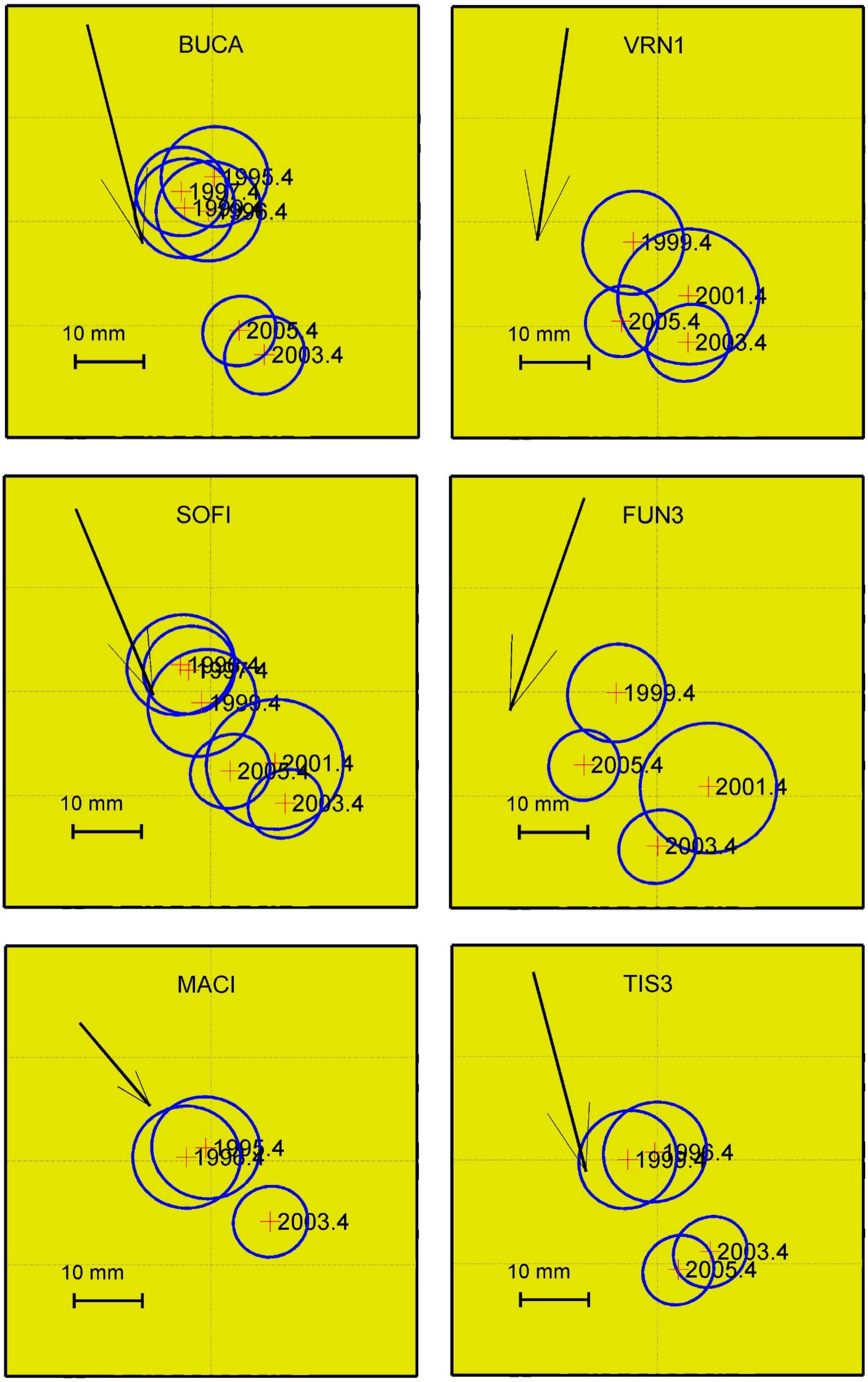


Fig. 5.2.1.3. Evolution of horizontal position of some CEGRN sites in eastern part of Balkan Peninsula. The vectors in upper left part indicate the observed motion during 11 years

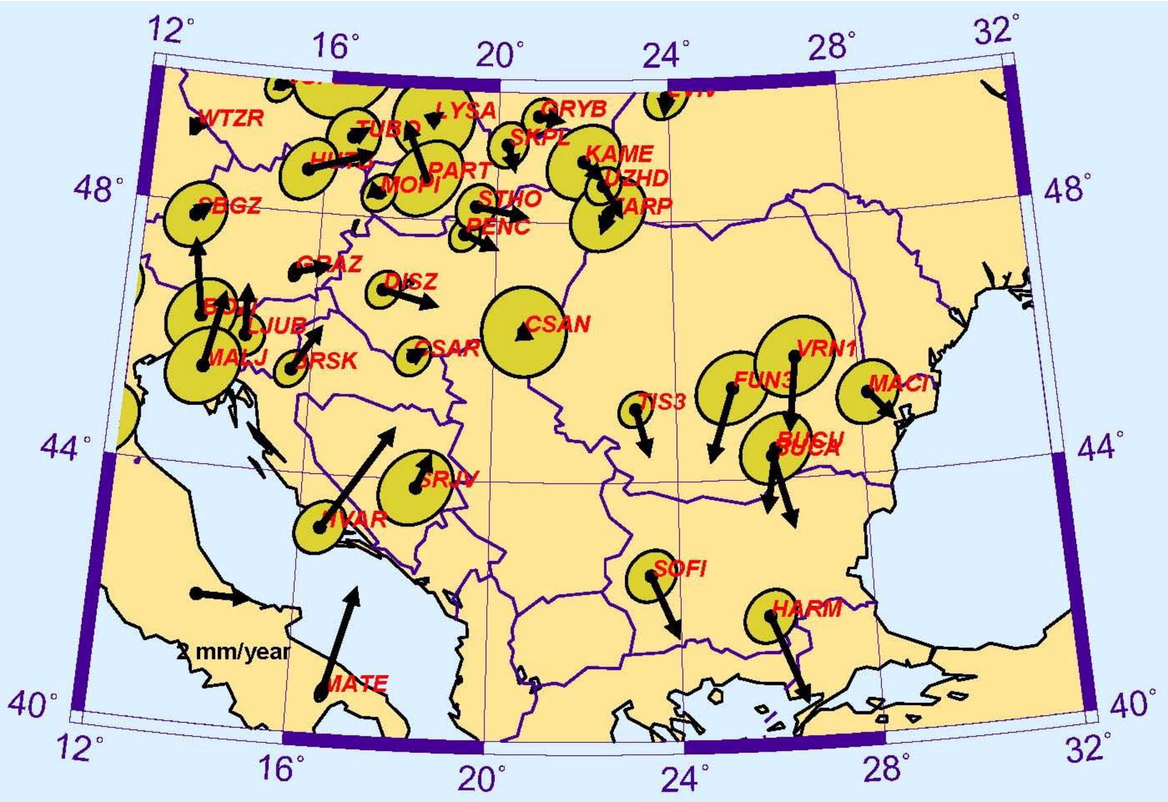


Fig. 5.2.1.4. Horizontal movements in Balkan Peninsula and adjacent region. The ellipses indicate the 2 σ confidence

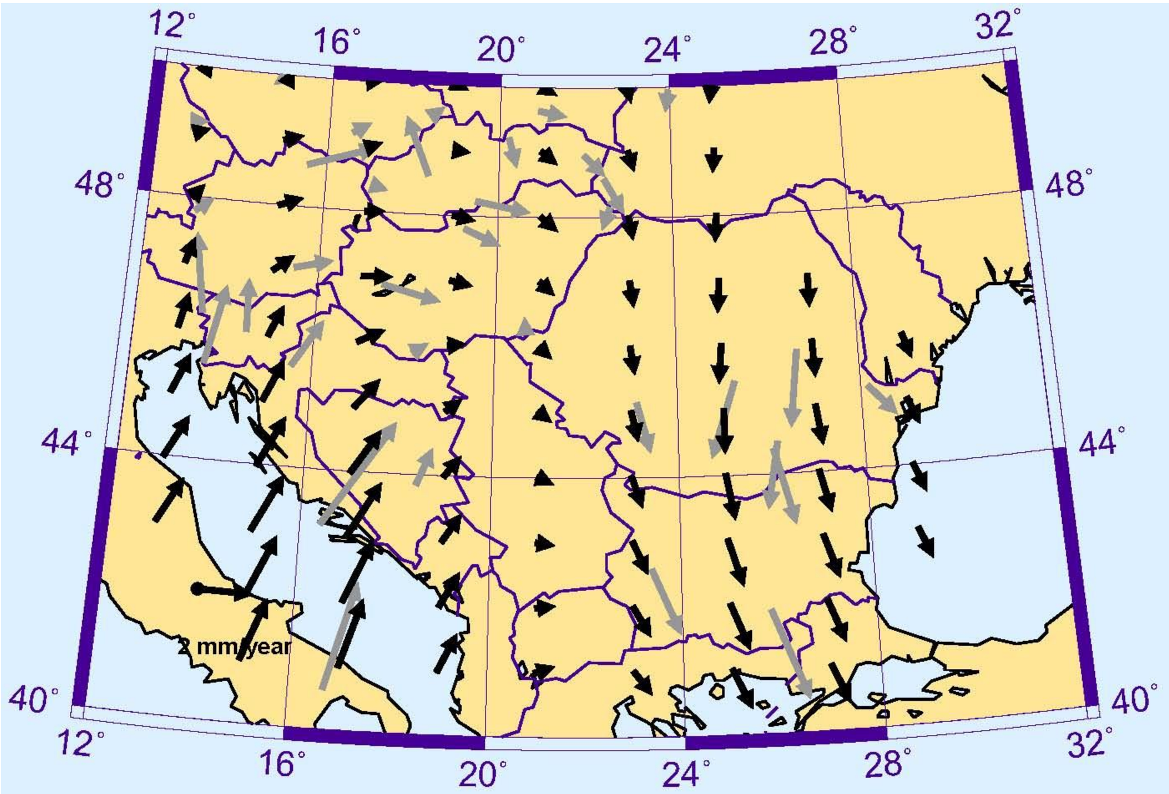


Fig. 5.2.1.5. Velocity field in regular grid obtained by interpolation using the least squares collocations (black vectors). The grey vectors are the original interpolated velocity field

The vertical movements with 1σ confidence are in Fig. 5.2.1.6. It is evident that vertical movements from epoch observations are below their observing accuracy. Situation at some station where the one-sigma interval is exceeded needs detailed investigations in future, stressing on antenna characteristics investigation.

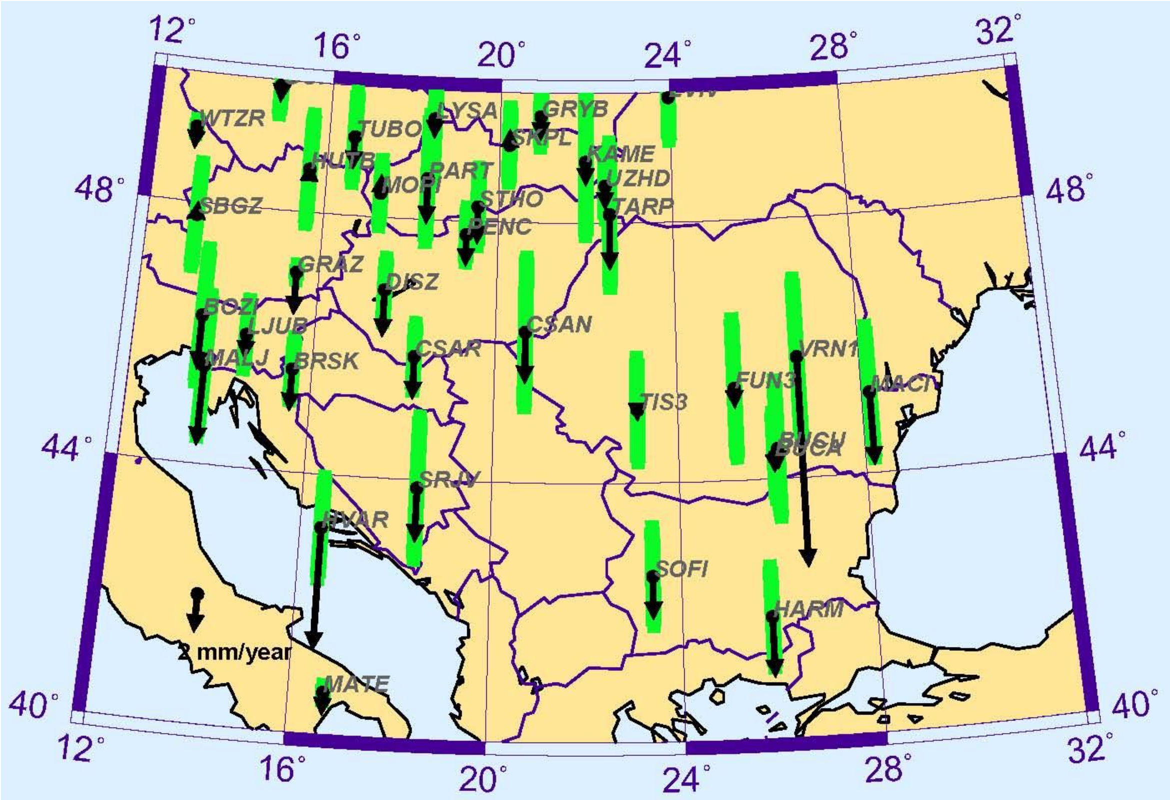


Fig. 5.2.1.6. Vertical coordinate changes in Balkan Peninsula and adjacent region with their mean errors.

5.2.1.3. Permanent observations

The number of permanent stations in Balkan region was in the past developed relatively slowly. Longer observation history (four or more years) have only five stations, namely GSR1, OROS, BUCU, SOFI and ORID. Only during last years more new stations were established. Majority of them are part of European Permanent Network of EUREF (EPN). Within the CERGOP-2/Environment Work Package 5 "GPS data analysis and the definition of reference frames" the network of permanent stations in the region of Central Europe and Balkan is continuously analyzed at SUT Bratislava. The analysis was starting from Jan. 2003 (GPS week 1200). The part of the analysed network comprising of EPN stations, CEGRN stations and other permanent stations is shown in Fig. 5.2.1.7., where are distinguished the longer analysed stations and the more recently analysed ones.

The method of analysis of the permanent network and the results obtained are described in (Hefty et al., 2005, Hefty, Igondová, 2006). Here we will present only the velocities relating to the area of interest. In Tab. 5.2.1.3. are summarised intraplate velocities of permanent stations in Balkan region. The values represent the relative velocities when the drift of Central European part of Eurasian plate is removed. This procedure of referencing gives velocities very close to ITRF2000 velocities with

removing APKIM 2000. For velocity estimation the permanent observations from more than 3-year interval (2003.0 – 2006.4) were used. For some sites (DUBR, OSJE and SRJV) only shorter or not continuous data are available. Number of weeks used for velocity estimation is given in last column of the table.

Fig. 5.2.1.7. Status of network of permanent stations include in the analysis at SUT Bratislava (Balkan Peninsula and adjacent region) in 2006. o – stations processed more than 3 years, ■ – stations processed approximately 2 years, + - stations processed one year or less

Table 5.2.1.3. Intraplate velocities estimated from permanent stations

Site	v_n (mm/yr)	σ_{vn} (mm/yr)	v_e (mm/yr)	σ_{ve} (mm/yr)	v_h (mm/yr)	σ_{vh} (mm/yr)	Number of weeks analyzed
GSR1	2.76	0.09	0.48	0.08	-1.51	0.28	165
PENC	0.70	0.12	0.97	0.09	-1.62	0.35	164
BUCU	-1.02	0.13	-1.12	0.16	3.22	0.54	165
DUBR	4.81	0.26	2.09	0.30	-0.86	0.50	128
ORID	-1.46	0.19	1.20	0.17	-0.06	0.61	158
OROS	1.72	0.13	-0.62	0.13	-1.90	0.38	164
OSJE	1.17	0.15	1.05	0.11	-2.00	0.36	138
SOFI	-1.27	0.24	0.62	0.23	0.36	0.62	162
SRJV	2.36	0.24	1.53	0.17	-1.49	0.98	91

The horizontal velocities are plotted in Fig. 5.2.1.8. It is clearly visible, that the orientation of these velocities in Balkan Peninsula in general matches the velocities from epoch observations in Fig. 5.2.1.4. Differences in magnitude exist but we have to stress that there are derived from different and independent data sources.

Fig. 5.2.1.8. Intraplate horizontal velocities from permanent observations

Vertical velocities are plotted in Fig. 5.2.1.9. Their magnitude is less than 2 mm/yr except BUCU, which shows an anomaly when compared to other permanent sites. Permanent stations give more consistent estimates of vertical velocities when compared to epoch observations, mainly because of stable antenna mounting and not exchange of antenna type on permanent stations. However the geodynamical interpretation of vertical velocities derived from 3-year interval of permanent GPS observations is still doubtful.

Fig. 5.2.1.9. Vertical velocities estimated from permanent GPS observations

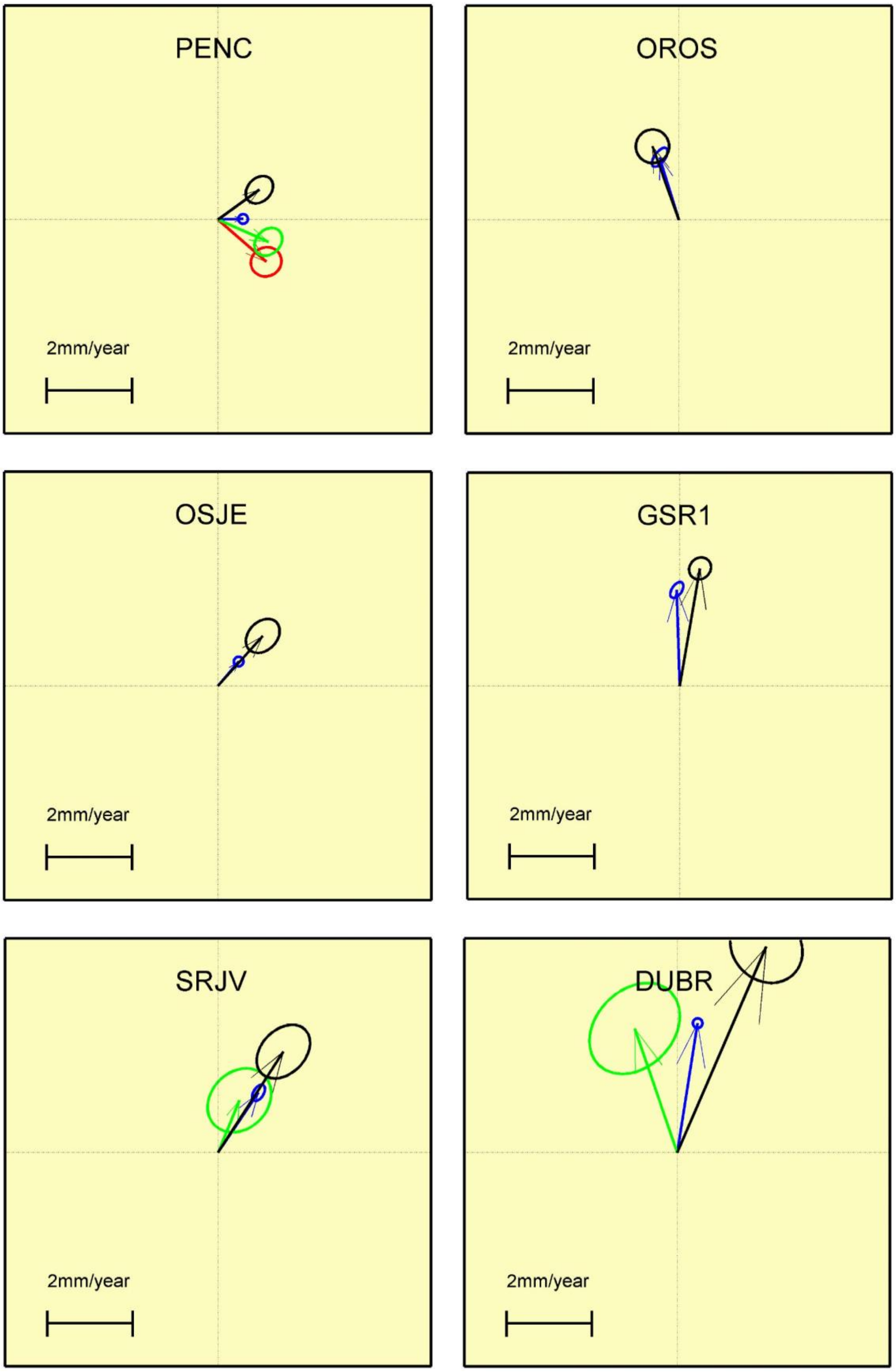
5.2.1.4. Comparison of velocities for some sites on Balkan Peninsula

For permanent stations with longer observation history are available more velocity estimates. We will compare information from four sources, which partly uses the same data, but the way of processing and referencing is quite different. Plotting of velocities of 8 sites is in Fig. 5.2.1.10.

Main characteristics of velocity fields used in comparison:

- **ITRF2000 velocities (Boucher et al., 2004) reduced for APKIM 2000 model (Drewes, 1998). The vectors and ellipses are in red colour.**
- **EPN velocities (Kenyeres, 2006) resulting from analysis of complete EPN series. They are referred to EUREF (blue colour). The estimated error ellipses are based on assumption of white noise model of time series.**
- **Velocities from permanent network analysis at SUT (previous chapter) with error ellipses considering the flicker noise of series (in black).**
- **Velocities from CEGRN epoch observations (green colour) expressed in ITRF2000 reduced form APKIM 2000.**

We can observe a general agreement of all compared values even some discrepancies can be noted. Namely the BUCU ITRF2000 velocity is outlied from other data (the velocity amplitude is more than 6 mm/yr, only a part of error ellipse is visible on Fig. 5.2.1.10.). The consistency at SOFI, SRJV, OROS, OSJE, GSR1 is satisfactory, at PENC, DUBR and BUCU are visible some discrepancies in orientation of the velocity vectors. But we have to keep in mind the different approach to analysis and referencing. In this way the coincidence of main tendency is satisfactory.



PENC
2mm/year
OROS
2mm/year
OSJE
2mm/year
GSR1
2mm/year
SRJV
2mm/year
DUBR
2mm/year

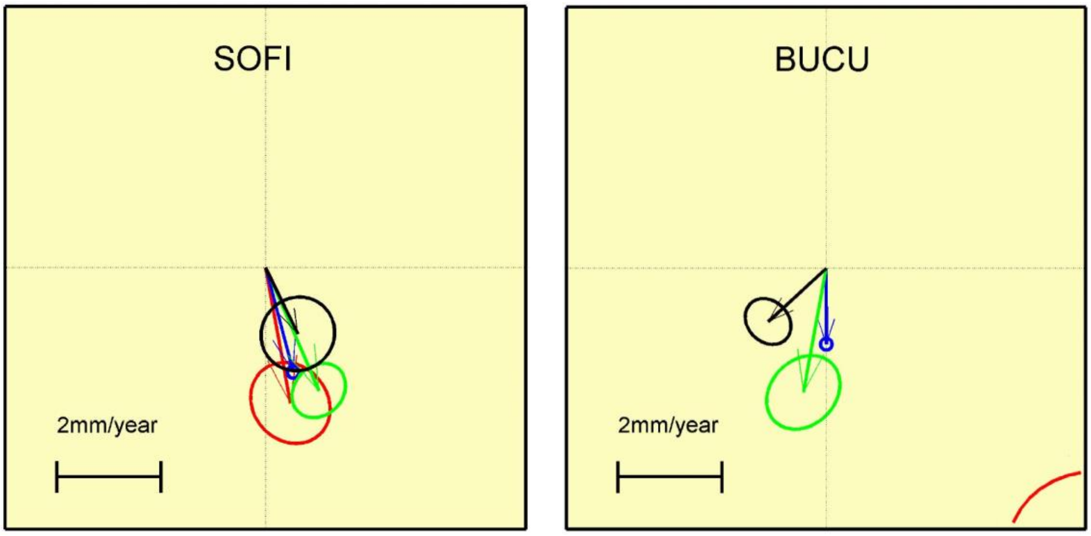


Fig. 5.2.1.10. (Continuation) Horizontal velocities from four different velocity estimations. ITRF velocities reduced form APKIM (red), EPN velocities (blue), intraplate velocities from permanent analysis at SUT (black) and intraplate CEGRN epoch velocities (green)

5.2.1.5. Conclusions

Epoch and permanent GPS observations in the Balkan Peninsula performed and analysed in the framework of CERGOP-2/ENVIRONMENT were proved as a very powerful tool for geodynamic investigations. Mainly the epoch observations are valuable because of the density of the network and long-term history of observations. Their shortcomings are in frequent destroying of GPS markers and equipment alterations. The consistency of epoch and permanent observations in the region was proved and the data from permanent networks can be regarded as an independent support of the quality of the kinematic information obtained.

The geokinematics of Balkan Peninsula can be characterized by some general features:

1. **The intraplate horizontal velocities are exceeding 2 mm/yr, and are significantly larger than velocities in the Central European part of the continent.**
2. **The orientation of velocities is opposite in the western and eastern part of the Balkan Peninsula. Fro the western part is characteristic northward tendency and form eastern part is characteristic southward tendency. Unfortunately at this moment the lacks of data do not allow to define the boundary between these two tendencies.**
3. **The comparison of velocities from different sources proved their consistency and supports the above stated tendencies.**
4. **Neither the epoch observations nor the permanent observations yield satisfactory information about the vertical movements in the region. However the permanent stations are more promising in this context.**

5.2.1.6 References

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