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GEO-KINEMATICS OF CENTRAL AND SOUTH-EAST EUROPE RESULTING FROM COMBINATION OF VARIOUS REGIONAL GPS VELOCITY FIELDS

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ABSTRACT

The region of Central Europe, Adriatic region and Balkan Peninsula were subjects of geo-kinematical monitoring in several projects performed since 1992. Independent GPS epoch-wise observing campaigns took place in several regions and the whole territory is now covered by tens of permanent stations. The long-term observational series from permanent stations generally yield reliable site velocities, however distribution of such stations is not dense enough to provide velocity field with sufficient resolution all over the monitored region. On the other side the epoch-wise campaigns sites are much denser than the permanent ones, however the repeated epoch observations are not very frequent and their referencing is not unique. In the paper we shortly describe velocity fields available from various national and regional GPS geo-kinematics projects and an attempt to homogenize the heterogeneous velocity fields is presented. The intraplate GPS velocities in Central and South-East Europe and their reliability are discussed, mainly focusing on Adria and East Balkan region where the geo-kinematics is mostly variable and complicated.

KEYWORDS: site velocities, permanent and epoch-wise GPS observations, Euler pole of rotation, regional geo-kinematics

1. INTRODUCTION

The countries in Central Europe and Balkan Peninsula are covered by several regional and national permanent and/or epoch-wise GPS networks devoted to geokinematical investigations. The history, purpose, observing schedule, monumentation, instrumentation, etc. of these networks is very variable. They depend on scientific intents, methodology of observations and analysis, financial abilities, etc. Such networks were processed and analyzed individually and usually quite mutually independently; they are yielding regional or local velocity fields usually not connected to velocity fields of the neighboring regions.

Simple combination of various individual site coordinates or velocities into a unique system is not straightforward because of different realizations of reference frames, different sets of reference sites, different epochs and various accuracy and quality of the input data. In this paper will be proposed and verified a method which can be applied to combine various horizontal velocity fields into common set resulting to homogenized detailed velocity field covering the area of interest. As the reference we will use the EPN station velocities (Kenyeres, 2007) expressed in ITRF2000, epoch 1997.0. EPN stations cover almost the whole territory of our interest and besides, the subset of EPN stations is usually included in the analysis of a majority of regional or local GPS networks. The method for alignment of individual local or regional networks to EPN velocity field applied in this paper is based on the adjustment of Euler pole and angular velocity of rotation for a set of identical points in the pairs of networks. Consecutively, the adjusted parameters will be used for transformation of the velocities at non-identical points.

The selection of local and regional velocity fields suitable for this study was dependent on the availability of the outputs in scientific journals and conference proceedings. Moreover, it was dependent on fulfilling two requirements:

- the site coordinates and horizontal velocities are available in a numerical form,
- there are at least two identical points with velocities in both EPN and regional velocity field.

Up to the present time we succeeded to gather 7 horizontal velocity fields obtained by analysis of epoch or permanent regional networks which fulfill the above requirements. The area of our interest is covering the Central Europe, Adria region, West and East Balkan and is approximately limited by geographical latitudes ranging from 40° to 54° and longitudes from 10° to 28°. We are aware of the fact that in the region considered there are more local velocity fields (or more dense networks and more

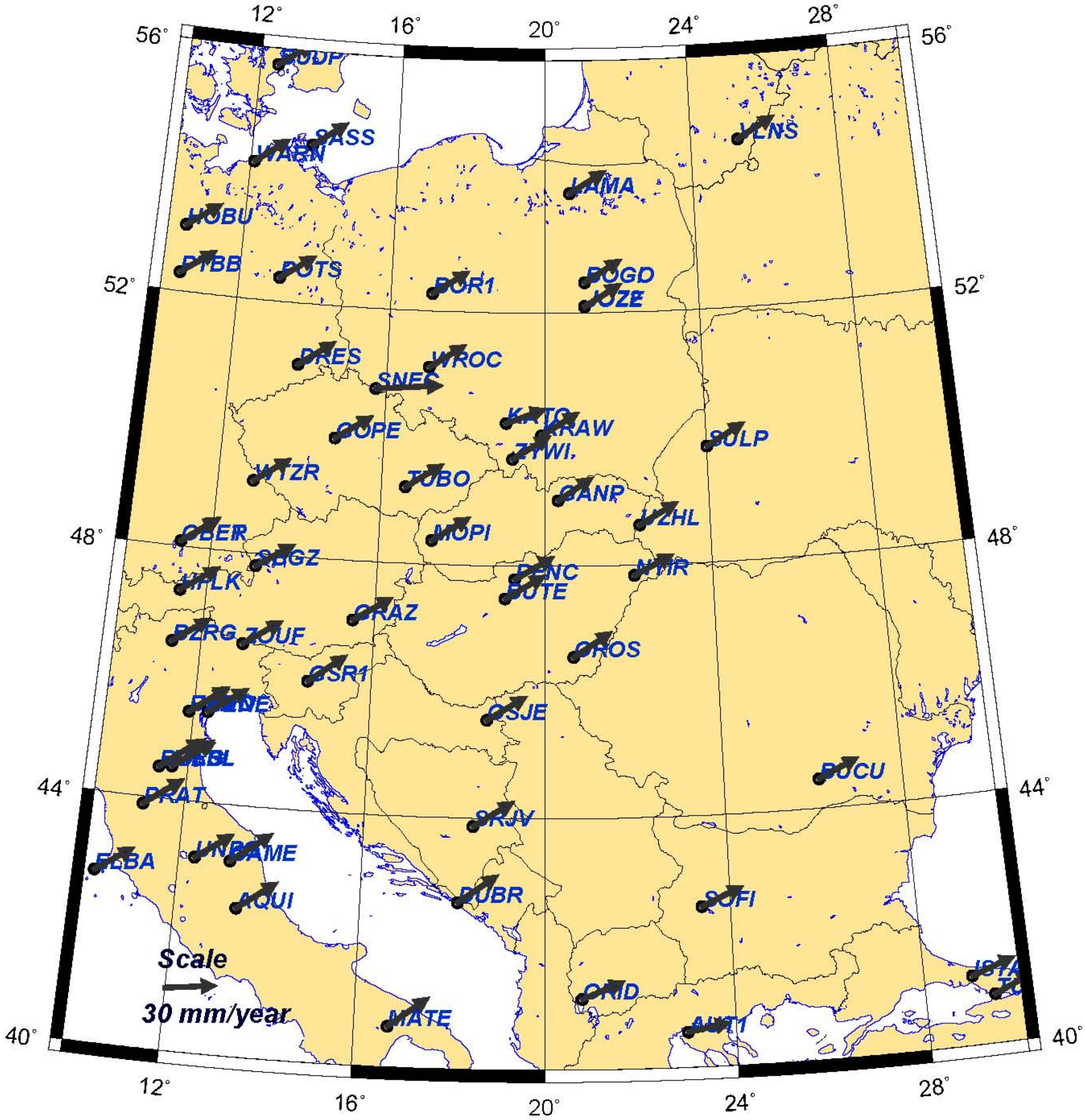

Fig. 1 The EPN velocities in the region of Central and South-east Europe evaluated in ITRF 2000.

recent solutions) available. However, in this paper we will concentrate mainly on the method of velocity combination and the related problems. The combination of potential larger number of input velocity fields will be the topic of another paper.

2. REGIONAL AND LOCAL VELOCITY FIELDS USED FOR COMBINATION

Firstly, we will shortly describe the datasets which will be used in the combination process. We will limit the information here only to basic facts necessary for the data analysis in this paper and to the references where the numerical values of velocities and further detailed information are available.

2.1. EUROPEAN PERMANENT NETWORK

In the region of our interest are situated more than 50 EPN permanent stations for which site velocities are estimated within the project The EPN Coordinate Time Series Analysis (EPN, 2007). We used the velocities referred to ITRF2000, epoch 1997.0 obtained by CATREF software (Altamimi, 2003) with minimum constraint solution. These data represent the most stable and homogeneous velocity field in the region; the sites are distributed all over the region, even though not quite uniformly. These velocities will be further used as the reference for other velocity fields as there is available a sufficient number of identical sites included in EPN and in local velocity fields. The multi-year solution of EPN is based on combined solutions from GPS week 0860 to 1378 (1996.5 – 2006.4), what means that for stations with longest observation history nearly 10-year interval was analyzed. As the lower limit we considered here the stations with 2-year observation data span. The declared formal precision of horizontal velocity components is from 0.01 to 0.10 mm/year (EPN, 2007). These precision characteristics are too optimistic as they do not consider the fact that the noise of permanent observations cannot be modeled as pure white noise but more complex model with inclusion of colored noise has to be introduced (Williams, 2003). Figure 1 shows the velocities of EPN stations used in our analysis.

2.2. CERGOP VELOCITY FIELD

The velocities evaluated from epoch-wise observations within the CERGOP and CERGOP-2/Environment (Fejes and Pesec, 2003) are covering the whole territory of Central Europe and Balkan. The solution based on observations from 1994 to 2005 is summarized in (Hefty et al., 2006). Totally 8 epoch network campaigns performed annually or biannually in late spring, each lasting from 5 to 7 days, were combined to yield site coordinates and velocities. The requirement for inclusion the site into velocity estimation procedure was participation in 3 observing campaigns at minimum. The final combined solution contains velocities of 61 sites related to ITRF2000, their geographical distribution is shown in Figure 2. Among them are 29 permanent EPN stations, their data were processed in the same mode as other epoch stations. The velocities are obtained by complex statistical model resulting also in the covariance matrix of the estimated parameters. The accuracy of horizontal velocity components is in the range from 0.4 to 1.2 mm/year according to the data span used at the epoch stations.

2.3. NETWORK OF PERMANENT STATIONS IN CENTRAL EUROPE AND BALKAN PENINSULA

The network of permanent stations situated in Central Europe and Balkan Peninsula (CEBAPER) is analyzed within the CERGOP-2/Environment project since the beginning of 2003. The purpose of this network is to maintain a sufficiently dense reference for regional GPS activities performed in framework of CERGOP-2/Environment (Hefty, 2006). The network comprises more than 50 permanent stations, mainly EPN, but there are also 12 non-EPN stations included. The velocity field is of relative character. The intraplate velocities are evaluated according to the method described in (Hefty et al., 2005). Generally four-year intervals of observations are used for velocities estimation, however also shorter datasets are used to fill in the gaps in regions covered by newly established permanent stations (the minimum interval used was 1.5 year of continuous observations). The intraplate velocity field is shown in Figure 3. Accuracy of horizontal velocities is from 0.07 to 0.20 mm/year obtained by a procedure not considering the colored noise approach.

2.4. NETWORK OF PERMANENT STATIONS IN ITALY AND CLOSE REGIONS

Weekly solutions from 45 permanent GPS stations covering Alpine Mediterranean area (ALPMED) are used in (Caporali et al., 2003) for estimation of horizontal velocity field aligned with the ITRF2000. Horizontal velocities and their uncertainties are evaluated for 36 EPN and 9 non-EPN stations. The published uncertainties are in the range from 0.01 to 0.27 mm/year. The uncertainties are not fully homogeneous as for four selected stations there are a-priori constrained to 0.01 mm/year. From the distribution of stations in Figure 4 it is evident, that only a part of stations situated eastward from meridian 10° will be usable for our analysis.

2.5. VELOCITIES OF CROATIAN AND SLOVENE GEODYNAMIC NETWORK

We used the results form the epoch-wise network CRODYN (Croatian and Slovene Geodynamic Network) published in (Altiner et al., 2006). The velocities of 17 stations are computed on a basis of three epoch campaigns performed from 1994 to 1998, 16 further sites were observed only in two epochs separated by two years. The network analysis included also seven EPN stations. The published velocities were obtained by setting one site (GRAZ) as a reference, so they are of relative character. Figure 5 shows the CRODYN velocities in the central part of network. The velocity uncertainties were obtained by scaling the formal errors from network processing and do only approximate the real accuracy of estimated velocities.

2.6. VELOCITIES OF BULGARIAN EUREF STATIONS

On the territory of Bulgaria two epoch observing campaigns in 1993 and 2003 within the EUREF activities were performed. The set of 15 stations forms the Bulgarian reference network (BULREF). The ITRF2000 referenced velocities of 11 BULREF sites together with 5 outside EPN stations are evaluated in (Milev et al., 2005). The reported RMS of estimated velocities are extremely small – 0.01-0.04 mm/year in horizontal components, and therefore we consider these information as unreliable. The BULREF velocity field is shown in Figure 6.

2.7. INTRAPLATE VELOCITIES OF HUNGARIAN GEODYNAMIC NETWORK

The velocities obtained form processing of Hungarian Geodynamic Reference Network (HGRN) are analyzed in (Grenerczy, 2002). The intraplate velocity field comprising of 13 HGRN sites is based

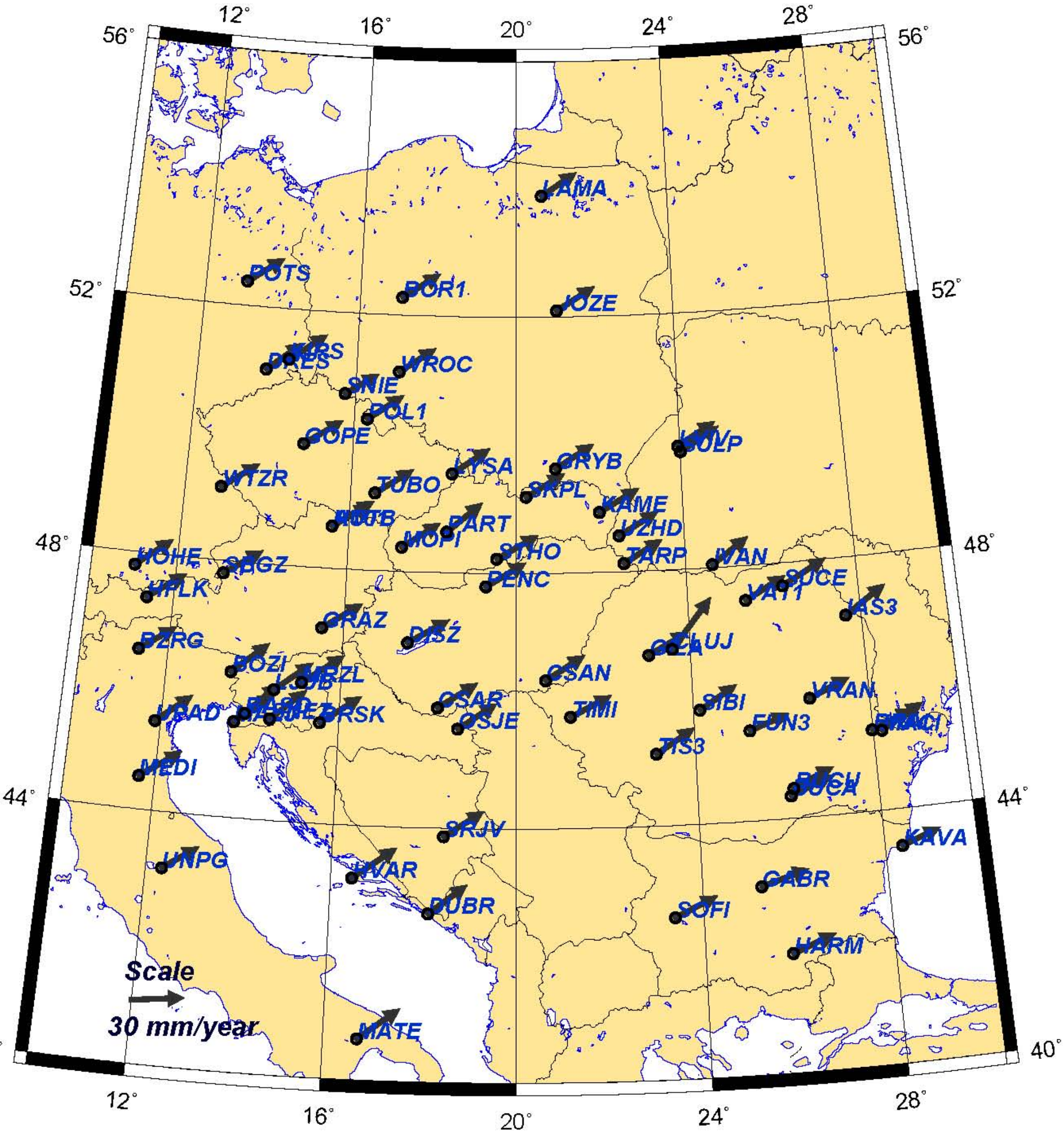

Fig. 2 The CERGOP velocity field referred to ITRF2000.

on 5 epoch campaigns performed from 1991 to 1999 in two-year intervals. The network which includes also two EPN sites PENC and GRAZ is shown in Figure 7. The declared accuracy of horizontal components of velocity vector is from 0.5 to 1.1 mm/year.

2.8. VELOCITIES OF SLOVAK GEODYNAMIC REFERENCE NETWORK

The basis of Slovak Geodynamic Reference Network (SGRN) comprising 17 points was established in 1993. Since the first epoch campaign in 1993 the network was gradually enlarged and re-observed 8 times (Leitmannová et al., 2001). The velocities of 29 sites shown in Figure 8 were obtained in complex coordinate and velocity estimation procedure yielding also the global covariance matrix (Hefty and Kováč, 2004). The adjustment of the network includes also 11 EPN sites. The accuracy of horizontal velocity components is from 0.4 to 1.6 mm/year depending on the time span of epoch-wise observations.

3. METHOD OF COMBINATION OF VARIOUS HORIZONTAL FIELDS INTO HOMOGENEOUS SYSTEM

If the horizontal velocities describe movement of a homogeneous, compact area on a spherical surface they can be described as a rotation around the Euler pole with spherical coordinates φ_E and λ_E. The

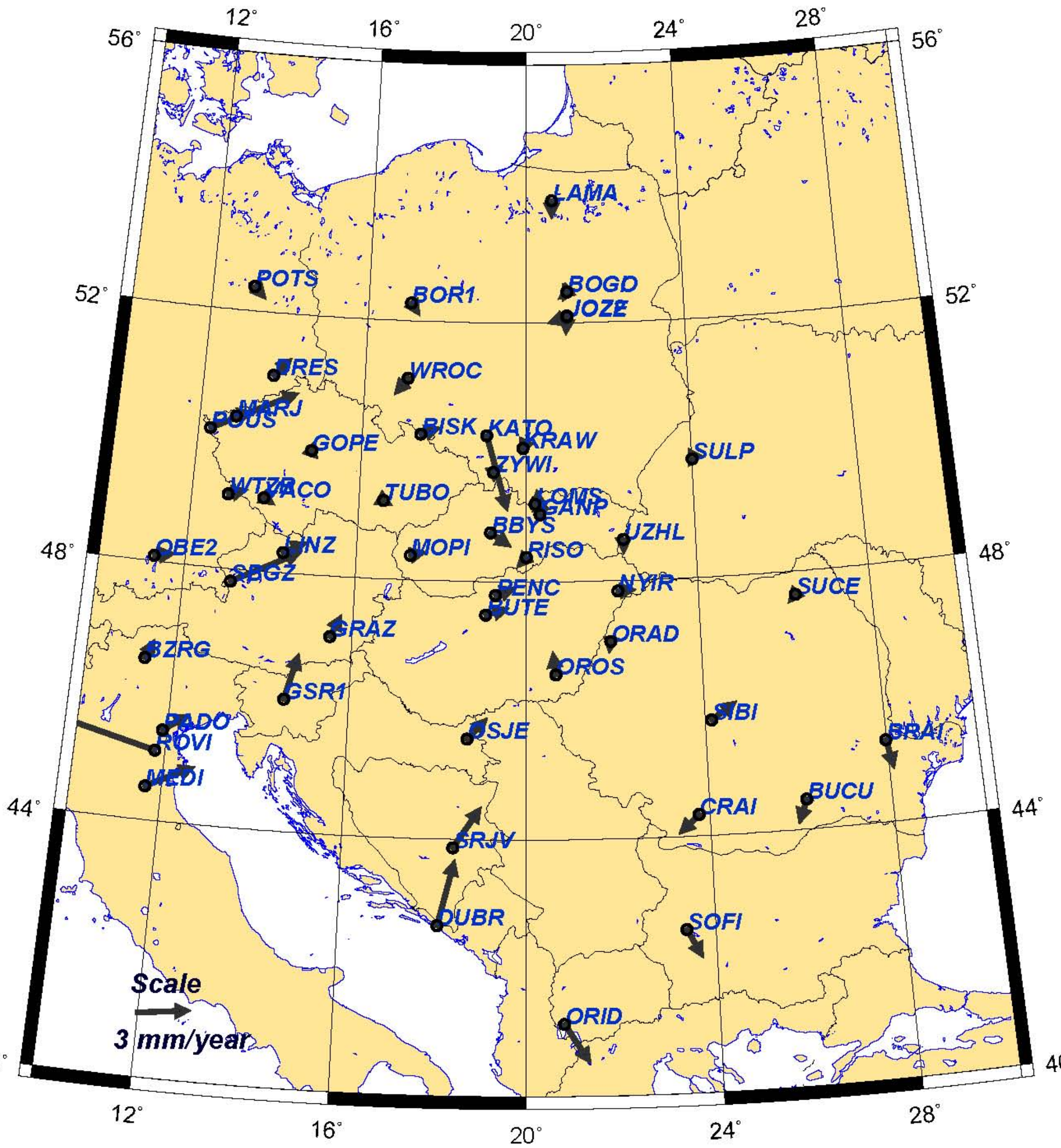

Fig. 3 The intraplate velocities from permanent stations in Central Europe and Balkan region (CEBAPER).

velocity components in north-south v_n and east-west v_e directions of the velocity vector $\boldsymbol{v}$ of the site with coordinates φ and λ are expressed as

$$\begin{aligned} v_n &= \omega \sin(\lambda - \lambda_E)\cos\varphi_E \\ v_e &= \omega[\cos\varphi_E \sin\varphi \cos(\lambda - \lambda_E) - \sin\varphi_E \cos\varphi] \end{aligned}, \quad (1)$$

where ω is the angular velocity around Euler rotation axis (see Fig. 9).

The same principle can be used for the determination of rotation between two velocity fields which are not evaluated in the same reference. If we denote velocity components in the reference (1) as $v_n^{(1)}$, $v_e^{(1)}$ and as $v_n^{(2)}$, $v_e^{(2)}$ the velocities in the reference (2) their differences are

$$\begin{aligned} \delta v_n &= v_n^{(2)} - v_n^{(1)} \\ \delta v_e &= v_e^{(2)} - v_e^{(1)} \end{aligned}. \quad (2)$$

Then these differences can be expressed as a rotation around the pole with coordinates φ_{ED} and λ_{ED}

$$\begin{aligned} \delta v_n &= \delta\omega \sin(\lambda - \lambda_{ED})\cos\varphi_{ED} \\ \delta v_e &= \delta\omega[\cos\varphi_{ED} \sin\varphi \cos(\lambda - \lambda_{ED}) \\ &\quad - \sin\varphi_{ED} \cos\varphi] \end{aligned} \quad (3)$$

where δω is the angular velocity describing the differential rotation of reference (2) relatively to reference (1).

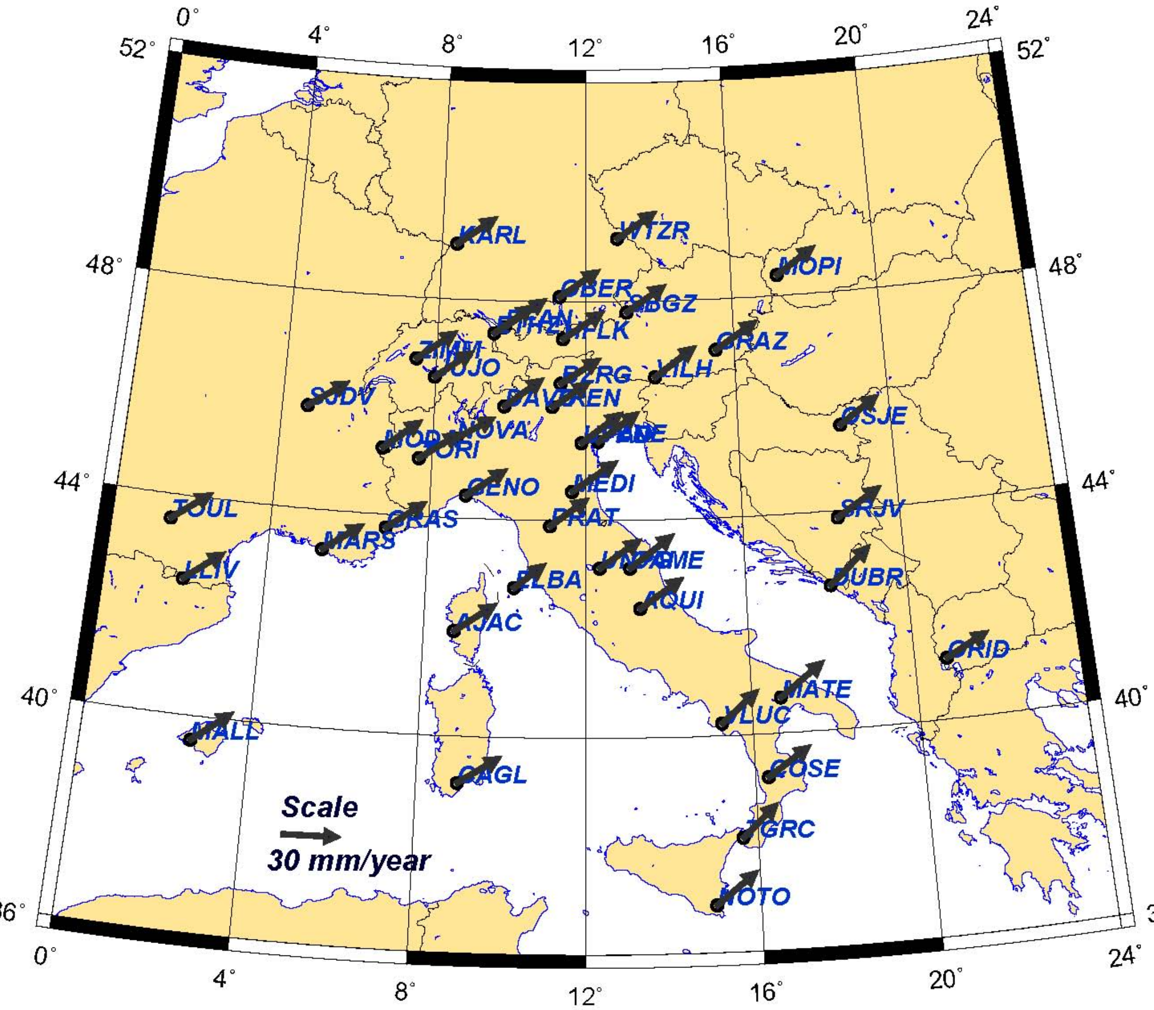

Fig. 4 The ITRF2000 related velocities from permanent ALPMED stations.

If the velocity differences δv_n and δv_e of at least two sites are available, then the position of pole of rotation φ_{ED} and λ_{ED} and the angular velocity $\delta\omega$ can be estimated using the method of least squares. Note that the parameters φ_{ED} and λ_{ED} are not in linear relationship with the observables δv_n and δv_e and the linearization of (3) is necessary. Then the approximate position of pole of rotation φ_{ED0} and λ_{ED0} has to be established. A problematic task can arise when δv_n and δv_e are small and rather arbitrarily spread out quantities; the estimation of approximate position of Euler pole is difficult. In such case an auxiliary approach, which uses the geometrical representation of the velocities δv_n and δv_e, can be helpful for determining the approximate coordinates φ_{ED0} and λ_{ED0}.

The unknown parameters $\delta\omega$, φ_{ED} and λ_{ED} will be estimated on the basis of a set of identical points for which velocities in two reference frames (1) and (2) are available. The covariance matrix of estimated parameters will be scaled by factor σ_0^2 obtained from residuals at identical points. The parameters $\delta\omega$, φ_{ED} and λ_{ED} will be subsequently used for transformation of velocities of non-identical points between frames (1) and (2).

4. TRANSFORMATION OF LOCAL VELOCITY FIELDS INTO SYSTEM CONSISTENT WITH EPN STATION VELOCITIES EXPRESSED IN ITRF2000

Equations (3) were used to estimate the parameters $\delta\omega$, φ_{ED} and λ_{ED} enabling the transformation of local horizontal velocity fields mentioned in previous chapter into the system which will be consistent with EPN station velocities. In this situation the velocity constituents $v_n^{(1)}$ and $v_e^{(1)}$ are taken from the EPN velocity field and the constituents $v_n^{(2)}$, $v_e^{(2)}$ are subsequently taken from regional or national velocity fields mentioned in chapters 2.2 - 2.8.

The results from least squares adjustments of 7 sets of identical velocities are summarized in Table 1. According to the values of estimated parameters it is evident that the used velocity fields are rather

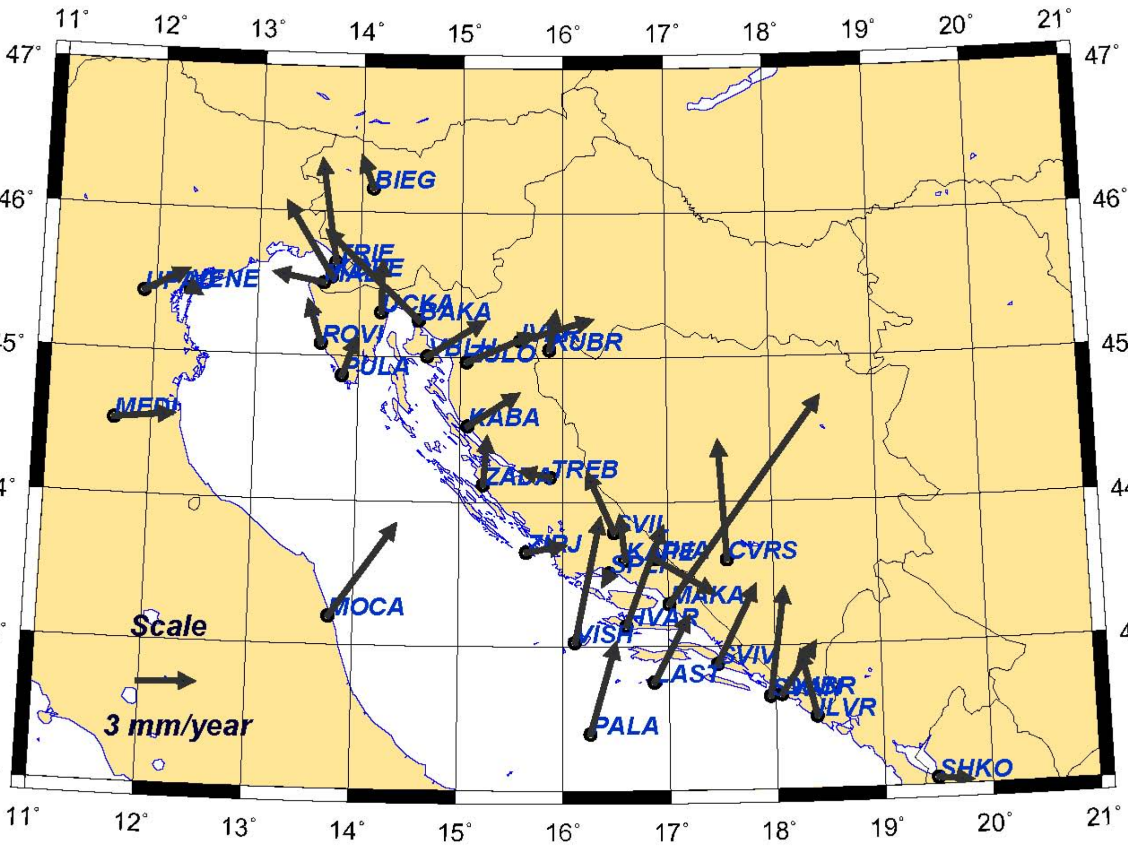

Fig. 5 The intraplate velocities of the CRODYN.

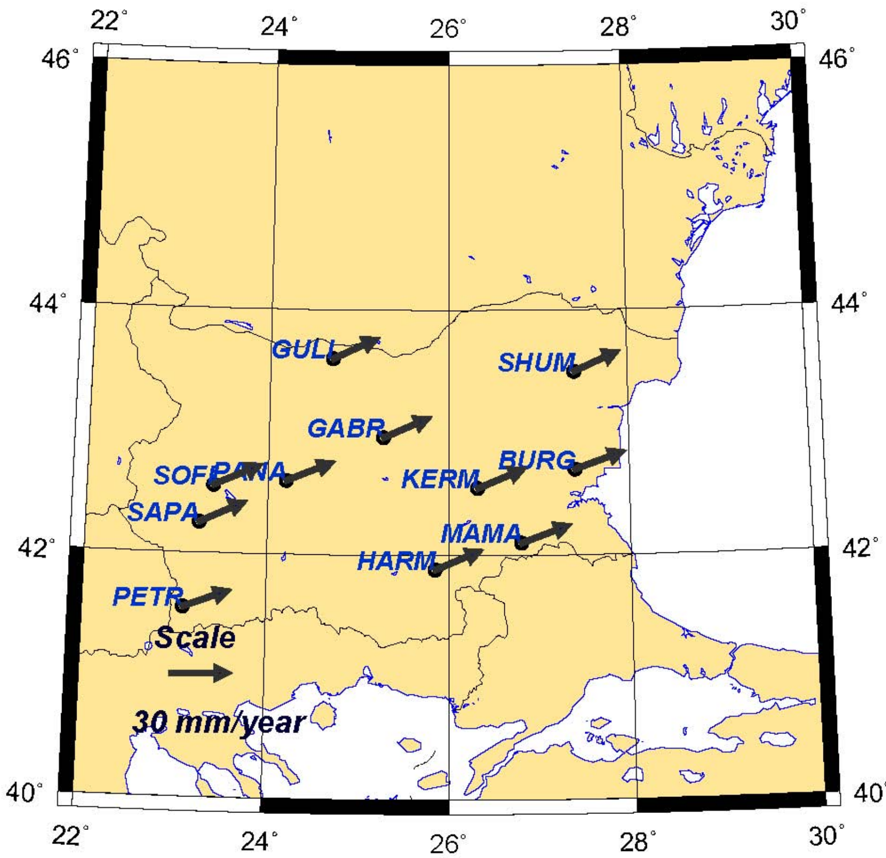

Fig. 6 Velocities in the territory of Bulgaria determined from two campaigns of BULREF.

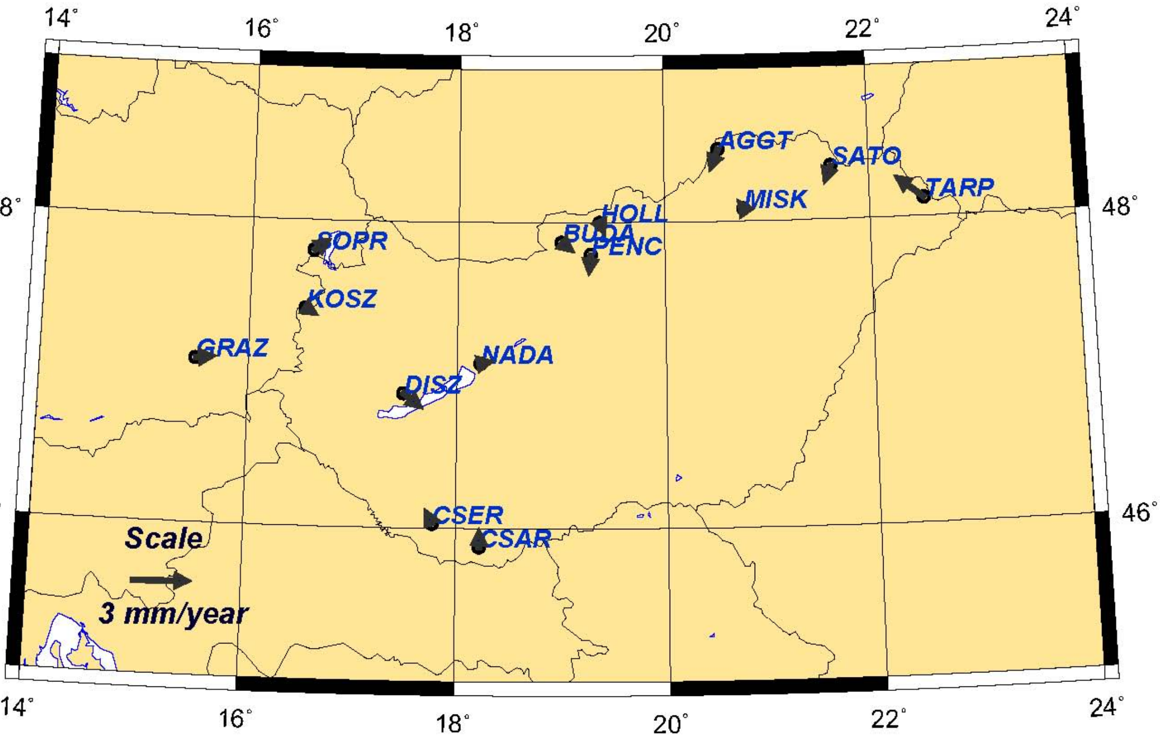

Fig. 7 The intraplate velocities in Hungarian epoch-wise network HGRN.

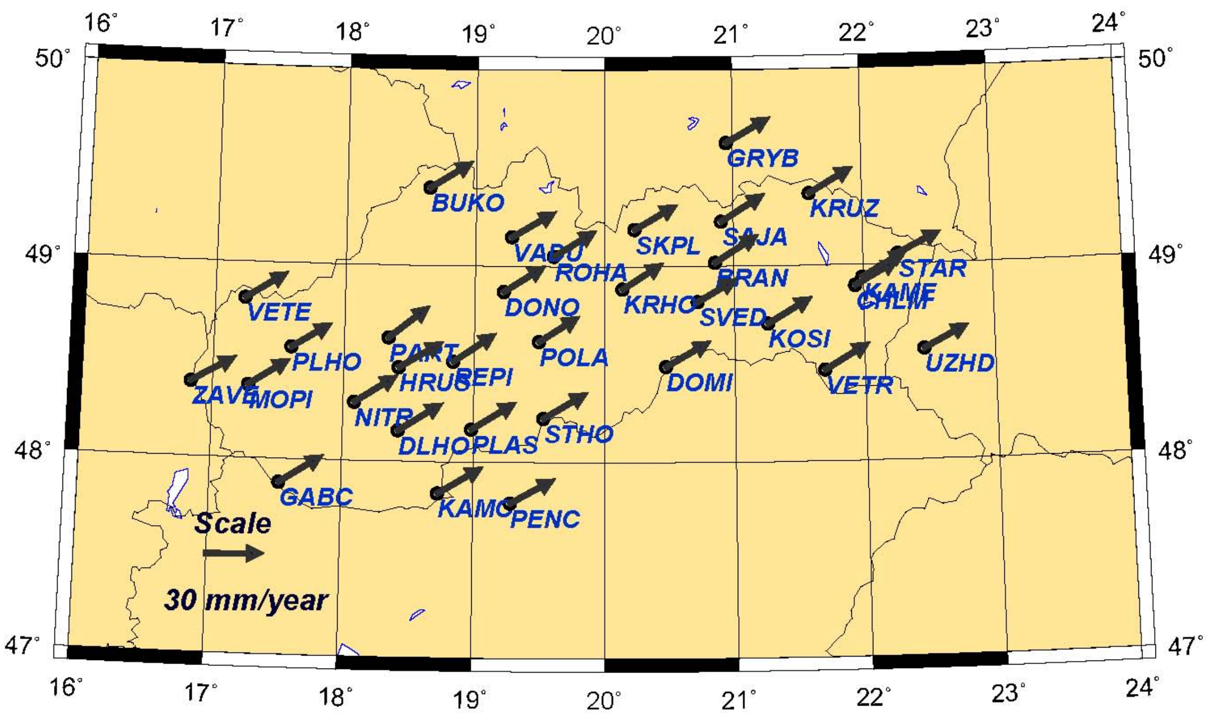

Fig. 8 The ITRF2000 related velocities from epoch-wise network SGRN in Slovakia.

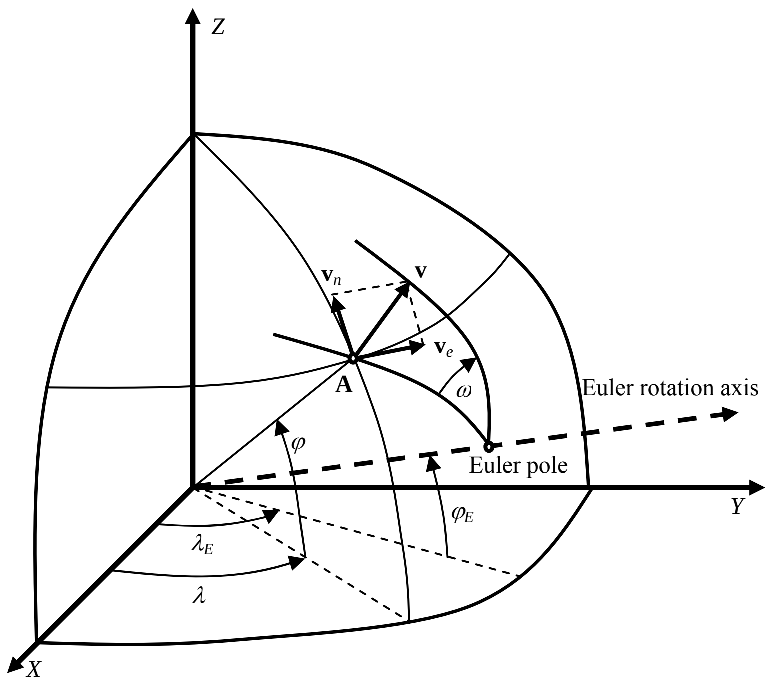

Fig. 9 The horizontal velocities expressed as the rotation around Euler pole.

heterogeneous. It concerns the types of network – epoch-wise or permanent, reference frames for velocities – ITRF or intraplate and in particular the number *m* of identical points between EPN and regional velocity field. The last mentioned quantity is varying from 36 points for CEBAPER to 2 points for HGRN. The overall characteristics of the transformation parameter definition is the RMS of unit weight σ_0 which is in range from 0.25 to 1.12 mm/year.

The transformation parameters $\delta\omega$ of velocity fields which are related to ITRF2000 are usually smaller or at the level of their uncertainties, except the ALPMED. Of course for intraplate velocities the rotations $\delta\omega$ which are relative to ITRF2000 are reaching 0.001″/zdar which correspond to about 30 mm/year on the Earth's surface – the velocity of Eurasian tectonic plate. The uncertainties of φ_{ED} and λ_{ED} are in some networks very large what can be explained by inconvenient geometry of identical points and by the fact that the rotation angles $\delta\omega$ are very small. However we have to stress that these parameter uncertainties are only minimally influencing the transformed velocities of non-identical points.

The transformation procedure applied for all networks mentioned in previous chapter yields 260 velocities, all of them are referred to ITRF2000. For more than 40 EPN sites are available velocities from two networks at least, and for more than 30 sites we have velocities from 3 networks. In Figure 10 are shown some examples of the sites where the velocities determined within three to six networks are available. For better visualization of variability of individual velocities we reduced the ITRF2000 related velocities for the Actual Plate Kinematics Model APKIM 2000 (Drewes, 1998). The Eurasia rotation angle and Euler pole coordinates according to this model are

$\delta\omega_A$ = 0.004509 rad/My = 0.930 mas/year ,
φ_{EA} = 57.9° , λ_{EA} =97.1°

From all the ITRF2000 related velocities was subtracted the model according to the relations

$$
\begin{aligned}
(v_n)_{INTRAPLATE} &= (v_n)_{ITRF} - \delta\omega_A \sin(\lambda - \lambda_{EA}) \cos\varphi_{EA} \\
(v_e)_{INTRAPLATE} &= (v_e)_{ITRF} - \delta\omega_A [\cos\varphi_{EA} \sin\varphi \cos(\lambda - \lambda_{EA}) \\
&\quad - \sin\varphi_{EA} \cos\varphi]
\end{aligned}
\tag{4}
$$

The intraplate velocities at twelve EPN sites determined within various networks which are shown in Figure 10 prove in general their good consistency. Velocity magnitudes agree at the level better than 1 mm/year. There are some anomalies observed in the orientation of velocity vectors, namely the ALPMED velocities at BZRG and ORID, and the CRODYN velocities at BOR1 and PENC. The main reason is probably in the fact that the ALPMED used only data before 2003 and CRODYN data before 1999 only.

Table 1 Estimated coordinates φ_{ED} and λ_{ED} of Euref pole and the differential rotation $\delta\omega$ among EPN and other regional/local velocity fields. The values *n* and *m* express the total number of velocities in the network and the number of identical sites with EPN.

Network	Observations used	Reference for velocities	*m* / *n*	σ_0 (mm/year)	$\delta\omega$ / $\sigma_{\delta\omega}$ (mas/year)	φ_{ED} / $\sigma_{\varphi ED}$ (°)	λ_{ED} / $\sigma_{\lambda ED}$ (°)
CERGOP	Epoch	ITRF2000	27	0.40	-0.001	63.3	16.1
			71		0.011	41.3	9.9
CEBAPER	Permanent	Intraplate	36	0.50	0.889	55.3	-103.8
			51		0.015	1.6	2.5
ALPMED	Permanent	ITRF2000	34	0.81	-0.121	42.9	11.0
			44		0.053	2.3	5.8
CRODYN	Epoch	Intraplate	7	1.12	0.765	22.0	-129.7
			42		0.025	13.3	7.8
BULREF	Epoch	ITRF2000	6	0.25	0.045	47.8	16.2
			16		0.040	4.7	6.1
HGRN	Epoch	Intraplate	2	0.54	1.077	64.7	-81.5
			14		0.336	10.8	43.8
SGRN	Epoch	ITRF2000	11	0.29	-0.012	62.3	-5.7
			42		0.021	8.9	78.9

5. THE INTRAPLATE VELOCITY FIELD IN CENTRAL AND SOUTH-EAST EUROPE

The intraplate velocities obtained after application of transformation and reduction procedures described in previous chapter form the velocity field which is homogeneous in the sense of the reference as all the individual velocity fields are consistent with EPN velocity field. However the stochastic parameters of the individual velocity fields are poorly known, in some networks they are overestimated or only approximated. In this situation the evaluation of velocities at sites where data from more networks are available cannot be based on a rigorous combination procedure. Therefore we adapted a following scheme for choice of representative site velocity:

- If the EPN site velocity is available we have taken this value as representative.
- In the case that at the site the velocities from more epoch campaigns are available the velocity evaluated from longer data set is preferred.

At the stations where velocities from both epoch and permanent observations are available we give preference to velocity from permanent observations if they were longer than the epoch observations or they lasted at least four years.

This selection led to a velocity field which includes horizontal velocities of 192 sites. The graphical representation of intraplate horizontal velocities is displayed in Figure 11. We stress that the vectors are obtained as the ITRF2000 horizontal velocities reduced for the Actual Plate Kinematics Model APKIM 2000. The origin of the velocities is distinguished by colors. The figure shows relatively sufficient coverage at a majority of the regions in our area of interest except Serbia, Montenegro and Macedonia.

We can generally distinguish four characteristic features of the magnitude and orientation of velocities:

- Predominantly northward oriented velocities of 3 – 5 mm/year in the Adriatic region.
- Eastward oriented velocities in East Alpine region, North Carpathian region and Pannonian Basin with magnitude up to 2 mm/year.
- The stable region of Bohemian Massive and North European Platform.
- Southward oriented velocities in the Southern Carpathian and East part of Balkan Peninsula with magnitude around 3 mm/year.

It is worth mentioning that these general trends are supported by all networks used in this study what proves the homogeneity of the data obtained. Some local anomalies are visible, they will be discussed later.

Besides the four velocity clusters mentioned above there are two other regions where the velocities show different behavior, but the number of available sites in our study is insufficient. It concerns the South-west Apennines with three westward oriented velocities and Eastern Carpathians with four northward oriented velocities.

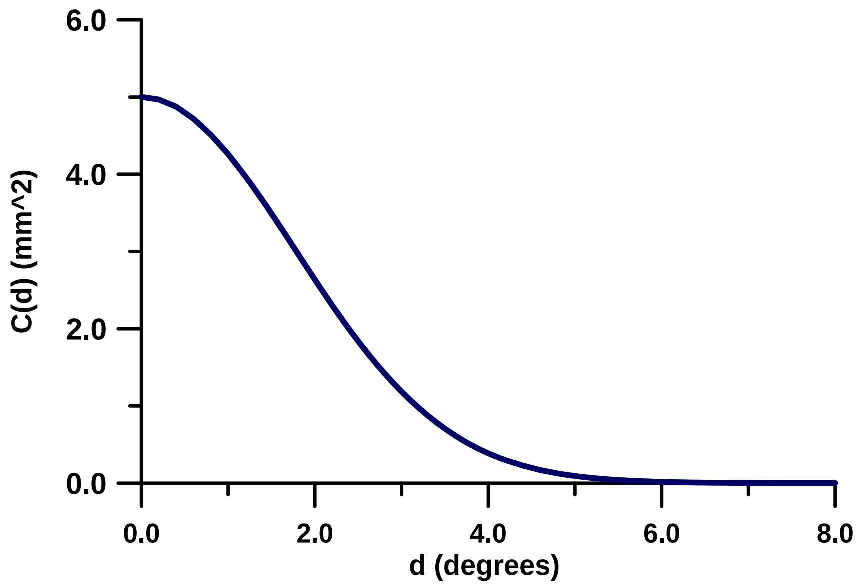

Fig. 12 Covariance function used for interpolation of velocities by Least Squares Collocation.

The general trends of intraplate velocities will be emphasized by smoothing the individual velocities using the Least Squares Collocation method. The application of collocation to interpolation and prediction of the horizontal velocities is used in (Hefty et al., 2006). Besides the evaluated site velocities also their covariance matrix is computed. The degree of smoothing is strongly dependent on the used covariance function of the signal $C(d)$. The latter is function of the spherical distances d among calculated and observed sites; the shape of $C(d)$ used in our approach is shown in Figure 12. The characteristic distance of 95% decorrelation is about 450 km.

The process of using the collocation procedure was divided in two steps: Firstly we computed the interpolated values in sites with observed velocities and then eliminated all the outliers exceeding the 3σ level. This procedure eliminated 6 sites (ASIA, KATO, MAKA, ROVI, SNIE, PART and POUS) which were demonstrated as anomalous also in Figure 11. The reasons of these local anomalies are not full explained and will require further studies. In the second step the interpolated velocities and parameters of error ellipses in regular grid were estimated.

In Figure 13 are shown velocities in 2° × 1° grid with 2σ error ellipses. The distribution of large ellipses points on areas where the available information about regional velocity field is not sufficient. Besides the territories at the margins of our area of interest, it is the territory of Serbia which is not covered by relevant information even in the interpolation approach. For emphasizing the areas where significant horizontal geokinematics is observed, we show in Figure 14 in 1° × 0.5° grid the interpolated velocities only in such points where their magnitude exceed the 2σ confidence. We stress that the empty places are either due to the fact that the velocities are very small, what is the case of part of Alpine region and North European Platform, or are due to the lack of data like in the territory of Serbia. Figure 14 clearly demonstrates the recent status of geokinematical information in Central Europe and northern part of Balkan Peninsula based on data published in available literature. We hope that our approach will be extended by other relevant information in near future.

6. CONCLUSIONS

We demonstrated a method of combination of regional and local velocity fields into a homogeneous system consistent with ITRF2000. The transformation of velocities is based on evaluation of Euler pole and angular rotation, expressing the relations among reference and regional or local velocities. The reference velocity frame is represented by EPN velocities which we consider as the most representative in the region of Central and South-East Europe. The horizontal velocities resulting from 7 various regional and local analyses were combined into a unique velocity field evaluated in ITRF2000 and subsequently reduced for the APKIM2000 model. The final set comprises of the intraplate horizontal velocities at 192 sites. We consider the obtained velocity field sufficiently homogeneous as concerns the reference frame which is unified for all used velocity sets. The accuracy characteristics and correlations among velocities are not yet satisfactory evaluated as the input velocities are of various qualities, which is not satisfactory reflected by the error modeling.

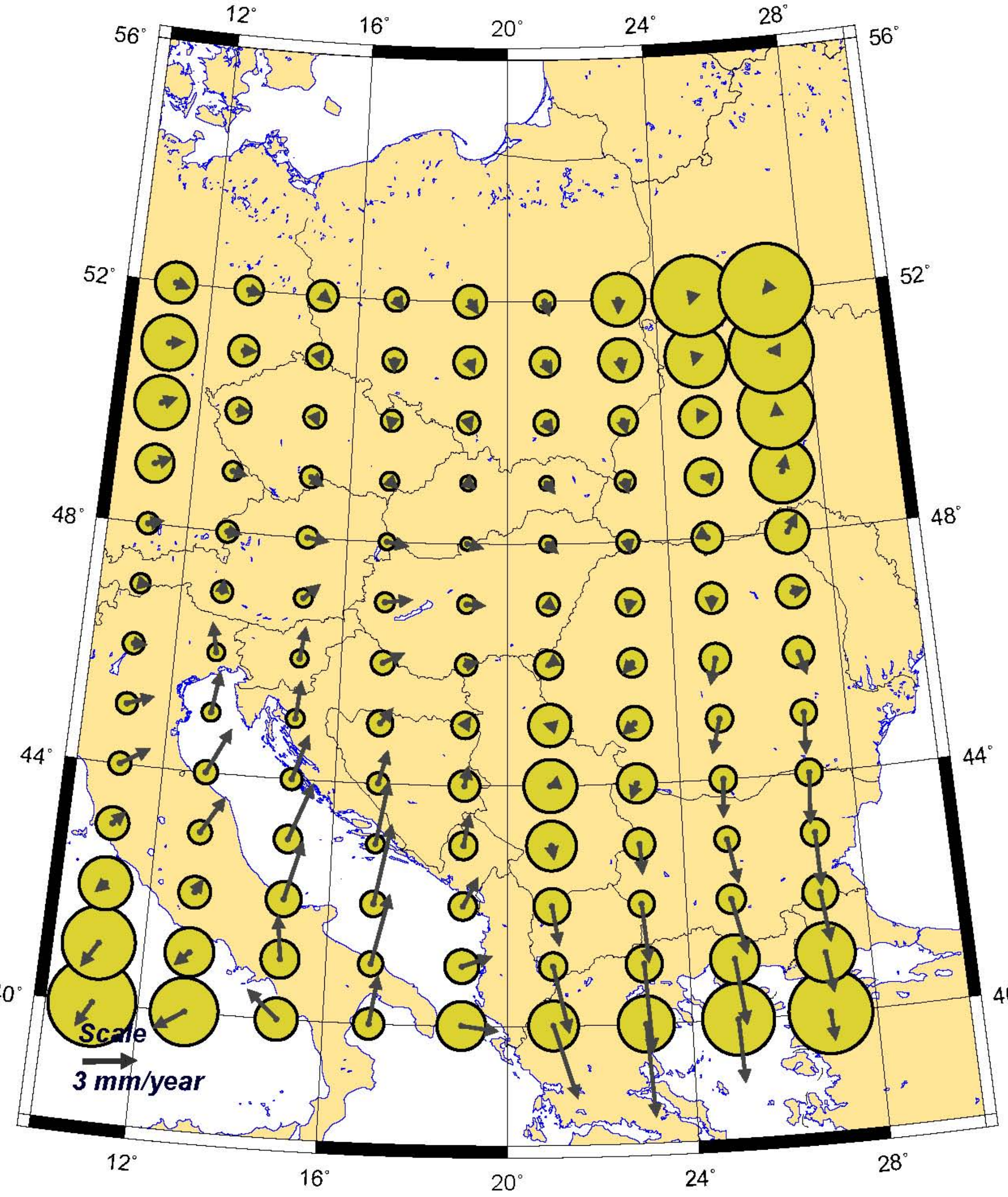

Fig. 13 Interpolated horizontal velocities with their 2σ confidence ellipses .

For the geokinematical picture of Central and South-east Europe are characteristic several blocks with significant horizontal velocity trends what was proved by all of the used velocity fields. The most remarkable issues are the northward oriented movement of the Adriatic region with magnitude of 3 – 5 mm/year and the southward oriented movement in the Southern Carpathian and East part of Balkan Peninsula with magnitude around 3 mm/year.

ACKNOWLEDGEMENT.

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REFERENCES

Altamimi, Z.: 2003, Towards a dense European Velocity Field. Presented at EUREF Symposium 2003, Toledo, Spain 4-7 June, 2003.

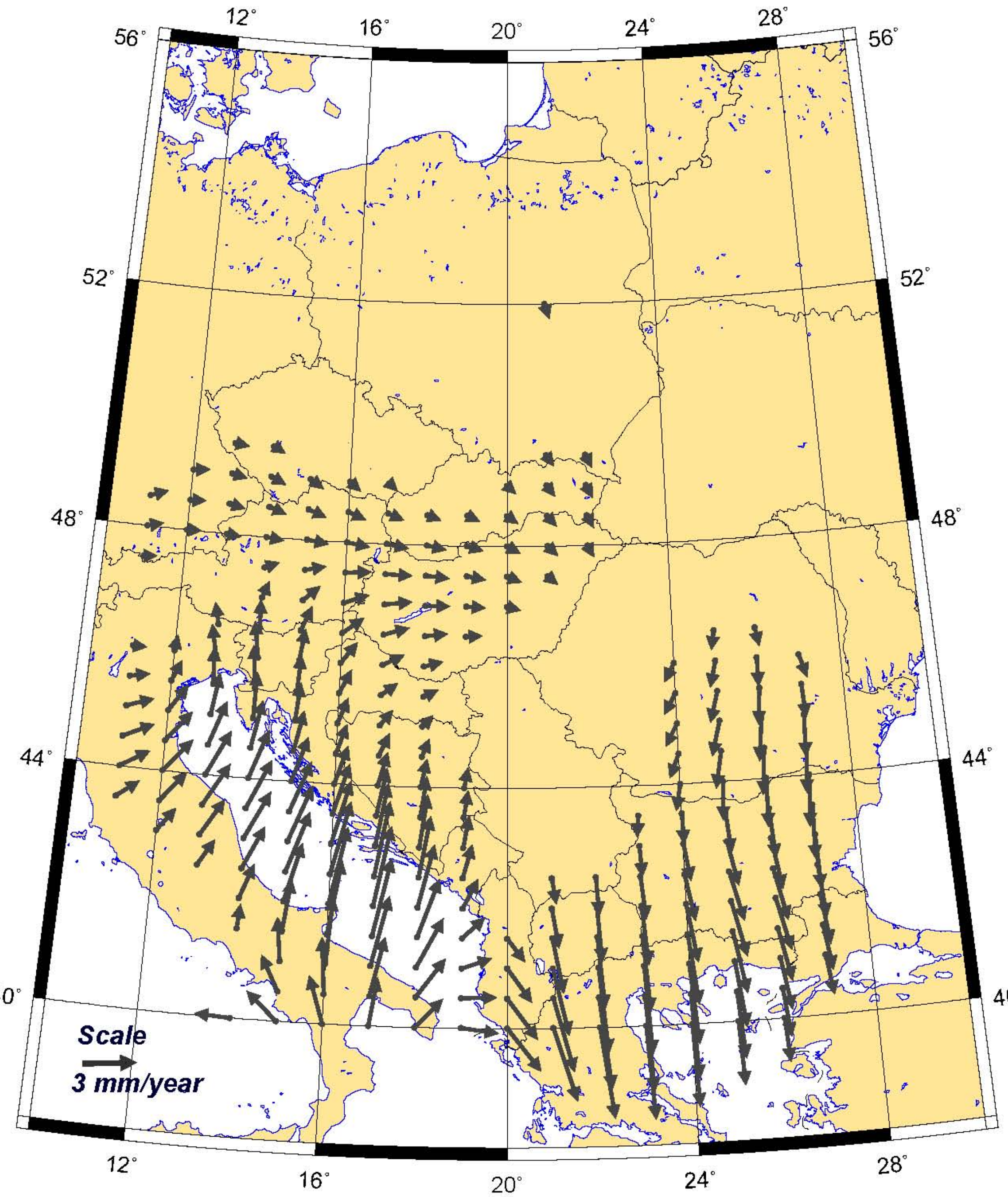

Fig. 14 Interpolated horizontal velocities in 1° × 0.5° grid. The velocity vectors are plotted in such points where their magnitude exceeds the 2σ confidence.

Altiner, Y., Bačič, Ž, Bašič, T., Coticchia, A., Medved, M., Mulič, M. and Nurce, B.: 2006, Present-day tectonics in and around the Adria plate inferred from GPS measuremets. Geological Society of America Special Paper 409, 43 – 55.

Caporali, A., Martin, S. and Massioroni, M.: 2003, Average strain rate in the Italian crust inferred from a permanent GPS network – II. Strain rate versus seismicity and structural geology. Geophys. J. Int. 155, 254 – 268.

Drewes, H.: 1998, Combination of VLBI, SLR and GPS determined station velocities for actual plate kinematics and crustal deformation models. In: Forsberg, R., Feissel, M., Dietrich, R. (eds.): Geodesy on the Move, Gravity, Geoid, Geodynamics, and Antarctica. IAG Symposia Vol. 119, Springer, 377-382.

EPN: 2007, The EPN Coordinate Time Series Analysis Special Project. Available at www.epncb.oma.be.

Fejes, I. and Pesec, P.: 2003, CERGOP-2/Environment – a challenge for the next 3 years. Proc. Of EGS-AGU-EUG G17 Symposium, Nice, 2003. Reports on Geodesy No.1 (64), 13-22.

Grenerczy, Gy.: 2002, Tectonic processes in the Eurasian-African Plate boundary zone revealed by space geodesy. Plate boundary zones. AGU Monograph Geodynamic Series Volume 30.

Hefty, J.: 2006, Work Package 5 of the CERGOP-2/Environment: GPS data analysis and the definition of reference frames. Final report: April 2003 – July 2006. Reports on Geodesy 3 (78), 51-84.

Hefty, J., Haslinger, C., Stangl, G., Becker, M. and Drescher, R.: 2006, Work Package 7 of the CERGO P-2/ Environment: Geokinematical modeling and strain analysis. Final report: April 2003 – July 2006. Reports on Geodesy 3 (78), 157-197.

Hefty, J., Igondová, M. and Hrčka, M.: 2005, Contribution of GPS permanent stations in Central Europe to regional geo-kinematical investigations. Acta geodynamica et geo-materialia 2, No. 3, (139), 75-86.

Hefty, J. and Kováč, M.: 2004, Detection of intraplate motion within the territory of Slovakia and their importance for reference frame realisation. Recent status and progress in reference frames, Brno, Institute of Geodesy, Technical University in Brno, 60 – 68, (in Slovak).

Leitmannová, K., Klobušiak, M., Priam, Š. and Ferianc, D.: 2002, SKTRF 2001 – Reference frame for national spatial network. Geodetic reference systems, Bratislava, Slovak University of Technology, 137 – 148, (in Slovak).

Milev, G., Vassileva, K., Becker, M. and Kirchner, M.: 2005, Analysis of the EUREF stations stability on the territory of Bulgaria. EUREF Symposium, Vienna, Ausrtia, June 1 – 4, 2005.

Williams, S.D.P.: 2003, The effect of coloured noise on the uncertainties of rates estimated from geodetic time series. J. Geodesy, 76, 483-494.

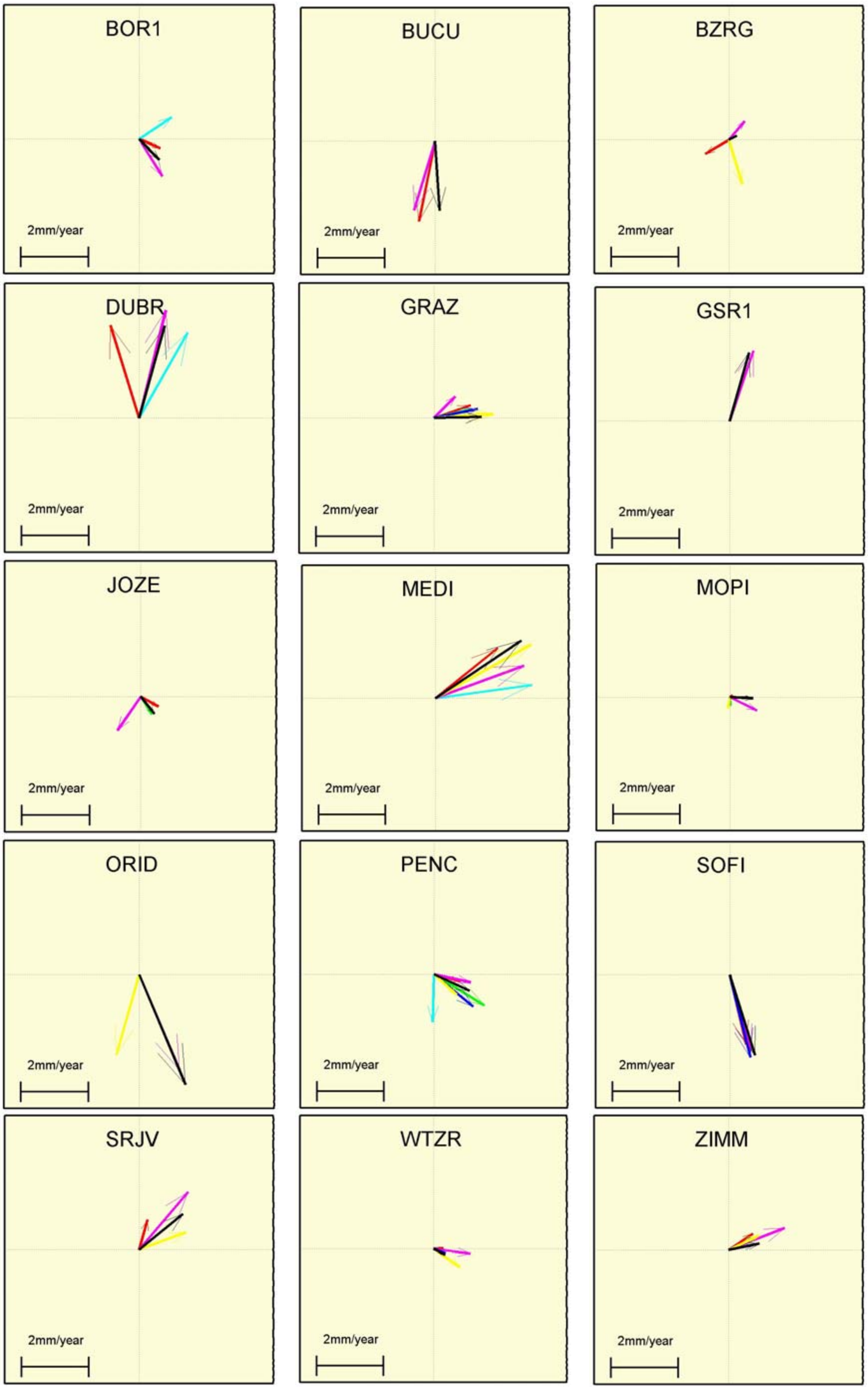

Fig. 10 Comparison of intraplate velocities obtained in different networks: EPN (black), CERGOP (red), CEBAPER (magenta), ALPMED (yellow), CRODYN (cyan), BULREF (blue) and SGRN (green).

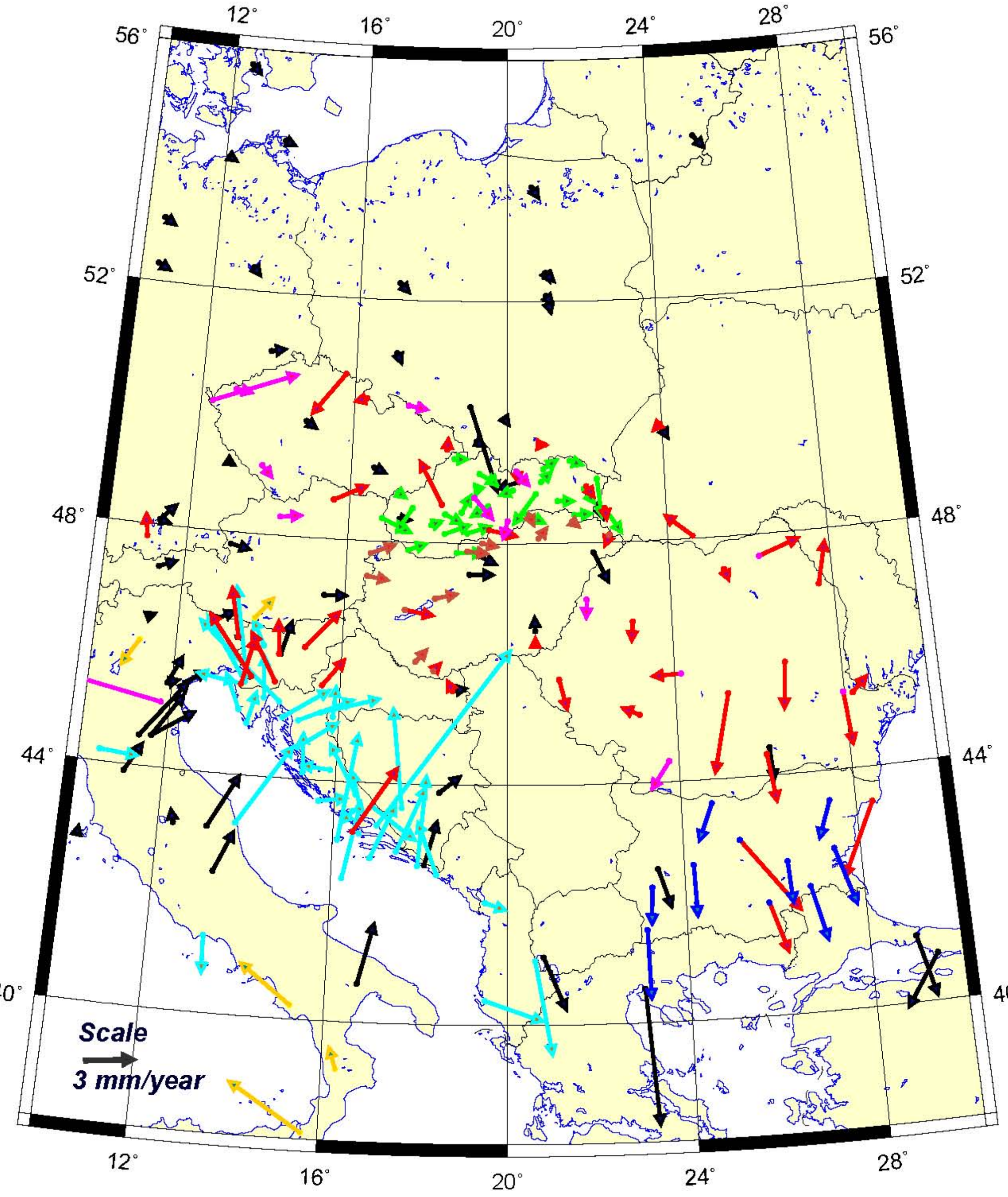

Fig. 11 Intraplate velocities obtained from combination of regional and local velocity fields: EPN (black), CERGOP (red), CEBAPER (magenta), ALPMED (yellow), CRODYN (cyan), BULREF (blue), HGRN (brown) and SGRN (green).