REFINEMENT OF THE VELOCITY FIELD IN CENTRAL EUROPE BASED ON REPROCESSED PERMANENT AND EPOCH-WISE GPS OBSERVATIONS

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ABSTRACT

The history of regular GPS monitoring aimed to investigation of geokinematics in Central Europe started in early ninetieth of the 20th century. In 1994 the first campaign of epoch-wise Central Europe Geodynamics Project (CERGOP) was organized and several permanent GPS stations in region became operational; relevant data from about 30 sites are available for that period. Since that time the number of permanent and epoch stations with accessible data suitable for geokinematical research increased to about 150. Although the GPS observations were continuously analyzed and also several re-analyses were performed, the complex combination of all data still suffer from inhomogeneities of various kind, e.g. no unique GPS antennae models, effects of reference frame evolution, troposphere models improvements, identification and modelling of discontinuities in observing series, etc. In this paper is introduced a new complex solutions for 3-dimensional site velocities which is based on GPS permanent and epoch data reprocessed by unified procedures and models related to homogeneous reference frame. The subsequent horizontal velocity field analyses are focused on modelling of regional geokinematical trends and identification of local anomalies where the significant disagreement of the actual site velocity with the regional pattern is observed.

1. INTRODUCTION

The extended time interval of GPS observation in Central Europe and availability of homogenised solutions of permanent and epoch-wise GPS networks are challenge for refinement of the regional velocity field in Central Europe (CE). The GPS data from this region of interest were consistently analyzed already for several times (the representative is the related study by Caporali et al., 2009) and the general pattern of the velocity field is generally known. Nevertheless, there are still several not completely resolved issues, like the consistency of epoch-wise and permanent observations, repeatability of coordinate determination at epoch sites, unexplained discontinuities in permanent site coordinate time series, etc. The problem which is studied only sporadically is related to spatial correlations among velocities of geographically close

sites. Such investigations enable to use the smoothed velocity field for detection and elimination of locally biased sites with anomalous velocity magnitude and/or direction. In the paper is summarized the basic information about analyzed permanent stations and epoch networks. The main characteristics of the rigorous approach for 3D velocity field adjustment using reprocessing outputs and the SINEX based network combination will be given. Finally, after exclusion of the evident outliers, the homogenized horizontal velocity pattern of the CE region will be presented.

2. DATA ANALYZED AND REPROCESSING ATTRIBUTES

The velocity estimation is based on combination of two partially overlapping networks:

i/ The network of selected permanent stations in Central Europe (CEPER) covering the period from 1996 to 2010 is shown in Fig. 1. The basis are the 45 EPN stations completed by 9 non-EPN permanent stations. The network is analysed by LAC SUT Bratislava and the weekly coordinate solutions in SINEX format are used in this study. The other details are given in (Hefty et al., 2009).

ii/ The epoch-wise Central European GPS Reference Network (CEGRN) observed in annual or bi-annual intervals from 1994 to 2009 (Caporali et al., 2008). Stations observed at least 3 times are shown in Fig. 2. The number of stations progressively increased from 27 in 1994 to 84 in 2009 (maximum of stations – 98 was observed in 2005). We include also data from four additional non – CEGRN epoch sites in Bosnia and Herzegovina to partially improve the network geometry in this region.

The processing strategy for both networks is consistent with the EPN reprocessing rules. The main attributes are as follows:

- **Analyzing software: BERNESE V5.0 (Dach, 2007).**
- **Use of IGS orbits and ERPs since 2006, until 2006 the Munich/Potsdam/Dresden IGS reprocessing products (Steinberger et al., 2006).**
- **Elevation mask 3 degrees (if data are available), elevation dependent weighting.**
- **24 h intervals processing, based on carrier phases only.**
- **Dry Niell and wet Niell mapping functions, 1-hour troposphere zenith delays and 24-hour troposphere gradients estimated.**
- **Ocean loading model FES2004.**
- **Satellite and receiver antennae informatgion from the IGS05 absolute calibration models.**

The processing and network solutions are performed in two steps:

At first, each network is processed separately with the same set of reference points yielding separate estimate of velocities from permanent and epoch stations. Next, the combined solution with application of stochastic model of coloured noise for permanent stations is performed. Finally, the unique 3D velocity for each station is estimated. For referencing we selected the stable set of 15 IGS sites with ITRF2005 coordinates and velocities (Fig. 3). The effective number of used reference sites varied from 6 to 14. The geometry of reference network is reasonable, however there are missing reference sites in Central Balkan area.

The expected outputs of this improved estimation process are the smooth time series from permanent stations, linear coordinate performance at epoch stations and coincidence of velocities obtained from epoch and permanent solutions.

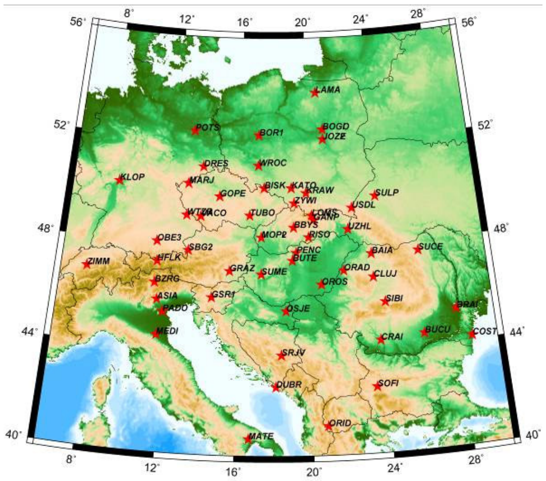

Fig. 1. Analyzed permanent sites.

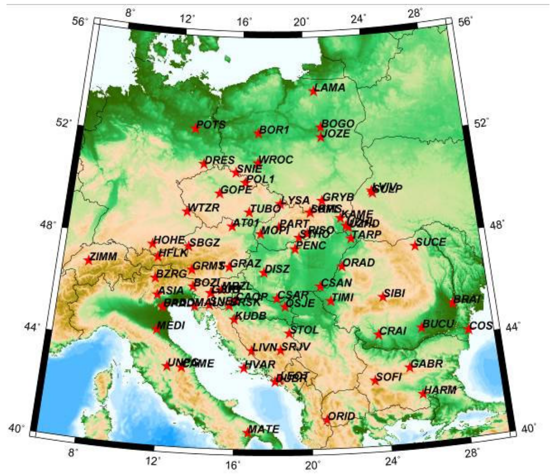

Fig. 2. Analyzed sites in the epoch-wise network.

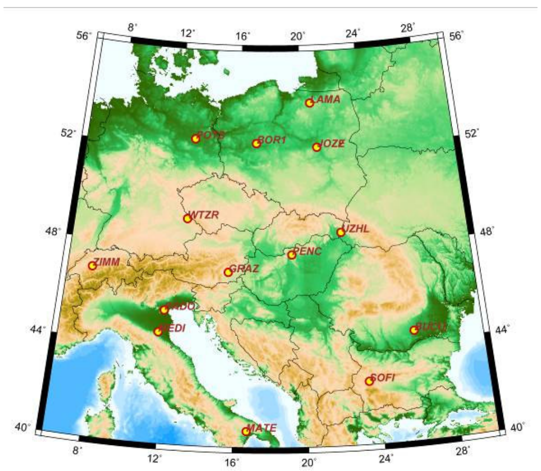

Fig. 3. Reference stations used to align both permanent and epoch networks to the ITRF2005.

3. SEPARATE VELOCITY ESTIMATION FROM EPOCH-WISE AND PERMANENT NETWORKS

The main problems encountered during inspection of continuity of station coordinates is the identification and repair of jumps in coordinate series. At the permanent stations, they occur mainly due to antenna replacements. The occurrence of such jumps is rather unexpected, because the absolute antennae calibration files were used. We detected about 75 discontinuities, some of them which are non-reported in EPN data base. The estimate and correction of magnitude of the detected jumps we performed iteratively. Problematic identification and corrections of antennae effects is at epoch sites. Only in some cases we identified outliers which can be associated with different antennae used at long-term monitored sites. Some examples will be given below.

Concerning the referencing to the ITRF2005 at permanent stations, the expected pattern of residuals is that the data are continuous, oscillating around zero, no sloped line, without jumps and without seasonal variability. In Fig. 4 are shown four residual time series in *dX*, *dY* and *dZ* constituents. The BOR1 exhibits discontinuity in *dZ*, no significant slope and larger scatter in *dX* and *dZ.* At WTZR the slope in *dX* and *dZ* is about 0.7 mm/year, slight seasonal effect are in *dY*, the series have no significant discontinuities and the larger scatter is in *dX* and *dZ*. GRAZ shows no slope, some intervals was necessary to exclude from using for referencing of both networks, larger scatter are in *dX* and *dZ*. Finally, the SOFI residuals have significant slope ~ 1 mm/year in *dX*, *dY*, *dZ* and larger scatter in all 3 constituents. We expect that it is consequence of inconsistency of the ITRF velocity of SOFI with regional networks solutions. The location of SOFI at the south-eastern part of our network will affects the site velocities estimation at Balkan Peninsula.

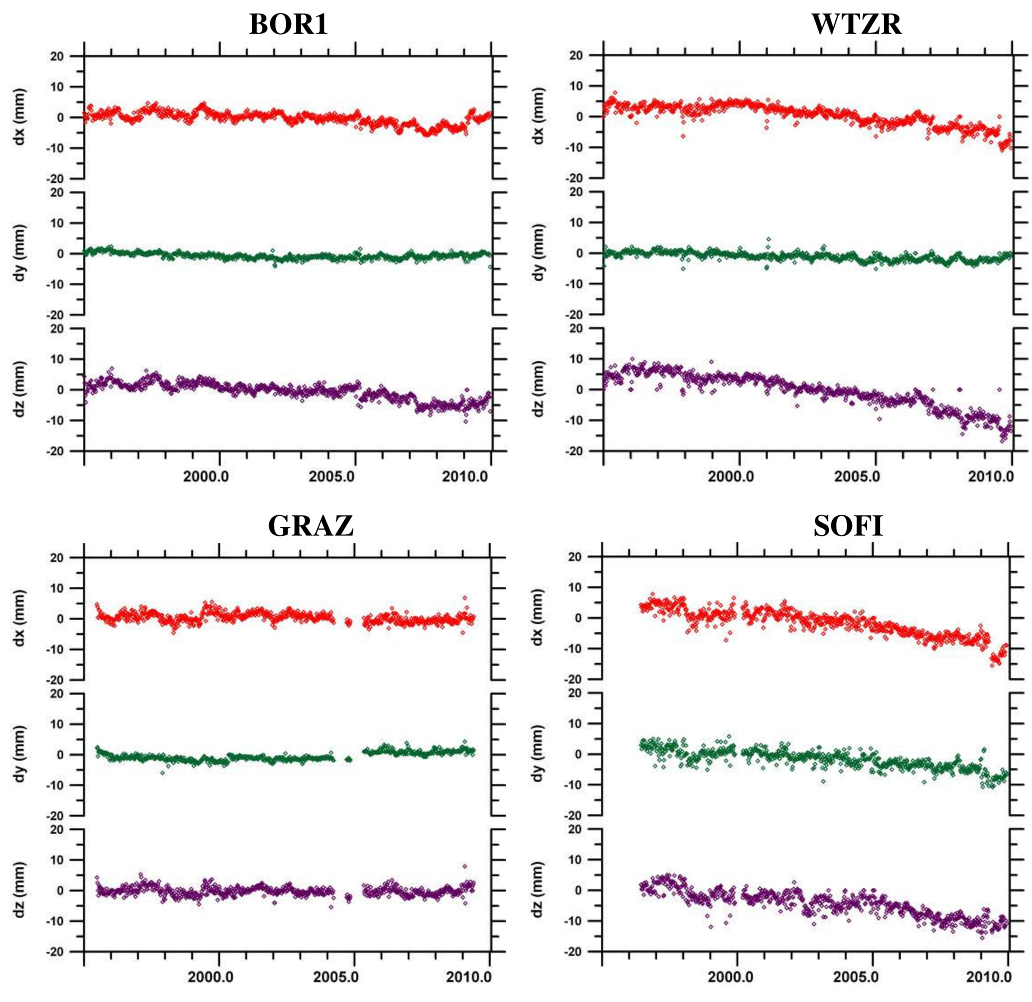

Fig. 4. Residuals from 3D transformation to ITRF.

Fig. 5 shows some typical situations from combining the epoch-wise network solutions with permanent network solutions at the sites where the station was included in both networks. The data presented are the station coordinates referred to the ITRF2005, reduced for the APKIM2005 and transformed to the local system. The station PENC is an example of favourable situation showing good coincidence of epoch-wise and permanent observations both in horizontal components and in height. Estimated velocity is identical for permanent and epoch-wise observations. At JOZE is visible also good coincidence of epoch-wise and permanent observations in horizontal components, but slight differences are in height. Velocity estimation for permanent and epoch-wise observations results generally to similar values. At DRES is strong seasonal variation in horizontal component of permanent observations; epoch observations performed at the same seasons are correctly mapping the linear trend. Corrections of offsets in vertical component were not identical in permanent and epoch network. At TUBO the velocity estimation for epoch-wise observation are influenced by the first two observations. It is evident that epoch observations before setting TUBO as permanent station are inconsistent.

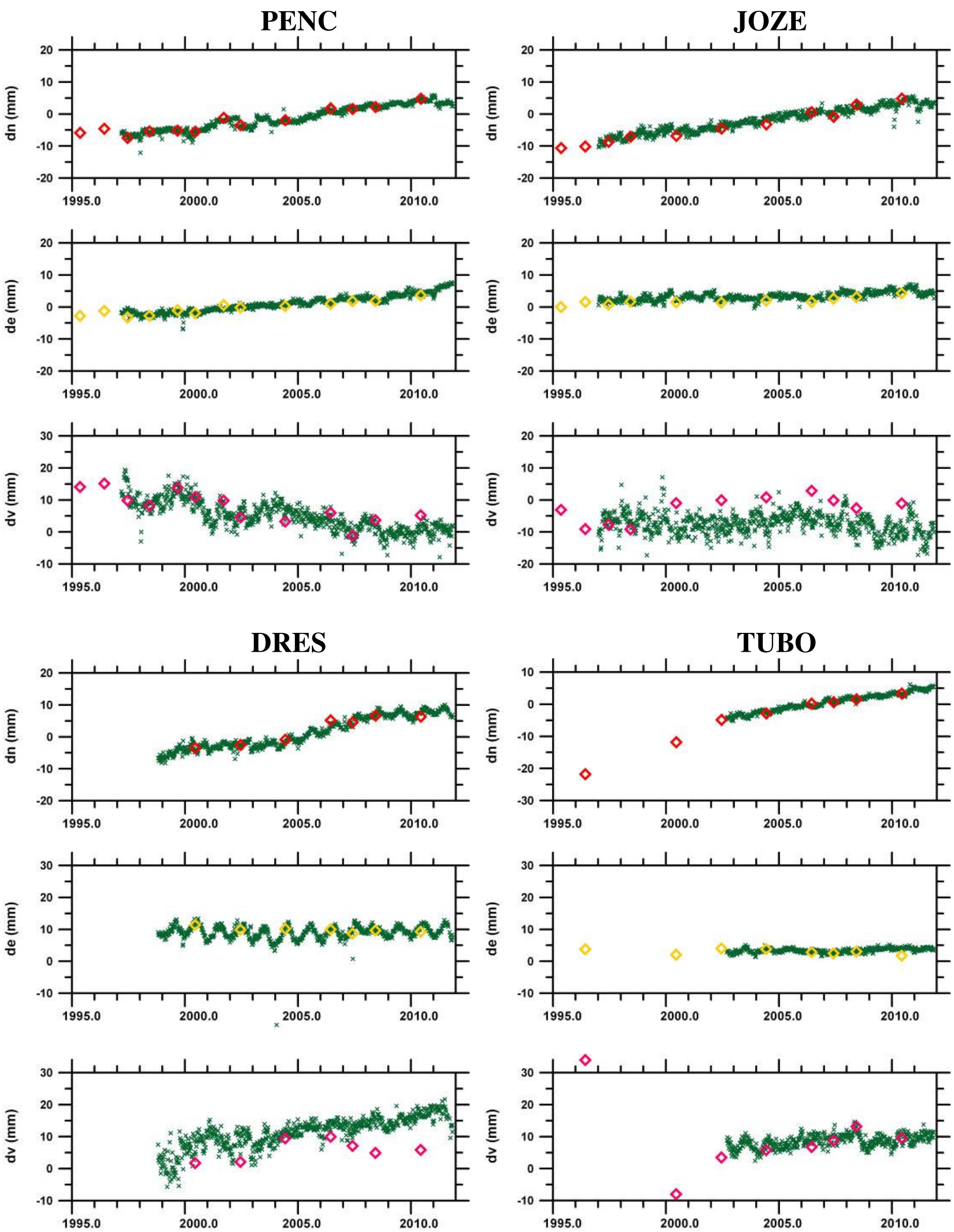

Fig. 5. Coordinate time series from permanent (x) and epoch-wise (◊) networks.

The evaluations of consistency at stations where only epoch observations are available are much more complicated. Fig. 6 shows two examples. At SNIE epoch station the consistency of epoch campaign data in horizontal components is very good and results to strong trend in east-west component. However, the evaluation of regional trends in the 4th chapter of this paper supports the suspicion that the observed motion is due to monument drift. The height component is noisy and no indicating any trend. At the epoch site PART first two epoch campaigns result in north component to values which are different from the next data, probably due to new obstacles close to antenna that arose in 2001. Differences in horizontal and vertical velocities between complete and selected observation sets of PART are implied in Fig. 6.

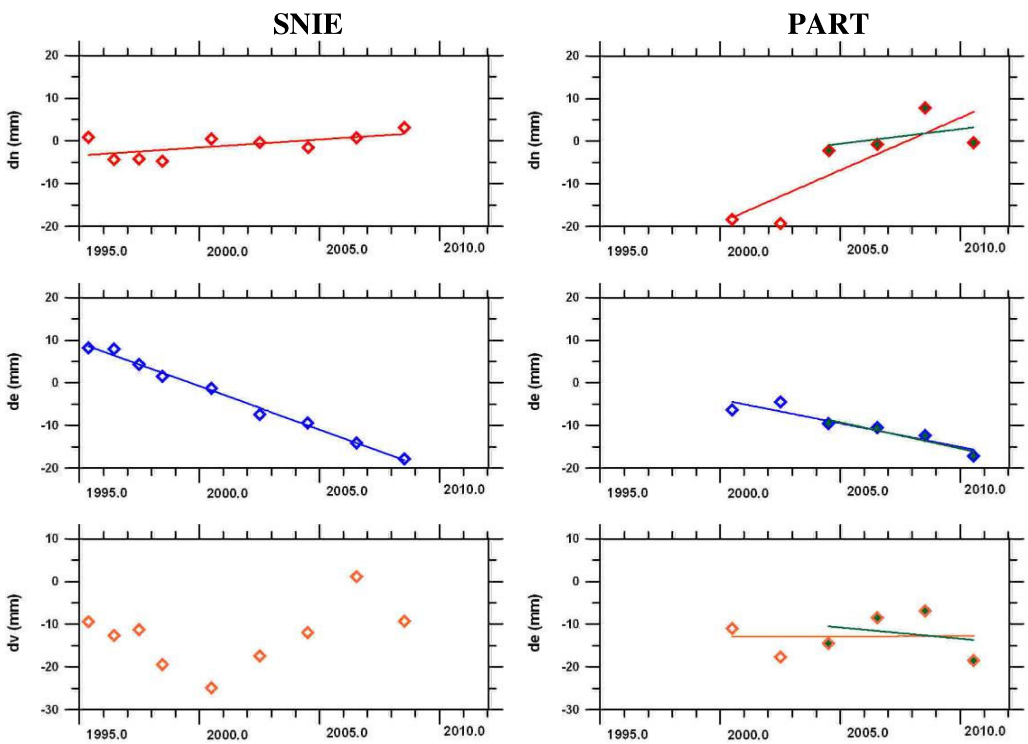

Fig. 6. Observed coordinates at epoch sites SNIE and PART.

Horizontal velocities from separate solutions of permanent and epoch-wise networks are shown in Fig. 7. We observe generally a good consistency of epoch velocities at permanent sites which is typically less than 1 mm/year. Such agreement is optimistic as it concerns the reliability of velocities from epoch campaigns. But such level of accuracy cannot be straight applied for epoch-only sites because more of frequent alteration of GPS antennae and receivers when compared to permanent sites. The permanent station CLUJ was apriori excluded from further analyses due to landslide which results to extreme velocity vector.

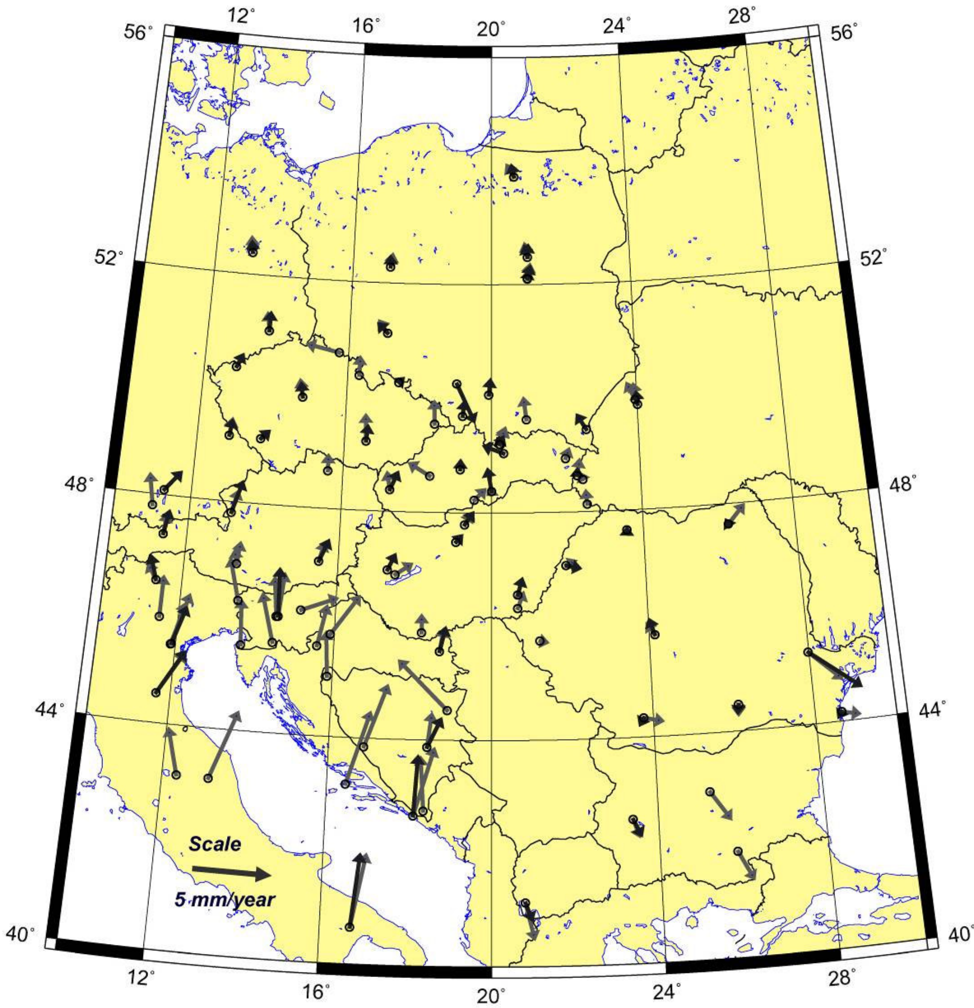

Fig. 7. Horizontal intraplate velocities from permanent (in black) and epoch (in gray) observations.

4. VELOCITY FIELD IN CENTRAL EUROPE FROM COMBINATION OF REPROCESSED PERMANENT AND EPOCH-WISE NETWORKS

The velocity estimates are strongly dependent on length of interval observations and of data consistency, especially for epoch stations. In the combination process the proper weighting of permanent and epoch observations is the most difficult task. We applied the coloured noise approach for permanent stations in order to not over-estimate their precision. The final formal accuracy of velocities is ~ 0.1 – 0.3 mm/year for permanent sites and ~ 0.2 – 0.7 mm/year for epoch stations.

As is visible from Fig. 7 the general pattern of intraplate velocities trends in Central Europe is followed by majority of stations. However, in some exceptions the station behaviour is different from the trends given by surrounding stations. For separation of regional signals from local anomalies we used smoothing of velocity field by the method of least square collocation. The primary velocity smoothing was based on information

from surrounding sites up to 200 km. The large residuals of smoothing indicated occurrence of velocity outliers. After applying iterative smoothing process with varying of the filtering strength, the permanent sites KRAW and BRAI, as well as the epoch sites MRZL, PART, STOL, SNIE and UNPG were excluded. Finally, the maximum residuals of horizontal velocities are 0.7 mm/year for permanent and 1.4 mm/year for epoch sites. Fig. 8 shows the smoothed velocity field obtained without the stations mentioned.

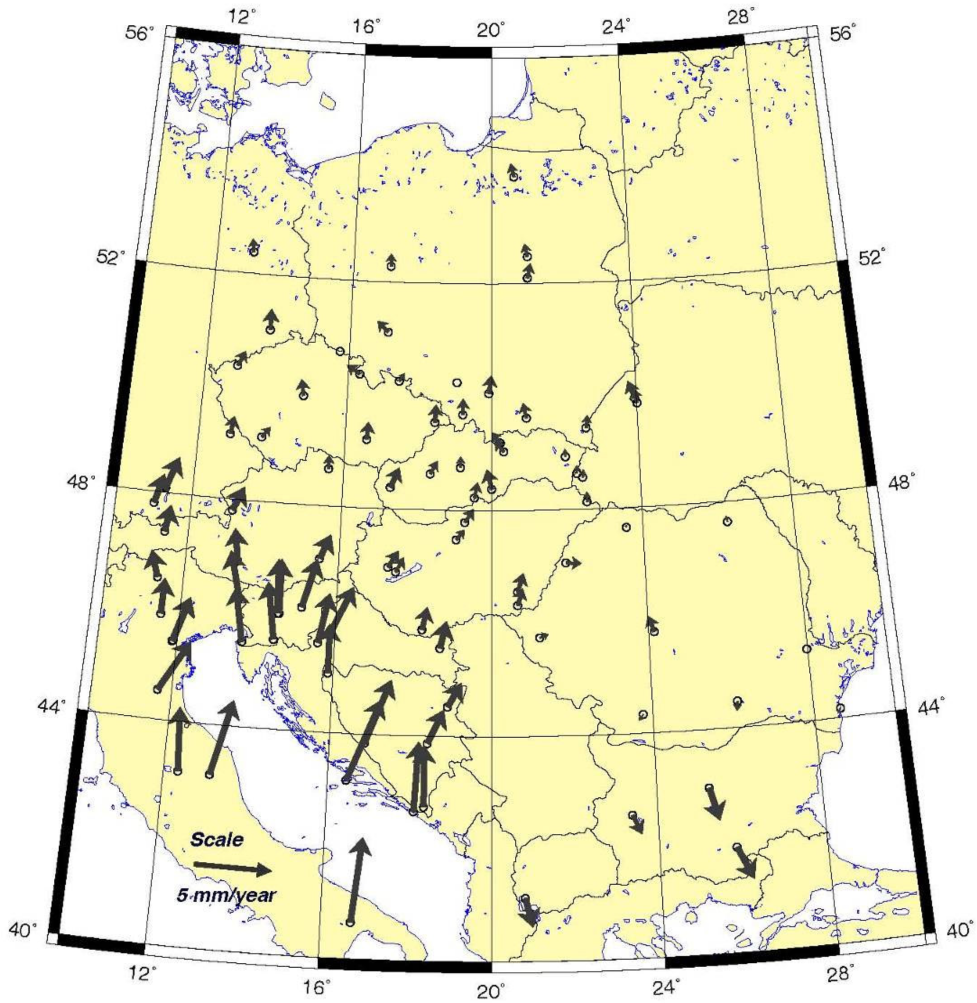

Fig. 8. Smoothed horizontal velocities at permanently and/or epoch-wise observed sites after exclusion of outliers.

The final refined CE velocity field pattern was obtained by interpolation of horizontal velocities by least square collocation based on data from 110 sites (7 sites were excluded). Maximum difference between the interpolated and observed velocity was checked at each site and reached less than 1.5 mm/year. The velocity pattern characteristic for the Central Europe region is in Fig. 9.

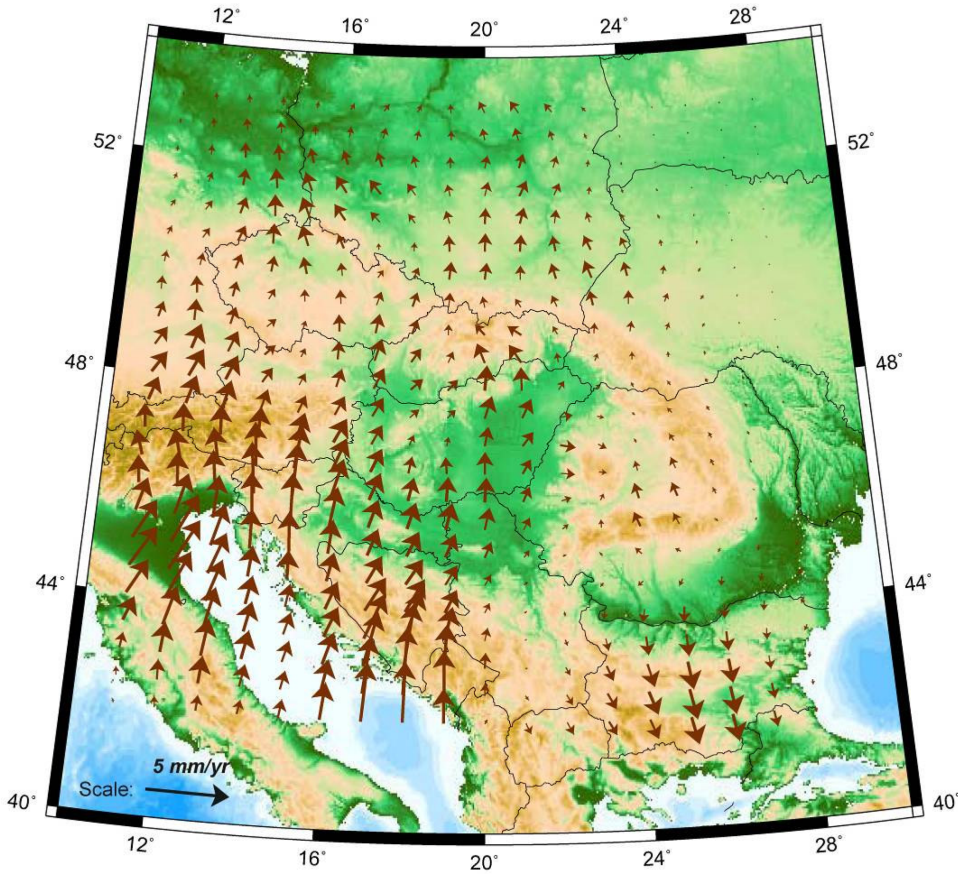

Fig. 9. The interpolated intraplate horizontal velocities pattern.

5. CONCLUSIONS

- **Reprocessing of permanent and epoch data significantly improved the horizontal velocity estimates, however did not completely remove the antenna issues. It was still necessary to inspect coordinate time series for their continuity and to repair the jumps.**
- **The reliability of referencing to ITRS is limited by discrepancies among ITRF velocities and the CE network solutions which are at the level ~ 1 mm/year.**
- **Non-homogeneous configuration of sites, mainly the 'white area' – the territories of Serbia, Monte Negro, FYR of Macedonia and Albania are the most serious problem for obtaining the homogeneous velocity field.**
- **The regional horizontal velocities pattern in CE obtained after exclusion of locally anomalous velocities could serve as an upper limit for intraplate velocity trends in the area of interest.**

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