Geo-kinematic investigations in Slovakia and the region of Central and Southeastern Europe based on combination of permanent and epoch-wise GPS networks

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Abstract: The region of Central and Southeastern Europe is covered by numerous GPS networks investigating geo-kinematical behavior of this area. These activities started in early nineties within the several projects as CERGOP and CERGOP-2/Environment. In this paper we describe the process of combination of four networks located in the region of Central and Southeastern Europe using the CATREF (Combination and Analysis of Terrestrial REFerence Frame) software developed in Institute Geographique National in France. We were particularly interested in the CEPER (Central European Permanent Network), CEGRN (Central European Geodynamic Reference Network), SGRN (Slovak Geodynamic Reference Network) and local network TATRY shortly described in this paper. Homogeneous velocity field obtained from the final combination is for the purpose of better interpretation divided into three parts: Central Europe, Slovakia and Tatra Mountains. Main interest is focused on the territory of Slovakia where the regional velocity field is not so frequently discussed in scientific community as the case of Central and Southeastern Europe.

Key words: permanent and epoch-wise GPS networks, velocity estimation, regional geo-kinematics

1. Introduction

Several projects devoted to geo-kinematic investigations in region of Central Europe were performed over the period of last 15 years. Mostly we can speak about epoch-wise networks which were created in order to increase the densification of existing permanent GPS networks. The results of processing were inhomogeneous in the past because of different models used in network adjustment and some inconsistencies involved in reference frame changing as well. For the purpose of homogenization of these data the results of measurements were completely reprocessed using the unified models and computation strategy. The Bernese GPS Software version 5.0 *(Dach et al., 2007)* was used for this purpose. This paper describes time series stacking and final combination of this type of solutions using the CATREF (Combination and Analysis of Terrestrial REFerence Frame) software, which were developed in IGN (Institute Geographique National) in France *(Altamimi et al., 2007)* for purposes of ITRF (International Terrestrial Reference Frame) activities. One permanent and three epoch-wise networks covering the region of Central and Southeastern Europe were introduced to the final combination in order to obtain the homogeneous velocity field of this area.

2. Permanent and epoch-wise networks included in the combination

Results of reprocessing of four networks were used for the final combination. In terms of computation strategy we can consider these input data as homogeneous and following the rules given by CEGRN consortium *(Fejes, 2006)*. On the other hand we can say that networks used are inhomogeneous because of unequal length of observation, network density, distribution of observation points, network size, number of reference points used for datum definition, etc. The highest quality data are provided by CEPER (Central European Permanent Network) given in the form of weekly solutions covering the time span of 8.48 years of permanent observations. Second one is CEGRN (Central European Geodynamic Reference Network) with 9 epoch-wise campaigns performed over the period of 13.14 years within CERGOP and CERGOP-2/Environnment projects (Table 1). The main interest is focused on the area of Slovak Republic, where the SGRN (Slovak Geodynamic Reference Network) (9 campaigns, 13.82 years) and local network TATRY (12 campaigns, 10.02 years) were included to the combination (Table 1). The quality of data resulting from the epoch-wise networks is not as good as in the case of permanent networks. The main reason is the small number of points used for datum definition and short length of the observation campaigns. The number of points included in the individual combinations is summarized in Fig. 1.

Table 1. The main parameters characterizing networks included in the final combination

Name	Number of points	Time span [year]	Number of campaigns	From – To [year]
CEPER	19 – 56	8.48	443 weeks	2000.00 – 2008.48
CEGRN	27 – 90	13.14	9	1994.33 – 2007.47
SGRN	14 – 33	13.82	9	1993.66 – 2007.48
TATRY	13 – 23	10.02	12	1998.67 – 2008.69

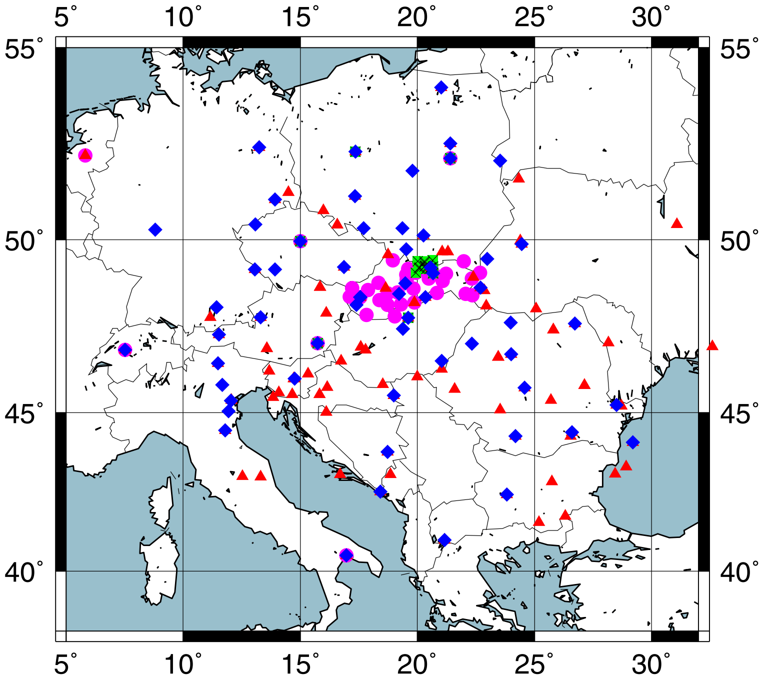

Fig. 1. Distribution of the networks included in the combination. Diamonds – CEPER permanent network, triangles– CEGRN, dots – SGRN, squares – TATRY.

2.1. CEPER – Central European Permanent Reference Network

The CEPER permanent network is analyzed since 1996. It covers the region of Central and Southeastern Europe. Figure 1 illustrates the distribution of permanent stations of CEPER permanent network (diamonds). For the purpose of combination, the time interval of 8.48 year was selected covering the time span from 2000.0 to 2008.48. After 2006.86 we can speak about routine processing *(Hefty et al., 2009)*, which respects processing rules described below.

The data from 2000.0 to 2006.86 were completely reprocessed for the purpose of homogenization. The number of stations gradually increased during the last 9 years from 19 in 2000.0 to 56 in 2006.48. In 2006.86 the 10 new stations were added to the processing (Fig. 2). There are 20 stations present in 80% of weekly solutions. It means that their observation interval is longer than 6.78 year. In 2008.5 this network consisted of 45 EPN (EUREF Permanent Network) permanent stations and 9 non EPN permanent stations *(Hefty et al., 2009)*.

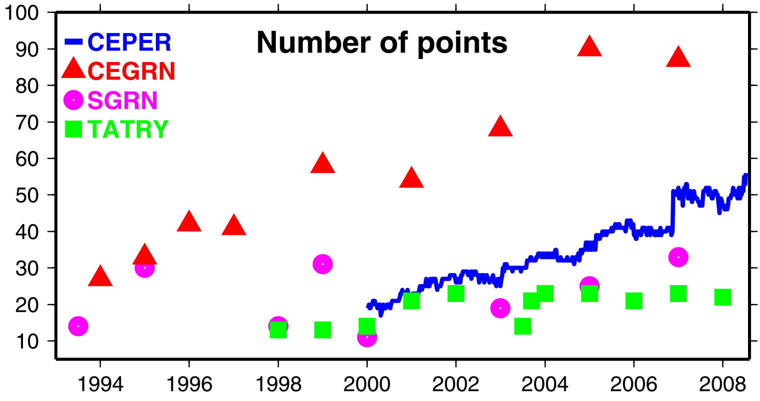

Fig. 2. Number of stations included in each individual combination. Line – CEPER permanent network, triangles– CEGRN, dots – SGRN, squares – TATRY.

2.2. CEGRN – Central European Geodynamic Network

The CEGRN network covers the area of Central and Southeastern Europe. This network was established in 1994 within the CERGOP and CERGOP-2/Environment projects. It consists of 73 non EPN and 20 EPN permanent stations. From 1994 to 2007 nine observation campaigns were performed *(Caporali et al., 2008)*. The observation interval takes 120 hours per campaign. The number of points included in the final combination per each year is summarized in Fig. 1 and oscillates from 27 points in 1994 to 90 points in 2005. These data are also reprocessed according to the rules which are mentioned later. Stations of CEGRN network are displayed in Fig. 1 as triangles.

2.3. SGRN – Slovak Geodynamic Reference Network

Slovak geodynamic reference network was established in 1993 and includes 17 points. Number of points gradually increased during the period of last 15 years and network now comprises of 42 points. Nine epoch-wise observation campaigns were realized from 1993 to 2007 (Table 1). The observation interval oscillates from 24 to 120 hours for one observation campaign. These data were progressively reprocessed in 2007. The processing strategy is the same with the networks mentioned previously. The SGRN 2001 observation campaign was excluded from the individual combination because of antennas rotations which were realized in the middle of observation campaign in order to eliminate uncertainties of a real position of the antenna phase centre *(Klobušiak et al., 2001)*. Figure 2 summarizes the number of points used for individual combination. Within the reprocessing strategy 8 EPN permanent stations, namely GRAZ, JOZE, KOSG, MATE, METS, MOPI, ONSA and ZIMM were included in the network adjustment. Distribution of the SGRN points is illustrated in Fig. 1 (dots).

2.4. Local network TATRY

The local geodetic network TATRY was established in 1997. First successful observation campaign was realized in 1998 comprising 7 points. This network was reobserved 12 times. It is situated in the Tatra Mountains on the borders of Slovakia and Poland. Last observation campaign was realized in 2008 in 18 points. Observation interval is no longer than 72 hours for one observation campaign. The data used for individual combination results from reprocessing of this network realized in 2008. The computation strategy is the same as in previous networks. The number of points entering to the individual combination is illustrated in Fig. 2. Five EPN permanent stations, namely BOR1, GRAZ, GOPE, JOZE and PENC, were included in the reprocessing for the purpose of datum definition.

3. Reprocessing strategy

The daily (0–24 UT) observation data written in RINEX (Receiver Independent Exchange Format) format were taken as an input for computation of daily network solutions. The reprocessing strategy follows the official rules given by CEGRN consortium. The computation procedure was realized in the Bernese GPS software version 5.0 *(Dach et al., 2007)*. The main features of computation strategy were *(Hefty et al., 2009)*:

- Processing in daily intervals (0–24 h UT).
- Celestial reference frame was realized by IGS (International GNSS Service) orbits and corresponding Earth Rotation Parameters since 2006, before this date the reprocessed data were used.
- 10° elevation cut off in case of CEGRN, TATRY and SGRN networks, 3° elevation cut off in case of CEPER permanent network *(Hefty et al., 2009)*.
- The constraints of 0.0001 m were applied in the station position of reference points in order to express the network solution into terms of the ITRF2005. The BOR1 or ZIMM permanent stations were used as reference points in case of CEPER permanent network. SGRN and TATRY networks were fixed to JOZE and in case of CEGRN network the BOR1 was chosen as a reference point.
- Station zenith delays estimated at hourly intervals. Niell mapping function were applied with elevation dependent weighting.
- Satellite and receiver antenna eccentricities are from the IGS05 absolute calibration model.
- Ocean loading model FES2004.

4. Combination strategy

CATREF software was developed for ITRF activities and is used for combination and analysis of the EPN weekly solutions *(Altamimi and Legrand,* *2004)*. It contains the modules for handling constraints, time series combination resulting from different space techniques as VLBI (Very Long Baseline Interferometry) DORIS (Doppler Orbitography Radio-positioning Integrated by Satellite), LLR (Lunar Laser Ranging), SLR (Satellite Laser Ranging) and GPS *(Altamimi and Legrand, 2004)*. The input data have to be provided in SINEX format. General combination model between two reference frames is expressed by Eqs. (1) *(Altamimi et al., 2007)*. This strategy assumes the relationship between individual reference frame k and combined reference frame c having appropriate station positions X_s^i at epoch t_s representing individual solution s, and X_c^i at epoch t_0 representing combined solution c

$$\begin{aligned} X_s^i &= X_c^i + (t_s^i - t_0)\dot{X}_c^i + T_k + D_k X_c^i + R_k X_c^i + \\ &\quad + (t_s^i - t_k)\left[\dot{T}_k + \dot{D}_k X_c^i + \dot{R}_k X_c^i\right] \\ \dot{X}_s^i &= \dot{X}_c^i + \dot{T}_k + \dot{D}_k X_c^i + \dot{R}_k X_c^i \end{aligned} \tag{1}$$

The parameters T_k represent the translations, R_k the rotation matrix and D_k the scale factor of each individual frame k. The dotted parameters designate their derivatives with respect to time *(Altamimi et al., 2007)*. Detailed combination model is described in *(Altamimi, 2006)*. Generally the combination strategy contains the two steps:

- Individual combination (time series stacking) per each network. Station positions X_c^i at a given epoch t_0 and velocities $\dot{X}_c^i$ expressed in the combined frame c. In this step also the transformation parameters T_k and their rates $\dot{T}_k$ between combined frame c and each individual frame (weekly solution) k are estimated *(Altamimi et al., 2007)*.
- Final combination – individual combinations provided in SINEX format resulting from the first step are combined together. The station position and velocities are estimated in order to obtain one homogeneous solution expressed in the selected reference frame.

Both steps mentioned above can be provided by minimum constraints and/or internal constraints approach described in *(Altamimi et al., 2007)*. In the first step of combination the following sub-steps were realized:

- The initial constraints were removed from each weekly or epoch-wise campaign solutions.

- The minimum constraints were applied to loosely constrained solutions.
- The dome numbers were checked and added to the points which were not recognized by CATREF.
- The combination model was formed individually for each of the mentioned networks.
- The ITRF2005 reference frame was chosen for datum definition.
- The discontinuities were handled and compared to official discontinuity file published in ITRF or EPN web sites. In case of discontinuity, the velocities before and after the jump are constrained to be the same.
- The outliers exceeding the value of 0.02 m were rejected or down-weighted.
- After eliminating the discontinuities and rejecting or down-weighting the outliers the refined combination is realized and final station positions and velocities of individual combination are estimated. The final results are expressed in selected reference frame.

Four individual solutions were formed respecting the combination strategy described above. The best way how to process such a big volume of data is to start with permanent network in order to identify the discontinuities which should be subsequently introduced in permanent stations included in selected epoch-wise network. The discontinuities are clearly visible and easy to identify in the time series of permanent networks. On the other hand we could not see veritable behavior of the points in epoch-wise networks because of absence of observation data. As we can see from the Table 2, 36 discontinuities were found in individual CEPER combination.

The EPN station DRES in Germany is given as an example illustrating the discontinuity in vertical component (Fig. 3). Jump about 40 mm is caused by antenna change in 2003 (Table 2). We can clearly see that the behavior of time series of permanent network is nicely followed by residuals of CEGRN epoch-wise network (triangles in Fig. 3) before and also after its elimination. List of the discontinuities was constructed in individual combination of CEPER permanent network and the jumps were reflected in combinations of epoch-wise networks. The discontinuity handling is quite a delicate procedure, which have to be taken into account also in case of epoch-wise networks.

Table 2. Discontinuities identified in CEPER individual combination and their time span.

Station	Sol. N°	From [Year:DOY]	To [Year:DOY]	Station	Sol. N°	From [Year:DOY]	To [Year:DOY]
BBYS	1	00:001	02:317	GSR1	2	01:361	08:180
BBYS	2	02:317	05:006	KLOP	1	00:001	01:130
BBYS	3	05:006	08:180	KLOP	2	01:130	08:180
BZRG	1	00:001	00:364	ORAD	1	00:001	08:073
BZRG	2	00:364	02:185	ORAD	2	08:073	08:180
BZRG	3	02:185	07:347	OROS	1	00:001	02:109
BZRG	4	07:347	08:180	OROS	2	02:109	07:157
DRES	1	00:001	03:023	OROS	3	07:157	08:180
DRES	2	03:023	08:180	PENC	1	00:001	03:142
GANP	1	00:001	06:236	PENC	2	03:142	07:201
GANP	2	06:236	08:180	PENC	3	07:201	08:180
GOPE	1	00:001	00:279	SBGZ	1	00:001	08:024
GOPE	2	00:279	06:194	SBGZ	2	08:024	08:180
GOPE	3	06:194	08:180	TUBO	1	00:001	05:349
GRAZ	1	00:001	05:076	TUBO	2	05:349	08:180
GRAZ	2	05:076	05:307	WROC	1	00:001	06:229
GRAZ	3	05:307	08:180	WROC	2	06:229	07:101
GSR1	1	00:001	01:361	WROC	3	07:101	08:180

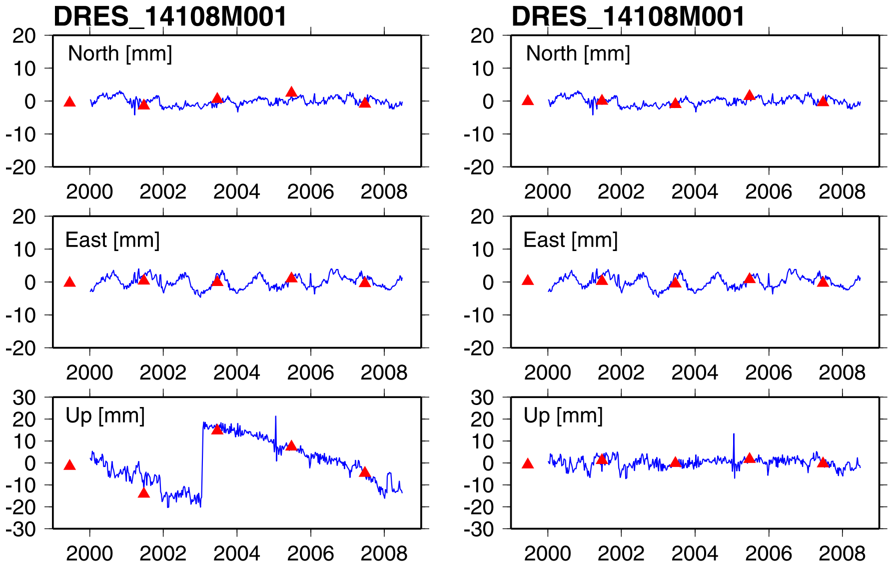

Fig. 3. Example of discontinuity in time series of EPN station DRES in vertical component before (left) and after (right) its elimination. The seasonal variations are present in east component.

Quality of combined weekly or campaign (in case of epoch-wise networks) solutions should be evaluated by computing the RMS of unit weight (WRMS) per week or campaign *(Altamimi et al., 2004)*. Figure 4 shows the WRMS based on output residuals of station positions resulting from each individual combination. We can see that WRMS of the CEPER permanent network indicates stable behavior reaching the value of 1.5 mm in horizontal component and 3 mm in vertical component. Behaviour of epoch-wise networks is not so explicit in comparison with CEPER permanent network. Local network TATRY reflects an improvement over the time reaching 2 mm in horizontal and 5 mm in vertical component. CEGRN and SGRN networks indicate roughly similar behavior from 1 mm to 3 mm in the horizontal component. Regarding the vertical component we can see the improvement from 8 mm to 4 mm in case of SGRN network and from 6 mm to 2 mm in case of CEGRN network.

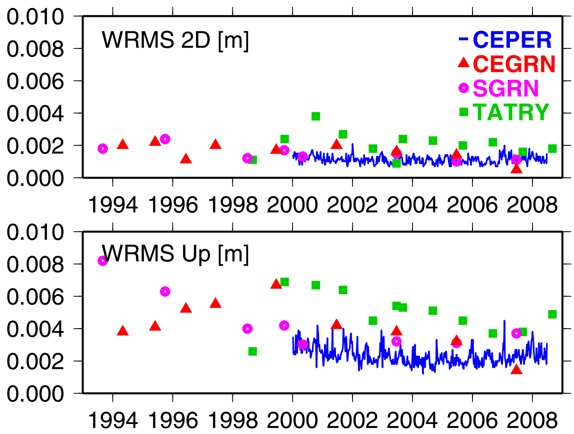

Fig. 4. RMS of unit weight per weekly or campaign solution corresponding to each individual combination. CEPER permanent network – line, CEGRN – triangles, SGRN – dots, local network TATRY – squares.

5. Velocity fields obtained from individual combinations

Results of individual combinations should be verified and evaluated before the final combination. For this purpose we selected 12 permanent stations.

The main interest was focused on the stations which are present in all or majority of investigated networks. Namely we can speak about stations BOR1, GOPE, GRAZ, JOZE, MATE, PENC and ZIMM. These stations cover the full observation interval of 8.49 years in CEPER permanent network and are present in analyzed epoch-wise networks. Unfortunately some discontinuities were found in stations GOPE, GRAZ, PENC and time series of these stations were partitioned according to appropriate solution numbers as we can see in Table 2. Figure 5 illustrates the time series of stations BOR1, GRAZ, GOPE, JOZE resulting from various individual combinations of four networks. As we can see (Fig. 5), the residuals of CEPER permanent network are followed by residuals of epoch-wise networks (CEGRN, SGRN and TATRY). After applying the discontinuities, and rejecting the outliers exceeding the value of 0.02 m, the refined individual solutions were formed and velocities were estimated. For the velocity estimation the stations with observation interval longer than 3 years were considered. In case of epoch-wise networks we considered stations with at least 2 repeated observation campaigns. Global velocities were reduced for APKIM2000 velocity model. The intraplate horizontal velocities were compared with ITRF2005 and are illustrated in Fig. 6. We can see that CEPER permanent network is in majority more consistent with official ITRF2005 velocities as three epoch-wise networks. The uncertainties were not displayed but in case of epoch-wise networks are two or three times bigger than in case of CEPER permanent network.

6. Final combination

In this step the results of individual combinations provided in SINEX format containing the station positions, velocities and full variance matrix were combined together. Mathematical model used in this step is described in *Altamimi (2006).* The ITRF2005 related velocities were reduced using APKIM2000 velocity model. Quality of final combination was evaluated by computing per network RMS of unit weight (WRMS). Results are given in Table 3. Figure 7 displays the intraplate velocities obtained in final combination.

The final output set consists of velocities of 145 sites. For the purpose

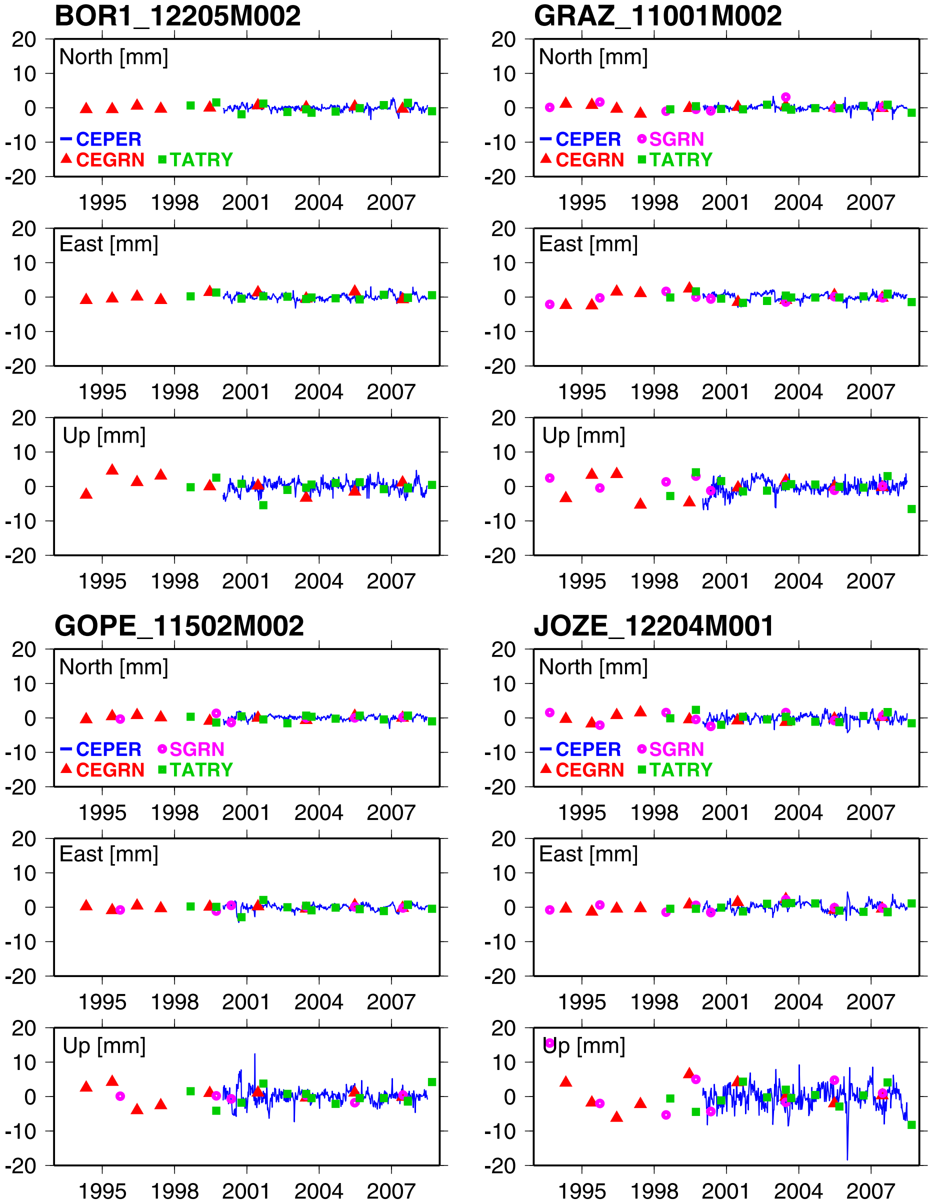

Fig. 5. De-trended time series of station position of permanent stations BOR1, GRAZ, JOZE, PENC resulting from individual combinations. CEPER permanent network – line, CEGRN –triangles, SGRN – dots, TATRY – squares.

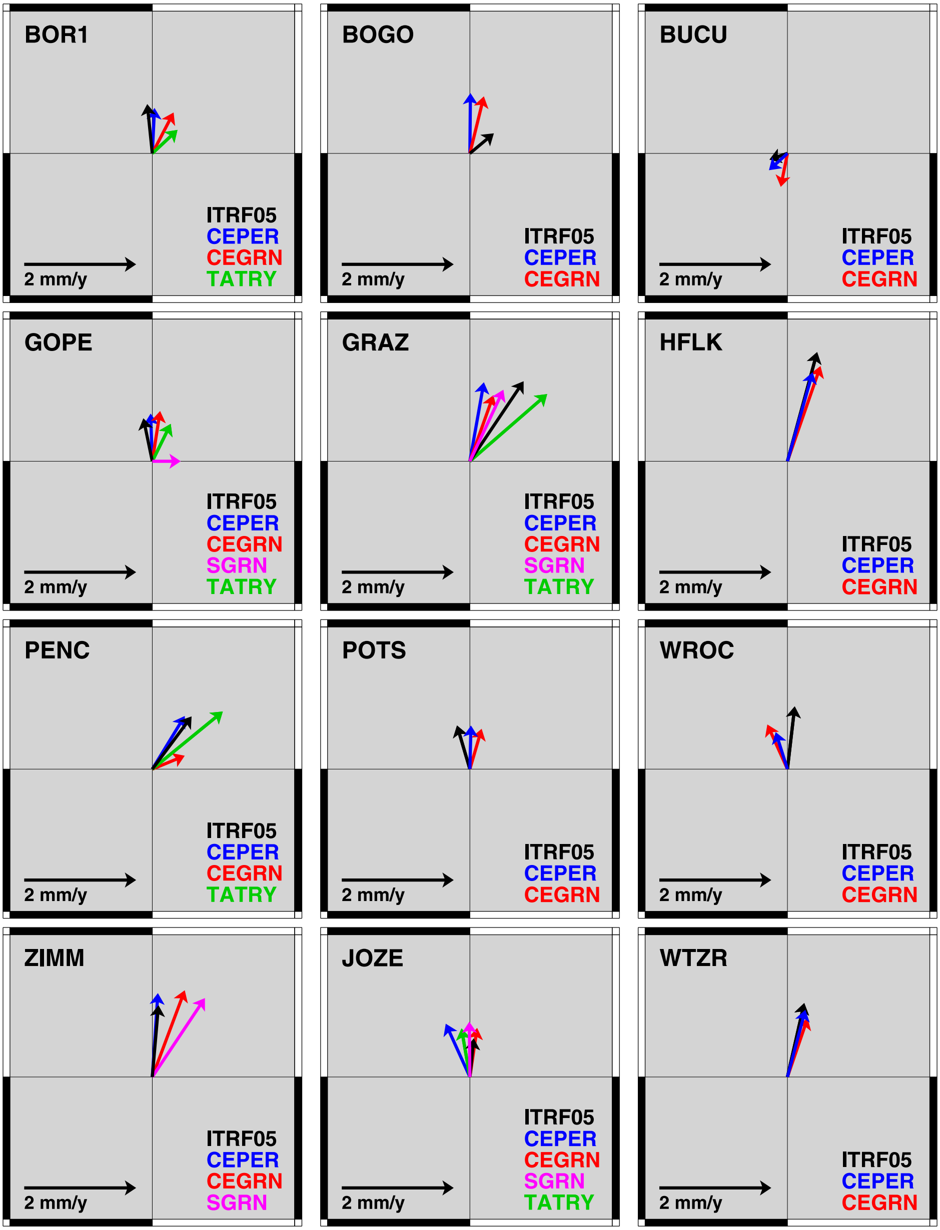

Fig. 6. Intraplate velocities resulting from individual combinations of CEPER, CEGRN, SGRN, local network TATRY and ITRF2005 velocities where available.

of this article we selected the subset of 21 permanent stations which are also present in ITRF2005 solution. Table 4 contains computed velocities of selected stations related to ITRF2005 and intraplate velocities reduced for APKIM2000 velocity model. Official ITRF2005 velocities are given in the last column for better comparison. All the selected velocities are expressed in the local horizontal system.

The difference between our results and official ITRF2005 velocities reaches the value of 0.5 mm in both horizontal components. Only the stations BOGO, GRAZ and GOPE manifest the difference about 0.7 mm. In case

Table 3. RMS of unit weight per individual solution (network) and their time span

	WRMS 2D [m]	WRMS UP [m]	Time span [year]
CEPER	0.0001	0.0003	8.48
CEGRN	0.0017	0.0031	13.14
SGRN	0.0013	0.0027	13.82
TATRY	0.0013	0.0033	10.02

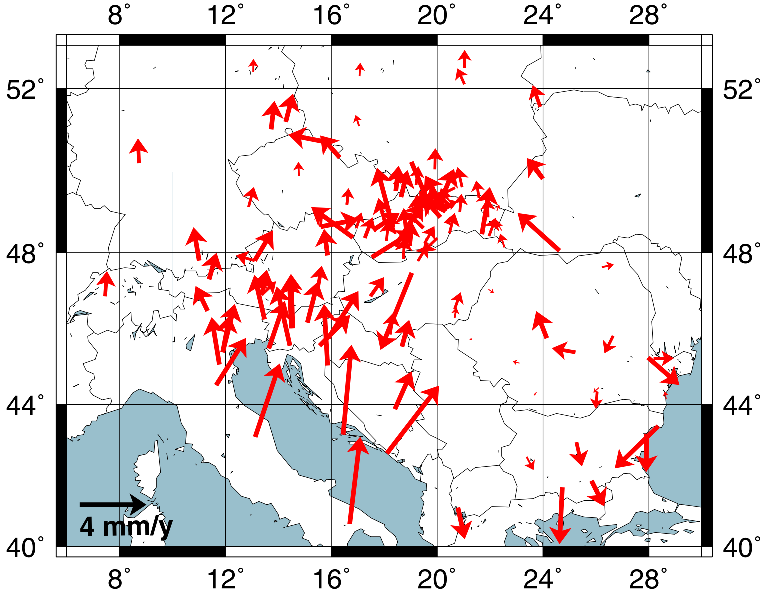

Fig. 7. Intraplate velocities obtained from final combination of four networks (CEPER permanent network, CEGRN, SGRN and local network TATRY).

Table 4. ITRF2005 related velocities (v_e, v_n, v_u), intraplate velocities (δv_e, δv_n, δv_u) and their uncertainties (σ_{ve}, σ_{vn}, σ_{vu}). Last column indicates the official ITRF2005 velocities.

Station name	v_e [mm/y]	δv_e [mm/y]	σ_{ve} [mm/y]	v_n [mm/y]	δv_n [mm/y]	σ_{vn} [mm/y]	v_u [mm/y]	δv_u [mm/y]	σ_{vu} [mm/y]	ITRF2005 v_e [mm/y]	ITRF2005 v_n [mm/y]	ITRF2005 v_u [mm/y]
BOGO	20.60	0.01	0.03	14.54	1.08	-0.01	0.51	0.47	0.08	21.02	13.82	-1.81
BOR1	19.94	0.04	0.03	14.74	0.81	0.00	0.78	0.74	0.05	19.81	14.81	0.52
BUCU	22.96	-0.33	0.03	12.49	-0.29	-0.03	3.19	3.15	0.10	22.97	12.67	1.22
GLSV	21.65	-1.10	0.34	12.73	0.63	0.00	0.55	0.51	1.81	22.01	12.65	0.34
GOPE	20.06	-0.03	0.04	15.02	0.85	-0.05	1.18	1.14	0.12	21.17	14.33	2.56
GRAZ	21.18	0.24	0.04	15.51	1.41	-0.03	0.88	0.84	0.12	21.90	15.53	0.16
HFLK	20.58	0.45	0.03	16.09	1.60	-0.02	2.40	2.36	0.09	20.76	14.16	1.70
JOZE	20.26	-0.43	0.03	14.42	0.95	0.00	2.11	2.07	0.05	20.76	14.16	2.40
KOSG	17.61	-0.07	0.12	15.80	0.92	-0.05	0.90	0.86	0.70	17.57	16.45	1.61
LAMA	19.89	-0.26	0.03	14.39	0.88	0.00	0.74	0.70	0.08	19.97	14.55	0.24
MATE	23.17	0.63	0.03	19.22	5.24	-0.01	1.40	1.36	0.03	23.15	19.40	1.15
MEDI	22.66	1.80	0.03	17.32	2.85	-0.02	-1.10	-1.15	0.09	22.28	17.56	-2.26
METS	19.84	0.78	0.17	12.55	-0.46	-0.01	4.93	4.89	0.95	19.77	12.75	5.20
ONSA	16.76	-0.60	0.14	14.73	0.30	-0.04	3.23	3.19	0.77	16.89	14.51	3.65
PENC	22.01	0.57	0.04	14.63	0.95	-0.03	0.69	0.65	0.12	22.14	14.62	-0.58
POTS	19.10	0.01	0.03	15.11	0.78	-0.01	0.85	0.81	0.05	18.86	15.11	0.26
SOFI	23.65	0.42	0.03	12.37	-0.80	-0.03	0.60	0.56	0.11	23.91	11.86	0.88
UZHL	21.63	-0.14	0.03	13.84	0.53	0.00	1.13	1.09	0.09	21.77	14.02	-0.07
WROC	19.99	-0.21	0.03	14.59	0.66	-0.02	2.09	2.05	0.10	20.33	15.05	3.76
WTZR	20.25	0.32	0.03	15.55	1.20	-0.02	0.69	0.65	0.06	20.23	15.67	1.51
ZIMM	19.62	0.11	0.03	16.30	1.51	0.00	2.32	2.28	0.04	19.58	16.08	2.32

of vertical component the majority of differences is below 1 mm. The outliers exceeding this value are BOGO (2.32 mm), BUCU (1.97 mm), GOPE (1.38 mm), PENC (1.27 mm) and WROC (1.67 mm).

In order to explain the results of final combination we divided the investigated area in three parts containing region of Central and Southeastern Europe, Slovak Republic and Tatra Mountains.

6.1. Central and Southeastern Europe

We divided the investigated area to the following five parts in order to interpret the computed velocities:

- Adriatic region – showing predominantly northward oriented velocities with magnitude of 3–5 mm/year.
- Eastern part of Balkan Peninsula is characterized by velocities with magnitude of 4 mm/year with southward orientation.
- Pannonian Basin – features northern and northeastern orientation of velocities vectors with magnitude up to 2 mm/year.
- Italian Peninsula – north-easterly oriented velocities of 3–5 mm/year.
- North European Platform – we consider this platform stable with northerly oriented velocities up to 1 mm/year.

Intraplate velocity field illustrated in Fig. 7 is consistent with geo-kinematical behavior described by several authors *(Caporali et al., 2008* and *Hefty, 2007).*

6.2. Slovak Republic

Figure 8 illustrates the horizontal and vertical residual velocity fields. As mentioned previously, APKIM2000 velocity model was used in order to obtain intraplate velocity field. As we can see (Fig. 8) the horizontal velocities are predominately oriented in the north-east direction with magnitude, about 1–4 mm/year. In vertical component the uplift of about 1–6 mm/year is visible. Here we have to mention that the stations distinguishing the biggest uplift are the points of epoch-wise observation, where the vertical intraplate velocities are in $1\,\sigma$ level and we could not consider these velocities significant. As mentioned in section 2 the observation interval of this type of points ranges from 24 to 120 hours per campaign.

6.3. Tatra Mountains

23 velocities of local network Tatry were estimated in the final combination. All vertical velocities are in $1\,\sigma$ level showing the uplift up to 4 mm/year. Horizontal velocities are oriented predominantly in north direction with magnitude up to 3 mm/year.

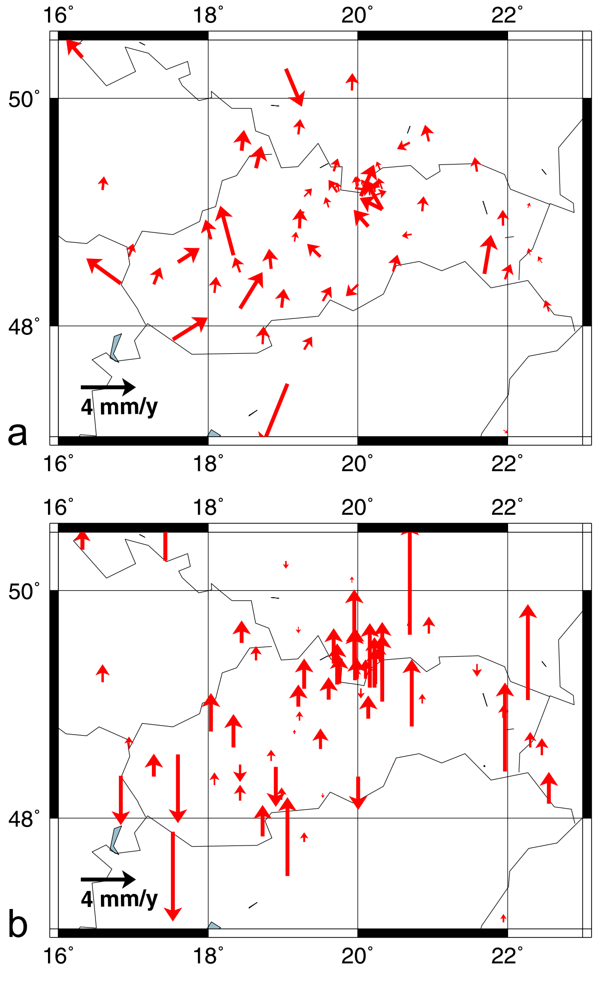

Fig. 8. Horizontal (a) and vertical (b) intraplate velocities in Slovakia resulting from final combination.

7. Conclusions

The general combination strategy employed in CATREF software *(Altamimi, 2006)* is described in this paper. The combination of four regional networks is taken as a practical experiment in order to obtain the homogeneous velocity field of the Central Europe. The ITRF2005 solution was used for datum definition in minimal constraint approach, where we minimize the transformation parameters between the external and combined reference frames. The most delicate step is to identify the discontinuities present in time series of station positions. Generally we estimated 36 discontinuities in 14 sites of permanent observations. These discontinuities were introduced in each individual combination of epoch-wise network. In terms of datum definition it is convenient to use the stations where no significant discontinuity is present in time series. Only the stations with observation interval longer than three years were included in the velocity estimation. The final output SINEX file consists of 145 sites which fulfill these conditions. ITRF2005 related velocities were reduced for the APKIM2000 model.

Final velocity field was for the purpose of better interpretation divided into regions of Central Europe, Slovak Republic and Tatra Mountains. In Central Europe we can observe the geo-kinematical behavior confirmed by several authors (*Caporali et al., 2008* and *Hefty, 2007).* The most significant are the predominantly north-east orientated horizontal velocities in Adria region, reaching the value 3–5 mm/year and southward oriented velocities of East part of Balkan Peninsula with magnitude about 4 mm/year. The intraplate velocity field in Slovakia is oriented northeast and reaches the values of 1–4 mm/year. In Tatra Mountains we observe mostly northward oriented velocity vectors up to 3 mm/year.

Acknowledgments. This work was supported by the Grant No. 1/4089/07 of the Grant Agency of Slovak Republic VEGA.

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