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CONTRIBUTION OF GPS PERMANENT STATIONS IN CENTRAL EUROPE TO REGIONAL GEO-KINEMATICAL INVESTIGATIONS

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ABSTRACT
At the Slovak University of Technology (SUT) in Bratislava we continuously analyse permanent GPS network comprising of more than 30 stations situated in Central Europe, designed mainly for European Terrestrial Reference Frame maintenance and regional geodynamic investigations. The purpose of such analysis is a detailed inspection of coordinate repeatability, systematic effects, and regional geodynamic phenomena influencing the behaviour of permanent stations. We present the mathematical model for referencing the regional network with aim to reduce global effects in evolution of station coordinates and to give detailed information about relative local effects. Station behaviour is then modelled by residual velocities and seasonal variations. The numerical outputs are results of the analysis of two-year interval of daily coordinates.

KEYWORDS: permanent GPS network, coordinate time series, relative site velocities, seasonal variations

1. INTRODUCTION

Analysis of time series obtained from permanent GPS stations is a unique tool for deeper understanding of systematic phenomena and quality of coordinates resulting from GPS geodetic observations. Within the EU project CERGOP-2/Environment (Fejes and Pešec, 2003) SUT processes network of permanent GPS sites situated in Central Europe. It consists mainly of stations of the European Permanent Network – EPN (details about EPN are available at www.epncb.oma.be) and several sites not belonging to EPN (5 stations in December 2004, their number is expected to gradually increase). The network analyzed in 2004 is shown in Fig. 1. The Bernese GPS software, version 4.2 - BV42 (Hugentbler et al., 2001) is used for processing the GPS observations and for station coordinate evaluation. The processing strategy follows similar rules to that of the EPN analysis at Local Analysis Centres (Bruyninx et al., 2003) with some slight modifications. More details about the network analysis of selected stations in Central Europe performed at SUT are in (Hefty et al., 2004, Hefty, 2004). For further analysis we will use the daily products of network adjustment: files with station coordinates and their covariance matrices. The solutions covering 24-hour intervals (from 0 to 24 h UT) of observations are obtained with constraining *X*, *Y* and *Z* coordinates of one reference site (BOR1) to 0.0001 m. This means that the daily coordinate outputs can be treated as free network solutions without any deformation due to primary referencing. In this paper we are analyzing the daily coordinates, in contrast to routine EPN analyses, where the weekly coordinates are used for station behavior investigations.

To eliminate common coordinate variations of the whole network due to variations of the constrained BOR1 station and due to systematic regional influences we will apply the referencing of the whole network to a set of selected stations, which appear stable from the long-term point of view. This step means that the station residuals from this referencing will reflect only the relative station variations when compared to the network mean. The residual time series of local station coordinates will then be analysed for linear trend and seasonal variations. In addition, we will examine if the series show polynomial trend which we regard as indication about possible unmodelled station variations. The residual noise of the horizontal coordinates and ellipsoidal height will also be discussed. Other statistical characteristics like the autocorrelation functions, spectral densities and Allan variances are topics of an other paper (Hefty et al., 2005).

2. MATHEMATICAL MODEL FOR REFERENCING TIME SERIES OF REGIONAL PERMANENT NETWORK COORDINATES

The aim of referencing procedure described in this chapter is to obtain series containing detailed information about time variations of permanent station coordinate components. We expect that elimination of

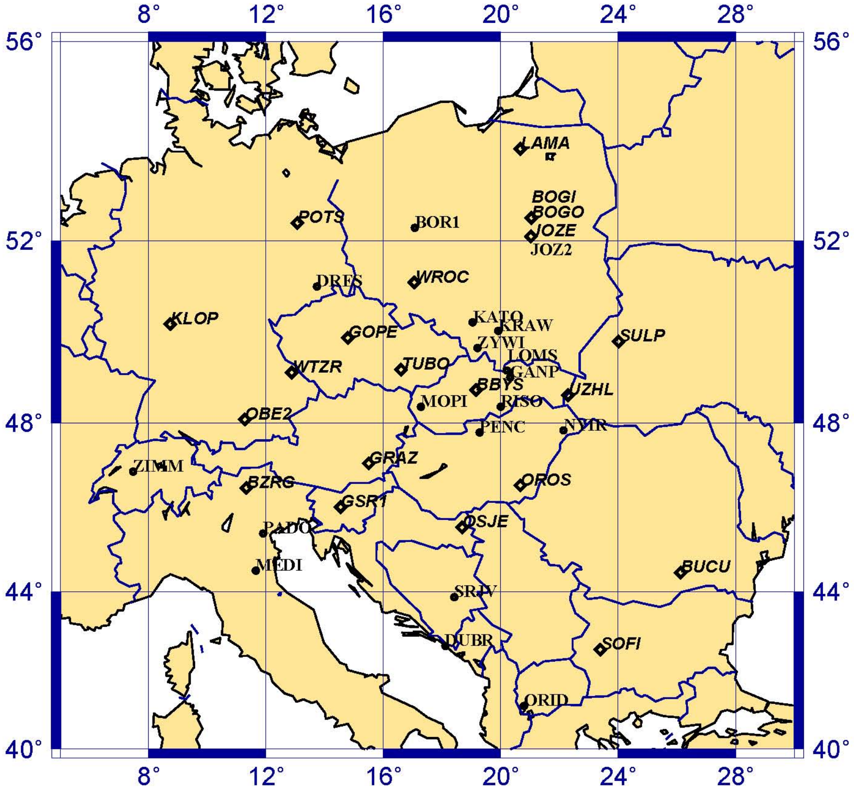

Fig. 1 Network of GPS permanent stations in Central Europe analysed at SUT within the CERGOP-2/Environment. Selected stations forming the reference are marked by diamonds, the other stations are marked with dots.

coordinate changes common to the whole network analysed (the network is situated on one tectonic plate) will enable to better investigate local station behaviour. We will describe the procedure of transformation of the daily stations coordinates referenced to the ITRF (through constraining the fiducial station BOR1) to relative station coordinates related to the "mean" position of the network at the epoch of observation t.

The network solution, which is output of separate processing of 24-hour observing interval, related to the actual epoch t includes set of coordinates

$$\mathbf{X}(t) = \begin{bmatrix} \mathbf{X}_1(t) \\ \mathbf{X}_2(t) \\ \vdots \\ \mathbf{X}_n(t) \end{bmatrix} \tag{1}$$

and their covariance matrix $\mathbf{\Sigma_X}(t)$.

The network solution contains coordinates $\mathbf{X}_i(t) = [X_i(t) \quad Y_i(t) \quad Z_i(t)]^T$ (i = 1, 2, … n) of n stations which were observed during 24-hours (exceptionally less) at the epoch t.

Daily geocentric coordinates $\mathbf{X}_j(t)$ of subset of m (j = 1, 2, … m, $m \le n$) selected stable stations will be further reduced for mean station position $\mathbf{X}_{0j}$ at reference epoch t_0 and the a-priori station velocity $\mathbf{v}_{0j}$ as

$$\Delta\mathbf{X}_j(t) = \mathbf{X}_j(t) - \mathbf{X}_{0j} - \mathbf{v}_{0j}(t - t_0) \tag{2}$$

In the case of well-predicted mean position $\mathbf{X}_{0j}$ and velocity $\boldsymbol{v}_{0j}$ the $\Delta\mathbf{X}_j(t)$ should vary only due to random errors of coordinates of the station j and due to random errors of the reference station (BOR1 in our case). The common part of $\Delta\mathbf{X}_j(t)$ variations reflect the whole network drift and actual network orientation at the epoch t. It can be modelled by three translation parameters $T_X(t)$, $T_Y(t)$, $T_Z(t)$ and three rotation angles $\omega_X(t)$, $\omega_Y(t)$, $\omega_Z(t)$. Intentionally we do not introduce the scale factor, because it could misinterpret the long-term stations behaviour from geodynamical point of view.

The relation among $\Delta\mathbf{X}_j(t)$ of individual stations and common parameters $\mathbf{T}(t)$ could be written as

$$\Delta\mathbf{X} = \begin{bmatrix} \Delta\mathbf{X}_1(t) \\ \Delta\mathbf{X}_2(t) \\ \vdots \\ \Delta\mathbf{X}_n(t) \end{bmatrix} = \begin{bmatrix} \mathbf{A}_1 \\ \mathbf{A}_2 \\ \vdots \\ \mathbf{A}_n \end{bmatrix} \begin{bmatrix} T_X(t) \\ T_Y(t) \\ T_Z(t) \\ \omega_X(t) \\ \omega_Y(t) \\ \omega_Z(t) \end{bmatrix} = \mathbf{AT}(t) \tag{3}$$

where submatrices of the design matrix **A** are given as

$$\mathbf{A}_i = \begin{cases} \begin{bmatrix} 1 & 0 & 0 & 0 & Z_{0i}-Z_B & -(Y_{0i}-Y_B) \\ 0 & 1 & 0 & -(Z_{0i}-Z_B) & 0 & X_{0i}-X_B \\ 0 & 0 & 1 & Y_{0i}-Y_B & -(X_{0i}-X_B) & 0 \end{bmatrix} & \text{if the station is among the selected reference} \\ \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} & \text{for other stations} \end{cases} \tag{4}$$

X_B, Y_B, Z_B are coordinates of barycentre of the network.

The estimate of parameters $\hat{\mathbf{T}}(t)$, which define the orientation and translation of the actual ‘daily’ network solution relatively to the modeled position of reference points we obtain as

$$\hat{\mathbf{T}}(t) = \left(\mathbf{A}^T \Sigma_{\mathbf{X}}^{-1}(t)\mathbf{A}\right)^{-1} \mathbf{A}^T \Sigma_{\mathbf{X}}^{-1}(t)\,\Delta\mathbf{X}(t) \tag{5}$$

The station residuals defined as

$$d\mathbf{X}(t) = \Delta\mathbf{X}(t) - \mathbf{A}\hat{\mathbf{T}}(t) \tag{6}$$

represent the actual shifts of positions of each of all n stations included in the network solution at the epoch t. The time series $\{d\mathbf{X}_i(t_k)\}$, $k = 1, 2, \dots p$, where p is number of observed epochs (24-hour intervals) describes the station behavior in time domain.

For better interpretation it is convenient to transform residuals of each station i expressed in geocentric system X, Y, Z to local system n, e, v according to formula

$$d\mathbf{N}_i(t) = \begin{bmatrix} dn_i(t) \\ de_i(t) \\ dv_i(t) \end{bmatrix} = \begin{bmatrix} -\sin\varphi_i\cos\lambda_i & -\sin\varphi_i\sin\lambda_i & \cos\varphi_i \\ -\sin\lambda_i & \cos\lambda_i & 0 \\ \cos\varphi_i\cos\lambda_i & \cos\varphi_i\sin\lambda_i & \sin\varphi_i \end{bmatrix} \begin{bmatrix} dX_i(t) \\ dY_i(t) \\ dZ_i(t) \end{bmatrix} = \mathbf{R}(\varphi_i, \lambda_i)\, d\mathbf{X}_i(t) \tag{7}$$

Then the $\{d\mathbf{N}_i(t_k)\}$ series represent the time dependent station evolution expressed in horizontal coordinate components and ellipsoidal heights. These variations are influenced mainly by effects, which are characteristic for each individual station. The station variations common to the whole network were eliminated by the procedure described above. In this way the $\{d\mathbf{X}_i(t_k)\}$ and $\{d\mathbf{N}_i(t_k)\}$ series reflect the relative variations of each site

3. ANALYZED STATIONS AND THEIR CHARACTERIZATION

The referencing procedure described in previous chapter was applied to network comprising of 30 GPS permanent stations in Central Europe. The daily network solutions for two-years interval from 2003.0 to 2005.0 (GPS weeks 1200 – 1304) were in the first step used for creating the reference series by estimating of parameters T(t) in the model (3). After checking the continuity and homogeneity of the observation series at individual stations, finally 21 sites were selected to form the reference. Distribution of these stations is shown in Fig. 1.

The series of translation parameters $\{T_X(t)\}$, $\{T_Y(t)\}$, $\{T_Z(t)\}$ transformed to components in local coordinate system $\{T_n(t)\}$, $\{T_e(t)\}$, $\{T_v(t)\}$ are plotted in Fig. 2. Time series of parameters defining the horizontal position of the ‘network mean’ $\{T_n(t)\}$ and $\{T_e(t)\}$ are stable and do not demonstrate significant long-term shift. This corresponds to the fact that the a-priori velocities v_{0j} in (2) accurately model the station motion. The height component $\{T_v(t)\}$ shows annual signal with about 10 mm amplitude. Such variation is visible at majority of ITRF referenced EPN sites situated in Central Europe (ITRF time series visualised at www.epncb.oma.be). According to (Bruyninx, 2005) this phenomenon is consequence of bug of computations of tidal corrections in BV42 software.

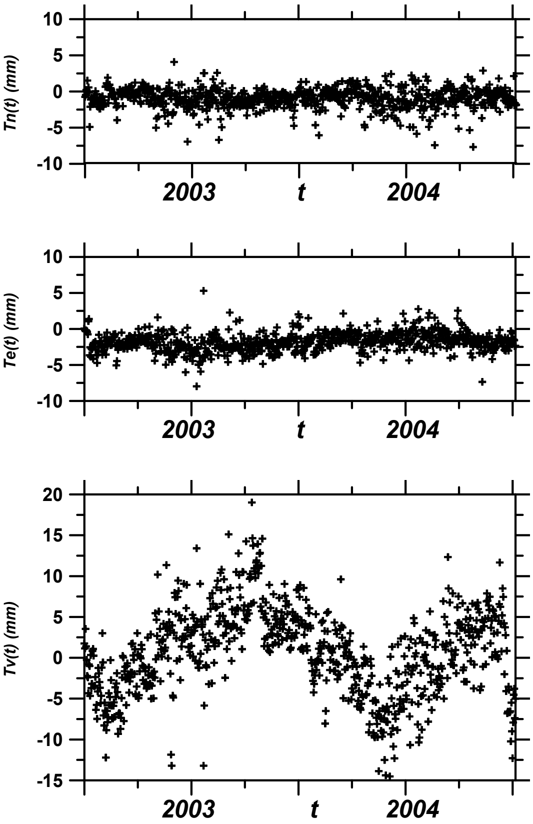

Fig. 2 Time series of reference translation parameters $\{T_n(t)\}$, $\{T_e(t)\}$, $\{T_v(t)\}$ expressed in local coordinate system components.

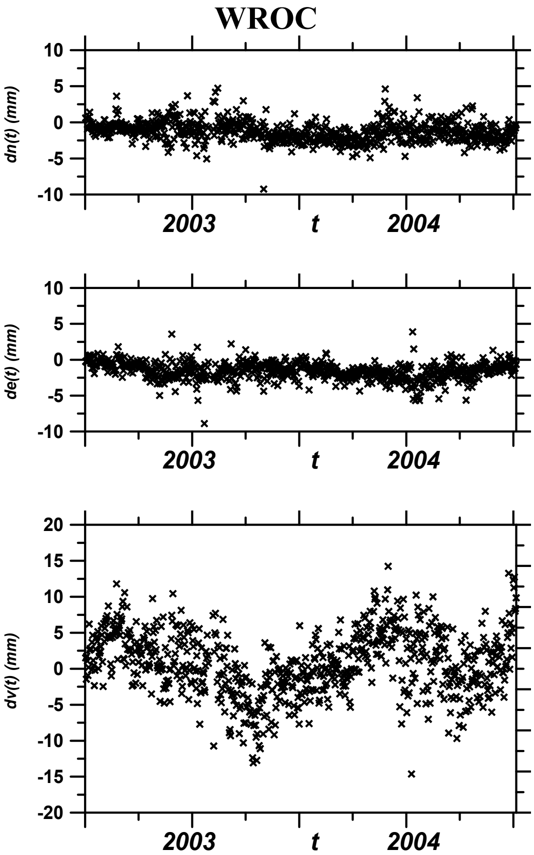

Fig. 3 Residual variations of station Wroclav (WROC) in north-south, east-west and up components

When applying the reference series to coordinate series of all stations in the network we obtain reduced time series of individual sites. These series will serve as input for further analyses. As an example we show in Fig. 3 time series of Wroclaw (WROC) permanent GPS station $\{dn_{WROC}(t)\}$, $\{de_{WROC}(t)\}$ and $\{dv_{WROC}(t)\}$. The WROC station appears quite stable in the horizontal components and shows seasonal variations in the height component. The other example, the series of station Kraków (KRAW) that is geographically not very distant from WROC are plotted in Fig 4. Strong annual signal is visible in $\{dn_{KRAW}(t)\}$ series and similar pattern is visible for up component of WROC and KRAW series. Another example is Sofia (SOFI) station. Significant residual linear trend in both horizontal coordinates series $\{dn_{SOFI}(t)\}$ and $\{de_{SOFI}(t)\}$is visible in Fig. 5, note also larger scatter of all three coordinate components.

Systematic behaviour of the $\{dn_i(t)\}$, $\{de_i(t)\}$ and $\{dv_i(t)\}$ series can be described according to the model (the station index i is omitted for simplicity)

$$\begin{aligned}
dn(t) &= n_0 + dv_n(t-t_0) + p_n(t-t_0)^2 + b_n \sin\left(\frac{2\pi(t-t_0)}{365.24}\right) + c_n \sin\left(\frac{2\pi(t-t_0)}{365.24}\right) + \\
&\quad d_n \sin\left(\frac{4\pi(t-t_0)}{365.24}\right) + e_n \sin\left(\frac{4\pi(t-t_0)}{365.24}\right) + \sum_{k=1}^{r} z_{n_k}\delta(t-t_0) \\
de(t) &= e_0 + dv_e(t-t_0) + p_e(t-t_0)^2 + b_e \sin\left(\frac{2\pi(t-t_0)}{365.24}\right) + c_e \sin\left(\frac{2\pi(t-t_0)}{365.24}\right) + \\
&\quad d_e \sin\left(\frac{4\pi(t-t_0)}{365.24}\right) + e_e \sin\left(\frac{4\pi(t-t_0)}{365.24}\right) + \sum_{k=1}^{r} z_{e_k}\delta(t-t_0) \\
dv(t) &= v_0 + dv_v(t-t_0) + p_v(t-t_0)^2 + b_v \sin\left(\frac{2\pi(t-t_0)}{365.24}\right) + c_v \sin\left(\frac{2\pi(t-t_0)}{365.24}\right) + \\
&\quad d_v \sin\left(\frac{4\pi(t-t_0)}{365.24}\right) + e_v \sin\left(\frac{4\pi(t-t_0)}{365.24}\right) + \sum_{k=1}^{r} z_{v_k}\delta(t-t_0)
\end{aligned} \tag{8}$$

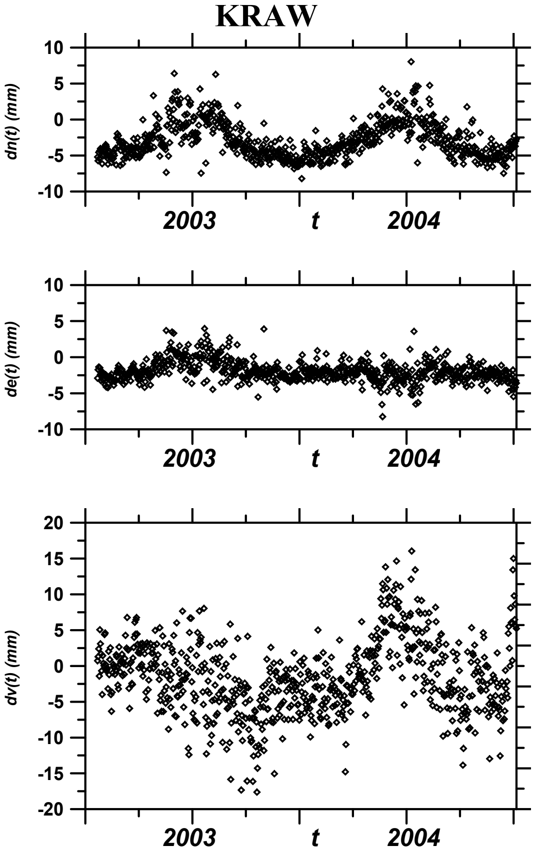

Fig. 4 Residual variations of station Kraków (KRAW) in north-south, east-west and up components

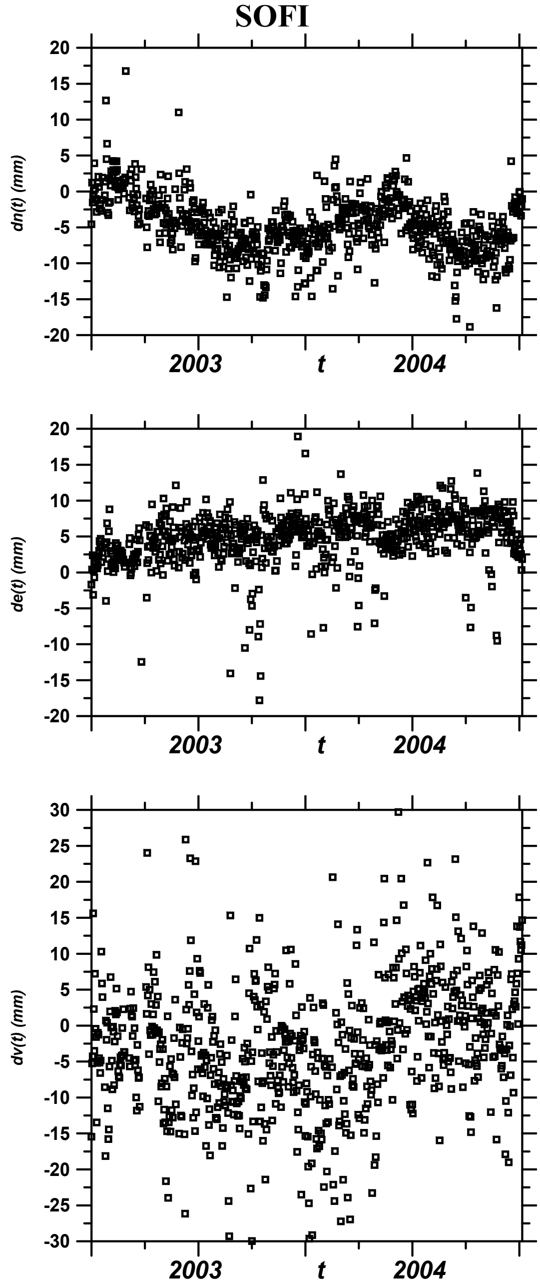

Fig. 5 Residual variations of station Sofia (SOFI) in north-south, east-west and up components.

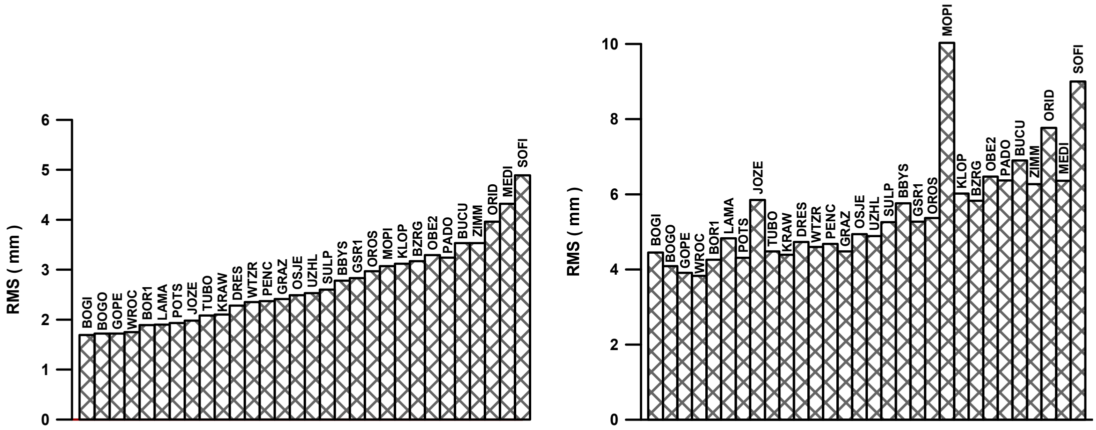

Fig. 6 RMS errors of horizontal position (left) and height (right) determination at analysed permanent stations. Their values are obtained after applying model (8) and correspond to 24-hours observing intervals.

where dv_n, dv_e, dv_v are the residual velocity components representing the linear station movement relative to reference station mean. Values p_n, p_e, p_v are the facultative coefficients which are used to check if the station shows polynomial trend in station coordinates. They are included only for testing purposes and not included for routine analysis. The amplitude coefficients b_n, b_e, b_v, c_n, c_e, c_v describe the annual and d_n, d_e, d_v, e_n, e_e, e_v the semi-annual variation of station position. Sudden changes of position due to station arrangements or equipment alterations are modelled using the known function $\delta(t-t_0)$ with estimated amplitudes z_n, z_e, z_v. If the values of some of the p_n, p_e, p_v polynomial coefficient are significant it is an indication that the modelling of station behaviour was not sufficient, e.g. not all the sudden changes were introduced in the modelling. Consistency of station daily coordinates can be characterized by RMS error of unit weight separately for each coordinate constituent after applying the model (8).

In the next sections we will present some outputs obtained form analysis of two-year interval of observations at 30 Central European permanent GPS stations.

3.1. CONSISTENCY OF DAILY COORDINATES

Values of RMS errors characterizing the repeatability of determination of station horizontal position and height after applying the model (8) are displayed in Fig. 6. The differences among individual stations are more dominant for horizontal position (the “worst” third of stations has about double RMS when compared to the “best” third of stations). For the vertical component (except of some stations as MOPI, ORID and SOFI) the differences are not above 30%. The repeatability of horizontal coordinates from 24 – hour observations is for majority of stations up to 3 mm and the vertical repeatability is up to 6 mm.

3.2. HORIZONTAL AND VERTICAL VELOCITIES

Horizontal relative velocities dv_n, dv_e and vertical relative velocities dv_v expressed in units mm/year are given in Tab. 1 and plotted in Figs 7 and 8. Velocities are evaluated only for those sites where the two-year interval is covered at least by 80% of observations. Uncertainties of horizontal velocities estimated from (8) are in range 0.2 – 0.4 mm/year and for vertical velocities are in range 0.3 – 0.6 mm/year. Note that due to referencing procedure these velocities reflect the station changes relative to “mean” of the network. It is worth to mention that we applied the white noise error model for series $\{dn_i(t)\}$, $\{de_i(t)\}$ and $\{dv_i(t)\}$. We name the uncertainties in Tab. 1 as ‘formal’. The real uncertainties of velocities are expected to be larger of factor four if the coloured noise model is applied (Caporali, 2003, Williams, 2003). The effect of coloured noise on parameter estimation from (8) will be studied elsewhere.

For majority of the stations the horizontal velocities are in the range of 1- 2 mm/year, generally exceeding their uncertainties given in Tab. 1. There are some visible common regional trends at BOGO, BOGI, LAMA, JOZE in north-eastern, WTZR, ZIMM, OBE2, BZRG in western and SOFI, ORID in the south-eastern part of the network.

The estimated vertical velocities are in the range of 2-4 mm/year, generally showing the uplift. However, the interpretation of both horizontal and vertical components should be done very cautiously as our analysis is based only on the two-year interval of data.

Part of the EPN stations with longer observational history analysed in this paper has the velocity determined in the ITRF 2000 (Boucher et al., 2004). We will use them for comparison with relative velocities given in Tab. 1. As not all the stations used for definition of the reference series in this paper (shown in Fig. 1) have ITRF 2000 velocities, it is no possible to evaluate relative ITRF 2000 velocities basing on the same reference stations as used for forming the reference series shown in Fig. 2. For the sake of comparison we will use ITRF 2000 velocities reduced for velocities of Actual Plate Kinematic Model - APKIM 2000 (Drewes, 1998). In Tab. 2 are given the reduced ITRF 2000 velocity components transformed into local horizontal coordinate system. denoted as δv_n, δv_e, δv_v. We believe that these values express similar phenomena as the velocities dv_n, dv_e, dv_v obtained in this paper, namely station velocities reduced for the global part of motion Central Europe within the Eurasian tectonic plate.

Detailed inspection of the corresponding values in Tab. 1 and Tab. 2 shows that the dv_i and δv_i velocity components (i = n, e, v) generally agree in their magnitudes (taking into account the uncertainties). The sign of the relative velocity components agrees only partially. This discrepancy can be ascribed to variety of factors, namely: relatively short (2-year) interval of observations used in this paper, relative velocities in Tabs. 1 and 2 are not evaluated by using the same reference, some ITRF 2000 velocities seems to be unrealistic (e.g. all components of BUCU, height components of BZRG and MOPI).

3.3. SEASONAL VARIATIONS

Cyclic coordinate variations with annual and semi-annual periods are besides of linear changes the most dominant phenomena characterizing the behaviour of the permanent GPS station. There is variety of potential sources for seasonal variations of permanent GPS observations: changes of monumentation of the GPS antenna (pillar, mast or building), environmental changes (vegetation surrounding the station, underground water storage, snow and ice layer, local troposphere), celestial reference frame realisation, etc.

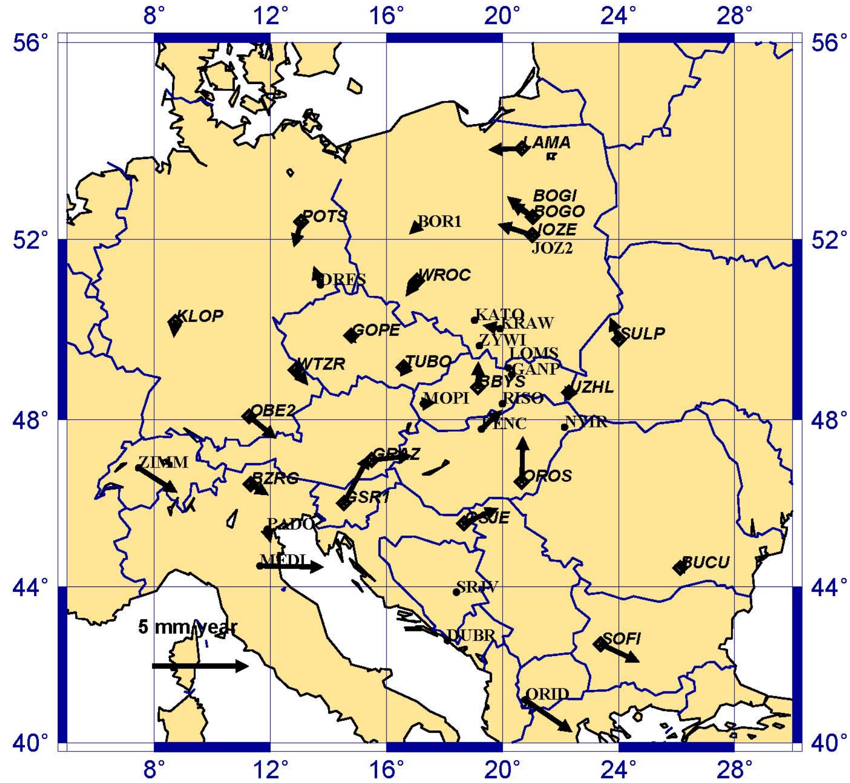

Fig. 7 Relative horizontal velocities of Central European permanent stations estimated from GPS observations during 2003-2004.

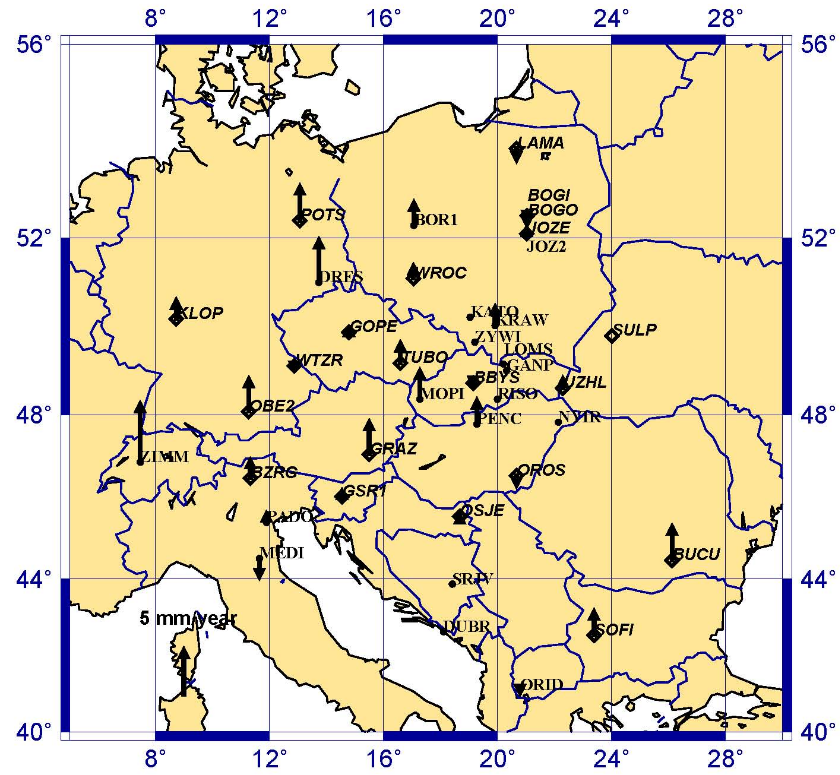

Fig. 8 Relative vertical velocities of Central European permanent stations estimated from GPS observations during 2003-2004.

Table 1 Station values of velocity components v_n, v_e v_v and amplitude coefficients b_n, b_e b_v, c_n, c_e c_v of annual terms and their one-sigma uncertainties estimated from two-years interval of observations (all values are in millimetres).

Station	dv_n	b_n	c_n	dv_e	b_e	c_e	dv_v	b_v	c_v
No.	σ_{dvn}	σ_{bn}	σ_{cn}	σ_{dve}	σ_{be}	σ_{ce}	σ_{dvv}	σ_{bv}	σ_{cv}
BOR1	-0.26	-0.51	-0.11	-0.30	-0.25	-0.00	2.16	4.09	-1.38
1	0.10	0.08	0.07	0.09	0.07	0.07	0.31	0.24	0.22
BOGO	1.04	-0.13	0.24	-1.14	-0.24	0.26	-1.60	3.35	-1.78
2	0.09	0.07	0.06	0.09	0.07	0.06	0.30	0.24	0.22
BOGI	0.68	-0.36	0.00	-0.95	-0.14	0.31	-1.04	3.04	-3.47
3	0.09	0.07	0.06	0.09	0.07	0.07	0.33	0.26	0.25
DRES	0.78	-0.30	-0.76	-0.38	-0.56	-2.54	4.73	3.00	-1.20
4	0.11	0.09	0.08	0.13	0.10	0.09	0.35	0.27	0.26
GOPE	-0.31	0.14	-0.41	0.00	-0.31	-0.42	0.21	1.75	-0.76
5	0.09	0.08	0.07	0.08	0.06	0.06	0.28	0.22	0.21
JOZE	0.53	-0.17	-0.70	-1.51	-0.29	0.68	0.04	1.97	0.61
6	0.10	0.08	0.07	0.10	0.08	0.07	0.42	0.33	0.31
LAMA	-0.06	-0.92	-0.08	-1.50	-0.19	0.46	-1.56	4.69	-3.88
7	0.10	0.08	0.07	0.09	0.07	0.07	0.35	0.28	0.25
PENC	0.68	0.92	-0.37	0.92	0.07	0.63	2.09	-1.23	-2.18
8	0.17	0.11	0.10	0.14	0.09	0.08	0.44	0.29	0.26
POTS	-1.25	-0.75	-0.28	-0.46	0.59	-0.64	3.57	2.94	-1.42
9	0.10	0.08	0.07	0.10	0.08	0.07	0.31	0.25	0.23
WROC	-0.75	-0.38	-0.40	-0.52	-0.03	0.57	0.98	2.71	-1.34
10	0.10	0.08	0.07	0.08	0.07	0.06	0.28	0.22	0.20
ZIMM	-1.54	0.73	-0.91	1.75	1.71	-0.80	6.45	3.29	1.80
11	0.16	0.12	0.11	0.20	0.16	0.15	0.45	0.36	0.33
BZRG	-0.70	1.09	1.09	0.74	0.06	-0.22	1.85	2.35	1.41
12	0.16	0.13	0.12	0.16	0.13	0.12	0.42	0.33	0.31
MEDI	-0.23	0.48	0.75	3.09	1.13	-1.17	-2.09	1.73	1.65
13	0.18	0.14	0.13	0.26	0.20	0.19	0.46	0.37	0.34
GRAZ	0.02	0.73	-0.21	1.95	0.15	-0.18	3.44	0.69	-0.27
14	0.14	0.11	0.10	0.11	0.09	0.08	0.33	0.27	0.24
GSR1	2.24	1.87	-0.60	1.39	0.64	0.09	0.34	-0.72	1.06
15	0.15	0.12	0.11	0.14	0.11	0.10	0.38	0.30	0.28
OBE2	-1.32	0.42	-1.17	1.13	0.22	-1.56	3.34	1.90	1.25
16	0.17	0.13	0.12	0.17	0.14	0.13	0.47	0.37	0.34
PADO	-0.67	2.06	3.60	0.04	-0.33	-1.42	1.02	2.08	1.94
17	0.31	0.15	0.15	0.26	0.13	0.12	0.79	0.38	0.38
TUBO	0.04	0.72	0.17	-0.14	0.04	-0.46	1.61	1.35	-0.64
18	0.11	0.09	0.08	0.10	0.08	0.07	0.32	0.26	0.24
WTZR	-0.81	-0.13	-0.61	0.42	0.31	0.28	-0.34	1.97	2.52
19	0.12	0.09	0.09	0.12	0.10	0.09	0.33	0.26	0.24
BBYS	1.14	0.88	-0.27	0.02	-0.35	-0.19	-0.83	2.49	-0.66
20	0.1	0.13	0.12	0.14	0.11	0.10	0.44	0.35	0.32
BUCU	0.08	1.20	-0.51	0.56	-0.40	0.89	2.93	-2.85	-2.11
21	0.18	0.14	0.13	0.18	0.14	0.13	0.49	0.39	0.36
KRAW	0.06	-0.15	-2.72	-0.70	-0.35	-0.54	1.58	2.37	-2.61
22	0.12	0.09	0.09	0.10	0.08	0.07	0.33	0.25	0.24
MOPI	-0.00	0.79	-0.12	0.33	0.03	-0.76	2.39	-2.94	1.37
23	0.16	0.13	0.12	0.15	0.12	0.11	0.86	0.69	0.64
ORID	-1.97	2.53	0.66	2.49	-0.15	-0.61	-1.32	-2.78	2.15
24	0.23	0.19	0.17	0.20	0.17	0.15	0.59	0.51	0.44
OROS	2.04	0.97	0.55	0.18	-0.24	-0.76	-1.77	-0.10	-2.17
25	0.17	0.13	0.12	0.14	0.11	0.10	0.39	0.31	0.29
OSJE	0.57	1.79	-0.89	1.72	-0.08	-0.42	-0.34	0.50	-0.32
26*	0.15	0.12	0.11	0.10	0.08	0.08	0.35	0.28	0.26
SOFI	-1.15	2.87	-0.38	2.21	0.09	-0.47	1.82	-0.76	-1.89
27	0.24	0.19	0.18	0.27	0.21	0.19	0.66	0.53	0.48
SULP	0.88	0.78	-1.25	-0.23	-0.78	0.75	-0.38	1.16	-2.19
28	0.13	0.10	0.09	0.14	0.11	0.10	0.38	0.30	0.28
UZHL	0.12	0.97	0.34	0.09	-0.18	0.65	0.39	-0.76	-2.51
29	0.14	0.11	0.10	0.13	0.10	0.09	0.36	0.28	0.27
KLOP	-0.80	-0.03	-0.26	-0.30	0.98	-0.96	2.05	2.82	0.78
30	0.14	0.11	0.10	0.18	0.14	0.13	0.44	0.35	0.32

Table 2 Station values for ITRF 2000 velocities reduced for APKIM 2000, evaluated in horizontal system. The velocities components δv_n, δv_e, δv_v and their uncertainties are given in millimetres

Station	δv_n	$\sigma_{\delta vn}$	δv_e	$\sigma_{\delta ve}$	δv_v	$\sigma_{\delta vv}$
GRAZ	1.42	0.17	1.13	0.13	-2.26	0.42
SOFI	-0.94	0.71	1.01	0.82	-0.78	3.67
PENC	0.37	0.36	1.04	0.34	-0.52	1.89
BUCU	-4.49	2.10	6.33	2.79	9.49	6.70
GOPE	1.03	0.22	0.18	0.18	-1.19	1.13
MOPI	1.83	0.82	-0.62	0.60	17.08	5.00
JOZE	1.31	0.22	0.42	0.22	-1.03	1.05
BOR1	0.92	0.20	-0.14	0.18	-1.17	0.77
BOGO	1.39	0.49	-0.08	0.35	1.58	2.66
LAMA	1.60	0.20	-0.98	0.16	-1.89	0.84
WROC	1.03	1.00	-0.40	0.73	0.37	5.97
BZRG	1.98	1.07	0.56	1.93	4.21	5.74
ZIMM	0.76	0.20	0.50	0.17	-0.48	0.57
POTS	0.79	0.17	-0.47	0.15	-1.29	0.57
WTZR	0.90	0.14	-0.05	0.11	-0.93	0.41

Using the outputs b, c, d and e obtained from solution of the model (8) on the basis of observations in 2003 - 2004, the seasonal variations can be evaluated for each coordinate component. The station values of amplitude coefficients b_n, b_e, b_v, c_n, c_e, c_v and their uncertainties obtained from least-squares adjustment are in Tab. 1. Geographical distribution of amplitudes and phases of annual variations is plotted in Figs. 9 – 11, separately for north-south, east-west and up components. Amplitudes of the annual variations are proportional to the length of vectors and the orientation of the vector implies the phase. Arrow directed to east means the maximum of the seasonal effect in January 1st and arrow directed to west means the maximum in July 1st.

Annual variations in north-south component are up to 3 mm (Fig. 9). Except some anomalies (KRAW and PADO) the amplitudes and phases form some regional patterns. The stations of southern part of network (ORID, SOFI, BUCU) have amplitudes in range 2 – 3 mm with maximum around October. Stations of northern part of the network have amplitudes about 1 mm. In the east-west component only DRES station has amplitude above 2 mm (Fig. 10). The stations in western part of the network (KLOP, ZIMM, OBE2, PADO, MEDI) show similar pattern with amplitudes above 1 mm and maxima in July-August. The up component in Fig. 11 can be characterized with annual variations up to 5 mm. Regional pattern is clearly visible for the northern part of the network (LAMA, POTS, BOR1, DRES, WROC, KRAW) with maximum in September. Also the western part (KLOP, WTZR, OBE2, ZIMM, BZRG, PADO) has similar behaviour with 2-3 mm amplitudes with maximum around November.

Figs 9 - 11 indicate that seasonal variations at majority of stations have some regional relationships. Only in several cases the single station has significantly individual behaviour (KATO, DRES, PADO, MOPI). This implies that the dominant part of the seasonal variations have origin in the processing strategy, and possibly also in celestial reference frame. It is evident that only longer homogeneous time series can contribute to solve this problem. We expect that longer observing interval will enable detect seasonal variations of those stations where they are an expression of real station dynamics.

3.4. POLYNOMIAL TRENDS IN HORIZONTAL AND VERTICAL COORDINATE TIME SERIES

Thorough inspection of time series $\{dn_i(t)\}$, $\{de_i(t)\}$ and $\{dv_i(t)\}$ shows that at some stations besides of the linear trend, seasonal variations and jumps with known reasons some residual non-linear change also exist. Therefore the model (8) alternatively contains also polynomial terms with coefficients p_n, p_e and p_v which were not included in first step computations. It is worth to mention that the polynomial term has no geodynamical interpretation in the region of Central Europe. However at some stations this term has significant value exceeding 2 mm/year^2 in horizontal coordinates and 6 mm/year^2 in height component. We can mention in this context ZIMM, BZRG, PADO, BUCU, OROS, SOFI in north-south and east-west coordinates and JOZE, BUCU, SOFI, ORID in up coordinate. It is difficult to interpret this phenomenon using only 2-year interval of data, however the observed amplitude indicate some problems with the station consistency. Note that in these cases the polynomial coefficient dominates

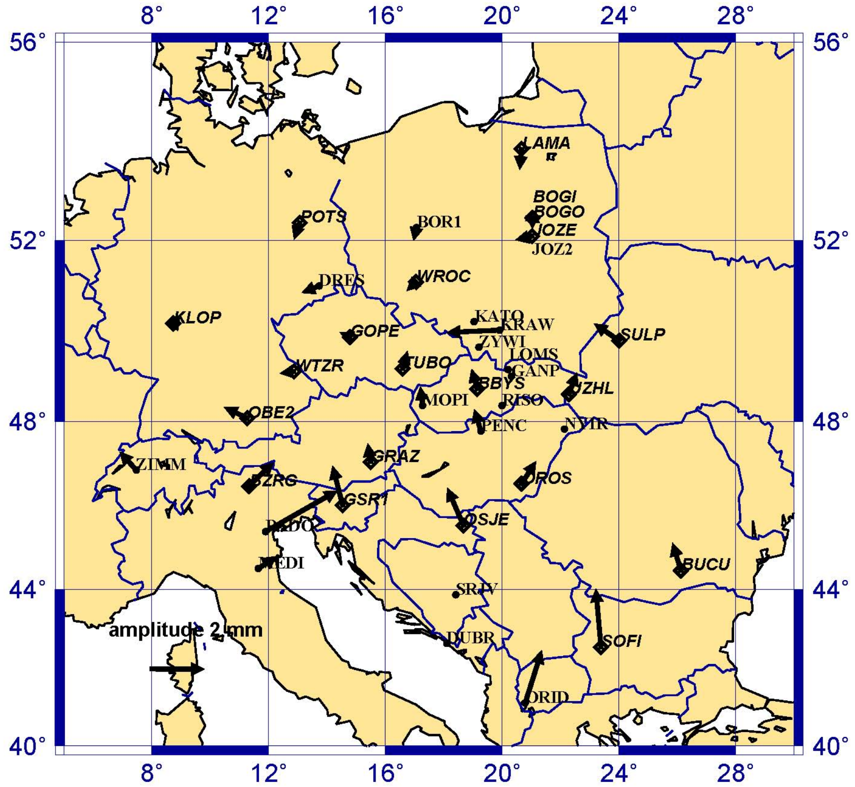

Fig. 9 Amplitudes and phases of annual variations in north-east component. The arrow direction → means maximum in January 1st, the arrow direction ← means maximum in July 1st.

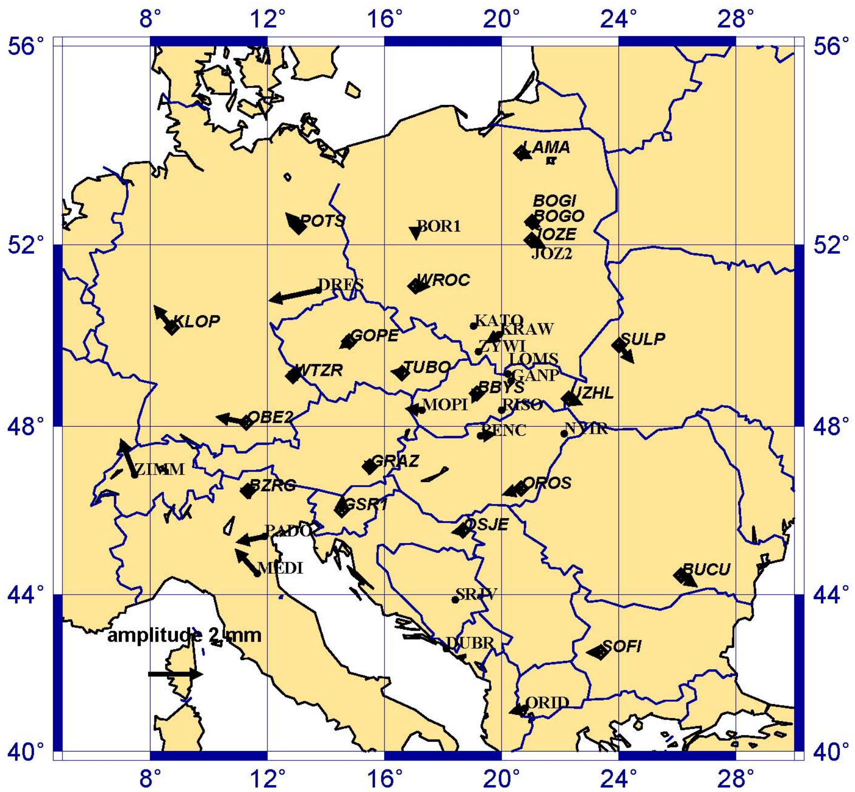

Fig. 10 Amplitudes and phases of annual variations in east-west component. The arrow direction → means maximum in January 1st, the arrow direction ← means maximum in July 1st.

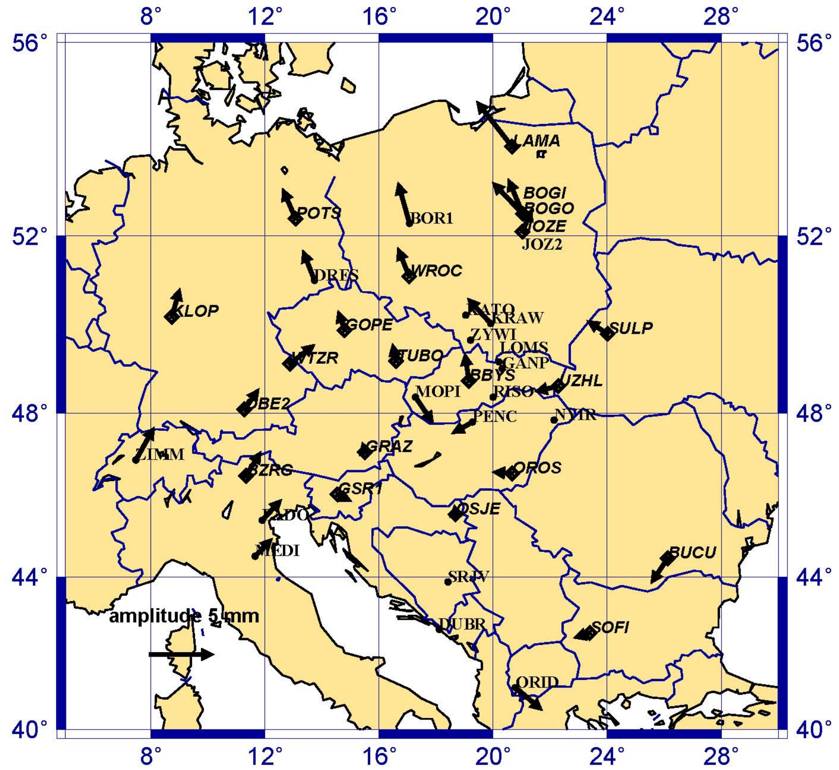

Fig. 11 Amplitudes and phases of annual variations in up component. The arrow direction → means maximum in January 1st, the arrow direction ← means maximum in July 1st.

over linear and seasonal variations. As the possible reason of this phenomenon we suppose changes in installation of the antenna, its environment, changes of elevation mask, new (or removed) obstacles in signal receptions.

4. CONCLUSIONS

Results from two-year interval of daily coordinates obtained at permanent GPS stations situated in Central Europe show very complex station behaviour. Besides of the relative linear drifts of individual stations, which can be associated with intraplate tectonics, seasonal variations at majority of stations were observed too. The applied method of referencing enabled to detect 1-2 mm station position systematic changes both in horizontal position and in height. The observed changes have partly regional pattern which indicates the possible effects of processing and referencing. As example of similar trends we can mention LAMA, BOGO, BOGI and JOZE horizontal velocity, ORID, BUCU and SOFI annual variation in *dn* component. However, some stations (KATO, PADO, DRES, MOPI in seasonal variations) clearly show individual behaviour, which is stressing the specific phenomena at these stations. All features mentioned are to be considered if the station is taken as reference for regional epoch campaign aimed at geodynamical investigations.

This paper focuses mainly on principles of permanent station analysis strategy. Reliable results can be expected after analysing of longer interval of observations. It is necessary to point out that also other statistical parameters of coordinate time series have to be investigated in parallel, like auto-correlations, spectral densities, Allan variances, etc. Such studies can be found e.g. in (Caporali, 2003) based on series with weekly resolution and in (Hefty et al., 2005) for time series with daily resolution.

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