Time Series Analysis of EPN Stations as a Criterion of Choice of Reference Stations for Local Geodynamic Networks

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Abstract

Local and regional geodynamic studies needs evaluation of inner (intraplate) velocities, reference points velocities first of all. Relative velocities between selected EPN stations can be evaluated using different approaches (time series analysis, ITRF2000 velocities, NUVEL1A-NNR velocities). Authors present the method of the mean trend congruency analysis of EPN stations coordinates time series (from weekly EUREF solutions). The results of time series analysis of EPN stations located no more then 700 km from our local geodynamic network (LGN) SUDETES located in Sudety Mts. and Sudety Foreland (Cental Europe), performed for the selection of the best reference stations are presented. Taking into account the results of performed classification as well as the distance between stations and the local research area (Sudety Mts., SW Poland), the best conditions of connection of local measurements to the European network have been fulfilled for the stations: BOR1, PENC, GOPE, GRAZ WTZR and POTS. Stations as WROC and MOPI, located also close to the research area possesses significantly worse quality parameters. Finally the influence of reference station selection on estimated velocities of local geodynamic network points is shown. The authors participate in EPN Special Project: Time series monitoring for geokinematics (Central Europe subnetwork).

1. Introduction and Motivation

The definition of a geodetic reference frame by modern techniques (GPS) requires a determination of the systematic temporal changes of the defining stations' positions. Local and regional geodynamic studies need evaluation of inner (intraplate) velocities, reference points' velocities first of all. Relative velocities between selected EPN stations can be evaluated using different approaches (time series analysis, ITRF2000 velocities, NUVEL1A-NNR velocities).

The authors propose a method of the mean trend congruency analysis of EPN stations coordinates time series (from weekly EUREF solutions) for this purpose. The results of time series analysis of EPN stations, located no more then 700 km from local geodynamic network (LGN) in Sudety Mts. and Sudety Foreland (Cental Europe), performed for the selection of the best reference stations are presented in the paper. Presented analysis have been limited only to the horizontal coordinates and velocities.

2. The Regional And Local Gps Networks

Since 1996 at the European Continent the GPS EUREF Permanent Network, supervised by the EUREF-Technical Working Group, has been functioned (EUREF TWG).

The EPN network was originally established for serving as an European regional geodetic reference frame. It has been treated as the regional as well as recognised as a part of International GPS Service (IGS). During the meeting in Tromso (21 June 2000) the EUREF TWG have created a new EPN Special Project (SP), charged with the tasks to monitor the EPN weekly combined SNX solutions and to analyse the EPN time series in order to further improve the network performance (*http://www.epncb.oma.be/projects/sp_timeseries.html*). Within the above mentioned project the authors of this paper have introduce a time series analysis of the EPN stations located at the one of the six network's regions (fig. 1) - (V. Central Europe STU/AUW).

In 1992 an investigation of the recent movement of the upper layer of lithosphere of the areas in Eastern Sudety Mts. and Sudety Foreland was begun. The following areas were investigated: Ðnieónik Massif, Paczków Tectonic Trough and Sto»owe Mts. In 1996 these separate projects were included into the GEOSUD ("GEOdynamics of SUDety") project and geodynamical GPS local precise network GEOSUD was established by Department of Geodesy and Photogrammetry of Agricultural University of Wroc»aw (CACO¼ S., et al. 1998).

The geodynamical GPS network SUDETES (Fig. 2) covers the area Middle- and East-Sudety Mts. and its foreland and links together existing Czech and Polish local GPS networks in this area. The Polish part of this network includes selected sites of the network GEOSUD. The Czech part consists mainly of the network SILESIA built in 1997 by the Institute of Rock Structure and Mechanics of the Czech Academy of Science in Prague (SCHENK V., et al. 1999).

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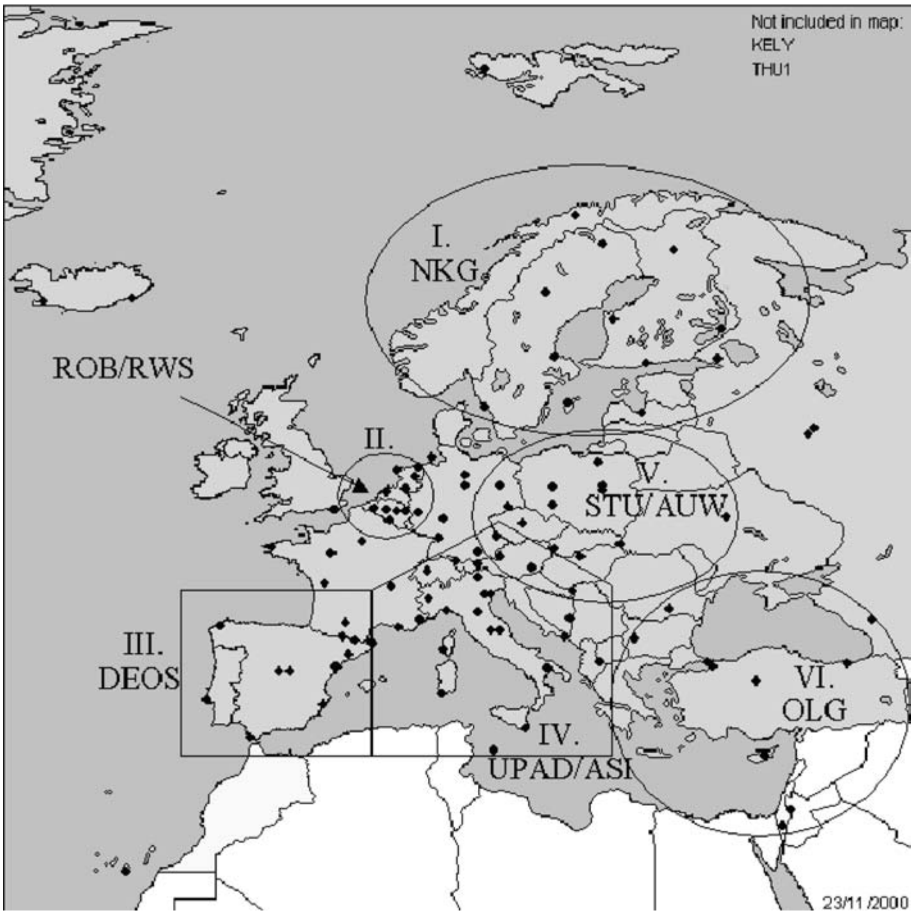

Fig. 1: The EPN subnetworks monitored by the SP groups (http://www.epncb.oma.be/projects/sp_ timeseries.html)

Fig. 2. The geodynamical local GPS network SUDETES

While the data processing the SUDETES network has been connected with the regional EPN by especially chosen particular permanent stations. The choice of the permanent stations has been depended on many factors as: station's location in relation to LGN and to geological structures existing in the investigated area as well as observation data quality and quantity. The authors have carried out the time series analysis based on the data obtained from stations which have been located in the range of 700 km from the area of the local geodynamics network SUDETES and which had been activated at least two years before. Furthermore, the results of analyses have been related to main geological structures of the Central Europe.

3. Time Series Analysis Of Selected Epn Stations

The input information used for time series of stations' positions summary $X_s(t_i), Y_s(t_i), Z_s(t_i)$ during the particular GPS weeks, $t_i = 860, 861, ..., 1115$, have been obtained from the EUREF network solution (the SINEX files). The geocentric coordinates of the station have been transformed into the geodetic coordinates $\{X_s(t_i), Y_s(t_i), Z_s(t_i)\} \rightarrow \{\varphi_s(t_i), \lambda_s(t_i), h_s(t_i)\}$, by following the algorithm presented in *(Fukushima 1999)*. Furthermore, the linear changes of station's position (Fig. 3) in the direction of *j* (N-S) and *l* (E-W) have been calculated following the formula:

$$\begin{aligned} \Delta\varphi_s(t_i) &= R_s\left[\varphi_s(t_i) - \varphi_s(t_0)\right] \\ \Delta\lambda_s(t_i) &= R_s\left[\lambda_s(t_i) - \lambda_s(t_0)\right], \end{aligned} \qquad (1)$$

where R_s is a average radius of the ellipsoid curvature related to the station *s*, $R_s = \sqrt{M_s N_s} + h_s$, and the mean curvature radiuses M_s and N_s, have been calculated on the basis of the WGS'84 parameters.

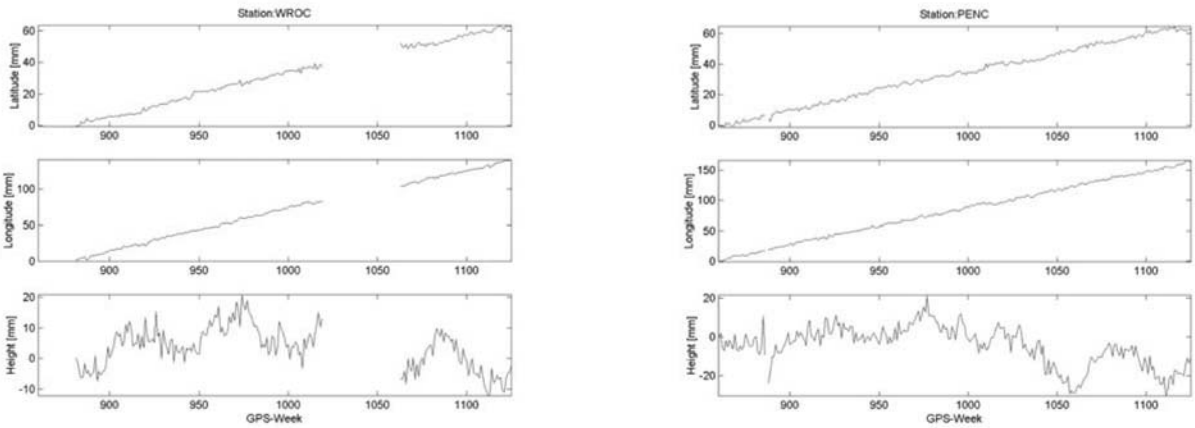

Fig.3. Time series of linear changes of position of the three selected EPN stations' in directions N-S and E-W.

Time series as $\Delta\varphi_s$ and $\Delta\lambda_s$ have been recognised as the base for the quality hierarchy of the station. The mentioned hierarchy has been introduced by following the iteration process where the criteria was discrepancy degree of time series of particular station in relation to the mean trend determined by using the least squares error's method based on the stations. The iteration process may be divided into three steps:

Step 1: Determination of *j* and *l* change trend (Fig. 4) based on $\Delta\varphi_s$ and $\Delta\lambda_s$ for *n* chosen stations, assuming the $p_{\varphi,\lambda} = a_0 + a_1 t$ as a model of station's movement, where coefficients a_0 and a_1 are estimated;

Step 2: Calculation of standard deviation $\sigma_s = \sqrt{\sigma_{\varphi_s}^2 + \sigma_{\lambda_s}^2}$, where $\sigma_{\varphi_s}^2 = \frac{1}{m}\sum_{i=1}^{m}\left[(p_\varphi - \Delta\varphi_s)\big|_{t_i}\right]^2$, $\sigma_{\lambda_s}^2 = \frac{1}{m}\sum_{i=1}^{m}\left[(p_\lambda - \Delta\lambda_s)\big|_{t_i}\right]^2$ and *m* is observations number done at particular stations;

Step 3: Rejecting the station with the maximal value of σ_s, decrease *n* value by one and return to Step 1.

Eliminated stations become the position of $n, n-1, n-2, ..., 1$ in hierarchy *(Table 1).*

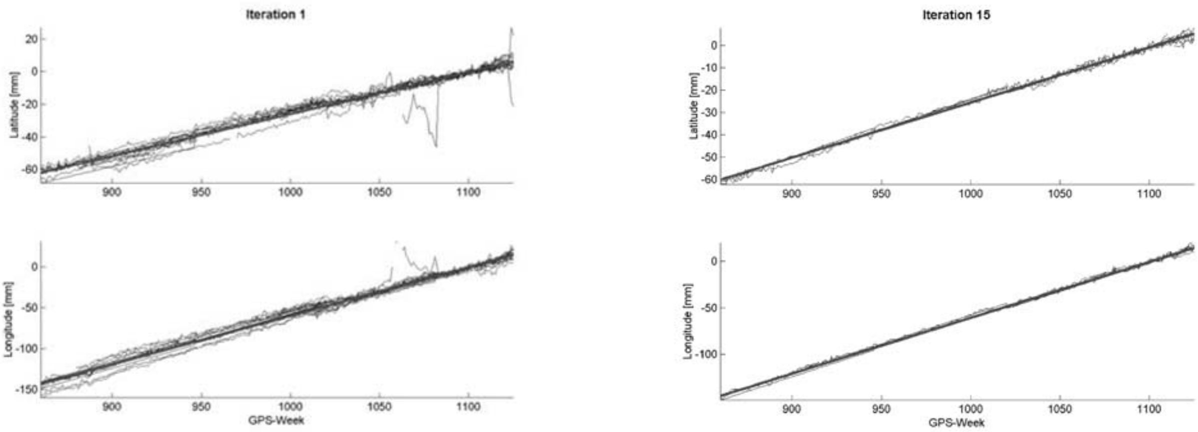

Fig. 4. Determination of j and l change trend based on $\Delta\varphi_s$ and $\Delta\lambda_s$ for n chosen stations (iteration No. 1 and 15)

Table 1

Station	Obs	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
BOR1	255	2.3	2.0	2.6	3.3	3.3	2.9	2.4	2.3	1.9	1.8	1.7	1.7	1.7	1.8	1.8	1.8	1.6	1.6	1.6	1.6	1.5	1.5	1.5
PTBB	57	1.9	1.8	1.8	1.8	1.9	1.9	1.8	1.7	1.7	1.6	1.6	1.7	1.6	1.6	1.7	1.7	1.7	1.7	1.7	1.7	1.6	1.7	-
UZHL	95	2.4	2.3	2.4	2.5	2.6	2.6	2.4	2.3	2.2	2.2	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	-	-
KLOP	81	2.7	2.6	2.6	2.6	2.9	2.7	2.7	2.5	2.6	2.5	2.6	2.5	2.4	2.4	2.4	2.3	2.2	2.2	2.2	2.2	-	-	-
HOBU	50	2.3	2.5	2.4	2.3	2.4	2.4	2.4	2.5	2.5	2.6	2.6	2.4	2.5	2.5	2.4	2.3	2.5	2.6	2.6	-	-	-	-
GSR1	12	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.3	2.3	2.4	2.4	2.3	2.4	2.4	2.4	2.4	2.5	2.6	-	-	-	-	-
OSJE	32	2.2	2.4	2.3	2.3	2.3	2.3	2.4	2.5	2.5	2.6	2.6	2.4	2.5	2.5	2.3	2.4	2.6	-	-	-	-	-	-
PENC	255	2.4	2.5	2.8	3.2	3.1	2.8	2.6	2.6	2.6	2.7	2.6	2.5	2.6	2.6	2.6	2.4	-	-	-	-	-	-	-
GRAZ	254	3.7	3.8	4.3	5.0	4.9	4.5	4.0	3.9	3.5	3.5	3.0	3.0	3.0	2.8	2.8	-	-	-	-	-	-	-	-
GOPE	255	3.3	3.2	3.7	4.2	4.1	3.8	3.4	3.3	3.1	3.1	2.8	2.9	2.9	2.8	-	-	-	-	-	-	-	-	-
POTS	256	2.9	2.7	2.7	3.0	3.1	2.9	2.8	2.7	2.7	2.7	3.2	3.1	3.1	-	-	-	-	-	-	-	-	-	-
DRES	82	3.8	3.9	3.9	3.9	3.8	3.8	3.9	4.0	4.1	4.2	4.2	4.1	-	-	-	-	-	-	-	-	-	-	-
SBGZ	120	5.3	5.1	5.3	5.4	5.4	5.3	5.1	5.0	4.9	4.9	4.8	-	-	-	-	-	-	-	-	-	-	-	-
WTZR	256	4.8	4.9	4.2	3.8	4.1	4.2	4.5	4.6	4.9	5.0	-	-	-	-	-	-	-	-	-	-	-	-	-
BZRG	125	4.8	5.0	4.8	4.5	4.4	4.6	4.8	4.9	5.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
WROC	192	5.5	5.7	5.0	4.3	4.3	4.7	5.2	5.3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
KARL	136	6.4	6.7	6.3	6.0	5.9	6.1	6.4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
MOPI	224	6.9	7.2	6.4	5.8	5.8	6.2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
OBER	229	7.1	7.4	6.7	6.0	5.9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
PFAN	211	6.8	6.6	6.4	6.4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BOGO	256	7.5	7.2	8.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
JOZE	256	10.2	10.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
LAMA	253	12.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
dB[mm/Y]		13.4	13.5	13.6	13.7	13.6	13.6	13.5	13.5	13.5	13.5	13.3	13.2	13.2	13.0	13.0	13.0	13.2	13.2	13.1	13.2	13.3	13.4	13.4
dL[mm/Y]		31.0	31.0	30.6	30.3	30.3	30.5	30.7	30.7	30.8	30.8	31.1	31.2	31.1	31.2	31.3	31.1	31.1	31.0	31.0	31.0	31.0	31.0	30.8

As the result of investigated time series analysis the stations hierarchy of 23 has been noticed with the observations quality as the mean point (reliability of correlation of individual station's position with trend).

Figure 5 presents the analysed data results (marked red) The following step of analysis was comparison of quality results with length of observation time. (Fig. 5, marked blue).

The group of 16 stations, observed at least two years (120 weeks), have been recognised. Observations have been processed by using the time series analyse and finally the hierarchy has been determined (Fig. 6).

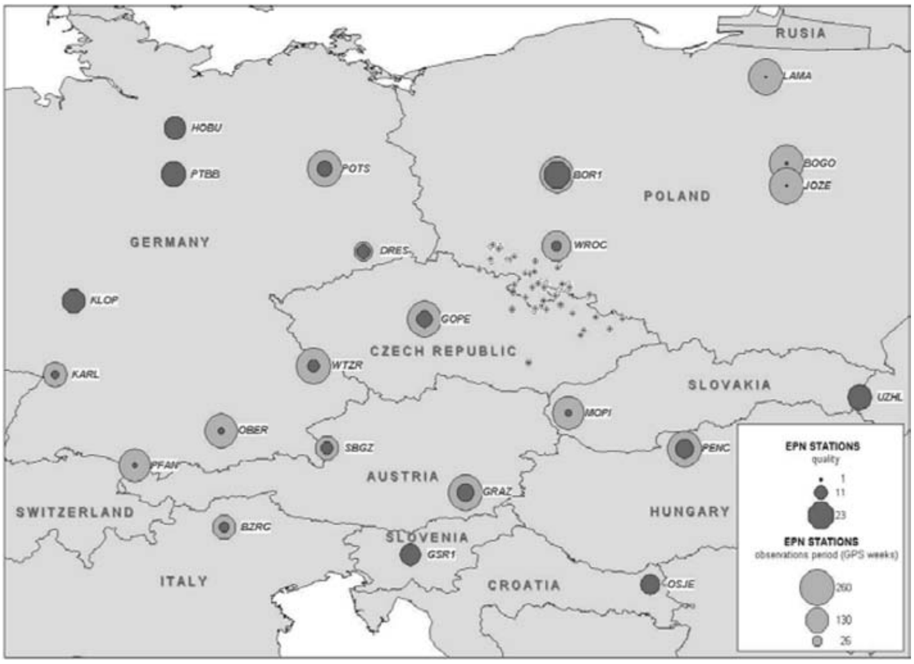

Fig. 5. Quality and quantity data analysis results at the EPN stations (observation time).

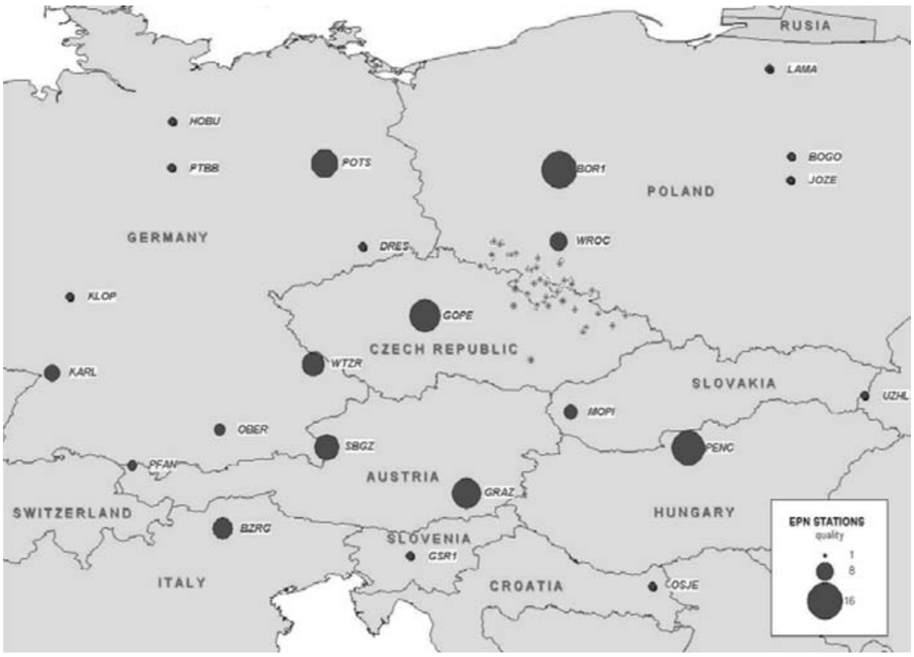

Fig. 6 Results of quality analyse for stations where the observation time was longer than 2 years.

Results of the analyses are taken as a base for weighting process while the GPS data processing of the local geodynamics network SUDETES. (Bosy, Kontny 1998).

The highest-qualified stations by quality (reliability of correlation of individual station's position with trend), observed at least two years (120 weeks), are located within the range of two basic structural units: Varyscides and Alpides, at the western side of the Teissere-Tornquist zone (T-TZ). All analysed stations situated at the eastern side of the T-TZ zone within the range of East European Craton – EEC (BOGO, JOZE, LAMA), are be situated in the presented hierarchy at the latest positions (Fig. 7). The reason of this fact is not explained yet. The stations' location as well as many other reasons would be taken into account. However, it could be emphasised that stations can not be taken as the connection points (reference) for local tectonic movements investigations in the Sudety Mts. and its foreland.

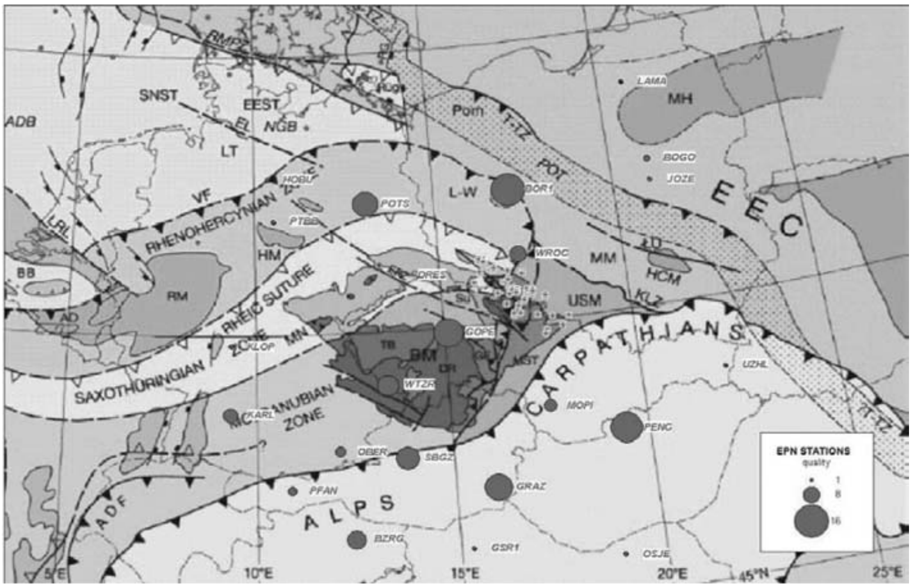

Fig. 7. The quality stations classification related to the mean tectonical units presented on the map (http://www.geofys.uu.se/eprobe).

4. Constraining and Fixing of Reference Station Coordinates and Velocities – Comparison Of Different Approaches

4.1 Global velocities models

The velocities of the selected reference EPN stations can be achieved from International Earth Rotation Service (IERS). Currently the ITRF2000 reference frame is available *(http://lareg.ensg.ign.fr/ITRF/ITRF2000)*. The ITRF2000 adjusted positions at epoch 1997.0 and velocities were computed using *(IERS Annual Report 2000)*:

- VLBI technique: ITRF2000_VLBI.SSC
- SLR technique: ITRF2000_SLR.SSC
- GPS technique: ITRF2000_GPS.SSC
- DORIS technique: ITRF2000_DORIS.SSC
- EUREF GPS stations: ITRF2000_EUR_GPS_PERM.SSC
- EUREF points (GPS and others in Europe): ITRF2000_EUROPE.SSC
- CORS Network: ITRF2000_CORS.SSC
- ALASKA Network: ITRF2000_ALASKA.SSC
- South America Network: ITRF2000_SIRGAS.SSC
- SCAR Network: ITRF2000_SCAR.SSC
- REGAL Network: ITRF2000_REGAL.SSC
- RGP Network: ITRF2000_RGP.SSC

On the base of the plate motion theory the points velocities can be computed using geological models: NUVEL1A (DEMETS, et al. 1990), NUVEL1-NNR (ARGUS and GORDON, 1991) and NUVEL1A-NNR *(DeMets, et al., 1994)*. NUVEL1A-NNR plate motion model *(http://www.unavco.ucar.edu/~chuckm/nnrcalc.html)* predicts directions that are the same as NUVEL1-NNR, but the rates are 4% slower due to an adjustment to the magnetic anomaly time scale. Table 2 shows values of selected reference stations velocities for both NUVEL1A-NNR and ITRF2000 models.

Table 2

Site	ITRF2000		NUVEL1A-NNR		differences	
	VN (mm/y)	VE (mm/y)	VN (mm/y)	VE (mm/y)	VN (mm/y)	VE (mm/y)
BOR1	13.7	20.4	12.7	**20.6**	1.0	-0.2
GOPE	14.2	20.6	13.1	20.6	1.1	0.0
PENC	12.7	22.6	12.3	21.6	0.4	1.0
POTS	14.2	19.3	13.4	19.8	0.8	-0.5
WTZR	14.4	20.3	13.4	20.3	1.0	0.0
WROC	13.8	20.2	12.7	20.8	1.1	-0.6

One assumed that intraplate velocities can be characterised by differenced velocities, ITRF2000 minus NUVEL1A-NNR (I-N) of analysed EPN stations(table 2).

4.2 Time series analyses - methodology of relative velocities evaluating

Relative velocity of movement between individual EPN stations can be appointed on basis of analyses of time series changes of its coordinates. General diagram of data processing flow was introduced on figure 8.

First the changes of relative position of two stations in individual moments of time are calculated:

$$\begin{aligned} \delta\varphi_{AB}(t_i) &= \Delta\varphi_A(t_i) - \Delta\varphi_B(t_i) \\ \delta\lambda_{AB}(t_i) &= \Delta\lambda_A(t_i) - \Delta\lambda_B(t_i) \\ \delta h_{AB}(t_i) &= \Delta h_A(t_i) - \Delta h_B(t_i)\,. \end{aligned} \tag{2}$$

Received in this way time series of differences give the information about relative movements *v* between individual stations in directions *j*, *l* and *h*. Linear character of this movement was assumed. The relative velocities were calculated on the way of the approximation of observation data using following formula:

$$p_{\delta\varphi,\delta\lambda,\delta h} = a_0 + vt\,. \qquad (3)$$

In the analysed time of EPN network operation two redefinitions of reference frame occurred, time series were divided onto three sections (intervals) showing linear shift in relation to itself. Observation data in individual intervals was approximated using equations (3) with condition of equality of coefficient v in alls intervals. The unknown parameters $a_{0(i)}$ and v were estimated with last squares method for particular time series. Estimated relative velocity components in *N*, *E* and *U* directions were introduced on figure 9.

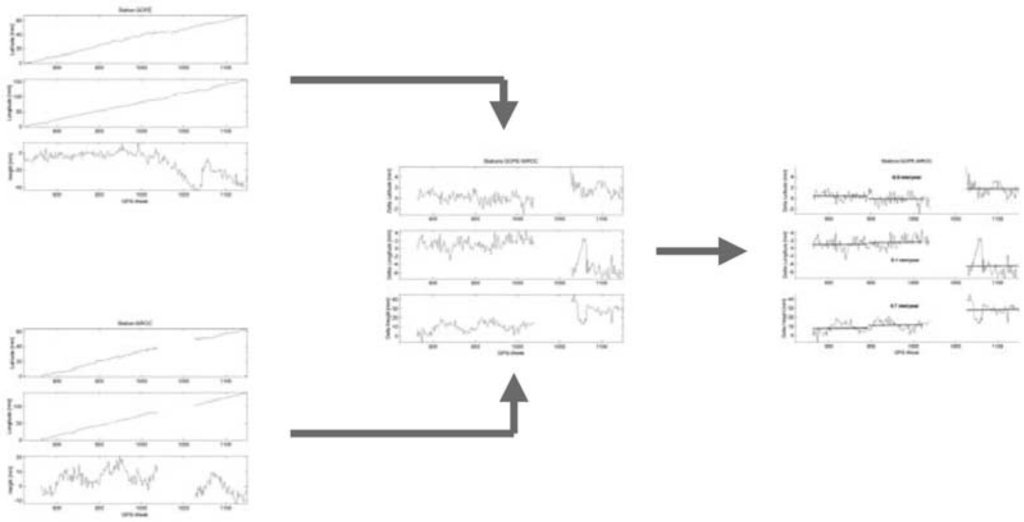

Fig. 8. Data processing flow for relative velocities evaluating

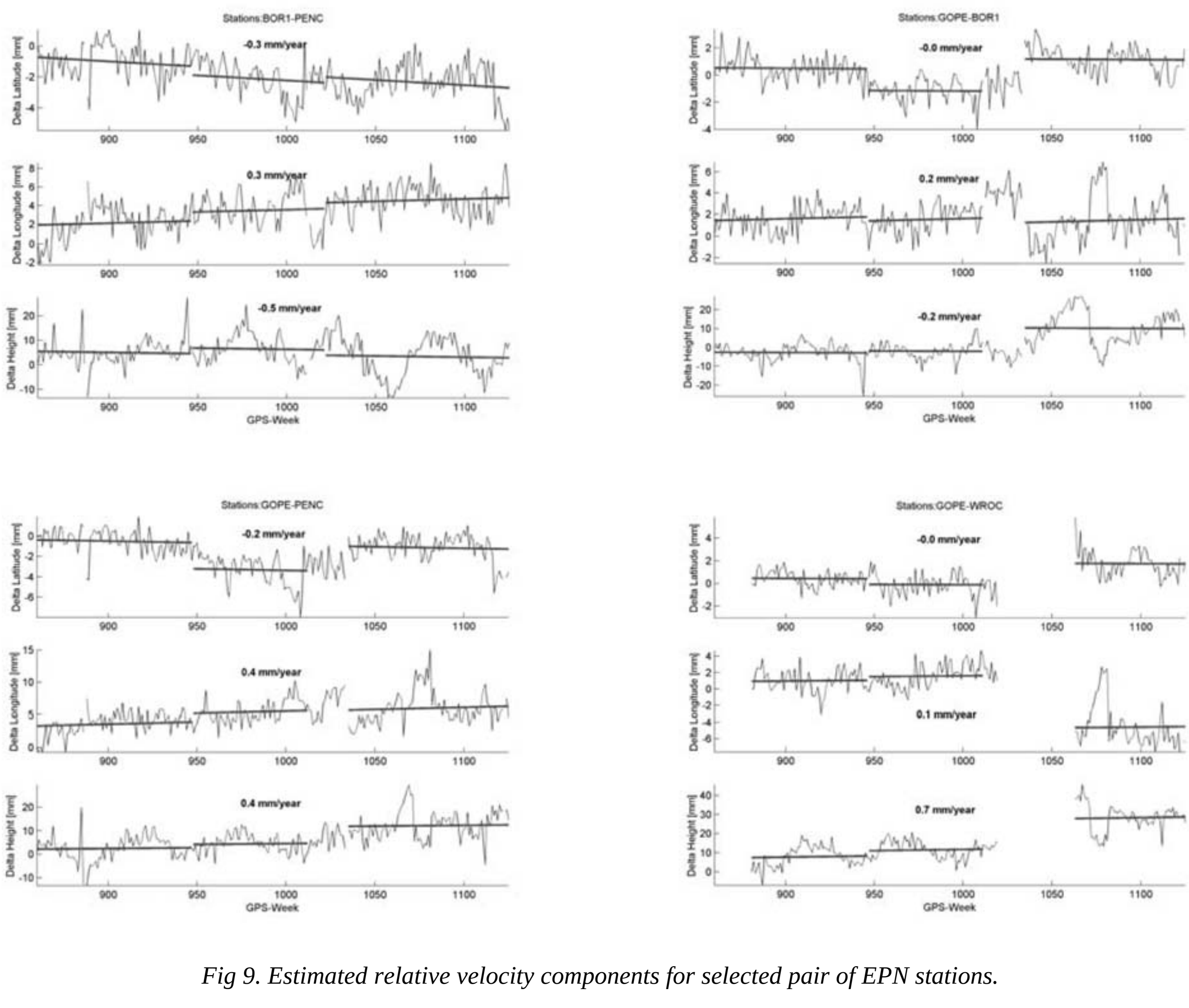

Fig 9. Estimated relative velocity components for selected pair of EPN stations.

4.3 Comparison of different approaches

For comparisons three different approaches (Time Series analyses – TS, ITRF2000 – ITRF, differences ITRF and NUVEL – I-N) of relative velocity determination were put together into the table 3

Table 3.

		GOPE			PENC			POTS			WTZR			WROC		
		TS	ITRF	I-N	TS	ITRF	I-N	TS	ITRF	I-N	TS	ITRF	I-N	TS	ITRF	I-N
BOR1	VN	0.0	0.5	0.1	-0.3	-1.0	-0.6	0.8	0.5	-0.2	0.0	0.7	0.0	-0.3	0.1	0.1
	VE	-0.2	0.2	-2.0	0.3	2.2	1.2	0.3	-1.1	-0.3	-1.0	-0.1	-0.2	-1.0	-0.2	-04
GOPE	VN				-0.2	-1.5	-0.7	0.1	0.0	-0.3	0.2	0.2	-0.1	0.0	-0.4	0.0
	VE				0.4	2.0	1.0	0.2	-0.7	-0.5	0.1	-0.3	0.0	0.1	-0.4	-0.6
PENC	VN								1.5	0.4	0.3	1.7	0.6	0.9	1.1	0.7
	VE								-1.3	-1.5	-1.3	-2.3	-1.0	-0.1	-2.4	-1.6
POTS	VN										-0.7	0.2	0.2	-0.9	-0.4	0.3
	VE										-1.3	1.0	0.5	-1.2	-0.9	-0.1
WTZR	VN													-0.4	-0.6	0.1
	VE													0.1	-0.1	-0.6

The data from table 3 were the a'priori data for estimation of SUDETES network points velocities using module ADDNEQ of Bernese GPS Software v. 4.2 (HUGENTOBLER, et al., 2001). The results in the form of velocity vectors of selected SUDETES network points are presented on the figure 10.

Fig. 10. Velocity vectors of the SUDETES network points – comparison of the approaches.

The applying of different definitions of reference points velocities made insignificant changes in direction and value of estimated network points velocities. It is the result of the choice of reference points. The selected points have very similar velocities in each analysed model. The choice of reference points (coordinates) has significantly bigger influence than the method of its velocity determination.

5. Conclusions

Taking into account the presented classification as well as the distance between stations and the local research area (Sudety Mts.), the best conditions of connection of local measurements to the European network have been fulfilled for the stations: BOR1, PENC, GOPE, GRAZ, POTS and WTZR. Stations as WROC and MOPI, located also close to the research area possess significantly worse quality parameters.

Relative velocities between selected EPN stations can be evaluated using different approaches (time series analysis, ITRF2000 velocities, NUVEL1A-NNR velocities). The proper selection of reference points based on the time series analysis (by proposed mean trend congruency method) causes, that a choice of method of reference velocities evaluation has an insignificant influence on estimated velocities of local network points.

6. Acknowledgment

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