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# PRELIMINARY RESULTS OF REPEATED MEASUREMENTS IN LOCAL GEODYNAMIC NETWORK MORAVA

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ABSTRACT

Among the first GPS geodynamics projects in Czech Republic the MORAVA network was founded in 1994 with aim to determine the positional changes at border zone between the Bohemian Massif and the Carpathians. Initial project included three successive GPS campaigns in period 1994 – 1996, but was not continued because of lack of support. It had been possible to carry out new measurements in southern part of the MORAVA network including five stations, after gap of 15 years. In the paper comparison of previous and contemporary results of epoch GPS measurements are presented, which indicate block movement tendencies at the Bohemian Massif and the Western Carpathians border, thus confirming activity of the area up to present days.

KEYWORDS: Southern Moravia., fault, tectonics, GPS displacements, movement tendencies

## INTRODUCTION

The local geodynamic MORAVA network was established for the purpose of monitoring the supra-crustal blocks motions at the Bohemian Massif and the Alpine-Carpathian Arc border, which is formed by Neogene and thick Quaternary sediments. The initial project realized in years 1994-1996 passed as project of Grant Agency of Czech Republic Nr. 105/94/J124. The applicants of the project were Technical University (TU) Ostrava, Faculty of Mining and Geology, and Czech Technical University (CTU) Prague, Faculty of Civil Engineering.

In 2010, after 16 years pause, the project had been partially continued by Brno University of Technology (BUT) internal research project which included re-observation of 5 points at South Moravia, with permanent station TUBO as reference. The measurements followed the monitoring of movement trends along the Čebín-Diendorf Tectonic Zone.

Basic results of the repeated GPS measurements are presented in the paper, which revealed surprising information about movements of some blocks at the Bohemian Massif and the Western Carpathians border. Problems of the MORAVA network points monumentation, identification and renewal, measurement methodology, and data processing procedure are also discussed.

## MORAVA NETWORK

**Layout** – MORAVA network includes 19 points, 17 in Czech Republic (CR) and 2 in Slovak Republic (SR). 11 points are on side of the Bohemian Massif, and 8 points are on side of the Carpathian Arc (Fig. 1 and Table 1- Foldyna et al., 1997). Point 100 – TEME (Temelín) is outside in Figure 1.

Great care had been paid to selection of points location with respect to geological and geodetic aspects. Definite locations were determined after careful prospecting and after consultation with local special authorities.

**Monumentation** – All points of the geodynamic network (with exception of one) are monumented so as to enable forced centring of GPS antennas. Most of the points are monumented directly on rock outcrops, with 0.30 m long underground part firmly attached into bedrock by concrete. Two points have markers welded to casing of deep boreholes. The centring rod of 0.28 m length is inserted into the underground part and the connection is fixed by screwed sleeve casing. The rod serves as carrier of GPS antenna. Individual rod is used on each network point in all measuring epochs.

Testing campaign had been carried out in December 1994, with only 8 occupied network points, also observed were the stations MOPI and TUBO. Observation time was 8 hours.

**Table 1** List of GPS points of the Morava network.

| | Name | Point Nr. | Code | Latitude (°) | Longitude (°) | H (ellips.) |
|---|---|---|---|---|---|---|
| 1 | **Načeratická hora** | 73 | NAHO | 48.83028 | 16.09777 | 332.6 |
| 2 | **Dukovany** | 72 | DUKO | 49.08472 | 16.18027 | 423.6 |
| 3 | **Stolová hora** | 76 | STOH | 48.84722 | 16.63910 | 502.6 |
| 4 | **VUT v Brně** | 100 | TUBO | 49.20333 | 16.59284 | 324.3 |
| 5 | **Koryčany** | 91 | VRSA | 49.08472 | 17.18868 | 533.7 |
| 6 | **Skalný** | 38 | SKAL | 49.38972 | 17.70000 | 732.0 |
| 7 | **Vávrova skála** | 47 | VAVR | 49.59306 | 15.96667 | 796.7 |
| 8 | **Na výhonkách** | 60 | VYHO | 49.27111 | 15.99583 | 537.8 |
| 9 | **Helišova skála** | 66 | HELI | 49.40667 | 16.75861 | 657.4 |
| 10 | **Kobrštejn** | 81 | KOBR | 50.20333 | 17.31667 | 970.6 |
| 11 | **Malé návrší** | 82 | NAVR | 50.23722 | 17.53333 | 411.2 |
| 12 | **Čelechovice** | 83 | CELE | 49.52528 | 17.10000 | 358.0 |
| 13 | **Budislav** | 85 | BUDI | 49.81333 | 16.18333 | 568.2 |
| 14 | **Slavíč** | 86 | SLAV | 49.55917 | 18.61667 | 950.4 |
| 15 | **Svinec** | 88 | SVIN | 49.55917 | 17.98333 | 583.3 |
| 16 | **Rasová** | 92 | RASO | 48.98278 | 17.81667 | 583.0 |
| 17 | **Zliechov** | 96 | ZLIE | 48.94889 | 18.44694 | 717.5 |
| 18 | **Modra** | 99 | MOPI | 48.37278 | 17.27389 | 578.9 |
| 19 | **Temelín** | 101 | TEME | 49.175 | 14.36972 | 548.6 |

The first measuring campaign had been realized in October 1995, in three successive 10 hours night sessions. Instrumentation in CR included Leica SR 399 and SR 299 receivers, the points in SR were occupied by Trimble 4000 SSE receivers. Total number of the occupied points was 19.

The data were processed by Research Institute of Geodesy, Topography and Cartography (RIGTC) Zdiby using the Bernese software (BSW), and by Gefos Ltd. Co. using Leica SKI software.

The second campaign had been carried out in June 1996, in time of the EXTENDED SAGET campaign. The observing time was 4 to 5 days continually, with the same instrumentation like in previous campaign. Again the total number of occupied points was 19, but the published results covered only 10 points.

**RESULTS OF EPOCHS 1994 - 1996**

For the purpose of our investigation of movement tendencies in the Southern Moravia the following five points of MORAVA network were selected: 72 - DUKO (Dukovany), 73 -NAHO (Načeratická hora), 76 – STOH (Stolová hora), 91-VRSA (Koryčany – Vršava), and 100 - TUBO (building of BUT).

The points are situated in places belonging to autonomous blocks of different geological units of the Bohemian Massif and the Western Carpathians, seen from the point of view of regional historical development. In Table 2 an overview of the five points together with characteristics of their underlay is shown.

An overview of the names, locations and geocentric coordinates of selected points is given in

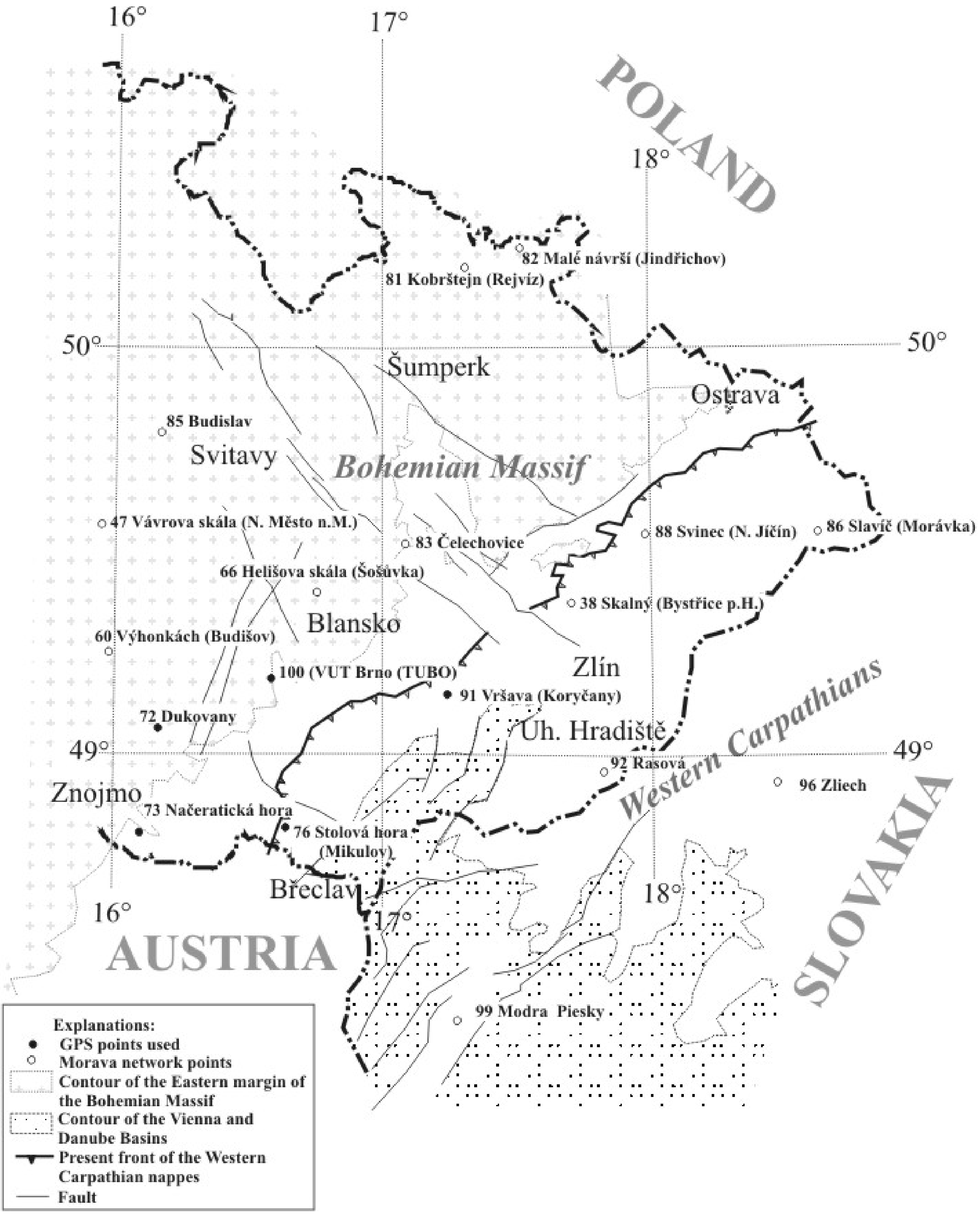


**Fig. 1** Local Geodynamic MORAVA Network.

**Table 2** Overview of the geological units under selected MORAVA network points.

| | | |
|---|---|---|
| 72 | DUKO (Dukovany) | Gneisses and granulites of the Moldanubian Varied Group |
| 73 | NAHO (Načeratická hora) | Granitoids of the Dyje massif (Brunovistulicum) |
| 76 | STOH (Stolová hora) | Jurassic Limestone of the Waschberg-Ždánice unit |
| 91 | VRSA (Koryčany – Vršava) | Soláň Formation of the Magura (Rača) unit |
| 100 | TUBO | Granitoids of the Brno massif (Brunovistulicum) |

**Table 3** Approximate ITRF geocentric coordinates of the selected MORAVA network points.

| Point | | 1995 | | |
|---|---|---|---|---|
| **Number/Location** | **Name** | **X [m]** | **Y [m]** | **Z [m]** |
| 72- Dukovany | DUKO | 4019778.6 | 1166352.0 | 4797078.1 |
| 73-Načeratická hora | NAHO | 4042237.1 | 1166561.0 | 4778124.2 |
| 76-Stolová hora | STOH | 4029954.3 | 1204373.2 | 4779337.2 |
| 91-Vršava | VRSA | 3997620.2 | 1236604.5 | 4798139.0 |
| 100-VUT Brno | TUBO | 4001470.6 | 1192345.3 | 4805795.3 |

**Table 4** MORAVA network - Baseline lengths and differences 1994-1996 in meters.

| Baseline | 1994 | 1995 | 1996 | Differences 1996-1995 | Differences 1995-1994 |
|---|---|---|---|---|---|
| TUBO-NAHO | 55609.694 | 55609.690 | 55609.692 | 0.002 | -0.004 |
| TUBO-DUKO | 32967.007 | 32967.005 | 32967.003 | -0.002 | -0.002 |
| TUBO-STOH | 40694.290 | 40694.276 | | | -0.014 |
| TUBO-VRSA | | 45081.215 | 45081.211 | -0.004 | |
| NAHO-DUKO | 29388.504 | 29388.500 | 29388.502 | 0.002 | -0.004 |
| NAHO-STOH | 39775.637 | 39775.647 | | | 0.010 |
| NAHO-VRSA | | 85424.564 | 85424.557 | -0.007 | |
| STOH-DUKO | 43172.848 | 43172.846 | | | -0.002 |
| STOH-VRSA | | 49374.679 | | | |
| DUKO-VRSA | | 73671.733 | 73671.725 | -0.008 | |

Table 3 (Foldyna et al., 1997). Resulting baseline distances in epochs 1994-1996 and respective baseline length differences are shown in Table 4 (Foldyna et al., 1997).

The results gained from the campaigns indicated a possible relative movement of the Alpine-Carpathian segment with respect to the Bohemian Massif. These findings led the authors to opinion that it is possible to corroborate existence of tectonic activity, but it is much more difficult to reliably quantify and orient the particular movement trends, especially from relatively short periods of monitoring. Recommended continuation of measurements in the MORAVA network using latest precise GNSS instrumentation and respecting the gained knowledge could be realized in 2010 – after more than 15 years.

**Fig. 2** Examples of point monumentations in the Morava network (Left - VRSA point, right – NAHO point).

***NEW MEASUREMENTS IN SOUTHERN PART OF MORAVA NETWORK***

In connection with other tasks resolved in period 2009-2010 the Institute of Geodesy of Brno University of Technology (BUT) seized an opportunity to realize repeated measurements in part of the MORAVA geodynamic network, which followed previous activities from the period 1994-1996. The measurements concerned the above mentioned 5 points situated in Southern Moravia region. The works could be successfully accomplished i.e. thanks to courtesy of interested staff members of the Department of Geodesy and Land Consolidation of Czech Technical University in Prague (CTU) who supplied besides the necessary information and the original observation data from previous campaigns also the original special antenna centring equipment used in the previous MORAVA network campaigns.

- Reobserved points - The five points at Southern Moravia: 72-DUKO, 73-NAHO, 76-STOH, 91-VRSA, and 100-TUBO were selected for re-measurement. Firstly the preparative reconnaissance of the actual state of the points monumentation markers had been realized, including the assessment of their usability.
- At all the points concerned it had been possible to identify uniquely the original position of the centring markers (with exception of the point VRSA with monumentation on casing of the geological borehole (Fig. 2), where the original antenna centring marker could be accessed only after removing of the cover extender).
- Measurement methodic - Within the remeasurements in part of the MORAVA network again the Leica instrumentation was used, namely the receivers SR520/530 and GX1230GG and the antennas LEIAT502, LEIAX1202GG a LEIAT504/504GG. Observing intervals were 24 hours. At three points (NAHO, STOH, VRSA) the antennas were attached to original special centring rod which is in more details described in Foldyna et al. (1997), Švábenský and Weigel (2005), at the point DUKO the antenna was centered with help of a tripod, and the point TUBO is a permanent GPS station included in EPN and CZEPOS structures.
- The data measured in campaigns 2009-2010 were processed by means of BSW 5.0 and concurrently by BSW 4.2 (according to the original processing of campaigns 1994-1996). Processing parameters were an elevation mask 10º, IGS precise orbits and earth rotation parameters, absolute antenna phase center offsets and variations, QIF strategy of ambiguity solution, troposphere parameters

**Table 5** MORAVA network - Baseline lengths.

| Baseline | 1995 [m] | 2009 [m] | 2010 [m] | Differences 1995-2010 [m] | Annual velocities [mm/year] |
|---|---|---|---|---|---|
| TUBO-NAHO | 55609.6905 | 55609.6949 | 55609.6948 | 0.0043 | 0.3 |
| TUBO-DUKO | 32967.0045 | | 32967.0015 | -0.0030 | -0.2 |
| TUBO-STOH | 40694.2764 | | 40694.2862 | 0.0098 | 0.7 |
| TUBO-VRSA | 45081.2146 | | 45081.2291 | 0.0145 | 1.0 |
| NAHO-DUKO | 29388.5003 | | 29388.5046 | 0.0043 | 0.3 |
| NAHO-STOH | 39775.6470 | | 39775.6456 | -0.0014 | -0.1 |
| NAHO-VRSA | 85424.5644 | | 85424.5878 | 0.0234 | 1.6 |
| STOH-DUKO | 43172.8455 | | 43172.8464 | 0.0009 | 0.1 |
| STOH-VRSA | 49374.6791 | | 49374.7074 | 0.0283 | 1.9 |
| DUKO-VRSA | 73671.7331 | | 73671.7474 | 0.0143 | 1.0 |
| **Session times** | **3 x 10 hours** | **22 hours** | **24 hours** | | |

**Table 6** MORAVA network - Comparison of BSW 4.2 and 5.0 processing.

| Baseline | Difference BSW 4.2 - 5.0 [m] | | Annual Velocity [mm/year] | | Velocity Difference |
|---|---|---|---|---|---|
| from to | 1995.80 | 2010.57 | BSW 4.2 | BSW 5.0 | BSW 4.2 - 5.0 [mm/year] |
| TUBO-NAHO | -0.001 | -0.002 | 0.3 | 0.2 | -0.1 |
| TUBO-DUKO | 0.000 | 0.001 | -0.2 | -0.2 | 0.0 |
| TUBO-STOH | 0.000 | -0.002 | 0.7 | 0.4 | -0.3 |
| TUBO-VRSA | -0.003 | -0.004 | 1.0 | 0.9 | -0.1 |
| NAHO-DUKO | -0.001 | -0.002 | 0.3 | 0.2 | -0.1 |
| NAHO-STOH | -0.001 | 0.000 | -0.1 | 0.0 | 0.1 |
| NAHO-VRSA | -0.004 | -0.004 | 1.6 | 1.5 | -0.1 |
| STOH-DUKO | 0.000 | -0.004 | 0.1 | -0.1 | -0.2 |
| STOH-VRSA | -0.001 | -0.002 | 1.9 | 1.9 | 0.0 |
| DUKO-VRSA | -0.003 | -0.002 | 1.0 | 1.0 | 0.0 |

estimated for 2 hours intervals. The final solution was computed using iono-free frequency combination. Differences in the results computed with ambiguities resolved by QIF and narrow lane strategies were negligible.

Table 5 shows the resulting baseline lengths between the five MORAVA network points from the previous campaign 1995 (Foldyna et al., 1997), and from the remeasurement as well as the differences between the results of previous and new measurements together with the estimation of annual velocities (Fig. 3). The 1995 campaign was selected as reference for the comparison because this campaign alone is the most complete and includes all the 5 points concerned.

To check the consistency of previous and new processing results the original data from campaigns 1995 and 1996 were reprocessed. It allowed to compute the coordinates of some points which were not included in published results – i.e. points TUBO and VRSA in 1996 campaign.

It is clear from the Table 6 that there are no substantial differences between the results obtained with BSW 4.2 and 5.0 for this network – maximal baseline difference was 4 mm and maximal velocity difference was 0.3 mm/year.

The above presented results are preliminary in sense that only baseline lengths were computed with reference station TUBO positions constrained to ITRF coordinates (EUREF) for each particular epoch. Another reason was the lack of complete observation information for campaigns 1994-1996 – antenna heights were not exactly known (+/- 0.1 m uncertainties).

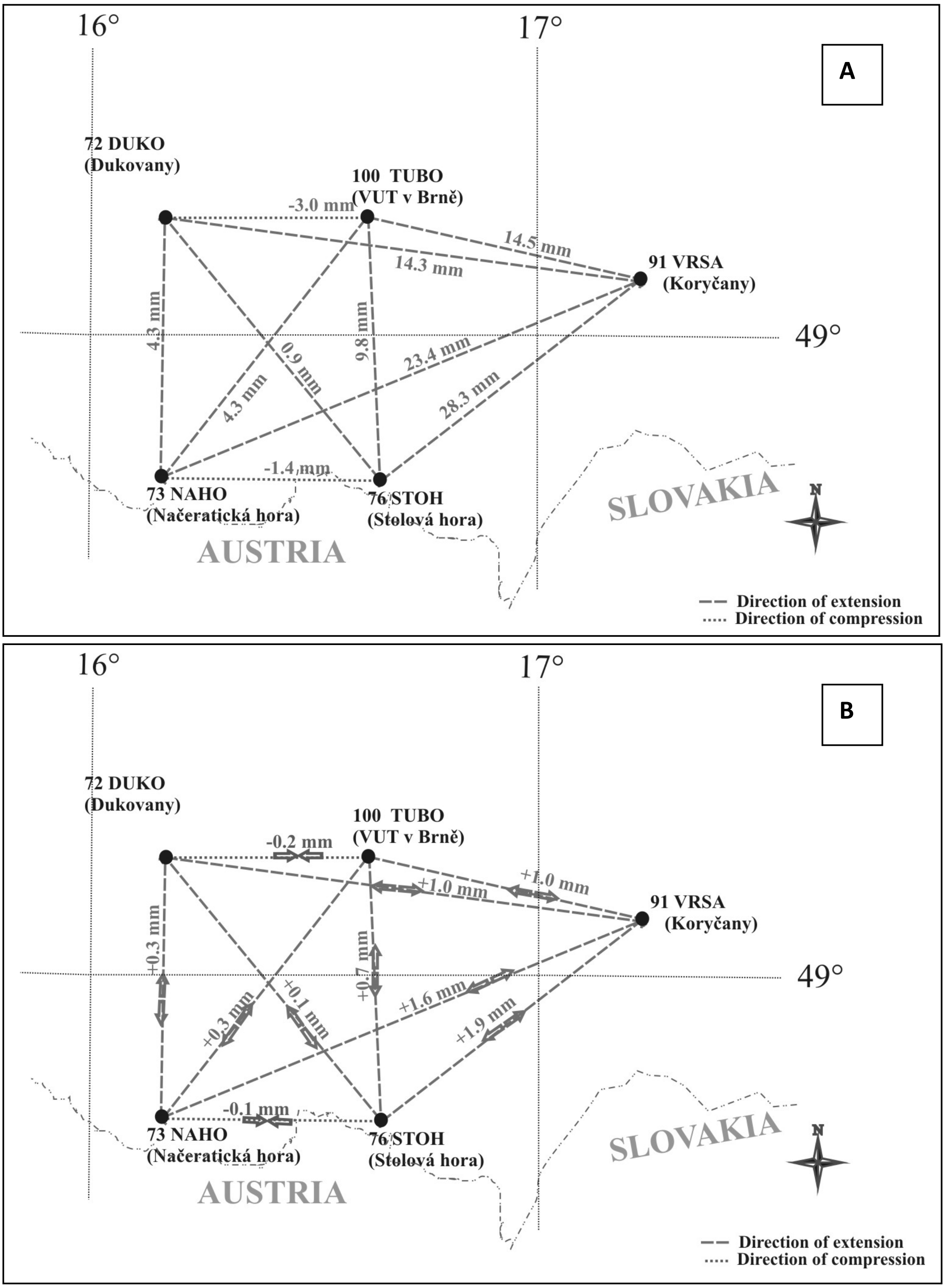


**Fig. 3** Estimated velocities of the selected GPS points of the MORAVA network.
A. Differences of period 15 years,
B. Annual velocities and the horizontal movement tendencies. Red arrow – direction of compression; blue arrow – direction of extension.

## GEOLOGICAL CHARACTERISTICS

The Morava network is located from the geological point of view on the contact of two main geological units – the Bohemian Massif and the Western Carpathians. The results of GPS monitoring enable to evaluate the zone between Boskovice furrow and Waschberg-Ždánice unit. In this space the following tectonic zones and faults can be identified: the Diendorf-Čebín tectonic zone (Pospíšil et al., 2009, 2010) where the Waizendorf and the Diendorf faults (Roštínský and Roetzel, 2005) can be distinguished, and the very complicated tectonic system combined with overthrusting of the Waschberg-Ždánice unit and disrupting of the Mesozoic-crystalline basement (e.g. Němec, 1973; Stráník et al., 1983; Čtyroký et al., 1995; Jiříček, 2002; Cháb et al., 2007).

The Waschberg-Ždánice Unit is located in Lower Austria and Southern Moravia in the transition zone between the Eastern Alps and the Carpathians. It contains the outermost nappes of the Alpine-Carpathian orogenic wedge that were emplaced on top of the European continental margin. Seismic mapping in industrial 2D and 3D seismic datasets reveals the complex deformation of both the autochthonous European foreland and the thrust nappes. High stratigraphic resolution constrains the timing of activation of faults in the foreland and the allochthon very accurately for the time window between the Eggenburgian (20.5 Ma) and the Lower Badenian stage (16.0 Ma). Within this time interval several distinct phases of foreland deformation were identified by Decker et al. (2002), which probably are related to stress coupling across the floor thrust of the wedge, and deformation within the allochthon.

Seismic mapping and structural field data establish the following deformation features (Zámolyi, 2008; Decker et al., 2002; Adámek, 2005):

1. Deformation of the European foreland in front of the Waschberg-Ždánice unit that is folded and thrusted. Structures include the sinistral reactivation of Variscan strike-slip faults such as the Diendorf fault system, and extensional basins formed at releasing bends of such faults during the Eggenburgian (20 Ma).
2. Inversion of Jurassic half-grabens in the European basement leading to folding of the overlying foreland basin strata. Inversion occurred in two distinct periods dated by Eggenburgian-Ottnangian (18 Ma) and Karpatian (17 Ma) growth strata. During the intervening period the fault was inactive. Karpatian inversion is characterized by blind thrusting and the formation of a growth trishear fold.
3. The termination of fold-thrusting is dated by the formation of extensional basins on top of the allochthon. Normal-slip reactivation of the former thrust faults led to the evolution of half-grabens and listric normal faults. Extension is dated by growth strata of Badenian to Pannonian age (16.0 to 10 Ma). Outcrop and seismic data indicate that probably all of the listed deformations occurred contemporaneously with sinistral strike-slip faulting along NNE-to NE-striking wrench faults.

## INTERPRETATION

The resulting changes over 15 years period were expressed in the form of baseline differences between single network points and subsequently divided into three categories: extension zones, compression zones, and stable zones where the annual velocity is under 0.5 mm (Figs. 3 and 4, Table 5).

The resulting preliminary horizontal differences were supplemented by map of recent vertical changes (Vyskočil and Pospíšil, 2009 - Fig. 5), from which the uplift of blocks located between main faults of NE-SW direction is observable. Tectonic zones alone are manifest of the subsidence tendencies. The compression between points at the Bohemian Massif (DUKO - TUBO - NAHO points) and points situated on the nappes of the Western Carpathians (VRSA - STOH points) is observable in Figure 4. In all other cases the extension movements were detected. The more detail analyses of the movements along single faults indicate the significant counter wise trend. On the Waizendorf fault it is possible to interpret dextral movement; the points NAHO and DUKO are drawing apart while the points DUKO and TUBO are drawing near. This tendency confirms the detail GPS measurements at the Znojmo polygon (Witiska, 2011).

Significant sinistral movement can be interpreted between the points STOH and VRSA, also between the points NAHO and VRSA (Fig. 6). One of possible explanations is the connection of the recent movement with the tectonic zone where many normal and thrusted faults can be observed (Ciprys and Thon, 1990; Němec, 1973). In addition, with this zone the opening of the Vienna Basin is connected and most of known faults reach to the crystalline basement formed by the Brunovistulicum here (Dudek, 1980).

## CONCLUSION

Regarding the expected values of points positional changes it will be necessary to carry out the measurements in equal extent at least in 5 years period. In relation with the geologic development of the region it would be convenient to densify the network in some localities, in particular in the area between the points STOH and VRSA. Respecting the previous geodetic measurements it would be also beneficial to realize repeated gravity measurements on selected points.

In present time the idea of supplying new GPS measurements in greater extent of the MORAVA network is being negotiated. This task would be realized in cooperation with other expert groups from CTU Prague, Czech Academy of Sciences (CAS), Slovak University of Technology Bratislava,

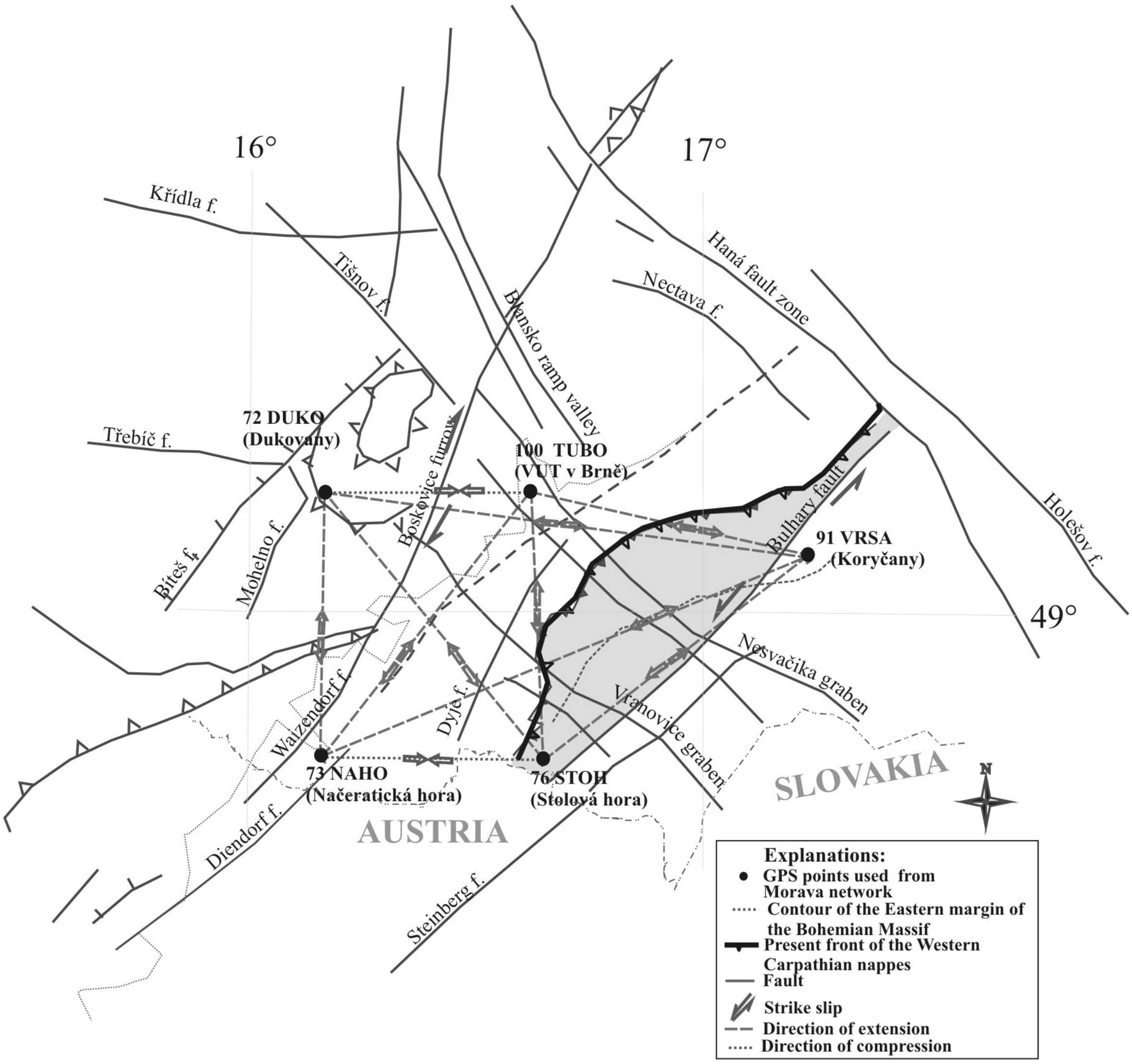


**Fig. 6** Final results of preliminary kinematic analyses in the South Moravia. Measured movement tendencies (Fig. 3B) combined with simplified tectonic map suggest the dextral movement along the Waizendorf fault and sinistral displacement along the Bulhary - Steinberg-Schrattenberg (?) fault zone: Dashed and dotted lines - compression and extension movements respectively. Grey contour – Ždánice – Waschberg unit in Moravia. Arrows – trend of movement.

University of Environmental and Life Sciences Wroclaw, and others. Within the scope of this cooperation new significant results and geodynamic information could be acquired and connection to other existing GNSS networks in the region could be realized.

In fine it is to say that the previous measuring campaigns in the MORAVA local geodynamic network were unique by the fact that in Czech and Slovak Republics never before operated so many GPS receivers of one type (Leica) simultaneously. But the most valuable is the information about positional changes over the period of 15 years.

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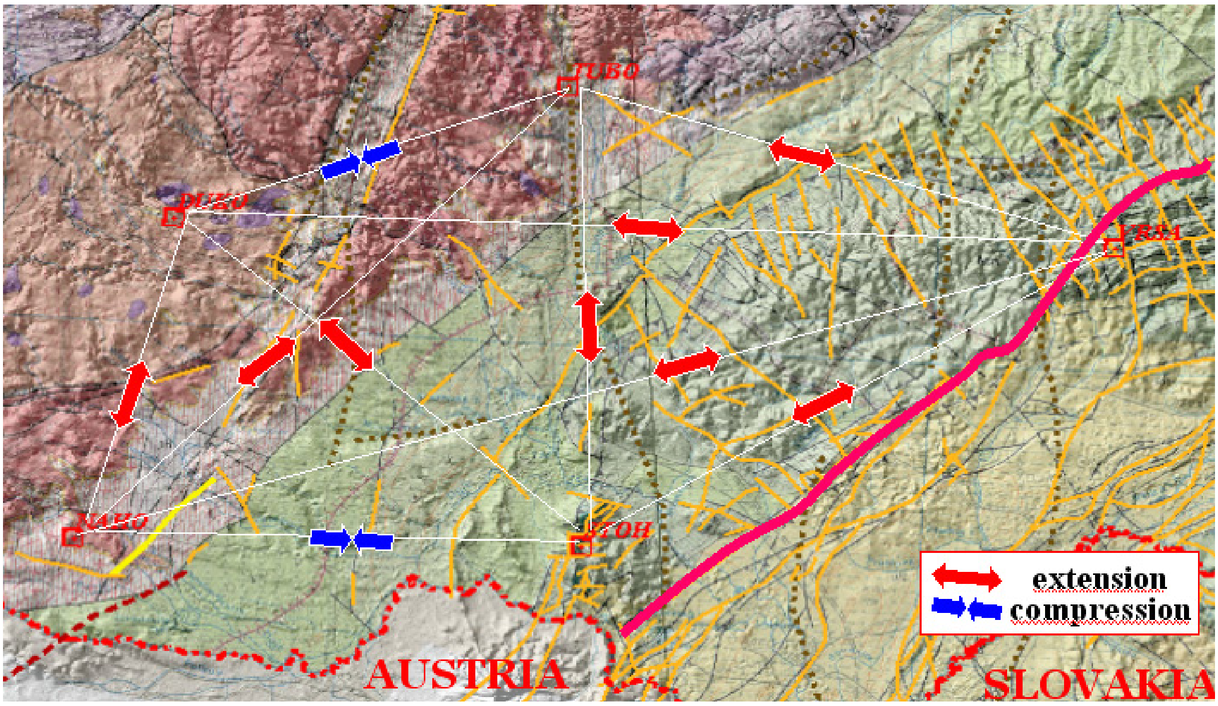


**Fig. 4** Final results of preliminary movement tendencies combined with tectonic map (ČGS -Praha): Red and blue arrows - extension and compression directions respectively. Red heavy line – the Bulhary fault.

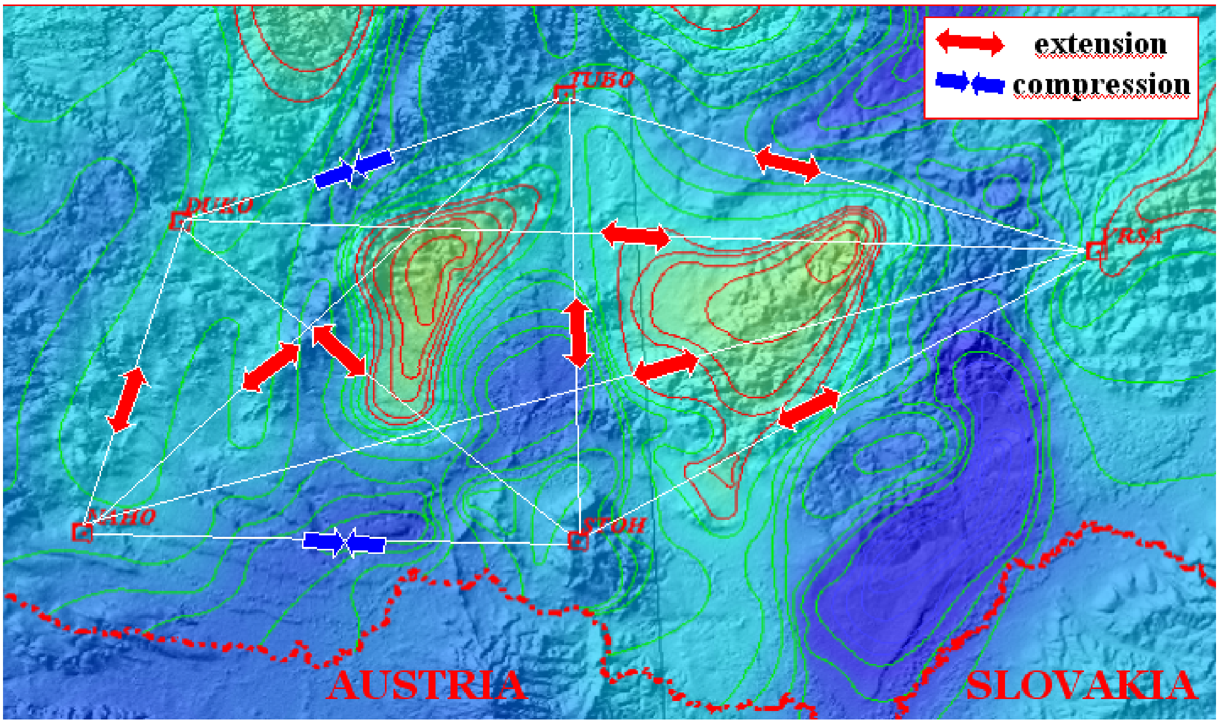


**Fig. 5** Map of preliminary movement tendencies in the South Moravian area. Polygon of horizontal velocities supplemented by vertical velocities (Vyskočil and Pospíšil, 2009). The extension zones in central zone of the polygon correlate with uplifted zones, while the compression zones are combined with decreases of vertical velocities.