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# GEODYNAMIC NETWORK SNĚŽNÍK: REPROCESSING AND ANALYSES OF SATELLITE DATA IN THE CZECH PART OVER THE PERIOD 1997 – 2011

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**ABSTRACT**
Latest studies of recent geodynamic movements going on major geological structures of the Sněžník metamorphic unit are closely related to geodetic satellite measurements, especially to permanent and epoch GNSS satellite methods.
For this reason the Institute of Geodesy, Faculty of Civil Engineering, Brno University of Technology (IG FCE-BUT) continues measurements in Local Geodynamic Sněžník Network (LGSN) which was established in 1992 in Czech-Polish cooperation for the purpose of lithosphere movement monitoring.
A special attention was devoted to detection of possible displacements of the local blocks of Králický Sněžník Massif. The results confirm the significant horizontal and vertical movements within relatively small territory. All these and other detected contemporary geodynamic phenomena are presented and discussed.

**KEYWORDS:** geodynamics, GNSS, geophysics, recent movement tendencies, Sněžník metamorphic unit

## INTRODUCTION

Research activities of the FCE BUT in the Králický Sněžník Massif date from 1992 when the Local Geodynamic Sněžník Network was established within Polish research project (Švábenský and Weigel, 1999). Latest studies of recent geodynamic movements going on major geological structures of the region are closely related to geodetic satellite measurements, especially by permanent and epoch satellite GNSS observations (Fig. 1).

For this reason the IG FCE-BUT made efforts for continuation of satellite GNSS measurements in the LGSN for the period of two decades. So as the instrumentation and the observation scheme changed in course of time, it can be considered that since the 1997 campaign the data amount is sufficient for reliable positional monitoring. A special attention was devoted to a detection of mobility trends of the local subunits of Králický Sněžník Massif.

The topic of the contribution is devoted several tectonic problems combined with the locality of Kralický Sněžník. On the bases of geodetical and geophysical data can be distinguished some anomalous blocks from point of view of the horizontal movements.

The basic geological map of the Bohemian Massif (Cháb et al., 2007), combined with satellite photomosaic and illuminated topographic relief map, open discussion on the real neotectonic and seismotectonic activity in the eastern part Lugicum area in relationship with the latest GPS Data.

## GEOLOGICAL CHARACTERISTICS

The geological map, presented in Figure 2 (Gawlikowska and Opletal, 1997), covers the eastern part of the Orlice-Sněžník Dome, a unit in the northeastern part of the Bohemian Massif. The crystalline rocks of this dome display a complex geological structure. The oldest rocks here are the metamorphic rocks of the Mlynowiec and Stronie Group formed in the Upper Proterozoic to Middle Cambrian (i.e. at the Proterozoic-Paleozoic boundary, 650 to 550 million years ago - Gawlikowska and Opletal, 1997). They were later folded and metamorphosed into gneisses and mica schists. They locally contain intercalations of crystalline limestones and dolomites (marbles), amphibolites, amphibole schists, quartzite and quartzite schists, graphite quartzites and mica schists, porphyroids and leptynites.

A granite magma intrusion that invaded the already folded rocks of the Mlynowiec and Stronie Group occurred at the Cambrian-Ordovician boundary (at the beginning of the Paleozoic, 500 million years ago). The subsequent metamorphism altered the granites into orthogneisses and migmatites of the Snieżnik-Gieraltów Group (Gawlikowska and Opletal, 1997).

The Śnieżnik orthogneisses are mostly highly contorted; mica flakes grow around elongated feldspar and quartz augen. The Gieraltów gneisses mostly appear as banded migmatites, with alternating dark-colored, mica-rich layers and light-colored, feldspar-

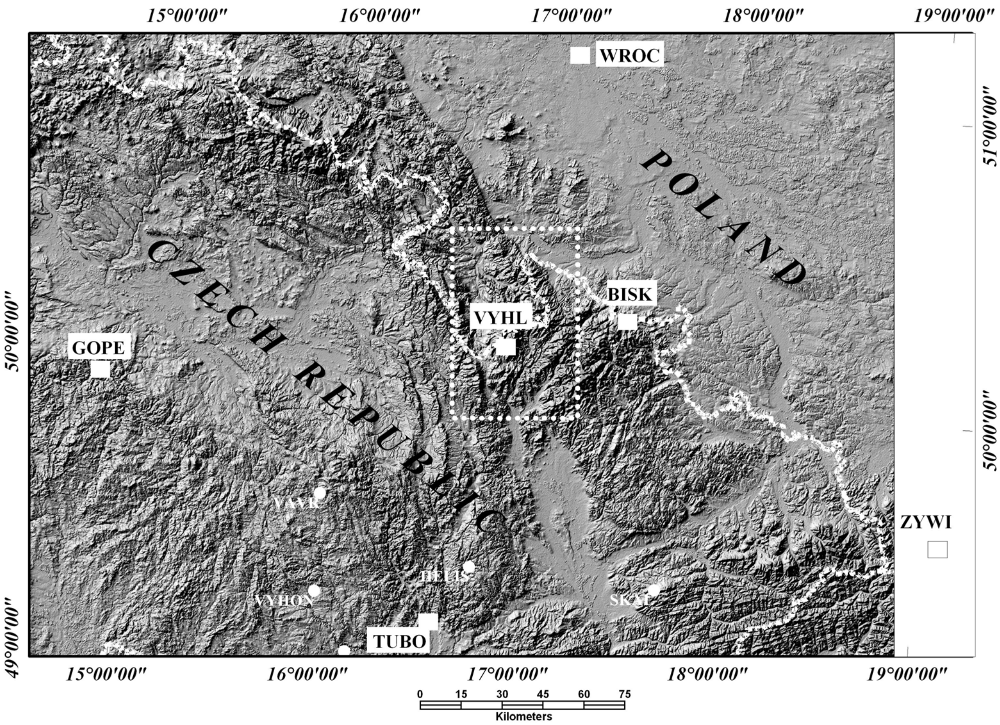


**Fig. 1** The situation of Králický Sněžník area of interest at the SRTM2 map (NASA/USGS 2006) with location of the VYHL point and the surrounding permanent GNSS stations.

and quartz-dominated ones. Light-colored garnet-bearing granulites, granulite gneisses and dark-colored pyroxene granulites and eclogites occurring in the Frontier area east and southeast of Lądek-Zdrój are some of the most interesting rocks. Eclogites also occur in the environs of Międzygórze. These rocks were formed under very high temperatures and pressures at depths of 15 km and more. The genesis of serpentinites, which locally occur at tectonic lines, is associated with similar settings.

East of the above described core units, there are two tectonically independent units: the Staré Město and the Velké Vrbno units, separated by an important tectonic dislocation zone - the Nýznerov thrust. Both have a very variegated petrographic composition and are probably of Late Proterozoic-Early Paleozoic units.

The Staré Město Group has three distinct complexes. Various types of amphibolites and metagabbros are the most common and in places they contain streaks of gneisses and acid metavolcanics (porphyroids). A belt of magmatic rocks, granodiorites, granites, diorites and tonalites, occurs in the central part. They are surrounded by migmatitic and augen gneisses. A belt of gneisses, mica schists and phyllonites, called "Skorošice series", occurs at the Nýznerov thrust zone, that separates the Staré Město unit in the west from the Velké Vrbno unit in the east. The Velké Vrbno unit consists of various types of gneisses, mica schists and phyllonites containing numerous interlayers of amphibolites, acid metavolcanics, crystalline limestones and dolomites.

East of the Velké Vrbno Dome, the important Ramzová tectonic line is situated with the Branná Group of probably Devonian age (Middle Paleozoic, around 380 million years) behind it, which covers only a small, southeastern section in the map. It consists of phyllites, phyllonites, graphitic phyllites, quartzites, greenschists and line-grained biotite granites. Magma intruded in the Paleozoic, to give rise to the Jawornik granitoids. The crystalline series of the Snieżnik metamorphic unit in the west are separated from the Cretaceous sediments (Upper Cenomanian, around 95 Ma old) of the Nysa-Kłodzka Trough by a fault structure which locally has the character of a reverse fault. Cretaceous sediments consist of calcareous marlstones, claystones, siltstones, sandstones, (see legend) and conglomerates and are up to ~ 1000 m thick.

The mountain range stretching from the Krkonoše to the Jeseníky Mountains (the Sudetes) was already dry land in the Tertiary and was subjected to intensive erosion and transport of the weathering products.

Small lacustrine basins were filled at the end of the Tertiary (around 5 Ma years ago) with gravelly sediments that reached a maximum thickness of 30 m near Králíky. In the environs of Ladek-Zdrój and

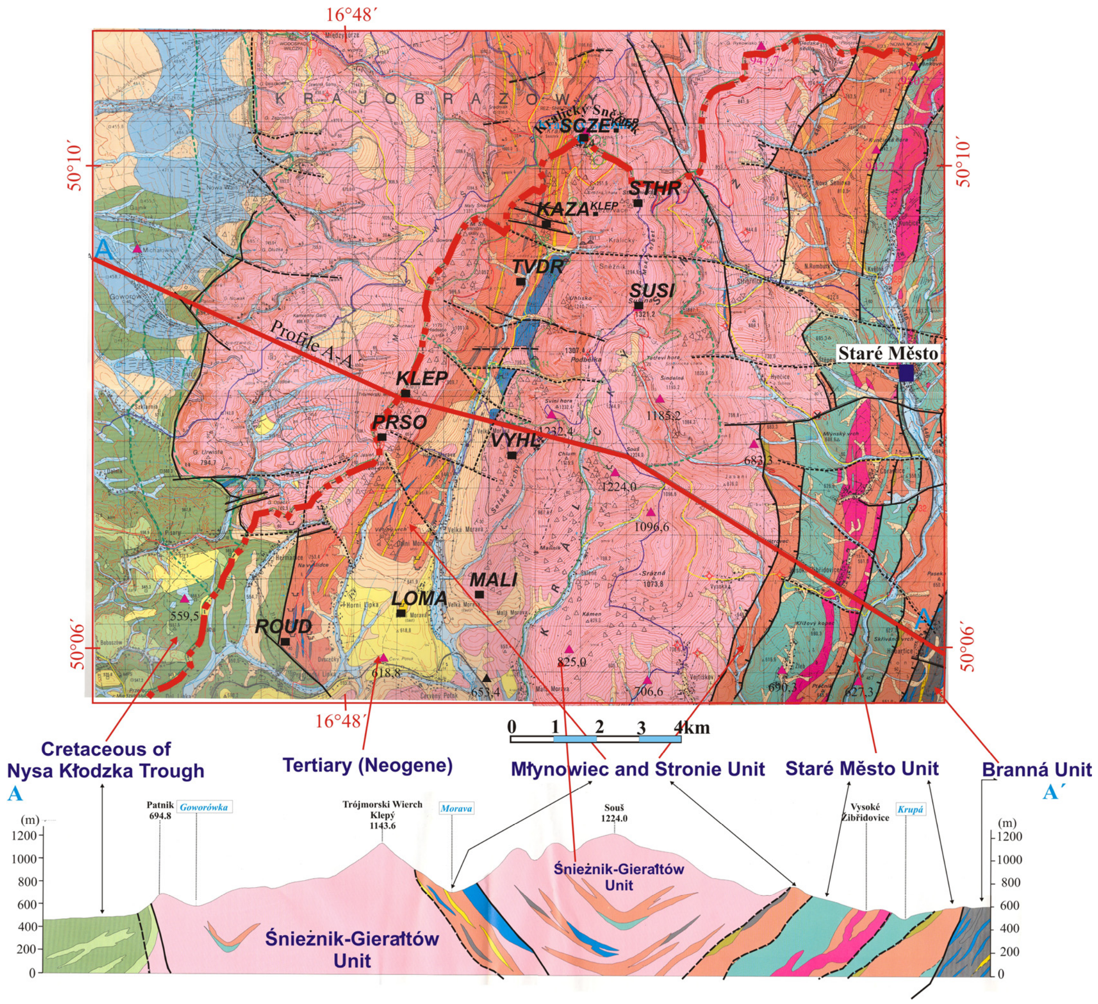


**Fig. 2** Geological map of the Králický Sněžník Mts. (after Gawlikowska and Opletal, 1997), supplemented by GPS points of the LGSN network.

Bruntál (outside the map), basaltic lavas poured out on the gravels deposited at the Tertiary-Quaternary boundary (Birkenmayer et al., 2002).

In the Early Quaternary the entire mountain belt was situated at the forefront of a continental ice sheet. Periglacial phenomena, such as nivation hollows and locally thick rock streams, are linked with the glacial activity. More or less widespread loamy-gravelly slope sediments were deposited during the Quaternary. Colluvio-fluvial and fluvial sediments, including river terraces (mostly sands and gravels), were deposited in the late Quaternary. Peat-bog formation, particularly in the apical parts of the mountains, has been continuing until present.

## GEODETIC MEASUREMENTS AND RESULTS

### *LOCAL GEODYNAMIC SNĚŽNÍK NETWORK*

In 1992 the Local Geodynamic „Sněžník“ Network was established in Králický Sněžník Massif, in cooperation of Department of Geodesy and Photogrammetry AU Wroclaw (now Institute of Geodesy and Geoinformatics, Wrocław University of Environmental and Life Sciences), and Institute of Geodesy, Brno University of Technology. The network spreads out on both sides of the state frontier in the Králický Sněžník Mt. area. It was established to monitor the upper lithosphere movement, but the network is also used for experimental testing of various geodetic measuring technologies (GPS, gravimetry, EDM, precise leveling, geodetic astronomy). Since 1994 it is also exploited in the Czech part for field practices of the BUT students. The LGSN layout and particular results were published e.g. in (Cacoń et al., 1996), (Švábenský and Weigel, 1999), (Cacoń et al., 2004).

### *MEASURING METHODS AND DATA EVALUATION*

The measuring campaigns were carried out on a yearly basis in first half of May. The basic observation mode was 24 hours, but also shorter intervals were included. On the other hand, at some points the amount of observations was in many cases greater. The central point VYHL was regularly observed in more than one diurnal session. In period 1997 - 2003 the measurements were realized with substantial support of cooperating private companies

**Table 1** Evaluated baseline changes over period 1997-2011.

| | Baseline change (mm/year) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| point | KLEP | SCZE | STHR | SUSI | VLAS | KAZA | TVDR | LOMA | MALI | VESE | PRSO | ROUD |
| VYHL | -0.1 | -0.1 | -1.0 | 0.0 | 0.1 | -0.4 | -1.4 | 1.3 | 1.5 | 0.4 | -1.1 | |
| KLEP | | 0.7 | | 0.5 | 0.1 | 0.7 | -0.5 | 1.2 | 0.6 | 0.4 | | -0.5 |
| SCZE | | | 0.4 | 0.3 | 0.0 | 0.3 | 1.3 | | | 0.5 | | |
| VLAS | | | | | | | -1.5 | -0.2 | 0.3 | | | |
| SUSI | | | -1.0 | | | -1.8 | -0.9 | | | | | |

**Table 2** VYHL to EPN baseline changes over period 2005-2011.

| | Baseline change (mm/year) | | | | |
|---|---|---|---|---|---|
| point | BISK | GOPE | TUBO | WROC | ZYWI |
| VYHL | 0.8 | -0.3 | -0.1 | -0.2 | 0.7 |

(Geovap Pardubice, Viageos Prague, Geodézie Krkonoše, Povodí Moravy, and others). Since 2004 the Institute of Geodesy has been equipped with instrumentation that allowed completion of campaign observations with own Leica receivers – GX1230GG, SR530, and SR399 with AT504GG, AX1202GG and AT502 antennas.

For analyses discussed in this paper the network data from the period 1997 – 2011 had been used, together with data from selected surrounding EPN stations BISK, GOPE, WROC, TUBO, ZYWI. All the data were processed using the latest processing tools and strategies. All the data obtained at > 6 hours observation intervals within the Czech part of LGSN were reprocessed using the Bernese software ver. 5.0 (and for some computations also the Leica LGO ver. 8.1), employing the unified processing strategy (latest consistent absolute antenna phase centre calibrations, CODE orbits and Earth rotation parameters, $\varepsilon = 13^o$, troposphere correction parameters estimated in 2 h intervals, QIF ambiguity resolution strategy, final solution using the ionosphere-free frequency combination).

As most of the data stemmed from Leica receivers, this strategy could be used for the first time for fully homogenized inclusion of observations gathered using various receivers of other manufacturers during the period processed (mostly Trimble and Ashtech, each with several antenna types). However, in campaigns where the receivers of more manufacturers are employed, the accuracy of results can be slightly lower.

In Table 1 the results of baseline changes evaluation between some points of LGSN over the period 1997 – 2011 are shown as velocity estimations in mm/year. The values over 0.7 mm/year are in bold and presented in graphics (Figs. 4 and 5).

Table 2 shows the changes in baselines between VYHL and surrounding EPN stations over the period 2005 – 2011. The values over 0.7 mm/year are in bold (Švábenský and Weigel, 1999).

## RESULTS

The analysis of the results of GPS measurements at the points of the Kralický Sněžník network is based on comparison of movement tendencies with the geological and geophysical data available. A distinct tectonic pattern indicates good correlation with magnetic anomalies. The complexes of Staré Město Unit exhibit a large variety of magnetic anomalies.

The GPS points are situated directly on the complexes of the Śnieżnik – Gieraltów Unit, where faults mostly of direction NW-SE dominate (Fig. *2*). To make possible the evaluation of movement tendencies in so small area the velocities of baseline changes between the VYHL point and the surrounding EPN stations (WROC, ZYWI, BISK, TUBO and GOPE). Resulting movement trends between VYHL and single EPN stations are displayed in Figures 3, 4 and 5, and in Table 2. While in respect to the stations WROC, GOPE and TUBO a lower compressive movement not greater than -0.3 mm/year is showing, in respect to stations BISK and ZYWI there is appearing extensive tendency of 0.7 mm/year.

Relative displacements between interior LGSN points evaluated in period of 15 years were therefore limited to a comparable velocity level – if the computed velocities were under 0.7 mm/year then they were not considered.

It has showed up that within the LGSN the compression trends are appearing for most of the points located north, south or west of the point VYHL, while the extensions are indicating for points mutually oriented in W-E direction. Exceptions are the points TVDR and SCZE, where the extensions reach up to +1.3 mm/year. In present time the repeated precise leveling measurements at the point TVDR (situated at foot of the slope) are analyzed,

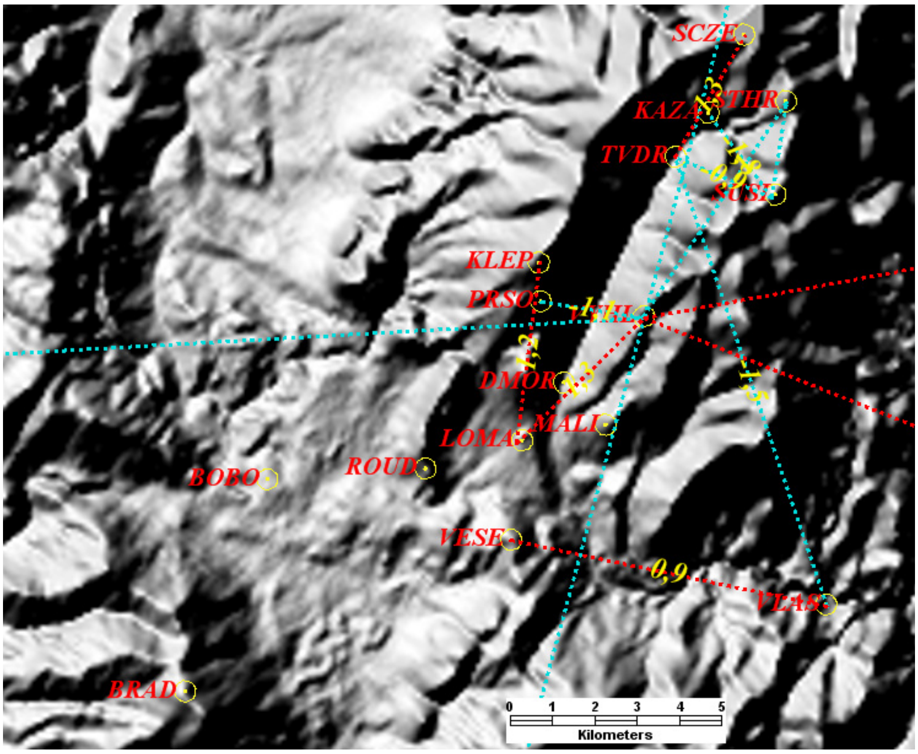


**Fig. 5** A detail view of movement tendencies at the LGSN points.

with aim to exclude eventual vertical changes induced e.g. by slope unstableness or influence of the underground carst in the zone of appearing of crystalline limestone of the Morava valley .

## EVALUATION OF RESULTS

As far as preliminary evaluations are concerned, we took into consideration besides the geomorphological and geological sources only the gravimetric and magnetic anomalies (Švábenský et al., 2011), and earthquake foci distribution at Northern Moravia (Špaček et al., 2006). Subject of evaluation were the results of the GPS measurements and their correlation with morphological and geophysical data.

Mutual movement tendencies – velocities – within the Local Geodynamic Sněžník Network were related to the VYHL point. For the purpose of assessment of regional dynamics of the area we also determined the relative movement tendencies between the VYHL point and the permanent stations GOPE, TUBO, BISK (in CR), WROC and ZYWI (in PL) which are included in EPN. Extensions appear in respect to the points ZYWI and BISK – almost 1 mm/year, while in respect to the points WROC and GOPE there are only insignificant compressions (-0.2 – -0.3 mm/year – Figs. 4 and 5).

The tectonic earthquakes registered in this area in the past years might have been manifestations of recent movements. The seismic activity is located at the contact of the Králický Sněžník Mts. and Staré Město crystalline complex. The recently conducted GPS measurements in the SUDETEN network (Schenk et al., 2000) and Králický Sněžník network helped to estimate the character and direction of the movements. Correlation with the geological analysis can support the geodynamic research of the Králický Sněžník Mts. Area.

On a local scale, as mentioned above, within the LGSN the trend exceptions are only the mutual movements between points SCZE and TVDR which have reversible (extension) character contrary to the compression trends between the surrounding points.

In the area of Králický Sněžník and Jeseník Mts. several hundreds of micro-earthquakes were recorded, with local magnitudes of − 0.6 to 1.8. The main seismic activity is concentrated in its northern part where a total of 153 microearthquakes were located during the period 1996−2003 (Špaček et al., 2006). Several epicentral zones have been distinguished, of which the zone Králický Sněžník and the zone NNW of Šumperk are related to the area of interest (Špaček et al., 2006).

A group of 8 earthquakes with foci at depths of 10-15 km as well as two shallower events, with maximum ML = 1.1, were detected in the area of Kralický Sněžník (5-9 km SSE of the peak of the Králický Sněžník Mt.). A historical earthquake has been reported from this area, too.

The epicentres NNW of Šumperk lie about 4 km south of Hanušovice. Most of the located microearthquakes with focal depths of 20 to 21 km and ML = 1.3 belong to the June 2002 swarm (eastern sub-cluster). Two solitary events with foci at depths of 12 and 18 km were located farther to the west.

The two computed fault plane solutions indicated a dextral pure to oblique strike-slip on ENE-WSW striking subvertical faults, or a sinistral movement on ENE-WSW striking subvertical faults. Two solutions (events D and E) show a sinistral oblique strike-slip on a subvertical NNW-SSE oriented fault, or a dextral strike-slip on a ENE-WSW trending vertical fault. In the case of events D and E improved data processing and new amplitude reading led to a pronounced change of the focal plane solutions compared with the preliminary results. These focal solutions are less constrained than the other three due to the inconvenient position of the events relating to the local seismic network.

It is surprising that the seismic activity seems to be reduced in the Kłodzko region, but it might also be the effect of poor coverage of the area by seismic stations. The morphological and exodynamic analyses suggest intensive recent tectonic movements at westerns slope of Králický Sněžník massif and Nysa - Kłodzka Trough (Batík et al., 1996).

Two groups of epicenters between Šumperk and Králický Sněžník roughly correspond with the NNE-SSW trending structures, where, in agreement with surface geology, the gravity map indicates a steep density gradient.

However, multiplet focal solutions D and E do not correlate with these structures (Špaček et al., 2006).

Even though the GPS measurements of movement tendencies provide preliminary results there is observed the relatively extensional movement of GPS point on the W side of VYHL point (Figs. 4 and 5). It may be a geological proof of the recent movements along the NW-SE to WNW-SES striking faults, which are unknown in this area or only a fragment of this character area is observable in geological maps.

The relief morphology of the NW-SE and WNW-ESE trending faults indicates their Cenozoic activity and a significant vertical slip component (Špaček et al., 2006).

## CONCLUSION

Evaluation of measurements in Local Geodynamic Sněžník Network area over period of 10 years has brought further factual results to discuss about the character of movement tendencies in the region. Movements of more than 1 mm/year velocities prove the increased activity at areas where relatively frequent seismotectonic activities had been also registered (Špaček et al., 2006).

For more precise analyses the following GNSS measuring campaigns are in planning which will include also the Morava Network points (Foldyna et al., 1997). As by the similar evaluations in southern (Czech) part of the LGSN (Fig. 6), this project could eventually bring evidence about further dependencies and movement trends over all the network area. It is clear also from Figure 6 where the results of EPN processing are displayed (Hefty et al., 2009) indicating N-E motion of the whole flysch zone.

It is evident that in following epochs it is necessary to unify the results of different GPS measuring campaigns and different departments, and also to realize well coordinated simultaneous measurements at selected Czech Massif points.

## ACKNOWLEDGEMENT

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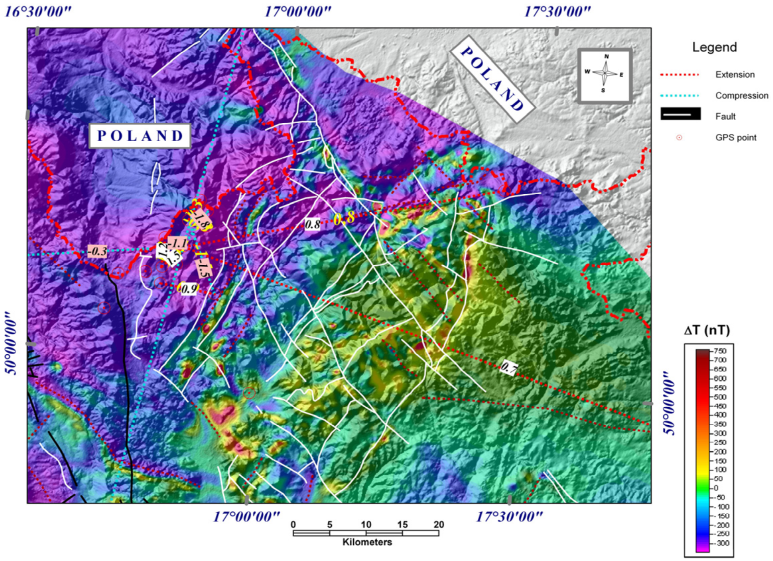


**Fig. 3** The results of the GPS measurements and their correlation with morphological and magnetic data.

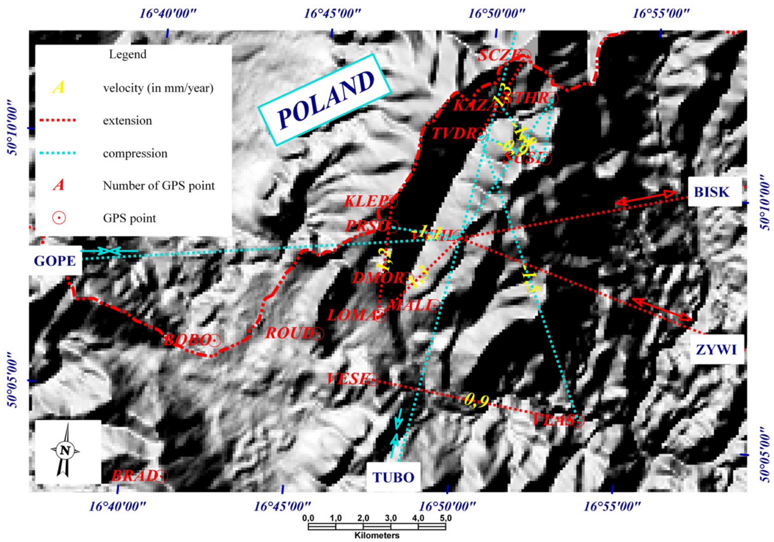


**Fig. 4** The results of the GPS measurements and their correlation with morphological data. Mutual movement tendencies are related to the point VYHL. Extensions appear in respect to the points ZYWI and BISK – almost 1 mm/year, while in respect to the points WROC and GOPE there are only insignificant compressions (-0.2 – 0.3 mm/year).

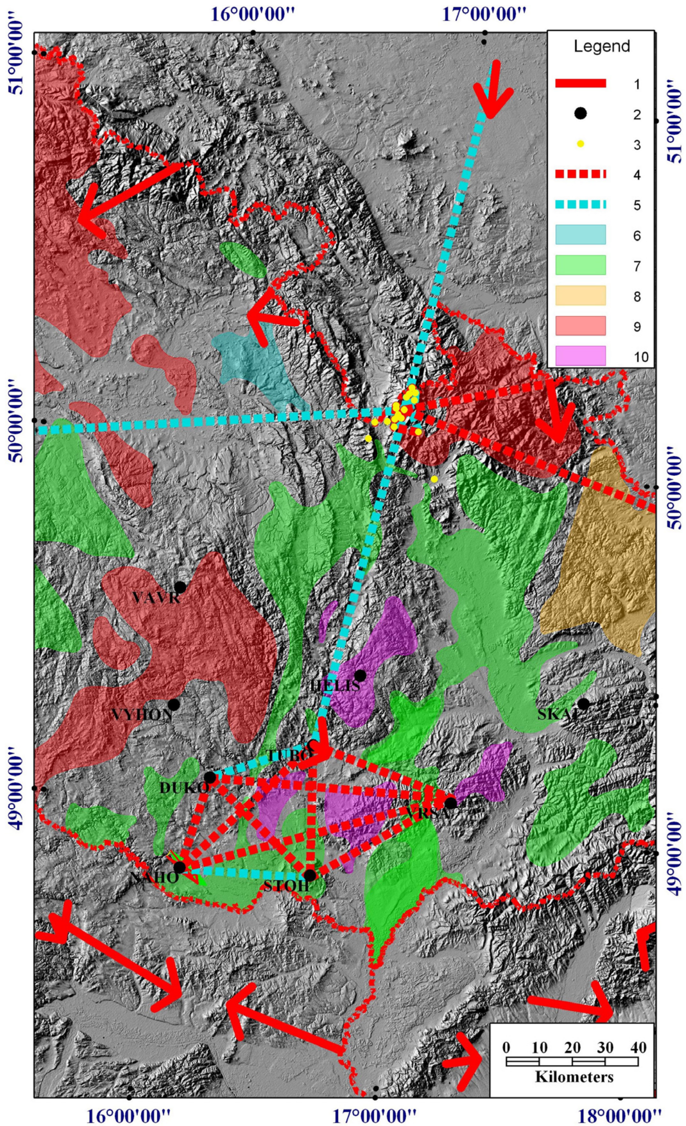


**Fig. 6** Images of the major movement tendencies near the GPS Králický Sněžník network. The regional character of movements can be observed from data (Hefty, 2007; Hefty et al., 2009). Explanations: 1- velocity and direction, 2- GPS point of Morava network, 3- GPS point of LGSN, 4- extension tendency, 5- compression tendency, Recent vertical movements: 6- max. subsidence, 7- subsidence, 8- neutral, 9- uplift, 10- maximal uplift.