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NEW VELOCITY ANALYSIS IN GEODYNAMIC NETWORK SNĚŽNÍK BASED ON GNSS MEASUREMENT REPROCESSING USING REPROCESSED IGS PRODUCTS

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ABSTRACT

Since 2006 the International GNSS Service (IGS) started with reprocessing of all IGS products (Steigenberger et al., 2006; Ferland, 2010) according newly adopted models and reference frame. The resulting reprocessed products are of superior quality and homogeneous through the whole time span. Moreover the IGS re-processing made available all the products also for the period before year 2000 when IGS originally started to provide them. The availability of those products was the main motivation for a comprehensive reprocessing of all GNSS data from the Local Geodynamic Sněžník Network from the period between 1997 and 2011. All calculations were performed in the Bernese GPS software 5.0. The absolute method of Precise Point Positioning (PPP) was used for the first time within the network providing interesting results. The main evaluation of recent movement tendencies was done using common relative method where the nearest IGS points were used as reference points.

INTRODUCTION

The history of research activities in the area of Králický Sněžník massif (Fig. 1) started in early 1990s. As a breakthrough can be considered the establishment of Local Geodynamic Sněžník Network (LGSN) which was build up in cooperation of Institute of Geodesy and Geoinformatics, Wrocław University of Environmental and Life Sciences (former Department of Geodesy and Photogrammetry AU Wrocław) and Institute of Geodesy, Brno University of Technology (BUT) in 1992. Detailed description of LGSN provides (Cacoň et al., 1996; Švábenský and Weigel, 1999; Cacoň et al., 2004). The main purpose of the network is the monitoring of upper lithosphere movement but it serves also for other research activities in field of geodetic astronomy, gravimetry and others (Cacoň et al., 2004). Detailed description of geological characteristics of the Králický Sněžník massif and surrounding areas is presented in (Gawlikowska and Opletal, 1997; Birkenmayer et al., 2002). Essential activities in the network are related to the GNSS measurements which are being realized in epoch-wise manner. Partial results of research activities in LGSN have been presented by many authors since the establishment of the network (Švábenský and Weigel, 2007; Jamroz, 2008; Cacoň et al., 2004, Švábenský et al., 2012). This article deals with comprehensive reprocessing of all GNSS data measured in Czech part of LGSN between years 1997 and 2011 and will refer to previously presented results from (Švábenský and Weigel, 2007; Švábenský et al., 2012) The main motivation for a complete reprocessing are the results

of the first IGS reprocessing campaign (Steigenberger et al., 2006; Ferland, 2010) which are being used for the first time within the LGSN. The reprocessed IGS products are not only of better quality but their quality is also homogenous through the whole processed time span (Meindl et al., 2012). More over the campaign of the first reprocessing had made available the IGS final products also for the period before year 2000 when IGS originally started to provide its products.

GNSS MEASUREMENT

The network was firstly observed using GNSS in 1992 but only since 1997 the observations are longer than 24 hours and therefore reliable for positional monitoring. The annual campaign is realized each year in May during the field practices of the BUT students. Most of LGSN points are located far from any infrastructure so there is no possibility to observe them permanently and due to this fact, all of the GNSS measurements from LGSN are epoch-wise. During the whole time span between 1997 and 2011, 12 different types of GNSS antennas were used. Since the 2005 started the unification of the used instrumentation, as well as its planned distribution on the points (same antenna on same point in different epoch). An overview of observation duration and number of used antenna types is listed in Table 1.

To be able to distinguish any geodynamic movements is absolutely crucial to eliminate all of systematic effects because unlike for evaluation of permanently observed networks the possibility of sophisticated filtering is for epoch-wise measured networks very limited. Therefore the comprehensive

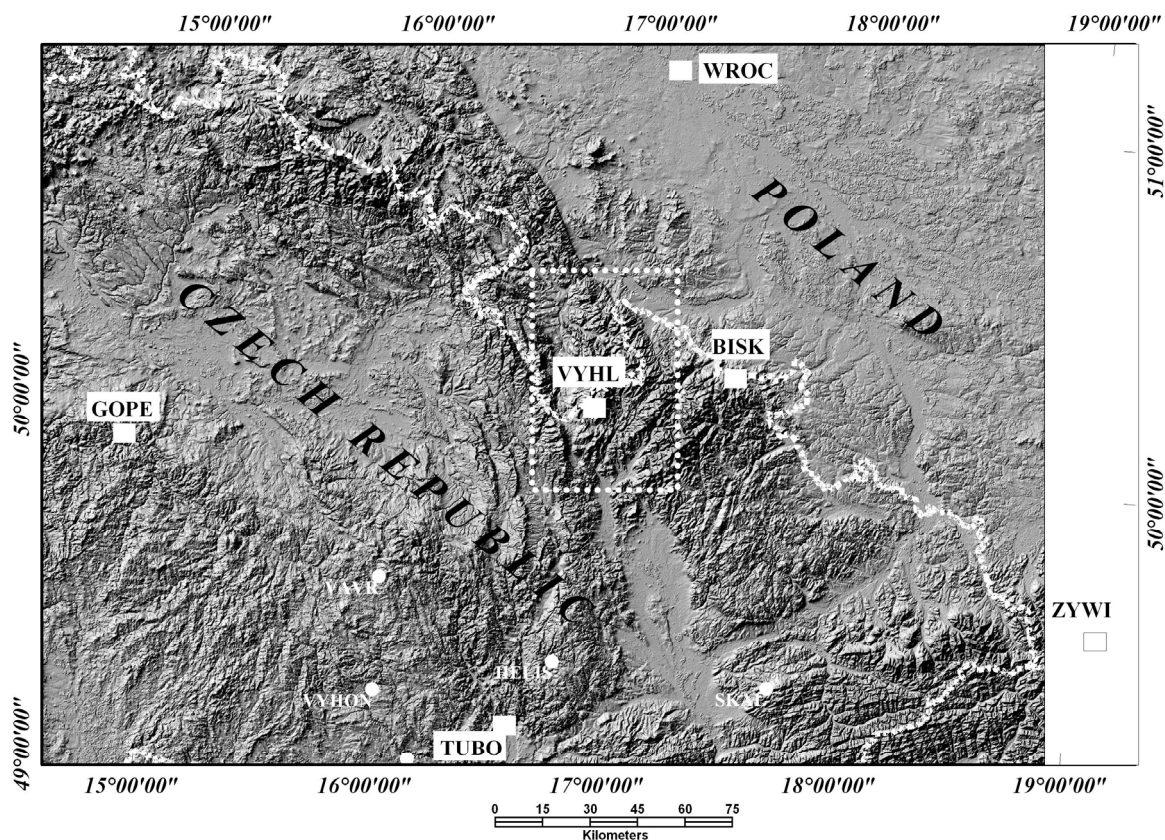


Fig. 1 Localization of the area of Králický Sněžník massif at the SRTM2 map (NASA/USGS 2006).

Table 1 Overview of observations realized in Local Geodynamic Sněžník Network.

Year	Duration of observations	Day of year	Number of measured points	Number of different antenna types
1992		Too short observations		
1993		Too short observations		
1994	1–3 h	141 a 142	13	1
1995		Too short observations		
1996	1–3 h	137–140 a 254–257	14	3
1997	6 h	125–138, 241–243, 265–268	7	1
1998	6 h	129–137, 261–264	9	5
1999	24 h	139–142	4	1
2000	24 h	125–134	13	4
2001	12 h	126–133	14	4
2002	24 h	129–139	11	3
2003	24 h	136–138	14	4
2004	24 h	129–137	11	4
2005	24 h	133–141	14	4
2006	24 h	127–133	12	3
2007	24 h	133–140	12	4
2008	24 h	128–135	9	4
2009	24 h	133–143	13	4
2010	24 h	136–143	12	4
2011	24 h	126–135	11	4

reprocessing using the IGS reprocessed products related to only one reference frame and to the absolute model of antenna phase center variation is very promising.

USED PROCESSING METHODS AND THEIR RESULTS

Determination of spatial coordinates using GNSS measurements can be done using two different approaches. First is the absolute method of Precise Point Positioning (PPP) which is on the one hand highly dependent on the quality of inputs (both measured data and supporting products) but on the other hand the estimation of point velocities is independent from velocities on reference points because the coordinates are determined directly from the measurements in the reference frame of satellite orbits. The second method is the widely used relative method, using which the coordinates and velocities are determined relatively to the chosen reference points. During the comprehensive reprocessing of GNSS measurement from LGSN both absolute and relative approach were used. All the data were processed in Bernese GPS software version 5.0 (BSW5), which allows the highest control over the processing including adoption of IGS products.

PPP METHOD

For the whole data set the daily solutions were computed using standard Bernese processing engine (BPE) script for PPP adopted for data from LGSN. Subsequently the daily solutions were combined using ADDNEQ2. The results are the coordinates and velocities in given epoch and reference frame. Because for most of the time span the IGS products were related to the IGS05, was the IGS05 used as a final reference frame. For the evaluation of possible geodynamic movements were the estimated velocities compared with two most common models, the geological No Net Rotation – Northwestern University VELOCITY model 1A (NNR-NUVEL-1A) introduced in (DeMets, 1994) and a plate motion and deformation model of Actual Plate Kinematic Model – version 2005 (APKIM2005) presented by (Drewes, 2009). Velocities of LGSN points in both models were calculated using University NAVSTAR Consortium (UNAVCO) web service of Tectonic Plate Motion Calculator (2008). Residual velocities were computed by subtracting the velocities in both models from velocities of the PPP method. The resulting residual velocities are shown in Figure 2. It is worth to mention the well correspondence of residual velocities related to the NNR-NUVEL-1A model for example with the results presented in (Bogusz et al., 2012, p. 76) from processing of ASG-EUPOS which points are close to the area of LGSN. But it is also clearly visible, that there is a difference between the resulting residual velocities in relation to both models. This phenomenon is caused by different velocity of IGS05 reference frame in relation to the both used models. For estimation of the relative

velocity between the reference frame of IGS05 and both models, the velocities of four closest IGS core stations given in IGS05 were compared to its velocities computed using the Tectonic Plate Motion Calculator of UNAVCO. The average difference between the IGS05 and NNR-NUVEL-1A was detected on the level of 2 mm/year in north direction and 0.6 mm/year in east direction and between the IGS05 and APKIM2005 is the average difference -1 mm/year in north direction and 0.5 mm/year for east direction.

After a removal of those differences the residual velocities in relation to the both agree on the level of 0.1 mm/year for north direction and 0.2 mm/year for east direction. The final residual velocities are listed in Table 2. Although the results gained from absolute method are quite impressive, it is better to use the relative method for the final evaluation because of the better elimination of the systematic errors. For information the average RMSE (Root Mean Square Error) of coordinates taken from comparison of daily solutions (repeatability of coordinates) is 6 mm in northing and 9 mm in easting as listed in Table 3. The height component of coordinates was not evaluated.

RELATIVE METHOD

When using relative method, the coordinates and velocities of LGSN points were determined in relation to the closest IGS points (Figure 3). Because of the wide time span, only few points were able to fulfill all the criteria (availability of observation data, contribution on reference frame realization and stability) for reference points so only four IGS core stations were chosen, namely BOR1, JOZE, POTS and WTZR. The processing was done using modified script of Bernese processing engine RNK2SNX. The modification stemmed besides to adaption to the LGSN data and reprocessed IGS products from use of STAR strategy for baseline creation, so that all baselines from central point VYHL were computed. Rest of the settings was kept unchanged. Initially all the daily solutions were resolved and subsequently combined using ADDNEQ2. The overall results are the coordinates and velocities in desired epoch in IGS05 reference frame. To evaluate the possible geodynamic movements, again the comparison with NNR-NUVEL-1A and APKIM2005 models was realized (Figure 3). The final residual velocities after subtraction of geologic model velocities and relative velocity between each model and used reference frame are listed in Table 4 while the resulting coordinates in IGS05 reference frame with their accuracies are listed in Table 5.

At first sight is visible that the residual velocities are in absolute value below 1 mm/year besides for points VLAS and KAZA. But the higher residual velocities for points KAZA and VLAS are probably caused by higher variance of each coordinate component in their time series.

Table 2 Residual velocities of PPP method after subtraction of geological model of NNR-NUVEL-1A, plate motion model of APKIM2005 and residual velocity of used reference frame.

Residual velocities after subtraction of both models and residual velocity of used reference frame [mm/year]						
Northing			Easting			
NNR-NUVEL- -1A	APKIM2005	RMSE of N velocity from BSW5	NNR-NUVEL- -1A	APKIM2005	RMSE of E velocity from BSW5	
0.5	0.4	0.1	-2.0	-2.1	0.2	
0.2	0.1	0.2	-0.3	-0.4	0.3	
-0.2	-0.3	0.1	-1.7	-1.8	0.1	
-1.1	-1.2	0.2	-1.3	-1.4	0.2	
-2.2	-2.3	0.1	-2.8	-2.9	0.2	
1.1	1.0	0.2	-1.5	-1.6	0.3	
-0.2	-0.3	0.1	-1.0	-1.1	0.1	
-0.6	-0.7	0.1	-0.7	-0.8	0.1	
-0.1	-0.2	0.1	-1.0	-1.1	0.1	
0.4	0.3	0.1	0.5	0.4	0.2	
-0.3	-0.4	0.1	-1.2	-1.3	0.2	
0.8	0.7	0.1	-2.2	-2.3	0.2	
0.9	0.8	0.1	-0.3	-0.5	0.1	
0.5	0.4	0	-1.3	-1.4	0.1	

Table 3 Coordinates and velocities gained using PPP method with their accuracy. (RMSE mean root mean square error of coordinates, RN and RE are the variances (repeatability) taken from comparison of individual solution from whole tome span, VN and VE are velocities in northing or easting respectively).

Point	Northing	RMSE N [mm]	RN [mm]	Easting	RMSE E [mm]	RE [mm]	VN [mm/r]	VE [mm/r]
DMOR	50° 7' 46.04088''	0.3	6.9	16° 48' 0.359222''	0.4	9.0	15.3	18.3
KAZA	50° 11' 22.84562''	0.8	4.9	16° 50' 18.058291''	1.3	25.5	15.0	20.0
KLEP	50° 9' 15.21663''	0.3	4.0	16° 47' 15.778657''	0.5	5.9	14.6	18.6
LOMA	50° 6' 58.37788''	0.7	8.8	16° 47' 18.259477''	0.9	7.9	13.7	19.0
MALI	50° 7' 16.99773''	0.4	11.3	16° 48' 55.205008''	0.7	11.0	12.6	17.5
PRSO	50° 8' 45.89299''	0.9	5.7	16° 47' 22.860957''	1.3	4.8	15.9	18.8
SCZE	50° 12' 25.29714''	0.4	5.2	16° 50' 50.857188''	0.6	5.6	14.6	19.3
STHR	50° 11' 37.89790''	0.4	4.4	16° 51' 48.730654''	0.6	7.0	14.2	19.6
SUSI	50° 10' 25.92042''	0.4	4.5	16° 51' 47.812231''	0.6	7.9	14.7	19.3
TARA	50° 8' 16.59092''	0.7	4.8	16° 48' 21.234901''	1.2	9.4	15.2	20.8
TVDR	50° 10' 46.79378''	0.4	7.9	16° 49' 44.623435''	0.5	12.6	14.5	19.1
VESE	50° 5' 41.75846''	0.2	5.9	16° 47' 17.932757''	0.4	6.4	15.6	18.1
VLAS	50° 5' 17.79710''	0.3	8.2	16° 53' 38.620189''	0.4	9.5	15.7	20.0
	50° 8' 42.55077''	0.2	3.9	16° 49' 27.171100''	0.3	6.2	15.3	19.0
		0.7	6.1		1.0	9.4		

Table 4 Residual velocities computed with the relative method after subtraction of geological model of NNR-NUVEL-1A, plate motion model of APKIM2005 and residual velocity of used reference frame.

POINT	Residual velocities after subtraction of both models and residual velocity of used reference frame [mm/year]					
	Northing			Easting		
	NNR-NUVEL -1A	APKIM2005	RMSE of N velocity from BSW5	NNR-NUVEL -1A	APKIM2005	RMSE of E velocity from BSW5
DMOR	0.2	0.1	0.1	0.3	0.2	0.1
KAZA	-0.6	-0.7	0.1	1.5	1.4	0.1
KLEP	-0.1	-0.2	0	-0.3	-0.4	0
LOMA	0.1	0.0	0.1	0.6	0.5	0.1
MALI	-0.7	-0.8	0.1	-0.1	-0.2	0.1
PRSO	0.7	0.6	0.1	0.6	0.5	0.1
SCZE	-0.1	-0.2	0	0.1	0.0	0
STHR	-0.6	-0.7	0	-0.1	-0.2	0
SUSI	0.1	0.0	0	0.4	0.3	0
TARA	-0.3	-0.4	0.1	0.6	0.5	0.1
TVDR	-0.6	-0.7	0.1	0.4	0.3	0.1
VESE	0.5	0.4	0.1	-0.2	-0.3	0
VLAS	1.2	1.1	0	0.5	0.3	0
VYHL	0.5	0.4	0	0.1	0.0	0

Table 5 Coordinates and velocities (IGS05) gained using relative method with their accuracy. (RMSE - root mean square error of coordinates, RN and RE are the variances (repeatability) taken from comparison of individual solution from whole time span, VN and VE are velocities in northing or easting respectively).

Point	Northing	RMSE N [mm]	RN [mm]	Easting	RMSE E [mm]	RE [mm]	VN [mm/r]	VE [mm/r]
DMOR	50° 7' 46.040956''	0.3	6.4	16° 48' 0.358332''	0.2	2.7	15.0	20.6
KAZA	50° 11' 22.845793''	0.9	4.0	16° 50' 18.057484''	0.7	6.1	14.2	21.8
KLEP	50° 9' 15.216585''	0.3	2.1	16° 47' 15.777583''	0.2	2.4	14.7	20.0
LOMA	50° 6' 58.377753''	0.5	5.0	16° 47' 18.258577''	0.3	2.3	14.9	20.9
MALI	50° 7' 16.997497''	0.4	6.2	16° 48' 55.204005''	0.3	5.0	14.1	20.2
PRSO	50° 8' 45.8931''	0.7	1.3	16° 47' 22.859641''	0.5	1.1	15.5	20.9
SCZE	50° 12' 25.297148''	0.3	3.1	16° 50' 50.85648''	0.2	3.1	14.7	20.4
STHR	50° 11' 37.897838''	0.3	3.7	16° 51' 48.730026''	0.3	6.3	14.2	20.2
SUSI	50° 10' 25.920371''	0.4	3.0	16° 51' 47.81151''	0.3	3.7	14.9	20.7
TARA	50° 8' 16.591097''	1.1	4.6	16° 48' 21.234701''	0.7	3.3	14.5	20.9
TVDR	50° 10' 46.793863''	0.3	4.1	16° 49' 44.622308''	0.3	3.3	14.2	20.7
VESE	50° 5' 41.758497''	0.2	4.5	16° 47' 17.932141''	0.2	3.9	15.3	20.1
VLAS	50° 5' 17.797104''	0.3	4.1	16° 53' 38.619439''	0.2	3.0	16.0	20.8
VYHL	50° 8' 42.550775''	0.2	2.8	16° 49' 27.170334''	0.2	2.7	15.3	20.4
		0.6	3.8		0.4	3.3		

CONCLUSION

Comprehensive reprocessing of GNSS data measured in Local Geodynamic Sněžník network over period of 15 years using the highest quality products

of first IGS reprocessing has brought further factual results to the discussion about the character of movement tendencies in the region. For the first time the absolute method of precise point positioning was

used within the LGSN and thanks to the quality of used IGS products provided interesting results unaffected by the relations to the reference points. However the accuracy of the PPP method is even when using IGS reprocessed products not sufficient for evaluation of geodynamic tendencies in the area of interest. Better overview of potential crustal movements in the area of Králický Sněžník massif was provided by the more common relative method of GNSS processing. According to its results the area of interest seems to be in good accordance with both compared models (NNR-NUVEL-1A and APKIM2005). Resulting residual velocities of LGSN points are despite relatively frequent seismotectonic activities (Špaček et al., 2006) below 1 mm/year for most of the points. Only for two points (KAZA and VLAS) the residual velocities are higher than 1 mm/year but are most probably caused by higher variance of each coordinate components in its time series. Although the most accurate inputs in form of IGS reprocessed products were used and whole reprocessing was oriented to obtain the final results of highest accuracy, there are still many systematic errors which influence the overall results. Among the others the influence of variations of phase centers for used antennas, near-field multipath or the effect of ionosphere and troposphere should be named as the main sources of remaining systematic errors.

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