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INVESTIGATION OF ENVIRONMENTAL INFLUENCES TO THE PRECISE GNNS SOLUTIONS

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ABSTRACT
The results presented in this paper concern investigation of environmental influences to GNNS coordinates on the example of ASG-EUPOS network. The problem of the impact of environmental effects is crucial for observing gravity. Satellite systems are not as susceptible to changes in local hydrology or atmospheric effects, although significant influences are clearly visible in the change of coordinates. The authors analyzed daily and sub-daily solutions (geocentric coordinates) in the context of different disturbances to eliminate sites suffering from poor quality for further researches (e.g. data from the most reliable ASG-EUPOS stations will be used for investigating the correlation of their movements with the lithosphere deformations on territory of Poland). There are many doubts regarding proper antennas' placement – as they are mostly placed on the roofs, there were questions if data from these sites can be used for scientific purposes like velocity estimations or geodynamical researches. Analysis of daily solutions was supposed to prove that the majority of Polish sites give fully valuable data. Some factors that may cause a precision decreasing can be avoided or eliminated in the future. Taking into consideration that GLONASS will be soon fully operational and it will be an alternative for commonly used GPS, the authors made separate elaboration of GPS and GLONASS data. Usage of two different satellite systems holds the potential to increase of solutions' reliability and eliminate errors that could be possibly related to the specific satellite system. Base on time series of coordinates residual values, systematic errors that could prove geophysical and geodynamical influence on GNSS measurements were investigated. In this elaboration only post-processing observations were taken into account, but the monitoring of the network in the near real-time by means of coordinates' stability is under development.

KEYWORDS: GPS, GLONASS, ASG-EUPOS, environmental influences

INTRODUCTION

Nowadays, permanent GNSS (Global Navigation Satellite Systems) networks like IGS (International GNSS Service) or EPN (EUREF Permanent Network) play the role of a fourth GNSS segment, beside space, control and users segments. Through processing of the data according to the newest achievable standards, precise and reliable solutions (geocentric coordinates of stations) are obtained, which realize particular reference system. EPN consists of about 200 stations evenly distributed over Europe and tightly connected to the European part of the Eurasian plate. They realize the ETRS89 (European Terrestrial Reference System).

ASG-EUPOS is the Polish multifunctional system of precise positioning consisting of 120 GNSS reference stations (98 on Polish territory and 22 foreign sites in June 2010). 14 stations are equipped with GPS (Global Positioning System) and GLONASS (Globalnaja Nawigacionnaja Sputnikowaja Sistiema) module.

Although some stations gather data since 2006 (or even longer – EPN involved stations), the system became operational in June 2008. Besides being an IGS and EPN densification, it delivers real time and post-processing services for GNSS users (differential technology). So the proper stations' activity is monitored in order to find any factors that could decrease it's reliability. The Polish Head Office of Geodesy and Cartography (HOGC) manages the system, while CAG (Centre of Applied Geomatics, Military University of Technology) processes the data and analyses solutions to ensure additional control and monitoring of the system. ASG-EUPOS is important for the ETRF (European Terrestrial Reference Frame) maintenance (i.e. ETRS89 realization) and it will become the main national geodetic frame in the near future.

This research is a continuation of previous investigations concerning ASG-EUPOS, described in the papers by Figurski et al.(2009) and Araszkiewicz et al. (2009). Researches made for mountainous areas were performed through common elaboration of data from Polish, Czech, Slovak and German sites (Figurski et al., 2010; Araszkiewicz et al., 2010). These publications dealt with the investigations of reference sites' coordinates stability in short- (diurnal and sub-diurnal) and long-period as well. They presented the preliminary results of the analysis of stability of the Polish national reference positioning system and drew an attention to the need for continuous monitoring of these changes and to eliminate the effects of periodicity or linear trends in coordinates as a result of interactions of a geophysical character.

The problem of the impact of environmental effects is crucial for observing gravity. The importance of this problem was underlined by the International Association of Geodesy (IAG), which has created the Working Group No 7 "Study Group on Environmental Effects in Tidal Records", acting within the Sub-commission 3.1: Earth Tides (Kroner and Jentzsch, 2005).

Satellite systems are not as susceptible to changes in local hydrology or atmospheric effects, although significant influences are clearly visible in the change of coordinates (Ray et al., 2008). Very important in the context of the upcoming solar maximum activity is research on the impact of ionospheric disturbances on the accuracy of GNSS positioning, affected by the components of higher-order ionospheric refraction (XiFeng et al., 2010). The introduction of higher order corrections increases the reliability of solutions, especially for global studies (Petrie et al., 2010). In the case of local and regional networks, this effect is minor, and his influence is noticeable only in the vicinity of maxima of solar activity. As in the case of the ionosphere a significant impact on the results of satellite data processing also has the troposphere. Atmospheric changes affect the satellite observations by introducing effects that need to be able to distinguish (Tregoring and Watson, 2009). Modeling the atmosphere for studies of satellite plays an important role (Scheuler et al., 2001), and therefore the numerical weather prediction models are frequently used (Guerova et al., 2003; Andrei and Chen, 2008; Ghoddousi-Fard et al., 2009). This is even more essential in the method of precise point positioning (PPP), where the implementation of accurate models, including ionosphere and troposphere is crucial (Hobiger et al., 2008).

Another problem in the analysis of satellite observations are all kinds of discontinuities occurring in the solutions, which can only be removed by re-processing of archival observations. This approach eliminates systematic errors resulting from changes of reference frame, used models, computational algorithms and periodic signals. Codification of computational methods and models, even for archival observation allows for significantly better results in terms such as satellite ephemeris (Steigenberger et al., 2006). From the other side the continuous increase in the total number of observation and processing of observations from various satellite systems increases the processing time and thus require the use of high performance computer clusters (Bruyninx, 2007). The solution of this problem can be the concept of reduction of analyzed parameters proposed in the paper by (Ge et al., 2006).

DATA PROCESSING

Investigations described in this paper concern two types of approaches: daily and sub-daily solutions obtained from data gathered from 2008 to 2010 (red dots in Fig. 1) or from 2009 to 2010 (yellow).

Processing was made using Bernese 5.0 software (Beutler et al., 2006), the strategy is compatible with this of EPN as used by Local Analysis Centres (Figurski et al., 2009). As the result, time series of daily and sub-daily solutions (geocentric coordinates) were determined. Daily solutions are expressed in ETRF2000(R05). They are available continuously on CAG's webpage (www.cgs.wat.edu.pl).

ENVIRONMENTAL INFLUENCES

Residual time series of solutions' were analyzed to test the models that were used and to find error sources that could possibly affect solutions by decreasing their reliability (in the terms of precision). There are many doubts regarding proper antennas' placement – as they are mostly placed on the roofs, there were questions if data from these sites can be used for scientific purposes like velocity estimations or geodynamical researches. Analysis of daily solutions was supposed to prove that the majority of Polish sites give fully valuable data. Some factors that may cause a precision decreasing can be avoided or eliminated in the future.

Time series of daily solutions were analyzed in the context of long-term oscillations, seasonal disturbances and significant linear trends that could be assigned rather to buildings' than geodynamic movements. Periodic oscillations that can be noticed on several sites are probably related to the thermal influence. Since such sites are distributed evenly through the whole country, this effect obviously depends also on antenna placements by comparing time series to meteorological data it was proved that the highest peaks reaching few centimetres occurred during extreme snowfalls. Investigations to answer the question why some sites seem to be 'snow-proof' are going on.

Linear trends that appeared especially in the vertical component time series show settlements of buildings or local influences (hydrology). The authors give here only some hypothesis explaining the observed phenomena.

LINEAR TREND IN HEIGHT

At some stations a very clear linear trend in the height component could be observed although the stations' coordinates are expressed in ETRF. It is important to exclude sites on which antenna displacement is caused by the movement of buildings rather than vertical movement of the local geological

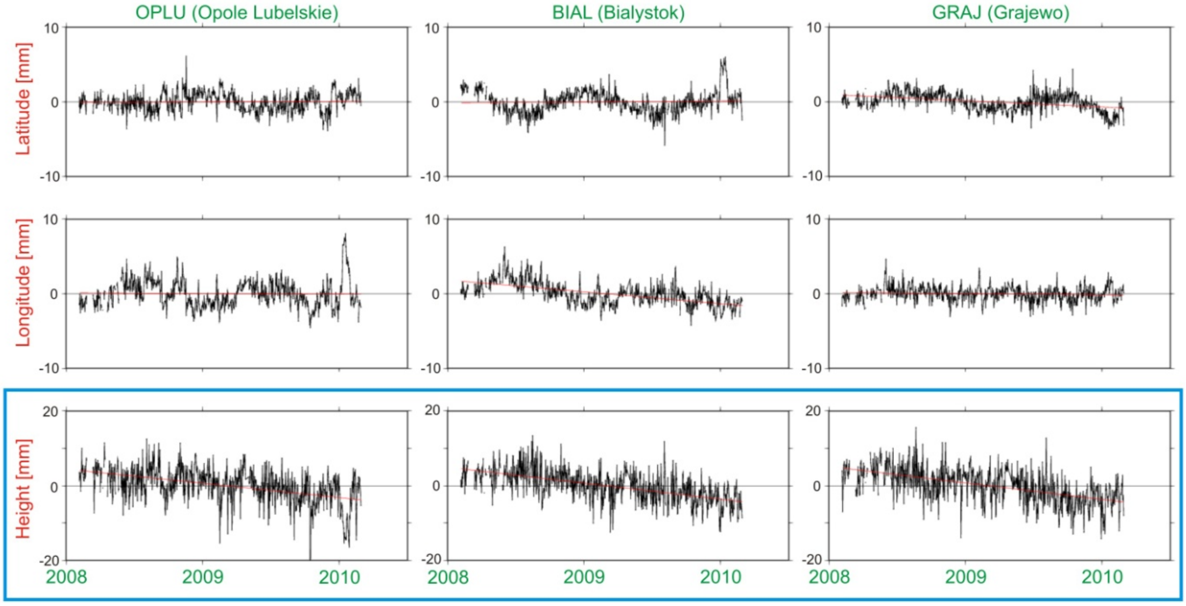

Fig. 2 Linear trend in height on the selected GNSS sites.

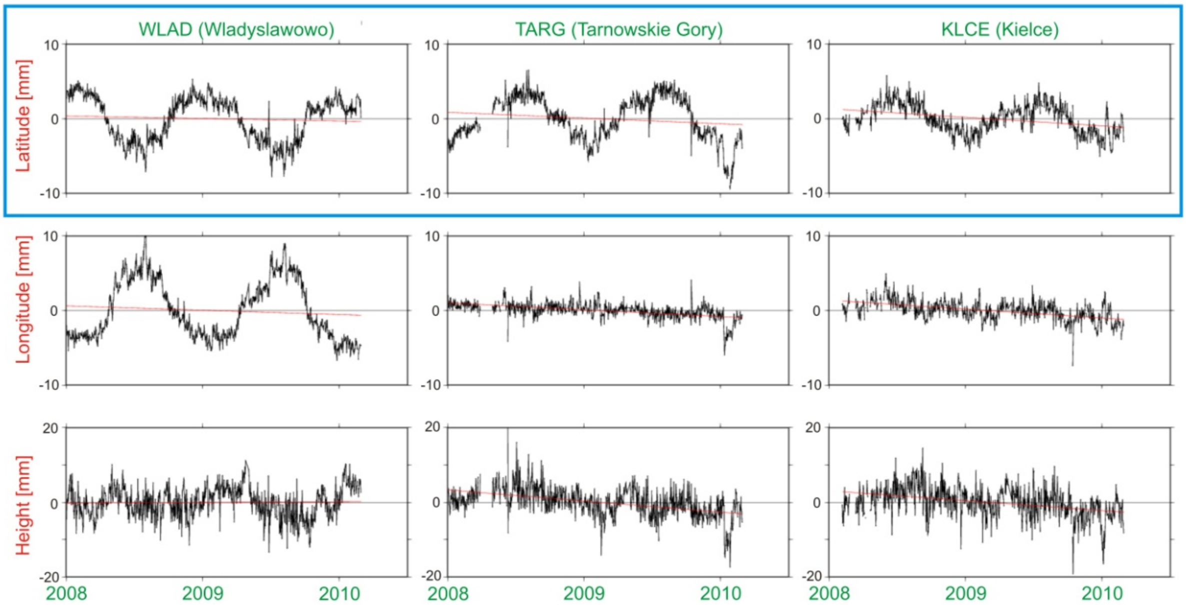

Fig. 3 Annual oscillation in geodetic latitude.

structure. A significant linear trend has been observed on 8 stations and each of them shows a negative (down) sign, and so it reflects rather influences related to the particular location (e.g. local hydrology or buildings' settlement). Comparing solutions from two sites located close to each other, but stabilized differently would constitute a suitable method to separate antenna displacement and vertical movement of Earth's crust as reasons for linear trends in the vertical component. Figure 2 presents solutions from three exemplary stations, where linear trend can be observed. All figures from 2 to 9 present geodetic coordinates time series from 2008 to 2010 which are residuals from the ETRF2000(R05).

Annual oscillations are probably caused by thermal influence. It can be related to building's reaction for temperature changes, but the problem concerns also antennas placed on low concrete pillars. Similar time series can be observed on EPN sites as well. Basing on two years of observations from Polish sites 20 stations with annual trend in latitude and 17 stations with annual trend in longitude were found. Figure 3 presents selected time series with significant annual oscillations in latitude. Station WLAD (Władysławowo) is a special case, because it is situated on a breakwater, so it is obvious that disturbances are caused by thermal and gravitational influence of the Baltic Sea. Examples of time series

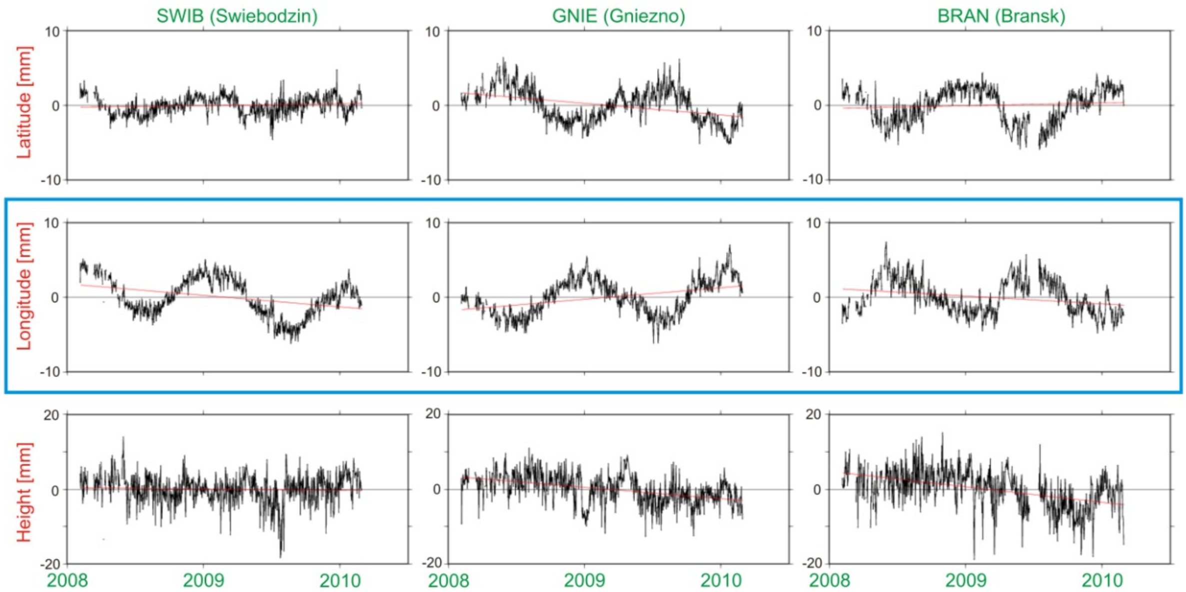

Fig. 4 Annual oscillation in geodetic longitude.

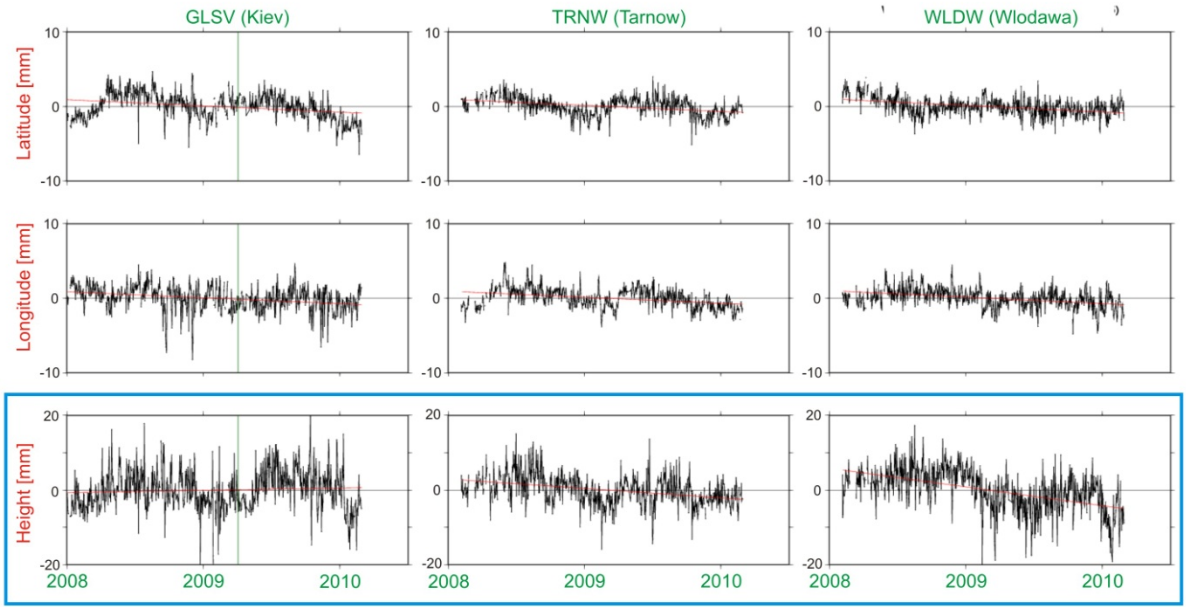

Fig. 5 Annual oscillation in height.

with annual oscillations in longitude are shown in Figure 4. Oscillations do not have impact on average coordinates values obtained from long-term observations (so called 'cumulative solution'), but they can cause decreasing of differential surveys' accuracy.

ANNUAL OSCILLATIONS IN HEIGHT

In total 8 stations with annual trend in height were found. Only two of them have maximums during wintertime (Fig. 6). This could be explained by the fact that on these sites the ground's freeze up (with associated uplift) is larger than the loading effect from the snow cover (down lift).

The main conclusion of time series analysis is that the majority of ASG-EUPOS sites can be used for scientific and practical usage. The quality of data is not diminished by placing antennas on the high constructions or roofs, so solutions from many Polish sites can be applied to geodynamical researches e.g. velocity field determination.

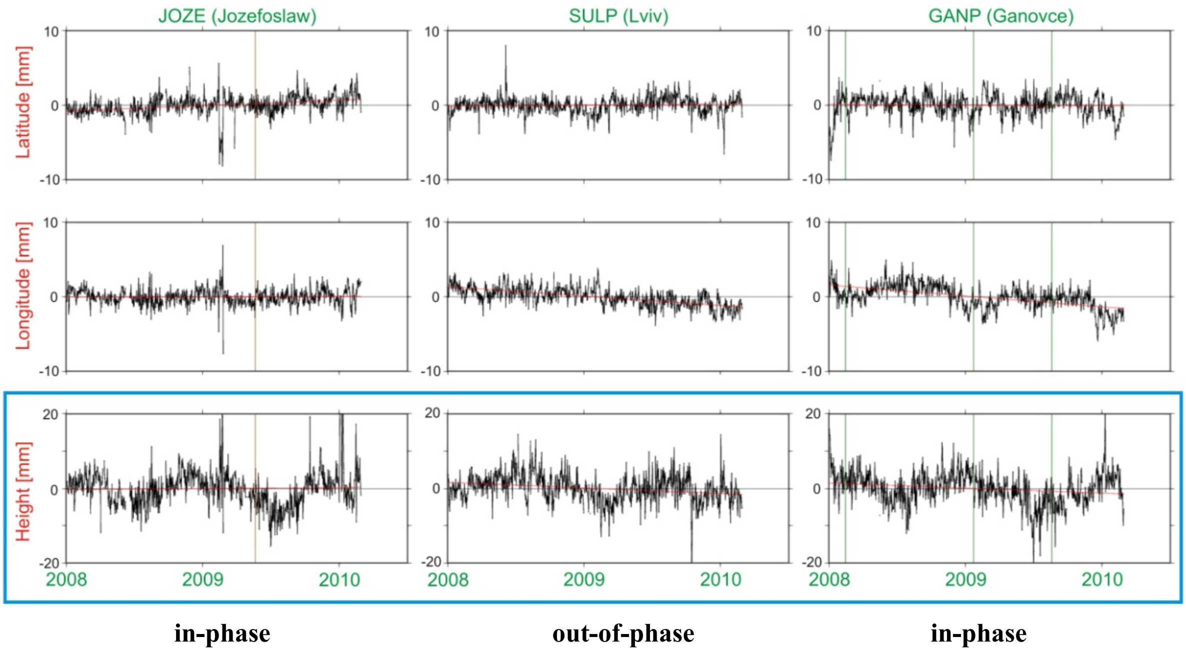

Fig. 6 Different behaviour of GNSS sites during winter- and summer-time.

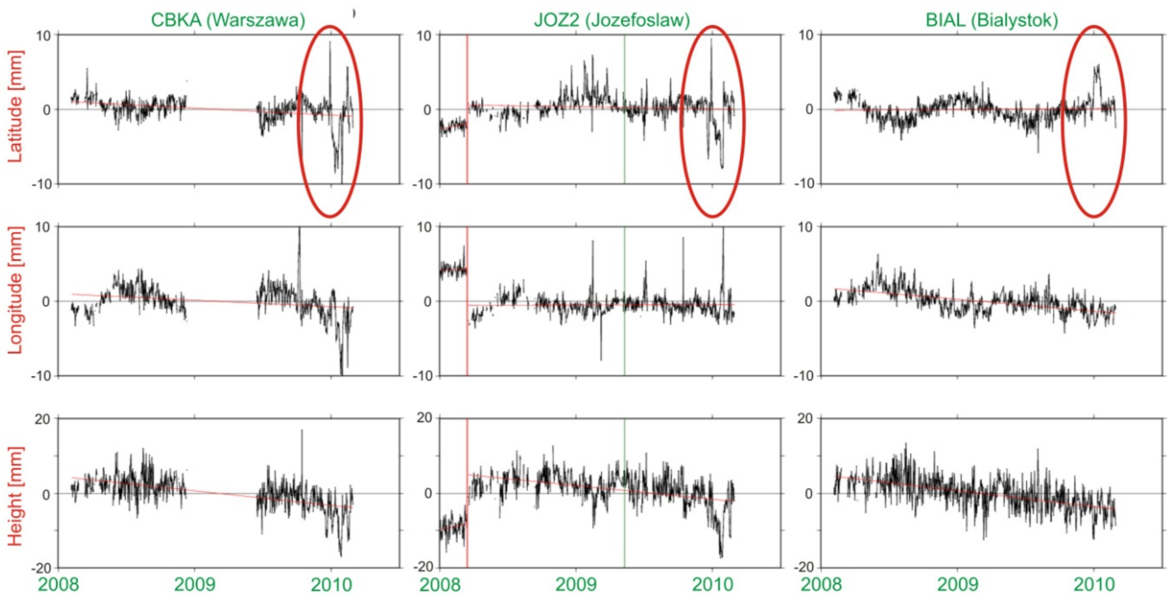

Fig. 7 Seasons-related variations in latitude.

SEASONS-RELATED VARIATIONS IN GEODETIC COORDINATES

The years 2009/10 winter season in Poland was very extreme, there were very low temperatures (below minus 25 Celsius degrees) and very intense snowfalls.

Significant jumps (several millimetres) in time series on many permanent sites can be noticed. They were strictly correlated with temperature's variations and extreme snowfalls.

Such state (deviation from the mean value) was kept for few weeks. Its impact on cumulative solution can be ignored (e.g. by excluding particular periods), but at the same time it can decrease reliability of differential surveys made during this period (real time and post-processing services). It is still to be explained whether this phenomena is caused by physical antenna displacements or environment influence to GNSS measurements. The question was raised why some sites seem to be ‘snow-proof’ and

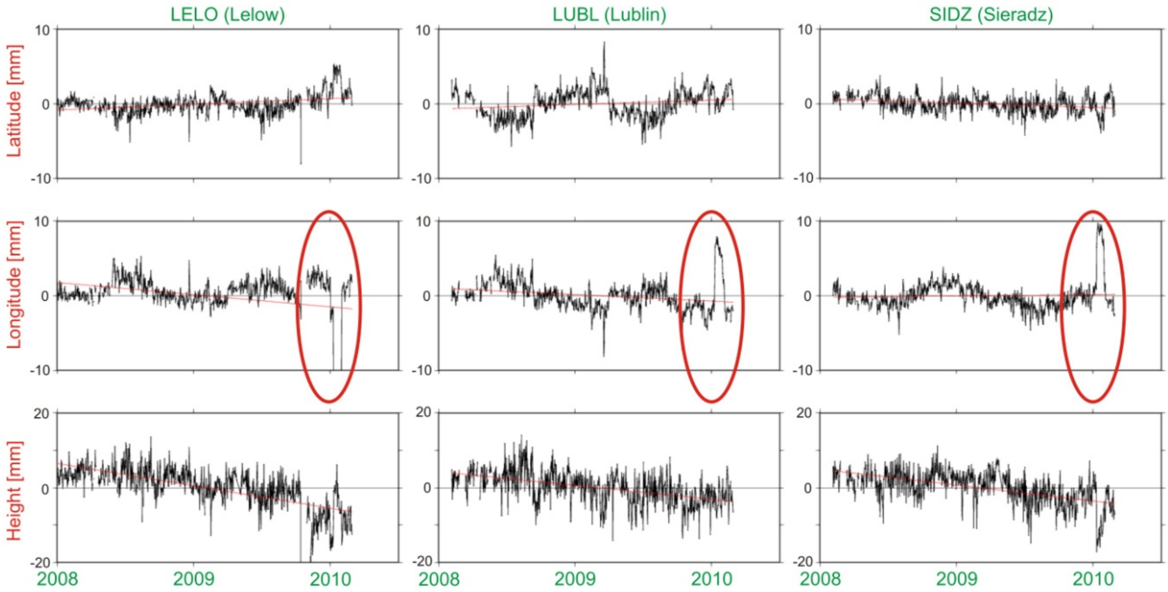

Fig. 8 Seasons-related variations in longitude.

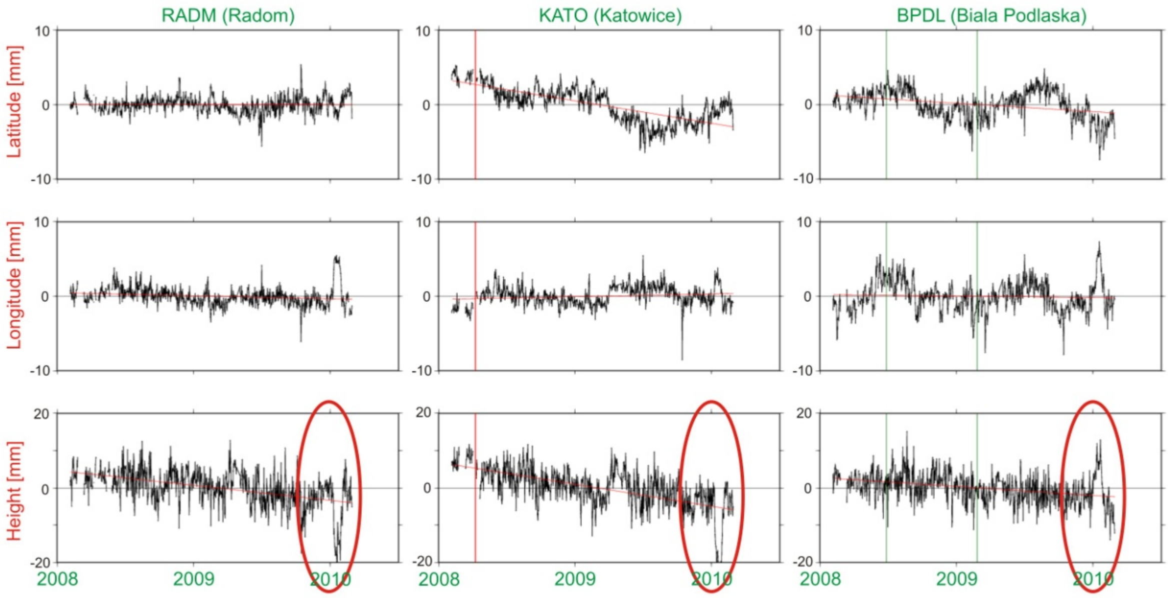

Fig. 9 Seasonal variations in height.

their solutions were stable for the whole winter period. This topic needs further investigation. Figures 7 and 8 presents examples of horizontal time series affected by extreme winter conditions. This problem concerns 16 stations regarding latitude component and 34 stations with significant deviations in longitude time series.

Significant (greater than 1 centimetre) changes in vertical component were noticed on 27 sites. Examples are given in Figure 9. These jumps are related to the different behaviour of antennas' vicinity under influence of external conditions (snow, freeze, local hydrology). On 5 investigated sites a down lift occurred, whereas on 22 – an uplift.

SUB-DIURNAL OSCILLATIONS

The special data processing aimed at investigation of the sub-diurnal site stability has been made. The innovation of the presented study is the usage of 3-hourlasting observational windows, which each of them was moved with a 1 hour step, and thus coordinates with 1-hour resolution were obtained. The adjusted network consisted of 132 GPS sites located in Poland and neighbouring countries (Germany,

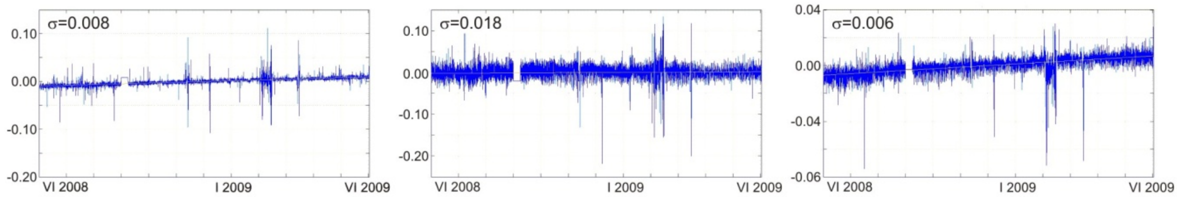

Fig. 10 Hourly NEU (from left to right) coordinates [m] of JOZE EPN site.

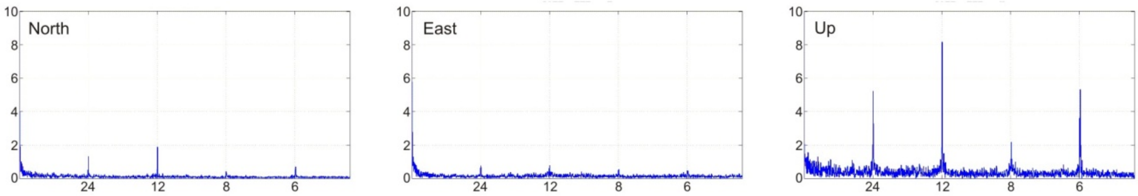

Fig. 11 Oscillations [mm] in NEU of JOZE site (in hours).

Table 1 Maximum amplitudes of oscillations.

	24-hours			12-hours			8-hours		
Site name	**N [mm]**	**E [mm]**	**U [mm]**	**N [mm]**	**E [mm]**	**U [mm]**	**N [mm]**	**E [mm]**	**U [mm]**
RWMZ	4.0	3.4	-	-	7.0	-	-	-	8.3
OSMZ	-	-	10.6	5.0	-	-	2.8	-	-
WLDW	-	-	-	-	-	11.8	-	-	-
DRWP	-	-	-	-	-	-	-	3.0	-

Czech Republic, Slovakia, Ukraine, Belorussia, and Lithuania). 5 stations were assumed as referenced in the adjustment (ONSA, METS, POTS, BOR1 and WTZR), and 24 of them are simultaneously part of the EPN network. The data covered the period from 8.06.2008 to 9.06.2009. The geocentric XYZ coordinates in the ITRF2005 reference frame were determined. For interpretation purposes these coordinates were recalculated to the topocentric North-East-Up coordinate frame. Example of NEU coordinates of JOZE EPN sites is presented in Figure 10.

A Fast Fourier Transform provided information about the frequencies of the site's coordinates. All analyses were performed in the MATLAB® Technical Computing Environment (licence number #350334). In Figure 11 the examples of diurnal, semi-diurnal and 8-hour oscillations of JOZE EPN site are presented. 6-hour oscillation, which comes from 3-hour windowing (Nyquist frequency) applied in the data processing was omitted.

The analysis showed that there is no regularity in the short-period oscillations in the GPS coordinates. Some stations have dominant oscillations in diurnal, some in semi-diurnal frequency bands. Table 1 presents the composition of maximum amplitudes of oscillations.

The spatial distribution of the diurnal and semi-diurnal oscillations is not regular and rather reflects local effects (Fig. 12).

GNSS SOLUTIONS

Currently, many research units work on GPS data usage for geophysical and geodynamical phenomena investigations development. CAG conducts researches of GPS systematic errors influence on precise solutions. GLONASS data processing enables obtaining separate and independent results, which can be compared with the most common GPS solutions. In our investigations analysis of both GNSS systems solutions were made in order to make mutual control of their reliability and systematic instrumental errors elimination.

Common processing of two different satellite systems encounters many difficulties (Habrich et al., 1999). As the most obvious advantage a significant increase (about 70 %) of amount of observation can be given. It allows obtaining higher precision, but also requires more time for calculations. Although even 20 satellites can be observed in the same time, accuracy of solutions is at the same level when GPS and both GPS and GLONASS (named GNSS) determinations are compared. Differences between GNSS and GPS solutions are about 2-4 millimetres. Efficiency of

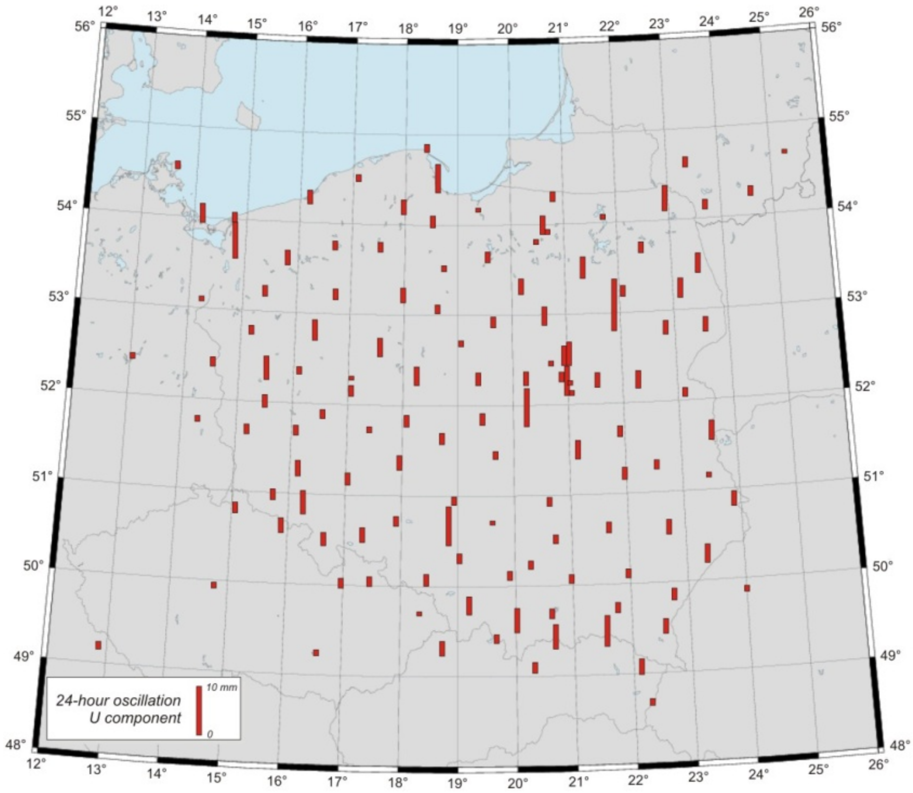

Fig. 12 Spatial distribution of ASG-EUPOS diurnal oscillations in Up component [mm].

calculations can be increased by independent processing of GPS and GLONASS data in two separate processes.

Coordinate precision as obtained from pure GLONASS data analysis suffers from a few disdvantages. The first source of problems is a smaller amount of satellites observed at the same time in comparison with GPS. The other one is a different system of satellite identification in both systems. Regarding the GPS system a CDMA (Code Division Multiple Access) method is used, whereas in GLONASS a FDMA (Frequency Division Multiple Access) method is a most commonly applied technique. Old fashioned two-phases GPS/GLONASS receivers do not precisely reconstruct phase observations and this results in insufficient quality of observation data. In our research such a problem was examined for example in Borowa Góra (BOGI site). Another problem concerning the FDMA method exists for the algorithm for marking the phase ambiguity. Properly working algorithms for GPS observations do not solve the phase ambiguity for the GLONASS system. Proper ambiguity calculations for GLONASS data will be fully correct, if ambiguity algorithms will be adjusted (Habrich et al., 1999). Differences between coordinates with solved ambiguities and real valued ambiguities (ambiguity fix/ambiguity free options) are on the level of few millimetres and do not have major impact on coordinates accuracy decrease.

Another problem that needs further investigations is usage of different PCV (Phase Center Variations) models for GPS and GLONASS. Currently, all GNSS elaborations use PCV for GPS. The first research done so far, proved that PCV antenna models applied independently for GPS and GLONASS systems results in coordinates discrepancies, which vary from 1 to 3 mm. This result should be rigorously examined in order to avoid any future inconsistencies. The problem of antenna phase centre models in GNSS processing was widely described in (Dach et al., 2010) and (Dilssner et al., 2010).

In elaborations where we expect sub-millimeter accuracy the precise ephemerides have to be used. Although GPS system uses WGS84 (World Geodetic System 84) whereas GLONASS uses PZ-90 (Parametry Zemli 1990) reference system, since 2007 ephemerides for these two satellite systems are expressed in current ITRS realization.

Data processing from 14 Polish GNSS sites showed that the majority of coordinate deviations (e.g. jumps or discontinuities) do not depend on the satellite system (Fig. 13).

Usage of both GPS and GLONASS increases the solutions' reliability, but also extends time of processing. With current satellites configuration (21 GLONASS and 30 GPS satellites in operation), solutions obtained using only the Russian system are comparable with the ones from GPS, but they are characterized with higher RMS errors and periodic dispersion. Differences between coordinates from both systems reach a few millimeters. The quality of solutions depends on a the receivers used for gathering the data.

SUMMARY

For more detailed description of seasonal time series disturbances information about the type of buildings (antennas' placement) should be taken into account. Thermal effects can be seen in daily (one-year oscillation) and probably sub-daily (24-hour, 12-hour and 8-hour oscillations) solutions as well. Further investigations will specify whether these sub-daily periodic effects are related to thermal or rather tidal factors (residuals from the tidal model). Seasonal effects can be observed on solutions based on GPS and GLONASS data. GLONASS solutions have slightly higher RMS than GPS ones, because of e.g. lower number of satellites, although common elaboration of data from two independent systems increases the reliability of the results. For proper interpretation full information about environmental effects (atmosphere and local hydrology) have to be monitored and modelled. The national GNSS networks such as Polish ASG-EUPOS give the opportunity to investigate the spatial distributions of deformational-related phenomena, despite its imperfectness in antenna’s fixing (mostly at the high buildings).

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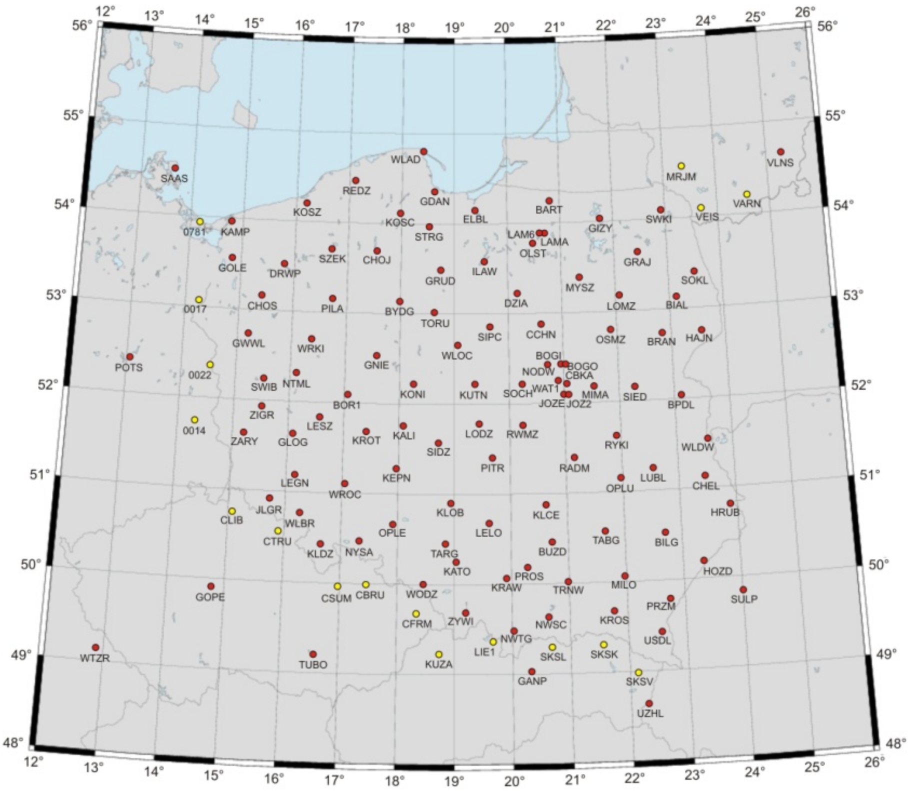

Fig. 1 GNSS network adjusted in the CAG.

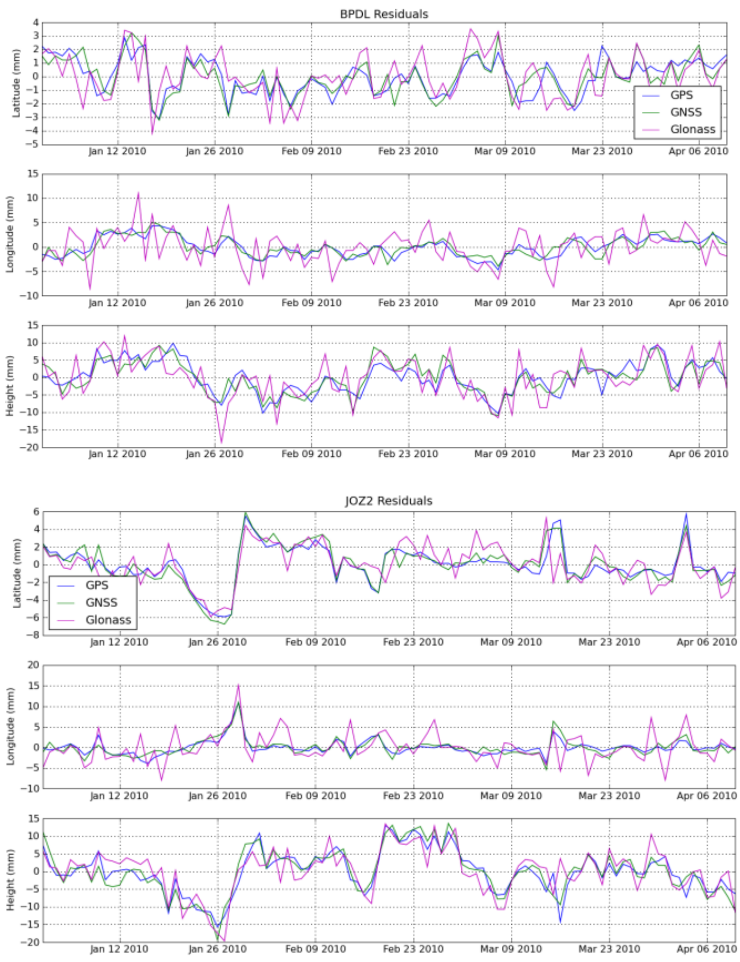

Fig. 13 Comparison of GPS, GLONASS and GNSS solutions for selected ASG-EUPOS sites.