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PERMANENT GPS STATION IN KSIAZ GEODYNAMIC LABORATORY FOR SUPPORTING INVESTIGATIONS OF NEO-TECTONIC MOTIONS IN THE KSIAZ MASSIF

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ABSTRACT
In Autumn 2010 a new permanent GPS station started observations intended to investigate the episodic displacements of rocks in the Książ Massif, where the Geodynamic Laboratory (LG) is situated. These investigations are being made for common interpretation with water-tubes and horizontal pendulums tiltmeters registering large (one order of magnitude greater than the tidal effects) non-periodic geodynamic signals. The studies conducted as up to date excluded instrumental and loading effects as potential reasons of those signals. The construction of water-tube tiltmeters and their measuring principles allowed to state that the strong non-tidal signals have a geodynamic nature. To support investigation of this problem, different analysis of the GPS data are performed in appropriate scales and applying various processing methods. The applied methods refer to selected reference GPS stations in Poland and their neighbors and are aimed at reduction of disturbance effects of geophysical origin such as tectonic activity, post-glacial rebound, anthropogenic effects, etc.

KEYWORDS: GPS measurements, station coordinates time series, recent tectonic movements, crustal movements, tidal and non-tidal signals.

1. INTRODUCTION

Installation in 1974 of two horizontal quartz pendulums working in perpendicular azimuths must be recognized as the beginning of geodynamic investigations in Książ. In 2003 the Geodynamic Laboratory (LG) in Ksiaz was enriched with new instruments – two water tubes of very high measurement accuracy and capacity of reducing of instrumental drift. The horizontal pendulums as well as water-tubes register extremely strong signals, which can be explained by complex motions of foundation of tectonic origin (Kaczorowski and Wojewoda, 2011). This phenomenon occurred in irregular epochs with time of duration not exceeding teens of days (Kaczorowski, 2007). In the period of 2004-2007 the water-tubes registered five separate epochs in which there occurred strong non-tidal signals with maximum amplitude 300 mas (one order greater than the tidal signals) (Kaczorowski, 2007). Similar phenomena were recognized in multi-year observational series (1974-2002) as measured by quartz pendulums (Chojnicki and Blum, 1996). In time of these phenomena the pendulums lost their balance and after several days of phenomena duration stuck to the limiters. The executed research excluded instrumental effects, loading effects, hydrological effects, as well as the meteorological ones, as the source of the observed signals (Kaczorowski, 2009b). Time characteristics of strong non-periodical signals and their resultant azimuth indicate the relationship with tectonic motions in the Sudetian region (Kaczorowski, 2009a). At the time of phenomena duration there occurred associated tiltings of foundation with horizontal and vertical displacements of the crust in the Książ Massif. Only the tiltings of foundation affect the horizontal pendulums, whereas the water-tubes are subject to tiltings of foundation and vertical motions of foundation under the tubes of instruments. In consideration of necessity of interpretation of locally observed effects, a decision was taken on construction of a permanent GPS KSIA station which will be necessary to apply in several research tasks. The main objective presented in the present work is to obtain support from the GPS technique in research on strong non-periodical signals of tectonic origin as registered in the Książ LG by pendulums and water-tube tiltmeters (Chojnicki, 2000; Kaczorowski, 2009b). The GPS station will make it possible to monitor the displacements of the Książ Massif, supporting the geodynamic interpretation of strong signals registered by tiltmeters. Application of the GPS technique in geodynamic research was made possible owing to a proper location of the GPS antenna in Książ ensures a lasting binding with the Książ Massif and the LG instrumentation inside it. Additional knowledge about

the neotectonic activity in the region will be obtained from the interferometric extensometer which will measure relative variations of the distances inside the rocky environment of Książ Massif. The results of analyses of GPS measurements will be applied also in common investigations of relative deformations of the local Earth crust with measurements of relative variations of the distances by the interferometric extensometer. Location in one site of interferometric extensometer, and GPS station will make it possible to execute comparative research of tidal deformations registered on local extensometric base in the LG with higher resolution of 10^{-10} order with GPS measurements executed on the base of hundreds of kilometers length. The GPS station will provide us with information on vertical motions in the Książ Massif which are connected with secular gravity variations. Research on the secular variations of absolute gravity have been executed on the measurement side in the Książ LG since the year 2007. Using the GPS method, the parameters of proper motions are determined, together with the directions and velocity of displacements and, which is of particular importance, the relative changes of vector lengths between the Ksiaz GPS Station and other referential GPS stations. This was one of the reasons for choosing the method of elaboration of GPS observations in Książ as connected to the reference networks of IGS, EPN and EUPOS, as well as to a choice of some other stations and their networks in Poland and her neighbors.

2. PERMANENT GPS STATION (KSIA)

The idea of establishing of GPS station in the LG in Książ was born in 2001. In June 2006 a test installation of GPS receiver on the roof of the laboratory building was executed. The objective of the executed tests was selection of measuring point location which would ensure optimal conditions for performing of the GPS observations supporting research program of the LG in Książ. The GPS measurement set consisting of 4000SSi Trimble receiver and L1/L2 Trimble Compact Geodetic antenna (TRM22020.00+GP) was used for the tests. The test results were encouraging. A strong, continuous and electromagnetic noise-free satellite signal was registered. Activation of the GPS station in the LG in Książ was made possible owing to the founds obtained from the scientific research project of the Ministry of Scientific Research and Information Technology (N N526 159538) entitled: "Research of movements of the Książ Geodynamic Laboratory using GPS technique for implementing in common interpretation with registered geodynamic signals", which was started in April 2010.

2.1. ESTABLISHMENT OF THE GPS STATION

Before taking the final decision concerning selection of placement of permanent GPS station antenna the measurements from which are dedicated to the interpretation of neotectonic phenomena, it was necessary to consider several requirements and conditions of technical and formal character. The approved solutions ensure stable mechanical connection of the GPS antenna with the bedrock of Książ Massif in a long range of time. Accepted location of the GPS antenna as well as the system of its fastening ensure transmission of tectonic movements of the massif onto the antenna movements. The selection of antenna location directly above the LG measurement system enabled us to get the GPS measurements system maximally close to the underground laboratory instrumentation. Geometrical closeness of the two systems (ca 80 m in all, in this 50 m in vertical direction) increases the chance that the GPS antenna and the underground measurement system are situated exactly at the same block of the massif, and therefore are subject to similar tectonic motions. This is one of fundamental assumptions ensuring correctness of interpretation of the GPS observations and studies of strong non-tidal, neotectonic signals to be performed in the LG.

At the same time location of the GPS antenna must ensure a possibly broadly open horizon both in azimuth and vertical angle. The area surrounding the station should be free of any electromagnetic noises which could damp the radio signals of the GPS satellites. In order to achieve this a series of control measurements of electromagnetic environment purity was performed giving a positive result around the intended location of the GPS antenna. In the laboratory building attics an entrance platform was performed and a low reinforced concrete pillar was built permanently mechanically bound to the structure of stable and massive ventilation chimney of the laboratory building (Fig. 1). The chimney foundation is directly based on the rocky outcrops of the Książ massif. The below figures present location of the GPS station in relation to the castle building, the horizontal openness as well as location of the GPS antenna in relation to the laboratory instrumentation in the LG underground (Fig. 2 and Fig. 3).

For servicing the GPS station in Książ a geodetic GPS set satisfying the IGS/EPN network standards was used, the GPS set being a property of the SRC, and consisting of SNR-8000 Turbo Rogue receiver together with Trimble GPS Dorne-Margolin Choke-Ring antenna (TRM29659.00 NONE). In July 2011 the GPS station was additionally equipped with a set of meteorological sensors for registering (in 10 min intervals) the mean values of temperature, relative humidity and pressure in the GPS antenna surroundings. The GPS unit work continuity is ensured by the UPS module of large capacity. The above components are included into the LAN network and controlled through the Internet. Since Autumn 2010, after performance of test measurement series, the GPS station started a regular continuous registration of observation data (2010:DOY316). Since that moment the GPS station in Książ has been

Fig. 1 GPS antenna (Trimble DM Choke-Ring (TRM29659.00 NONE) of KSIA station, mounted on the roof of the Książ Geodynamic Laboratory building.

Fig. 2 GPS antenna mounted on Książ Geodynamic Laboratory building.

working without defects registering all the diurnal sessions. The observation files are subject to conversion to the Compact RINEX (30 sec.) format together with testing of their quality using the TEQC program. The test results show good quality of observation. Their only drawback is a smaller number of channels in the applied receiver which results in registering of only ca 85-92 % (for 10º-15º elevation angles) for all theoretically accessible observations. The data files will be generally accessible inter al. on the Internet site of LG in Książ (in construction).

2.2. GPS DATA PROCESSING

The scientific tasks intended for the GPS station in Książ require application of such methods of data elaboration which will guarantee obtainment of the highest accuracy of determination of station coordinates. In consideration of differences among the tasks, it is necessary to slightly modify the general method of GPS data processing, respecting the requirements of a given scientific problem.

In the present work three independent processes of the GPS data elaboration were applied, basing on which three sets of time series of GPS station coordinates are constructed, one for each separate scientific task.

Common assumptions were established for all scientific tasks.

- In order to determine the real motions of the GPS station in Książ (i.e. linear trend, annual component, non-seasonal and non-periodical variations) with satisfactorily high accuracy, it was accepted that a minimum 3-4 years long observation interval is necessary;
- This observation interval is also necessary because of lack of seasonality and periodicity of occurrence of very strong non-tidal signals in time series from water-tubes and horizontal pendulum tiltmeters;
- The chosen reference stations must satisfy the highest accuracy in determination of their coefficients as well as in determination of time series;
- Both reference stations and the Książ GPS station should be based on separate geologic/tectonic structures, and the reference stations ought to have long and stable time series of observations which can be a base for precise determination of velocity vectors of these stations;
- The chosen reference points must be situated at suitable distances in relation to the KSIA station and in azimuths which will satisfy the optimal possibility of tectonic phenomena modeling with consideration of the most probable directions of displacements;
- The reference frame in which all types of solutions are implemented is defined by a reference frame of generally accessible precise orbits of GPS satellites and global parameters which are coherent with them (so called 'IGS combined solution');
- In the first year of work of the GPS station in Książ (in the epoch of 2011:DOY106/107) there was a replacement of reference frame from 'IGS05', as based on GPS data elaboration until the epoch of 2006.0 as well as on the relative models of antennas for the new 'IGS08' reference frame as based on longer observation series, for implementation of which the absolute models of antennas were used for the first time. Figure 5 shows influence of changes in antenna modeling method on the coordinates determination;
- All variants of data elaboration are executed applying the Bernese GPS Software Ver. 5.0 (Dach et al., 2007), "Release 11-May-2011". It the beginning of year 2012 a networks reprocessing is planned, after edition of program upgrade for 5.2 version, which will include a lot of processing improvements and model updates, consisted with the newest IERS Conventions 2010 (Petit et al., 2010);
- The parameters of algorithms and models applied in elaborations are compatible with IERS international conventions (McCarthy et al., 2004), (Petit et al., 2010) in force and coherent with elaboration strategies as applied in IGS and EPN services;
- The effects which were not implemented in the packets of GPS observations elaborations e.g. atmospheric loading effects will be considered in analyses at the stage of time series construction (in accordance with IERS recommendations).

Elaborations of GPS data are executed with help of two conceptually different methods, 'Precise Point Positioning' (PPP) and 'Double Differences' (DD). In order to minimize possible impact of software applied for elaboration of GPS observations on determined stations coordinates (Habrich, 2004), (Kierulf et al., 2008), the elaborations using the Bernese GPS Software with PPP method will be compared with determinations of PPP (CSRS, Canada) service, whereas elaborations with DD method will be compared with solutions obtained from GAMIT/GLOBK packet. PPP solutions in which there are no connections applied to the ground reference stations will make it possible to evaluate the influence of network structure used in the DD method for possible deformations of determined coordinates of KSIA station. In the differential method (DD), the proper motions of the Książ Massif are determined on the base on network solutions on the regional scale, as well as more locally, where references are related to the nearest GPS stations of EUPOS network i.e. ASG-EUPOS in the Sudeten and Lower Silesia regions as well as Czech border GPS stations (CZEPOS) and German stations (SAPOS). Moreover, for interpretation purposes, there are monitored and analyzed

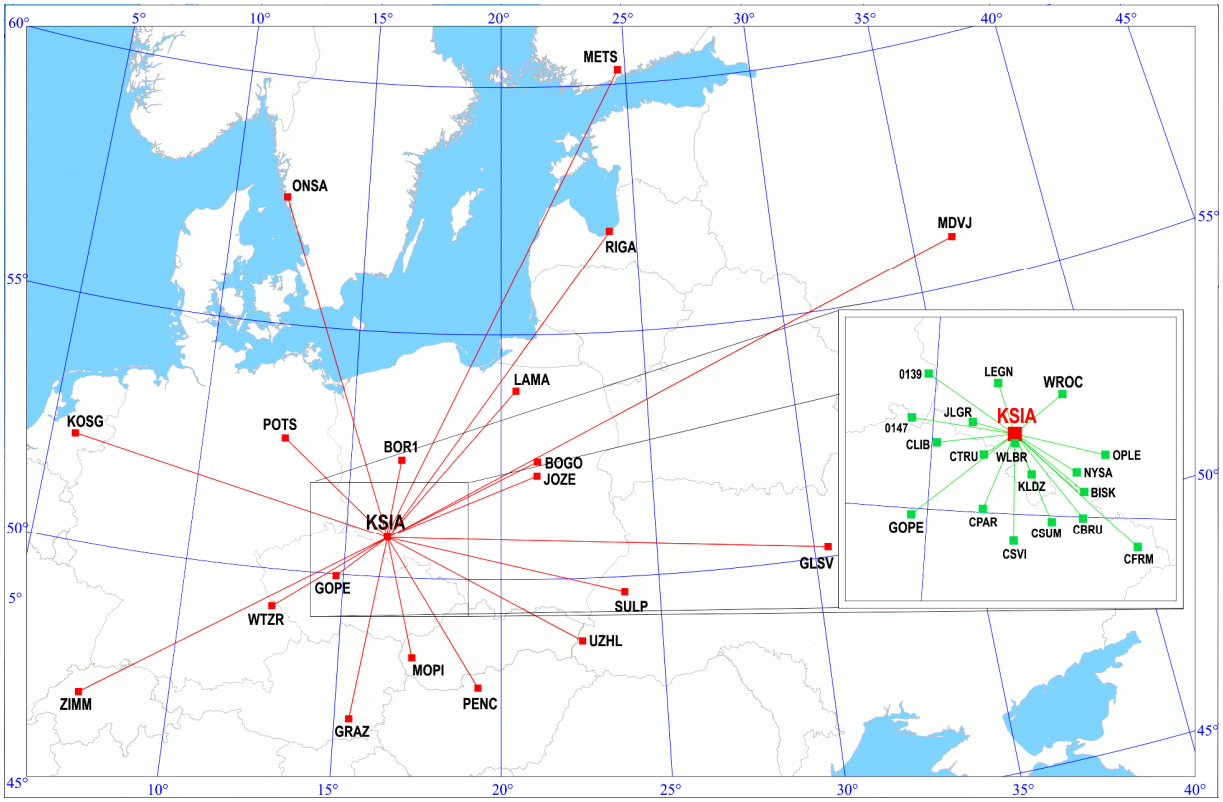

Fig. 4 IGS/EPN stations selected for regional network and EUPOS stations for local network used in Double Difference (DD) method.

the time series of baselines lengths between the stations situated at opposite azimuths in relation to the KSIA station. Before initiation of elaboration of local network, for EUPOS stations it is necessary to determine its velocities in the ITRF reference frame, respecting the whole observation period, i.e. from the middle of year 2008. Selected regional and local networks for proper determination of KSIA station movements are presented in Figure 4. In Figure 5 the preliminary time series of PPP method as generated in order to evaluate and verify the determinations of velocity vectors of EUPOS stations in the global ITRF reference frame are presented.

For evaluation of initial results of elaborations using the PPP method, the catalogue values of velocity vectors as determined in the ITRF2005 and ITRF2008 together with horizontal components of velocities of selected EUPOS stations determined in the ITRF2005 from the period of 2008-2010 (Bogusz et al., 2012) are used. For the station of EUPOS network located nearest to the Książ GPS station (WLBR, situated at the distance of 8.4 km south from the KSIA station), the difference of horizontal components of velocity vector (KSIAZ from PPP, WLBR from DD ASG-EUPOS solutions) amounted to –0.1 mm per year in Latitude (B) and to 1.1 mm per year in Longitude (L) component. However, it should be noticed that the PPP series of solutions are at the present time very short (only 1.23 years for KSIA station and 1.66 years of public data available on the website for ASG-EUPOS stations) and contain till-now unreduced effects, among others a not completely eliminated of jumping effects of change of reference frame as well as seasonal variations, which have essential impact on evaluation of linear trend and velocity vector of Książ GPS station from thus short observation series.

3. CONCLUSION

The results of evaluation of observations quality in the KSIA GPS station together with the very first solutions of time sequences of coordinates of the PPP method presented themselves as promising, even though they are at this moment too short to be properly analyzed. At the present moment several elaborations of data from water-tubes and horizontal pendulums from the period of 2007-2011 are being finished as well as the network variants of elaborations for the first 15 months of observations from the KSIA GPS station. These elaborations will provide data for the common analyses of results and first attempts of geodynamic interpretations. The initial evaluation of displacement trends of the stations being determined (KSIA GPS station and neighboring stations of ASG EUPOS network) is difficult because of too short measurement period and executed replacement of the ITRF reference frame. In the time sequences of the stations coordinates it can be

distinctly seen that for some of the stations the replacement of IGS05 reference frame for the newest realizations IGS08 produces greater differences than for the remaining stations. For the KSIA station, on which the GPS antenna Dorne-Margolin Choke-Ring without the snow cover is installed (once a typical reference antenna for the relative models of antennas), the jumps in the time sequences for the epoch of reference frame replacement are essentially smaller (mainly in vertical component) as compared with the ASG EUPOS stations working with the Trimble NetRS receivers and the Trimble Zephyr Geodetic antennas with radomes (TRM41249.00 TZGD). Some minor changes can be noticed for the former stations also in the horizontal components, and in Latitude component in particular. Doubtless their source is the fact of replacement of the antenna models of the receivers from the relative for the absolute models. The appropriate correction of this effect is scheduled to take place only after generation of time sequences from much longer time intervals. The results of elaboration of the GPS station observation series confirm appropriateness of the GPS station location in Książ, correctness of the antenna system fastening, and correctness of the mechanical bind of the antenna, which guarantees transmission of the Książ Massif's motions onto the antenna. The following works will be published in order to gathering and elaborations of observations series.

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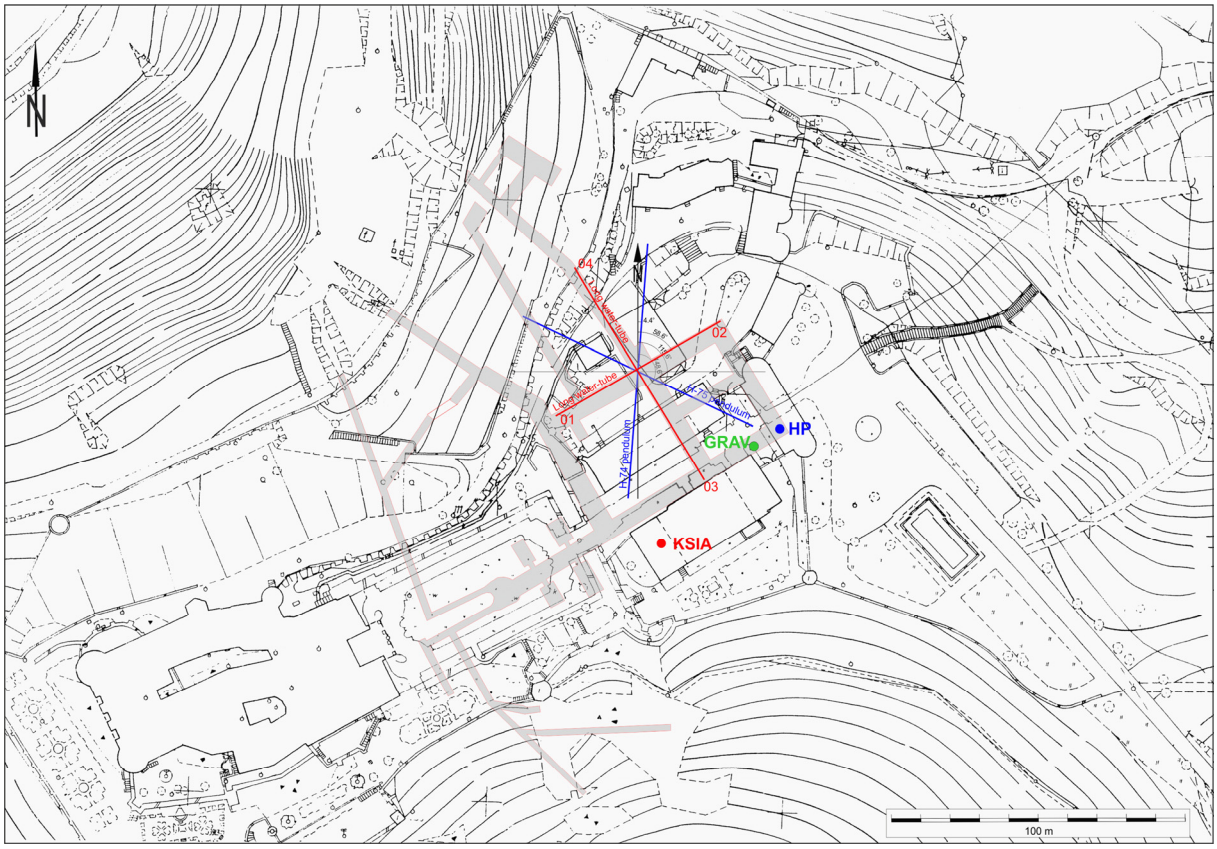

Fig. 3 Relative location of GPS antenna (KSIA), water-tube tilt-meters (red lines), gravity measurements site (GRAV) and horizontal pendulums (HP) (blue lines mark azimuths of measurements of pendulums in relation to water-tube).

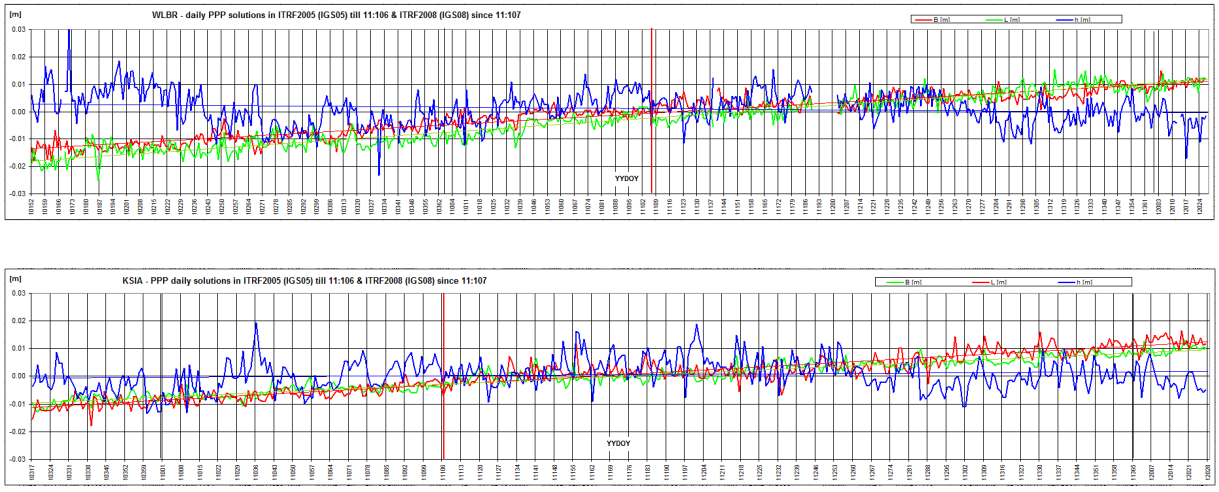

Fig. 5 Examples of time series of WLBR (ASG-EUPOS station) and of the new KSIA GPS stations from preliminary PPP daily solutions. Red vertical lines indicate the moment date of the reference frame changing (IGS05 > IGS08). In these graphs jumps have been partially removed to better determine linear trends in each component.