National Report of Poland to EUREF 2010

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1. Introduction

Since 2008 the main geodetic activities at the national level in Poland concentrated on maintenance of the national gravity control, gravity survey for geodynamic research, continuing operational work of permanent IGS/EPN permanent GNSS stations, conducting GPS data processing on the regular basis at the WUT and MUT Local Analysis Centres, activity within the EUREF-IP Project, works towards monitoring troposphere, monitoring and modelling ionosphere, status of the ASG-EUPOS network in Poland, further research and computational work on a centimetre quasigeoid model in Poland, activity within Galileo project, monitoring of Earth tides and non-tidal gravity variations, activity in satellite laser ranging, and in geodynamics.

2. Maintenance of the national gravity control and gravity survey for geodynamic research

The modernization on the Polish zero-order absolute gravity control started in 2006 as an effort of the joint team of the Institute of Geodesy and Cartography, Warsaw, and the Warsaw University of Technology (Kryński and Rogowski, 2009) was continued in 2009. Works on the Vertical Gravimetric Calibration Baseline in Tatra Mountains that is an extension of the Central Gravimetric Calibration Baseline in Poland were completed (Sas et al., 2009).

Quasi-permanent absolute measurements of gravity have been carried out with the use of FG5-230 gravimeter in the WUT Astrogeodetic Observatory in Jozefoslaw since 2005 (Fig. 1).

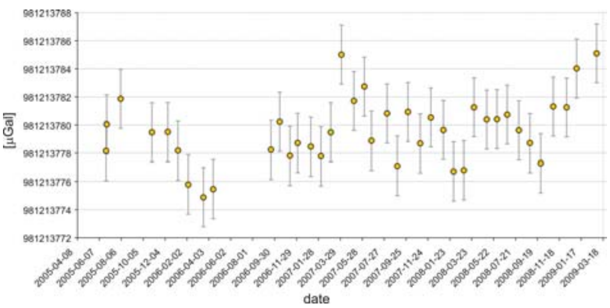

Fig. 1. Results of absolute gravity measurements with FG5-230 at Jozefoslaw (100 cm height)

Till 2009 more than forty observation sessions with the FG5-230 at Jozefoslaw were completed. Also tidal gravity data were recorded at the Observatory since 2002 with LCR ET-26 gravimeter. Both gravimeters, the absolute and the relative one, in connection with JOZE permanent GNSS station provide a unique data for the investigations the geodynamic and geophysical phenomena on a regional scale of Poland (Barlik et al., 2009a, 2009b).

Since September 2008 the Institute of Geodesy and Cartography uses its absolute ballistic A10-020 portable gravimeter (Krynski and Rogowski, 2009). A series of absolute gravity measurements at the gravimetric laboratory of the Borowa Gora Geodetic-Geophysical Observatory (Fig. 2) shows high quality of A10 data. It also indicates its potentiality for monitoring non-tidal gravity variations (Krynski, 2009; Krynski and Roguski, 2009).

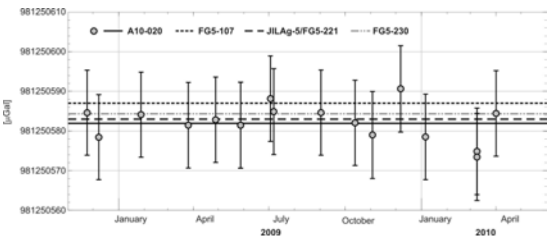

Fig. 2. Results of absolute gravity measurements with A10-020 at Borowa Gora

The absolute gravimeter A10-020 has also been successfully tested for field measurements with the use of the mobile laboratory for precise absolute gravity survey (Krynski and Sekowski, 2010). In August 2009 as many as 19 stations of the Finnish gravity network were surveyed with the A10-20 gravimeter (Mäkinen et al., 2010).

Both Polish absolute gravimeters, i.e. FG5-230 and A10-020 took a part in the international calibration campaign ICAG 2009 in the BIPM in Sèvres. The results of the comparison are being processed; they will be published in 2010 in Metrologia.

3. Participation in IGS/EPN permanent GNSS networks

3.1. Operational work of permanent IGS/EPN stations

Permanent IGS and EUREF Permanent Network (EPN) GNSS stations operate in Poland since 1993.

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Recently 18 permanent GNSS stations, i.e. Biala Podlaska (BPDL), Borowa Gora (BOGO, BOGI), Borowiec (BOR1), Bydgoszcz (BYDG), Gorzow Wielkopolski (GWWL), Jozefoslaw (JOZE, JOZ2), Krakow (KRAW, KRA1), Lamkowko (LAMA), Lodz (LODZ), Katowice (KATO), Redzikowo REDZ (Suwalki (SWKI), Ustrzyki Dolne (USDL), Wroclaw (WROC) and Zywiec (ZYWI) (Fig. 3) operate in Poland within the EUREF program.

The stations BOGI, BOR1, JOZE, JOZ2, LAMA and WROC operate also within the IGS network (http://www.epncb.oma.be/_trackingnetwork/stations.php).

Fig. 3. EPN/IGS permanent GNSS stations in Poland (2010)

3.2. Data processing at Local Analysis Centre at WUT

Warsaw University of Technology has been operating the WUT EPN Local Analysis Centre since 1996.
The EPN subnetwork being analysed by the WUT LAC which consists of 74 stations (December 2009) located mainly in Central Europe (Fig. 4). Four new stations were added to the network in 2009.

The WUT LAC contributes to EUREF with weekly and daily results based on IGS final products, and with rapid daily coordinate solution based on IGS rapid products. The development of software providing rapid daily solutions was completed at WUT in December 2009, but official submission of the solutions to EPN started in January 2010.

The WUT LAC uses the Bernese v.5.0 GPS Software to analyse GPS observations. Data are processed according to EPN AC guidelines. All WUT products are available at the EPN Regional Data Centre at BKG (ftp://igs.bkg.bund.de/EUREF/products).

In 2010 WUT LAC has joined the EPN Re-processing project. In the Pilot Re-processing project the data of 55 stations from 2066 were re-processed and submitted to the BKG EPN Data Centre.

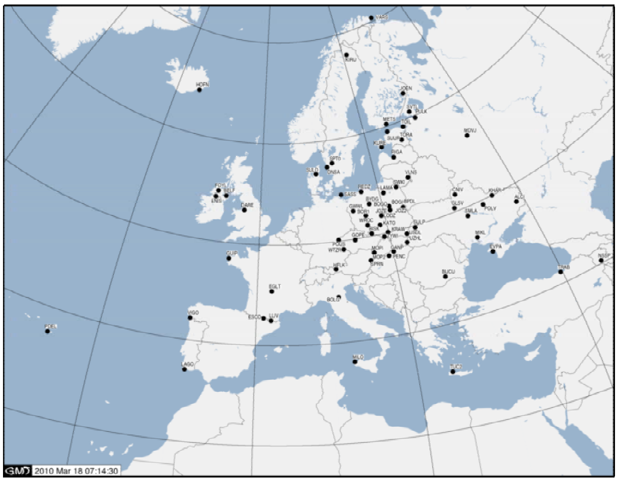

Fig. 4. EPN stations providing data processed at WUT EUREF LAC (December 2009)

3.3. Data processing at Local Analysis Centre at MUT

The 17th Analysis Centre MUT LAC operates since December 2009 in the Centre of Applied Geomatics at the Faculty of Civil Engineering and Geodesy of the Military University of Technology. The first official solutions were performed for 1560 GPS week. GNSS data from sub-network of 114 EPN permanent stations, distributed evenly in Europe (Fig. 5) are processed in the Centre (Figurski et al., 2009). Every week the solutions are delivered to the Regional Data Centre BKG, where together with the respective ones from other LACs they are used to produce final official weekly EPN solutions.

Apart from routine elaborations of almost half of the European reference stations, the MUT LAC takes part in the research project concerning re-processing of data from EPN network to provide most reliable time series of station coordinates. The archive GNSS data are processed with the use of the newest models, strategies and tools (Kenyeres et al., 2009). First test computations were done for the data from the year 2006.

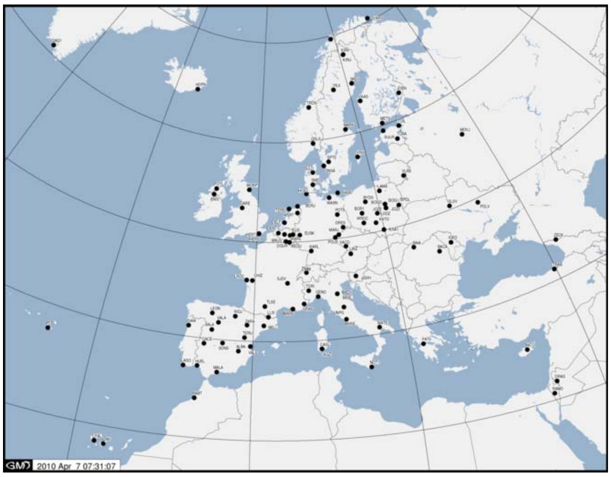

Fig. 5. EPN stations providing data processed at MUT EUREF LAC (December 2009)

3.4. Activity within the EUREF-IP Project

The EPN stations at Borowa Gora (BOGI), Borowiec (BOR1), Jozefoslaw (JOZ2, JOZ3), Krakow (KRAW), Lamkowko (LAM5), Warszawa (WARS) and Wroclaw (WROC) take part in the EUREF-IP project (http://www.epncb.oma.be/_organisation/projects/euref_IP/index.php). Three of them, i.e. BOGI, BOR1 and JOZ2 participated also in IGS IP project (Fig. 6).

Since March 2005 Ntrip Broadcaster is installed at the AGH University of Science and Technology (gps1.geod.agh.edu.pl). The Ntrip Caster broadcasts RTCM and raw GNSS data from 17 sources, mainly from KRAW EPN permanent station in the framework of EUREF-IP project.

Fig. 6. Polish stations participating in EUREF–IP project

3.5. Other EPN and IGS activities

GNSS for meteorology

The team of the Warsaw University of Technology continued the analysis of ZTD estimation results as well as IPW (Integrated Precipitable Water) time series derived from GPS solutions obtained at the WUT LAC as well as EPN combination (Kruczyk, 2009).

WUT LAC ZTD series monitoring is a proof of good tropospheric solution quality: decrease of differences between WUT LAC solutions and EPN combination after 2007 is shown in Figure 7.

Reliability of IPW values determined from GPS (WUT and other EPN LAC solutions and combination) was tested with three meteorological water vapour data sources: radiosoundings, sunphotometer (CIMEL, Central Geophysical Observatory PAS, Belsk) and numerical weather prediction model COSMO-LM (treated as meteorological database). CIMEL-318 sunphotometer data seems the most genuine source.

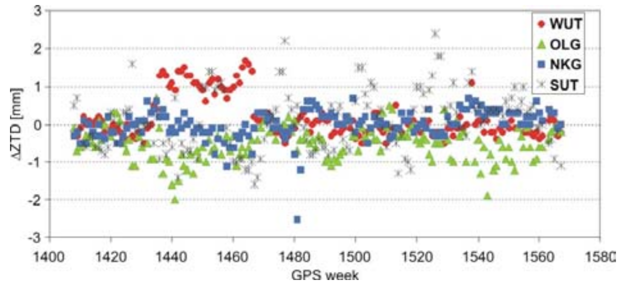

Fig. 7. ZTD weekly mean absolute differences:
EUR combined product – product of individual LAC
for all EPN stations processed

Basing on the experience gained in precious investigations the GPS measurements were collocated with sunphotometer data (Kruczyk and Liwosz, 2009). GPS receiver Trimble 4000 SSE of WUT operates permanently since May 2009 at the Central Geophysical Observatory PAS in Belsk. Data was analysed with the similar strategy used to obtain EPN standard tropospheric solution but in a smaller network that consists of 27 stations only. Results from September 2007 show clearly decreasing data conformity with the increase of GPS receiver distance (Fig. 8).

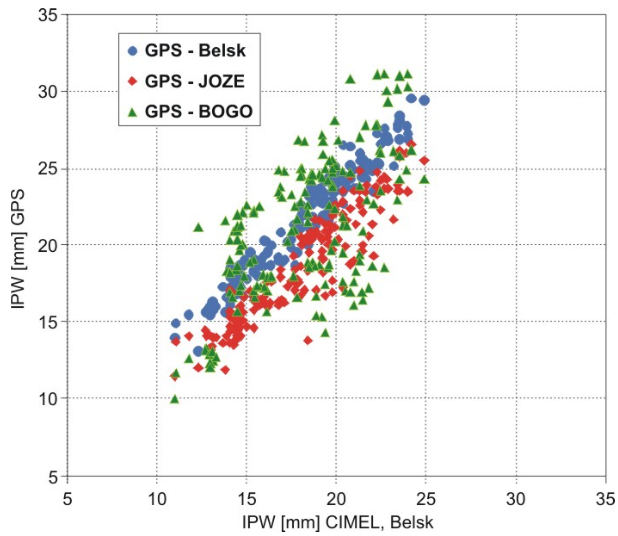

Fig. 8. IPW from sunphotometer in Belsk and GPS data
'in situ', JOZE (33 km away) and BOGO (73 km away)
in September 2009

In the Institute of Geodesy and Geoinformatics, Wroclaw University of Environmental and Life Sciences, research in the field of GNSS meteorology initiated in 2005 was continued. The distribution of the wet refractivity was investigated with the use of 3D tomography – the technique to invert the integrals over the space into the distribution of the sensed compound. The solution to basic problems were found in the course of numerical simulations (Rohm and Bosy, 2009).

To assess the quality of the ground sensors data needed as reference when applying the tomography model on the real world situations, the special differential wavelet based method was developed. The results shows that the pressure measurements are highly inconsistent and just few stations comply with the accuracy standards needed in the GNSS tomography method. Regarding the temperature, the sensors performs better and the accuracy expectations are lower. The Coupled Ocean Atmospheric Mesoscale Predictions System (COAMPS) model outputs after interpolation (self developed algorithm) to the locations of meteorological sensors shows good agreement between pressure sensors and COAMPS model outputs in terms of pressure and temperature and fair agreement in case of water vapour (Bosy et al., 2010).

Recent study concerns applying the model to the real world case, verification of the results of GNSS tomography model with the COAMPS outputs and inclusion of additional constraining scheme based on the flow analysis. The outputs of this analysis shows good accuracy and reliability of the tomography model itself but reveals the drawbacks in the model space formulation – the scanning rays which leaves the model from the face are not trimmed accurately, which in turns produces numerical instabilities. Also the impact of the flow analysis shows to have slight impact on solution (Rohm and Bosy 2010). First attempts were performed to build the strategy and methodology to construct near real-time GNSS tomography model of the troposphere over the network of receivers (Rohm and Bosy 2010). It is meant to result in constructing real-time GNSS tomography model for the area of Poland.

Monitoring ionosphere and ionospheric models

The Geodynamic Research Laboratory (GRL) of the University of Warmia and Mazury in Olsztyn in collaboration with West Department of the Institute of Geomagnetism, Ionosphere and Radio-Wave Propagation of the Russian Academy of Sciences in Kaliningrad continues the analysis of long time series of GNSS data from EPN stations to study the Earth's ionosphere. In 2009, simultaneous GPS observations from about 150 stations of EPN have been used for studying dynamics of latitudinal profiles and structure of mid-latitude ionospheric trough (MIT) (Krankowski et al., 2009). The TEC maps over Europe were created with high spatial and temporal resolution. The diurnal, seasonal as well as storm-time dynamics of the latitudinal profiles and the trough-like structure during different geomagnetic conditions were also analysed.

A methodology for GPS ultra rapid positioning that requires single minutes of dual frequency GPS observables for medium-length baseline processing was developed in GRL. It does not require ionospheric corrections and the ionospheric delays are treated as pseudo-observations with certain a priori values and respective weights in the adjustment procedure An a priori knowledge of a user's position is not needed. The proposed methodology may be applied in near real time processing. Numerical tests based on actual GNSS data show that the proposed methodology is suitable for rapid static positioning within 50-70 km from the closest reference network station and the centimetre-level precision in positioning is feasible when using just one minute of dual frequency GNSS data. It is believed that this approach is suitable for application in, e.g., ASG-EUPOS active geodetic network where a minimum of 15 minutes of dual frequency GPS data is currently required for static positioning with on-line automatic service (Grejner-Brzezinska et al., 2009; Cellmer et al., 2010).

The IGS VTEC maps of last ten years were analysed as a reliable source of ionospheric information since (Hernandez-Pajares et al., 2009). Also near Earth space plasma monitoring under COST 29 was reported (Altadill et al., 2009)

Since January 2008, the IGS Ionosphere Combination Centre is located at GRL/UWM. Nowadays, the Ionosphere Working Group of IGS generates three types of ionospheric products: final, rapid and predicted, respectively. There are currently four IGS Associate Analysis Centres (IAACs) for the ionospheric products: CODE (Centre for Orbit Determination in Europe, University of Berne, Switzerland), ESA/ESOC (European Space Operations Centre of ESA, Darmstadt, Germany), JPL (Jet Propulsion Laboratory, Pasadena, U.S.A) and gAGE/UPC (Technical University of Catalonia, Barcelona, Spain). These centres provide ionosphere maps computed using different approaches. Their maps are uploaded to IGS Ionosphere Product Coordinator at GRL/UWM, which computes official IGS combined products. The IGS GIMs are provided in Ionosphere Exchange (IONEX) format with spatial resolution of 5.0 degrees in longitude and 2.5 degrees in latitude, and temporal resolution of 2 hours. Latency of the final and rapid GIMs is 10 days and 1 day, respectively. In November 2009, the IGS Iono WG started to generate predicted ionospheric products 1 and 2 days in advance (requested for ESA's SMOS mission). These new IGS products are currently based on predicted ionosphere maps prepared by UPC and ESA. During over 10 years of continuous IGS ionosphere operation, the techniques used by the IAACs and the strategies of combination have improved in such a way that the combined IGS GIMs are now significantly more accurate and robust. Future plans include, among others, increasing temporal resolution to 1 hour and studies on taking advantage of COSMIC occultation data.

4. Status of the ASG-EUPOS network

The ASG-EUPOS network, fully operating since 2008 (Krynski and Rogowski, 2009), is based on 98 reference stations located on the Polish territory and 22 foreign stations located in neighbouring countries (Fig. 9). In reference to 2008, locations of two reference stations have been changed: station KAMP, now called KAM1, and station SZEK, now called SZE2. Changes were made because of roof of building reconstruction. In 2009, 4 new foreign EUPOS reference stations located near German and Czech Republic border: 0139 and 0147 from SAPOS network and: CPAR, CSVI from CZEPOS network were included into the ASG-EUPOS system. CPAR is an EPN station. In 2009, additional 3 ASG-EUPOS stations were included in the EPN network: CFRM, CLIB and CPAR. Currently ASG-EUPOS network contains 19 EPN stations.

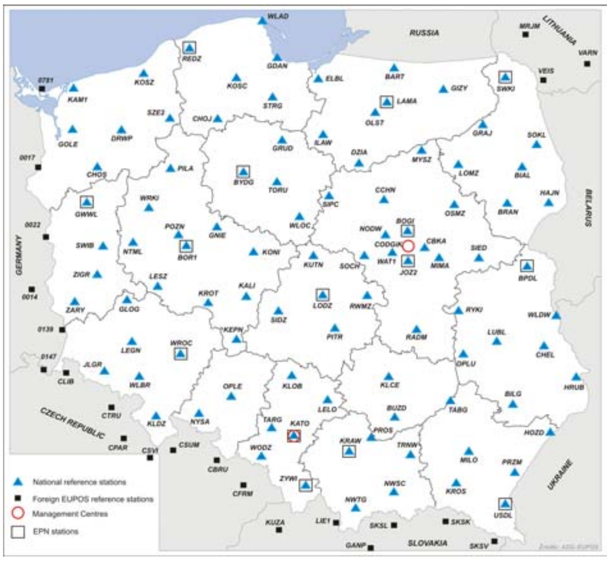

Fig. 9. Reference stations of the ASG-EUPOS system

The permanent analysis of the stations coordinates performed by ASG-EUPOS management centre confirmed that stability of the reference stations is sufficient and deviation of coordinates has not exceeded 3.0 mm in horizontal and 5.0 mm in vertical component (http://www.asgeupos.pl).

The market of GNSS users in Poland was further growing in 2009. The number of registered users of the ASG-EUPOS services reached 5000 at the end of 2009. Among the real-time services the most popular one is definitely NAWGEO based on RTK and applied for high precision real-time surveys. The usage of that service has grown up from 98.7% in 2008 to 99.2 % in 2009 (Fig. 10), against KODGIS and NAWGIS services, which were used mainly for GIS applications. In case of offered post-processing services, POZGEO – offering an automated calculation of user RINEX files, has processed 16 201 files from total 20 403 requested, which gives a 79.4 % effectiveness rate.

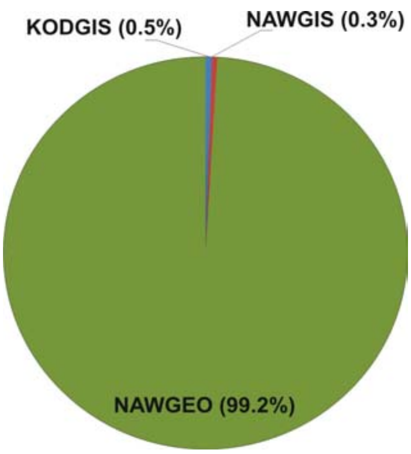

Fig. 10. The percentage of real-time services usage of the ASG-EUPOS system in 2009

The system is being used mostly in areas where construction of roads and railways takes place and also in large municipalities. Approximate coordinates of users were the basis for creating a map of system usage in its operational period until December 2009 (Fig. 11).

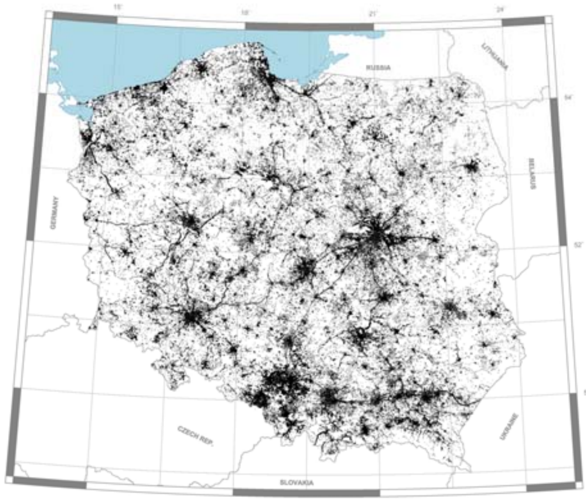

Fig. 11. The map of the usage of real-time services of the ASG-EUPOS system from 2008.5 to the end of 2009

5. Modelling precise geoid for Poland

Research on combined use of gravity data with the deflections of the vertical for quasigeoid modelling was continued. The improvement of pure gravimetric quasigeoid model by simultaneous use of deflections of the vertical with gravity data for modelling quasigeoid was shown when using least squares collocation (Lyszkowicz et al., 2009).

The effect of uncertainty in height and position of gravity points as well as uncertainty of digital terrain model on the accuracy of computed terrain corrections was extensively investigated (Szelachowska and Krynski, 2009a). Analytical formulae for the respective error propagation were developed and they were supported, when needed, by numerical evaluations. Propagation of height data errors on calculated terrain corrections was independently conducted purely numerically. Numerical calculations were performed with the use of data from gravity database for Poland and digital terrain models DTED2 and SRTM3. The results obtained using analytical estimation are compatible with the respective ones obtained using pure numerical estimation. The estimated accuracy of terrain corrections computed using height data available for Poland is sufficient to model gravimetric geoid with a centimetre accuracy (Szelachowska and Krynski, 2009b).

The performance of the new EGM2008 global geopotential model, over Poland, has been evaluated. The tide-free release of the EGM2008 model was also used for the assessment of quality of three precise quasigeoid models developed in the last decade in Poland. The EGM2008 model was compared with precise GPS/levelling (Krynski and Kloch, 2009; Łyszkowicz, 2009) as well as regional gravimetric quasigeoid models (Krynski and Kloch, 2009). The results obtained confirm high quality of quasigeoid models in Poland. They are in agreement with the previous estimate of their accuracy. Regional quasigeoid model calculated using the EGM2008 model has been found fully comparable with the existing precise quasigeoid models. EGM2008-based quasigeoid model was used to detect outlying GPS/levelling heights in the data set used for the assessment of quality of gravimetric quasigeoid models in Poland (Krynski and Kloch, 2009).

6. Activities in Galileo project

In 2009 new GESS+ (Galileo Experimental Sensor Station) station GWAR was installed in the Space Research Centre PAS, Warsaw. After few months of data quality tests, station was included as fully operational to the global network of monitoring GIOVE satellites starting from 16 December 2009 (Fig. 12).

Fig. 12. GWAR GESS+ station of the global Galileo ground control network

PECS Project “EGNOS – EUPOS integration” is run in the Space Research Centre PAS in cooperation with Head Office of Geodesy and Cartography, Malopolska Voivodeship and commercial companies. Its objective is to improve the effectiveness and range of applications of the EGNOS system by achieving the full compatibility and integration with the ASG-EUPOS system. Due to the poor configuration of the RIMS stations in eastern part of Europe, the accuracy and availability of corrections in Poland are degraded. The improvement of the EGNOS corrections, by including additional ASG-EUPOS reference stations located in the eastern part of Poland as complementary EGNOS monitoring stations is expected.

New receivers, the TTS-4 (Fig. 13) observing GPS, GLONASS, and Galileo satellites were developed at the end of 2008 at the Astrogeodynamical Observatory at Borowiec. The receivers equipped with 116 channels carry on observations at GPS L1, GPS L2/L2C, GPS L5, Galileo E1/E5A, GLONASS L1/L2.

Fig. 13. New TTS-4 receiver with touch-control screen

Work on the Precise Time Facility (PTF) for Galileo at the Astrogeodynamical Observatory at Borowiec has passed from the design phase to realization. From March 2008 AOS team started to write final version of the software package in ANSI C language. The work is carried on:

7. Earth tides monitoring

Earth tides are monitored in the Astrogeodetic Observatory of the Warsaw University of Technology in Jozefoslaw using LCR ET-26 gravimeter since January 2002. The data acquired is analysed with one year spacing and the results are sent to the International Centre for Earth Tides Parallel observations with the FG5-230 ballistic gravimeter allowed for precise determination of gravimeter scale factor and investigation of its variation.
Almost 40 absolute gravity measurements acquired within last three years in Jozefoslaw were used for studying correctness of the procedure applied depending on length of observation, tidal range during session, number of sets used, parameters in least squares algorithm and others (Rajner and Olszak, 2010).

The gravity records from Jozefoslaw were used to study different tidal effects (Rajner, 2010). Tidal gravity parameters in diurnal and semi-diurnal bands were computed using internationally recognized standard algorithms. The use of pressure data improves results significantly The calculated pressure admittance factor equals -3.5 nm/s^2.

Accuracy assessment, as well variation in time of amplitude factors and phases were computed. The standard deviation for data set was below 1 nm/s^2 showing very good quality of measurements. Additionally long series of consistent data allows to investigate week signals such as gravity changes due to ocean loading. Subtracting body tides from the results yields a differences up to 1 μGal which well match with computed indirect effect of ocean using most recent models.

Research at the Geodynamic Laboratory of the Space Research Centre PAS in Ksiaz in Sudeten Mountains was continued. Confirmation of correlations between non-tidal signals registered by HP and WT tiltmeters as well as excluding local effects disturbing observations indicate that strong clinometric signals - tilting of foundation in Geodynamic Laboratory in Ksiaz is produced by geodynamic phenomenon (Kaczorowski, 2009a). Convergence of resultant azimuths of strong effects provides an information confirming the hypothesis that the real physical phenomenon is observed. Similarities between plots of strong non-tidal signals show five events of strong signals originated from one, irregularly repeating phenomenon of non-seasonal character. The hypothesis of relation between plate tectonic motions and tilting of foundation in Ksiaz laboratory was presented (Kaczorowski, 2009b).

8. Activity in Satellite Laser Ranging

In 2009 the Satellite Laser Ranging station at Borowiec (7811) in the framework of the International Laser Ranging Service (ILRS) and EUROLAS Consortium performed 720 successful passes (8428 normal points) of 17 SLR satellites with the mean normal point precision of all passes at the level of 5 mm and accuracy of 25 mm (ILRS, 2009). The data of the Borowiec SLR station supported research programs and was used for orbits calculations and determination of geodynamic parameters by many institutions and international organizations. In October 2009 the Borowiec SLR station participated in the Time Transfer by Laser Link (T2L2) international campaign.

Processing of the SLR observations was continued in Borowiec. GPS and SLR data (25 stations) were used for the determination of station positions and velocities for the same reference epochs in the period 1993.0-2009.0. The results show a good agreement of positions (several mm) and velocities (below 1 mm/year) for both satellite techniques for the most stations (Schillak and Lehmann, 2009). The determination of the SLR station positions and velocities from low satellites Starlette, Stella and Ajisai was continued. The results indicate that the data from low satellites such as Ajisai, Starlette and Stella can successfully be applied for the determination of the SLR station coordinates (Lejba and Schillak, 2009).

9. Geodynamics

Non-tidal gravity changes were continued to be monitored at 4 absolute gravity stations: Borowiec (Borowiec Astrogeodynamic Observatory of the Polish Academy of Sciences), Jozefoslaw (Astrogeodetic Observatory of WUT), Lamkowko (Satellite Observatory of the University of Warmia and Mazury), Ojcow (Seismic Observatory of the Polish Academy of Sciences) using the FG5-230 gravimeter with a total error not exceeding 2.5 µGal. Results of repeated after 3 years (2006–2009) absolute gravity measurements show the decrease gravity with a rate between 2 and 3 µGal/y (Barlik et al., 2009a). In comparison with previous gravity determinations (1997–2001) the recently determined gravity on these stations has decreased for about 15 µGal (Barlik et al., 2009b).

Some other stations in Poland: Borowa Góra (Geodetic-Geophysical Observatory of the Institute of Geodesy and Cartography) – a fundamental point of the Polish national gravity control network, Cracow (Academy of Mine and Metallurgy, AGH), Wroclaw, Kłodzko and Lubiąż (three stations in Lower Silesia installed by the Wroclaw University of Environmental and Life Sciences), Kacwin, Lacko and Niedzica (three stations in the Pieniny Klippen Belt installed by WUT) have been chosen for absolute gravity determinations to construct a unified level of gravimetric works for geodynamic investigations (Walo et al., 2009).

The results of absolute gravity determination performed after 2006 by the WUT are available in "A Grav Database webpage" (Wilmes et al., 2009) as Meta Data (stations of zero-order network) and with gravity observations on all stations included in fundamental scientific works (Fig. 14).

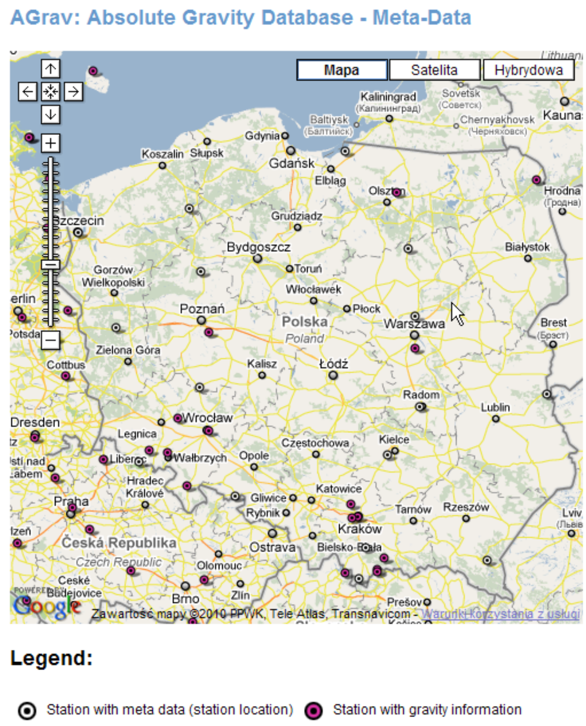

Fig. 14. Map of absolute stations in Poland and neighbouring countries with Metadata in AGrav database

The methodology of reference stations selection for connecting local network to IGS and EPN station network to enable the realization of the reference system in the local network was developed. It was tested on the example of the GPS GEOSUD network, situated in Polish Sudetes and its foreland. A method for estimating velocities based on sporadic (campaign) observations was also discussed. Mean trend congruency analysis for EPN/IGS stations coordinates time series provides one of the criterion for reference stations selection of local GPS networks. Grouping of EPN/IGS stations based on the cluster analysis verifies mean trend congruency analysis methods which were used for reference stations selection. Dividing stations into groups, using cluster analysis, harmonizes with their location within main tectonic units. It is essential for the geodynamical interpretation of geodetic monitoring results from local GPS networks. To remove the additional effects, e.g. seasonal variations, from the time series of coordinates of local networks stations a method based on the interpolation of the residuals of permanent and semi-permanent stations was suggested (Bosy et al., 2009).

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