National Report of Poland to EUREF 2013

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1. Introduction

Since 2011 the main geodetic activities at the national level in Poland concentrated on maintenance of gravity control, gravity survey for geodynamic research, continuing operational work of permanent IGS/EPN GNSS stations, GNSS 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 ionosphere and ionospheric storms, status of the ASG-EUPOS network in Poland, status of geodetic control, status of vertical control, the use of data from satellite gravity missions, monitoring of Earth tides, activity in satellite laser ranging and in geodynamics.

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

Absolute gravity measurements were carried out on regular basis with the use of FG5-230 gravimeter in the Jozefoslaw Astrogeodetic Observatory of the Warsaw University of Technology (WUT) since 2005 (Fig. 1).

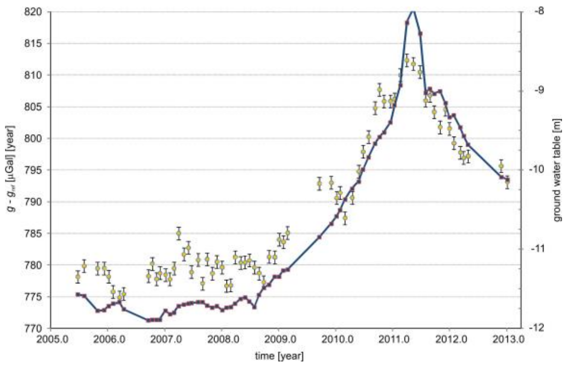

Fig. 1. Absolute gravity surveyed with the FG5-230 at Jozefoslaw (100 cm height)

A series of absolute gravity measurements at the gravimetric laboratory of the Borowa Gora Geodetic-Geophysical Observatory of the Institute of Geodesy and Cartography (IGiK) conducted on monthly basis with the A10-020 gravimeter since September 2008 (Fig. 2) shows high quality of A10 data. The effect of laser and clock stability and meteorological conditions on gravity surveyed with the A10-020 (Sekowski et al., 2012) as well as performance and stability of metrological parameters of the A10-020 were investigated (Dykowski et al., 2012a). The results of both, the 8th International Comparison of Absolute Gravimeters 2009 in Paris and European Comparison Campaign of Absolute Gravimeters ECAG 2011 in Walferdange in Luxemburg proved high quality performance of the A10-020 gravimeter (Jiang et al., 2012; Francis et al., 2012).

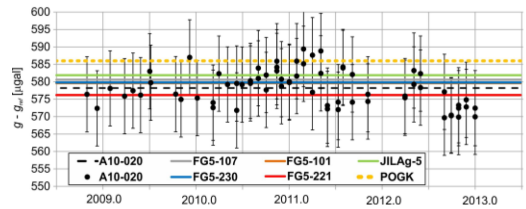

Fig. 2. Absolute gravity surveyed with the A10-020 at Borowa Gora (pillar level)

Activities towards modernization of the Polish gravity control were continued. Suitability of the A10-020 absolute gravimeter for the establishment of new gravity control in Poland has been tested (Dykowski et al., 2012b).

New gravity control, planned to be established in 2012-2014, consists of 28 fundamental points surveyed with the FG5 gravimeter (1 in 15 000 km^2 and 7 of the gravimetric calibration baselines) and 169 base points surveyed with the A10 gravimeter (1 in 2 000 km^2) (Fig. 3) (Krynski, 2012b; Krynski and Barlik, 2012; Krynski et al., 2012a, 2012c).

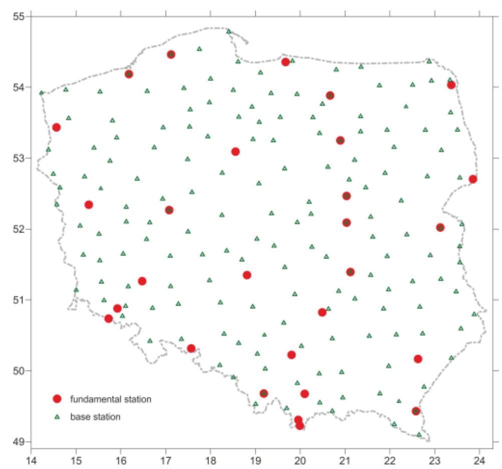

Fig. 3. Stations of new gravity control in Poland

Base points (well monumented field stations) include 87 chosen existing gravity control (POGK) points, 63 eccentric stations of the ASG-EUPOS network, 9 POLREF stations, and 5 EUVN stations.

The realization of the project of a new gravity control (Barlik et al., 2011) based only on absolute gravity measurements started in 2012. The team of the Institute of Geodesy and Cartography, Warsaw, conducted absolute gravity measurements with A10-020 as well as vertical gravity gradient measurements on the first 50 base stations of the gravity control (Fig. 4) (Krynski et al., 2012b).

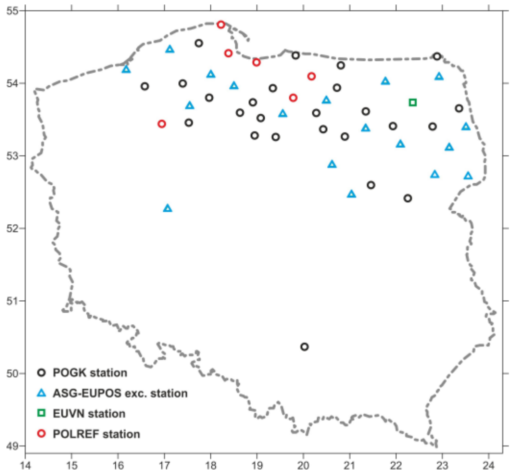

Fig. 4. Base stations of new gravity control surveyed in 2012

The A10-020 has further been successfully used in 2012 to re-survey gravity control in Sweden (Fig. 5).

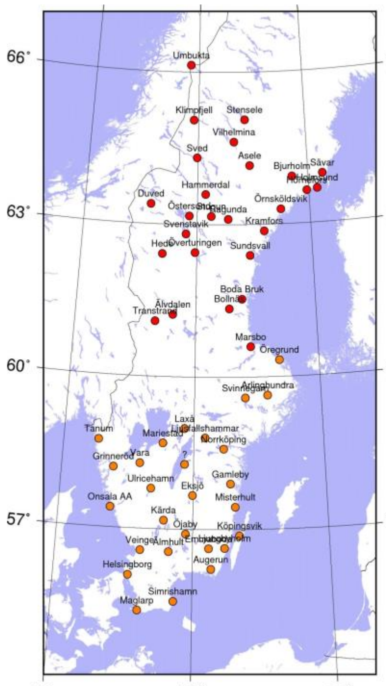

Fig. 5. Stations of gravity control networks of Sweden, surveyed with the A10-020 in 2012

First results of renovation of the Finnish First Order Gravity Network (Mäkinen et al., 2012a) and of gravity change in Finland 1962-2010 from the comparison of legacy relative measurements with new measurements made with the A10-020 were obtained (Mäkinen et al., 2012b).

Research on modern vertical gravity reference systems (Krynski, 2012a, 2012b) and on the use of the A10 gravimeter for calibration of spring gravimeters (Dykowski 2012b) was continued at the Institute of Geodesy and Cartography, Warsaw.

3. Participation in IGS/EPN permanent GNSS networks

3.1. Operational work of permanent IGS/EPN stations

Permanent IGS and EPN GNSS stations operate in Poland since 1993. 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. 6, Table 1) operate in Poland within the EUREF program. A brief characteristics of those stations is given in Table 2.

The stations BOGI, BOR1, JOZE, JOZ2, LAMA and WROC operate also within the IGS network (http://www.epncb.oma.be/_trackingnetwork/stations.php). The EPN stations at Borowa Gora (BOGI), Borowiec (BOR1), Jozefoslaw (JOZ2, JOZ3), Cracow (KRAW, KRA1), Lamkowko (LAM5), and Wroclaw (WROC) take part in the EUREF-IP project (http://igs.bkg.bund.de/root_ftp/NTRIP/streams/streamlist_euref-ip.htm) (Fig. 7, Table 3). Three of them, i.e. BOGI, BOR1 and JOZ2 participated also in IGS-Real time GNSS Data project.

Fig. 6. EPN/IGS permanent GNSS stations in Poland (2013)

Table 1. Permanent GNSS stations in Poland

Name (abbreviation)	Latitude	Longitude	Status	Receiver
Biala Podlaska (BPDL)	52º02'07"	23º07'38"	EUREF	TRIMBLE NetR5
Borowa Gora (BOGI)	52º28'30"	21º02'07"	IGS, EUREF	Javad TRE_G3T DELTA
Borowa Gora (BOGO)	52º28'33"	21º02'07"	EUREF	TPS Eurocard
Borowiec (BOR1)	52º16'37"	17º04'24"	IGS, EUREF	TRIMBLE NetRS
Bydgoszcz (BYDG)	53º08'04"	17º59'37"	EUREF	TRIMBLE NetR5
Cracow (KRAW)	50º03'58"	19º55'14"	EUREF	Ashtech μZ-12
Cracow (KRA1)	50º03'58"	19º55'14"	EUREF	TRIMBLE NetR5
Gorzow Wielkopolski (GWWL)	52º44'17"	15º12'19"	EUREF	TRIMBLE NetR5
Jozefoslaw (JOZE)	52º05'50"	21º01'54"	IGS, EUREF	Trimble 4000 SSI
Jozefoslaw (JOZ2)	52º05'52"	21º01'56"	IGS, EUREF	LEICA GRX1200GGPRO
Katowice (KATO)	50º15'11"	19º02'08"	EUREF	TRIMBLE NetR5
Lamkowko (LAMA)	53º53'33"	20º40'12"	IGS, EUREF	LEICA GRX1200GGPRO
Lodz (LODZ)	51º46'43"	19º27'34"	EUREF	TRIMBLE NetR5
Redzikowo (REDZ)	54º28'21"	17º07'03"	EUREF	TRIMBLE NetR5
Suwalki (SWKI)	54º05'55"	22º55'42"	EUREF	TRIMBLE NetR5
Ustrzyki Dolne (USDL)	49º25'58"	22º35'09"	EUREF	TRIMBLE NetR5
Wroclaw (WROC)	51º06'47"	17º03'43"	IGS, EUREF	LEICA GR 25
Zywiec (ZYWI)	49º41'12"	19º12'21"	EUREF	TRIMBLE NetR5

Table 2. Characteristics of Polish EPN stations

4 char Station ID	Domes Number	**Location**/ Institution	**Receiver**/ Antenna	**Started operating/** as EPN station	**Meteo** Sens./ Manufacturer	Data transfer blocks	Observations performed
BOGI	12207M003	**Borowa Gora** Inst. of Geodesy and Cartography	**Javad TRE_G3T DELTA** ASH701945C_M SNOW	**03JAN2001/** since 265/2002 (GPS week No 1185)	**LB-710HB** LAB-EL Poland **MET4A** Paroscientific Inc.	24 h 1h	Ground water level Astrometry Gravity GPS/GLONASS Geomagnetic field
BOGO	12207M002	**Borowa Gora** Inst. of Geodesy and Cartography	**TPS Eurocard** ASH700936C_M SNOW	**08JUN1996/** since 182/1996 (GPS week No 0860)	**LB-710HB** LAB-EL Poland	24 h 1h	Ground water level Astrometry Gravity GPS/GLONASS Geomagnetic field
BOR1	12205M002	**Borowiec** Space Research Centre, PAS	**Trimble NetRS** AOAD/M_T NONE	**10JAN1994/** since 365/1995 (GPS week No 0834)	**HPTL.3A** NAVI Ltd. **SKPS 800/I** Skye Instr. Ltd. **ARG 10/STD** Skye Instr Ltd.	24 h 1h	SLR GPS/GLONASS Time service
BPDL	12223M001	**Biala Podlaska** Head Office of Geodesy and Cartography	**Trimble NetR5** TRM55971.00 TZGD	**04DEC2007/** since 160/2008 (GPS week No 1483)	**MET4A** Paroscientific Inc.	24 h 1h	GPS/GLONASS

BYDG	12224M001	**Bydgoszcz** Head Office of Geodesy and Cartography	**Trimble NetR5** TRM55971.00 TZGD	**04DEC2007/** since 160/2008 (GPS week No 1483)	**MET4A** Paroscientific Inc.	24 h 1h	GPS/GLONASS
GWWL	12225M001	**Gorzow Wielkopolski** Head Office of Geodesy and Cartography	**Trimble NetR5** TRM55971.00 TZGD	**10DEC2007/** since 160/2008 (GPS week No 1483)	**MET4A** Paroscientific Inc.	24 h 1h	GPS/GLONASS
JOZE	12204M001	**Jozefoslaw** Inst. of Geodesy and Geod. Astr., WUT	**Trimble 4000SSI** TRM14532.00 NONE	**03AUG1993/** since 365/1995 (GPS week No 0834)	**LB-710RHMS** LAB-EL Poland	24 h 1h	Ground water level Astrometry Gravity tidal GPS
JOZ2	12204M002	**Jozefoslaw** Inst. of Geodesy and Geod. Astr., WUT	**Leica GRX1200GGPRO** LEIAT504GG NONE	**03JAN2002/** since 257/2003 (GPS week No 1236)	**LB-710RHMS** LAB-EL Poland **MET4A** Paroscientific Inc.	24 h 1h	Ground water level Gravity absolute Gravity tidal GPS/GLONASS
KATO	12219S001	**Katowice** Marsh. Off. of the Siles. Prov.	**Trimble NetR5** TRM57971.00 TZGD	**30JAN2003/** since 222/2003 (GPS week No 1231)	**MET4A** Paroscientific Inc.	24 h 1h	GPS/GLONASS
KRAW	12218M001	**Cracow** AGH UST	**Ashtech µZ-12** ASH701945C_M SNOW	**01JAN2003/** since 026/2003 (GPS week No 1203)	**LB-710** LAB-EL Poland	24 h 1h	GPS
KRA1	12218M002	**Cracow** AGH UST	**Trimble NetR5** TRM57971.00 NONE	**01JAN2010/** since 080/2010 (GPS week No 1576)	**MET4A** Paroscientific Inc.	24 h 1h	GPS/GLONASS
LAMA	12209M001	**Lamkowko** Inst. of Geodesy, UWM	**Leica GRX1200+GNSS** LEIAT504GG LEIS	**01DEC1994/** since 365/1995 (GPS week No 0834)	**MET4A** Paroscientific Inc.	24 h 1h	Ground water level Gravity GPS/GLONASS
LODZ	12226M001	**Lodz** Head Office of Geodesy and Cartography	**Trimble NetR5** TRM55971.00 TZGD	**03DEC2007/** since 160/2008 (GPS week No 1483)	**MET4A** Paroscientific Inc.	24 h 1h	GPS/GLONASS
REDZ	12227M001	**Redzikowo** Head Office of Geodesy and Cartography	**Trimble NetR5** TRM55971.00 TZGD	**07DEC2007/** since 160/2008 (GPS week No 1483)	**MET4A** Paroscientific Inc.	24 h 1h	GPS/GLONASS
SWKI	12228M001	**Suwalki** Head Office of Geodesy and Cartography	**Trimble NetR5** TRM55971.00 TZGD	**05DEC2007/** since 160/2008 (GPS week No 1483)	**MET4A** Paroscientific Inc.	24 h 1h	GPS/GLONASS
USDL	12229M001	**Ustrzyki Dolne** Head Office of Geodesy and Cartography	**Trimble NetR5** TRM55971.00 TZGD	**03DEC2007/** since 160/2008 (GPS week No 1483)	**MET4A** Paroscientific Inc.	24 h 1h	GPS/GLONASS
WROC	12217M001	**Wroclaw** Univ. of Env. & Life Sciences	**Leica GR 25** LEIAR25.R4	**28NOV1996/** since 329/1996 (GPS week No 0881)	**MET4A** Paroscientific Inc.	24 h 1h	Ground water level GPS/GLONASS
ZYWI	12220S001	**Zywiec Marsh. Off. of the Siles. Prov.**	**Trimble NetR5** TRM55971.00 TZGD	**30JAN2003/** since 222/2003 (GPS week No 1231)	**MET4A** Paroscientific Inc.	24 h 1h	GPS/GLONASS

Table 3. Characteristics of Polish EPN stations producing real time data streams

Location	St. ID	Observations	Latitude [deg]	Longitude [deg]	Receiver	RTCM type - message types (update rate [s])
Borowa Gora	BOGI	GPS+GLO	52.48	21.04	Javad TRE_G3T DELTA	RTCM 3.0 - 1004(1),1006(10),1008(10), 1012(1)
Borowiec	BOR1	GPS+GLO	52.28	17.07	TRIMBLE NetRS	RTCM 2.3 - 1(1),3(10),18(1),19(1), 22(10)
Cracow	KRAW	GPS	50.01	19.92	Ashtech μZ-12	RTCM 2.2 - 1(1),3(60),16(60),18(1), 19(1),22(60)
Cracow	KRA1	GPS+GLO	50.01	19.92	TRIMBLE NetR5	RTCM 3.0 - 1004(1),1006(10),1008(10), 1012(1),1013(10),1033(10)
Jozefoslaw	JOZ2	GPS+GLO	52.02	21.03	Leica GRX1200GGPro	RTCM 3.0 - 1004(1),1006(60),1008(60), 1012(1)
Jozefoslaw	JOZ3	GPS+GLO	52.02	21.03	Leica GRX1200GGPro	RTCM 3.0 - 1004(1),1006(15), 1008(15),1012(1),1033(15)
Lamkowko	LAMA	GPS+GLO	53.89	20.67	*Leica GRX1200GGPro*	RTCM 3.0 - 1004(1),1006(15),1008(15), 1012(1),1019,1020,1033(15)
Warsaw	WARS	GPS+GLO	52.00	21.00	Leica GRX1200GGPro	RTCM 3.0 - 1004(1),1006(15), 1008(15),1012(1)
Wroclaw	WROC	GPS+GLO	51.11	17.06	Leica GR 25	RTCM 3.0 - 1004(1),1006(15),1008(15), 1012(1)

Fig. 7. Polish EPN stations participating in the EUREF-IP project (2013)

Since March 2005 Ntrip Broadcaster is installed at the AGH Univ. of Science and Techn. (http://home.agh.edu.pl/~kraw/ntrip.php). The Ntrip Caster broadcasts RTCM and raw GNSS data from 17 sources, mainly from permanent station taking part in the framework of EUREF-IP project.

3.2. Data processing at WUT LAC

The WUT EPN Local Analysis Centre operates since 1996. Data from 79 EPN stations are processed at WUT LAC (April 2013) located mainly in Central Europe (Fig. 8). It contributes to EUREF with weekly and daily solutions based on IGS final products, and with rapid daily coordinate solution based on IGS rapid products since January 2010.

Fig. 8. EPN stations providing data processed at WUT EUREF LAC (April 2011)

The WUT LAC uses the Bernese Software v5.0 for the analysis of GPS observations. Since

December 2010 solutions are based on both GPS and GLONASS observations (CODE products has been used in analysis since then) (Krynski and Rogowski, 2012). Data are processed according to EPN AC guidelines. All WUT products are available at the EPN RDC at BKG (ftp://igs.bkg.bund.de/EUREF/products).

3.3. Data processing at MUT LAC

The Military University of Technology in Warsaw (MUT) LAC Analysis Centre operates since December 2009 (Krynski and Rogowski, 2012). The GNSS data from 117 EPN stations distributed evenly in Europe (Fig. 9) are processed in the Centre starting from 1558 GPS week.

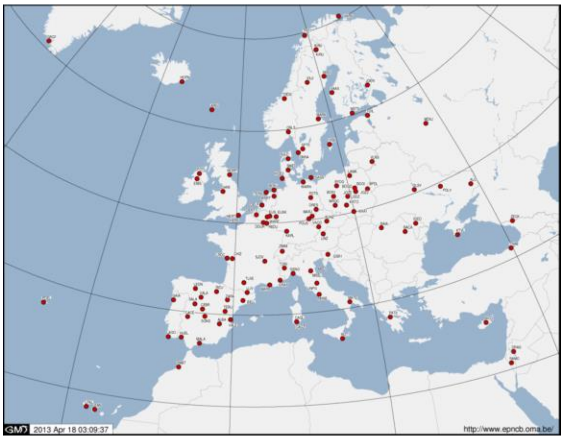

Fig. 9. EPN stations providing data processed at MUT EUREF LAC (April 2011)

Every week the solutions are delivered to the RDC BKG, where together with the respective ones from other LACs they are used to produce final official weekly EPN solutions

3.4. Other EPN and IGS activities

GNSS for meteorology

The team of the Institute of Radio Astronomy of NASU, Kharkiv, Ukraine in cooperation with IGiK investigated weekly cycles search in global weather variations and in behaviour of electromagnetic noise intensity (Zanimonskiy et al., 2012),

One of main objectives of WUT LAC is a standard ZTD estimation, monitoring of the results and research on Integrated Precipitable Water (IPW) time series derived both from GNSS and NWP (Numerical Weather Prediction) models. Two operational numerical prediction models: COSMO-LM (maintained by Polish Institute of Meteorology and Water Management) in two different resolutions of 14 km and 2.8 km and a global model GFS (operated by now NCEP) were used as input data to generate IPW and ZTD needed for GNSS tropospheric products quality assessment (Kruczyk et al., 2012a, 2012b).

Various factors affect final results of the determination of IPW and ZTD from model grid, i.e. interpolation of data in space, numerical integration in zenith direction, correction for model topography, physical equations applied for humidity parameters conversions etc. Different models with different GNSS products exhibit systematic differences (Table 4). For individual stations the observed bias might substantially vary (e.g. Fig, 10)

Table 4. Statistics of differences between IPW and ZTD obtained from GNSS solution and NWP model in 2011

GNSS solution	NWP	GPS - NWP [mm]	Std. dev. [mm]	RMS [mm]	No of stations
EUR comb IPW - station meteo	COSMO_14 ver I	-1.31	2.46	3.26	38
EUR comb IPW - station meteo	COSMO_14 ver II	-0.85	2.21	2.88	38
EUR comb IPW - station meteo	COSMO_14 2 × lev	-0.89	2.19	2.87	38
EUR comb IPW - model meteo	COSMO_14 ver II	-0.87	2.34	2.74	163
EUR comb ZTD	COSMO_14 hydro	-6.47	14.82	17.60	163
EUR comb ZTD	COSMO_14 EF	49.17	14.63	51.37	163
EUR comb IPW - station meteo	COSMO_2.8 ver II	-1.06	2.06	2.44	19
EUR comb IPW - station meteo	COSMO_2.8 ver II	-0.78	2.09	2.28	31
EUR comb ZTD	COSMO_2.8 EF	8.30	13.43	16.03	31
EUR comb IPW - station meteo	GFS global IPW	-0.30	1.70	2.41	35
IGS final tropo (JPL/USNO)	GFS global IPW	0.08	2.09	3.10	48

with the following notification: ver I – water vapour pressure from density by empirical formula; ver II – water vapour pressure from density by equation of state; 2 × lev – IPW integrated from vertical profile using both levels and half levels as layer boundaries; hydro – ZTD calculated hydrostaticaly; EF – ZTD by integrating Essen-Froome refractivity formula for moist air in microwaves.

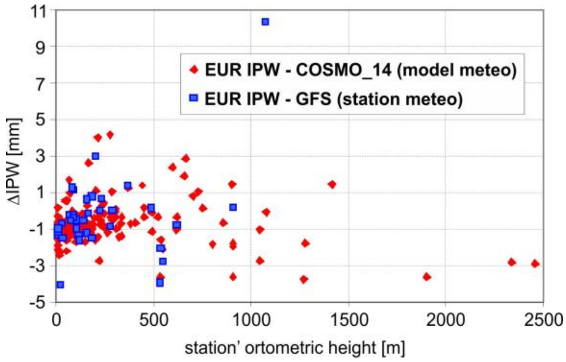

Fig. 10. IPW mean difference of GNSS EUR - NWP model (COSMO_14 red, GFS blue) vs. station height for 2011 [mm]

Besides GNSS data and NWP model meteorological water vapour data sources (radiosoundings and sun photometer CIMEL 318) were also used for independent verification. Valuable information on GNSS tropospheric solutions quality was also obtained considering the new IGS final solution (PPP mode in Bernese) (Fig. 11) (Kruczyk and Liwosz, 2012).

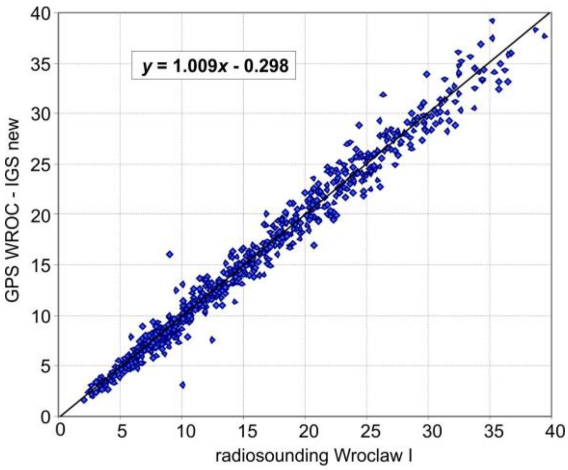

Fig. 11. IPW GPS (IGS final tropospheric product) vs. radiosounding at Wroclaw 2011

Tropospheric product on global scale is of serious interest for climatological analysis (Kruczyk and Liwosz, 2012). Annual model for multi-year series of ZTD from IGS was applied to detect climate change signal in residuals (ver. 1). Also more complicated model consisting of annual and semiannual terms as well as linear trend was fitted using least squares approach (ver. 2). Its use reduces RMS of residuals down, e.g. for THU2 (Thule, Greenland) to 2.1 mm from 2.5 mm IPW (Fig. 12). For many stations negative IPW trends were observed, e.g. for THU2 -0.13 mm/year (ver. 1) and -0.11 mm/year (ver. 2). No evidence of global warming has been observed from the analysis of GNSS data performed.

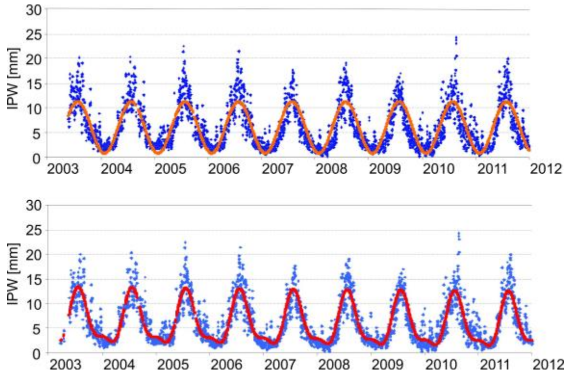

Fig. 12. Two versions of IPW model for THU2 from IGS tropospheric product: ver. 1 (annual term), ver. 2 (annual and semiannual terms plus trend)

Research on Near Real Time models of water vapour NRT 4DWVD and meteorological parameters: temperature and pressure NRT 4DTPD in the atmosphere for geodetic and meteorological applications was conducted at the Institute of Geodesy and Geoinformatics (IGG) of the Wroclaw University of Environmental and Life Sciences (WUELS). NRT ZTD estimation service to monitor the state of troposphere from GPS observations for the area of Poland is under development. The ZTD (IGGHZ-G) is estimated in hourly intervals for 100 ASG-EUPOS reference GNSS stations and 25 EPN/IGS GNSS stations located close to the Polish border (Bosy et al., 2012a, 2012b; Kapłon et al., 2012). It is provided on the regular basis to the EUMETNET EIG GNSS water vapour program (E-GVAP: http://egvap.dmi.dk/) and used for high resolution IWV determination above Europe. The comparison of estimated NRT ZTDs (IGGHZ-G) with EPN combined ZTD is shown in Figure 13.

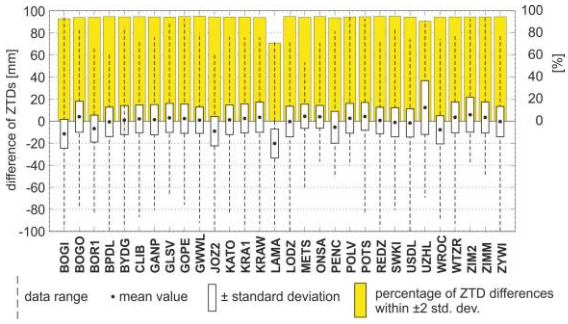

Fig. 13. Comparison of estimated NRT ZTDs for 30 EPN stations with EPN combined weekly solution for the period of 120 days of 2012 (Bosy et al., 2012)

The second ZTD model named IGGHZ-M based on data from ground meteorological sensors from Poland and neighbouring countries, with different time resolutions (SYNOP: 3h, ASG-EUPOS: 1h, METAR: 0.5h) has been developed at WUELS (Bosy et al., 2012). The IGGHZ-M model is available in real-time. The IGGHZ-G and IGGHZ-M ZTD models can be used for positioning in post processing and real-time mode. Figure 14 shows the results of real-time kinematic PPP positioning for the station WROC in various scenarios of troposphere estimation (Hadaś et al., 2012, 2013).

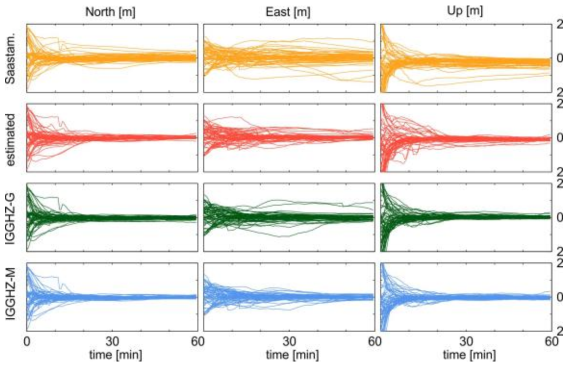

Fig. 14. Coordinate residuals for WROC station in various scenarios of real-time kinematic PPP (Hadaś et al., 2013)

The research on near real-time (NRT) estimation of water vapour in the troposphere using ground GNSS and the meteorological data and the GNSS tomography model ins continued at WUELS. The development of GNSS tomography model concerning analyses of the precision of humidity in GNSS tomography (Fig. 15) was performed (Rohm, 2012).

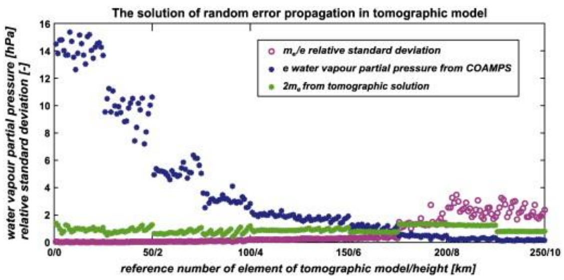

Fig. 15. Water vapour partial pressure decrease with height (COAMPS derived), the double limit of standard deviation (significance level of 0.05), and the relative error me/e. The maximum number of scanning rays, epoch 22 (Rohm, 2012)

New unconstrained approach of GNSS tomography was investigated (Rohm, 2013). The results of water vapour error analysis for new model are shown in Figure 16.

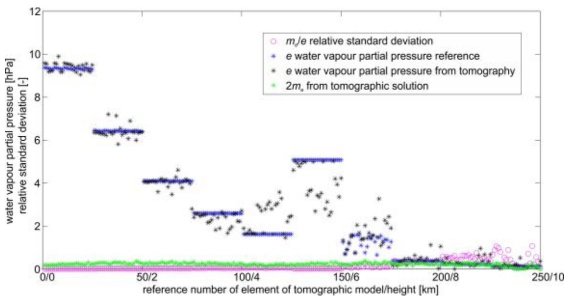

Fig. 16. Water vapour partial pressure error related to height obtained in L-curve fitting procedure 10 epochs stacked

Unconstrained stacked GNSS tomography in combination with other sounding techniques like Radio Occultation, with a priori models from Numerical Weather Prediction models could be a very useful tool to monitor the state of the troposphere above the network of GNSS receivers (Rohm, 2013).

Accuracy of two near real-time tropospheric delay estimation models IGGHZG and IGGHZM in fast-static precise positioning, developed within ASG+ project by researchers from Wroclaw University of Environmental and Life Sciences, was analysed. The first model is based on processing of GPS data collected from ground-based reference stations while the second one uses metrological data fed into Saastamoinen model. The accuracy of these models was evaluated by comparison with tropospheric Zenith Total Delays obtained from ASG-EUPOS network final solution and UNB3m model. The applicability of these models to precise positioning was studied by their application to ultra-fast static positioning, where resulting coordinates accuracy and ambiguity resolution performance were analysed. The obtained results show that the GPS-based model can be successfully used in precise positioning, and the meteo-based model still requires improvements, mostly related to the interpolation technique (Wielgosz et al., 2012a). In addition, tropospheric delays derived from COAMPS numerical weather prediction model (NWM) were tested in precise positioning. It has been shown that NWM-derived ZTDs need to be used with additional estimation of residual delays (Wielgosz et al., 2012b).

Monitoring ionosphere and ionospheric storms

The Geodynamic Research Laboratory (GRL) of the University of Warmia and Mazury (UWM) 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 the last year simultaneous GPS/GLONASS observations from about 200 stations of IGS, EPN and POLENET networks have been used for studying dynamics of latitudinal profiles and structure of mid- and high-latitude ionosphere (Cherniak et al., 2012; Zakharenkova et al., 2012, 2013a, 2013b). GPS/GLONASS measurements were also used to study the occurrence of TEC fluctuations at the northern high latitude ionosphere. (Shagimiratov et al., 2012; Sieradzki et al., 2013). The main goal of these studies was the analysis of the application of the ground-based GNSS observations to create maps of the electron concentration variability at high latitudes of the northern hemisphere. Two parameters Rate of TEC (*ROT*) and Rate of TEC Index (*ROTI*) were used in the investigations.

$$ROT = \frac{f_1^2 * f_2^2}{40.3(f_1^2 - f_2^2)}\left((L_1 - L_2)_{tj} - (L_1 - L_2)_{ti}\right) \quad [TECU/\mathrm{min}]$$

$$ROTI = \sqrt{\langle ROT^2 \rangle - \langle ROT \rangle^2}$$

It is well-known that these parameters describe the dynamic changes in the concentration of the electrons derived from a single track of GNSS satellite. *ROT* allows detecting the ionospheric irregularities with spatial size of about 30 km and larger while *ROTI* which is the standard deviation of ROT for 5-minute interval, gives information about the variability of the electron concentration during a specified time period.

Based on this methodology the automatic TEC fluctuation test service has been established in 2012 at GRL/UWM (Sieradzki et al., 2013). The ionospheric variability maps are generated with 1 day delay. These works correspond with the last recommendation of the Ionosphere Working Group of the International GNSS Service (IGS) from the IGS 2012 Workshop held in Olsztyn and the results presented here are a first step towards establishing a new IGS iono product containing information on ionospheric variability at high latitudes.

The occurrence of TEC fluctuations was analysed using ROT along individual stations. Figure 17 presents the development of TEC fluctuations over Kiruna and Thule during the geomagnetic activity period of 17–18 March 2013. It illustrates the occurrence of TEC fluctuations for all passes of the satellites observed at the Northern hemispheres over a 24-hour interval on a quiet and disturbed day. In such conditions strong fluctuations were observed in the polar ionosphere especially during a geomagnetic storm.

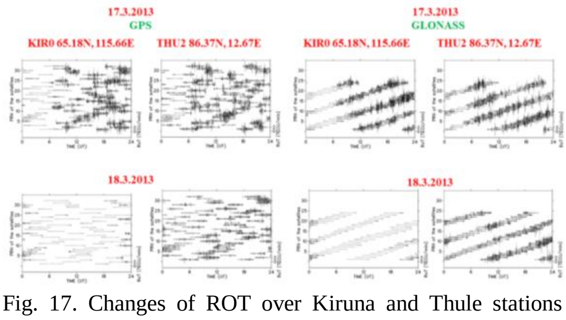

Fig. 17. Changes of ROT over Kiruna and Thule stations (from GPS and GLONASS data) for disturbed day 17 March 2013 and quiet day 18 March 2013

Figure 18 illustrates the spatio-temporal structure and intensity of the ionospheric irregularities for the three quiet days and one disturbed day of 17 March 2013. For quiet days the irregularity oval is similar to the auroral oval. The occurrence of the irregularities strongly depended on the geomagnetic activity. Even during the moderate disturbances on 17 March the irregularity oval sharply expanded and moved equatorward relative to a quiet day.

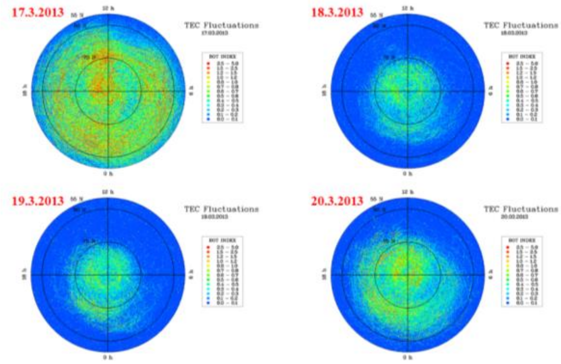

Fig. 18. Daily maps of the ROTI index for specified magnetic local time and geomagnetic latitude

For the purpose of the 6-hour map the mean (MROTI) and standard deviation (DROTI) were calculated in cells with dimensions (5° × 2°). Figure 19 shows the first examples of subdaily maps of MROTI and DROTI for disturbed (17 March) and quiet day (18 March).

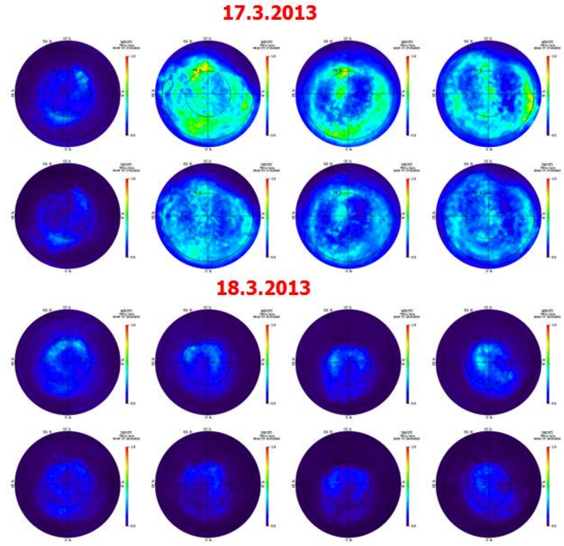

Fig. 19. Subdaily maps of MROTI and DROTI

Metrological investigations

Metrological investigations of GNSS receivers on the basis of data from IGS/EPN and EUPOS stations or local permanent GNNS network in Poland and Ukraine have been conducted by the IGiK team in cooperation with the research group from the Institute of Metrology, Kharkiv, Ukraine (Cisak et al., 2012).

4. ASG-EUPOS network

4.1. Status of the ASG-EUPOS network

At the end of 2012 r. 100 ASG-EUPOS permanent reference stations operated in Poland (25

GPS/GLONASS stations). Other 22 reference stations from neighbouring countries were included to the common solutions within ASG-EUPOS (Fig. 20). Additionally, station WIEL (Wielun) in Poland and 4 foreign stations: 0026 (Guben, DE), CJES (Jesenik, CZ), SHAZ (Shatsk, UA) and VBER (Velykyi Bereznyi, UA) were being tested in the system.

Fig. 20. Reference stations of the ASG-EUPOS system (4 January 2013)

The number of changes in the ASG-EUPOS stations took place in 2012. The station ELBL (Elblag) was upgraded to GPS+GLO+GAL tracking new Trimble NetR9 receiver and choke ring antenna. The antenna of TARG (Tarnowskie Gory) was moved to a nearby site TAR1. Two stations have been replaced: KRA1 (Krakow) EPN G2 station replaced former KRAW station and KROL (Olsztyn) G3 station replaced the OLST station in RTN solution. In Czech Republic the station CBRU was replaced with CJES station. The upgrade of the equipment on the ASG-EUPOS stations in Malopolska region allowed to launch GPS/GLONASS RTN service on a larger area (Fig. 20).

Current statistics show, that the use of ASG-EUPOS services is continuously growing. At the end of 2012, the number of registered users exceeded 8500 and use of the most popular real-time service NAWGEO (RTK) reached up to 700 simultaneous connections in the peak hours (over 2000 users log in daily). Free of charge ASG-EUPOS services for registered users are continued.

5. Local GNSS networks

Besides the ASG-EUPOS three other GNSS permanent station networks in Poland are being developed for commercial use. There are: TPI NET PRO (developed by TPI the local Topcon and Sokkia equipment reseller) which encompasses nationwide distributed 115 stations, VRSNET.PL (developed by Geotronics Polska the local Trimble equipment reseller) which encompasses 13 stations located in NW part of Poland, and Leica SmartNet Poland (developed by Leica Geosystems Polska the local Leica equipment representative) which encompasses 47 stations concentrated mainly near Gdansk and Lodz.

6. Geodetic control

In 2012 the Head Office of Geodesy and Cartography (GUGiK) has completed the work related to the development of a new reference datum for national permanent station network ASG-EUPOS by integrating the ASG-EUPOS reference station network with 1st order geodetic control network (including EUREF-POL, EUVN and POLREF points). The new reference PL-ETRF2000 was determined basing on the results of GNSS campaigns performed in 2008 and 2010/2011. GNSS data from almost 700 permanent or epoch stations (Fig. 21) were analysed in daily sessions using Bernese GPS software (ver. 5.0).

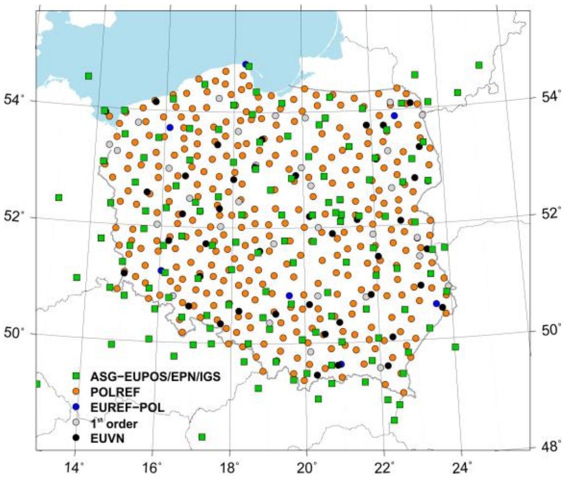

Fig. 21. Stations of the Poland's national GNSS reference network

The solutions were obtained using two elevation masks: 5º and 10º. Daily coordinate solutions of both campaigns were stacked and final solution was expressed in ITRF2005 and ETRF2000 at epoch 2011.0. Coordinates and velocities of reference stations were taken from EUREF cumulative solution (C1600). All GNSS observations were computed in two cumulative adjustments carried out by the Warsaw University of Technology (Liwosz and Rogowski, 2012) and the Space Research Centre of the Polish Academy of Sciences. Better station coordinate repeatabilities and a posteriori RMS were obtained for solution with elevation mask 5º. The results of adjustment for particular solution variants are presented in Table 5.

The adjusted coordinates in PL-ETRF2000 were compared with those stored in existing databases and appropriate transformation parameters between EUREF89 and PL-ETRF2000 were calculated (Table 6).

Table 5. The results of the adjustment for different solution variants

Sub campaign	Adjustment variant	Repeatability [mm]			RMS [mm]	N [%][1)]	Total No of observations
		N	E	U			
2008	GPS 5°	0.97	0.99	2.64	1.30	92.2	10 175 270
	GPS 10°	1.15	1.23	2.94	1.32	93.9	8 958 888
2010	GPS 5°	1.30	1.37	3.34	1.29	92.8	21 602 786
	GPS 10°	1.49	1.38	3.74	1.32	94.3	18 674 394
	GNSS 5°	1.23	1.31	3.08	1.27	92.8	27 140 216
2011	GPS 5°	0.85	0.83	2.21	1.29	92.5	6 839 723
	GPS 10°	0.99	0.83	2.51	1.32	94.2	5 899 616
	GNSS 5°	0.84	0.82	2.24	1.28	92.4	8 506 863

1) ambiguity solution effectiveness

Table 6. Transformation parameters from ETRF89 (EUREF89) to PL-ETRF2000 on 2011.0 epoch

T_1 [cm]	T_2 [cm]	T_3 [cm]	R_1 ["]	R_2 ["]	R_3 ["]
-27.33 ±2.81	-37.49 ±2.85	22.37 ±2.03	0.01301 ±0.00086	-0.01048 ±0.00109	-0.00156 ±0.00083

Following the Resolution 2 of the EUREF2010 Symposium (Gavle, Sweden) ETRF2000 has been accepted as the new realization of ETRS89 in Poland. The reference frame named PL-ETRF2000 (epoch 2011.0) has been introduced into the Polish technical standard (Regulation of the Council of Ministers of 15 October 2012 on spatial reference system in Poland). Currently there are in use two realizations of ETRS89 in Poland. The PL-ETRF2000 is recommended to be used in GNSS surveying with ASG-EUPOS corrections whereas the EUREF89 will still be maintained in an interim period as reference for geodetic network.

7. Vertical control

In 2012 the measurements of 2nd order levelling network over Silesia region has been completed and adjusted in Kronstadt2006 datum. This task finishes the 4th levelling campaign in Poland which started in 1998. The 1st order levelling network (16 226 benchmarks and 17 516 km of 382 levelling lines) was completed in 2003. The 2nd order levelling network consist of 25 868 benchmarks over 17 930 km of levelling lines. The final adjustment of both networks will be performed in 2013 in EVRF2007-NH vertical datum which is to be the new vertical datum in Poland since 1 January 2014.

8. The use of data from satellite gravity missions

Temporal variations of the gravity field over Europe obtained from GRACE data in terms of geoid height and mass variation were further analysed (Kloch-Glowka et al., 2012). In particular variability of geoid in Europe had been investigated Krynski et al., 2012d):

Recent GOCE global geopotential models (GGMs) were evaluated over the area of Poland (Godah and Krynski, 2012b). Accuracy assessment of the 3rd release of GOCE GGMs was performed over the area of Poland using EGM2008 and GPS/levelling (Godah and Krynski, 2012a).

The results of absolute gravity survey with the A10-020 in Norway in 2011 were used for the validation of GOCE GGMs (Pettersen et al., 2012a; 2012b).

9. Earth tides monitoring

Earth tides were continued to be monitored in the Astrogeodetic Observatory of WUT in Jozefoslaw using LCR ET-26 gravimeter. The continuous gravity record was used for several studies. The results of tidal parameter estimation, ocean tidal loading, Earth free oscillation and Free Core Nutation (FCN) were presented (Rajner, 2012b). Also atmospheric effects in gravity measurements, both tidal and absolute, were investigated (Rajner and Olszak, 2012b). The study on the estimation of Free Core Nutation period and quality factor from tidal gravity measurements showed that even in the era of superconducting gravimetry, spring gravimeters still can be a source of valuable information about FCN (Rajner and Brzeziński, 2012).

Earth tides were continued to be monitored in 2012 at the Borowa Gora Observatory of IGiK with the LCR G gravimeter equipped with the modern feedback (Fig. 22).

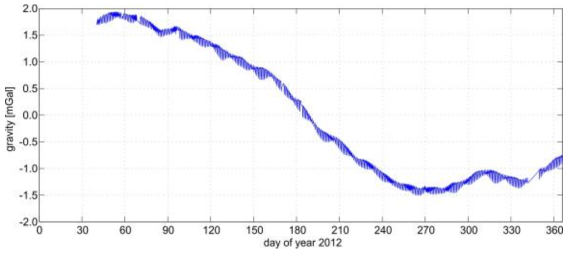

Fig. 22. Gravity record with LCR-G gravimeter in Borowa Gora averaged in 10 minute window

10. Activity in Satellite Laser Ranging

Accuracy of the SLR data and stability of station positions over the period 1983-2011 were estimated (Schillak et al., 2012a). The results show that the SLR stations accuracy is stable from January 1997 up to now. The earlier data, especially those from before 1993, exhibited too large biases mainly because they were based on only one LAGEOS satellite. The variations in positions from 1993-1996 are too large for most stations. In the last several years systematic biases are observed for the most accurate stations. Due to earthquake on 26 February 2010 the Concepcion station (7405) changed its position by about 3 m, while Arequipa (7403) and San Juan (7406) - by more than 3 cm. The tsunami in Japan in 11 March 2011 changed positions of the SLR stations Koganei (7308), Simosato (7838), and Changchun (7237) by 40 cm, 3 cm, and 2 cm, respectively.

The detailed analysis of SLR data of the stations in Riyadh (7832) (Alothman and Schillak, 2012, 2013) as well as Orroral and Mt. Stromlo (7843,7849,7825, and two GPS stations TIDB, STR1) (Schillak et al., 2012b) was performed for control positions and velocities and verification of the long distance geodetic tie between Australian stations. The results show the agreement in position and velocity for these Australian five sites an the level of several mm and below 1 mm/year, respectively, which confirms the possibility to use all these sites as one point.

Positions and velocities 18 GPS-SLR sites were determined for the period 1996-2011 from SLR and GPS data (Szafranek et al., 2012, 2013). The GPS solutions were reduced to the SLR reference point using local geodetic ties. Solutions of both techniques were analyzed in cooperation with Military University of Technology, Warsaw, in order to evaluate the agreement of both techniques and verify local ties, as improvement in further ITRS realization.

11. Geodynamics

Complex spectral analysis of a long-standing rotational time data series from 1986.0-2010.6 based on astronomical observations conducted at Borowa Gora Observatory was performed at the Institute of Geodesy and Cartography, Warsaw (Krynski and Zanimonskiy, 2012).

Earth crust deformation due to environmental loading was investigated at the Department of Geodesy and Geodetic Astronomy WUT. The effects of geodynamic processes such as Earth tides, ocean tidal loading, atmospheric tides, polar motion, indirect oceanic effect of polar motion, atmospheric and hydrology loading and non-tidal variation of sea level on the position determination in the area of Poland have been discussed (Rajner, 2012a). The significance of those effects and their impact on the results of absolute positioning was shown. Some of them are not negligible in case of relative positioning within a few hundred kilometres when sub-centimetre accuracy is required. Special attention was paid to the effect of atmospheric loading that was evaluated using data from the ASG-EUPOS network (Rajner and Liwosz, 2012a, 2012b).

A distinct correlation between absolute gravity measurements and hydrological loading was found for chosen periods (Rajner et al., 2012) but contribution of local hydrology and other effects on absolute gravity measurements are more significant. The seasonal gravity variation of 3 μGal is often hidden by environmental effects.

The effects of direct gravitational and indirect deformation on the gravity networks were investigated. Numerical weather model was used for computing atmospheric correction (Rajner and Olszak, 2012a). Program for computing atmospheric gravity correction is under development.

Polish research institutions providing geodetic observations in the framework of the IAG services (including GGOS) have signed in 2011 an agreement on the establishment of research network GGOS-PL integrating research activity of eight Polish observatories. The objective of GGOS-PL is to conduct coordinated joint research projects and joint activities to raise standards and services. GGOS-PL is open to cooperation with national and international research institutions involved in monitoring the Earth and its environment. The following observatories are participating in GGOS-PL: Borowa Gora Geodetic-Geophysical Observatory on the Institute of Geodesy and

Cartography, Astrogeodynamic Observatory Borowiec of the Space Research Centre of the Polish Academy of Sciences, Astronomic-Geodetic Observatory Jozefoslaw of the Warsaw University of Technology, Satellite Observatory in Cracow of the AGH University of Science and Technology, Lower Silesian Geodynamic Observatory in Ksiaz of the Space Research Centre of the Polish Academy of Sciences, Satellite Observatory in Lamkowko of the University of Warmia and Mazury, Satellite CGS Observatory in Warsaw of the Military University of Technology, Satellite Observatory in Wroclaw of the Wroclaw University of Environmental and Life Sciences (Fig. 23) (Bosy et al., 2012c).

Fig. 23. Observatories of GGOS-PL scientific network

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