National Report of Poland to EUREF 2014

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1. Introduction

Since 2012 the main geodetic activities at the national level in Poland concentrated on maintenance of gravity control, continuing operational work of permanent IGS/EPN GNSS stations, GNSS data processing on the regular basis at the WUT and MUT Local Analysis Centres, activities of MUT and WUT EPN Combination Centre, activity within the EUREF-IP Project, works towards monitoring troposphere, monitoring ionosphere and ionospheric storms, status of the ASG-EUPOS network in Poland, establishment of geodetic control point information system, 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).

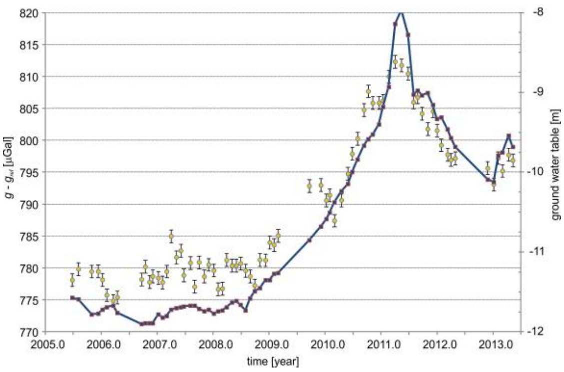

Fig. 1. Absolute gravity surveyed with the FG5-230 at Jozefoslaw (100 cm height)

Gravimetric investigations at Borowa Gora Geodetic – Geophysical Observatory of the Institute of Geodesy and Cartography (IGiK) were continued (Dykowski et al., 2013a). A series of absolute gravity measurements on the test stations of the Borowa Gora Geodetic-Geophysical Observatory conducted on monthly basis with the A10-020 gravimeter since September 2008 (Fig. 2) shows high quality of A10 data.

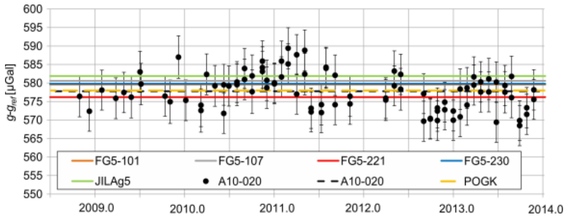

Fig. 2. Absolute gravity surveyed with the A10-020 at Borowa Gora (pillar level)

The comprehensive study on the estimation of total uncertainty budget for the A10-020 gravimeter was conducted (Dykowski et al., 2013b) The final results of the European Comparison Campaign of Absolute Gravimeters ECAG 2011 in Walferdange in Luxemburg proved high quality performance of the A10-020 gravimeter (Francis et al., 2013).

Activities towards the realization of the project on modernization of the Polish gravity control (Krynski et al., 2013; Krynski and Rogowski, 2013) were continued..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 118 base stations of the gravity control (Fig. 3).

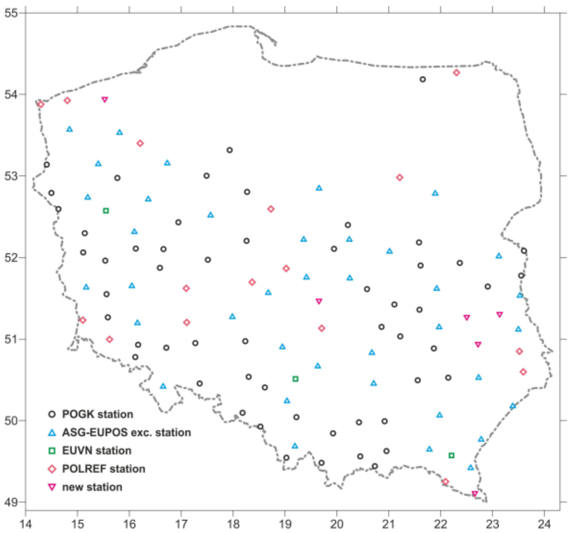

Fig. 3. Base stations of new gravity control surveyed in 2013

A comprehensive uncertainty analysis for both gravity and vertical gravity gradient was performed. The relation between the existing POGK98 gravity system in Poland and the newly established one was initially determined using data on 77 common stations (Krynski et al., 2013a; Krynski and Dykowski, 2013, 2014).

The A10-020 has further been successfully used in 2013 to complete the initiated in 2011 (Krynski and Rogowski, 2013) re-survey of gravity control in Sweden (Fig. 4).

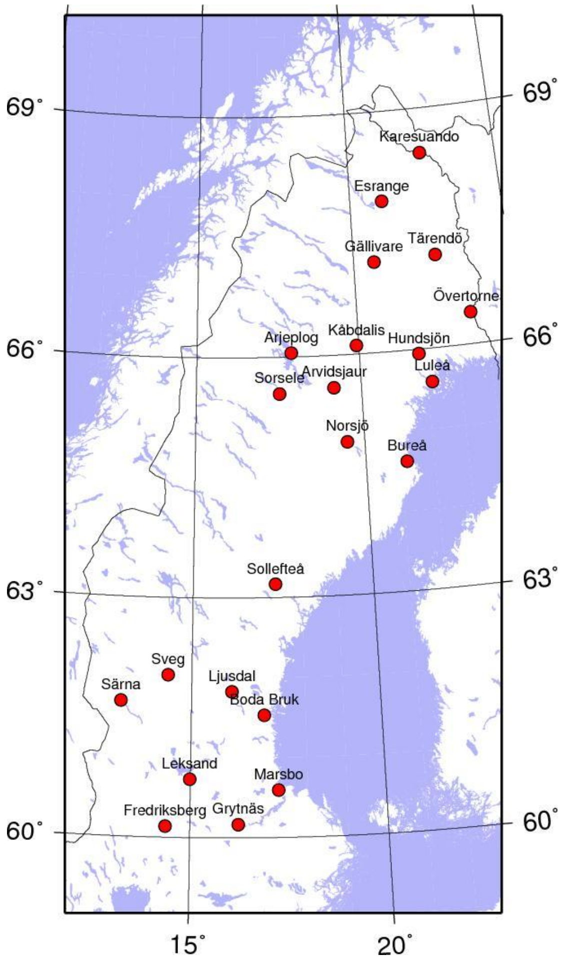

Fig. 4. Stations of gravity control networks of Sweden, surveyed with the A10-020 in 2013

New results on gravity change in Finland 1962-2010 from the comparison of legacy relative measurements with new measurements made with the A10-020 in 2009-2010 were obtained (Mäkinen et al., 2013).

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 (Table 1), 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. 5) 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. 6, Table 3).

Three of them, i.e. BOGI, BOR1 and JOZ2 participated also in IGS-Real time GNSS Data project.

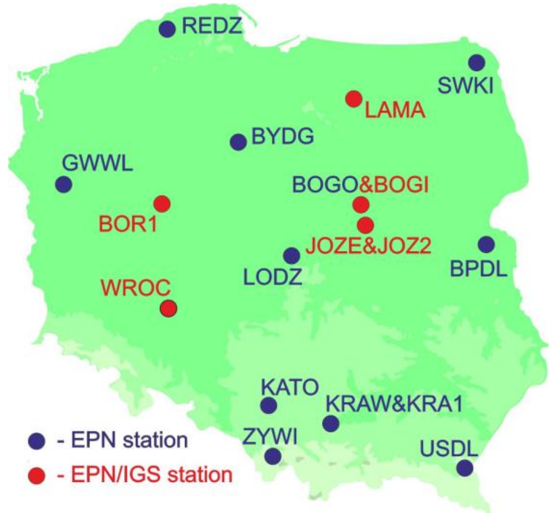

Fig. 5. EPN/IGS permanent GNSS stations in Poland (2014)

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
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
Krakow (KRAW)	50º03'58"	19º55'14"	EUREF	Ashtech μZ-12
Krakow (KRA1)	50º03'58"	19º55'14"	EUREF	TRIMBLE NetR5
Lamkowko (LAMA)	53º53'33"	20º40'12"	IGS, EUREF	LEICA GRX1200+GNSS
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	3JAN2001/ 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	4DEC2007/ 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	4DEC2007/ 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	3JAN2002/ 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	Krakow 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	Krakow 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 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	3DEC2007/ 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	7DEC2007/ 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	5DEC2007/ 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	3DEC2007/ 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)
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)
Krakow	KRAW	GPS	50.01	19.92	Ashtech µZ-12	RTCM 2.2 - 1(1),3(60),16(60),18(1), 19(1),22(60)
Krakow	KRA1	GPS+GLO	50.01	19.92	TRIMBLE NetR5	RTCM 3.0 - 1004(1),1006(10),1008(10), 1012(1),1013(10),1033(10)
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 GRX1200+GNSS	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. 6. Polish EPN stations participating in the EUREF-IP project (2013)

Since March 2005 Ntrip Broadcaster is installed at the AGH University of Science and Technology (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 Warsaw University of Technology operates the WUT EPN Local Analysis Centre (LAC) since 1996. WUT LAC contributes to EUREF with final weekly and daily solutions based on IGS final products, and rapid daily solutions of the EPN subnetwork (Liwosz and Rogowski, 2013). At the end of 2013, the WUT LAC subnetwork consisted of 93 GNSS stations (14 stations added and 1 removed in 2013) (Fig. 7).

Fig. 7. EPN stations providing data processed at WUT EUREF LAC (April 2014)

WUT LAC products can be accessed from the following EPN data centers: BKG (ftp://igs.bkg.bund.de/EUREF/products) and EPN (ftp.epncb.oma.be/epncb/product/clusters).
Since GPS Week 1765 (November 2013) WUT LAC uses the Bernese GNSS Software (BSW) v.5.2 for GNSS data processing (BSW v.5.0 was used before). The main changes in the processing strategy, due to the software change, involve, e.g.,

ambiguity resolution for GLONASS observations, the use of the GLONASS-specific receiver antenna phase center variations for GLONASS observations, correction of observations due to the higher-order ionospheric terms, and the use of the global mapping function for the zenith tropospheric delay estimation.

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, 2013). Currently MUT LAC processes data from 130 EPN stations distributed evenly in Europe (Fig. 8). Since GPS week 1773 due to GOP LAC reorientation (GOP LAC got focused on reprocessing activities instead of routine weekly contribution) 10 stations (CLIB, CPAR, CTAB, KRAW, MALL, MIKL, PUYV, TOR2, UZHL, ZYWI) were added to the MUT LAC subnetwork.

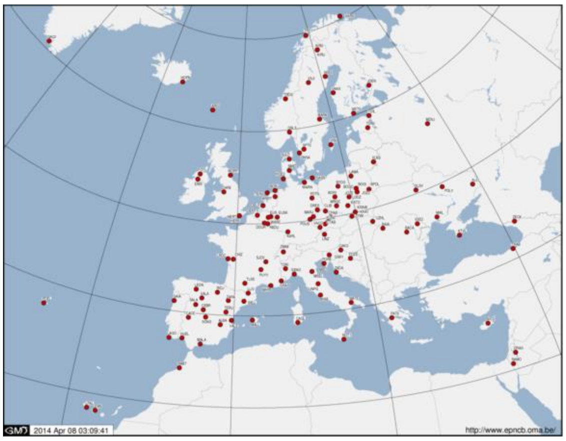

Fig. 8. EPN stations providing data processed at MUT EUREF LAC (April 2014)

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.

In 2013 the processing software was updated. Since GPS week 1755 MUT LAC uses Bernese 5.2, which besides GPS data is capable to processes GLONASS observations. In GPS week 1755 the GMF tropospheric model (Boehm et al., 2006)has been implemented as a priori model.

Since GPS week 1765 MUT LAC provides also final daily solutions. As a reference several stations with coordinates expressed in IGb08 are being used.

MUT LAC also participates in the new campaign of reprocessing project (repro2) and will provide full solutions for the entire network. The processing will be done for GPS weeks 834-1765 (18 years) using GAMIT software (only GPS observations). Main campaign was preceded by the benchmark test. In analysis the revised strategy (in relation to repro1) was used: 2nd and 3rd ionospheric corrections were applied as well as atmospheric loadings (tidal and non-tidal). Additionally some models were updated to the current version of IERS Conventions.

3.4. Activities of MUT and WUT EPN Combination Centre

According to the decision of EUREF Technical Working Group from 28 May 2013, a consortium of the Military University of Technology (MUT), and the Warsaw University of Technology (WUT) acts as the Analysis Combination Center (ACC) for a period of 4 years.

The new scripts for the combination of the solutions provided by the EPN Local Analysis Centers (LAC) based on the ones used in BKG were developed considering different reference frame (new solutions are tied to IGb08 instead of IGS08 in the old ones). The ACC preformed several tests concerning the selection of reference stations (only IGS stations were taken into consideration) and since GPS week 1788 started to use a new set of IGS reference stations with coordinates expressed in igb08. MUT/WUT solution also uses a slightly different method of excluding stations from the LACs contributions then the BKG one; usually it is a matter of 1 station. Several tests confirming that the quality of the combined solution does not decrease in comparison to the hitherto delivered solutions have been conducted during an overlap period of 3 months. MUT/WUT consortium started to provide routine combinations with GPS week 1768 (beginning of 2014). Since 1788 GPS week also daily combinations are provided. MUT is responsible for final (weekly and daily) combinations, while WUT takes care about rapid daily and ultra-rapid hourly combinations.

The web page (http://www.epnacc.wat.edu.pl) of the new ACC has also been developed. Currently it presents mainly the details of the weekly combined solutions, i.e. comparison of station coordinates, Helmert transformation parameters for each LAC solution with reference to the combined solution, and link to the full combination report available (ftp://epncb.oma.be/pub/product/reports/) from the EPN Central Bureau. The weekly reports sent by LAC email have been shortened; they now contain only the most important information. The full combined solutions are still available from the BKG server (ftp://igs.bkg.bund.de/EUREF/products/).

The EPN ACC is also responsible for setting up the processing strategy for all LACs. To keep it up to date, several changes have been introduced into the “Guidelines for the EPN Analysis Centres”, available from http://epncb.oma.be/_documentation/guidelines/guidelines _analysis_centres.pdf. First, final daily solutions became mandatory. Final weekly combined solutions are still the core EPN product delivered to the IGS as its European densification, but the daily combinations are developed in parallel. To avoid overlapping among LACs and to prepare for the new challenges which the EPN faces, the LACs have been encouraged to consider a possible re-orientation of their contribution to the EPN.

The updated analysis guidelines recommend to use orbits and clocks consistent with the analysis options and software used by each LAC (or to use combined IGS products) and require to exclude the defective satellites. Concerning troposphere parameter estimation, it is now mandatory to estimate hourly troposphere parameters for each station and it is recommended to submit tropospheric gradients estimated using the Chen-Herring model or the equivalent one. The updated guidelines also introduce the requirement of using GMF or VMF mapping function to map the tropospheric delay. Several other processing options have also been updated. Starting with GPS week 1765 the elevation cut-off angle was set to 3°, application of atmospheric tidal loading corrections is recommended and it is mandatory to include 2nd order ionospheric corrections and ionospheric ray bending corrections.

3.5. Other EPN and IGS activities

GNSS for meteorology

Research on integrated precipitable water (IPW) and zenith tropospheric delay (ZTD) time series derived from numerical weather prediction models was continued in 2013 in the Warsaw University of Technology.

Greatest attention is paid to input fields (and first prognosis steps) of operational numerical weather prediction model COSMO-LM maintained by the Institute of Meteorology and Water Management in Poland. Different static solutions (mainly IGS and EPN) and IPW/ZTD calculated from numerical weather prediction model grid in several tested modes were compared.

ZTD provided by IGS and EPN, recalculated to IPW show good agreement with IPW from COSMO model. COSMO reveal positive IPW bias of about 1 mm, i.e. the model is ‘too wet’ (see Fig 9). Many factors affect both procedure of IPW derivation from COSMO model as well as its calculation from tropospheric delay. The most crucial is the difference between the actual height of GNSS station and its height from the model, but even minor ones like water vapour density formula or barometric equation can affect IPWV at sub-millimetre level (Kruczyk and Mazur, 2013).

GNSS networks provide vertically integrated humidity information (precipitable water) which can feed COSMO model (nudge water vapour content in right direction) in much denser network then the one used in radiosoundings.

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 continued at the Institute of Geodesy and Geoinformatics (IGG) (http://www.igig.up.wroc.pl/igg/) of the Wroclaw University of Environmental and Life Sciences (WUELS). In 2013 it was performed within the COST ES1206 action "Advanced Global Navigation Satellite Systems tropospheric products for monitoring severe weather events and climate" - GNSS4SWEC (http://gnss4swec.knmi.nl/) (Bosy et al., 2013).

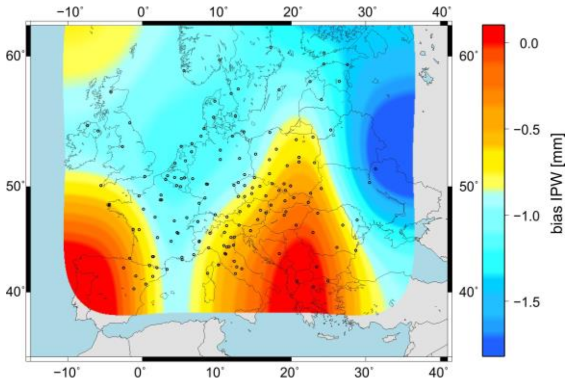

Fig. 9. IPW difference (GNSS EUR tropospheric combination - COSMO-LM_14; annual average) map for 2011, meteo from COSMO model [mm]

The NRT ZTD estimation service to monitor the state of troposphere from GPS observations for the area of Poland is provided. The ZTD (IGGHZ-G) is estimated continuously since December 2012 in hourly intervals for 125 GNSS stations including 100 ASG-EUPOS reference stations and 25 EPN/IGS stations located close to the Polish border (Bosy et al., 2013). Together with ZTDs, the horizontal gradients of ZTDs are estimated. Following the COST ES1206 Action guidelines, the tests to obtain the most reliable procedure of ZTD and its gradients estimation of are performed as well as the tests to speed-up the processing procedures to obtain the ultra-fast troposphere products (Kapłon et al., 2014). Table 4 presents the comparison of NRT ZTDs + gradients (WUEL) with the reference troposphere product (ASR) from the Centre of Applied Geomatics of MUT in Warsaw (http://www.cgs.wat.edu.pl/).

The IGGHZ-G NRT ZTD outputs are sent to the EUMETNET EIG GNSS water vapour programme (E-GVAP: http://egvap.dmi.dk/) in 1h intervals and used for IWV determination in high resolution above Europe (Bosy et al., 2013, Kapłon et al., 2014).

The model of ZTD based on meteorological data (IGGHZ-M) has been investigated (Bosy et al., 2013, Kapłon et al., 2013). The meteorological data are available from ground meteorological sensors from Poland and neighbouring countries, with different temporal resolutions (SYNOP: 3h, METAR: 0.5h, ASG-EUPOS: 1h). The IGGHZ-M model is an alternative to IGGHZ-G and is available in real-time (Bosy et al., 2013; Hadas et al., 2013; Wielgosz et al, 2013b). The IGGHZ-G and IGGHZ-M ZTD models were tested by Wielgosz et al. (2013a) for positioning in fast static mode. Table 5 depicts the IGGHZ-G and IGGHZ-M impact on positioning and ambiguity resolution success rate (AVSR %).

Table 4. The comparison of NRT troposphere products to the reference product (ASR) (Kaplon et al., 2014)

Processing scheme	Processing time	Average from	ZTD bias [mm]	Std dev. [mm]	Gradient north component bias [mm]	Std dev. [mm]	Gradient east component bias [mm]	Std dev. [mm]
12 h without gradients	25 min	720 h	-1.11	7.27				
4 h without gradients	9 min	336 h	-1.84	7.67				
4 h with gradients	9 min	336 h	-1.11	11.20	-0.13	1.88	-0.15	1.81

Table 5. The statistics of the positioning results obtained with the application of different troposphere models for the LELO-KRAW baseline (Wielgosz et al., 2013)

Strategy	dN (m)	dE (m)	dU (m)	STD N (m)	STD E (m)	STD U (m)	AVSR (%)	AVF (%)
ASG (1)	−0.004	−0.003	**0.013**	0.009	0.005	**0.017**	83.3	2.1
IGGHZG (2)	−0.004	−0.003	**−0.007**	0.008	0.005	**0.021**	**89.6**	1.4
IGGHZM (3)	−0.005	−0.002	**−0.045**	0.009	0.005	**0.018**	83.3	1.4
UNB3m (4)	−0.003	−0.003	**−0.004**	0.009	0.005	**0.019**	84.0	2.1

The research on the use of discrete mesoscale mapping functions delivered from MWP models (Kroszczynski, 2014) in GNSS real time data processing (Bosy et al., 2013, Wielgosz et al., 2014) was related to COST Action ES1206.

The research on the improvements of tropospheric water vapour near real-time (NRT) estimation system was also conducted. The unconstrained approach for GNSS tomography model was proposed (Rohm, 2013). New limited constraint robust Kalman filtering tomography model implementation has been shown (Rohm et al., 2013b). The model was validated against reference real and synthetic observations (Fig. 10); the obtained results show that the observations (of ZTD origin) contaminated with outliers will produce spurious estimates of water vapour. Therefore the application of robust filter is essential to successfully establish 3D model of troposphere.

The quality of the GNSS tomography retrieval is similar to the water vapour fields produced by the Numerical Weather Prediction Models (Manning et al., 2014) and is equal to 1 – 2 hPa (Rohm et al., 2014a). This confirms the results obtained from other GNSS tomography models (Rohm et al., 2014b)

Research on application of GNSS observations to weather forecasting (Rohm et al., 2014a) and severe weather in particular (Manning et al., 2014), improving our understanding of the storms on the propagation of GNSS signals was conducted in collaboration with SPACE Research Centre at RMIT University in Melbourne, Australia. As a consequence the methodology to derive tomography based statistics aiming to show precursors of dangerous weather phenomena (Fig 11). These studies (Rohm et al., 2014a) also confirmed high quality of all-weather data available from real-time GNSS ground based observations (Fig. 12)

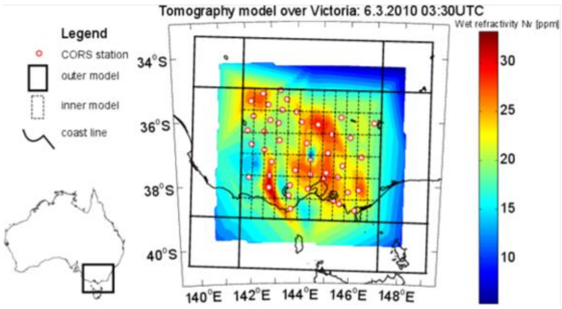

Fig. 10. The TOMO2 tomography model voxel settings superimposed on the wet refractivity field of 6 March 2010, 3:30UTC. The wet refractivity field is the output of tomography model in the RG2SAD mode (Rohm et al., 2013)

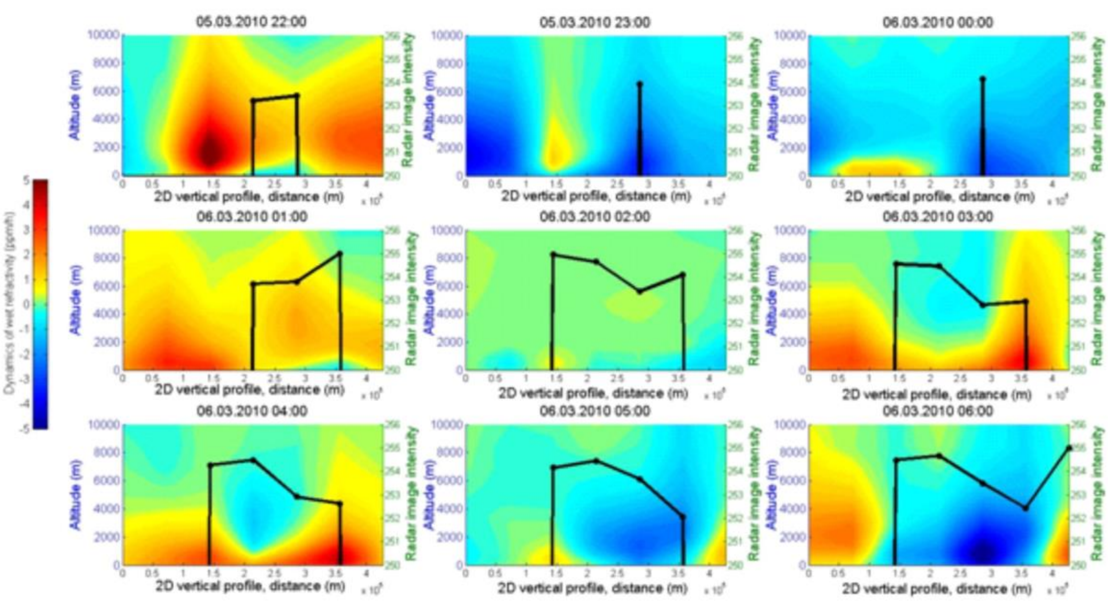

Fig. 11. The time series from 5 Mar 2010 22:00 to 6 Mar 2010 06:00 (UTC) presenting 2D tomographic cross section against the weather radar image intensity (Manning et al., 2014)

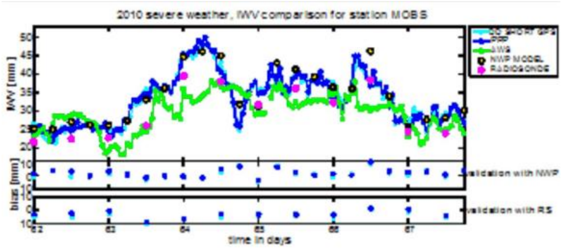

Fig. 12. The integrated water vapour comparison between four different techniques: GNSS (DD SHORT GPS, PPP), Automatic Weather Station (AWS), NWP model and radiosonde. Residuals in bottom two panels show agreement of GNSS IWV with other data (Rohm et al., 2014a)

Space-based GNSS observations, were applied as an assimilation product, for NWP models in Australia (Norman et al., 2014). The analysis performed resulted in identifying COSMIC profiles as a valuable data source.

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., 2013).

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 the dynamics of latitudinal profiles and structure of mid- and high-latitude ionosphere.

Cross-hemisphere comparison of mid-latitude ionospheric variability during 1996–2009 has been performed. Analysis of a long-time series of hourly median characteristics of the ionospheric plasma at two mid latitude locations in the Northern and Southern hemisphere, Juliusruh (54.6N; 13.4E) and Hobart (42.9S; 147.3E), reveals patterns of their synchronous and independent variability (Zakharenkova et al., 2013c). During the high solar activity in 2000–2002, seasonal variations show a complicated cross-hemisphere behaviour influenced by the winter and semi- annual anomalies, with the largest noon-time values of TEC and NmF2 observed around equinoxes. The winter anomaly in GPS vTEC values was much weaker than in NmF2 for the Northern hemisphere mid-latitudes and was entirely absent at the Southern hemisphere (Fig. 13, Fig. 14 and Fig. 15). Analysis of IRI vTEC demonstrates the model limitations, related with the absence of the plasmaspheric part, and actual demand in a reliable and standard ionosphere–plasmasphere model for analysis of GPS vTEC.

A comparative study of foF2 measurements with IRI-2007 model predictions during extended solar minimum was performed. The effect of the uncertainties in the predictability of solar activity indices on the IRI outcome was analysed and the

IRI values calculated with predicted and observed indices were compared to the actual measurements (Zakharenkova et al., 2013a).

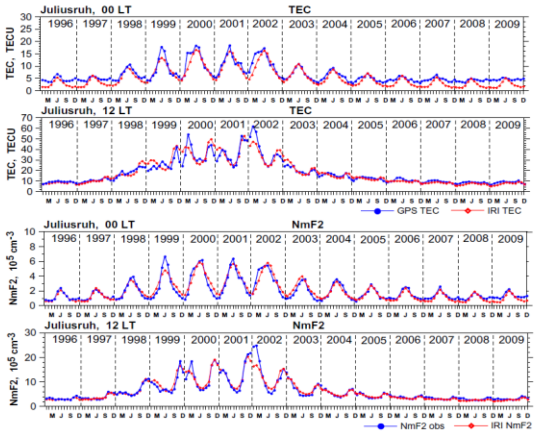

Fig. 13. Comparison of GPS vTEC and NmF2 versus the model predictions by IRI-2012 at local noon (12 LT) and local midnight (00 LT) for Juliusruh; observations are marked by line with circles, model simulations – by line with rhombuses

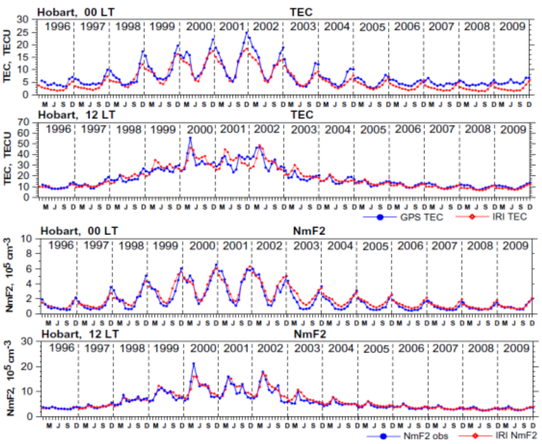

Fig. 14. Comparison of GPS vTEC and NmF2 versus the model predictions by IRI-2012 at local noon (12 LT) and local midnight (00 LT) for Hobart; observations are marked by line with circles, model simulations – by line with rhombuses

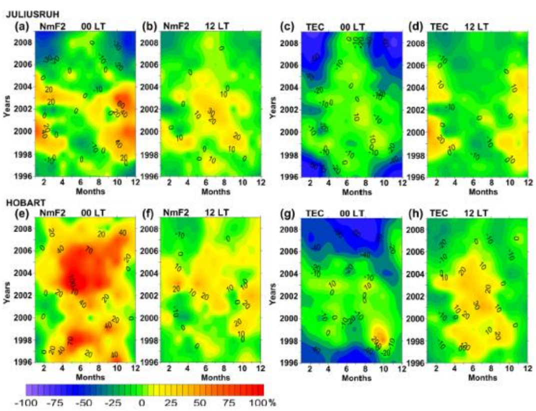

Fig. 15. Percentage model-data differences for Juliusruh and Hobart as a function of month and year

Monthly median values of F2 layer critical frequency (foF2) derived from the ionosonde measurements at the mid-latitude ionospheric station Juliusruh were compared with the International Reference Ionosphere (IRI-2007) model predictions (Fig. 16). It has been shown that the use of an older index file can lead to serious IRI overestimations of F-region electron density during the recent extended solar minimum.

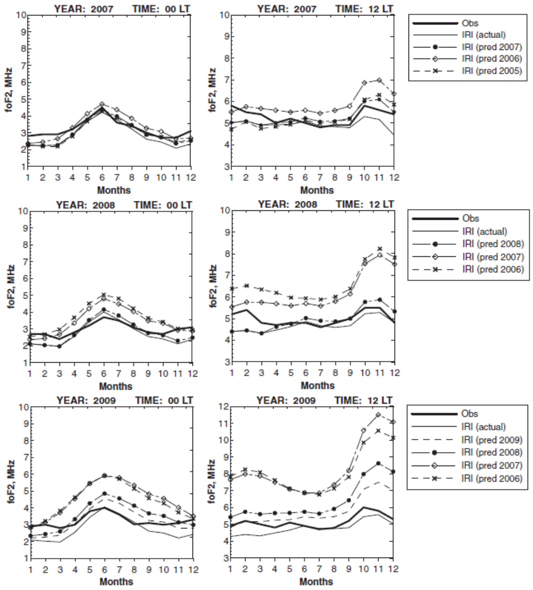

Fig. 16. Comparison of the measured monthly median values of the critical frequency foF2 for local noon and midnight with IRI results derived with different predicted/observed indices of solar activity level

Comparative analysis of GPS TEC data and FORMOSAT-3/COSMIC radio occultation measurements was carried out for Japan region during period of the extremely prolonged solar minimum of cycle 23/24 (Zakharenkova et al., 2013b). Joint analysis of GPS TEC and COSMIC data allows to extract and estimate electron content corresponded to the ionosphere (its bottom and topside parts) and the plasmasphere (h > 700 km) for different seasons of 2007–2009 (Fig. 17).

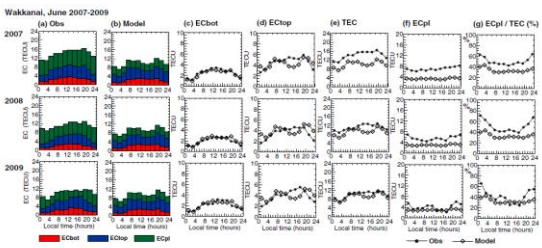

Fig. 17. Monthly median estimates of electron content over Wakkanai point for summer solstice of the years 2007–2009. Bar graphs show median diurnal variation of TEC divided into portions for observed (a) and modeled (b) values. Graphs (c)–(f) illustrate comparison of separate portions in more detail. Observations are marked by line with black circles, model simulations – by line with rhombuses. Graph (g) shows the percentage contribution of ECpl to GPS TEC

The obtained results were compared with TEC, IEC and ECpl estimates retrieved by Standard Plasmasphere–Ionosphere.

Approximation techniques for local total electron content mapping were validated (Krypiak-Grzegorczyk et al., 2013).

3.6. Advanced methods for satellite positioning

Research on advanced methods for satellite positioning was carried out at the University of Warmia and Mazury (UWM) in Olsztyn. It was focused on the development of the Modified Ambiguity Function Approach for precise GNSS positioning (Cellmer et al. 2013). Also the algorithm for GPS + Galileo and multi-frequency Galileo precise positioning was developed (Paziewski and Wielgosz, 2013).

4. ASG-EUPOS network

4.1. Status of the ASG-EUPOS network

At the end of 2013 r. 101 ASG-EUPOS permanent reference stations operated in Poland (31 GPS/GLONASS stations). Other 23 reference stations from neighbouring countries were included to the common solutions within ASG-EUPOS (Fig. 18).

Fig. 18. Reference stations of the ASG-EUPOS system (14 April 2014)

In 2013 the Trimble® Pivot Platform GNSS infrastructure software has been successfully implemented in ASG-EUPOS management centres. The number of changes in the ASG-EUPOS stations took place in 2013. The stations CHOJ (Chojnice), GDAN (Gdansk), KOSC (Koscierzyna), and STRG (Starogard Gdanski) have been upgraded to GPS&GLONASS capability (including GALILEO tracking). They are being prepared to launch a new multi-GNSS network RTK service in the area of Gdansk along with the existing BYDG (Bydgoszcz), REDZ (Redzikowo), ELBL (Elblag) and WLAD (Wladyslawowo) stations. NWTG (Tarnowskie Gory) station was moved to a nearby station NWT1. The new station MIEL (Mielec) have been included into the ASG-EUPOS system and the new station WIEL (Wielun) replaced the old one. Two existing stations CBKA (Warszawa) and OLST (Olsztyn) were excluded from the RTK network solution due to obsolete hardware. Moreover, CBKA station was temporarily excluded from the system due to hardware failure.

New automatic postprocessing module for ultra-fast static positioning (POZGEO-2) designed for the ASG-EUPOS system in the frame of the ASG+ project was developed and validated.

Current statistics show, that the use of ASG-EUPOS services exhibits further growth. At the end of 2013, the number of registered users exceeded 12 500 (of which about 7500 had active accounts in 2013) and use of the most popular real-time service NAWGEO (RTK) reached up to 700 simultaneous connections in the peak hours. All ASG-EUPOS services are provided free of charge for registered users. However, some activities have been initiated in the area of legal changes in order to introduce charges in the 2014.

5. Local GNSS networks

Besides the ASG-EUPOS three other GNSS permanent station networks in Poland are operating for commercial use. There are: TPI NET PRO (developed by TPI the local Topcon and Sokkia equipment reseller) which encompasses nationwide distributed 118 stations, VRSNET.PL (developed by Geotronics Polska the local Trimble equipment reseller) which encompasses 21 stations located in NW part of Poland and Silesia region, and Leica SmartNet Poland (developed by Leica Geosystems Polska the local Leica equipment representative) which encompasses 60 stations concentrated mainly near Gdansk and Lodz, and southern part of Poland.

6. The geodetic control point information system

In 2013 a state register of geodetic, gravimetric and magnetic control network (PRPOG) has been established which contains a database on horizontal, vertical, gravimetric and magnetic fundamental network points. The PRPOG will provide all users with the geo reference data through a standardised exchange interface.

In 2013 three geodetic data models have been released containing identical grid points on which differences of coordinates and heights between horizontal as well as vertical datums in Poland had been determined. The models are publicly available at the home page of the Head Office of Geodesy and Cartography, Warsaw, and may be used for the purpose of a data transformation with centimetre accuracy.

7. Vertical control

In 2013 the final adjustment of the 4th levelling campaign in Poland was completed. The campaign started in 1998 with precise spirit levelling of 1st order network (16 226 benchmarks and 17 516 km of levelling lines) and then continued with spirit levelling of 2nd order levelling network (25.868 benchmarks and 17.930 km of levelling lines) was finished in 2012. Also, 63 EUVN and EUVN DA points as well as 71 eccentric points of a network of ASG-EUPOS permanent stations were included into adjustment. All heights were reduced to zero tidal system.

The final common solution was performed in EVRF2007-NH using 49 stable EUVN points as datum points. The accuracy of levelling was estimated as 0.74 mm/km, standard deviation of the height of a single benchmark is 3.5 mm and its maximum error is 7.5 mm (at the state border). The differences between the heights in EVRF2007-NH and KRON86-NH datums are presented in Figure 19.

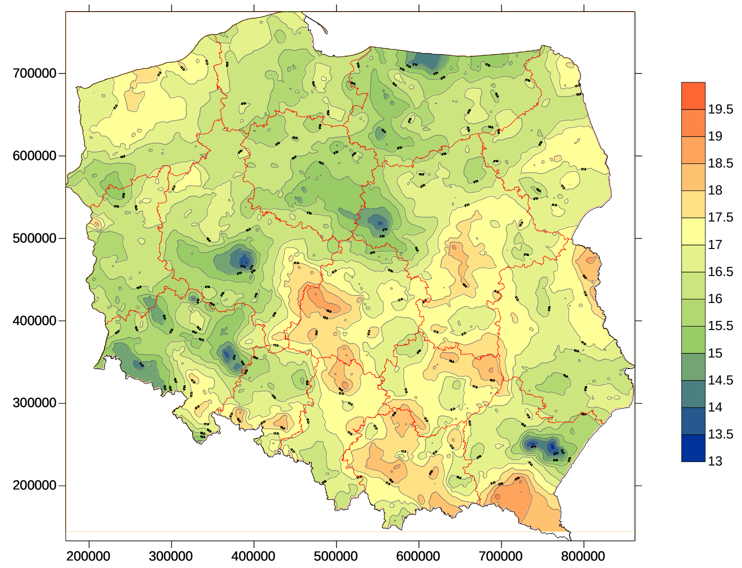

Fig. 19. Differences of heights between vertical datums PL-EVRF2007-NH and PL-KRON86-NH [cm]

8. The use of data from satellite gravity missions

Recent GOCE global geopotential models (GGMs) were evaluated over the area of Poland (Godah and Krynski, 2012). The use of GOCE-based geopotential models for modelling the gravimetric quasigeoid for Poland was assessed (Godah et al., 2014). The 3rd release GOCE GGMs were also assessed over the area of Sudan (Godah and Krynski, 2013). The studies on GOCE-based GGMs conducted over the area of Poland have efficiently been applied for the evaluation of quality of terrestrial gravity and GNSS/levelling data in Sudan.

9. Earth tides monitoring

Earth tides were continued to be monitored in 2013 at the Borowa Gora Observatory of IGiK with the LCR G gravimeter equipped with the modern feedback (Fig. 20).

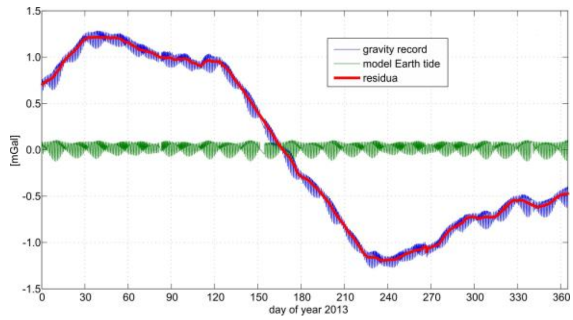

Fig. 20. Gravity record with LCR-G gravimeter in Borowa Gora Observatory averaged in 1 hour window

10. Activity in Satellite Laser Ranging

Although satellite laser ranging station at Borowiec (7811) was still non-operational in 2013 several tasks of the orbital analysis of the SLR data were performed by the SLR team of Borowiec Astrogeodynamic Observatory of the Space

Research Centre PAS in cooperation with other research tems.

The analysis of observations of LAGEOS-1 and LAGEOS-2 satellites in 1983-2012 from 74 fixed SLR stations and 63 sites of mobile stations was completed in 2013. The station velocity vectors were determined for 90 sites for which time span was longer than 3 years. The range biases and RMS of fit in five years span satellites were determined for each site independently for both LAGEOS satellites. The geocentric and topocentric coordinates in ITRF2008 and their standard deviations, and velocity vectors of all stations were also computed (www Borowiec, 2013). The quality of the best SLR stations was estimated (Schillak et al., 2013b). The significant improvement of the results quality from ±4 cm in 1983 to ±5 mm in 1997 was detected. After 1997 the quality of the best SLR stations was at the level ±5 mm with slight deterioration in 2005-2012 which is due to periodical systematical deviations of some stations, jumps in the station position caused by changes in the SLR system, and mainly Earthquakes, which in the last several years caused position and velocity changes of the six important SLR stations, the largest for Concepcion (2010) and Koganei (2011) (Schillak and Lejba, 2013; Schillak et al., 2013a). The analysis of SLR results from Zimmerwald shows annual dependence between laser light wavelength (423 nm and 846 nm) and station range bias with 5 mm amplitude for both LAGEOS-1 and LAGEOS-2 (Schillak, 2013a, 2013b).

The analysis of the time series of GNSS solutions for the stations on Arabian tectonic plate confirmed the results concerning the plate motion obtained for Riyadh SLR station from the analysis of SLR data (Alothman et al., 2013)

The analysis based on comparison of SLR and GNSS solutions was continued in 2013. The positions and velocities were determined for all 34 co-location stations, which performed observations by both techniques from 1996.0 to 2013.0. The station position was determined for SLR reference point considering local geodetic tie SLR-GNSS from IERS which allowed the verification of local geodetic ties with the use of GPS solutions (Szafranek et al., 2013). The differences between the solutions of SLR and GPS in N, E, U did not exceed 10 mm components for most stations. The agreement in station velocities was at the level of 1 mm/year. The use of the both techniques allowed for more accurate analysis of the position and velocity changed due to earthquakes (Schillak et al., 2013a).

At the end of 2013 the new laser was installed in Borowiec Observatory and its SLR station will soon become operational.

11. Geodynamics

Atmospheric effects in gravity measurements records were investigated at the Warsaw University of Technology. The extensive numerical tests of the performance of different atmospheric gravity correction approach using numerical weather models were conducted (Rajner and Olszak, 2014). The numerical results were confronted also with real gravity data (Rajner, 2014).

The open source software called *grat*, that handles single admittance corrections as well as physical 2D and 3D methods, taking the full advantage of modern numerical weather models has been developed. It is freely available as a git repository (https://code.google.com/p/grat/). For the users with limited programming skills the gr@ system has been developed which is the internet service, where all the processing settings are easily selected with the browser and results are send to user (www.grat.gik.pw.edu.pl/gr@).

Activity of research network GGOS-PL (Fig. 21) established in 2011 (Krynski and Rogowski, 2013), integrating research programs of eight Polish observatories related to GGOS project of IAG was continued. The contribution of the GGOS-PL network to EPOS project was discussed (Bosy et al., 2013).

Fig. 21. Observatories of GGOS-PL scientific network

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