NATIONAL REPORT OF POLAND TO EUREF2021

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Main geodetic activities at the national level in Poland since 2019



- activities in the horizontal and vertical control
- maintenance of the gravity control
- maintenance of the magnetic control
- operational work of permanent EPN/IGS stations
- data processing at Local Analysis Centres at WUT and MUT
- activities of MUT and WUT EPN Combination Centre
- status of the ASG-EUPOS network in Poland
- modelling precise geoid
- the use of data from satellite gravity missions
- GNSS for meteorology
- monitoring of ionosphere
- monitoring gravity changes and geodynamics
- activities in SLR







Head Office of Geodesy and Cartography (GUGiK)

Activities in the horizontal and vertical control

Continuation of field inspection of geodetic control network

In 2020 initiated works related to the new levelling campaign in Poland

EVRF2007 solution should be locally implemented in Poland by the end of 2023





Maintenance of national gravity control (1)



Jozefoslaw Astrogeodetic Observatory, Warsaw University of Technology <u>WUT</u>

quasi-permanent absolute gravity measurements with FG5-230







Maintenance of national gravity control (2)

Borowa Gora Geodetic-Geophysical Observatory Institute of Geodesy and Cartography <u>IGiK</u>, Warsaw

quasi-permanent absolute gravity measurements with A10-020







Maintenance of national gravity control (3)



Borowa Gora Geodetic-Geophysical Observatory Institute of Geodesy and Cartography <u>IGiK</u>, Warsaw

gravity determined with the A10-020 and iGrav-027 gravimeters from more than 4 years of operation at the Borowa Gora Observatory







Maintenance of national gravity control (5)



gravity control survey in the Ireland island with the A10-020 gravimeter

network stations:

red – both absolute and vertical gravity gradient surveys done green – vertical gravity gradient survey done only







Maintenance of magnetic control



IGiK

repeat stations, permanent stations and magnetic observatories



3 independent components of the magnetic intensity vector measured at

- 7 repeat stations (2019)
- 5 repeat stations (2020)





Operational work of permanent GNSS IGS/EUREF stations



EPN stations in Poland (19)

- Biala Podlaska (BPDL)
- Borowa Gora (BOGE)
- Borowa Gora (BOGI)
- Borowa Gora (BOGO)
- Borowiec (BOR1)
- Bydgoszcz (BYDG)
- Gorzow Wielkopolski (GWWL)
- Jozefoslaw (JOZE)
- Jozefoslaw (JOZ2)
- Katowice (KATO)
- Krakow (KRAW)
- Krakow (KRA1)
- Lamkowko (LAMA)
- Lodz (LODZ)
- Redzikowo (REDZ)
- Suwalki (SWKI)
- Ustrzyki Dolne (USDL)
- Wroclaw (WROC)
- Zywiec (ZYWI)

EPN Stations participating in EUREF-IP (7) ♥ BOGO ♥ BOR1 ♥ JOZ2 ♥ KRA1 ♥ KRAW ♥ LAMA ♥ WROC







Data processing at LACs



<u>WUT</u>

data from 138 EPN stations routinely processed (*April 2021*)



<u>MUT</u>

data from 153 EPN stations routinely processed (*April 2021*)







GNSS activities at MUT AC (1)



Two sets of daily products are provided

- based on GPS data
- based on Galileo data



coordinate repeatability of GPS-only and Galileo-only solutions





GNSS activities at MUT AC (2)



Processing local GNSS data and providing

- station coordinates monitoring service RefMON
- data QC service
- within the EPOS project

webpage of the coordinate monitoring service RefMON



displacement of the point located in the mining area







MUT–WUT EPN Combination Centre



16 ACs were submitting SINEX solutions for the weekly EPN combination

 test phase concerning the evaluation of the impact of adding Galileo observations on combined EPN station positions was finished in 2019

mean differences of station positions between combined three-system (GPS, GLONASS, and Galileo) test solutions and EPN combined two-system (GPS and GLONASS) operational solutions



 since the week 2106 (17 May 2020) the daily and weekly combined solutions have been aligned to the new IGS reference frame - IGb14





ASG-EUPOS network in Poland



Head Office of Geodesy and Cartography <u>GUGiK</u>



- 125 stations track GPS + GLONASS
- 119 stations track
 GPS + GLONASS + Galileo
- 118 stations track GPS + GLONASS + Galileo +BDS

New reference stations planned to be established in 2021-2023

GUGiK and MUT participate in the EPN Densification project









UWM with ASTRI Poland

- development and implementation of field calibration procedure for multi-frequency and multi-system GNSS antennae
 - differences of derived full PCVs (GPS L1 frequency) between the final PCCs model and IGS calibration values



improvement in an ambiguity function-based GNSS precise positioning





GNSS receiver antenna calibration (2)



• study of the influence of antenna phase centre modelling on the determined positions

impact of using G2 (GPS) corrections for E5a frequencies (Galileo); darker columns refer to the DD approach



eurst



Advanced methods for satellite positioning (1)



<u>UWM</u>

- multi-constellation and high-rate signal processing
- application of smartphone GNSS observables to precise positioning
- application of 100 Hz multi-constellation GNSS measurements
- methodology aiming precise wide-area RTK and static relative positioning in the presence of <u>severe ionospheric conditions</u>
- analysis of sub-hourly (30 min) PPP solutions



Advanced methods for satellite positioning (2)



UWM

 contribution of Swarm data to the prompt detection of tsunamis and other natural hazards - COSTO project TET SPECTROGRAM day 253

co-located Swarm pass and ground GNSS observations at time of SID triggering











accuracy analysis of global ionosphere maps provided by lonosphere Associate Analysis Centers (IAACs) of the International GNSS Service (IGS)

F10.7 index and daily RMS distribution based on a comparison with ground GNSS observations for all analysed GIMs in 2014





Advanced methods for satellite positioning (4)



WUELS

quality control of GNSS data processing using information criteria

RMSE between coordinates estimated with GPS and Galileo in five different variants and IGS weekly combined solution (SPP-single point positioning, PPP-precise point positioning, B-broadcast ephemeris, R-real-time service products, M – IGS MGEX Final products)



<u>MUT</u>

 research on the change of the performance of the PPP positioning with the development of GNSS systems





Modelling precise geoid (1)



<u>IGiK</u>

 new gravimetric quasigeoid model GDQM-PL19 was developed and compared with the official Polish quasigeoid models (std < 1.5 cm)

<u>WUT</u>

• validation of EGG2008 and EGG2015 at ASG-EUPOS network stations (~2 cm)

UWM

analysis of the southern Baltic Sea level changes





Modelling precise geoid (2)



 Wroclaw University of Environmental and Life Sciences <u>WUELS</u>
 integrated modelling of local quasigeoid in South-Western Poland using 4 approaches



• the use of the Geophysical Gravity data Inversion (GGI) approach for geoid modelling









- validation of the newest GGMs
 - GOCE-based GGMs: GO_CONS_GCF_2_TIM_R6; GO_CONS_GCF_2_DIR_R6
 - combined GGMs: GO_CONS_GCF_2_TIM_ R6e; XGM2019e (d/o 5540)
- contribution of gravity satellite missions to the Earth's gravity field modelling research for areas of Ethiopia and Uganda in the Eastern Africa
- a model of temporal mass variations within the Earth system developed using GRACE and GNSS data
- the use of national CORS networks for determining temporal mass variations within the Earth's system and for improving GRACE/GRACE-FO solutions
- assessment of orthometric/normal heights changes using GRACE satellite mission data







• temporal variations of geoid heights obtained from RL06GRACE-based GGMs over the area of Poland represented by 4 subareas



GRACE/GRACE-FO

MSC#400 MSC#401 2710 2019.5 2019 2019.5 2020.5 2006.5 Mascon #:40 deeron a diffe time (year) time (year Maston #470 Mascon # 47 MSC#470 MSC#471 2018.5 2019 2019.5 2021 2018.5 2019 2019.5 2020 2020 5 2025

GRACE-FO

 analysis of the Earth's surface deformations in North-East India and Nepal Himalaya



Use of data from satellite gravity missions (3)



<u>UWM</u>

• analysis of changes in groundwater level in Poland obtained from direct measurements in wells and groundwater storage anomalies calculated using GRACE data



<u>WUT</u>

 analysis of accuracy of gravity field changes from GRACE RL06 and RL05 data compared to in situ gravimetric measurements \in the context of choosing optimum filtering







Space Research Centre of the Polish Academy of Sciences SRC PAS

- investigation of geophysical interpretation of <u>polar motion</u> based on the GRACE data and hydrological models
- $\chi 1$ and $\chi 2$ components of GAO and HAM from GRACE gravity models and from GRACE & SLR





• usefulness of gravity models based on kinematic orbits of LEO satellites in the study of polar motion excitation







Use of data from satellite gravity missions (5)



Space Research Centre of the Polish Academy of Sciences SRC PAS

 comparison of methods of HAM/CAM estimation and investigation of the compatibility between data from various GRACE/GRACE-FO data centres

time series of χ1 and χ2 components of HAM/CAM computed from the GRACE & GRACE-FO monthly solutions provided by various data centres







GNSS for meteorology (1)



<u>UWM</u>

 assessment of GNSS IWV estimates over central and north-eastern Amazonia

time series and of Radiosonde- and GNSS-IWV and the differences from Radiosonde

 analysis of the impact of different GNSS antenna calibrations models on the quality of the tropospheric estimate series for climate applications

mean ZTD differences between [GPS+GLO+GAL] processing (PPP) and ERA-Interim (navy blue) as well as GPS only processing (zerodifferenced network solution) and ERA-Interim (orange), 2017









GNSS for meteorology (2)



WUELS

• maintenance the analysis centre for near real-time (NRT) troposphere state retrieval for meteorology purpose

GNSS stations processed in NRT mode for E-GVAP (2020-03-20)



NRT ultra fast test selected stations



Statistics of ZTD comparison between EPN AC, FPP, and NRT









Gdansk University of Technology (GUT)

use of GNSS tropospheric products to meteorology application



over the study area on 11 August 2017 (19:30 to 20:30 UTC) in 30-minute steps





GNSS for meteorology (4)



Gdansk University of Technology (GUT)

use of GNSS tropospheric products to meteorology application (cont.)

gridded gradients estimated from the GNSS observations (left: 19:30 UTC; right: 20:00 UTC) on the background of the composite reflectivity derived from the meteorological radars

 establishing of a new model for water vapour weighted mean temperature estimation based on the surface temperature

RMS values of the precipitable water vapour (PWV) estimated using Bevis and ETmPoly coefficients; the PWV derived from RS profiles were adopted as a reference









Monitoring ionosphere (1)



<u>UWM</u>

- validation of global ionosphere models for different solar activity levels
- investigating of different parametric modelling techniques
- application of TEC derived from dual-frequency altimetry missions in the validation of regional ionospheric TEC maps based on GNSS data



Ionospheric corrections for Kuband along selected tracks











Monitoring ionosphere (2)



<u>UWM</u>

- investigations of current methods of ionosphere sounding with an algorithm aimed at extraction of information on large-scale plasma structures
- analysis of the applicability of the relative STEC values to detection of largescale ionospheric structures occurring at high latitudes
- investigation of a capability of continuous detection of polar patches with the relative STEC values





Monitoring ionosphere (3)



<u>GUT</u>

analysis of ionospheric disturbances based on GNSS observations

scheme of the idea of the height of ionospheric inhomogeneities (HII) estimation



changes of the estimated height of the ionospheric inhomogeneities (HII) for the analysed period of time (13–20 March, 2013)







Monitoring ionosphere (4)



<u>GUT</u>

• analysis of ionospheric disturbances based on GNSS observations (cont.)

topocentric coordinates for the quiet (13 March 2015, the green line) and the stormy (17 March 2015, the magenta line) days







Improving consistency between SLR and GNSS solutions (1)

HUNNERSTRUC

WUELS

- method of determining the Blue-Sky effect
- processing of SLR observations to GNSS satellites
- processing of SLR observations to Low Earth Orbiters (LEO) for a GNSS-SLR integration onboard satellites

distribution of laser observation residuals to the microwave orbits of the Sentinel-3A satellite without (left) and after (right) taking into account the reduction of range biases and corrections to station coordinates for all SLR stations in 2016



quality of experimental multi-GNSS IGS orbits validated using SLR observations







Improving consistency between SLR and GNSS solutions (2)



WUELS

 troposphere delay model for SLR and improving the consistency between SLR and GNSS

horizontal gradients of the tropospheric delay for 1.01. 2016, 0:00 based on numerical weather models





Symposium of the IAG Subcommission for Europe European Reference Frame - EUREF 2021 Ljubljana, Slovenia, 26-28 May 2021

SLR laser observations



GNSS for navigation



GUT and Gdynia Maritime University

• improving the accuracy of geometric parameters of a railway track with a specific number of GNSS receivers

mobile railway platform with sensors installed during the campaign in Klosnowo







Monitoring gravity changes (1)



Borowa Gora Geodetic-Geophysical Observatory of IGiK

 analysis of gravity record of the iGrav-027 superconducting gravimeter using LCR gravimeters

tidal record with the iGrav-027 from first 1080 days of operation



tidal adjustment residuals from the iGrav-027



the iGrav-027 residuals vs. MERRA2 and GLDAS2 hydrological loading models







Monitoring gravity changes (2)



EPOS-PL and EPOS-PL+ projects

gravimetric tidal records in Poland as recognized in late 2020 within the EPOS-PL project







Satellite Laser Ranging (1)



SRC PAS

SRC PAS Borowiec station BORL tracked 100 different objects in 2019 & 2020

2019

- 1468 full passes
- 30 LEO and 14 MEO average RMS from 1.20 to 3.81 cm (1079 passes, 15 197 normal points)
- 38 space debris average RMS from 2.04 to 221.72 cm (388 passes, 4074 normal points)

2020

- 2050 full passes
- 27 LEO and 13 MEO average RMS from 1.49 to 4.11 cm (1352 passes, 18 644 normal points)
- 57 space debris average RMS from 1.42 to 187.58 cm (698 passes, 7396 normal points)





Satellite Laser Ranging (2) SRC PAS



number of passes recorded by the BORL station (active satellites and debris) in 2019

number of passes recorded by the BORL station (active satellites and debris) in 2020













orbiting objects with diameter ≥10cm







Satellite Laser Ranging (4)



SRC PAS

observational statistics of geodetic satellites tracked at BORL station in 2018 in 2020

Sat. name	Passes	Returns	Normal	Avg RMS
			points	[cm]
Ajisai	62	84860	785	3.81
Etalon-1	3	453	14	3.76
Etalon-2	4	295	20	2.60
Geo-IK-2	3	4229	31	2.19
GRACE-FO-1	23	9880	564	3.08
GRACE-FO-2	11	5291	285	2.88
LAGEOS-1	100	125946	923	1.76
LAGEOS-2	43	43780	440	1.82
LARES	75	37186	821	1.55
LARETS	56	21245	405	2.16
STARLETTE	53	46889	573	2.31
Stella	13	7851	103	2.07

Sat. name	Passes	Returns	Normal points	Avg RMS [cm]
Ajisai	111	189595	1387	3.41
Etalon-1	0	0	0	0
Etalon-2	3	364	14	3.61
Geo-IK-2	6	4705	38	2.22
GRACE-FO-1	21	10077	432	3.45
GRACE-FO-2	15	7731	350	3.19
LAGEOS-1	46	45220	423	1.73
LAGEOS-2	50	30870	388	1.78
LARES	104	36486	1004	1.51
LARETS	92	37412	713	1.98
STARLETTE	97	70903	931	2.02
Stella	7	5109	65	2.02





Satellite Laser Ranging (5) SRC PAS



regular evaluation of the BORL laser sensor quality based on the tracking results of LAGEOS-1 and LAGEOS-2 satellites

LAGEOS normal point RMS

LAGEOS measurements in a normal point

BORL Average LAGEOS Session RMS



BORL Average LAGEOS Obs in a Normal Point



LAGEOS full rate measurements per pass



BORL LAGEOS Fullrate Observations per Pass

• quality analysis of SLR station coordinates determined from laser ranging to the LARES satellite





Satellite Laser Ranging (6)



SRC PAS

 developing a new software dedicated for the reduction of the laser measurements

results of the measurements reduction of ENIVSAT (O–C residuals)



results of the measurements reduction of TOPEX/Poseidon (O–C residuals and normal points) results of the measurements reduction of Chang Zheng 4C rocket (O–C residuals with noise points)









Satellite Laser Ranging (7)



SRC PAS

orbital calculations of space debris based on laser measurements

input initial orbital elements ephemerides vs. laser measurements in RSW frame



- running Space Situational Awareness programme implemented by the ESA (Space Safety in the next years) and the EC
- operating a second independent optical-laser system, dedicated to the SST programme
- computation of the coordinates of the BORL station based on LAGEOS measurements performed by the ILRS network for the years 2016–2019





Satellite Laser Ranging (8)



WUELS

 hosting the Associated Analysis Center of the ILRS that provides products for validating orbits of Galileo, GLONASS, BeiDou, and QZSS satellites generated by the Center for Orbit Determination in Europe with respect to laser observations collected by SLR stations distributed worldwide - the service is available through a dedicated website





Geodynamics (1)



IGiK, WAT, WUELS

- EPOS–PL project the Polish Earth science infrastructure integrated with the European Plate Observing System Programme (EPOS) continued
 - developing centres of research infrastructure for geomagnetic and gravimetric data integrated with GNSS infrastructure
 - monitoring of Earth surface displacements using integrated multi-GNSS, gravity, seismic, and InSAR data in test areas of the Upper Silesia was initiated











<u>IGiK</u>

- comparison of vertical deformations of the Earth' surface obtained using GRACEbased GGMs and GNSS data for the south-eastern Poland
- the use of tidal gravimeters to acquire complementary information on the <u>distribution</u> <u>of velocities of seismic wave in the Earth's interior</u>





Geodynamics (3)



WUELS

 the use of high-rate position series for the determination of high-frequency time displacements

GPS (black) and SM (grey) displacement, velocity and acceleration time series of Norcia earthquake (2016-10-30 06:40:18 UTC, Mw 6.6) cropped to analysed time with correlation coefficients of station GUMA



determination of Earth rotation parameters and geocenter motion using GNSS





Geodynamics (4)



WUELS

• investigation of the influence of geophysical signals on coordinate variations

spatial distribution of correlation coefficients for SUM geophysical deformation



spatial distribution of correlation coefficients between coordinates of the WROC station and coordinates of the neighbouring GNSS stations











<u>MUT</u>

 determination of optimum strategy for GPS position time series analysis to study the Post-Glacial Rebound effect

vertical rates derived from the GPS position time series



 new methodology of non-linear motion presentation using GPS position time series by accounting for co-seismic offsets, changes in the vertical velocities, and post-seismic relaxation





Geodynamics (6)



<u>UWM</u>

- analysis of modern vertical crustal movements of the southern Baltic coast from tide gauge, satellite altimetry and GNSS observations
 - correlation coefficients between the satellite altimetry and tide gauge data (1993-2017)



moving averages for analysed tide gauge stations



