# DATA PROCESSING OF THE ASG-EUPOS NETWORK TEST CAMPAIGN

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## 1. INTRODUCTION

An idea to establish Active Geodetic Network in Poland as permanent GNSS network is the consequence of more than ten years efforts to implement this technique into the geodetic, navigation and other wide range of professional and private applications. Starting in the beginning of 1990's with the first polish GPS receivers and first two permanent IGS/EPN stations, in 1992, with the GPS EUREF-POL campaign the unification of Polish and European reference networks and the introduction of ETRS'89 geodetic system in Poland has been completed. This network was re-surveyed in September 2001 with the same set of 11 stations. In 1994-95 POLREF densification network was established and measured to provide the ETRF reference frame for geodetic, surveying and mapping applications as well as to verify the existing classical national horizontal geodetic networks. Along with the EUVN'97 campaign, performed in 1997 for unification of the European vertical datum, all stations of these three networks in Poland constrain the fundamental Polish national GPS network which was densified in the next few years. The first, test permanent network with GPS automatic services in Poland was established in Upper Silesia by the end of 2002 as ASG-PL pilot project which, during next few years, was connected with Malopolska Precise Positioning System (MPPS). ASG-EUPOS system as a multifunctional precise satellite positioning system is a country-wide realization of the concept of GNSS real-time and postprocessing services for precise positioning and navigation, fully agreed with EUPOS requirements and standards. Due to the fact that the reference stations of the ASG-EUPOS system will create the geodetic control (reference) network and by means of it's services provide ETRS'89 system on the whole Polish territory, calibration of all ASG-EUPOS stations had to be done before starting it in fully operational mode. This paper describes the measurement, data processing and results of the calibration campaign.

## 2. CALIBRATION CAMPAIGN – GOALS AND REQUIREMENTS

The main goal of the ASG-EUPOS calibration campaign was:

- to determine 3D precise coordinates of all GNSS antennas installed on ASG-EUPOS reference stations and to connect ASG-EUPOS network and include it to the existing primary national geodetic network, defined by EUREF-POL, POLREF and EUVN points;

- to perform test measurements in order to create on Polish territory homogeneous geodetic network in ETRS'89 system and to verify coordinates accuracies of all ASG-EUPOS permanent reference stations;
- to test of ASG-EUPOS reference stations operation as well as the whole system functioning basing on selected points of the primary national GPS networks: EUREF-POL, POLREF and EUVN.

The following Technical Requirements were worked out for the calibration campaign:

- GPS measurements should be made on all available points of the GPS networks: EUREF-POL, EUVN and on selected points of POLREF network;
- it is recommended to use on all 'field' points the same types of GPS receivers and antennas. In a case of using different types of GPS equipment an additional test-calibration campaign have to be done;
- in order to minimize costs of the measurements contractor should use all GPS receivers bought by the Head Office of Geodesy and Cartography (GUGiK) within a framework of ASG-EUPOS project;
- all reference stations of ASG-EUPOS as well as all other permanent GPS stations associated with ASG-EUPOS network, located on polish territory, must be included in the campaign;
- during the data processing and network adjustment it is strongly recommended to include EUPOS reference stations from neighbouring countries;
- in order to connect the observed network with EPN, the following stations should be included in the campaign: BOR1, GLSV, JOZE, METS, ONSA, POLV, POTS, WTZR ZIMM;
- it is assumed that an error of the coordinates determined from two independent observing sessions will be less than 1 cm in horizontal and less than 1.5 cm in vertical component.

In order to realize such big campaign, special consortium was created in the following constitution:

1. University of Warmia and Mazury in Olsztyn (UWM) – leader
2. OPGK in Olsztyn Ltd.
3. 'OPEGIEKA' in Elblag Ltd.

with the following partners:

1. Space Research Centre of the Polish Academy of Sciences in Warsaw (SRC PAS)
2. Wroclaw University of Environmental and Life Sciences
3. AGH University of Science and Technology in Cracow (AGH)
4. Institute of Geodesy and Cartography in Warsaw (IGiK)
5. 'GEOKART International' in Rzeszow

All tasks concerned with the campaign were made since 2008-04-11 till 2008-05-31, but observation sessions were performed since April 23 to May 11, 2008 (114 – 131 DOY).

## 3. THE MEASUREMENT

Due to damage or lack to have an opportunity to observe of 24 points (sixteen EUVN and eight POLREF), alternative points have been chosen, previously prepared for such a case. Finally GPS observations were performed on previously selected subset of 151 'field' points of the primary national geodetic network:

| | |
|---|---|
| EUREF-POL | 8 points (planned 7 points plus 0216 Borowiec) |
| EUVN | 41 points (planned 57 points) |
| POLREF | 102 (planned 86 points). |

In addition to the ‘filed’ and all ASG-EUPOS reference stations the following EPN stations were selected as reference stations in order to connect the network to ETRS’89 system: BOR1_12205M002, GLSV_12356M001, GRAZ_11001M002, METS_10503S011, ONSA_10402M004, POLV_12336M001, POTS_14106M003, WTZR_14201M010, and ZIMM_14001M004.

All observation sessions performed on ‘field’ stations were recorded in 5 seconds time intervals and with 0˚ elevation mask.

EUREF-POL points were occupied during seven days (daily sessions, since 00:00 to 23:59 UT) but POLREF and EUVN points only during two sessions, 24 hours each, starting from 12:00 UT and ending at 12:00 UT next day.

All ‘field’ points were measured by means of 58 GPS Trimble R8 receivers with internal antennas (IGS model TRM_R8  NONE). This equipment was made available to observers by GUGiK.

Finally, after finalizing of all measurement sessions, network selected for data processing consisted of 286 points: (Fig. 1.)

- 8 points of EUREF-POL network;
- 102 points of POLREF network;
- 41 points of EUVN network;
- 18 points of foreign EUPOS stations from neighbouring countries: SAPOS (4), LITPOS (3), SKPOS (6) and CZEPOS (5);
- 97 ASG-EUPOS stations;
- 29 EPN/IGS stations (15 foreign stations).

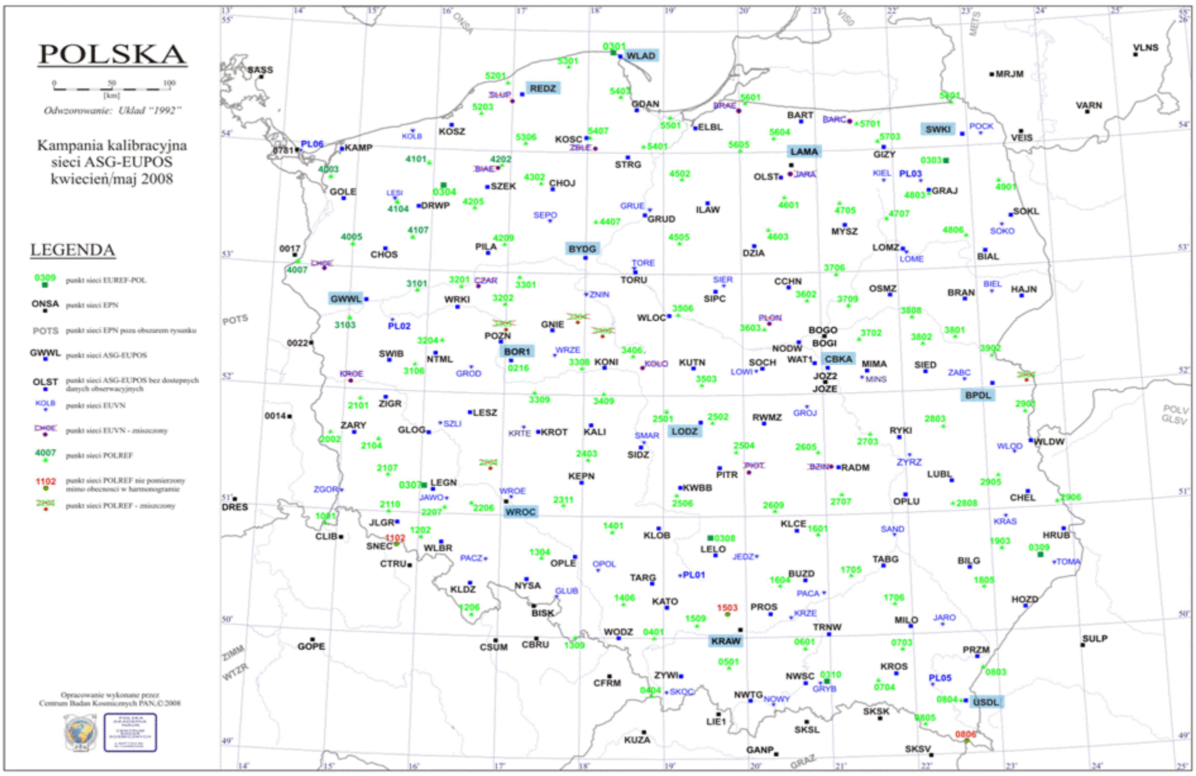


Fig. 1.  Stations involved into the calibration campaign.

## 4. ANALYSIS (QUALITY CHECK) OF OBSERVATION DATA

As a first step all available data files from 'field' points were converted from binary format to the RINEX and then checked for consistency with existing paper and electronic documentation, performed during the measurement. RINEX data from all other stations (ASG-EUPOS reference stations, EPN and associated stations) were also checked with specific site-log files created for each such station. After that but before defining vectors for network construction all available observation data files were first checked using TEQC program, particularly for detecting number of cycle slips and ratio of observations recorded to theoretically available as a function of elevation mask. From this step we can conclude that even for some EPN/IGS stations we observe relatively poor signal, particularly for elevations below 15-10˚, caused mainly by environmental effects, horizontal obstructions and/or older equipment still operating on some stations. (see Fig. 2.)

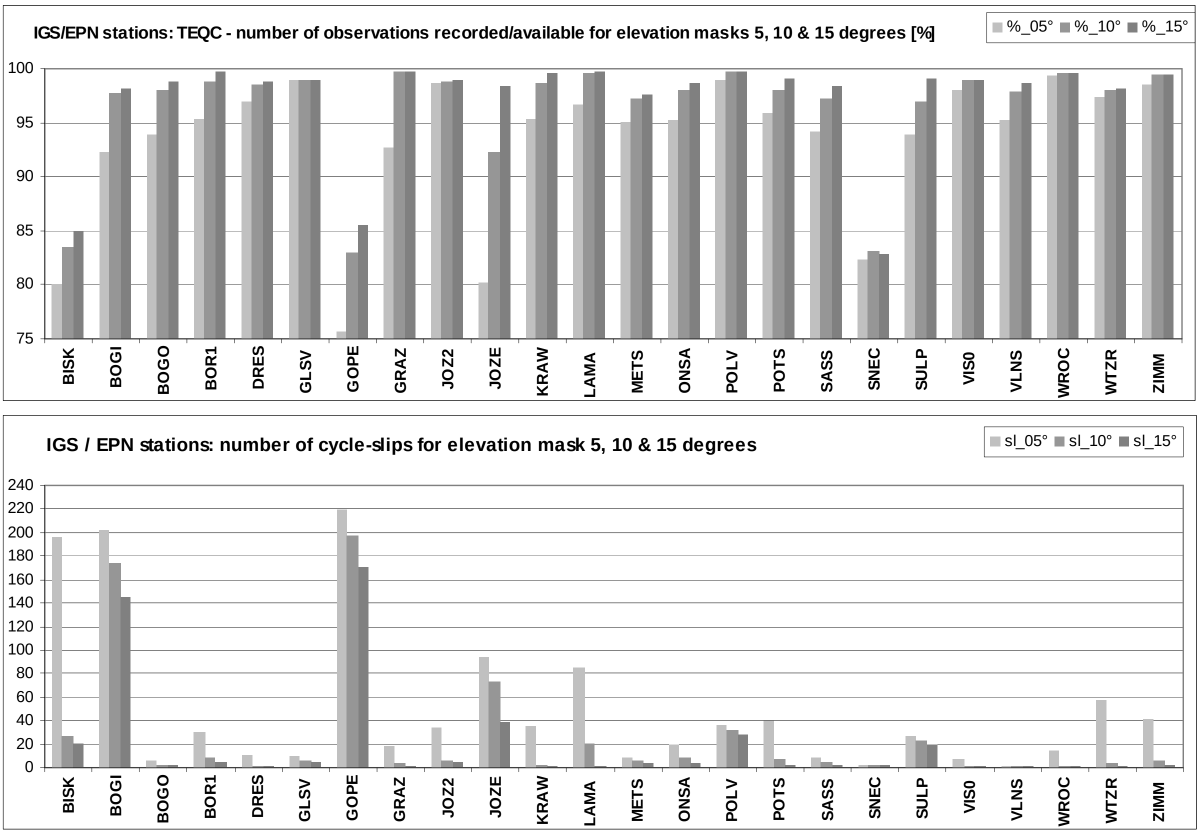


Fig. 2. Data analysis for EPN/IGS stations from TEQC program.

## 5. DATA PROCESSING

Preliminary, control GPS data processing was performed on UWM in Olsztyn using IGS Rapid Orbits.
SRC PAS has started to analyse the GPS data using the Bernese GPS Software ver. 5.0 in Double Difference mode, IERS and IGS conventions for geophysical models and parameters.
For this step of data processing following analysis approach was applied:

- observation data: in 30 seconds sampling rate with 5˚, 10˚ and 15˚ of the elevation cut-off angles and elevation dependent weighting (cos(*z*));
- 'ionosphere-free' (L3) linear combinations of double-difference carrier phase;
- antenna phase centre corrections: the absolute models (IGS antenna calibration models) of elevation and azimuth dependent phase centre corrections were applied;
- global parameters: constrain the orbits, clocks and ERP information from IGS Final Combined solution;
- coordinates of the reference stations: in ITRF2005 Reference Frame for the epoch of the campaign (2008.33);
- nutation and precession parameters: IAU2000 standard;
- tidal model: IERS2000 standard;
- site specific ocean loading corrections: computed using Scherneck's (FES2004) table of amplitudes and phases;
- stochastic estimation of station clocks;
- ambiguity resolution strategy: Quasi-Ionosphere-Free (QIF) with stochastic ionosphere parameters;
- troposphere corrections method for Zenith Path Delay for each point: "Dry-Niell" with Niell Mapping Function (NMF) for one hour intervals;
- troposphere corrections method for Horizontal Gradient Parameters: Tilting method;
- network adjustment approach: daily solution with 'Correct' method - minimally constrained network with *n-1* vectors for *n* points.

Concerning the antenna phase centre corrections problem, seven new established by ASG-EUPOS reference stations with the GPS/GLONASS receiving module which are involved to EPN network are equipped with NetR5 GNSS receivers and Zephyr II Geodetic antennas with TZGD type of snow cover (TRM55971.00 TZGD). For those stations absolute and individual for each station antenna phase centre variation models were applied.

The other ASG-EUPOS reference stations (which are neither EPN nor associated with ASG-EUPOS stations) are equipped with Trimble NetRS GPS receivers and Zephyr I Geodetic antennas also with TZGD type of snow cover. For all these stations the one absolute antenna model was used (for antenna model IGS TRM41249.00 TZGD). Similar situation was for all 'field' points on which Trimble R8 receivers were used and one absolute antenna model was applied for antenna model (IGS model TRM_R8  NONE).

SAPOS and CZEPOS EUPOS stations were equipped with the antenna types for which absolute antenna models exist and were used in computation.

Due to the lack of absolute model for TRM29659.00 SCIT antenna type, installed on three stations of MPPS network: NWTG, PROS and TRNW, relative NGS antenna phase centre corrections models were applied for them.

Network construction of the calibration campaign, measurement schedule, quality of observations collected on each station during the campaign and different equipment used on different kind of stations/points caused the specific vectors definition for data processing. All Polish EPN points (all previously established and involved as 'associated stations' and seven new ASG-EUPOS reference stations) were connected with the foreign EPN reference stations in order to connect the calibration campaign to the European reference system and to set the stable frame which was the base for construction a 'star' type of baseline connection with all other measured points. This specific geometry approach is presented on Fig. 3. and Fig. 4.

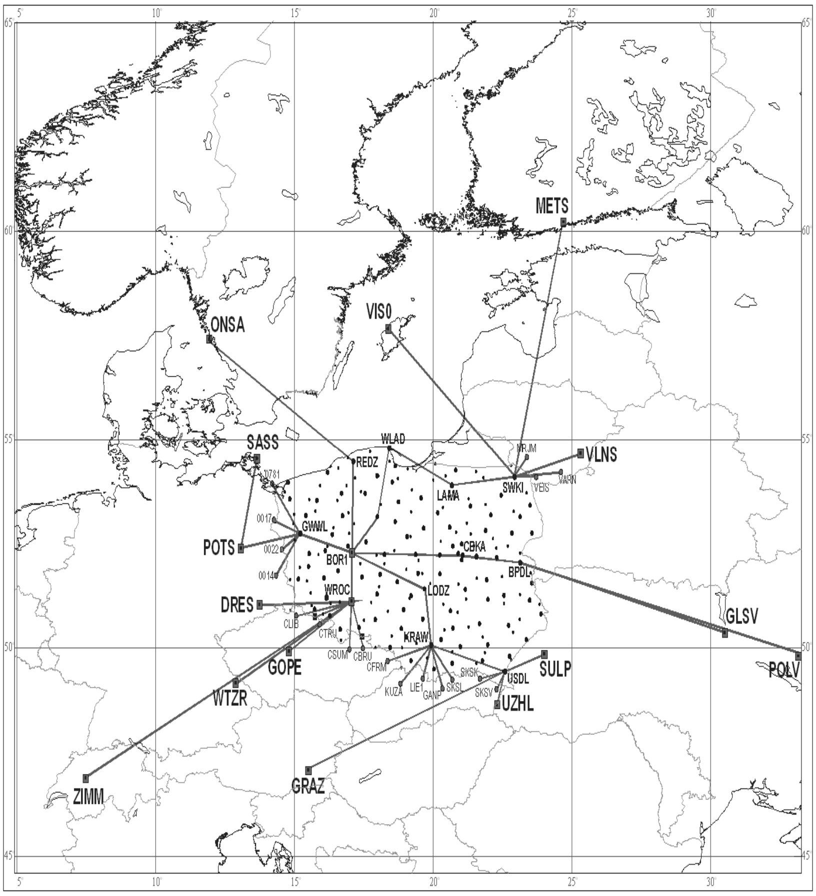


Fig. 3. EPN reference stations and connection vectors.

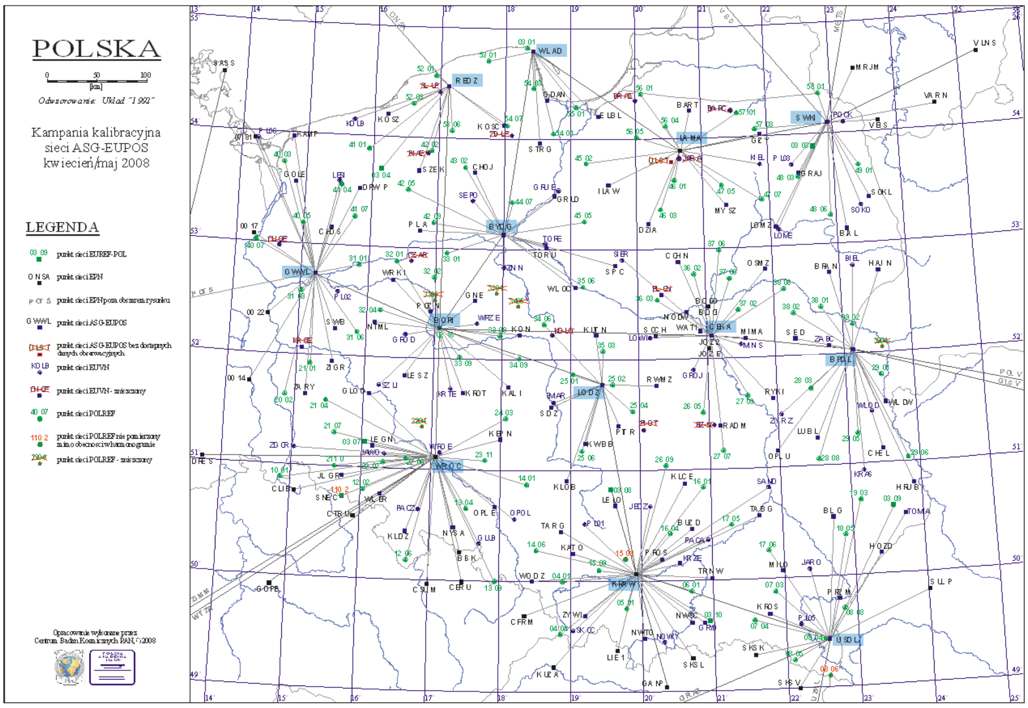


Fig. 4. Vector definitions for calibration campaign network solutions.

Different variants of network adjustment were processed for three different elevation masks: 5, 10, 15 degrees for daily solutions (sessions: 0:00 – 23:59 UT) and one 24 hours solution (session defined since 12:00 to 12:00 UT next day).
Selection of final result was based on internal consistency analysis of daily solutions and comparison of combined results for different variants of network adjustment.
Table 1. shows that in practice very similar accuracy characteristics were obtained for all four processed variants.

Table 1. Mean value of daily repeatability of station coordinates.

| **Solution type** | **N [mm]** | **E [mm]** | **U [mm]** |
|---|---|---|---|
| Elevation mask 05˚ | 1.12 | 1.09 | 2.90 |
| Elevation mask 10˚ | 1.15 | 1.13 | 3.04 |
| Elevation mask 15˚ | 1.18 | 1.17 | 3.72 |
| 24 hours | 1.03 | 1.12 | 3.50 |

Increasing elevation mask we observed the decreasing number of observations and total number of ambiguity parameters which were better and easier resolved as integer numbers.
Ratio of resolved to unresolved ambiguities was greater between solutions for 5˚ and 10˚ than for 10˚ and 15˚ of elevation masks what can suggest that the optimal solution is achieved for 10˚ of elevation mask. The same conclusion can be formed when we compare stations coordinates for different elevation masks. Values obtained for 10˚ were close to the mean from results for 5˚ and 15˚ solutions. Due to these reasons the network solution for 10˚ elevation mask was recommended as final.
For this variant of data processing, after connection of daily solutions in ADDNEQ2 program, the mean daily repeatability of network solution was: ±1.08 mm, ±1.12 mm and ±2.94 mm in North, East and Up components and much less coordinate error estimations – for POLREF and EUVN points about 2 times less.

## 6. COMPARISON WITH THE PREVIOUS REALIZATIONS OF POLISH PRIMARY GPS NETWORK

In order to compare the final network solution of the calibration campaign with the previous realizations of polish fundamental GPS networks: EUREF-POL'1992, EUREF-POL'2001, EUVN'97, POLREF and EUVN'99, transformation of ASG-EUPOS stations coordinates from ITRF2005 ep. 2008.33 to the ETRF'89 reference frame were performed in 3 variants:

1. converting of coordinates in ITRF2005 ep. 2008.33 to ETRF2005 using transformation parameters taken from (Boucher C. at al,. 2007),
2. converting of coordinates in ITRF2005 ep. 2008.33 to ITRF2000 ep. 2000.0 and then to from ITRF2000 ep. 2000.0 to ETRF2000 ep. 2000.0 also using transformation parameters from Memo version 6 (Boucher C. at al,. 2007),
3. transformation of coordinates from ITRF2005 ep. 2008.33 to ETRF'89 (EUREF89) ep. 1989.0, performed directly using transformation parameters obtained from 97 common points of POLREF network. Five from observed 102 POLREF stations were excluded from the transformation due to a big errors of coordinates.

Table 2 shows the accuracy characteristics for different components obtained for each campaign in different ITRS realizations.

Table 2. Mean square errors of adjusted coordinates of the EUREF-POL, POLREF and EUVN sites in the different ITRS realizations.

| Campaign | ITRS realization | N [mm] | E [mm] | U[mm] |
|---|---|---|---|---|
| EUREF-POL 1992 | ITRF'91 | 3.3 | 4.8 | 6.6 |
| POLREF-SE | ITRF'92 | 4.4 | 3.3 | 10.4 |
| POLREF-NE | ITRF'92 | 1.4 | 1.8 | 5.0 |
| POLREF-W | ITRF'92 | 2.7 | 2.6 | 9.3 |
| EUVN 1997 | ITRF'96 | 1.2 | 0.8 | 3.1 |
| EUVN 1999 | ITRF'96 | 1.9 | 2.2 | 3.8 |
| EUREF-POL 2001 | ITRF 2000 | 1.1 | 0.9 | 2.3 |

6.1. Comparison of ASG-EUPOS calibration and EUREF-POL campaigns

Table 3. Differences of coordinates between ASG-EUPOS and EUREF-POL'92.

| Num | Name | Residuals in millimetres | | |
|---|---|---|---|---|
| 1 | 0216 BOROWIEC | -3.0 | -5.6 | -4.5 |
| 3 | 0301 ROZEWIE | -2.0 | 1.4 | 2.9 |
| 5 | 0303 MASZE | -3.2 | 1.3 | 4.4 |
| 6 | 0304 CZARNKOWIE | 1.5 | -2.8 | -5.7 |
| 8 | 0307 STUDNICA | -0.1 | 1.6 | 10.6 |
| 9 | 0308 ROGACZEW | 3.1 | 2.6 | -10.9 |
| 10 | 0309 ZUBOWICE | -1.7 | 4.9 | -2.5 |
| 11 | 0310 GRYBOW | 4.8 | -3.5 | 5.7 |
| | **RMS / component** | **2.9** | **3.6** | **7.1** |

Table 4. Differences of coordinates between ASG-EUPOS and EUREF-POL 2001.

| Num | Name | Residuals in millimetres | | |
|---|---|---|---|---|
| 216 | 0216 BOROWIEC | -4.1 | -1.0 | -6.2 |
| 304 | 0304 CZARNKOWIE | -0.4 | -5.4 | 1.5 |
| 307 | 0307 STUDNICA | -0.9 | -0.8 | -0.6 |
| 310 | 0310 GRYBOW | 7.4 | -2.3 | 5.1 |
| 308 | 0308 ROGACZEW | 3.6 | -0.2 | 8.6 |
| 301 | 0301 ROZEWIE | -0.1 | -2.7 | 13.0 |
| 303 | 0303 MASZE | -7.8 | 8.9 | -5.5 |
| 127 | JOZE 12204M001 | 1.7 | 2.2 | -8.1 |
| 131 | WROC 12217M001 | 3.4 | 1.0 | -36.3 |
| 309 | 0309 ZUBOWICE | 0.5 | 1.3 | 0.5 |
| 129 | BOGO 12207M002 | 0.5 | -1.0 | -31.4 |
| 128 | BOR1 12205M002 | -0.7 | 0.1 | -8.3 |
| 130 | LAMA 12209M001 | -2.6 | 0.2 | -24.7 |
| | **RMS / component** | **4.1** | **3.8** | **7.3** |

There are four stations with high residuals in Up component in this comparison. At time of the data processing of this campaign, available models of antenna phase centre variation were the same for antennas with and without installed of different types of snow covers. This fact could create some additional differences, particularly in height component.
In the EUREF-POL 2001 campaign the antennas with snow cover were used on BOGO, BOGI, LAMA and WROC stations. In addition, on LAMA and WROC stations, the GPS equipment (receiver and antennas) were changed before the calibration campaign.

6.2. Comparison of ASG-EUPOS calibration and POLREF campaigns

102 points of POLREF network were measured and mean values of RMS errors from transformation were equal ±6.5 mm, ±6.8 mm and ±14.4 mm in North, East and Up component respectively.  The maximum values were obtained for point number 0404 with the 0.7 mm, -13.4 mm and -51.4 mm in N, E, U, but only the height component could suggests an error in coordinates or site movement. Analogical situation occurs for point number 1001 with the errors: 12.0 mm, 16.1 mm and 48.5 mm in N, E, U. For all measured POLREF stations, due to the large number of points used in comparison, instead of table, the graphic presentation of coordinate differences is presented above on Fig. 5.

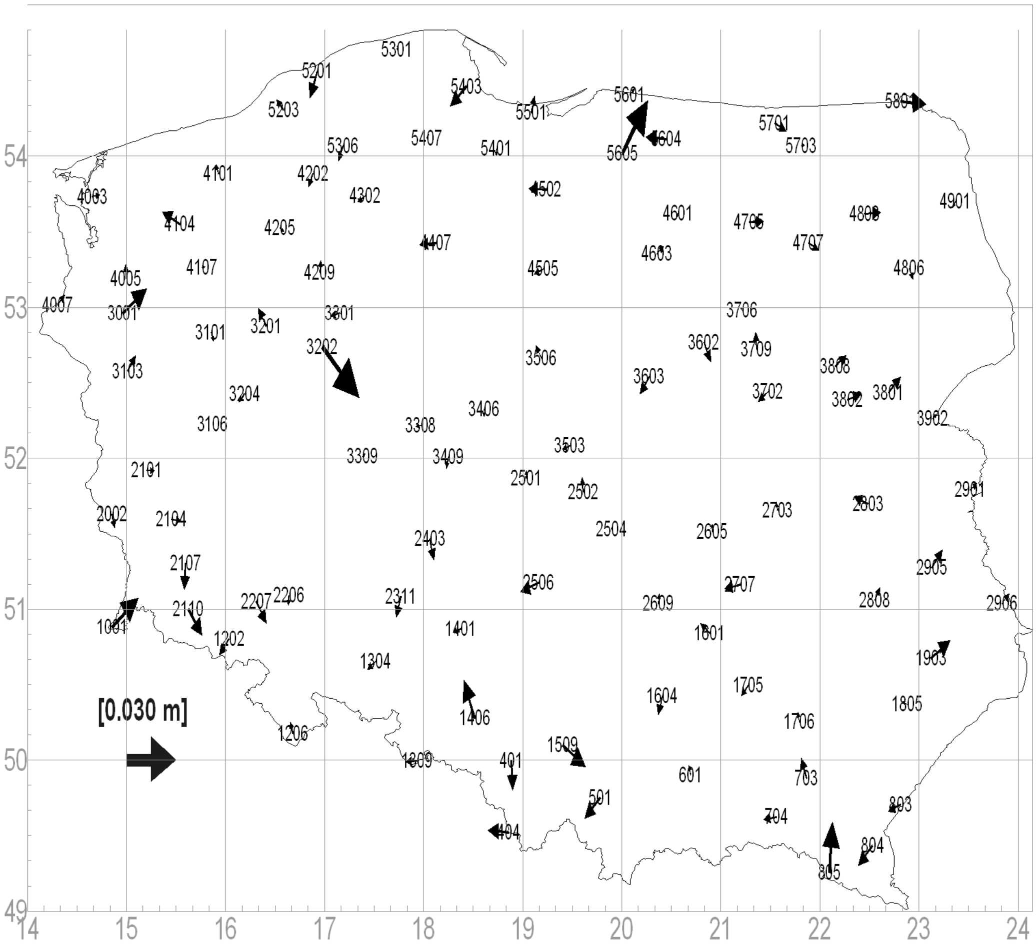

Fig. 5. Coordinate differences between POLREF and ASG-EUPOS network solutions (horizontal component).

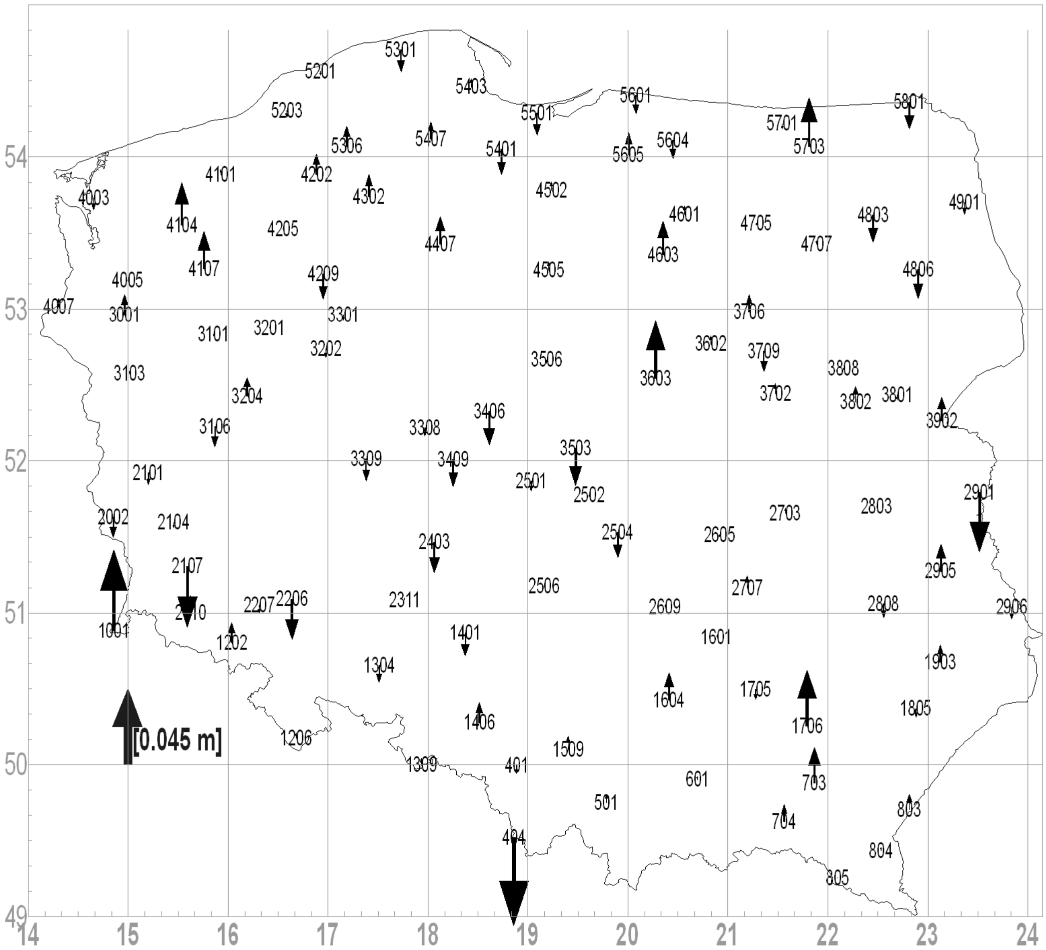


Fig. 6. Coordinate differences between POLREF and ASG-EUPOS network solutions (vertical component).

6.3. Comparison of ASG-EUPOS calibration and EUVN'97 campaigns

Table 5. Differences of coordinates ASG-EUPOS and EUVN'97.

| Num | Name | Residuals in millimetres | | |
|---|---|---|---|---|
| 30 | BOGI 12207M003 | -0.5 | 3.6 | -18.0 |
| 139 | BOR1 12205M002 | 0.2 | -3.9 | -5.8 |
| 140 | PL01 | 5.4 | -1.3 | -2.1 |
| 141 | PL02 | -2.4 | -1.3 | 2.4 |
| 142 | JOZE 12204M001 | -2.9 | -2.3 | -3.7 |
| 144 | LAMA 12209M001 | -3.5 | 9.6 | -15.4 |
| 145 | PL03 | -3.4 | -1.5 | 5.0 |
| 146 | 0301 ROZEWIE | 2.1 | 0.4 | -5.5 |
| 147 | PL06 | 1.5 | 3.2 | 6.1 |
| 226 | PL05 | -0.6 | 6.5 | 3.7 |
| | **RMS / component** | **3.0** | **3.4** | **4.8** |

In the EUVN'97 campaign all points except LAMA were measured with the same receiver and antenna type (TRIMBLE 4000SSi with COMPACT L1/L2 GP antennas). The residuals in above table probably show the rest effects in absolute models of antenna phase centre variation which still exist for stations BOGO and LAMA.
Three of all compared stations became the permanent stations (BOGI 12207M003, JOZE 12204M001, LAMA 12209M001) and additionally on sites BOGI and JOZE the reference points for antenna height measurement were changed. For a few stations we notice the bigger values for residuals, which could be caused by some inaccuracies in absolute antenna phase centre models.

## 7. CONCLUSION

The analysis of obtained coordinates shows that the adopted criteria of GPS measurements in the calibration campaign meet assumed requirements for the accuracy.
Although the long time interval (more than ten years) between the calibration campaign and the previous ones used for comparisons, the big progress accomplished in GNSS hardware and software (firmware as well as the data processing packages), high compatibility of the coordinates in horizontal components was achieved comparing with the results obtained from the previous solutions. Only a very few points of the primary national GPS networks indicates quite big differences in coordinates, particularly in height component.
Final analysis shows very high agreement of particular realizations of GPS networks for territory of Poland.
In order to define the homogeneous primary national geodetic network, which meets the needs and requirements of the modern geodesy, cartography, navigation and all other fields of human activity, it is necessary to perform in the near future the GPS measurements on the rest points of the POLREF network (~ 250 points) in conjunction with common adjustment of both campaigns.

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