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COMPARISON OF COORDINATES OF POLREF – THE FIRST ORDER POLISH NATIONAL NETWORK - OBTAINED FROM CAMPAIGNS IN 1994/95 AND 2008/2010

Leszek Jaworski, Anna Swiatek
Space Research Centre Polish Academy of Sciences
Warsaw, Poland

leszek@cbk.waw.pl, ana@cbk.waw.pl

ABSTRACT

The integration of ASG-EUPOS network with the national first order networks was prepared in two measurement campaigns carried out in 2008 and 2010/2011. The measurements included a total of 340 points of POLREF – the first order national GNSS network. That set of data gives the possibility for comparison of solutions prepared for comprehensive analysis of the points' position and coordinates changes in the long term. Because the results of POLREF were not published the paper includes a brief description of campaigns from 1994 and 1995 and prepared solutions as well as the results of coordinates comparison with campaigns 2008 and 2010/2011. For points of significant deviations in coordinates the analysis of causes was presented.

Keywords: GPS, GNSS, geodetic network, coordinate comparison

INTRODUCTION

The history of Polish national first-order GNSS geodetic networks began in 1992. In that year, 11 points of the Polish part of EUREF were established and measured in the EUREF-POL 92 campaign. The campaign and its results were reported on the EUREF 1994 conference held in Warsaw 8-11 June 1994 (Zielinski et al. 1994). At the same conference Polish EUREF points were accepted as the points of class B, defined as the points with the accuracy about 1 cm at the epoch of observation (see Resolution no 1). The next step in development of national GNSS geodetic network in Poland was the foundation of the POLREF network. The POLREF was established as the densification of EUREF-POL. It consists of 348 points steadily distributed on the territory of country in a way that the average distance between neighbouring points was about 30km. The measurement campaigns were carried out in 1994 and 1995. In 2008 the ASG-EUPOS permanent network was established as the Polish part of EUPOS network. The necessity of integration of new stations with existing national geodetic networks provoked the measurement campaigns carried out in years 2008 and 2010/2011. The measurements and the results were presented at national and international conferences and published (Jaworski et al., 2008, Jaworski et al., 2011a, Jaworski et al., 2011b). During these campaigns the most of POLREF points were re-measured.

POLREF NETWORK

The POLREF – Polish national geodetic reference network was established as a first, uniform, three-dimensional (horizontal and vertical) GNSS network covering the whole country. It consisted of 348 main points and 348 direction points. The EUREF-POL points were measured during the campaigns and were taken as a reference points for computation.

Due to the size of the project, measured using the GPS technique, and data processing for the POLREF network all work on this object has been divided into three parts and carried out in three observational campaigns:

The first campaign (POLREF-SE) for south-eastern part of Poland was performed within the period 10-27 July 1994. It consisted of 103 main POLREF points, 103 direction points and 4 EUREF-POL points.

The second one (POLREF-NE) covered the area north-eastern part of Poland and was performed in the period 17-27 October 1994. It consisted of 75 main POLREF points (8 of them were common with the first campaign), 67 direction points (measured only for new main points) and 3 EUREF-POL points.

The third campaign (POLREF-W) covered the western part of Poland and was performed within the period 24 April-25 May 1995. It consisted of 197 main POLREF points (19 of them were common with the POLREF-SE and POLREF-NE campaigns), 178 direction points (measured only for new main points) and 4 EUREF-POL points.

The POLREF-SE and POLREF-NE campaigns were managed by Space Research Centre and POLREF-W campaign was managed by Institute of Geodesy and Cartography from Warsaw. The coverages of campaigns are shown in Figure 1.

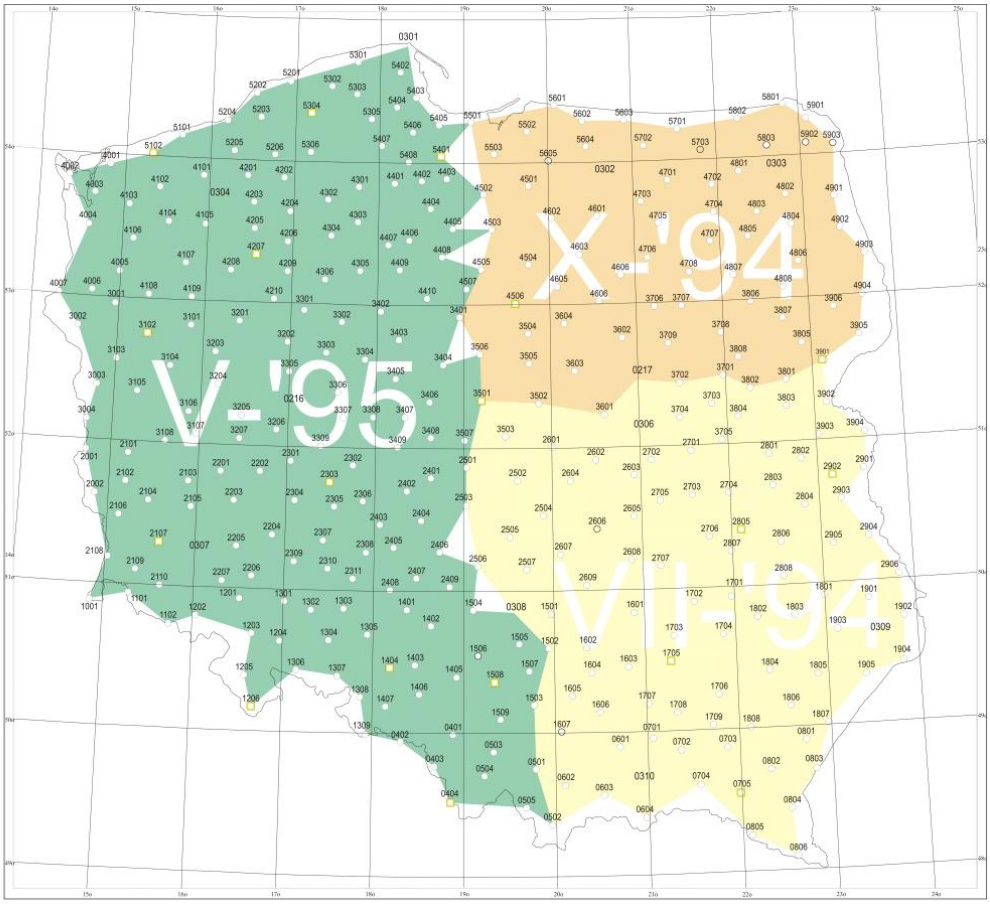


Fig. 1. The coverage of POLREF-SE, POLREF-NE and POLREF-W campaigns.

In order to ensure uniformity throughout the POLREF network, for all three campaigns the same criteria were adopted for the measurement method and also for the different types of GPS receivers used for each type of points:

for the EUREF-POL points the observations were made using Turbo-Rogue or Trimble 4000SSE receiver. The observation were almost permanent (short break for record of data) for points located in the areas of observatories, or in sessions of 10 to 12 hours per day for the rest points. These sessions should cover the observation sessions, designed for measurements at POLREF points located in neighbourhood.

For the POLREF points in at least two sessions of the minimum 3.5 hours each, observations were made using Leica Wild-type series 200 receivers,

For directional points observations were made in at least two sessions for at least 45 minutes each, using the same type of receivers.

All campaigns were computed in Space Research Centre. The final solution was prepared as joint data processing in reference to 11 EUREF-POL points.

The POLREF network solution was carried out in two steps. The first one – preliminary processing was prepared using TRIMVEC-PLUS software (the commercial software prepared by Trimble) for calculating the approximate coordinates of points. That commercial software allowed processing of data from different receivers using the RINEX data format. The second step of data processing was performed using Bernese GPS Software version 3.5 created in University of Bern (Rothacher et. al 1993).

The computations were carried out according to following procedure:

L3 – ionosphere free linear combination for phase observation computations,

introducing the fixed L1 and L2 ambiguities computed using two step approach L5 linear combination (wide-lane) and L3 linear combination (iono-free)

introducing the ionosphere regional model for each measurement session,

introducing the troposphere parameters for each session for point,

combined IGS final orbit together with IGS Earth Rotation Parameters,

reference frame – ITRF-93 rotated to observation epoch for computation and EUREF-89 for final coordinates. The individual campaigns were processed in actual realization of the ITRF reference frame at mean epoch of each campaign (ITRF-92 for POLREF-SE and POLREF-NE campaigns and ITRF-93 for POLREF-W campaign).

combination of solutions for the eastern and western parts of programs COMPAR and ADDNEQ

The baselines formed the structure of triangles where they combined nearest neighbour points measured simultaneously in the session. The definition of the baseline network is presented in Figure 2.

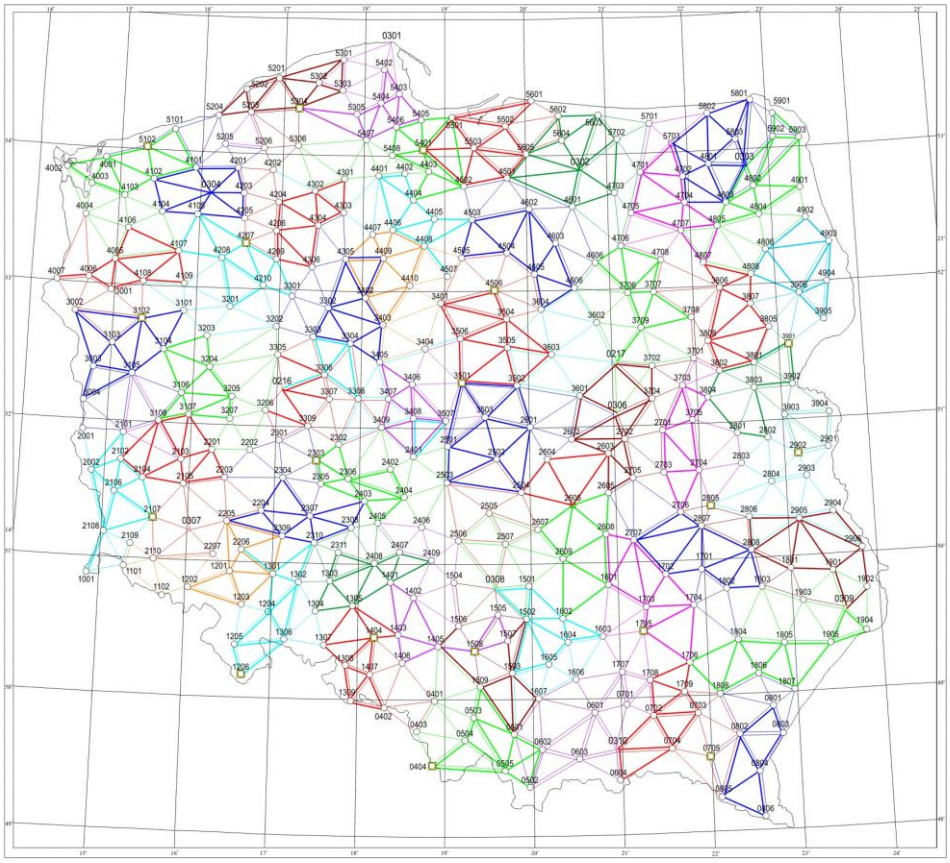


Fig. 2. Baselines definition adopted for processing of POLREF campaigns. The individual measurement daily sessions were marked by different colors.

In order to assess the real accuracy of the obtained coordinates the differences of coordinates of common points located at the edges of independently processed parts – east and west were analysed. The analyses of obtained results allow to determine the accuracy of the solution below 1 cm for horizontal components, with the worst case for point:

4503 Piotrowice: 3.5cm for E component;

and 1 cm for vertical component, with the worst case for points:
0502 Rolow Wierch: 6cm
3501 Zieleniec: 5cm.

ASG-EUPOS INTEGRATION CAMPAIGNS

The integration of the ASG-EUPOS stations was divided into two campaigns: the first was carried out in 2008 and the second one in 2010 and 2011.

All computations were carried out in Bernese GPS Software ver. 5.0. The computations were carried out according to the procedure recommended in guidelines C. Bruyninx et. al (2010) for:

reference frame - ITRF2005 rotated to observation epoch,
L3 – ionosphere free linear combination for phase observation computations,
introducing the fixed L1 and L2 ambiguities resolved from QIF strategy for baseline

The measurements as well as data computations and results of campaigns 2008 and 2010/2011 were accordingly described in (Jaworski et al., 2008) and in (Jaworski et al., 2011b).

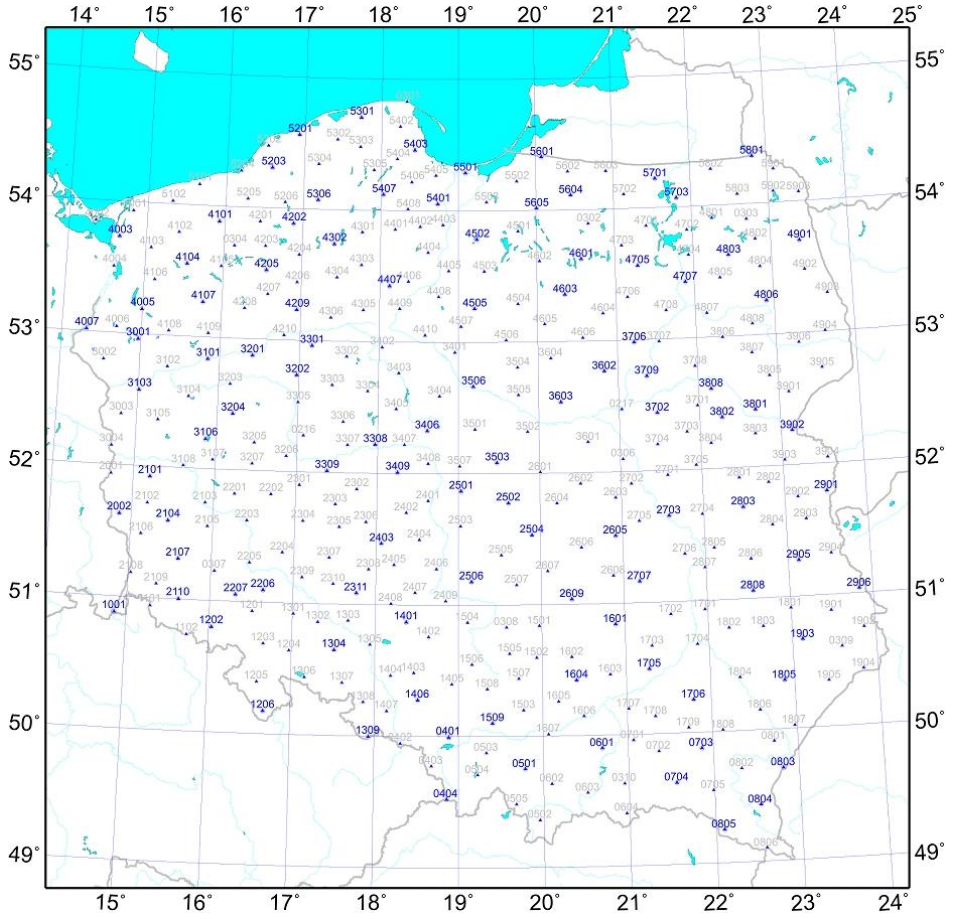


Fig. 3. The location of POLREF points measured during the 2008 campaign (blue).

The original solution of the 2008 campaign was prepared according to assumptions different than those adopted for the campaign of 2010. For joint solution of data from 2008 and 2010/2011 campaigns, the data from the 2008 campaign was recomputed, according to the parameters adopted for the 2010/2011 campaign with unchanged baseline definition.

The 2008 campaign was carried out from 23.04.2008 till 11.05.2008. Total field points, by the amount of 151 measured during the campaign, include 102 POLREF points. Their location was presented in Figure 3.

The 2010/2011 campaign was made from 12.10.2010 till 04.04.2011. It was divided into three parts: autumn, winter and spring. The second measurement, of 481 field points, include 242 POLREF points. Their location was presented in Figure 4.

Because some of POLREF points appeared to be moved, they were renewed before the 2010/2011 campaign was carried out. The analyses of their coordinates changes are described in chapter: Analyses.

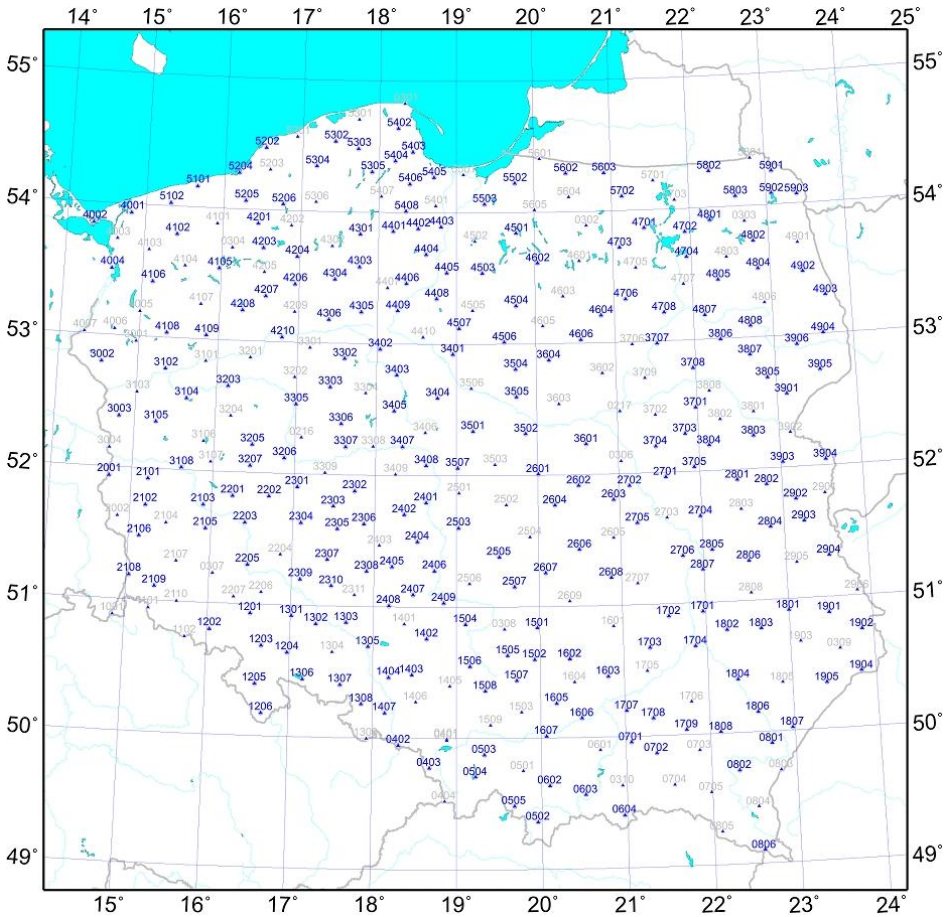


Fig. 4. The location of POLREF points measured during the 2010/2011 campaign (blue).

METHOD OF COMPARISON

The basic problem that arises during comparing the GPS network solutions from different periods, occurs due to the variability in time the points' coordinates and using the various implementations of geocentric systems. An additional difficulty is the lack of real velocities of field points measured periodically. Models of tectonic plates' movement (eg NUVEL 1A) used for points of not known velocities do not include the vertical component but only the mutual rotation and horizontal shift of tectonic plates. As a result of that method of reduction, for the distant measurement periods, we get the big differences of coordinates. In the following study to compare coordinates, the seven-parameter conformal space transformation was used assuming, that the effects of drift of tectonic plates will be included in the parameters of the transformation (rotation and shift of systems). Changes in the location of points resulting from local or regional movements (eg uplift of the Scandinavian Peninsula) show up as differences in the common points.

For transformation the POLREF points' coordinates in two different reference frame were used. For final results of three POLREF campaigns the coordinates in EUREF'89 were used when for ASG-EUPOS campaigns respectively the coordinates in ITRF 2005 reference frame were applied.

For the 2008 campaign in transformation all 102 points were used. The mean errors of transformation between the catalogue coordinates and the new ones have taken the following values in the components (NEU) respectively:

N ±6.5mm, E ±6.8mm, U ±14.4mm

The scale difference of both solutions was 0.0496×10^{-6} (it means 5 mm/100km).

The vectors of differences in horizontal components and height are presented in Figures 5 and 6 respectively.

For 2010/2011 campaign from 242 points in transformation 17 points were excluded for the following reasons:

4 points were the new eccentric points of existing POLREF points.

10 renewed POLREF points. In this case, after renewing the horizontal position of marker should be restored while the height of marker has been lost.

Point 1602 was measured two times. After autumn part of campaign it appeared that marker was moved so it was renewed and re-measured.

During the preliminary analyses two POLREF points: 2705 and 3305, were excluded from transformation because revealed big changes in height since last measurement.

Finally, for 2010/2011 campaign in transformation 225 POLREF points were used. The mean errors of transformation between the catalogue coordinates and the new ones have taken the following values in the components (NEU) respectively:

N ±7.6mm, E ±8.5mm, U ±14.8mm

The scale difference of both solutions was 0.0539×10^{-6} (it means 5 mm/100km).

The vectors of differences in horizontal components and height are presented in Figures 7 and 8 respectively.

The very similar results obtained from campaigns 2008 and 2010/2011 suggest no differences between these two solutions.

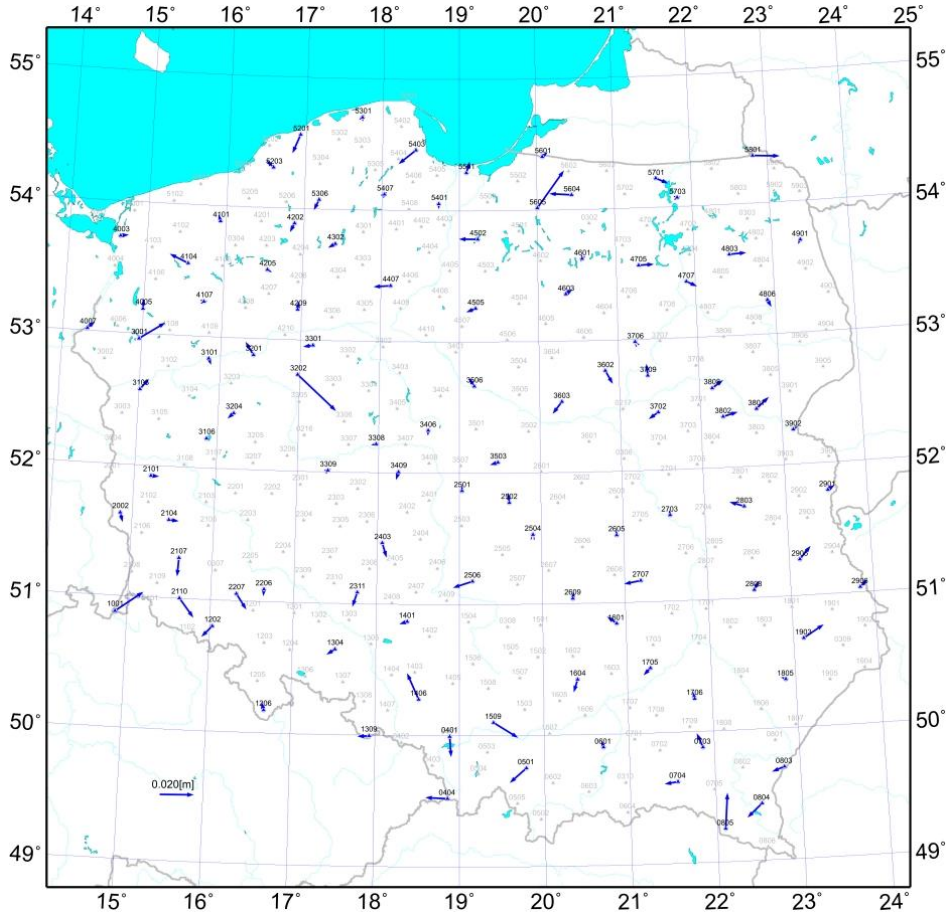


Fig. 5. The vectors of differences in horizontal components for POLREF points' coordinates between the final results of three POLREF campaigns and the 2008 campaign.

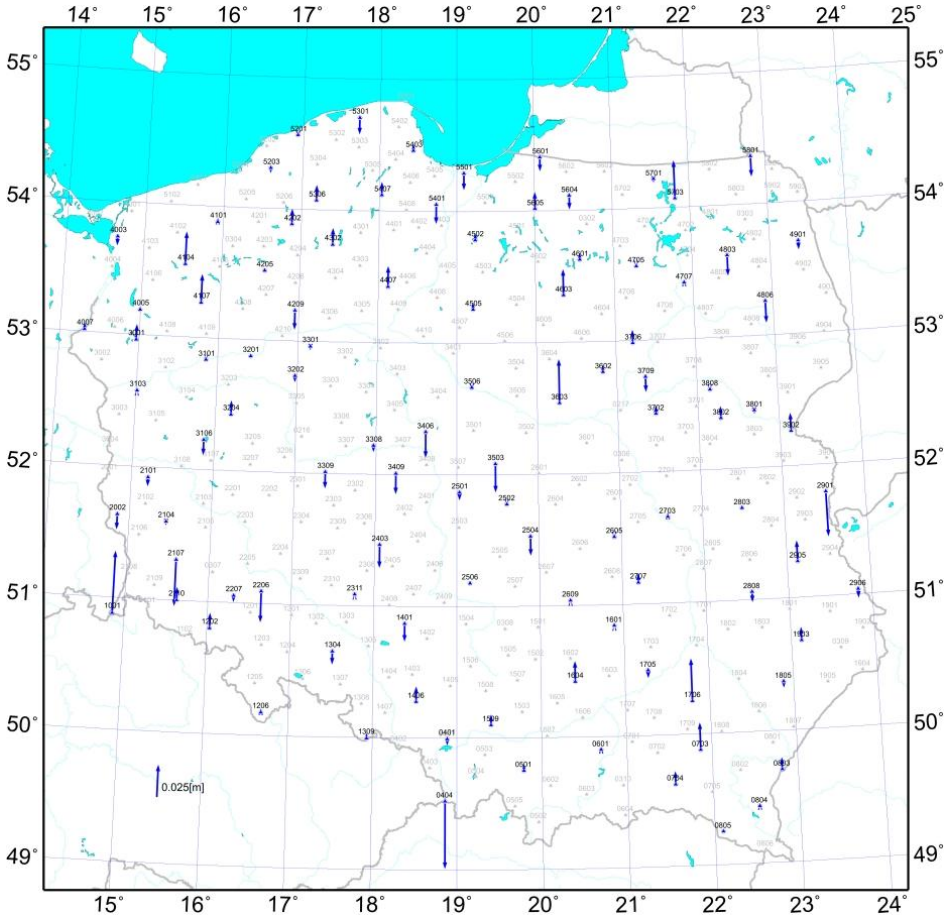


Fig. 6. The vectors of differences in height for POLREF points' coordinates between the final results of three POLREF campaigns and in the 2008 campaign.

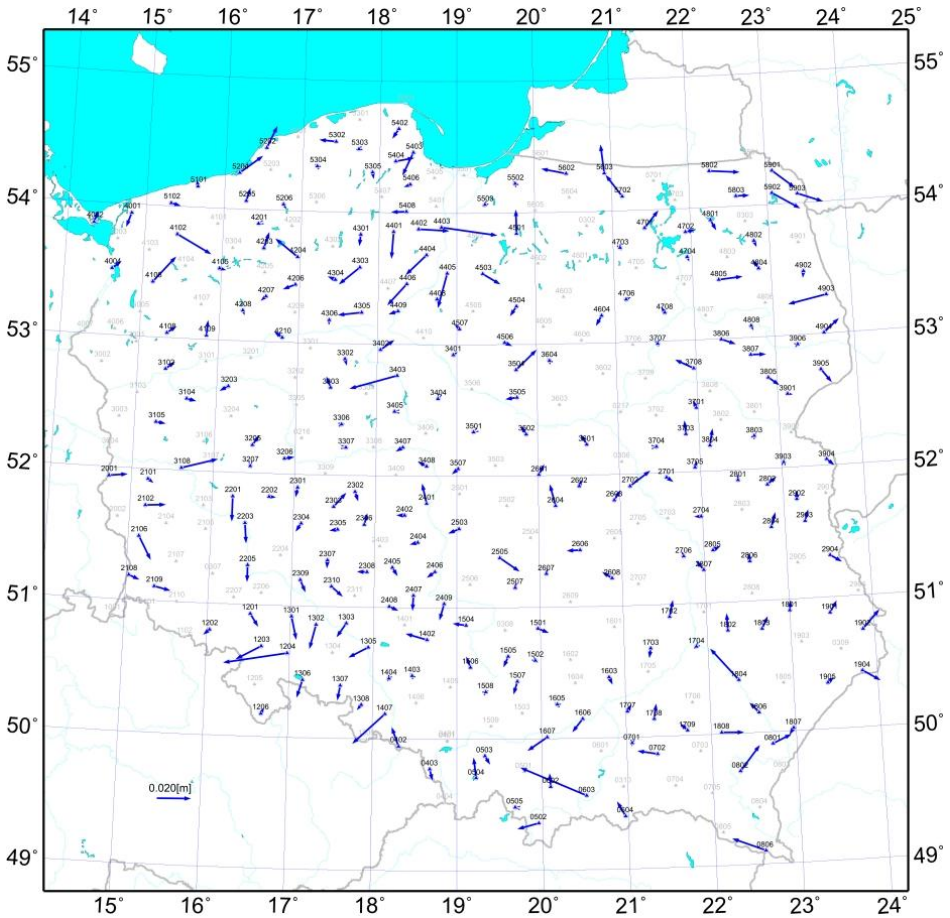


Fig. 7. The vectors of differences in horizontal components for POLREF points' coordinates between the final results of three POLREF campaigns and the 2010/2011 campaign.

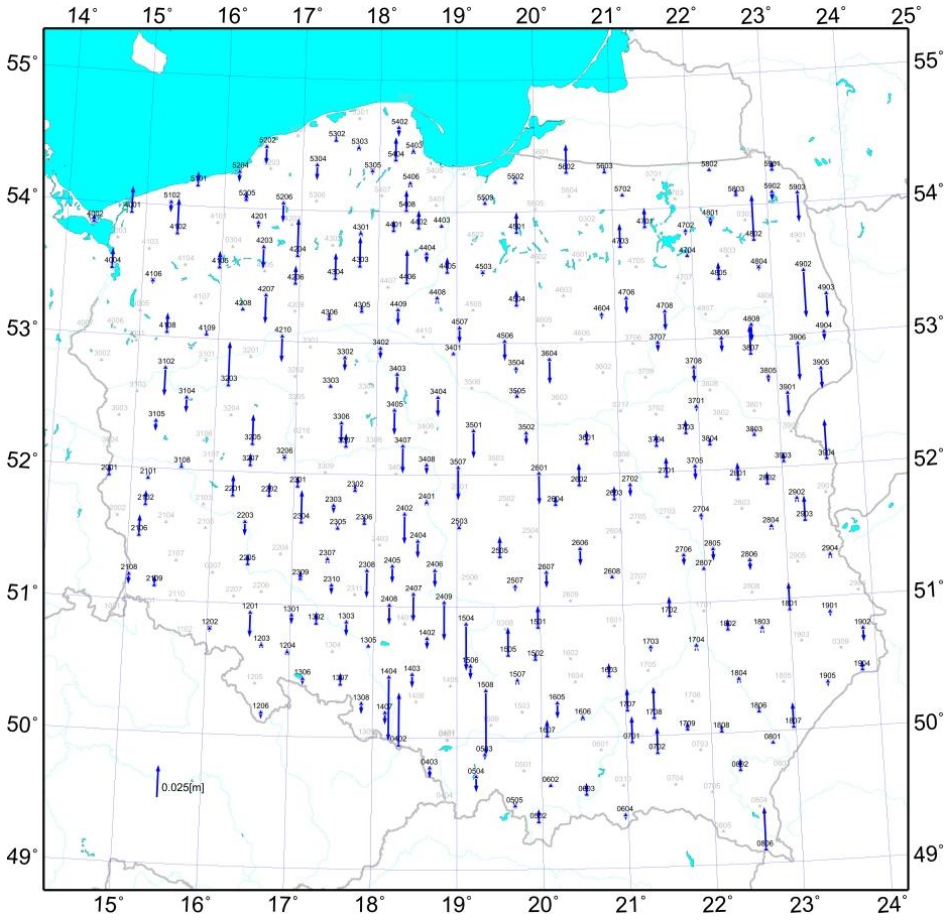


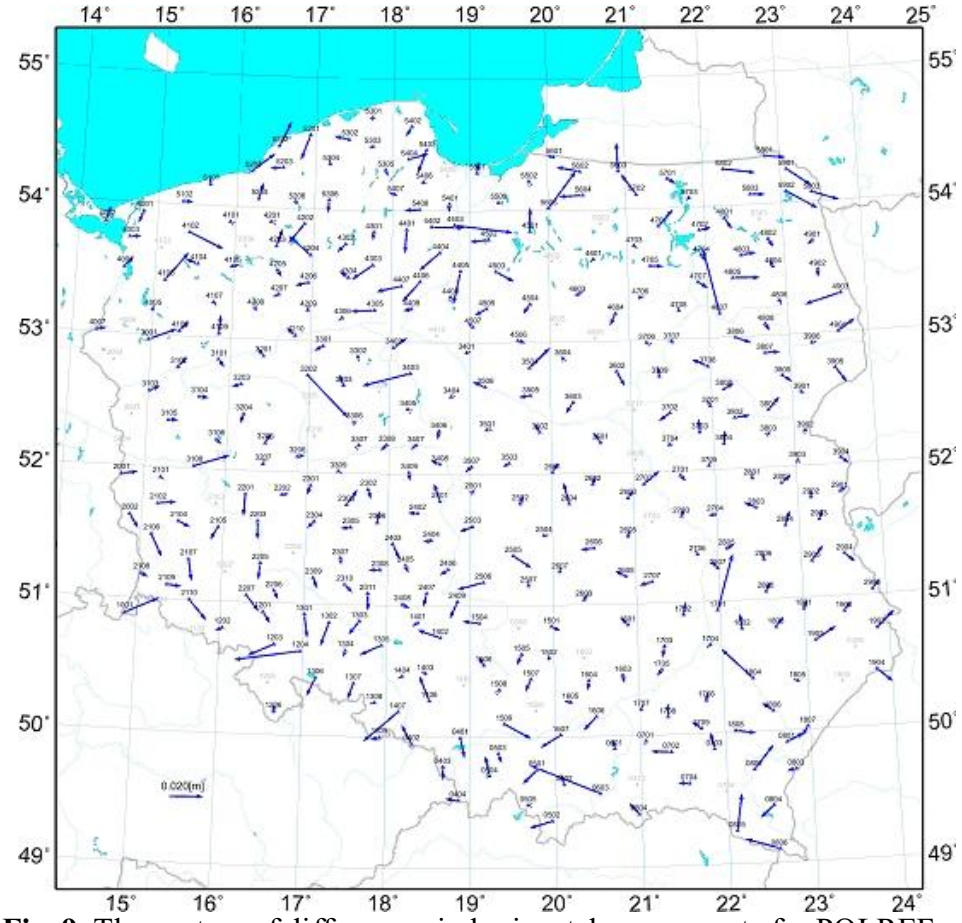
Fig. 8. The vectors of differences in height for POLREF points' coordinates between the final results of three POLREF campaigns and the 2010/2011 campaign.

For joint solution of 2008 and 2010/2011 campaigns in transformation 323 POLREF points were used. According to previously described reasons 17 points measured in the 2010/2011 campaign were excluded. Additionally four points were measured in both campaigns. The mean errors of transformation between the catalogue coordinates and the new ones have taken the following values in the components (NEU) respectively:

$$N \pm 7.3\text{mm},\quad E \pm 8.2\text{mm},\quad U \pm 14.8\text{mm}$$

The scale difference of both solutions was 0.0524×10^{-6} (it means 5 mm/100km).

The vectors of differences in horizontal components and height are presented in Figures 9 and 10 respectively.



. **Fig. 9.** The vectors of differences in horizontal components for POLREF points' coordinates between the final results of three POLREF campaigns and for joint solution of the 2008 and 2010/2011 campaigns.

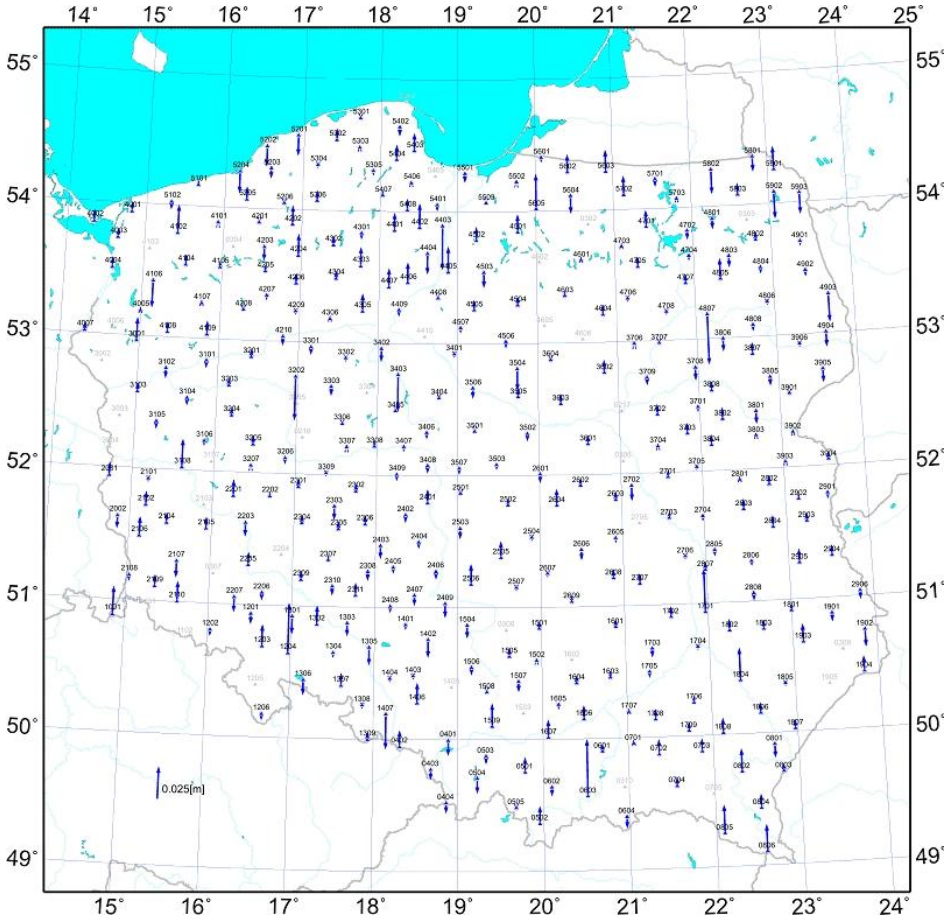


Fig. 10. The vectors of differences in height for POLREF points' coordinates between the final results of three POLREF campaigns and for joint solution of the 2008 and 2010/2011 campaigns.

ANALYSES

The residuals obtained for thirteen points of excluded from transformation are presented in Table 1.

Table 1. The residuals obtained for points excluded from transformation for the 2010/2011 campaign.

NUM	NAME	FLG	RESIDUALS IN MILLIMETERS		
43	1205	P A	5.4	-3.4	31.1 M
71	1602	P A	-13.2	8.5	212.6 M
471	160Z	P A	81.9	-50.1	12.2 M
98	1905	P A	1.7	4.7	-3.8 M
103	2103	P A	-14.9	7.0	66.9 M
108	2108	P A	-3.6	5.9	-11.4 M
158	2705	P A	8.0	27.5	-82.1 M
176	3002	P A	-29.1	33.5	30.9 M
177	3003	P A	10.5	-0.9	26.4 M
198	3305	P A	2.3	3.9	140.8 M
296	4602	P A	7.1	-0.4	-50.7 M
300	4606	P A	-23.0	2.8	-5.7 M
339	5405	P A	5.5	-9.9	-193.3 M



Fig. 11. The picture taken at the point 1602. It shows that the marker might be moved.

Presented in Table 1 point numbered as 160Z and 1602 is the cases described in chapter: Method of comparison. Point described was measured two times during the 2010/2011 campaign. After the first measurement (autumn part of campaign) the results of computation and pictures taken at the point (see Figure 11) suggested that the marker was moved. Then it was renewed and re-measured. It got two different numbers for computation process: 160Z – for the first measurements and 1602 – for re-measurements. The residuals of horizontal components show that truly the marker was moved. The big value of vertical and small values for horizontal residuals for the renewed marker show that it was precisely renewed, but of course it was impossible to preserve the previous height.

In case of point 3002 the differences in horizontal components are big. Unfortunately that point is located within the flood plain area. Because of the problems with proper renewing and possible instability of coordinates in time it was suggested that it should be rejected from POLREF – the first order GNSS national network.

The remaining renewed points show good agreement in horizontal components with catalogue coordinates.

The point 3305 has been excluded from transformation due to the large difference in vertical component suggesting coarse error. The basis for this conclusion might be no change in the horizontal components. The review of point coordinates determination made in 1995 campaign, showed that result of a height calculation using GPS data was consistent with the result of levelling. This check practically excluded the possibility of antenna height measurement error in 1995 year. The results of two independent observation sessions have shown no error in antenna height measurements in 2010/2011 campaign. In order to find the cause of this difference re-levelling of this point would have had to be done. If the results

confirm the change in height of marker, it will mean changing the physical location of the point.

A different situation is with the POLREF point number 2705 which was excluded from the transformation. It is located at the edge of the young forest (see photo in Figure 12) and the horizon for GNSS measurements has been considerably obstructed. Despite the theoretically correct results of coordinates computation for the 2010/2011 campaign, they may be distorted by the lack of observation of almost a half of the horizon. Additionally, due to its location in the line of trees, the marker can also be shifted by roots of growing trees. Also in this case it would be advisable to check the height of the point using the levelling.



Fig. 12. The picture taken at the point 2705. It shows that the horizon is obstructed strongly by the forest.

CONCLUSIONS

Re-measurement of most POLREF network points allows to validate the accuracy and stability of their coordinates in a long time. It was found that despite the passage of several years after the appointment of POLREF network, catalogue coordinates still show very high accuracy. However, some points require a renewing, and other points in the network suggest a change in the position. Due to those reasons re-measurement and new computation of network points was advisable.

Unfortunately, for financial reasons, both campaigns lacked re-designating the height of POLREF points using geometric levelling. In many cases it would be used to verify suspicions of moving the marker. This is a very important element, which again would involve the geometric determination of the GNSS measurements with heights obtained from levelling. Its absence in many cases leads to doubting whether the new information from the GNSS measurements shall be compatible with old references heights from levelling.

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