Results of the EUREF–POL'2001 GPS Campaign

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Abstract

The *EUREF–POL'2001 GPS Campaign* was carried out in September 2001. The main objective was to check the quality of coordinates of the Polish part of EUREF network established in 1992 during the EUREF–Pol'92 GPS Campaign.

Measurements were performed between 26th and 30th September using Trimble 4000SSi receivers during five 24–hour sessions. Computations were done with the use of Bernese GPS Software version 4.2. The IGS final precise orbit was used for the processing.

Network was computed basing on the ITRF2000, epoch 2001.74 and transformed to the ETRS89.

1. Introduction

The Polish part of EUREF network was established during the GPS Campaign EUREF–POL'92 and contained eleven points (fig.1).

During the next few years, five Polish stations were included into the IGS/EUREF permanent network:

- stations: LAMA 12209M001 and JOZE 12204M001 are identical with EUREF–POL points: 0302 LAMKOWKO and 0306 JOZEFOSLAW[3],
- two stations: BOR1 12205M002 and BOGO 12207M002 are located eccentrically to EUREF–POL points 0216 BOROWIEC and 0217 BOROWA GORA,
- one EPN station WROC 12217M001 is new.

Additionally, point 0217 BOROWA GORA was established as the second permanent station in Borowa Góra Observatory with JPS EUROCARD receiver and ASH701945-01C SNOW antenna.

The main goal of GPS campaign, called EUREF–POL'2001 was to control positions of existing EUREF points. It should be pointed out that ETRF'89 was introduced as the official terrestrial reference frame in Poland in August 2000. The network of 11 points of EUREF'92 campaign, accepted by the resolution of EUREF Subcommision in 1994, constitutes the datum (PAZUS R., 2001).

The EUREF-POL'2001 Campaign was carried out by the *Department of Planetary Geodesy* of the *Space Research Centre, the Polish Academy of Sciences.*

2. Network Design

The network designed for the EUREF–POL 2001 GPS Campaign includes:

- seven EUREF–POL'92 points: 0301 ROZEWIE, 0303 MASZE,0304 CZARNKOWIE, 0307 STUDNICA, 0308 ROGACZEW, 0309 ZUBOWICE, 0310 GRYBOW.
- one EUREF–POL'92 point – 0216 BOROWIEC, located eccentrically to EPN station BOR1 12205M002,
- one EUVN97 point – PL05 SANOK,
- one EUREF–POL'92 point – 0217 BOROWA GORA, located eccentrically to EPN station BOGO 12207M002.

To connect this points to ITRF reference frame, twelve EPN stations were included into the network:

- five EPN stations in Poland mentioned above:
  BOR1 12205M002, BOGO 12207M002, LAMA 12209M001, JOZE 12204M001 and WROC 12217M001.
- seven stations located outside the Polish territory:
  GOPE 11502M002, GRAZ 11001M002, METS 10503S011, ONSA 10402M004, PENC 11206M006, RIGA 12302M002 and WTZR 14201M010

Final baselines configurations of the processed network is presented in figure 2.

3. GPS Observations Campaign

The observations for EUREF–POL'2001 GPS Campaign were carried out from Wednesday 26 th to Sunday 30th September 2001.

On the field points the measurements were performed using Trimble 4000SSi receivers and Trimble Compact L1/L2 with Groundplane antenna (IGS model TRM22020.00 GP) with the following parameters:

observations session	24 hours with 5 minutes breaks at 23:55 UT for downloading the data from receiver to PC
elevations cut–off mask	10^0
observations sampling rate	30 seconds

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[3] JOZE 12204M001 has got different definition of antenna height than 0306 JOZEFOSLAW. In IGS/EPN, the antenna height is referenced to the bench mark ( ) h=+0.198m), but in EUREF–POL, the antenna height is referred to upper surface of the pillar (for ARP) h=+0.000m).

antenna installation	on pillar with centring device
antenna orientation	on the North
antenna height	measured from upper surface of pillar to the antenna Groundplane and then reduced to ARP

All observations on these points were performed successfully. A summary of observations including EPN points, is given in Table 1.

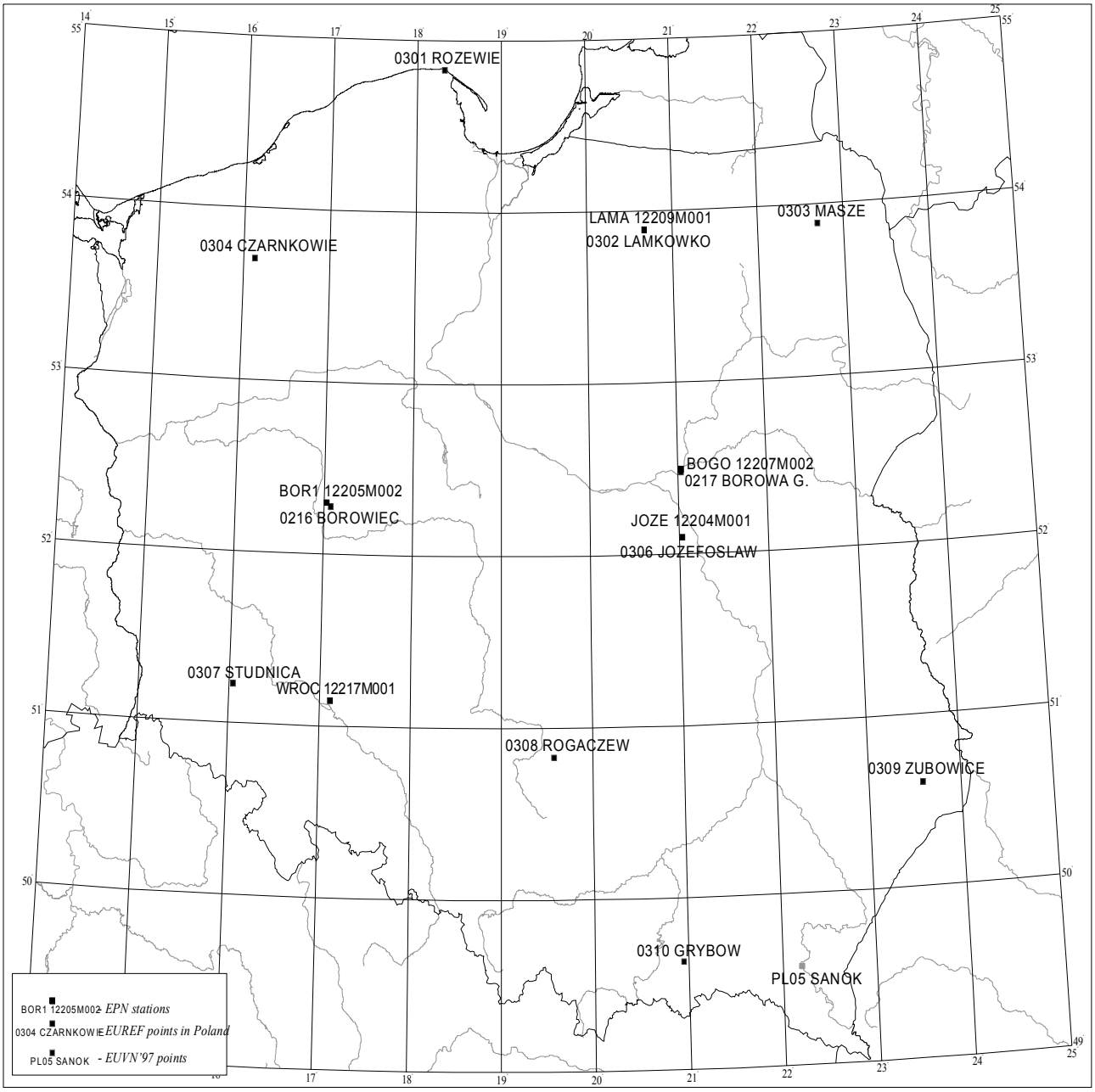


Figure 1. Stations in Poland included in EUREF–POL 2001 GPS Campaign .

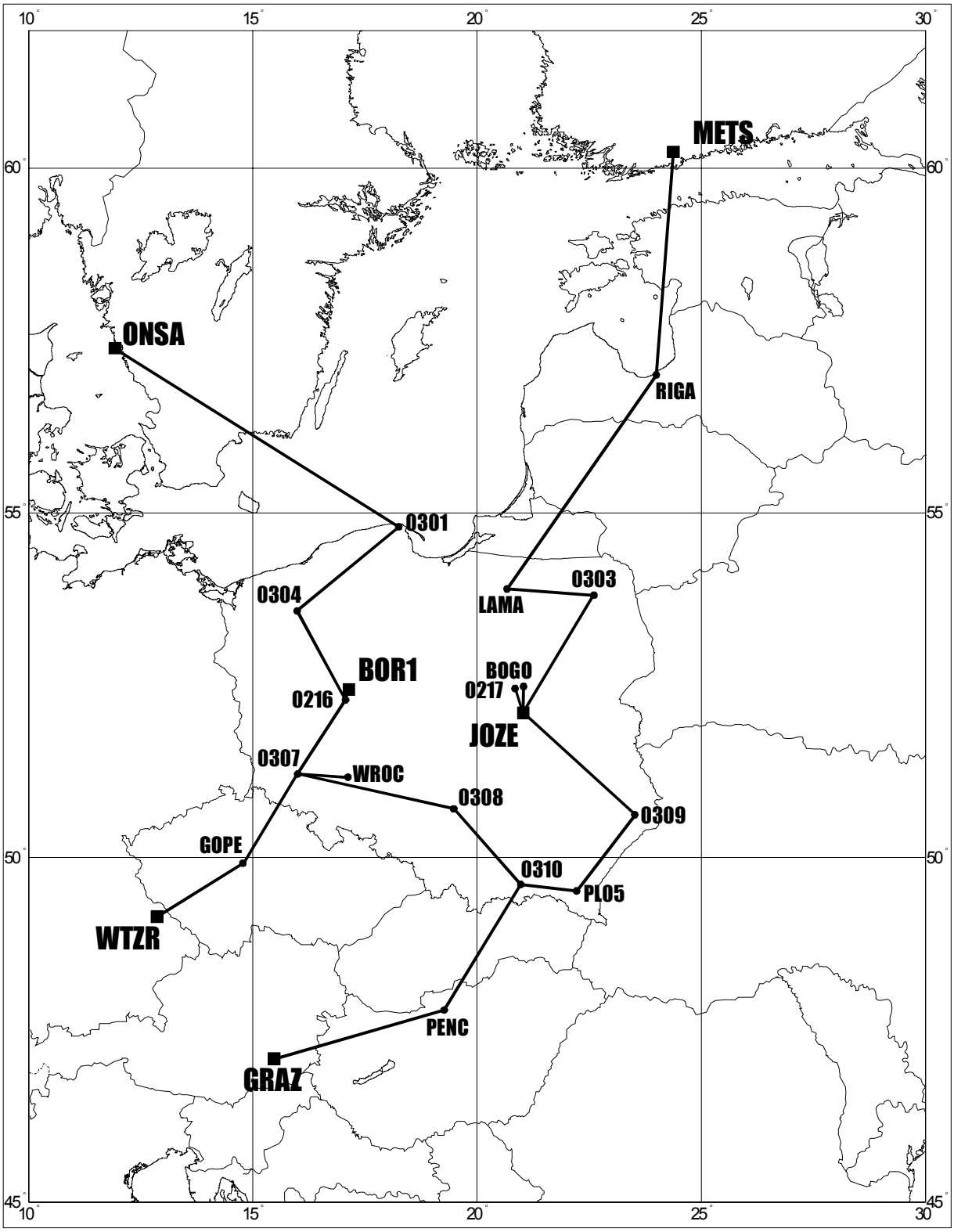


Figure 2. The EUREF–POL 2001 GPS Campaign – baselines network.

Table 1. Used GPS observations.

Stations	Day of year				
	269	270	271	272	273
Fields EUREF points					
0216 BOROWIEC	**********	**********	**********	**********	**********
0301 ROZEWIE	**********	**********	**********	**********	**********
0303 MASZE	**********	**********	**********	**********	**********
0304 CZARNKOWIE	**********	**********	**********	**********	**********
0307 STUDNICA	**********	**********	**********	**********	**********
0308 ROGACZEW	**********	**********	**********	**********	**********
0309 ZUBOWICE	**********	**********	**********	**********	**********
0310 GRYBOW	**********	**********	**********	**********	**********
PL05 SANOK	**********	**********	**********	**********	**********
Fields EUREF in Poland					
0217 BOROWA GORA	**********	**********	**********	**********	**********
BOGO 12207M002	** *********	**********	**********	**********	**********
BOR1 12205M002	**********	**********	**********	**********	**********
JOZE 12204M001	**********	**********	**********	**********	**********
LAMA 12209M001	**********	**********	**********	**********	**********
WROC 12217M001	*****	*********	**********	**********	**********
External EUREF points					
GOPE 11502M002	**********	**********	**********	**********	**********
GRAZ 11001M002	**********	**********	**********	**********	**********
METS 10503S011	**********	**********	**********	**********	**********
ONSA 10402M004	**********	**********	**********	**********	**********
PENC 11206M006	**********	**********	**********	**********	**********
RIGA 12302M002	**********	**********	**********	**********	**********
WTZR 14201M010	**********	**********	**********	**********	**********

* – 2 hours interval,

– WROC 12217M001 for day 269 (September 26, 2001) - observation only to 9:00 UT,

– WROC 12217M001 for day 270 (September 27, 2001) - observation from 6:22 UT,

– BOGO 12207M002 for day 270 (September 27, 2001) - no observation from 3:07 UT to 6:36 UT.

4. Data Pre–Processing

Raw data were converted from Trimble 4000SSi to RINEX format with checking of the antenna heights. Fields values were reduced to ARP – Antenna Reference Point, – (bottom of Trimble antenna mount TRM22020.00+GP) as in IGS/EPN network (Table 2).

Information about receiver/antenna pair and antenna height for station 0217 BOROWA GORA was obtained from J. CISAK (Institute of Geodesy and Cartography, Warsaw).

For EPN points values from RINEX header files and station log files were used (table 3).

[2] Antenna mounted directly on the pillar (without tribrach)

Table 2. Equipment (receiver/antenna) and antenna heights for field points (reduced to ARP).

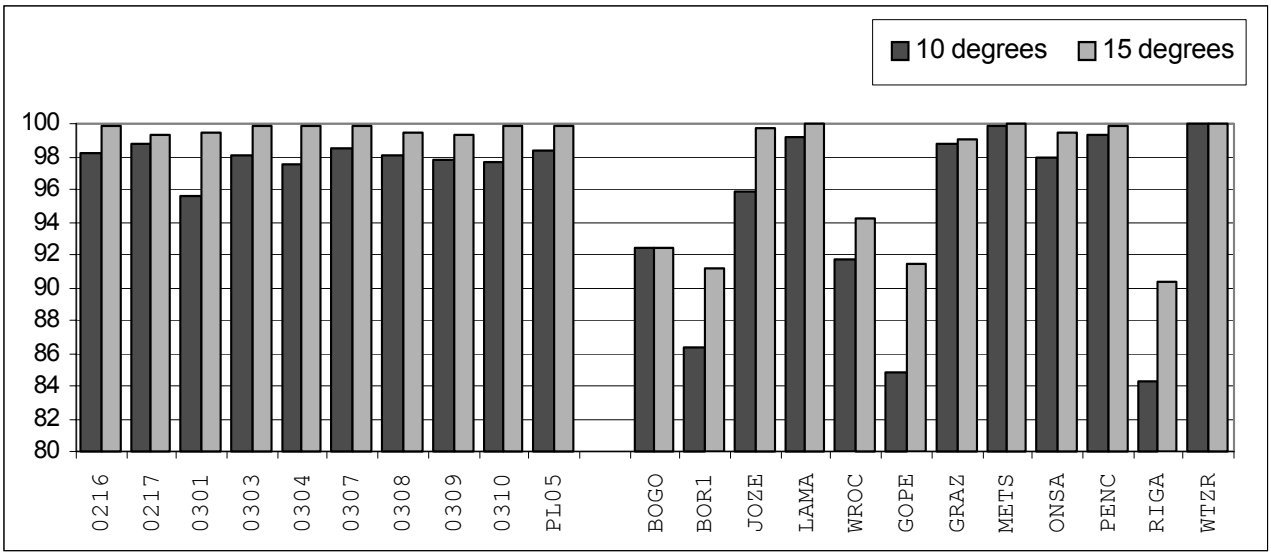
Station	Receiver / antenna	Antenna height (ARP)				
		269	270	271	272	273
0216 BOROWIEC	Trimble 4000 SSi / TRM22020.00	0.000[2]	0.000[2]	0.000[2]	0.000[2]	0.000[2]
0301 ROZEWIE	Trimble 4000 SSi / TRM22020.00	0.065	0.065	0.065	0.065	0.065
0303 MASZE	Trimble 4000 SSi / TRM22020.00	0.065	0.065	0.065	0.065	0.065
0304 CZARNKOWIE	Trimble 4000 SSi / TRM22020.00	0.064	0.064	0.064	0.064	0.064
0307 STUDNICA	Trimble 4000 SSi / TRM22020.00	0.068	0.069	0.069	0.069	0.069
0308 ROGACZEW	Trimble 4000 SSi / TRM22020.00	0.056	0.056	0.056	0.056	0.056
0309 ZUBOWICE	Trimble 4000 SSi / TRM22020.00	0.061	0.061	0.061	0.061	0.061
0310 GRYBOW	Trimble 4000 SSi / TRM22020.00	0.063	0.063	0.063	0.063	0.063
PL05 SANOK	Trimble 4000 SSi / TRM22020.00	0.066	0.066	0.066	0.066	0.066

Table 3.Equipment (receiver/antenna) and antenna heights on EPN stations included in EUREF–POL'2001 solution

EPN station	Receiver / antenna	Antenna height	Institution / Country
0217 BOROWA GORA	JPS EUROCARD / ASH701945-01C SNOW	0.088	IGC, Poland
BOGO 12207M002	ASHTECH Z-XII3 / ASH700936C_M SNOW	0.000	IGC, Poland
BOR1 12205M002	ROGUE SNR-8000 / AOAD/M_T	0.0624	SRC P.A.S., Poland
JOZE 12204M001	Trimble 4000 SSE / TRM14532.00	0.1980	IG&GA WUT, Poland
LAMA 12209M001	ASHTECH Z-XII3 / ASH700936C_M SNOW	0.061	UWM Olsztyn, Poland
WROC 12217M001	ASHTECH Z18 / ASH701941.1 SNOW	0.0000	DG&P AU Wroc»aw, Poland
GOPE 11502M002	ASHTECH Z18 / ASH701946.3 SNOW	0.0464	RIGTC – GO PECNY, Czech
GRAZ 11001M002	ASHTECH UZ-12 / ASH701945C_M	1.9640	ISR GRAZ, Austria
METS 10503S011	ASHTECH Z-XII3 / AOAD/M_B	0.000	FGI, Finland
ONSA 10402M004	ASHTECH Z-XII3 / AOAD/M_B OSOD	0.9950	NLS, Sweden
PENC 11206M006	Trimble 4000 SSE / TRM14532.00	0.0300	SGO, Hungary
RIGA 12302M002	ROGUE SNR-8000 / ASH700936D_M	0.0850	OSO, Latvia
WTZR 14201M010	AOA SNR-8000 ACT / AOAD/M_T	0.0710	BKG-Wettzell, Germany

Finally, quality of GPS data was checked using TEQC program. Numbers of cycle slips and information about real observed data for L1 and L2 frequencies as compared with its theoretical values are shown in table 4.

Table 4. Number of observations (in percent) for each station



5. Data Processing

5.1 Processing strategy

The data processing was performed using the Bernese GPS Software, version 4.2. In computation we have used the procedure recommended for EUREF, i.e.:

- Use of IGS final precise orbits and IERS Earth Rotation Parameters (C04 pole series),
- Antenna Phase Centre from PHAS_IGS.01 file (version 03-DEC-2001),
- reference frame for the fixed station – ITRF2000 rotated to observation epoch 2001.74,
- elevation cut–off angle – 10 degrees with elevation-dependent weighting,
- using the ionosphere-free linear combination L3,
- introducing the fixed L1 and L2 ambiguities resolved from QIF strategy for baseline,
- estimating tropospheric zenith delay parameters for every hour with *„dry Neill"* mapping function and without a priori global tropospheric model
- daily network solutions with storing normal equations,

5.2 Free network solution

In a first step free network daily solutions (minimally constrained) were computed with fixing WTZR 14201M010 to its co-ordinates in ITRF97 and ITRF2000 for epoch 2001.74. The normal equations from daily solutions were combined with Bernese program ADDNEQ. This solution was used to analyse the stability of the co-ordinates and for comparison with another data. For all stations, the co-ordinates vary within few millimetres for horizontal and vertical components (Table 5, 6).

Table 5. RMS of stations co-ordinates computed from daily repeatability. Free network solutions with station WTZR 14201M010 fixed. All values in millimetres.

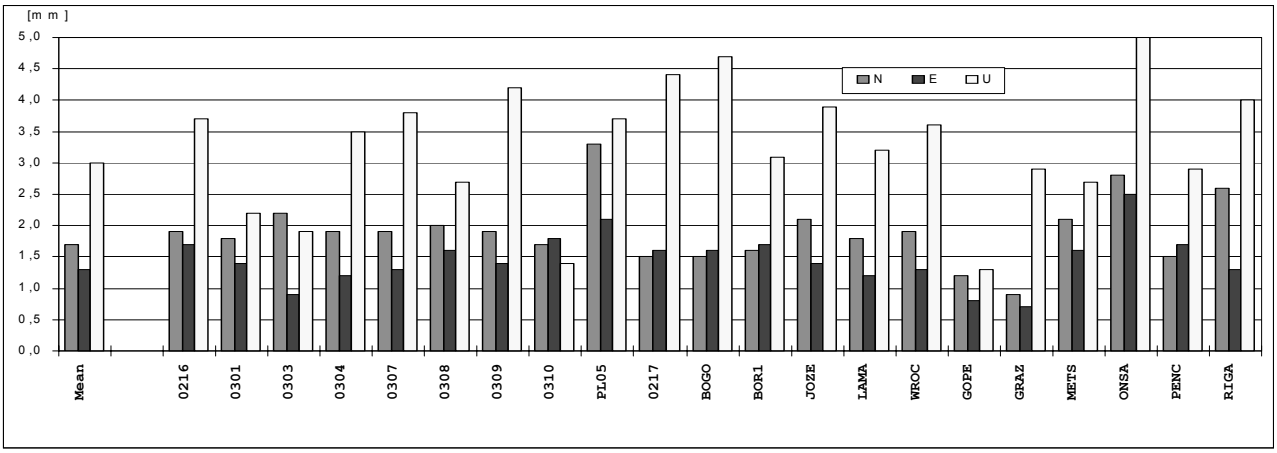


Table 6. Daily repeatability for the station co-ordinates. Free network solutions with station WTZR 14201M010 as fixed. All values in millimetres.

Station		Days RMS	269	270	271	272	273
0216 Borowiec	N	1.9	-1.4	-0.5	3.3	-0.8	0.1
	E	1.7	2.5	-1.5	0.4	-1.8	0.1
	U	3.7	15	-3.0	-3.2	0.0	58
0301 Rozewie	N	1.8	-14	-1.8	1.9	1.9	0
	E	1.4	1	-1.9	-0.3	-1.0	1.6
	U	2.2	-2.7	2.4	0.6	-1.6	1.7
0303 Masze	N	2.2	-0.8	-2.6	3.1	1.5	-0.5
	E	0.9	0.4	-0.9	0.2	-1.3	1
	U	1.9	0.5	1.7	0.7	-3.3	0.8
0304 Czarnkowie	N	1.9	-0.2	-0.5	3.5	-0.9	-1.2
	E	1.2	0.6	-1.0	0.8	-1.7	0.9
	U	3.5	-4.3	1.9	-2.5	3.9	2.3
0307 Studnica	N	1.9	-0.1	-1.0	3.5	-1.4	0.0
	E	1.3	-0.6	-0.4	1.9	-1.5	0.3
	U	3.8	-3.5	-2.1	-2.0	3.1	5.2
0308 Rogaczew	N	2.0	0.0	-1.7	3.3	0.6	-1.5
	E	1.6	1.8	0.5	-0.3	-2.5	0.2
	U	2.7	1.2	0.2	-2.9	-1.7	4.1
0309 Zubowice	N	1.9	-0.9	-1.5	3.4	-0.1	-0.1
	E	1.4	1.8	0.0	0.3	-2.2	0.0
	U	4.2	-5.9	2.1	-0.4	5.6	-0.7
0310 Grybow	N	1.7	2.3	0.6	0.7	-2.2	-0.8
	E	1.8	2.9	-0.7	0.1	-2.0	-0.6
	U	1.4	2.3	-1.4	0.2	-0.3	0.6
Pl05 Sanok	N	3.3	3.0	3.6	0.0	-4.1	-2.0
	E	2.1	2.5	1.4	-0.6	-2.8	-0.8
	U	3.6	-4.7	0.8	-2.0	2.5	4.5
0217 Borowa Gora	N	1.5	-0.3	-1.1	2.7	-0.6	0.2
	E	1.6	0.5	0.0	0.4	-2.7	1.4
	U	4.4	-2.7	2.0	-3.8	-1.1	7.0
BOGO 12207M002	N	1.5	-0.4	-1.2	2.6	-0.5	0.3
	E	1.6	0.4	-0.1	0.2	-2.7	1.5
	U	4.7	-2.0	0.2	-4.1	-1.3	8.1

Station		Days RMS	269	270	271	272	273
BOR1 12205M002	N	1.6	-0.8	-0.5	2.9	-0.9	0.1
	E	1.7	2.5	-1.4	0.0	-1.8	0.3
	U	3.0	-3.5	0.5	-1.9	0.3	4.6
GOPE 11502M002	N	1.2	0.1	-0.8	2.2	-0.6	-2
	E	0.8	-0.1	0.3	0.8	-1.3	-0.1
	U	1.3	-0.5	-0.8	-0.3	2.5	-0.2
GRAZ 11001M002	N	0.9	-0.3	-1.2	1.0	0.8	0.4
	E	0.7	-0.1	-0.4	1.0	-0.1	-0.7
	U	2.9	-2.1	3.9	-3.1	1.0	1.7
JOZE 12204M001	N	2.1	-0.4	-0.8	3.8	-0.4	-1.3
	E	1.4	1.1	0.3	0.1	-2.4	0.4
	U	3.8	1.2	-2.1	-5.4	2.7	4.1
LAMA 12209M001	N	1.8	-1.2	-2.1	2.6	1.1	0.3
	E	1.2	-0.6	-0.5	0.5	-1.6	1.7
	U	3.2	-3.7	2.9	-1.8	-0.8	3.9
METS 10503S011	N	2.1	0.9	-0.8	3.4	-2.2	-0.6
	E	1.6	1.9	-1.8	-0.1	-1.6	1.1
	U	2.7	-3.6	2.9	0.3	-0.9	2.5
ONSA 10402M004	N	2.7	-0.7	-3.0	2.8	3.2	-1.7
	E	2.5	0.1	-3.5	-1.2	3.5	0.2
	U	5.0	-4.3	1.8	-6.1	3.8	5.2
PENC 11206M006	N	1.5	-1.8	1.4	1.6	0.5	-1.1
	E	1.7	1.3	0.6	0.7	-3.0	0.2
	U	2.8	3.1	-0.4	-3.1	-1.8	3.1
RIGA 12302M002	N	2.6	-1.4	-1.7	4.4	0.8	-1.4
	E	1.3	1.5	-1.0	0.8	-1.9	0.1
	U	4.0	-6.3	1.1	1.2	0.4	4.7
WROC 12217M001	N	1.9	1.8	-0.7	3.0	-0.6	-1.4
	E	1.3	1.1	-1.3	0.5	-1.7	0.7
	U	3.5	-2.7	2.4	-4.4	1.3	4.0
Combination	N	1.7	12	1.6	2.9	1.6	1.0
	E	1.3	1.5	1.2	0.7	2.1	0.9
	U	3.0	3.4	2	2.9	2.4	4.1

5.3 Co-ordinates of the fixed station

Twelve EPN stations were included in the network. Co-ordinates of EPN stations were determined by a free network solution (with WTZR 14201M010 as fixed). Next, the results were compared with their ITRF97 and ITRF2000 coordinates after a 7–parameter Helmert transformations. Table 5 shows residuals of the co-ordinates in both reference frames.

Problem with co-ordinates of station RIGA 12302M002 in ITRF2000 is probably caused by its velocity vector in this reference frame (table 7).

Table 7: Residuals after 7–parameters Helmert transformation between the coordinates of EPN points determined by free network solution and their ITRF97 and ITRF2000 coordinates. In ITRF2000 point RIGA 12302M002 was excluded from transformation.

EPN station	ITRF97 N	E	U	ITRF2000 N	E	U
BOGO 12207M002	-0.1	2.6	-12	2.4	1.3	-5.9
BOR1 12205M002	1.4	4.8	3.9	0.9	3.3	2
GOPE 11502M002	-2.9	2.4	-4	-2.8	4.1	-8.3
GRAZ 11001M002	0.5	-2.5	4.6	-1.3	-2.5	6.6
JOZE 12204M001	-2.6	-1.1	9.8	-3.2	-1.6	5
LAMA 12209M001	-4.6	-5.3	-6.7	-2.3	-5.7	-8.5
METS 10503S011	1.3	-2.2	4.3	2.2	-1.8	6.6

EPN station	ITRF97 N	E	U	ITRF2000 N	E	U
ONSA 10402M004	1.1	3.1	-9.5	2.6	3.6	-2.6
PENC 11206M006	-0.8	-1	-9.9	0.1	0.5	-1.5
RIGA 12302M002	4.2	-0.6	7.6	2.5	-1.8	48.1
WROC 12217M001	1	-0.1	-1.8	0.8	-1.5	1.6
WTZR 14201M010	1.5	-0.2	13.5	0.8	0.3	4.9
RMS	2.4	2.8	8.4	2.1	3	5.7

Table 8: Station velocity vector (m/year) for RIGA 12302M002 in ITRF97 and ITRF2000 reference frames.

Station	ITRF97			ITRF2000		
	V_X	V_Y	V_Z	V_X	V_Y	V_Z
RIGA 12302M002	-0.0174	0.0139	0.0038	-0.0221	0.0131	-0.0001

On two stations GOPE 11502M002 and LAMA 12209M001 bigger residuals for East and Up components were observed as the result of the installation of the new antenna with snow cover. Movements of heights for this points were observed in EPN solutions too (see Figure 3).

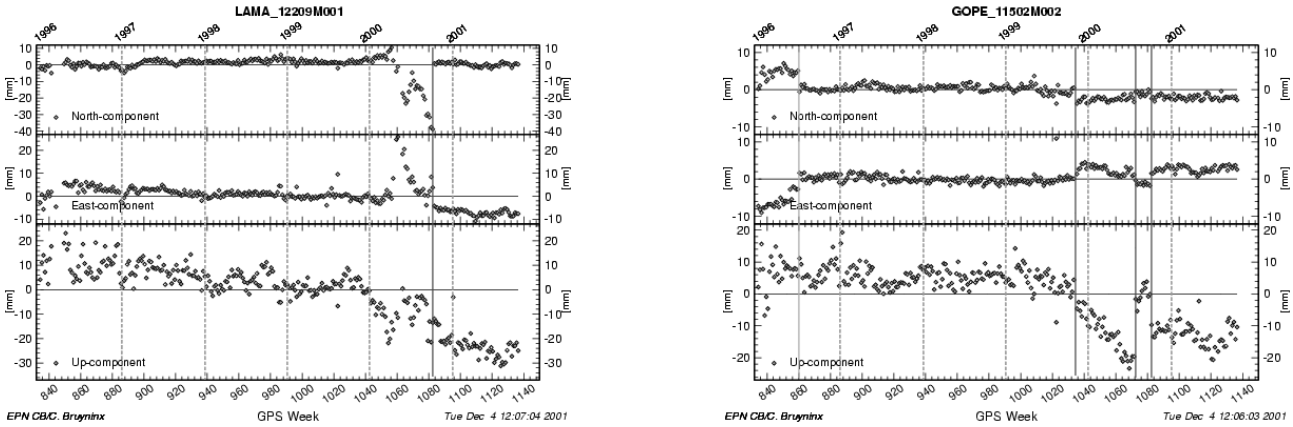


Figure 3. Standard Time Series from EPN for stations LAMA 12209M001 and GOPE 11502M002.

To avoid the deformation of co-ordinates, only six most stable EPN stations were fixed in constrained solution:

– two in Poland:
  BOR1 12205M002 and JOZE 12204M001.
– four outside Poland:
  GRAZ 11001M002, METS 10503S011,
  ONSA 10402M004 and WTZR 14201M010

In tables 9, 10 and 11 official co-ordinates in ITRF2000 at epoch 1997.0, corresponding to velocity vectors for each station and final co-ordinates in ITRF2000 at epoch of the campaign (2001.74) are given respectively.

Table 9. Geocentric co-ordinates of reference stations in ITRF2000 at epoch 1997.0

Station	X	Y	Z
BOR1 12205M002	3738358.5980	1148173.5820	5021815.7050
GRAZ 11001M002	4194423.9590	1162702.5490	4647245.3280
JOZE 12204M001	3664940.3150	1409153.7410	5009571.3230
METS 10503S011	2892570.9230	1311843.3300	5512634.0570
ONSA 10402M004	3370658.6630	711877.0230	5349786.8770
WTZR 14201M010	4075580.6850	931853.6600	4801568.0540

Table 10. Velocity vectors for reference stations in ITRF2000 (m/year).

Station	V_X	V_Y	V_Z
BOR1 12205M002	-0.0170	0.0161	0.0075
GRAZ 11001M002	-0.0176	0.0181	0.0082
JOZE 12204M001	-0.0181	0.0162	0.0074
METS 10503S011	-0.0160	0.0149	0.0088
ONSA 10402M004	-0.0134	0.0148	0.0095
WTZR 14201M010	-0.0157	0.0172	0.0087

Table 11. Geocentric co-ordinates of reference stations in ITRF2000 at epoch of GPS Campaign EUREF–POL'2001 (2001.74).

Station	X	Y	Z
BOR1 12205M002	3738358.5174	1148173.6583	5021815.7406
GRAZ 11001M002	4194423.8756	1162702.6348	4647245.3669
JOZE 12204M001	3664940.2292	1409153.8178	5009571.3581
METS 10503S011	2892570.8472	1311843.4006	5512634.0987
ONSA 10402M004	3370658.5995	711877.0932	5349786.9220
WTZR 14201M010	4075580.6106	931853.7415	4801568.0952

5.4 Constrained solution

The final solution was performed using co-ordinates of six EPN stations in ITRF2000 and with constrained errors of 0.1mm. In table 12 geocentric co-ordinates with their formal errors of the EUREF–POL 2001 GPS Campaign are given in ITRF2000 reference frame (epoch 2001.74).

Table 12. Geocentric co-ordinates in ITRF2000 for epoch of GPS Campaign EUREF–POL'2001 (2001.74).

Station	X	RMS (m)	Y	RMS (m)	Y	RMS (m)
0216 BOROWIEC	3738396.9000	0.001	1148285.8979	0.001	5021752.3434	0.002
0217 BOROWA GORA	3633815.3803	0.002	1397454.0633	0.001	5035280.9143	0.002
0301 ROZEWIE	3495579.3574	0.001	1157845.6712	0.001	5190403.7535	0.002
0303 MASZE	3475730.3818	0.001	1453976.6721	0.001	5129448.9228	0.002
0304 CZARNKOWIE	3635006.5418	0.001	1051224.6392	0.001	5117503.3576	0.002
0307 STUDNICA	3846614.0801	0.001	1106084.0397	0.001	4949572.6117	0.002
0308 ROGACZEW	3803542.6597	0.001	1352681.2683	0.001	4921845.9450	0.002
0309 ZUBOWICE	3717652.3064	0.001	1622949.0584	0.001	4905873.0500	0.002
0310 GRYBOW	3866100.0018	0.001	1479953.1519	0.001	4836446.5423	0.002
PL05 SANOK	3836865.2808	0.001	1565871.6952	0.001	4832580.9232	0.002
BOGO 12207M002	3633739.0300	0.001	1397434.0806	0.001	5035353.4301	0.002
GOPE 11502M002	3979316.1741	0.002	1050312.4225	0.001	4857067.0472	0.002
LAMA 12209M001	3524522.9822	0.001	1329693.5797	0.001	5129846.3090	0.002
PENC 11206M006	4052449.5428	0.001	1417681.0707	0.001	4701407.0712	0.002
RIGA 12302M002	3183899.2641	0.001	1421478.4462	0.001	5322810.7718	0.002
WROC 12217M001	3835751.3508	0.002	1177249.9049	0.001	4941605.1999	0.002

Repeatability of separated daily solutions is good. The co-ordinates are different for all stations within few millimetres for horizontal and vertical components (Table 13). It is similar to free network solutions.

Table 13. Daily repeatability for the stations co-ordinates. Constrained network solution with six EPN stations fixed. All values in millimetres.

Station		Days					
		RMS	269	270	271	272	273
0216 BOROWIEC	N	1.0	-1.1	0.4	1.0	-0.9	0.7
	E	1.2	1.6	-0.4	0.3	-1.5	-0.1
	U	3.6	4.1	-3.9	0.3	-3.6	2.8
0217 BOROWA GORA	N	0.6	0.0	-0.2	0.3	-0.8	0.8
	E	1.3	-0.7	1.2	0.2	-1.7	1.3
	U	3.0	-0.8	1.1	-0.1	-3.9	4.2
0301 ROZEWIE	N	1.5	-1.4	-0.9	-0.7	2.3	0.7
	E	0.9	0.2	-0.6	-0.4	-0.8	1.5
	U	3.2	0.1	1.5	4.1	-4.5	-1.6
0303 MASZE	N	1.2	-0.6	-1.6	0.6	1.6	0.1
	E	0.7	-0.9	0.4	-0.1	-0.1	0.9
	U	4.0	2.5	0.8	4.4	-5.9	-2.0
0304 CZARNKOWIE	N	0.7	-0.2	0.5	1.0	-0.6	-0.5
	E	1.0	-0.2	0.2	0.9	-1.6	0.6
	U	1.1	-1.5	1.0	1.0	0. 0	-0.9
0307 STUDNICA	N	1.0	0.1	-0.1	1.3	-1.6	0.5
	E	1.4	-1.4	0.7	2.0	-1.4	0.0
	U	2.2	-1.1	-3.1	1.5	-0.3	2.4
0308 ROGACZEW	N	0.9	0.4	-0.8	1.2	0.3	-1.0
	E	1.5	0.9	1.8	-0.6	-2.0	0.1
	U	3.2	3.6	-0.6	0.6	-5.1	1.3
0309 ZUBOWICE	N	0.8	-0.4	-0.6	1.4	-0.6	0.3
	E	1.0	0.6	1.3	-0.4	-1.4	0.0
	U	3.2	-3.7	1.3	3.2	2.1	-3.3
0310 GRYBOW	N	2.2	2.8	1.4	-1.3	-2.7	-0.4
	E	1.2	1.8	0.6	-0.3	-1.3	-0.7
	U	3.7	4.4	-2.4	3.6	-3.7	-2.0
PL05 SANOK	N	3.9	3.6	4.4	-2.0	-4.7	-1.6
	E	2.0	1.4	2.7	-1.1	-2.1	-0.8
	U	1.8	-2.6	0.0	1.6	-0.9	1.9
BOGO 12207M002	N	0.6	-0.1	-0.3	0.3	-0.7	0.8
	E	1.3	-0.8	1.1	0.0	-1.7	1.4
	U	3.4	-0.1	-0.6	-0.4	-4.0	5.4
GOPE 11502M002	N	0.6	0.5	0.1	0.2	-1.0	0.2
	E	1.1	-0.8	1.3	1.0	-1.1	-0.4
	U	2.3	1.6	-1.6	2.8	-0.4	-3.0
LAMA 12209M001	N	1.0	-1.0	-1.1	0.0	1.1	0.9
	E	1.2	-1.7	0.6	0.4	-0.6	1.5
	U	2.4	-1.7	2.0	1.9	-3.4	1.1
PENC 11206M006	N	1.3	-1.1	2.2	-0.1	-0.3	--0.8
	E	1.6	0.3	1.8	0.5	-2.5	0.0
	U	3.6	5.1	-1.6	0.3	-4.8	0.5
RIGA 12302M002	N	1.4	-1.4	-0.7	1.6	1.3	-0.7
	E	0.4	0.1	0.4	0.5	-0.6	0.0
	U	3.3	-4.3	-0.2	4.1	-1.7	2.3
WROC 12217M001	N	1.3	2.0	0.2	0.8	-0.9	-1.0
	E	0.8	0.3	-0.2	0.5	-1.4	0.5
	U	1.4	-0.3	1.4	-0.9	-2.0	1.1

6. Comparison with other solutions

6.1 Comparison with EPN solution

All EPN stations used in EUREF–POL 2001 are included in EPN subnetwork computed by Warsaw University of Technology. Sinex solution for week 1133 (week of the EUREF–POL 2001 GPS Campaign) was used for comparison. The residuals of 3–parameter (translation) transformation, show good coincidence for both solutions. Only for station RIGA 12302M002 difference for East component was above 0.010m, but in EPN solution for week 1133 RIGA 12302M002 station has rather weak repeatability.

Table 14. Residuals (in mm) after 3–parameters Helmert transformation (translation) between the co-ordinates of EUREF–POL 2001 solution in ITRF2000 epoch 2001.74 and EPN solution for GPS week 1133 (WUT11337.SNX) in ITRF97 co-ordinates. RIGA 12302M002 station was excluded from transformation.

Station	N	E	U
BOGO 12207M002	-0.5	-0.3	-2.0
BOR1 12205M002	0.4	0.9	-6.8
GOPE 11502M002	1.2	0.7	-3.3
JOZE 12204M001	-2.0	-2.5	3.2
LAMA 12209M001	0.2	-0.3	1.9
METS 10503S011	-0.5	-1.4	4.6
ONSA 10402M004	1.1	2.0	6.7
PENC 11206M006	-0.2	-0.8	-1.5
WROC 12217M001	0.4	1.2	-2.2
WTZR 14201M010	-0.1	0.6	-0.6
RMS	0.9	1.3	4.1
RIGA 12302M002	3.1	18.7	-2.1

6.2 Comparison with EUVN97 solution

Thirteen stations included in EUVN97 were observed and computed in EUREF–POL 2001 GPS Campaign. Because the EUVN97 GPS Campaign was computed in ITRF96 (epoch 1997.4) reference frame and EUREF–POL 2001 in ITRF2000 (epoch 2001.74), the comparison was made through 7–parameters Helmert transformations. It must be notified that three stations (GOPE 11502M002, 0217 BOROWA GORA and LAMA 12209M001) with redefined antenna mounts (new antenna with snow covers) were excluded from the transformations. Obtained residuals show good agreement on the level of few millimetres (table 15).

Table 15. Residuals (in mm) after 7–parameters Helmert transformation between the co-ordinates of EUREF–POL 2001 solution in ITRF2000 epoch 2001.74 and EUVN97 solution in ITRF97 co-ordinates. Stations GOPE 11502M002, 0217 BOROWA GORA and LAMA 12209M001 were excluded from transformation.

Station	N	E	U
0301 ROZEWIE	-0,7	1.0	5.4
PL05 SANOK	-1.5	8.4	-4.3
BOR1 12205M002	-0.3	-1.2	6.2
GRAZ 11001M002	-1.4	-3.3	-3.8
JOZE 12204M001	-1.6	-3.6	6.4
METS 10503S011	1,5	-4.0	-2.9
ONSA 10402M004	0,6	3.9	-3.2

Station	N	E	U
PENC 11206M006	2,4	-2.9	0.1
RIGA 12302M002	0,6	1.2	-2.5
WTZR 14201M010	0.7	0.9	-1.5
Mean	**1.4**	**3.9**	**4.3**
0217 BOROWA GORA	2.6	5.3	19.7
GOPE 11502M002	1.6	-4.1	19.0
LAMA 12209M001	-0.2	7.2	25.7

6.3 Comparison with EUREF-POL'92 solution

Comparison with EUREF–POL'92 GPS Campaign in ETRS89 reference frame was made only for eleven Polish stations through 7–parameters Helmert transformations.

Two stations (0217 BOROWA GORA and LAMA 12209M001) were excluded from this transformation. Residuals show good agreement on the level of few millimetres for horizontal components and about 0.01m for heights (table 16).

Because comparison was done through transformation without reductions of co-ordinates to common epoch and reference frame, part of the observed differences is caused by unmodelled velocities for field stations.

Table 16. Residuals (in mm) after 7–parameters Helmert transformation between the co-ordinates of EUREF–POL 2001 solution in ITRF2000 epoch 2001.74 and EUREF–POL'92 in ETRS89 co-ordinates. Stations 0217 BOROWA GORA and LAMA 12209M001 were excluded from transformation

Station	N	E	U
JOZE 12204M001	-4.0	-8.7	-10.2
0216 BOROWIEC	1,7	-4.0	4.5
0301 ROZEWIE	-1,3	4.7	-6.7
0303 MASZE	5,2	-6.6	14.1
0304 CZARNKOWIE	2,5	3.1	-4.4
0307 STUDNICA	1.0	3.0	13.6

Station	N	E	U
0308 ROGACZEW	-0,2	3.7	-16.1
0309 ZUBOWICE	-1,9	4.9	1.3
0310 GRYBOW	-2,5	-0.1	3.9
Mean	**2,9**	**5.2**	**10.3**
LAMA 12209M001	-4,9	8.4	19.2
0217 BOROWA GORA	5.5	-3.6	20.0

Table 17. Local transformations parameters given for 7–parameters Helmert transformation from the co-ordinates of EUREF–POL 2001 solution in ITRF2000 epoch 2001.74 and EUREF–POL'92 in ETRS89 co-ordinates.

```
NUMBER OF PARAMETERS  :  7
NUMBER OF COORDINATES : 27
RMS OF TRANSFORMATION :  7.5 MM


PARAMETERS:

TRANSLATION IN  X     :          92.8    +- 88.9    MM
TRANSLATION IN  Y     :         -31.8    +- 84.4    MM
TRANSLATION IN  Z     :        -323.9    +- 74.5    MM
ROTATION AROUND X-AXIS:  -  0  0  0.0036 +-  0.0025 "
ROTATION AROUND Y-AXIS:  -  0  0  0.0011 +-  0.0031 "
ROTATION AROUND Z-AXIS:     0  0  0.0037 +-  0.0024 "
SCALE FACTOR          :           0.0366 +-  0.0098 MM/KM
```

7. Conversion into ETRS89

Standard procedures for conversions of EUREF subnetworks into ETRS89 epoch 1989.0 is described (BOUCHER, 2001):

$$\underline{X}^{E}(t_{2001.74}) = \underline{X}_{2000}(t_{2001.74}) + \underline{T}_{2000} + \underline{R} \times \underline{X}_{2000}(t_{2001.74}) \times (2001.74 - 1989.0)$$

where:

$\underline{X}^{E}(t_{2001.74})$ co-ordinates in ETRS89 epoch 2001.74

$\underline{X}_{2000}(\underline{t}_{2001.74})$: co-ordinates in ITRF2000 epoch 2001.74

$\underline{T}_{2000}$: shifts for ITRF2000:
$\underline{T}_{2000}$ = (+0.054m, +0.041m, -0.048m).

$\underline{R}$: rotation for ITRF2000 to epoch 1989.0 (in mas/year):
$\underline{R}$ = (+0.081, +0.490, -0.792)

Second formula from (Boucher,2001) to express co-ordinates in the ETRS89 at epoch 1989.0.

$$\underline{X}^{E}(t_{1989.0}) = \underline{X}^{E}(t_{2001.74}) + \dot{\underline{X}}^{E} \times (1989.0 - 2001.74)$$

where:

$\underline{X}^{E}(t_{1989.0})$: co-ordinates in ETRS89 at epoch 1989.0

$\dot{\underline{X}}^{E}$: approximated velocities for EPN station in Poland (from ETRF2000.SSC)

$\dot{\underline{X}}^{E}$ = (-0.0008m, -0.0002m, -0.0010m).

Two variants of conversion with standard procedure were computed:

– first without including velocities within European plate ($\dot{\underline{X}}^{E}$ ={0, 0, 0}),

– second with approximated velocities in Poland.

For this method of transformations, we do not change the scale of ITRF2000 reference frame. In effect, co-ordinates of EUREF–POL 2001 in ETRS89 epoch 1989.0 computed from standard procedures (BOUCHER, 2001) and from local parameters (table 17) have systematic small effects in shift and scale (see table 18).

Table 18. Co-ordinates difference of EUREF–POL 2001 stations in ERTS89 epoch 1989.0. Computed with standard procedures (BOUCHER, 2001) minus computed with local transformation. All values in mm.

Station	ETRS89(2001.74) – ETRS89(LOCAL)			ETRS89(1989.0) – ETRS89(LOCAL)		
	N	E	U	N	E	U
0216 BOROWIEC	5.9	-8.4	-22.8	5.4	-8.9	-6.3
0217 BOROWA GORA	-1.5	-16.6	-18.4	-2.0	-17.8	-2.0
0301 ROZEWIE	-5.8	-3.3	-13.8	-7.1	-4.0	2.6
0303 MASZE	-9.3	-16.4	-12.7	-10.2	-17.9	3.7
0304 CZARNKOWIE	2.4	-1.9	-19.3	1.4	-2.2	-2.8
0307 STUDNICA	11.6	-9.4	-27.2	11.3	-9.7	-10.7
0308 ROGACZEW	6.9	-18.2	-24.9	6.8	-19.1	-8.4
0309 ZUBOWICE	1.8	-27.9	-21.7	1.8	-29.6	-5.3
0310 GRYBOW	9.2	-24.7	-27.4	9.4	-25.9	-11.0
PL05 SANOK	7.4	-27.6	-26.3	7.7	-29.0	-9.9
BOGO 12207M002	-1.5	-16.6	-18.4	-2.0	-17.8	-2.0
BOR1 12205M002	5.9	-8.3	-22.8	5.4	-8.8	-6.3
JOZE 12204M001	0.1	-17.8	-19.4	-0.4	-19.0	-3.0
LAMA 12209M001	-6.1	-11.5	-14.5	-7.0	-12.7	1.9
WROC 12217M001	10.1	-11.8	-26.6	9.9	-12.3	-10.1

In tables 19 and 20 co-ordinates of Polish points of EUREF–POL 2001 GPS Campaign converted to ETRF89 reference frame with local parameters of transformation are indicated.

Table 19. Geocentric co-ordinates. Final solution of EUREF–POL'2001 GPS Campaign in ETRS89 (epoch 1989.0). Derived from ITRF2000 (epoch 2001.74) converted into ETRS89 with local parameters for Poland.

Station	X	Y	Y
0216 BOROWIEC	3738397.178	1148285.754	5021752.202
0217 BOROWA GORA	3633815.658	1397453.930	5035280.779
0301 ROZEWIE	3495579.627	1157845.529	5190403.620
0303 MASZE	3475730.656	1453976.543	5129448.793
0304 CZARNKOWIE	3635006.814	1051224.492	5117503.219
0306 JOZEFOSLAW	3664940.622	1409153.729	5009571.378
0307 STUDNICA	3846614.360	1106083.894	4949572.467
0308 ROGACZEW	3803542.943	1352681.133	4921845.804
0309 ZUBOWICE	3717652.591	1622948.935	4905872.913
0310 GRYBOW	3866100.289	1479953.02	4836446.400
PL05 SANOK	3836865.568	1565871.568	4832580.782
BOGO 12207M002	3633739.308	1397433.948	5035353.295
BOR1 12205M002	3738358.795	1148173.515	5021815.600
JOZE 12204M001	3664940.509	1409153.685	5009571.222
LAMA 12209M001	3524523.256	1329693.445	5129846.176
WROC 12217M001	3835751.632	1177249.762	4941605.056

* JOZE 12204M001 has got different definition of antenna height than 0306 JOZEFOSLAW.

Table 20. Geodetic co-ordinates. Final solution of EUREF–POL'2001 GPS Campaign in ETRS89 (epoch 1989.0). Derived from ITRF2000 (epoch 2001.74) converted into ETRS89 with local parameters for Poland.

Station	Latitude [/ ' "]	Longitude [/ ' "]	Height [m]
0216 BOROWIEC	52 16 33.99697	17 04 29.49258	116.858
0217 BOROWA GORA	52 28 29.96049	21 02 06.75821	139.886
0301 ROZEWIE	54 49 39.01593	18 19 35.35977	70.813
0303 MASZE	53 53 09.78857	22 42 02.36947	210.354
0304 CZARNKOWIE	53 42 14.42345	16 07 46.50902	238.939
0306 JOZEFOSLAW	52 05 50.17993	21 01 53.52451	141.663
0307 STUDNICA	51 13 37.97917	16 02 32.82313	203.843
0308 ROGACZEW	50 36 10.52293	23 35 01.59029	318.015
0309 ZUBOWICE	49 37 43.04108	20 56 49.10281	408.369
0310 GRYBOW	50 49 47.44863	19 34 38.19192	303.628
PL05 SANOK	49 34 33.35159	22 12 03.49008	319.972
BOGO 12207M002	52 28 33.40186	21 02 07.22202	149.623
BOR1 12205M002	52 16 37.03412	17 04 24.42803	124.391
JOZE 12204M001	52 05 50.17993	21 01 53.52451	141.465
LAMA 12209M001	53 53 32.63089	20 40 11.77491	187.030
WROC 12217M001	51 06 47.72902	17 03 43.33003	180.827

* JOZE 12204M001 has got different definition of antenna height than 0306 JOZEFOSLAW.

8. Conclusion

1) The EUREF–POL 2001 GPS Campaign was successfully processed using Bernese GPS Software ver. 4.2 taking into consideration all EUREF recommendations.

2) The accuracy derived from repeatability of the daily solutions can be estimated to about 1 mm in horizontal components (North and East) and 3 mm in height component. Comparison with EPN and EUVN97 solutions confirm the above accuracy. Because comparison with previous EUREF–POL'92 GPS Campaign show good agreement on the level of 0.01m, we suggest to transform EUREF–POL 2001 final solution into ETRS89 reference frame with the use of local parameters.

3) Comparison of two co-ordinate data sets obtained from both EUREF-POL GPS Campaigns shows that during the last decade no significant displacements have taken place.

4) Adjustment results of EUREF-POL 2001 Campaign have confirmed the estimated accuracy for stations co-ordinates in EUREF-POL'92 solution.

5) Differences of the station co-ordinates for both EUREF-POL campaigns are about few millimetres in horizontal components and about 1 centimetre in heights.

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