DETERMINATION OF THE BOROWIEC SLR COORDINATES

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ABSTRACT Borowiec satellite laser ranging station has been carrying out continuous laser observations since 1993. The accuracy of measurements reached the level of 1-2 cm for LAGEOS-1 and LAGEOS-2. The paper presents results of determination of the position of the Borowiec SLR (7811) station in the period 1995-2000. The coordinates were calculated by GEODYN-II orbital program on ALPHA computer in Borowiec Observatory from LAGEOS-1 and LAGEOS-2 monthly arcs of thirteen fixed SLR stations in ITRF97 coordinates system. The accuracy of the monthly orbital arcs was about ±2 cm. The stability of the Borowiec SLR geocentric and topocentric coordinates in the whole period was equal to ±20 mm. Some vertical systematic variations on the level of a few centimetres were detected. A similar effect was observed in the range bias. The final geocentric coordinates of the Borowiec SLR station from 1995-2000 differ from those in ITRF97 system by a few millimetres.

1. INTRODUCTION

The Borowiec SLR station (7811) has been working since 1988, initially as a second generation station giving results at the level of accuracy of ±20 cm, and since September 1991, after introduction of a new laser CONTINUUM, as a third generation station. Since July 21st, 1993, after elimination of a serious systematic error (Rutkowska at al., 1994, 1995) the station has been providing results with an accuracy of ±2-3 cm. The results of hitherto laser observations, in particular of the satellites LAGEOS-1 and LAGEOS-2, permit a determination and analysis of changes in the geocentric coordinates and assessment of the quality of their determination. The relevant work was conducted at the Space Research Centre of the Polish Academy of Sciences for the period 1993-1995 (Rutkowska at al., 1999, Rutkowska 1999). The installation of an ALPHA computer in 1999 at the Borowiec station and access to the NASA program GEODYN-II enabled taking up works related to determination of coordinates from laser observations directly in Borowiec. In the first stage, the coordinates of the station were determined for 1999 (Wnuk at al., 2000), and now for the period from January 1995 to May 2000.

2. THE ORBITAL PROGRAM GEODYN-II

The calculations were performed using the orbital program GEODYN-II (McCarthy at al., 1993), version 9903 on the ALPHA computer in Borowiec. The program has been slightly modified to be adjusted to the ALPHA computer and Fortran f95 compiler NAGWare 4.0. The accuracy of the input meteorological data of pressure and temperature has been improved to 0.1 mbar and to 0.1 Celsius degree. An important option for the accuracy of the orbital arcs is the determination of accelerations in the three directions: radial, across and along the orbit. As a result the accuracy of the orbit was close to that of the observations. When the coordinates of one station are determined with the fixed coordinates of the other stations, such an artificial improvement of the orbit does not deteriorate the results but quite the opposite – leads to a better accuracy of the parameters determined. The parameters and options applied in determination of the coordinates of Borowiec SLR station are listed below. The coordinates have been determined from the observations of the satellites LAGEOS-1 and LAGEOS-2 on the basis of the one month orbital arcs.

I Force model

Earth gravity field: EGM96 20x20
Gravity field of the Sun and Moon
Earth and ocean tide model: EGM96
Gravity field of the planets: DE200
Solar radiation pressure
Earth albedo
Solar and magnetic flux
Relativistic correction
Thermal drag

II Observation model

Stations coordinates and velocities: ITRF97
Tropospheric refraction: Marini/Murray model
Polar motion and UT1: IERS – Bulletin B
Dynamic polar motion
Stations tides

III Estimated quantities

Satellite state vector
Borowiec SLR station (7811) geocentric coordinates
Solar radiation pressure coefficient
Tide amplitude – k_2, k_3 and phase k_2
General acceleration: 9 parameters at 5 days intervals

IV Satellites: LAGEOS-1 and LAGEOS-2

Centre of Mass Correction: 25.1 cm
Cross section area: 0.2827 m^2
Mass: 406.965 kg

V Arc parameters

One month arc
Integration step size: 30 sec
Edit criterion: $5\sigma \approx \pm 10$ cm

3. LASER RANGING DATA

Selection of the laser stations, whose constant coordinates in the period 1995-2000 in the system ITRF97 were used for determination of the coordinates of the Borowiec SLR station, has been made on the basis of high quality of their results and continuity of their observations in this period. The procedure was applied to avoid the effect of the station configuration on the coordinates determined. The results of observations for all SLR stations in the period analysed is shown in Fig. 1. There are only 3 stations satisfying the condition of continuity of observations (69 months of observations of the satellites LAGEOS-1 or LAGEOS-2). Eventually we have chosen 13 stations, and from among them the station Orroral because of the scarcity of observations has been replaced by the station Mt.Stromlo since Dec. 1998, the station Simosato by Koganei in 1999 and the station Haleeakala by Tahiti in 2000, see Table 1. The results for particular orbit arcs including the number of normal points and standard deviation are given in Table 2. A significant increase in the accuracy of orbit arcs determination since 1997 has been a consequence of a considerable decrease of the range bias for a number of stations.

Table 1. Fixed SLR Stations Coordinates – System ITRF97

STATION	ILRS SOD	X [m]	Y [m]	Z [m]
McDonald	70802419	-1330021.4371	-5328403.3371	3236481.6697
Yarragadee	70900513	-2389008.1332	5043331.8546	-3078526.4654
Greenbelt (- 1.99)	71050724	1130720.1669	-4831352.9691	3994108.4981
Greenbelt (2.99 -)	71050725	1130720.1647	-4831352.9684	3994108.5011
Monument Peak	71100411	-2386279.4299	-4802356.5529	3444883.3000
Haleakala (- 9.99)	72102313	-5466007.1040	-2404427.6352	2242188.7491
Tahiti (1.00-)	71240801	-5246406.7450	-3077284.9740	-1913814.1960
Simosato (95-98,00)	78383602	-3822388.3690	3699363.5710	3507573.1250
Koganei (1999)	73287101	-3941961.4594	3368148.5288	3702208.6863
Arequipa	74031303	1942808.9401	-5804072.1635	-1796916.2396
Grasse	78353102	4581691.6620	556159.5440	4389359.4810
Potsdam	78365801	3800639.6890	881982.0470	5028831.6760
Graz	78393402	4194426.5300	1162694.0400	4647246.6390
Herstmoceux	78403501	4033463.7250	23662.4830	4924305.1630
Orroral (-11.98)	78432502	-4446477.0690	2678127.0060	-3696251.2580
Mt. Stromlo (12.98-)	78498001	-4467063.6638	2683034.4947	-3667007.4056
Wettzell	88341001	4075576.8660	931785.4630	4801583.5510

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                                                          Max = 69
1864  ---------- -- -- -------------------------   ---------------------    63
1868  --------  - -----   --- ----     --- - ---     -------   -------       42
1873     ---  --     ---- --     - --  -      -----                   --    22
1884  ---------- ---------------------------------------------- -------    67
1893    ------       -------    -- - --      ---         ---     -----      29
1953  -- --  ----       --                                                  10
7080  ------------------------------------------------------------------   69
7090  ----------------------  ----------------------------------------     67
7105  ---------     ------------------------------------------------       64
7109   ------------------- -- ----                                          26
7110  ----------------- -------------------------------------------------   68
7124                                 -------------------     - ------       27
7210  --------------------------------------------------------          -   58
7236          --    -   -------  --- ---   --   ---- -                     23
7237               -----------  ---------- ---------------    ------------ 50
7249      -           -     - ------------------- -   --   -------------- -- 42
7308          -    - --   --------- --  -----                               20
7328                                          --------------------          21
7335                                          -   - -------------  --       18
7337                                          --------  ---------           17
7339                                          ---------- --------  --       20
7403  ----------------------   ---------------------  - ----------   ------ 61
7404        --- ---  -------                                                13
7548  -    -- ---    ------------------      -  -  ----   --  -------    --- 42
7805  -----   -   ----         -                                            11
7806                                 ----  -    ----    ----------  --      21
7810  ----                  ----  -------------   ------------------ -----  44
7811  -------- ---------------------------------------------------------   68
7820                                           ------   ----------          16
7824                        ------- -------- ---     ------------------     36
7831      -- --       ---       --- -      -- -   --     -----  -  -   -  - 25
7832                 ------------ ---    -                                  16
7835  ------------------------------ --------- --------------------------   67
7836  ---------------------------------------------------------------------  69
7837  -----------------   -------  ------------ ----------------------------  65
7838  ----------------- --- ------------ ---------------- --    ----------  62
7839  ---------------------------------------------------------------------  69
7840  ---------------------------------------------------------------------  69
7843  ---------------------------------------------                         46
7845                                          -- -------------------        22
7849                                          ------------------------      23
7918        ---------- - ----  ---   -                                      19
7939  ----------------   -------------------------------------------------   66
8834  ----------------------------------------  -------------------------   67
         1995       1996      1997       1998        1999      2000
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Fig. 1 Number of months with LAGEOS-1 or LAGEOS-2 passes 1995.01 – 2000.09

Table 2. Orbital arcs – number of normal points and arc accuracy (mm)

MONTH	1995	1996	1997	1998	1999	2000
JAN	9754 ±36	5048 ±28	5104 ±21	9190 ±30	7486 ±18	8157 ±23
FEB	8192 ±32	6449 ±31	5475 ±17	10475 ±19	6898 ±17	7289 ±17
MAR	9150 ±27	7514 ±29	6143 ±18	9739 ±18	8730 ±20	6581 ±17
APR	5894 ±24	8255 ±31	9623 ±17	7834 ±24	7832 ±19	6926 ±19
MAY	6314 ±28	7254 ±26	8004 ±17	7873 ±14	8680 ±18	8852 ±19
JUN	7679 ±27	6365 ±22	6729 ±16	7064 ±17	7779 ±17	
JUL	9193 ±28	6012 ±24	6997 ±16	9461 ±17	8950 ±17	
AUG	10085 ±32	7179 ±23	6043 ±16	9647 ±20	8486 ±17	
SEP	7202 ±33	7546 ±20	8962 ±18	8012 ±20	9088 ±16	
OCT	8934 ±34	8065 ±25	9116 ±18	7839 ±21	10903 ±18	
NOV	6512 ±29	5024 ±29	7522 ±17	5982 ±19	9508 ±20	
DEC	3761 ±26	5606 ±25	7501 ±19	5687 ±17	7282 ±20	
TOTAL	92670 ±30	80317 ±26	87239 ±18	98803 ±20	101622±18	37805 ±19

4. BOROWIEC COORDINATES.

The results obtained for the Borowiec station including the number of normal points, range bias and standard deviation for each satellite separately for each year, are shown in Table 3. The accuracy and range bias for the both satellites are not significantly different. A substantial improvement in the accuracy of observations is noted throughout the period from 1995 to 2000. The range bias for the Borowiec station is significant (Table 3, Fig. 5) and equals on average about -10 mm.

The geocentric and topocentric coordinates of the Borowiec station are given in Table 4, and the results for each month arc are shown in Figs. 2 and 3. The monthly positions of Borowiec relative to the ITRF97 coordinates on the Earth surface are presented in Fig. 4, from which a slight dependence on the azimuth is noted. The results have shown that the position of the station has not changed significantly throughout the whole period 1995-2000, and the difference between these coordinates and the ITRF97 ones was just a few millimetres. The stability of the coordinates has been substantially improved in the years 1999-2000 as a consequence of a twice increased number of observations. The systematic changes in the vertical component visible in Fig. 3 are a result of the variation in range bias (Fig. 5). Regarding their significant value (a few cm) they are probably the effects following from the instrumental errors.

Table 3. Borowiec SLR station (7811) – results of orbital arcs

Year	SATELLITE	Number of NP	Range Bias mm	ARC RMS mm
1995	LAGEOS-1 LAGEOS-2	547 415	-7 ± 24 -22 ± 26	45 47
1996	LAGEOS-1 LAGEOS-2	954 530	-4 ± 12 -10 ± 17	35 35
1997	LAGEOS-1 LAGEOS-2	900 480	-2 ± 14 -7 ± 20	28 29
1998	LAGEOS-1 LAGEOS-2	959 694	-12 ± 11 -14 ± 10	27 22
1999	LAGEOS-1 LAGEOS-2	2017 1302	-18 ± 11 -14 ± 8	28 25
2000	LAGEOS-1 LAGEOS-2	358 396	-4 ± 8 -2 ± 11	20 18
1995-2000	LAGEOS-1 LAGEOS-2	5735 3817	-8 ± 13 -11 ± 15	31 29

Table 4. Borowiec SLR station coordinates from monthly arcs in ITRF97 system for epoch 1997.0 (ITRF97: X=3738332.844 m, Y=1148246.498 m, Z=5021816.023 m)

Year	X mm	Y Mm	Z mm	North mm	East mm	Up mm	σ mm
1995	831±28	499±30	028±28	13±25	5±30	9±31	29
1996	856±22	515±30	016±10	-17±25	13±26	5±15	22
1997	841±14	498±16	026±29	5±25	2±15	0±21	21
1998	852±19	493±24	032±25	1±23	-7±26	11±20	23
1999	862± 8	498± 9	042±12	-2± 6	-5± 8	25±13	10
2000	839±17	489± 9	032± 9	12±18	-7± 7	3± 8	12
1995-2000	848±21	500±23	029±22	0±23	1±22	10±21	22

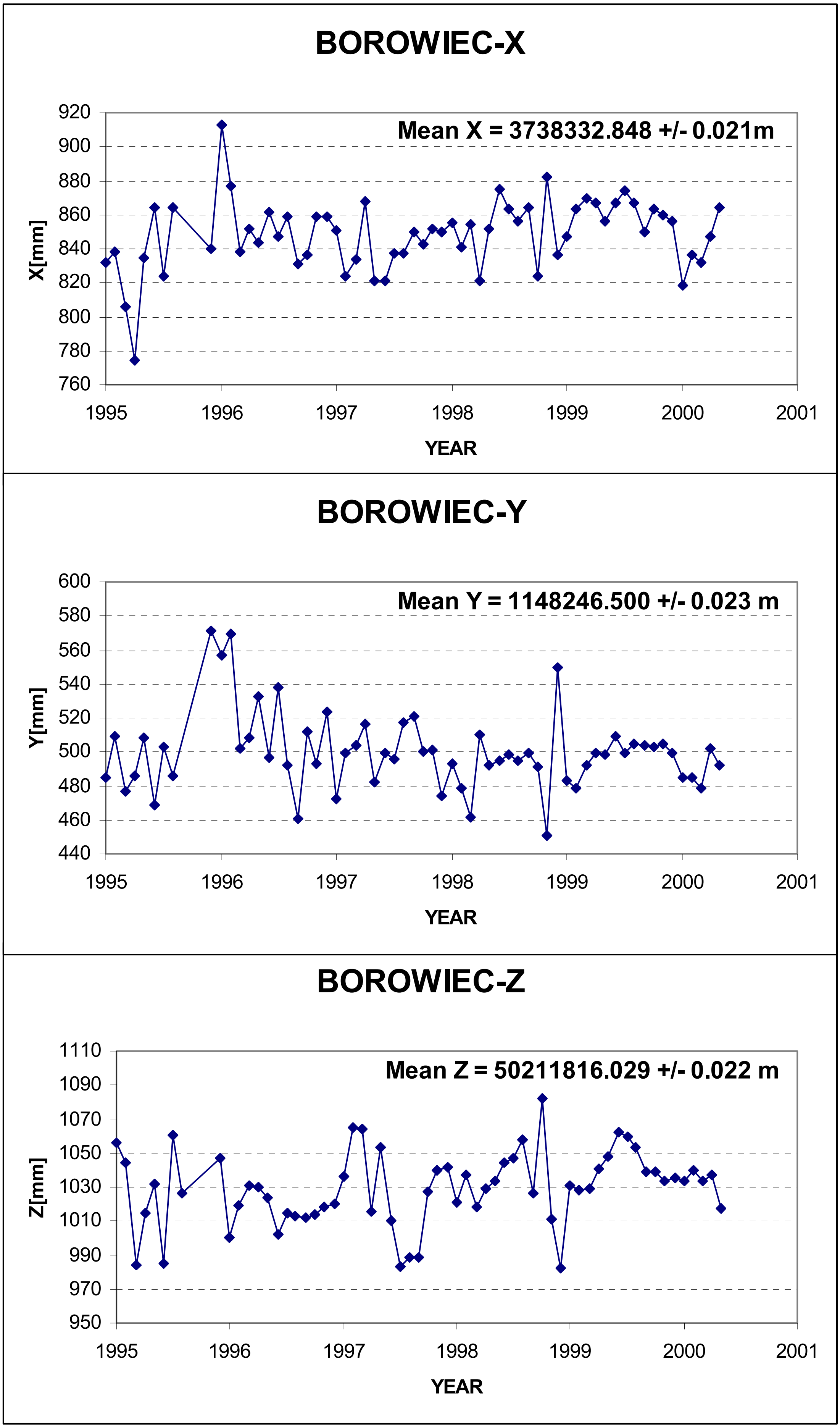

Fig. 2 Geocentric coordinates of the Borowiec SLR from monthly arcs 1995-2000

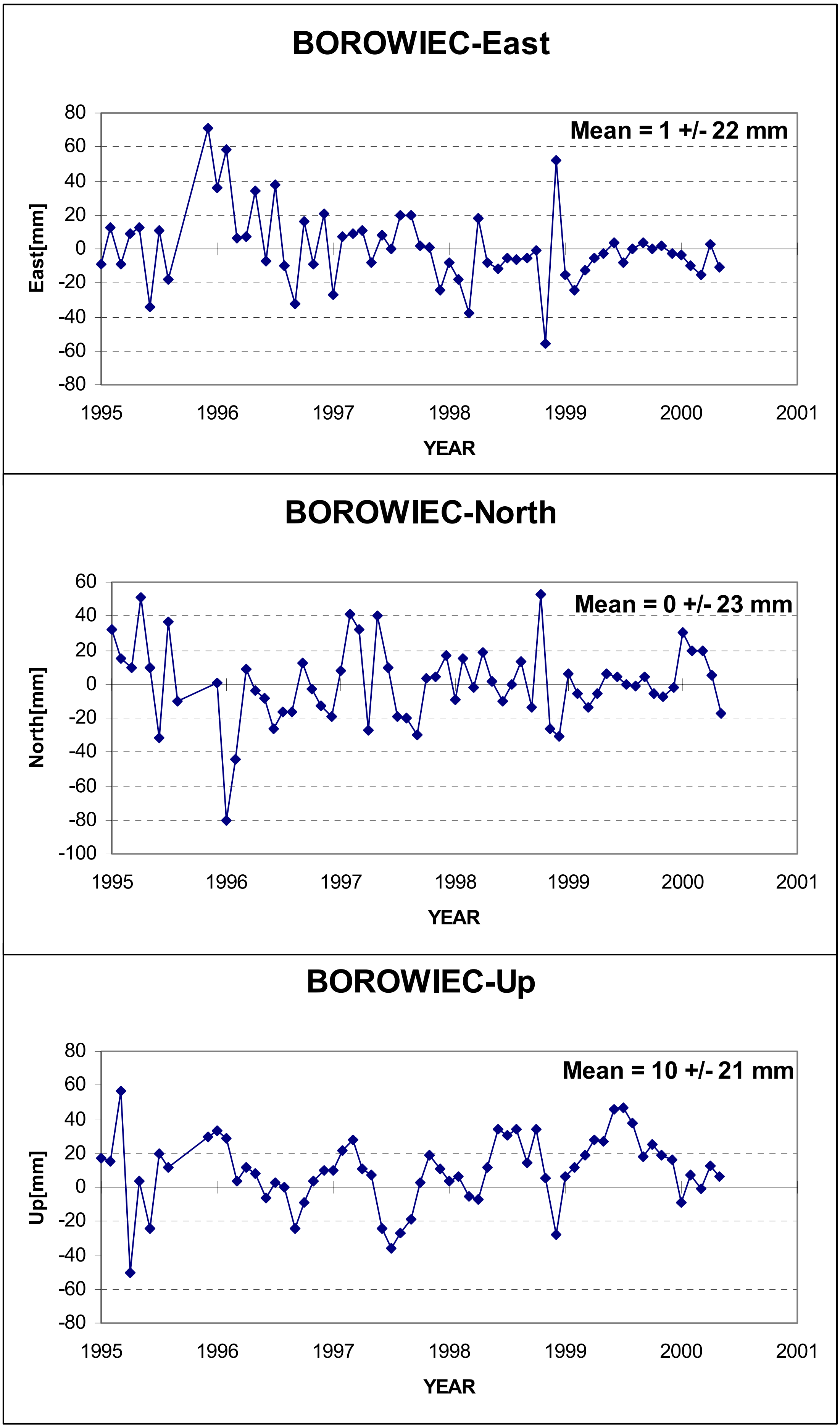

Fig. 3 Topocentric coordinates of the Borowiec SLR from monthly arcs 1995-2000

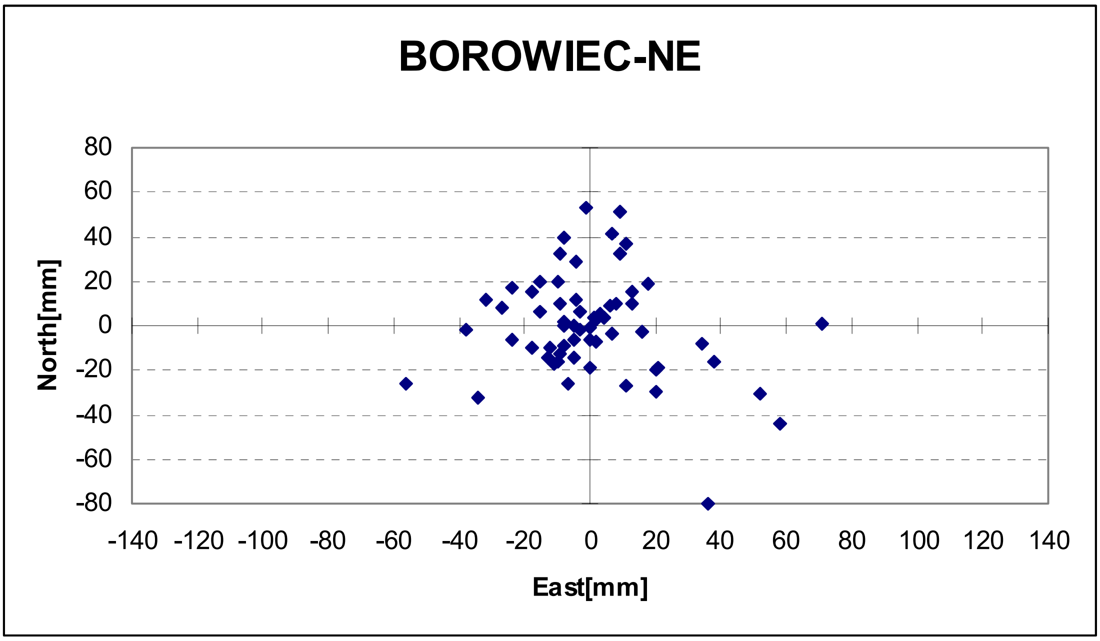

Fig. 4. Earth surface coordinates (East-North) of the Borowiec SLR from monthly arcs 1995-2000

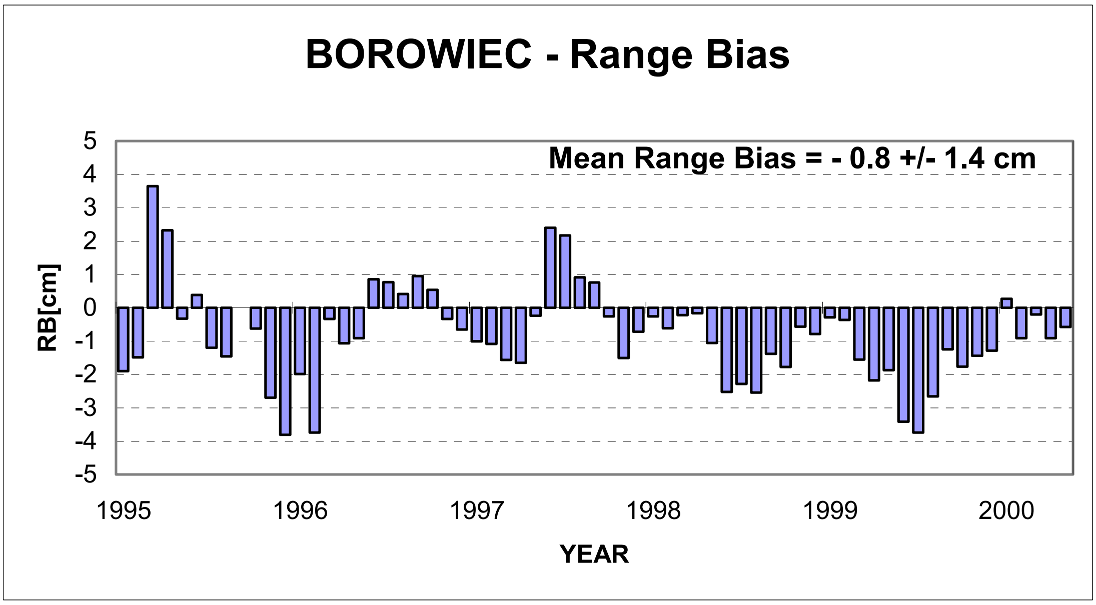

Fig. 5 Borowiec SLR range bias from monthly arcs 1995-2000

5. CONCLUSIONS

Improvement of the quality of the results obtained at the Borowiec SLR station requires a detailed analysis of the errors such as range bias and their elimination. This requirement does not refer only to the Borowiec station but to the other 13 stations as well, because their data especially in the period 1995-1996 were charged with a considerable range bias. The majority of points with large residuals from the mean (Figs. 2, 3) have been obtained on the basis of only a few normal points, and thus a criterion of rejection of such points should be developed. An attempt is being made to extend the period of analysis over

1993-1994 and the whole year of 2000. A comparison will be made between the coordinates determined from SLR observations and those obtained from GPS. It is expected that in this way the quality of the coordinates determined from Borowiec laser observations will be improved.

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