STABILITY OF COORDINATES OF THE SLR STATIONS ON A BASIS OF SATELLITE LASER RANGING

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ABSTRACT

One of the most important tasks in the satellite geodesy is a determination of the station coordinates and the control of their stability. The paper presents results of determination of positions of a group of SLR stations calculated in the ITRF97 system on the basis of the data provided by the LAGEOS-1 and LAGEOS-2 laser ranging from the results of selected 15 laser ranging stations and the station which coordinates were determined. The calculations were performed with the use of the GEODYN II program. The coordinates of the stations were determined from monthly arcs for 1999. Typical RMS of (O-C) values for monthly observation arcs was on a level of 1.8 cm. The final stability of the geocentric coordinates of SLR stations for all components per one year varies form ±4 mm to 10 mm.

INTRODUCTION

It is a group of the SLR stations conducting continuos observations in the last decade. The accuracy of the SLR measurements for LAGEOS 1 and LAGEOS 2 reached the level of 1-2 cm for the most observing stations, and in the case of some stations is on the sub-centimeter level. Continuous and systematic determination of station coordinates from the SLR measurements, on the one hand site, is one of the most important application of the SLR observations for geodynamic and geodetic investigations, and on the other hand site, is very useful for controlling the stability of the station's laser ranging system. An essential factor, necessary for correct interpretation of the results in geodetic and geodynamic applications, is assessment of the quality of the coordinates determined.

Analysis of the stability of stations coordinates, presented in this paper, was performed on the basis of results of the LAGEOS 1 and LAGEOS 2 observations performed in the year 1999 at a chosen group of SLR stations. The station coordinates were determined for monthly arcs using both satellites observations simultaneously. Calculations were performed by the GEODYN II orbital program (McCarthy and al., 1993-1996) on the ALPHA station at the Astronomical Observatory of the Adam Mickiewicz Univeristy, Poznan.

DETERMINATION OF THE COORDINATES

For the individual months of the year 1999 we determined coordinates X, Y, and Z of 16 stations in the ITRF97 system. The coordinates of a given station were calculated with the fixed coordinates of the other 15 stations (Table 1).

Table 1. Fixed stations coordinates for the epoch 1997.0 - ITRF97 (Boucher at al., 1999).

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	71050724	1130720.1669	-4831352.9691	3994108.4981
Greenbelt	71050725	1130720.1647	-4831352.9684	3994108.5011
Monument Peak	71100411	-2386279.4299	-4802356.5529	3444883.3000
Haleakala	72102313	-5466007.1040	-2404427.6352	2242188.7491
Koganei	73287101	-3941961.4594	3368148.5288	3702208.6863
Arequipa	74031303	1942808.9401	-5804072.1635	-1796916.2396
Zimmerwald	78106801	4331283.6889	567549.7491	4633140.2526
Borowiec	78113802	3738332.8440	1148246.4980	5021816.0230
Grasse SLR	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
Grasse LLR	78457801	4581692.2040	556196.0330	4389355.0600
Mount Stromlo	78498001	-4467063.6638	2683034.4947	-3667007.4056
Wettzell	88341001	4075576.8660	931785.4630	4801583.5510

Table 2. Number of normal points for LAGEOS 1 and LAGEOS 2 for all SLR stations.

STATION	**ILRS SOD**	**NUMBER OF NORMAL POINTS**	
		LAGEOS-1	**LAGEOS-2**
Mc Donald	70802419	2305	2597
Yarragadee	70900513	6204	6386
Greenbelt	71050724/5	4261	3889
Monument Peak	71100411	9412	8906
Haleakala	72102313	1023	1037
Koganei	73287101	995	1353
Arequipa	74031303	808	1298
Zimmerwald	78106801	2796	1767
Borowiec	78113802	1951	1233
Grasse SLR	78353102	2387	2213
Potsdam	78365801	1874	1097
Graz	78393402	4981	4292
Herstmoceux	78403501	6692	5398
Grasse LLR	78457801	2501	2228
Mount Stromlo	78498001	5761	5180
Wettzel	88341001	3858	3145

The observations of LAGEOS 1 and LAGEOS 2 have been taken from the Eurolas Data Center. We have chosen only the data from stations performing a large number of observations and whose observations in the year 1999 were uniformly distributed in time (Table 2). For the four stations: Grasse LLR (7845), new Zimmerwald (78106802), Mt. Stromlo (7849) and

Koganei (7328) the data were connected to the system ITRF97, introducing the difference in the coordinates respectively for Grasse SLR (7835), old Zimmerwald (78104801), Orroral (7843) and Tokyo (7308) from the SSC(CSR)95L01 (CSR, SLR Station Positions) and private information. The station coordinates determined for the markers (stations 7080, 7090, 7105, 7110, 7210, 7328, 7403) were connected to the reference point of a given station according to the data from NASA, DUT and CSR-Stations Eccentricities. For the data of the station HOLLAS (7210) the corrections to epoch of observation in the time from June 2nd to August 4th were introduced according to the data from ILRS.

The following model of forces and the following constants were used for determination of the stations coordinates:

I Force model

Earth gravity field: EGM96 20x20 (Lemoine at al., 1998)
Gravity field of the Moon and Sun
Complete EGM96 Earth and ocean tide model
Gravitational effects of the all planets: DE200
Solar radiation pressure
Earth albedo
Solar and magnetic flux
Relativistic correction
Thermal drag

II Observation model

Stations coordinates and stations velocities: ITRF97 solution (Boucher at al., 1999)
Tropospheric refraction: Marini/Murray model (Marini, Murray, 1973)
Dynamic polar motion
Polar motion: Bulletin B IERS

III Constants

Gravitational constant times the mass of the Earth (GM): $3.986004415 \times 10^{14}$ m^3/s^2
Semi-major axis of the Earth (a_e): 6378.1363 km
Inverse of the Earth's flattening ($1/f_e$): 298.2564
Value of love number of the second kind (H2): 0.609
Value of love number of the third kind (L2): 0.0852
Speed of light: 299792.458 km/s
Laser pulse wavelength: 532 nm (Zimmerwald 423 nm)
Orbit integration step size: 30 sec

III Estimated quantities

Satellite state vector
Stations coordinates (a priori ITRF97)
Solar radiation pressure coefficient (a priori 1.14)
General acceleration parameters at 5 days intervals
Tide amplitudes – k_2, k_3 and phase k_2 (a priori respectively: 0.3, 0.093, 0.0)

IV Satellites: LAGEOS 1 and LAGEOS 2

Centre of Mass Correction: 25.1 cm (McCarthy, 1992)
Cross section area: 0.2827 m^2
Mass: 406.965 kg

RESULTS

All calculations were performed with the use of the GEODYN II (version 9912) orbital program working on the ALPHA station at the Astronomical Observatory of the Adam Mickiewicz University, Poznan. Coordinates of the 16 SLR stations were determined on the basis of monthly arcs from the combined data of LAGEOS-1 and LAGEOS-2, taking into account the accepted number of normal points for the 16 selected laser stations given in Table 2. The coordinates of the SLR stations were corrected assuming the initial position as in the system ITRF97. The cycle of the coordinates determination was carried out in two steps: at the first the observations and normal points charged with significant errors were eliminated and then also the normal points with deviations over 10 cm were withdrawn. This procedure ensures that all good results are taken into account even at a large Range Bias of the station. The Range Bias values were not eliminated. At the second step the coordinates of the individual stations were calculated from the purified data, estimated the satellite state vector, k_2 and k_3 amplitudes, and phase k_2 of the Earth tide, solar radiation pressure coefficient (CR) as well as 9 parameters of general acceleration at 5 days interval.

For each coordinate X, Y, Z the appropriate stability σ_X, σ_Y, σ_Z over a period of 12 months of the year 1999 was found from the formulas:

$$\sigma_X = \sqrt{\frac{\sum_{i=1}^{n}\left(X_i - \overline{X}\right)^2}{n-1}}, \tag{1}$$

$$\sigma_Y = \sqrt{\frac{\sum_{i=1}^{n}\left(Y_i - \overline{Y}\right)^2}{n-1}}, \tag{2}$$

$$\sigma_Z = \sqrt{\frac{\sum_{i=1}^{n}\left(Z_i - \overline{Z}\right)^2}{n-1}}, \tag{3}$$

where $\overline{X}, \overline{Y}, \overline{Z}$ are mean values.

The total stability σ of the coordinates in 1999 for the given station was calculated from the formula:

$$\sigma = \sqrt{\frac{\sigma_X^2 + \sigma_Y^2 + \sigma_Z^2}{3}}. \tag{4}$$

For example, the stability of particular coordinates for the Borowiec SLR station (7811) are: σ_X = 7.8 mm, σ_Y = 9.1 mm, σ_Z = 10.4 m,, and the total stability σ = ±9.2 mm. The coordinates of Borowiec SLR station and the accuracy of determination of the monthly arcs are given in Table 3. The values of each of the coordinates component X, Y, Z per month are also given separately in Figs. 1-3.

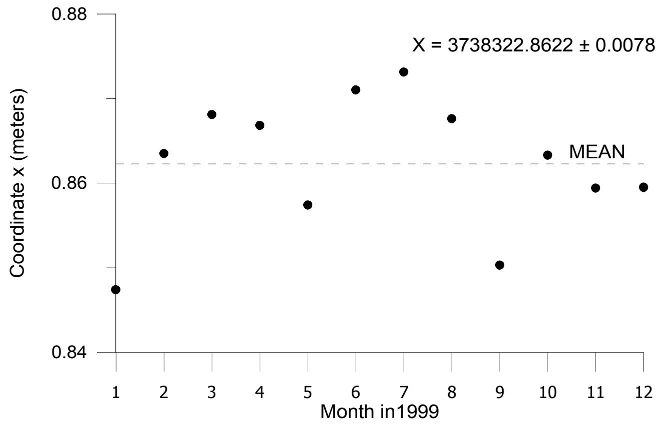

Fig.1. Borowiec X coordinate.

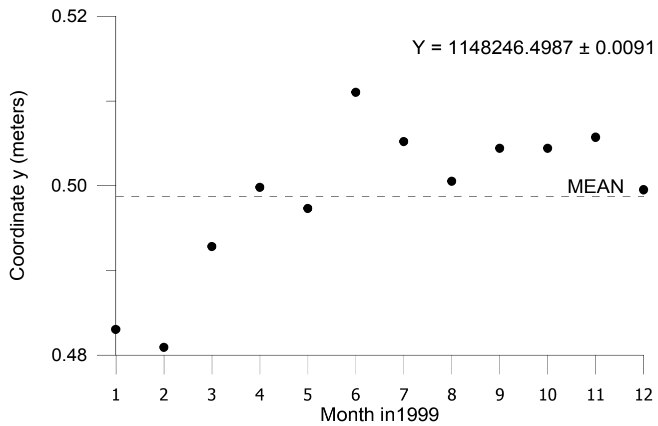

Fig.2. Borowiec Y coordinate.

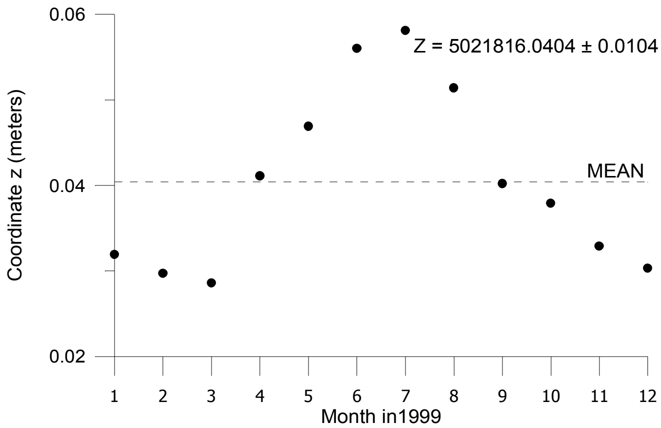

Fig.3. Borowiec Z coordinate.

Figures 4-6 and 7-9 presents coordinates X, Y, Z for the Greenbelt and Graz SLR stations respectively.

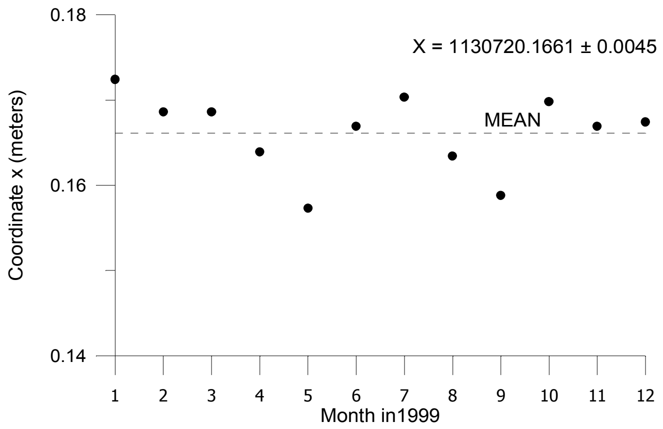

Fig.4. Greenbelt X coordinate.

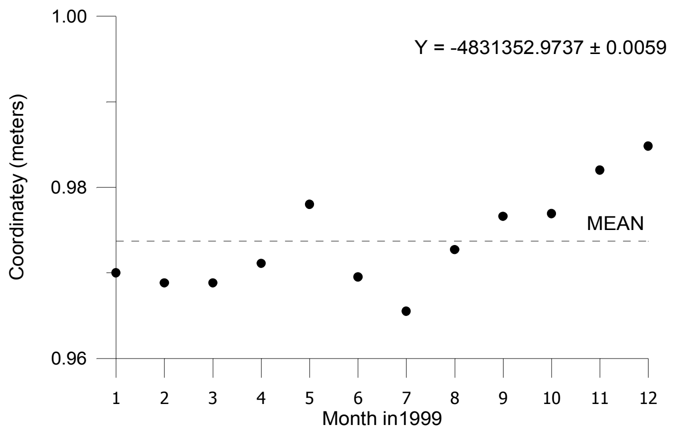

Fig.5. Greenbelt Y coordinate.

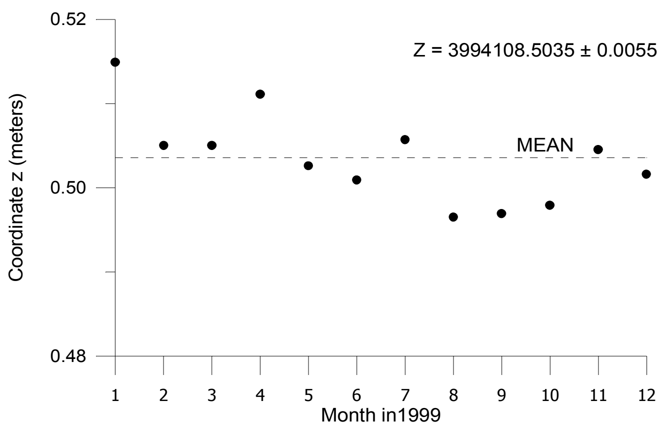

Fig.6. Greenbelt Z coordinate.

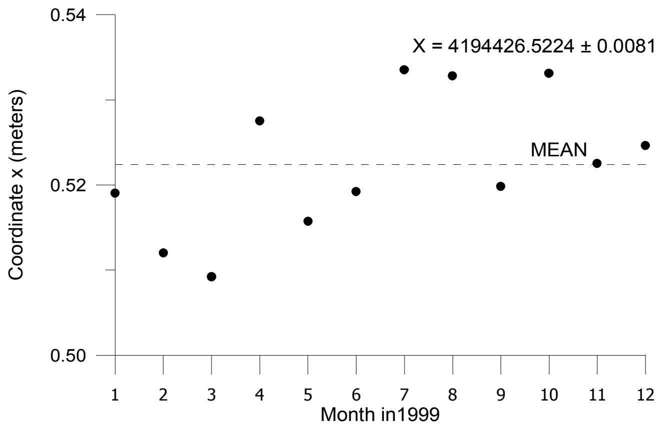

Fig.7. Graz X coordinate.

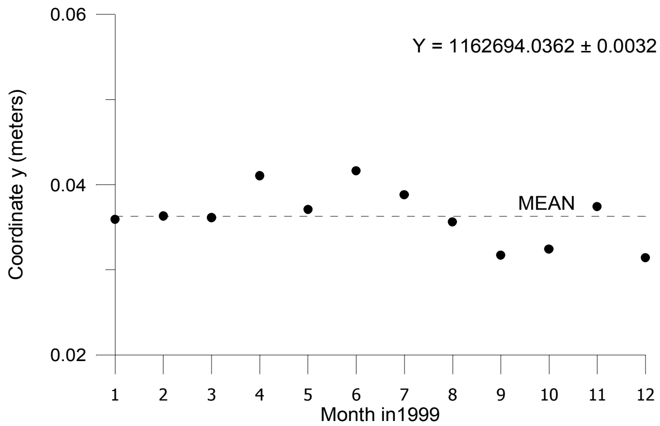

Fig.8. Graz Y coordinate.

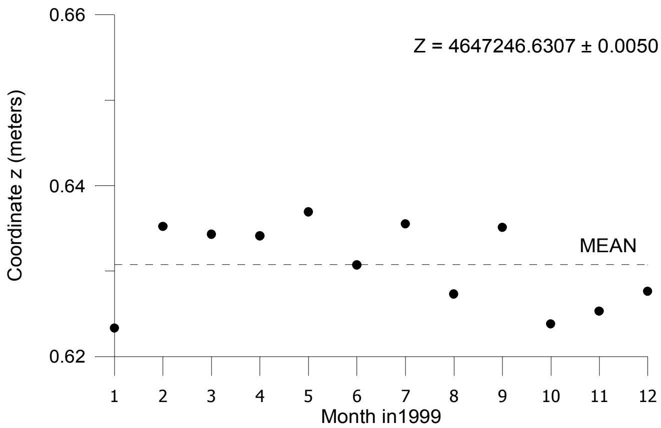

Fig.9. Graz Z coordinate.

The coordinate Y for Boorwiec (Fig 2.) systematically increase in the time and values of the Z coordinate (Fig 3.) revealed a significant maximum in summer. Values of the Y coordinate for Graz (Fig.8) and values of the X coordinate for Greenbelt (Fig.4) are very close to the mean values. The Y coordinate for Greenbely (Fig.5) systematically increase in the time.

In the Table 4 we collected the values of stabilities of particular coordinates and the total stability for the all 16 SLR stations. We can see that the smallest total stability 4.8 mm is for the Herstmoceux SLR station. The stability of all other stations, except of the Haleakala station (24.6 mm – due to very small number of normal points in August and September), has the values between 5 and 10 mm.

Table 3. Borowiec SLR (7811) coordinates from 1999 monthly arcs

MONTHS	**TOTAL NUMBER OF OBSERVATIONS LAGEOS 1 AND LAGEOS 2**	**ARC RMS [cm]**	**X [m] 3738332.**	**Y [m] 1148246.**	**Z [m] 5021816.**
JANUARY	7487	1,76	0.8474	0.4830	0.0319
FEBRUARY	7552	1,80	0.8635	0.4809	0.0297
MARCH	9568	2,00	0.8681	0.4928	0.0286
APRIL	8020	1,90	0.8668	0.4998	0.0411
MAY	9013	1,85	0.8574	0.4973	0.0469
JUNE	8987	1,74	0.8710	0.5110	0.0560
JULY	10304	1,77	0.8731	0.5005	0.0581
AUGUST	9032	1,77	0.8676	0.5052	0.0514
SEPTEMBER	9380	1,66	0.8503	0.5044	0.0402
OCTOBER	11735	1,85	0.8633	0.5044	0.0379
NOVEMBER	10570	2,03	0.8594	0.5057	0.0329
DECEMBER	8180	1,98	0.8595	0.4995	0.0303
TOTAL	109 828				

Table 4. Stability of coordinates of the SLR stations in 1999.

STATION	**ILRS SOD**	**σ_x [m]**	**σ_y [m]**	**σ_z [m]**	**σ [m]**
Mc Donald	70802419	0.0049	0.0079	0.0078	0.0070
Yarragadee	70900513	0.0067	0.0079	0.0046	0.0066
Greenbelt	71050724/5	0.0045	0.0059	0.0055	0.0050
Monument Peak	71100411	0.0072	0.0083	0.0104	0.0087
Haleakala	72102313	0.0130	0.0171	0.0368	0.0246
Koganei	73287101	0.0102	0.0123	0.0097	0.0108
Arequipa	74031303	0.0085	0.0062	0.0114	0.0090
Zimmerwald	78106801	0.0085	0.0098	0.0113	0.0100
Borowiec	78113802	0.0078	0.0091	0.0104	0.0092
Grasse SLR	78353102	0.0055	0.0062	0.0071	0.0063
Potsdam	78365801	0.0108	0.0094	0.0078	0.0094
Graz	78393402	0.0081	0.0032	0.0050	0.0058
Herstmoceux	78403501	0.0047	0.0049	0.0050	0.0048
Grasse LLR	78457801	0.0098	0.0097	0.0072	0.0090
Mount Stromlo	78498001	0.0049	0.0039	0.0058	0.0049
Wettzel	88341001	0.0057	0.0056	0.0098	0.0073

Beside the determination of the SLR coordinates and their stability, an interesting result of the calculations are the values or RMS of observation residuals. From Table 3 one can see that that values of RMS for monthly arcs for both Lageos 1 and Lageos 2 are equal 1.8 – 2.0 cm.

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