THE STABILITY OF THE SLR STATIONS COORDINATES DETERMINED FROM MONTHLY ARCS OF LAGEOS-1 AND LAGEOS-2 LASER RANGING IN 1999-2001

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ABSTRACT

The determination of coordinates stability of the satellite laser ranging stations is one of the methods for control the quality of the laser ranging data. This work is continuation of the similar paper about coordinates stability of the all SLR stations in 1999 and 2000. The paper presents results of the coordinates stability determination for all SLR stations in the period 1999-2001 calculated in the ITRF2000 system on the basis of data provided by the LAGEOS-1 and LAGEOS-2 laser ranging. The calculations were performed with the usage of the GEODYN II program. Coordinates of the stations were determined from monthly arcs. Typical RMS of (O-C) values for the monthly orbital arcs was on a level of 1.7 cm. The final stability of the coordinates of SLR stations for all components varies from several millimetres to several centimetres. It was found real movement for two stations; Tateyama in 2000 and Arequipa in 2001.

INTRODUCTION

Determination of the SLR stations coordinates stability from the laser ranging measurements is very important task for control of the quality of the SLR systems. The earlier authors' papers on determination of coordinates stability from the laser measurements presented the method of determination of the station position, results of determination of the coordinates and their stability for the Borowiec SLR station (Schillak, 2000, Wnuk et al., 2002), and for the all laser stations in the years 1999 (Schillak et al., 2001) and 2000 (Schillak, Wnuk, 2002). The main conclusion following from the hitherto study points to a necessity to extend the period of the coordinates determination over a few years, which is expected to permit better assessment of the quality of individual laser stations. The aim of this study was to determine the coordinates stability of all SLR stations working in the years 1999-2001 and propose a method for systematic control of the quality of laser observations on the basis of determination of their coordinates.

THE METHOD FOR DETERMINATION OF THE STATION COORDINATES

The laser station coordinates were determined on the basis of the laser observations of LAGEOS-1 and LAGEOS-2 satellites obtained from the Eurolas Data Center in the form of two-minute normal points. The orbit determination for both satellites in the years 1999-2000 was performed for 16 laser stations, while in 2001 for 17 stations (Table 1). The criteria of choice of the stations were:

- good stability of coordinates in the ITRF system (ITRF96, ITRF97, ITRF2000),
- the use of at least two measurement techniques at a given station,
- high quality and a large number of observations,
- continuity of observations,
- location of the station.

Table 1. The fixed SLR stations – system ITRF2000

STATION	ILRS SOD	X [m]	Y [m]	Z [m]
McDonald	70802419	-1330021.4404	-5328403.3271	3236481.6790
Yarragadee	70900513	-2389008.1303	5043331.8388	-3078526.4440
Greenbelt	71050725	1130720.1577	-4831352.9638	3994108.5091
Monument Peak	71100411	-2386279.4259	-4802356.5473	3444883.3081
Haleakala 1999, 2001	72102313	-5466007.0890	-2404427.6325	2242188.7575
Tahiti 2000	71240801	-5246409.3220	-3077286.4951	-1913815.1363
Koganei 1999	73287101	3941961.4490	3368148.5067	3702208.6608
Simosato 2000, 2001	78383602	-3822388.3630	3699363.5670	3507573.1390
Arequipa	74031303	1942808.9308	-5804072.1597	-1796916.2176
Hartebeesthoek 2001	75010602	5085403.6786	2668331.4414	-2768690.2938
Zimmerwald	78106801	4331283.6760	567549.7430	4633140.2670
Borowiec	78113802	3738332.8340	1148246.4910	5021816.0350
Grasse SLR	78353102	4581691.6410	556159.5390	4389359.4910
Potsdam	78365801	3800639.6760	881982.0400	5028831.6840
Graz	78393402	4194426.5170	1162694.0330	4647246.6500
Herstmoceux	78403501	4033463.7120	23662.4780	4924305.1710
Grasse LLR	78457801	4581692.1810	556196.0240	4389355.0720
Mount Stromlo	78498001	-4467063.6480	2683034.4800	-3667007.3710
Wettzell	88341001	4075576.8500	931785.4560	4801583.5590

The coordinates and velocities of the fixed stations needed for the orbit determination were assumed in the ITRF2000 system for the epoch 1997.0 (ITRF, 2001). The orbits and coordinates for the epoch 1997.0 were calculated with the use of the NASA orbital program GEODYN-II (McCarthy et al., 1993) at the Astrogeodynamic Observatory in Borowiec. The model of forces and the basic program parameters are presented in table 2. The number of normal points and their RMS for all arcs of the fixed stations are given in table 3. The station coordinates were calculated on the basis of the residuals of the normal points from the orbit for both satellites. The orbits calculated from the results provided by the fixed stations were each time supplemented with the results obtained at one station not included among the fixed stations whose coordinates were to be determined. This method ensures the minimum effect of the errors introduced by the less accurate stations on the coordinates determined.

Table 2. GEODYN II – Force model and parameters

I Force model
• Earth gravity field: EGM96 20x20
• Earth and ocean tide model: EGM96
• Third body gravity: Moon, Sun and planets: DE200
• Solar radiation pressure: C_R = 1.14
• Earth albedo
• Dynamic polar motion
• Solar and magnetic flux
• Relativistic correction
• Thermal drag
• Tide amplitude – k_2, k_3 and phase k_2 : 0.3, 0.093, 0.0
II Observation model
• Stations coordinates and velocities: ITRF2000, epoch 1997.0
• Tropospheric refraction: Marini/Murray model
• Polar motion and UT1: Bulletin B IERS
• Tidal uplift; Love model H2=0.609, L2=0.0852
• Pole tide
III Estimated parameters
• Satellite state vector
• Station geocentric coordinates
• Acceleration parameters along-track, cross-track and radial 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: LAGEOS-1 409 kg, LAGEOS-2 405 kg
V Arc parameters
• One month arc
• Integration step size: 30 sec
• Cut-off elevation: 10 deg.

The criteria assumed for rejection of the normal points, passes and coordinates are as follows (sigma – estimated standard deviation):

- individual points very significantly differing from a given population of results; 5 sigma of the random distribution of points with respect to the orbit for a given station,
- points with significant deviations in the passes; 2.5 sigma of the inner scatter of points in a pass,
- passes; 3 sigma of the scatter of range biases in one month,
- the coordinates; 3 sigma of the coordinates determination over three years.

Table 3. Orbital arcs from the fixed stations, LAGEOS-1 and LAGEOS-2
*NNP – Number of Normal Points

MONTH	1999		2000		2001	
	NNP*	RMS (mm)	NNP	RMS (mm)	NNP	RMS (mm)
JANUARY	8443	15.8	8867	19.5	6977	16.7
FEBRUARY	7549	15.6	7742	16.4	8002	16.8
MARCH	9551	17.8	7062	16.5	7491	16.3
APRIL	8013	17.0	7202	18.5	7134	15.9
MAY	8990	17.1	10924	19.1	11646	17.2
JUNE	8973	15.7	9813	18.3	11591	17.7
JULY	10267	16.3	7755	17.6	15007	18.1
AUGUST	9296	16.5	10508	16.6	12057	17.6
SEPTEMBER	9342	15.1	9450	17.2	9392	18.7
OCTOBER	11755	16.4	7158	17.0	12657	19.4
NOVEMBER	10557	16.7	7371	16.4	9144	16.8
DECEMBER	8170	17.7	8310	18.0	7694	16.9
AVERAGE	**9242**	**16.5**	**8514**	**17.6**	**9899**	**17.3**

THE STATIONS COORDINATES AND THEIR STABILITY

Stability of the coordinates was calculated as a standard deviation of all points accepted by the above criterion of coordinates rejection in a given period, that is for the maximum number of 12 points in a year and 36 in the period of 1999-2001, averaged over the three components (Wnuk et al., 2002). The results for all the laser stations working in the years 1999-2001 are given in table 4. The coordinates of the laser station Herstmonceux determined after transformation from the geocentric to the topocentric system, referred to the ITRF 2000 coordinates are given in Figure 1 as an example. For each coordinate a 1% confidence interval determined from the estimated standard deviation of coordinates determination is presented. For each component, a mean difference between the coordinate determined and the corresponding coordinate in the ITRF 2000 system (ΔN, ΔE, ΔU) is given and the stability (S) of each component is presented.

For the laser station Monument Peak (7110) (Figure 2) the unexplained and unique annual wave-like changes in the East-West component have been detected, moreover, a similar effect was detected also for vertical component. These changes are responsible for significant deterioration of the Monument Peak station stability relative to the stabilities of the other Moblas type stations (7090, 7105). As the number of results obtained for the Monument Peak station is one of the greatest, the elimination of these wave-like changes is essential for improvement of the orbit quality.

For the two stations Tateyama and Arequipa real changes in their positions were observed. For the Tateyama station the change was 5.6 cm (Schillak, Wnuk, 2002) and occurred over the time of two months (July-August 2000) caused by the seismic and volcanic activity on the Izu island localised at a distance of 150 km from the station (Yoshino et al., 2002). The shift of the Arequipa station by 62.3 cm was a result of the earthquake of June 23rd, 2001 (Figure 3). No changes in the vertical component were detected at these two stations.

Table 4. Stability (S) of the SLR stations coordinates over the years 1999-2001
(ACC – accepted months, REM – removed months)

	STATION	NR ILRS	MONTHS		S 1999 [mm]	S 2000 [mm]	S 2001 [mm]	S 99-01 [mm]
			ACC	REM				
1	HERSTMONCEUX	7840	36	0	4.1	3.9	3.7	4.1
2	GRAZ	7839	36	0	6.2	5.1	3.7	5.2
3	GREENBELT	7105	35	0	5.2	5.7	5.5	5.6
4	MOUNT STROMLO	7849	36	0	4.8	4.2	7.1	6.4
5	GRASSE SLR	7835	36	0	6.4	5.1	5.6	6.4
6	MC DONALD	7080	36	0	7.2	7.0	5.0	6.5
7	YARRAGADEE	7090	36	0	6.5	5.5	7.6	6.7
8	ZIMMERWALD	7810	33	2	5.7	6.0	5.8	7.1
9	HARTEBEESTHOEK	7501	17	1	-	9.4	7.1	8.2
10	POTSDAM	7836	36	0	7.8	10.0	7.5	8.5
11	MONUMENT PEAK	7110	36	0	7.9	9.4	8.1	8.7
12	GRASSE LLR	7845	35	0	8.9	7.0	8.8	9.4
13	MATERA (MLRO)	7941	6	0	-	-	9.4	9.4
14	PAPEETE	7124	21	1	12.2	7.6	7.3	9.6
15	WETTZELL	8834	33	0	6.7	10.2	7.4	10.0
16	AREQUIPA	7403	22	1	11.2	9.4	6.4	10.6
17	CHANGCHUN	7237	33	0	10.5	13.6	9.2	11.2
18	BOROWIEC	7811	35	1	8.7	9.4	10.2	12.3
19	RIYAD	7832	12	0	-	-	12.9	12.9
20	HALEAKALA	7210	23	2	12.5	15.6	12.6	13.6
21	KASHIMA	7335	20	1	12.6	15.4	-	14.3
22	LHASA (TROS)	7356	5	0	-	-	14.7	14.7
23	WUHAN	7231	8	3	-	15.0	-	15.0
24	SHANGHAI	7837	34	2	14.7	18.0	11.9	15.1
25	MIURA	7337	9	5	12.0	15.1	-	15.1
26	BEIJNG (TROS)	7343	2	1	-	15.6	-	15.6
27	KOGANEI	7328	17	2	12.7	20.8	-	16.4
28	URUMQI (TROS)	7355	3	0	-	-	16.5	16.5
29	TATEYAMA	7339	26	4	14.3	12.0	16.3	16.7
30	SIMOSATO	7838	30	2	24.6	13.5	12.1	18.7
31	RIGA	1884	31	5	16.3	26.4	18.0	21.0
32	METSAHOVI	7806	22	4	24.3	15.4	21.9	21.7
33	HELWAN	7831	4	7	26.1	-	-	22.2
34	MATERA	7939	21	1	16.6	30.3	-	25.1
35	KATZIVELY	1893	13	4	28.5	21.8	13.1	25.5
36	BEIJING	7249	25	9	16.2	21.6	35.7	27.1
37	SAN FERNANDO	7824	30	1	22.1	28.6	27.4	29.5
38	KOMSOMOLSK	1868	9	7	32.8	13.5	-	31.4
39	MAIDANAK	1864	22	4	23.6	29.8	-	33.2
40	KIEV	1824	6	4	-	-	41.1	41.1
41	SIMEIZ	1873	7	5	-	-	53.2	55.4
42	CAGLIARI	7548	7	9	70.3	78.6	-	63.5
43	KUNMING	7820	23	4	28.0	14.0	18.2	68.7

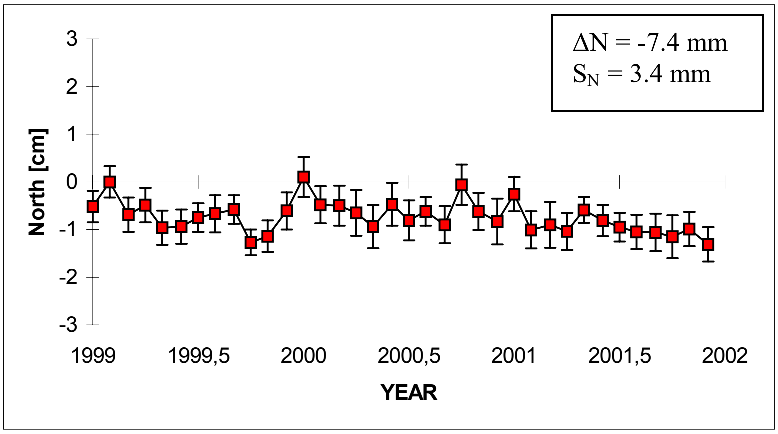


Fig. 1a. North-South component of the station Herstmonceux (7840) over the years 1999-2001 with reference to ITRF2000

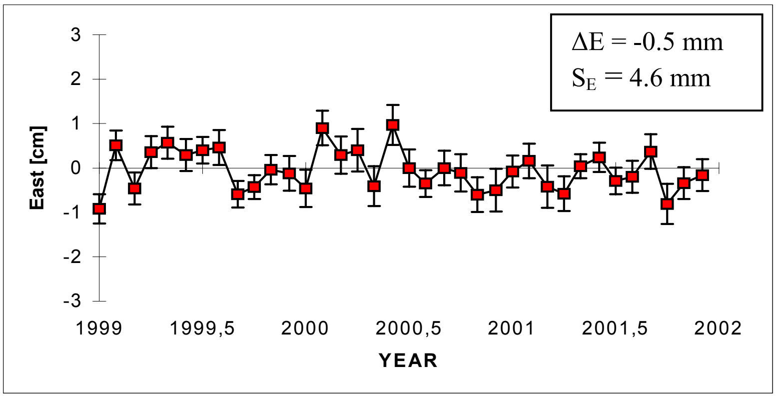


Fig. 1b. East-West component of the station Herstmonceux (7840) over the years 1999-2001 with reference to ITRF2000

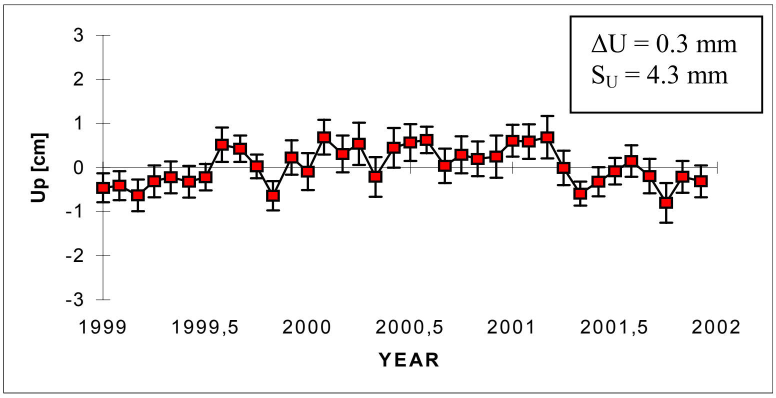


Fig. 1c. Vertical component of the station Herstmonceux (7840) over the years 1999-2001 with reference to ITRF2000

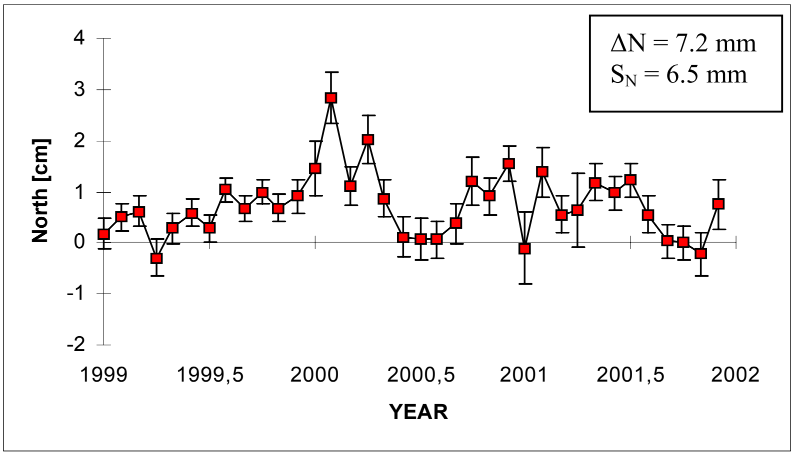


Fig. 2a. North-South component of the station Monument Peak (7110) over the years 1999-2001with reference to ITRF2000

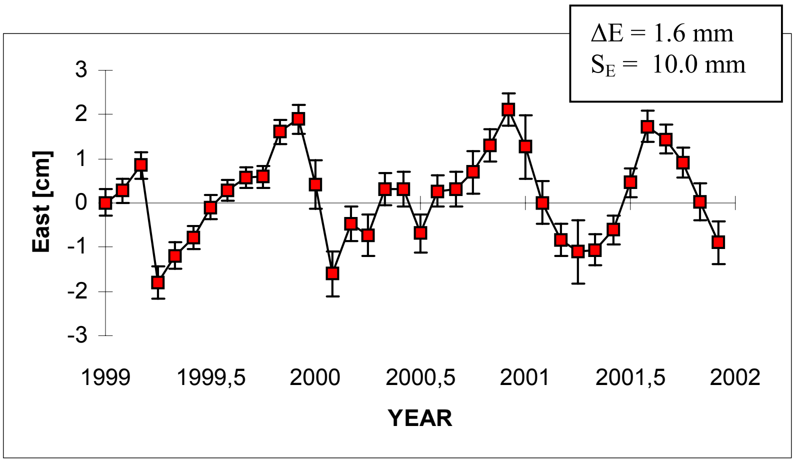


Fig. 2b. East-West component of the station Monument Peak (7110) over the years 1999-2001with reference to ITRF2000

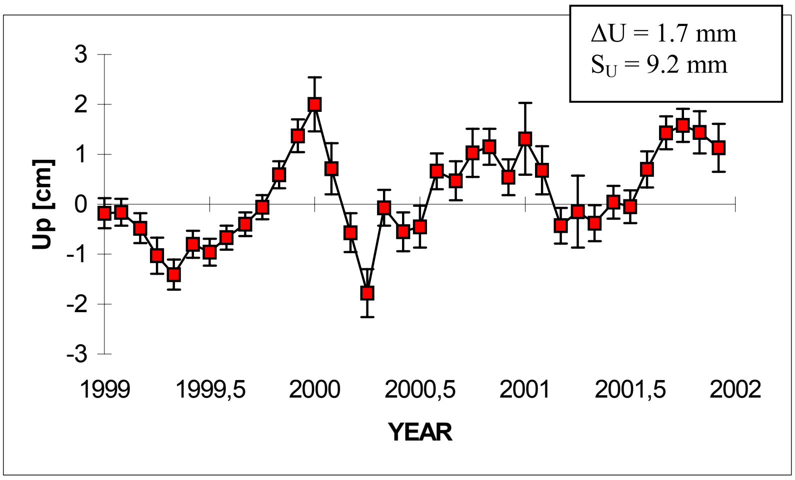
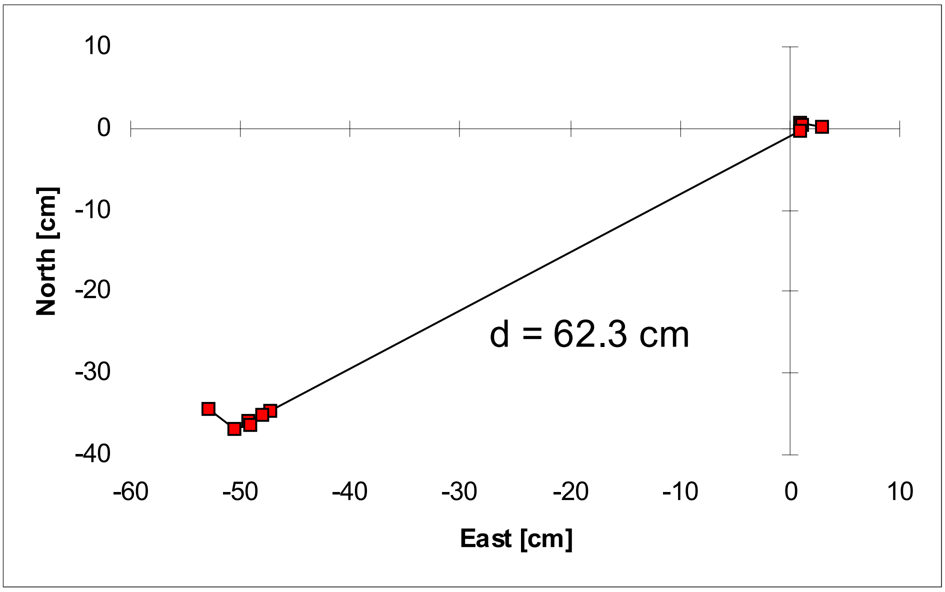


Fig. 2c. Vertical component of the station Monument Peak (7110) over the years 1999-2001with reference to ITRF2000

Horizontal components



Vertical component

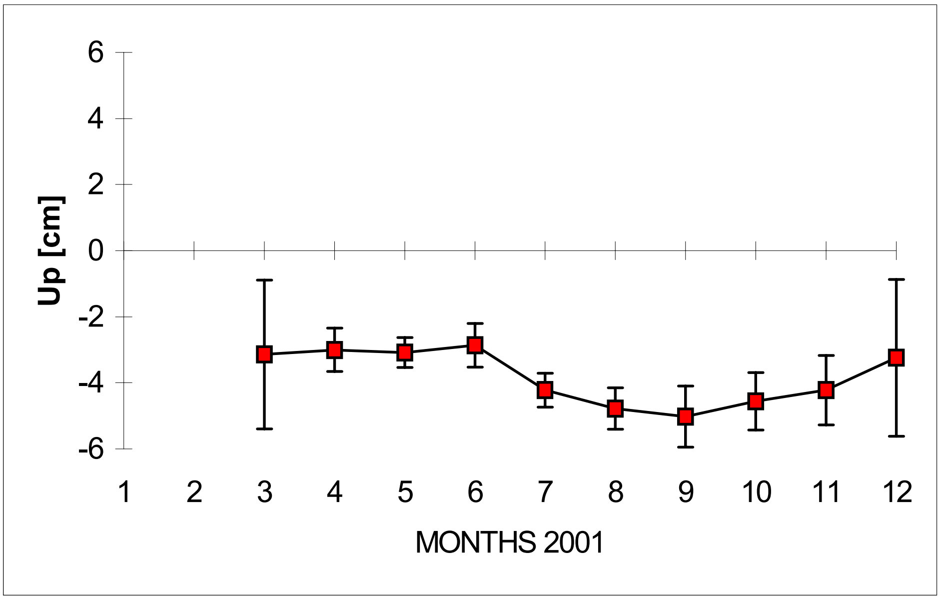


Fig. 3. The shift of the Arequipa SLR 7403 (Peru) as a result of the earthquake on June 23rd, 2001.

CONCLUSIONS

The stability of the coordinates of the 43 laser stations working in the years 1999-2001 varies from 4 mm to over 6 cm, but it should be emphasised that only 15 stations worked without breaks in activity longer than 3 months. The stability variations are results of the instrumental errors of individual laser systems, for the two stations Tateyama and Arequipa are a result of real changes in the stations positions. In the three-year period of observations the stability of only 15 stations was maintained below 10 mm. The results confirm the necessity of the orbit determination on the basis of the results from selected best stations, as otherwise the effect of the irregular distribution of the "weak" stations and the quality of their results will disturb the coordinates determined. It is necessary to improve the quality of laser observations and equalise their level. A possible recommended solution is an increase of the number of observations by elimination of the technical problems, performance of observations during the day and improvement of the quality of observations, which however, may require some expensive changes in the equipment. It would be important to explain the reasons for the wave-like changes in the coordinates of the Monument Peak station. The possible reasons for their occurrence are orbital effects not taken into account, systematic errors of the station position of annual character or the real changes in the position of the station localised near the San Andreas fault.

The method of continuous monitoring of the station coordinates permits an exact control of the quality of the laser observations to a much greater extent than the hitherto used method for control of the accuracy of the measured distances to the satellites. The accuracy of determination of the station coordinates and analysis of their changes and systematic deviations in all three components permits an assessment of the quality of laser observations and a comparison of the results with those obtained by other measuring techniques. Analysis of the changes in the vertical component permits an estimation of stations range biases.

The accuracy of orbit determination by means of the GEODYN-II program for monthly arcs is 17 mm and has been stable for the analysed period of three years. Further effort on improvement of the quality of the orbit determination is needed to increase the quality of the coordinates determination. The effects due to the atmosphere and oceans loading, the effect of underground waters should be added, the model of the atmosphere should be improved, better inclusion of empirical accelerations and in future also the effects due to changes in the position of the Earth mass centre should be taken into account. The accuracy of measurements of the distance to the satellites estimated for the best stations is better than 1 cm, and 1 cm should soon be the level of accuracy of the orbit determination for LAGEOS-1 and LAGEOS-2.

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