Determination of the SLR stations coordinates in 1994–2008

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Abstract. The paper presents results of the determination of SLR stations coordinates from the observations of LAGEOS-1 and LAGEOS-2 satellites for 5 years spans from 1994 until 2008. The computations of the station positions were performed by NASA Goddard's GEODYN-II orbital program with a new models and parameters. The main purpose of this work is estimation of the SLR station position accuracy and its stability in the long time period. The accuracy is presented in the form of the station position stability, range biases and RMS of fit per station. The best results are for the span 1999-2003. In 2004-2008 the results show deterioration in the position accuracy of the several important stations. This effect can be explained by smaller number of normal points for some stations and jumps in the vertical component.

Keywords: satellite geodesy, satellite laser ranging, orbital analysis, station coordinates

1 Introduction

One of the most important task of the satellite laser ranging (SLR) data analysis is estimation of the accuracy of the SLR measurements. The analysis centers use several parameters which give information about accuracy based on the differences between observed and computed values (O-C). The list of the parameters which can to estimate accuracy of the SLR measurements is as follows:

- Long term bias stability - variation of the monthly range biases (Fig. 1, SLR Global Performance Report Card)

- Short term bias stability - variation of the satellite pass range biases (SLR Global Performance Report Card)
- RMS of fit per station (Fig. 2)
- Station position stability (3D) (Fig. 3, Table 1)
- N, E, U deviations of the station position - graphic presentation including GNSS deviations (Fig. 4)
- Normal points (NP) residuals per one arc - graphic presentation (Figs. 7, 8)

From the list of these parameters the best estimation of the accuracy is the station position stability in 3D form. The answers for two main questions are very important for future activity of the SLR: why SLR accuracy is lower in the last several years (Schillak, 2011a) and why SLR quality of ITRF2008 is little bit worse than ITRF2005 (Schillak, 2011b)? The other important questions: what we can to do for accuracy improvement of the best stations? What limits are from observation side and computation side? The excellent job of the ILRS (Pearlman *et al.*, 2002) Analysis Working Group (AWG) gives answers for some parts of these questions. But very important is also view on the long time process of the SLR accuracy. Have we really the better results with time? How quality of results change? What is the reason of these changes? This work tries to answer for these questions.

2 Data analysis

The computations of the station positions were performed in Borowiec Observatory by NASA Goddard's GEODYN-II orbital program from results of LAGEOS-1 and LAGEOS-2 satellites. The station positions were determined only for the sites which had continuous work in the 15 years 1994-2008 with a high quality of measurements. These stations are presented in table 1. The stations Potsdam and Orroral-Mount Stromlo had two and three different SLR systems in the time of study.

The final results of the computations contain station geocentric coordinates for the first day of each month transformed to the common epoch 2005.0, standard deviation of the coordinates

Table 1. *The position stability and number of normal points (NP) of the SLR stations in 1994-2008*

SLR STATION	1994 - 1998			1999 - 2003			2004 - 2008		
	No	S*	No of NP	No	S	No of NP	No	S	No of NP
McDonald	7080	9.5	19812	7080	6.7	26927	7080	8.8	17293
Yarragadee	7090	10.7	61852	7090	6.1	72511	7090	5.6	112322
Greenbelt	7105	7.8	35330	7105	5.5	40325	7105	7.0	17492
Monument Peak	7110	9.0	59045	7110	7.2	58348	7110	8.3	30596
Zimmerwald	7810	11.9	8822	7810	7.0	40292	7810	10.0	63317
Borowiec	7811	16.8	6181	7811	14.2	10453	7811	10.6	6529
Riyadh	7832	16.4	3980	7832	8.8	35126	7832	6.7	34770
Graz	7839	13.8	37947	7839	5.6	50716	7839	5.1	44958
Herstmonceux	7840	7.4	45896	7840	4.7	57709	7840	5.6	55778
Wettzell	8834	22.5	31101	8834	8.3	28068	8834	5.1	37006
Potsdam	7836	10.9	17506	7836	8.1	10354	7841	8.6	18099
Orroral – Mt.Stromlo	7843	13.4	26272	7849	5.6	40136	7825	5.0	68217

*Stability [mm]

determination, stability of each component and 3D, for three five years spans: 1994-1998, 1999-2003, 2004-2008.

3 Results

The 3D station position stability is presented in Fig. 3 and Table 1. All stations had significant improvement of stability between spans first (1994-1998) and second (1999-2003). In the comparison to the next span (2004-2008) only six stations had better results, the most significant improvement is observe for Wettzell. These results are also confirmed by SLR analysis centers (Evaluation and monitoring of ILRS AWG products), (Mueller *et al.*, 2011). The explanation of the worse stability of the stations McDonald, Greenbelt and Monument Peak is visible in table 1 (bold) as the effect of significant decrease of the number of normal points in the last span. In the case of Zimmerwald and Herstmonceux the worse stability in the last span is result of the jumps in vertical component in February 2006 (Fig. 4) and February 2007 (Fig. 5) (Appleby *et al.*, 2008) respectively,

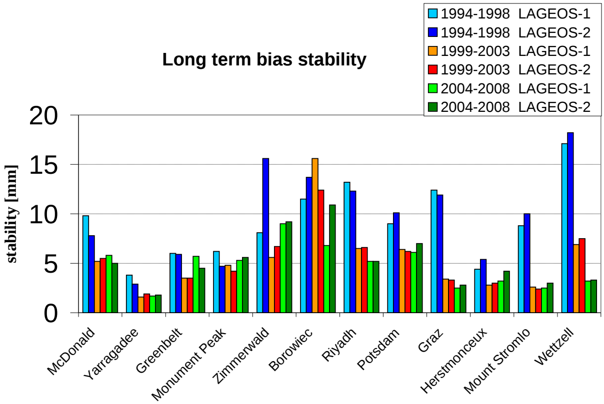

Figure 1. *Long term bias stability (Range Bias variation) 1994-2008*

due to exchange of the Time Interval Counter to the Event Timer. Potsdam in the last period used different SLR system.

The results presented in Fig. 3 and table 1 show also limit of the station position stability on the level of 5 mm which any station can not to exceed from 1999 despite the fact that in the last ten years precision of the SLR measurements was significantly improved and many systematical biases were eliminated. It means that it is some unknown effect which blocked further improvement of the SLR accuracy. It is probably the atmospheric correction which uncertainty in the opinion of many analysts is estimated on the level of 5 mm. In this case without two-color ranging the improvement of the quality of the SLR results will be rather impossible.

On the other hand it is observable step by step improvement of the station positions stabilities as result of the introduction of the new models in orbital program. The difference between the same data computed in 2000 and presented here in table 1 is 2 mm. This is the effect of the better models of the Earth gravity field (most important), ocean tides, or terrestrial reference frame. The important problem is answer the question what part of our uncertainty of the station positions comes from observation errors and from computations? The lack of significant improvement of the station positions in the last 15 years is presented in Fig. 6 as

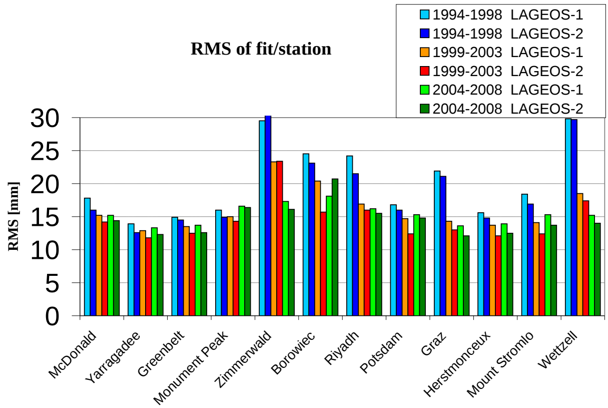

Figure 2. *RMS of fit of LAGEOS-1 and LAGEOS-2 per station*

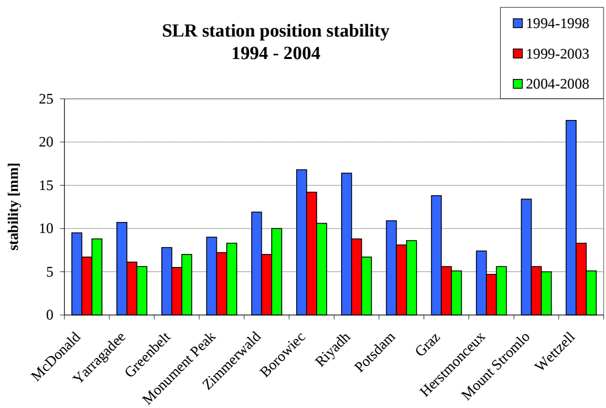

Figure 3. *Stability of the station positions*

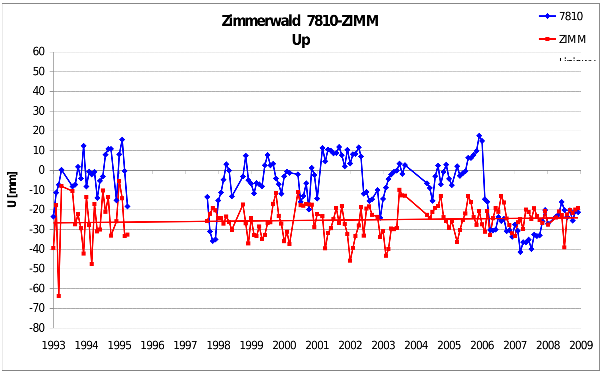

Figure 4. *Jump in SLR vertical component (February 2006), Zimmerwald station, blue-SLR, red-GPS*

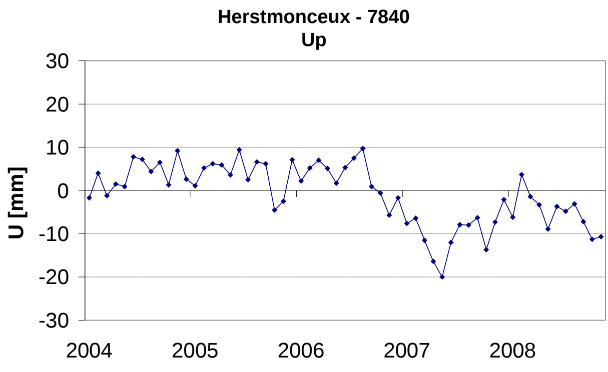

Figure 5. *Jump in vertical component (after February 2007), Herstmonceux station.*

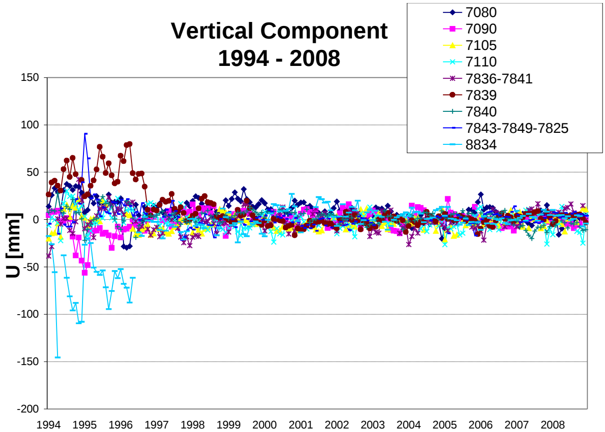

Figure 6. *Vertical component for the nine SLR stations 1994-2008*

residuals of the vertical component of the nine the best stations. The significant data improvement is observed in 1996/1997, later the residuals are on the near same level with little bit improvement with time.

4 Control of the SLR data

The several analysis centers present current quality results for each station. These results are in different forms: range bias, precision, single shot RMS per each pass, long term bias stability, short term bias stability, N, E, U deviations of the station positions in the graphic presentation. The author suggest to complement the graphic presentation of the station position N, E, U by GNSS results, then will be better control of the significant deviations as for example is presented in Fig. 4. This figure shows 25 mm jump in the SLR results after exchange time interval counter to event timer in February 2006. After jump the SLR results are in good agreement with GPS. The normal points residuals per one site in the graphic form is another presentation of the quality of the SLR data (Figs. 7, 8). The erroneous points and passes then are clearly visible and the stations can very quickly to correct systematic errors. Also some trends in residuals can to be detected.

5 Conclusions

The paper gives several answers for the questions presented in Introduction. The best estimation of the SLR accuracy seems to be 3D stability of the station coordinates. Analysis of the 15 years data of the twelve stations shows the accuracy limit on the level of 5 mm, which can to be result of the atmospheric correction model. The new two-color SLR system in Wettzell can to answer for this question. An increase of the number of normal points per site is very important for SLR accuracy improvement. The stations have to observe as many points of LAGEOS satellites as possible. Also detection of the all significant jumps in results and their quick elimination by current control of the common SLR and GNSS results is important. The problem of the estimation of the errors sources from the observation side and the computation side is not too clear. The new models and new effects including in the orbital process should little bit to explain the role of orbital computations in the global SLR error budget. Deterioration in the SLR accuracy in the last years for the several the best stations is alarming. Come back to the quality of results from beginning of 2000 is important. The control of the data form the next five years 2009-2013 gives answer if the further significant improvement of the SLR accuracy up to 1 mm in the next few years will be possible.

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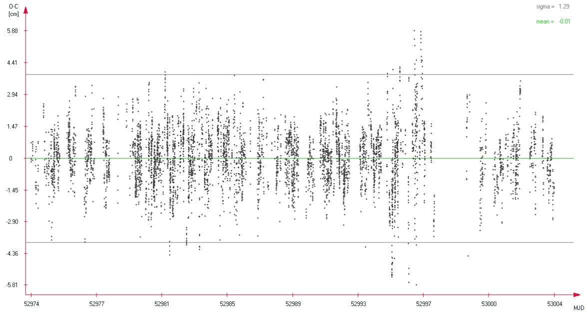

Figure 7. *The normal points residuals for monthly arc (all stations) – October 2003*

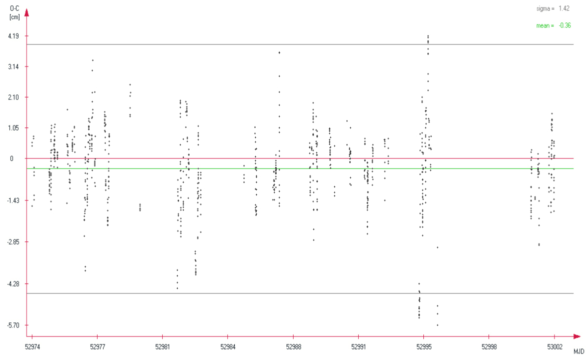

Figure 8. *The normal points residuals for monthly arc per one station (station Monument Peak) – October 2003*

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