Further Studies on the Influence of Range Biases

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1. Introduction

Among other error sources of SLR observations the systematics of the laser ranging systems are taken care of by estimating so-called "Range Biases" (RB). Those RB are expected to lead to improved parameters estimated of solutions of a Terrestrial Reference Frame (TRF). In order to find a practicable strategy the ILRS has launched a Pilot Project (PP) on systematic error monitoring, the SSEM (Station Systematic Error Monitoring). As there are various possibilities to model RB, at BKG different SLR-based TRF solutions using distinct RB setups are computed and evaluated. The characteristics as well as the results of these solutions are presented in the following.

2. Solution Setup

An overview of the common main characteristics of the solutions generated are listed in Table 1. Each solution covers the time span 2000 to 2017 for studying the behavior of the relevant parameters with a long-term perspective. The arc length of seven days as well as the parameterization of station positions, Earth Rotation Parameters (ERP), and the RB follows well ILRS standards. Concerning EOP the a priori model is C04_14 in order to reach consistency with ITRF2014. The geometric datum of the solutions is defined by NNR-conditions over the official ILRS core stations.

Table 1. Common characteristics of the processing carried out ("EOP": Earth Orientation Parameters, "ERP": Earth Rotation Parameters), "RB": Range Biases).

Items	Setup
Time span	2000.0-2018.0
Arc length	7 days
Station positions	weekly (global XYZ per arc)
ERP	daily
RB	weekly (per arc)
A-priori Models - **Station positions** - **EOP**	 ITRF2014 C04_14
Datum definition	minimum constraints (NNR over core stations)

In total four solutions are derived whose distinct properties are listed in Table 2. As indicated, they differ in the satellites involved as well as in the RB parameters estimated. Regarding the RB parameterization, "combined" denotes a single RB parameter common for both LAGEOS or both Etalon satellites, respectively, whereas "per satellite" refers to an RB parameter set up for every single satellite.

Table 2. Distinct characteristics of the processing carried out ("LAGEOS" = LAGEOS-1 + LAGEOS-2, "Etalon" = Etalon-1 + Etalon-2).

Test Case	LC	LS	LS_E0	LS_EC
Satellites	LAGEOS		LAGEOS+Etalon	
Range Biases				
• **LAGEOS**	combined	per satellite	per satellite	per satellite

• **Etalon**	-	-	-	combined

While the processing is carried out as Precise Orbit Determination (POD) with associated parameter estimation, Helmert transformations between the estimated and the a-priori station positions are performed afterwards.

3. Results

Within the work presented here the main focus is on RB, Earth Rotation Parameters (ERP), and differential scale stemming from the Helmert transformations.

- 3.1 Range Biases

Inspecting the time series of the RB estimated suggest that there are two main types of stations regarding RB behavior to be called “Yarragadee-type” (Y-type) as well as “McDonald-type” (M-type).

RB behavior of Y-type is similar to the time series of RB estimated for station Yarragadee as shown in Fig. 1. It is characterized by time series of small scatter and medians of only a few mm. The Etalon combined RB (LS_EC case) reveals a small positive offset of about one to two cm w.r.t. the LC case and mostly only a little higher scatter.

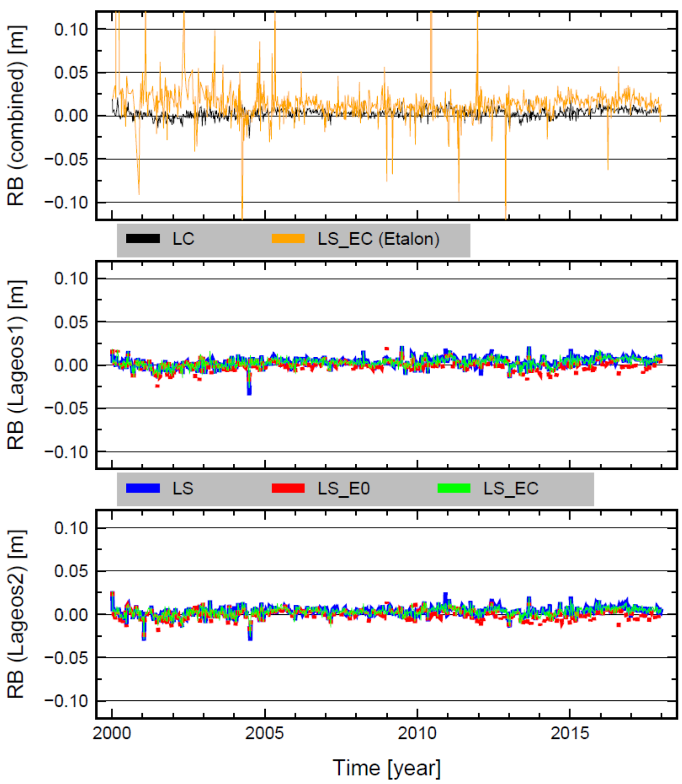

Fig. 1. Time series of RB estimated for station Yarragadee (7090).

On the other hand, the RB of stations of M-type reveal similar behavior as those estimated for station McDonald, see Fig. 2. Here, especially the scatter of the RB time series is distinctively higher as compared to the Y-type stations. Moreover, the RB in the LS case contain a number of outliers. Though some of them are mitigated when the Etalon satellites are included (cases LS_E0 and LS_EC) others may appear (e.g. towards the end of 2013 in Fig. 2).

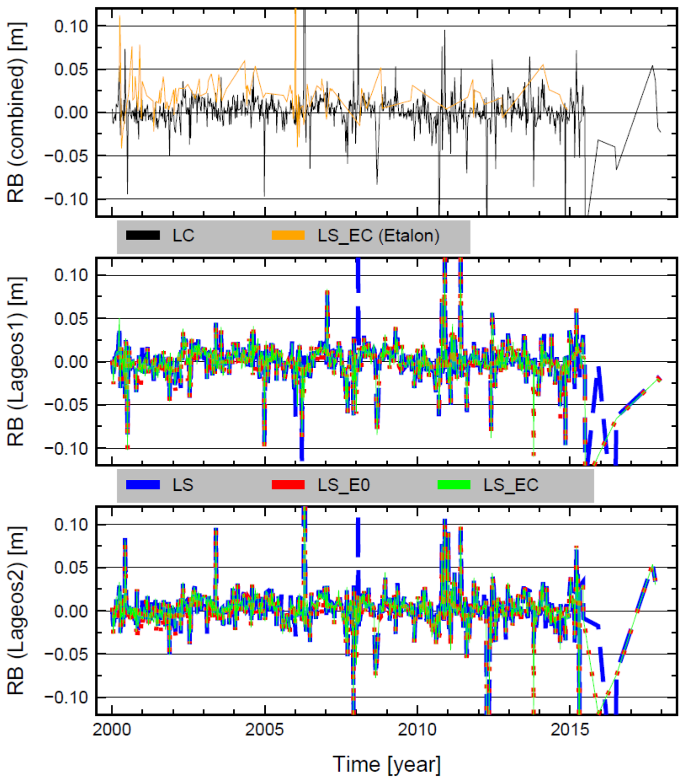

Fig. 2. Time series of RB estimated for station McDonald (7080).

Overall, it may be stated that the M-type stations reveal regular RB of good quality whereas the Y-type stations may be regarded as excellently calibrated laser ranging systems. An overview of classifying the remaining core stations as either Y- or M-type is given by Table 3.

Table 3. Classification of core stations according to RB behavior.

Station	Code	M-type	Y-type
Greenbelt	7105	X	
Monument Peak	7110	X	
Haleakala	7119, 7210	X	
Changchun	7237	X	
Arequipa	7403	X	
Hartebeesthoek	7501	X	
Zimmerwald	7810	X	X (as of 2008.0)
Mt. Stromlo	7849, 7825	X	
Riyadh	7832	X	
Grasse	7835	X	
Potsdam	7836, 7841	X	
Shanghai	7837	X	

Graz	7839		X
Herstmonceux	7840		X
Matera	7939, 7941	X	X (as of 2009.0)
Wettzell	8834	X	

- 3.2 Earth Rotation Parameters

Regarding the ERP the impact of the different RB setups are studied by comparing the statistical measures of their time series given in Table 4. It may be noted that the main difference in statistics is observed between the cases without (LC, LS) and with Etalon (LS_E0, LS_EC), and that there are only minor differences between the modelling of combined or separate RB.

Table 4. Statistics of time series of ERP estimated ("Series" denotes the underlying time series, "Median of STD" is the median of the standard deviations a single RB parameter is estimated with, "STD": standard deviation).

Test Case	LC	LS	LS_E0	LS_EC
X_P				
Median of Series [µas]	-27	-30	**+7**	**+12**
STD of Series [µas]	358	365	**255**	**255**
Median of STD [µas]	**59.7**	**61.2**	**61.3**	**60.4**
Y_P				
Median of Series [µas]	-50	-49	**-14**	**-21**
STD of Series [µas]	245	254	**237**	**239**
Median of STD [µas]	**63.0**	**64.5**	**64.1**	**63.5**
LOD				
Median of Series [µs/d]	**+0.36**	**+0.48**	+0.67	+0.58
STD of Series [µs/d]	46.0	47.1	**42.1**	**42.1**
Median of STD [µs/d]	**8.2**	**8.2**	**8.3**	**8.1**

Concerning polar motion, including the Etalon satellites leads to a reduction of the absolute value of the median of the time series roughly from 30 to about 10 µas as well as from 50 to 18 µas for Xp and Yp, respectively. The STD of the series is significantly reduced, too, roughly from 360 to 255 µas as well as from 250 to 238 µas, respectively for X and Yp. In case of LOD there is also improvement in temporal scatter as the STD of the time series reduces approximately from 46 to 42 µs/d. However, the offset of the LOD series from C04_14 as represented by the median of the time series increases approximately from +0.4 to +0.6 µs/d.

For all three polar motion parameters, on the other hand, the precision of the estimates as expressed by the median of the STD remains stable.

- 3.3 Scale w.r.t. ITRF2014

The time series of the differential scale for the LC case as well as the differences w.r.t. to this case are shown in Fig. 3. In the LC case the time series is characterized by a median of -3.6 mm and a STD of 4.8 mm. Modelling the RB for the LAGEOS satellites separately (the LS case; median: -3.8 mm, STD: 4.9 mm) affects the time series only negligibly as reflected by the LS-LC series.

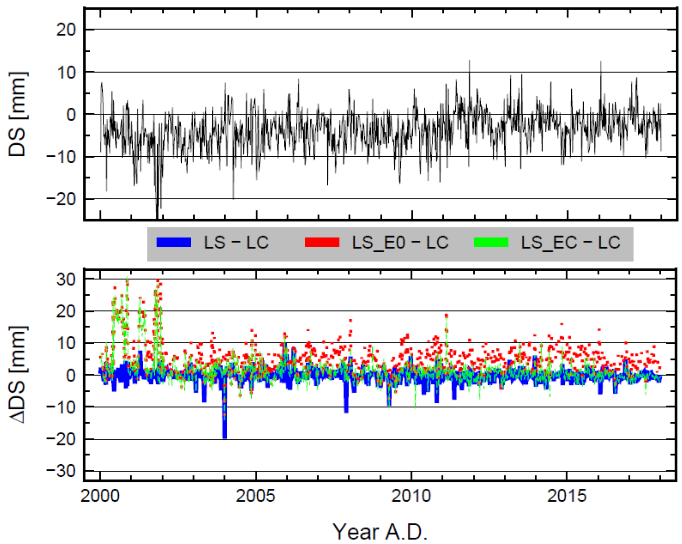

Fig. 3. Above: time series of differential scale estimated (LC case); below: differences of differential scale estimated w.r.t. LC case.

By contrast, there is significant reduction in the absolute value of the time series median to +0.9 and -2.6 mm for the LS_E0 (LS_E0-LC series) and the LS_EC (LS_EC-LC) case, respectively. Thus, including the Etalon satellites helps to stay closer to the high quality a priori ERP of C04_14. This effect is more pronounced if no RB is estimated for the Etalon satellites. On the other hand, the time series' scatter slightly increases to 6.0 and 5.6 mm for the LS_E0 and LS_EC case, respectively.

4. Conclusions

In the context of the ILRS SSEM Pilot Project for monitoring station systematic errors, at BKG additional TRF solutions testing different range bias (RB) setups as well as satellite constellations are generated covering the time span of 2000.0-2018.0. Regarding satellite constellations there is one group of test cases including only LAGEOS-1 and -2, and another one involving LAGEOS-1 and -2 as well as Etalon-1 and -2. Examining the results is done here by studying the effect on the long-term behavior of the RB themselves as well as on the Earth Rotation Parameters (ERP) and the scale between the a priori and the estimated positions of the ground station network.

Concerning the RB, special interest is given here to classifying the core stations according to their RB time series obtained over the whole 19-year interval. Overall, it may be deduced that there are two groups of core stations regarding RB behavior. Into the first group those stations fall that exhibit RB behavior similar to station Yarragadee ("Y-type") whereas the second group is populated with those stations similar to station McDonald ("M-type"). M-type stations already revealing quite stable RB behavior, the Y-type stations (Yarragadee, Graz, Herstmonceux, partly Matera and Zimmerwald) emerge as extremely well calibrated laser stations with very small offsets as well as scatter of their RB time series. On the other hand, significant improvement in RB behavior is to be expected for those SLR stations which will receive major upgrades or which will be replaced by next-generation systems (e.g. NASA-developped NGSLR).

Regarding the ERP, improvement in time series median as well as STD is clearly found for Xp and Yp as well as in time series STD in case of LOD. However, the internal accuracy as expressed by the median of the STD of the RB estimates remains on same level throughout. Interestingly, there is negligible difference in ERP precision and quality between estimating separate RB or a combined RB in the LAGEOS-only cases (LC, LS) or between estimating no RB or a combined RB for the Etalon satellites (LS_E0, LS_EC).

Looking at the scale parameter it is revealed that adding the Etalon satellites to both LAGEOS satellites leads to improvement in time series median and to slight degradation in time series STD. Reduction in the offset as represented by the median may well be attributed to the stabilizing effect of including the high-altitude Etalons. On the other hand, the increase in time series STD may partly be explained by the much less amount of SLR data for the Etalons as compared to the LAGEOS satellites.

Overall, based on the results obtained so far, it may be stated that highest improvement in the ERP as well as scale is obtained by including the Etalon satellites without estimating a RB for them. Further studies, e.g. based on upgraded center-of-mass values for the satellites or by processing according to the ILRS standard RB setup, are required to investigate in more detail the effects not explained for.