Homogeneous formation of SLR Normal Point data at AIUB

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Abstract

Since 2018, the ILRS requested the SLR stations to provide not only the normal point data but also the full-rate data. This enables the analysts to generate the normal points homogenously for all stations to reduce systematic errors. Therefore, a normal point generator offering different screening techniques, e.g., RMS-based filter or leading-edge filter, was designed at the Astronomical Institute of the University of Bern. The newly derived normal points can then be used immediately to perform weekly SLR analyses for LAGEOS-1/2, where the orbits are determined in 7-day arcs together with station coordinates and other geodetic parameters. First evaluations, i.e., comparison of geodetic and instrument parameters with newly formed normal points of the Zimmerwald station, indicate that the leading-edge filter performs better than the RMS-based filter.

1. Introduction

The Astronomical Institute of the University of Bern (AIUB) is an Associate Analysis Center (AAC) of the International Laser Ranging Service (ILRS, Pearlman et al. (2019)) and performs Satellite Laser Ranging (SLR) processing to estimate especially geodetic parameters and to perform precise orbit determination. For this purpose, so-called Normal Point (NP) data provided by the ILRS form the basis of all analyses. The NPs are compressed full-rate data, which are generated by each SLR station following more or less the ILRS NP algorithm (ILRS 2022). However, since 2018, the SLR stations also provide their full-rate data, such that the analysis centers have the possibility to generate the NPs homogenously for all SLR stations in order to study their impact.

Hence, a NP generator was designed in collaboration with the Swiss Optical Ground Station and Geodynamics Observatory (SwissOGS) in Zimmerwald (ZIML) offering different screening techniques, e.g., Root Mean Square (RMS) based filter or leading-edge filter (see Section 2). The newly derived NPs can then be used immediately to perform weekly SLR analyses for LAGEOS-1/2, where the orbits are determined in 7-day arcs together with station coordinates and other geodetic parameters (see Section 3). The quality of different sets of NPs is evaluated by comparing, e.g., station coordinates, Earth rotation parameters or observation residuals (see Section 4).

2. Generation of the Normal Points

The ILRS developed an algorithm to standardize the generation of the SLR NP data (ILRS 2022). First, the full-rate data are screened based on computed Fit Residuals (FR) with a rejection level of n·RMS over the entire satellite pass, where n represents a pre-defined factor, until the procedure converges. The fitting function is either a polynomial or an (adjusted) orbit trajectory. Then, the accepted FR data are used to build the corresponding NP data in pre-defined intervals. This screening technique is subsequently called RMS-based filter, where the data are assumed to be normally distributed (see Figure 1). However, for SLR stations ranging at single-photon level and using a Compensated Single-Photon Avalanche Diode (CSPAD, Kirchner and Koidl (1999)) detector such as for the SwissOGS in Zimmerwald, the distribution of the full-rate data is represented by a convolution of the system response and the satellite signature and is therefore no longer normally distributed (Appleby and Gibbs 1995). Hence, a different screening technique, i.e., leading-edge filter, was developed and demonstrated by, e.g., Kirchner et al. (2008). In this approach, the Leading Edge at Half Maximum (LEHM) at the front of the distribution is determined. Afterwards, a fixed interval around this LEHM, e.g. -50ps and +90ps, is applied as a rejection criterion (see Figure 2).

3. Data set and orbit parametrization

In this study, weekly SLR analyses based on LAGEOS-1/2 NP data are validated for four months (July - October 2019). Only the SLR NP data of the ZIML station are formed with the new NP generator using the following two different screening techniques

- S-RMS: RMS-based filter with a rejection level of $\pm 2.5 \cdot RMS$,
- S-LEHM: leading-edge filter with a rejection level of $[-50ps, +90ps]$.

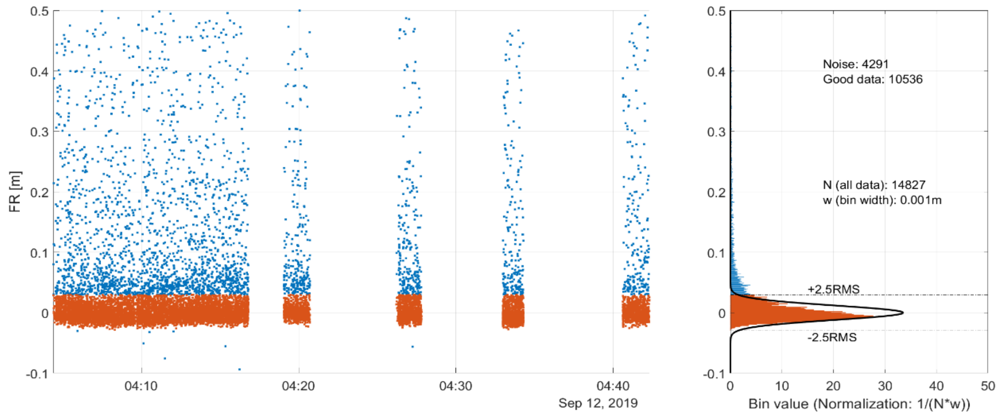

Figure 1: Accepted fit residuals of a LAGEOS-1 pass observed from ZIML station using an RMS-based filter with a rejection level of $\pm$2.5·RMS.

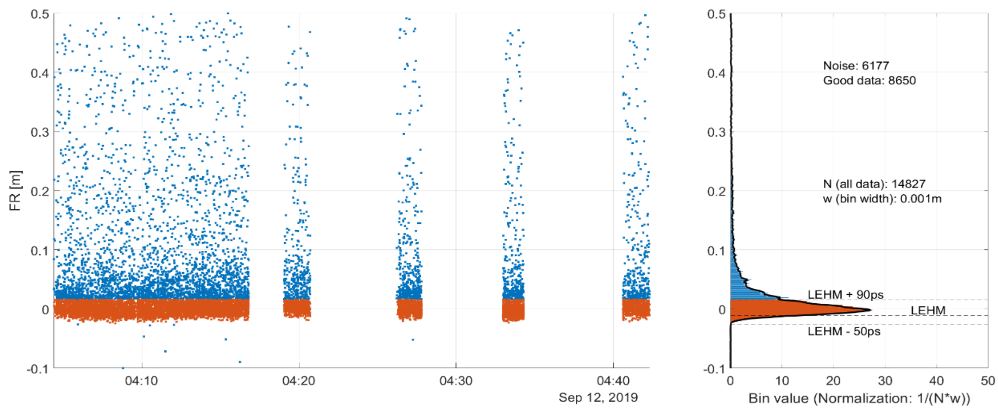

Figure 2: Accepted fit residuals of the same LAGEOS-1 pass observed from ZIML station using the leading-edge filter with a rejection level of $[-50ps, +90ps]$.

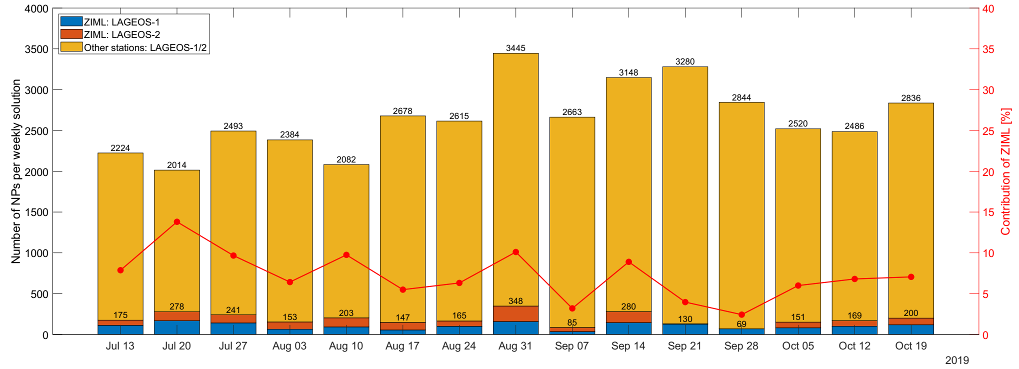

Figure 3: Number of NPs per weekly SLR analyses of LAGEOS-1/2 and the contribution of ZIML station.

All other NP data from the other SLR stations are acquired from the data base of the ILRS. In addition, the NP data of ZIML are screened based on an a posteriori residual validation, such that NP outliers do not effect the results. Consequently, only 2-14 % of the NP data are generated at the AIUB with the NP generator (see Figure 3).

The SLR NP data are processed with the Bernese GNSS Software (Dach et al. 2015), where the 7-day LAGEOS-1/2 orbits are represented by six initial osculating orbital elements referring to the beginning of the arc and five dynamic orbit parameters, i.e., one constant acceleration in along-track (S) and once-per-revolution (OPR) sine and cosine accelerations in along-track and cross-track (C). Based on the background models listed in Table 1, the orbital parameters are estimated simultaneously with geodetic and instrument parameters

- six osculating elements (1 set per 7 days),
- five dynamic parameters: constant (S_0) and OPR sine resp. cosine (S_S, S_C) acceleration in S and OPR sine resp. cosine (C_S, C_C) accelerations in C,
- station coordinates (1 set per 7 days),
- geocenter coordinates (1 set per 7 days),
- daily Earth rotation parameters (modeled by a piecewise linear function),
- range biases for selected stations and ZIML (1 set per 7 days).

Table 1: Background models

Models	Description
Reference frame	SLRF2014[1]
ERPs	IERS-14-C04 (Bizouard et al. 2019)
Nutation model	IAU2000 (Mathews, Herring, and Buffett 2002)
Subdaily pole model	DESAI (Desai and Sibois 2016)
Ocean tide model	FES2014b: d/o 30 (Lyard et al. 2021) + admittances
Earth tides	Solid Earth tides, pole tides and ocean pole tides: IERS 2010 (Petit and Luzum 2010)
Loading corrections	Ocean tidal loading: FES2014 Atmospheric tidal loading: Ray and Ponte (Ray and Ponte 2003)
De-aliasing products	Atmosphere + Ocean RL06: d/o 30 incl. S1- and S2-atmosphere tides (Dobslaw et al. 2017)
Earth gravity field	GGM05S: d/o 90 (Ries et al. 2018)

[1] ftp://edc.dgfi.tum.de/pub/slr/aux_data/ILRS_Data_Handling_File.snx

The datum is defined by No-Net-Translation (NNT) and No-Net-Rotation (NNR) minimum constraint conditions applied on the ILRS core stations[2], which provide more than 30 observations per week. Furthermore, the a priori center-of-mass corrections and the range biases of ZIML are computed by Rodríguez et al. (2019) based on NP data provided by ZIML using the NP generator implemented at ZIML for the operational production of SLR normal points. Therefore, in our experiments, the range biases of ZIML are estimated again.

4. First results

The quality of the SLR analyses (called S-RMS and S-LEHM) and therefore of the screening techniques is evaluated by comparing the estimated Earth Rotation Parameters (ERPs), station coordinates and the range biases for ZIML.

The bias and the Weighted Root Mean Square (WRMS, weighted with the formal error) of the X-pole can be slightly improved by 5 %, when the leading-edge filter is applied. Additionally, the bias of UT1-UTC is reduced by 1.9 µs. The quality of the station coordinates is determined by comparing the weighted mean RMS (weighted with the number of used core stations) of the Helmert transformation w.r.t. SLRF2014. While the weighted mean RMS of the East component in case of S-LEHM is reduced by 7 %, the weighted mean RMS, weighted with the number of core stations per weekly SLR analysis, North and Up components are increased by 10 %, resp., 2 % (see Figure 4, left). The range biases of LAGEOS-1 and LAGEOS-2 for ZIML differ only in the sub-millimeter level. Nevertheless, the variation of the range biases of LAGEOS-2 is reduced by 2 mm for the S-LEHM analysis (see Figure 4, right).

Further, SLR analyses are generated based on the Variance Component Estimation (VCE, e.g., Koch (2004)). It determines the weights of the normal equation systems, which are set up per satellite and per station. Therefore, each station will get an individual weight. Figure 5 shows the weights of LAGEOS-1 and LAGEOS-2 for ZIML,

Table 2: Estimated ERPs are compared w.r.t. the IERS-14-C04 reference series.

	X-pole [µas]		Y-pole [µas]		UT1-UTC [µs]	
	Bias	WRMS	Bias	WRMS	Bias	WRMS
S-RMS	99.6	179.7	53.8	145.3	7.6	71.6
S-LEHM	93.9	170.9	53.4	140.9	5.7	71.7

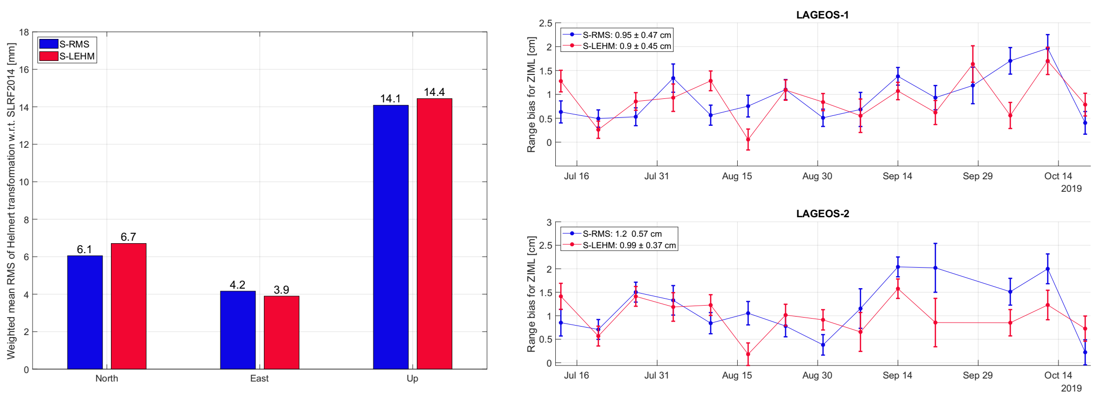

Figure 4: Weighted mean RMS of the Helmert transformation w.r.t. SLRF2014 (left). Range biases of LAGEOS-1 and LAGEOS-2 for ZIML station (right).

[2] https://ilrs.dgfi.tum.de/fileadmin/data handling/

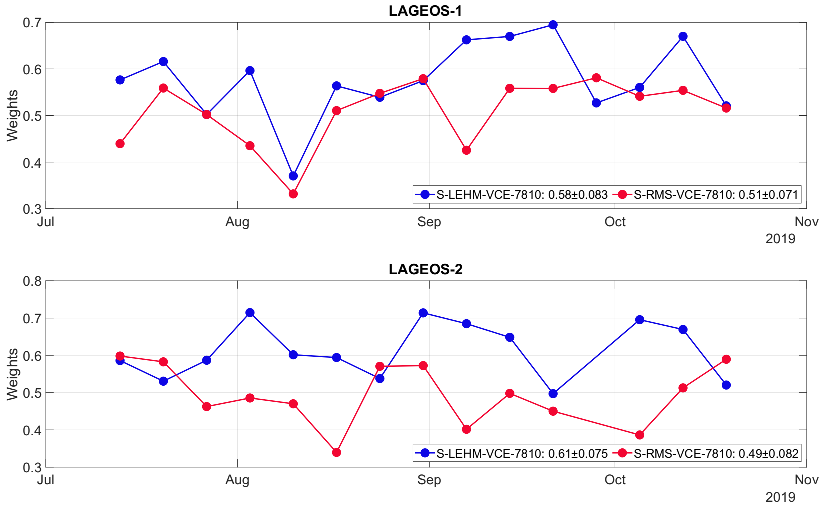

Figure 5: Weights from the VCE for LAGEOS-1 (top) and LAGEOS-2 (bottom) for ZIML station.

where, in general, S-LEHM-VCE obtains a higher weight for the contribution of ZIML station.

5. Conclusion and Discussion

SLR normal points can be generated using different screening techniques, e.g., using the RMS-based or the leading-edge filter. For this study, we have generated NPs for ZIML station using the two different screening techniques. While ZIML station contributed 2-14% of the entire data, small differences in the SLR analyses can already be seen. While the ERPs are improved with the leading-edge filter, the station coordinates (except for the East component) are worse compared to the RMS-based filter. In addition, the range biases of LAGEOS-1/2 for ZIML station are slightly reduced by the leading-edge filter. Hence, in this example, the leading-edge filter is preferred.

This conclusion is supported by the second experiment, where VCE is used for the combination of station- and satellite-specific normal equation systems. The VCE-derived weights indicate that the observations of ZIML station based on the leading-edge filter fit better to the mathematical model than the observations resulting from the RMS-based filter.

For future work, to study the full potential of the different screening techniques, also the full-rate data from all other SLR stations should be used to generate the corresponding NP data.

Acknowledgements: This research was supported by the European Research Council under the grant agreement no. 817919 (project SPACE TIE). All views expressed are those of the authors and not of the European Research Council. Calculations were performed on UBELIX (http://www.id.unibe.ch/hpc), the HPC cluster at the University of Bern.

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