# Novel Data Analysis Strategy at the SwissOGS Zimmerwald (7810)

**Julian Rodriguez-Villamizar (1), Pierre Lauber (2) and Thomas Schildknecht (3)**

(1,2,3) Astronomical Institute University of Bern, Bern, Switzerland

(julian.rodriguez@unibe.ch)

**Abstract**

A standard figure of merit to assess the quality of satellite laser ranging (SLR) observations, for a given station, may be a time dependent average describing the root-mean-square (RMS) after the formation of the so-called normal points. The nominal RMS per normal point depends on the station technical specifications and target characteristics, such as the so-called target depth, which describes the location of the target's reflective elements with respect to the target's centre of mass and their orientation with respect to the observing station. However, other information affecting the quality of the observations, e.g. the return rates, are presumably not analysed even though those quantities potentially provide useful information about the health, or status, of specific system components. In this work, we will use the latter as the observables from which we want to infer indicators for the status of the system, and therefore the quality of the observations.

Specifically, the questions addressed by the present work are: how can we make use of historical raw data to derive and define key performance indicators (KPIs)? To which specific system components might these KPIs relate? Is there any benefit on using such KPIs for detecting system flaws?

To answer these questions, we analysed passes to the target Lageos-1 during one year, considering the correct discrimination of the target's backscattered photons from the background noise. One outcome shows a decreasing return rate per month matching with independent in situ laser power measurements utilizing a power meter. In this case, the KPIs helped to identify health issues related to our laser source.

## 1. Introduction

If we understand a Satellite Laser Ranging (SLR) system as a distributed one, we may decompose it into specific units according to a well-defined task. In a non-exhaustive list, we find the optical paths for receiving or transmitting – if applicable, the telescope mount and the beam alignment, the laser head, the timing units, etc. All units should work according to their specifications meeting the needed performance and quality. Once the SLR system is operational, any change on the performance or quality of a specific unit may affect the quality of the final deliverable: the timestamped time-of-flight (ToF). To prevent that, the correct bookkeeping of such figures of merit per observable unit becomes interesting. In the following, we refer to such figures of merit as key performance indicators (KPIs).

## 2. KPIs: Definition and Scope

The KPIs provide a quantitative assessment of the performance, or quality, of an observable unit over time permitting the operational or even strategic enhancement. In case of any anomalous behaviour on a given unit, the available key performance indicators may help to: schedule unit-oriented technical sessions benefitting e.g., from the bad weather, judge the readiness of the system for dedicated short-notice observation campaigns, or just as an output to reassure the expected working mode of a given station.

In the following, we provide examples of existing KPIs available at the SwissOGS Zimmerwald.

- Epoch registration in a universal time scale. The synchronization of the 1 PPS coming from the maser with the 1 PPS provided by the reference timing unit, e.g., a GPS receiver, follows the recommendations provided by the International VLBI Service for Geodesy and Astrometry (IVS). Those recommendations include the zero-crossing avoidance besides keeping the drift rate positive. The key performance indicator in this case is provided by monitoring the time offset between the two PPS employing a counter, besides the drift both in magnitude and in sign.
- ToF timing unit and internal system delays. The comparison of the measured range against a fiducial one, obtained ideally with an independent measurement technique, allow us to monitor the stability of the observed range plus the system delays besides the dispersion of the so-called single shot with respect to a defined central tendency.
- Receiving or transmitting optical paths. All elements within the optical paths may be monitored by comparing their measured transmissivities against their respective nominal specification.
- Telescope pointing and beam alignment. Both the telescope pointing and the beam alignment are monitored through the so-called mount model. Specifically, we monitor the a posteriori standard deviation of unit weight after its estimation. It is worth to note that we obtain the observations from satellites, therefore including the alignment in the receiving Coudé-path.
- Controlling software unit. The changes in the controlling software unit due to new developments, refactoring, etc. may come from the outcome of scoring functions measuring efficiency, length of the code, portability, among others.

## 3. New KPIs: Return Rates

We define return rates as the number of detected events on the receiver per unit of time. Within our system, every time that we detect a return rate larger than 10 detections in a second, the system activates a neutral variable density filter, which attenuates the incoming power. The latter is critical if we want to assess e.g., the return rates as a function of the elevation for Low Earth Orbiters. Taking into account the previous remark, for the following analysis, we consider only observations to Lageos-1. In addition to rarely exciding the 10% threshold for the return rates, we have available an average optical cross-section estimated within ILRS activities, together with accurate predictions which have an impact on the width of the set range gate. We will use the optical cross-section further on to compare the estimated return rates with respect to the theoretical expected values.

In Figure 1, we show the impact of binning the number of detections with different sizes for all Lageos-1 passes observed in March 2020 from 7810.

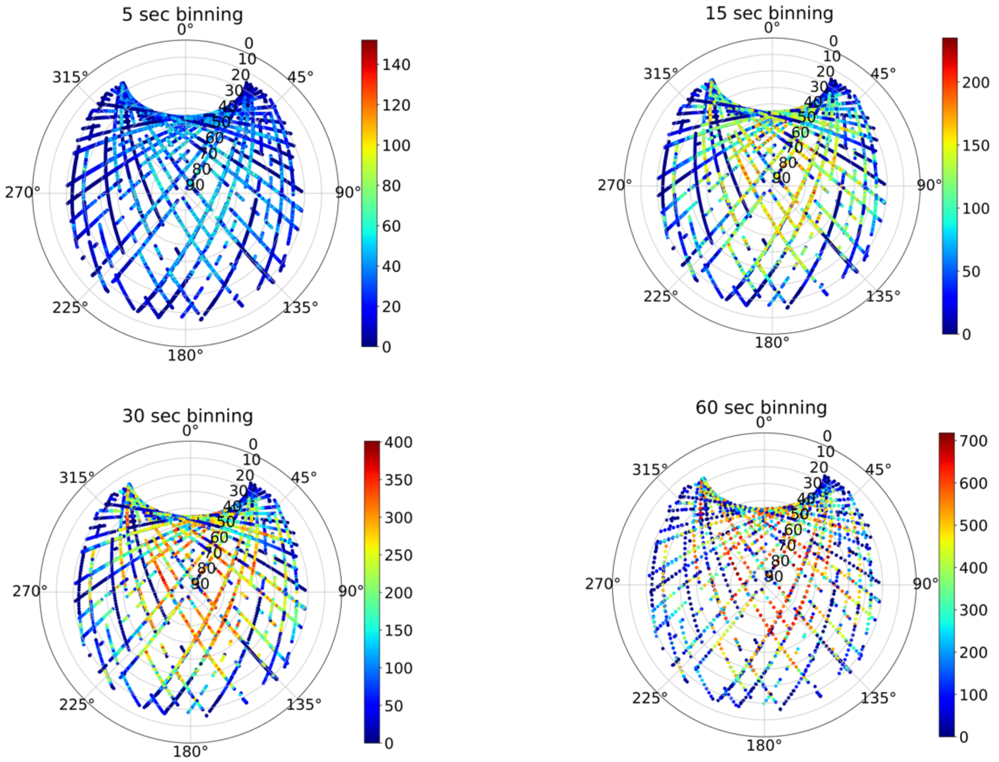


*Figure 1 - Impact of binning the number of detections with different sizes for all Lageos-1 passes observed in March 2020 from 7810.*

If we divide the range of the colour bars (depicting the number of detections) into the size of the bin, we see that we get comparable results. Nevertheless, bins with a size larger than 2 minutes were acting as a low pass filter smoothing the signal considerably. On the figure, we can also see the two-class feature space: bins containing either signal or noise, from which we can compute the signal-to-noise ratio per pass.

To extract the spatial distribution of the return rates, we fit a 2D Fourier series expansion of degree and order = 2, using as observables the binned monthly data as a function of the position on the sky (azimuth and elevation). In Figure 2 we show the observed return rates and estimated surfaces for Lageos-1 passes observed in January 2019 (top) and 2020 (bottom).

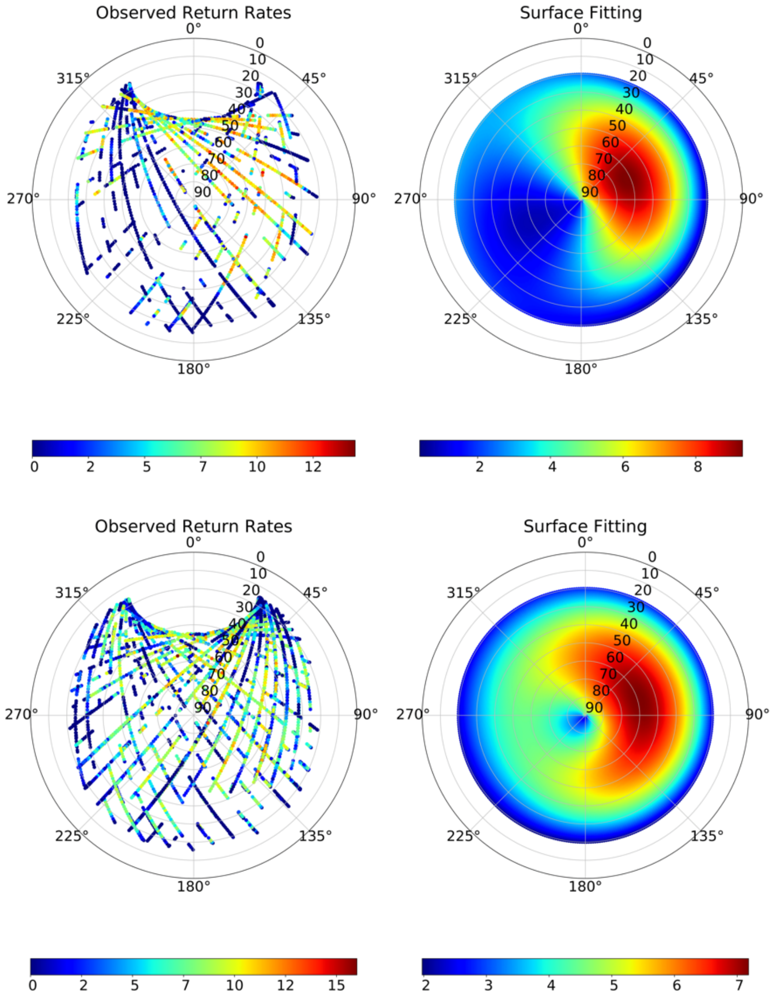


*Figure 2 - Observed return rates and estimated surfaces for Lageos-1 passes observed in January 2019 (top) and 2020 (bottom).*

From the link equation, we would expect the surface to be a paraboloid with its apex exactly on the zenith where the slant range is minimum, which is shifted towards the east in the estimated surfaces. It should also be considered that the optical link equation does not include the azimuthal dependencies being clearly visible in the estimated surfaces. In addition, after estimating the return rates using the nominal specifications of our station, we see that the theoretical link is in agreement with the one estimated from the observations. As an example, we calculated the link equation and obtained 7.1 photoelectrons/sec for Lageos-1 at an elevation of 45°. Note that the spatial distribution of the return rates is providing hints towards the optimization of observation sessions e.g., by increasing the elevation mask to 30°. In spite of observing a shorter arc, this time could be used to observe targets with better observability, increasing the productivity of the station along with the quality of the so-called normal points. Furthermore, we see the impact of passes with very low to no signal. We expect those to come from a suboptimal atmospheric transparency. In the latter case, a cloud detection algorithm could aid to avoid the tracking on those portions of sky with limited chances of retrieving backscattered photons from the target object of interest.

Once we have analysed the spatial distribution of the return rates over the sky for a given month, we can conduct the analysis for one year of observations. Data from one year is expected to be a representative sample accounting for seasonal, or monthly, variabilities. Furthermore, we fix the binning size to 30 sec for all subsequent analysis to preserve consistency. In Figure 3, we present the so-called box plot including observations for 15 months.

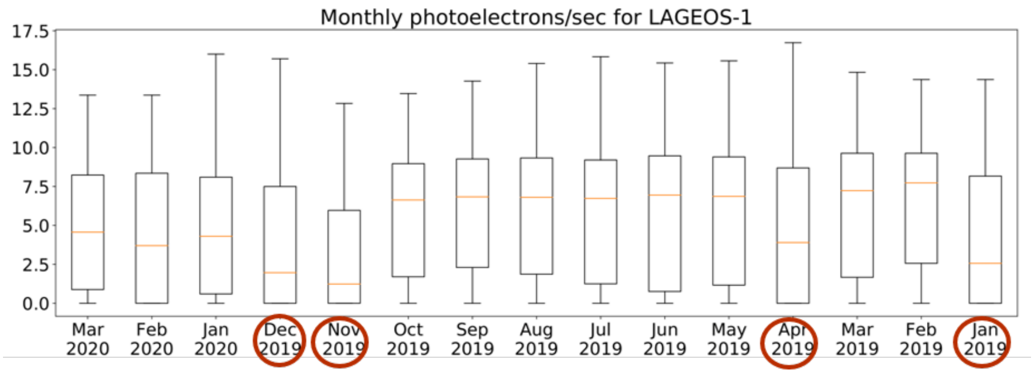


*Figure 3 - Box plot of return rates (30 sec bins) including observations for 15 months.*

We may notice the impact of the relatively low number of returns and observed passes within January, April, November and December 2019 due to bad weather. The inclusion of those passes with no, or very little, signal affects the overall statistics and may lead to wrong conclusions. To prevent the latter, we filter those bins where we did not get any returns. The applied filter consists of a binary classification between signal or noise, besides the screening after an orbit improvement per pass.

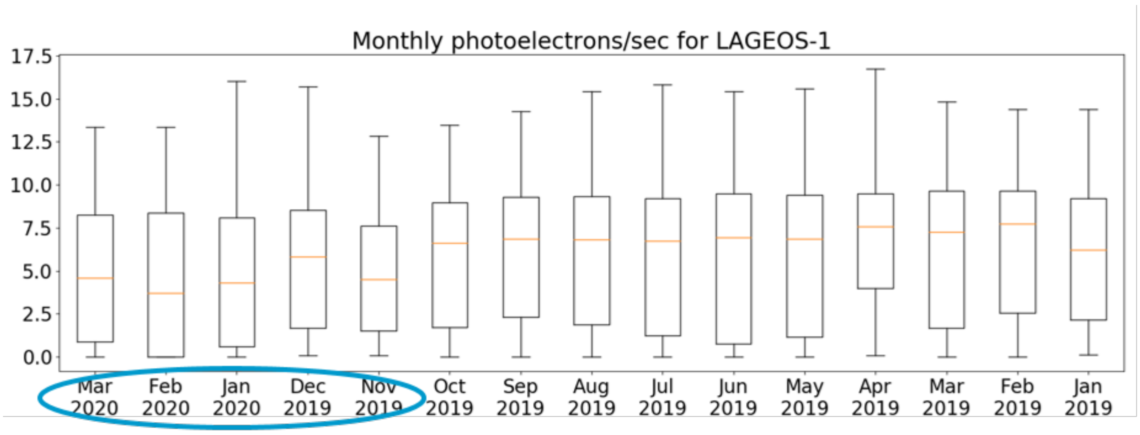


*Figure 4 - Box plot of return rates for filtered data (30 sec bins) including observations for 15 months.*

Once we filter the data and focus only on the signal, we notice that the return rates are quite stable between January and October 2019 (Figure 4). After October, we see fluctuations that could not be addressed to the processing strategy. Additional in-situ energy measurements employing a power meter measured: 7.8 mJ on October 2019, 6.7 mJ on November 2019 and 5.4 mJ on December 2019. The correlation suggests that the fluctuation that we see by the end of 2019 has to do with the health of our laser source.

## 4. Summary

Key performance indicators may help to identify system flaws to specific system components. The monitoring of the KPIs may report a significant input for operational or even strategic enhancement in SLR system.

We propose new KPIs using the return rates per observed pass of a specific target (Lageos-1). The analysis of the observed return rates provided us with:

- Evidence of changes that could be done at the observation level to increase the productivity and quality of observations on site.
- Quantitative information about the overall performance of the system over time including a comparison against calculated theoretical return rates using the nominal specifications of the station.
- Evidence of a system flaw, which shows a correlation with a fluctuating decreasing energy from our laser source.

## References

Rodriguez-Villamizar, J. C. (2022). Efficient laser ranging to space debris (Doctoral dissertation, Universität Bern).