The SLR observations to GNSS satellites: Preliminary results and open questions

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Abstract. In the present study, we show the results of the multi-year processing of SLR observations to GNSS satellites (both for GPS and GLONASS satellites), using the Bernese GNSS Software. The aim of the study is to investigate the associated SLR range residuals, defined as the differences between: (a) the observed SLR ranges and (b) the computed spatial distances between the ground stations and the GNSS (precise) orbits, respectively. The residuals are estimated on daily basis, taking into account inter alia, the Non Tidal Atmospheric Loading (NTAL) and the Atmospheric Ocean De-aliasing (AOD) effect. The results indicate different biases for the GPS and GLONASS satellites and show remarkable variability among the ground stations.

1. Introduction

The analysis of the SLR observations to GNSS satellites is already in detail discussed by Thaller et al. (2011), Thaller et al. (2012), and Sosnica et al. (2015). This is the first step of our project which deals with the optimal combination (on the normal equation level) of the following data sources: (a) SLR observations to GNSS satellites, (b) SLR observations to the classical satellites, i.e., LAGEOS and ETALON, and (c) GNSS microwave observations. We used SLR observations both for GPS and GLONASS satellites from the 1st Jan. of 2000 to 6th. Jun. of 2015. Totally, 43 out of 46 SLR stations of the global network of the ILRS (Pavlis et al. 2017) are involved (Fig. 1), and 35 satellites (33 GLONASS and 2 GPS satellites, respectively) are used. We employed the utilities of SLR analysis of the Bernese GNSS Software (Dach et al. 2015).

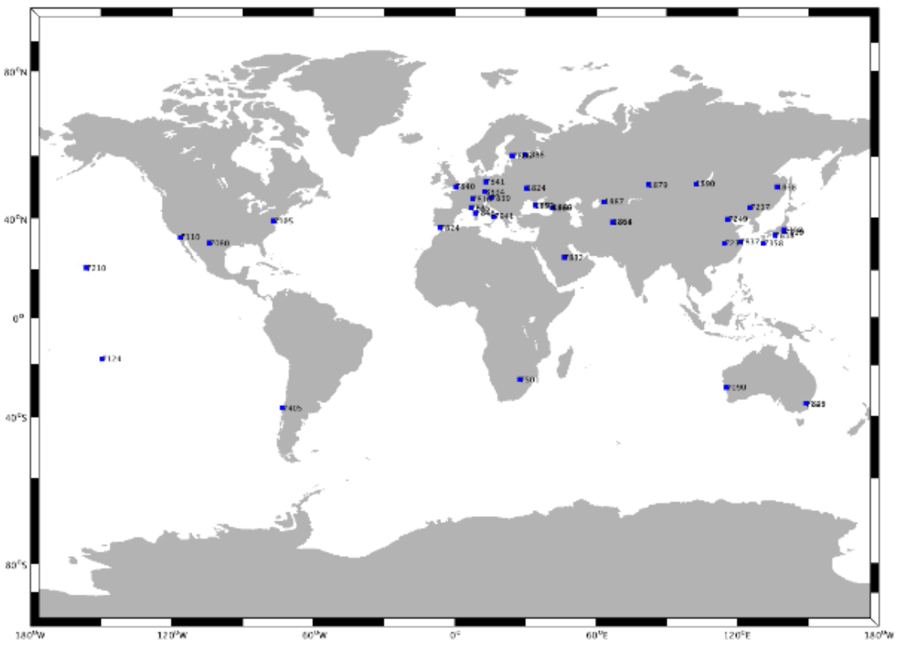

Fig. 1: The global SLR network used for this study.

2. Rationale of the Daily SLR Residuals Computation (DSRC)

The observed quantity used for the data statistics and data screening was the Daily SLR Residuals. The Daily SLR Residuals Computation (DSRC) is done by comparing the spatial distance differences between (a) the direct SLR to GNSS satellite range measurements and (b) the theoretically computed distances between the station coordinates and the GNSS satellite positions. The station positions are taken from the ITRF2014 exploiting the full PSD model (Altamimi et al., 2016), the GNSS orbits are derived from the Center for Orbit Determination in Europe (CODE) precise orbits in the frame of EGSIEM – REPRO (Susnik et al., 2016, Susnik et al., 2017). The mathematical formula yields:

$$DSRC_i^j = \rho_i^j - S_i^j \quad (1)$$

where $DSRC_i^j$ is the DSRC between the ground SLR station *i* and the GNSS satellite *j*, $S_i^j = \sqrt{(X_i - X^j)^2 + (Y_i - Y^j)^2 + (Z_i - Z^j)^2}$ is the 3D computed distance (X,Y,Z the 3D coordinates). In addition, we take into account the Non-Tidal Atmospheric Loading (NTAL, van Dam and Wahr 1987, Tregoning and van Dam 2005) and the Atmospheric Ocean De-aliasing (AOD) effect for the SLR residual computations. We used the models (for NTAL and AOD) provided by the German Centre for Geosciences (GFZ, Dobslaw et al. 2017).

There is a number of possible reasons for this bias performance: (a) SLR instrumental biases, (b) discrepancies in the Laser Range Array (LRA) offsets of the GNSS satellites, (c) the satellite antenna phase center modelling used for the GNSS transmitting antennas, (d) the stability of the stations, (e) the number of SLR to GNSS satellite observations, and (f) the quality of the GNSS orbit.

3. Results

The global SLR network comprises of 43 stations in the time span considered which have tracking record of GNSS satellites. In order to proceed with a more rigorous analysis, we screened the delivered residuals using the well-known 3σ criterion. Each of the observation should fulfil the following criterion:

$$DSRC_i^j - \overline{DRSC} < 3\sigma_{\hat{e}} \quad (2)$$

where the $\overline{DRSC}$ is the mean average of the DSRC and $\sigma_{\hat{e}}$ is the standard deviation of the residuals. The DSRC was realised using two different group-patterns, namely: I. the DSRC per station in order to investigate the site specific SLR to GNSS residuals behavior and II. The DSRC per satellite in order to investigate the satellite specific SLR to GNSS residuals behavior. Figures 2 and 3 show the final number (after screening) of the observations per station and satellite, respectively.

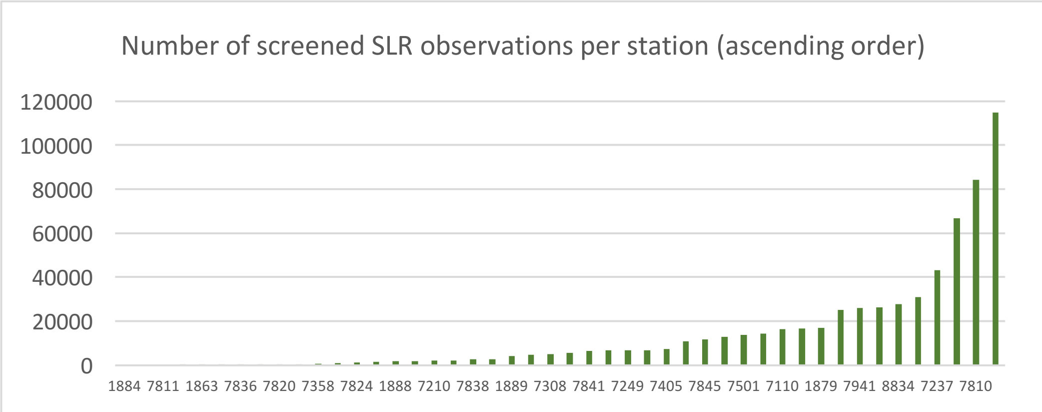

Fig. 2: The number of SLR observations (after screening) per station (in ascending order of observations, GPS+GLONASS).

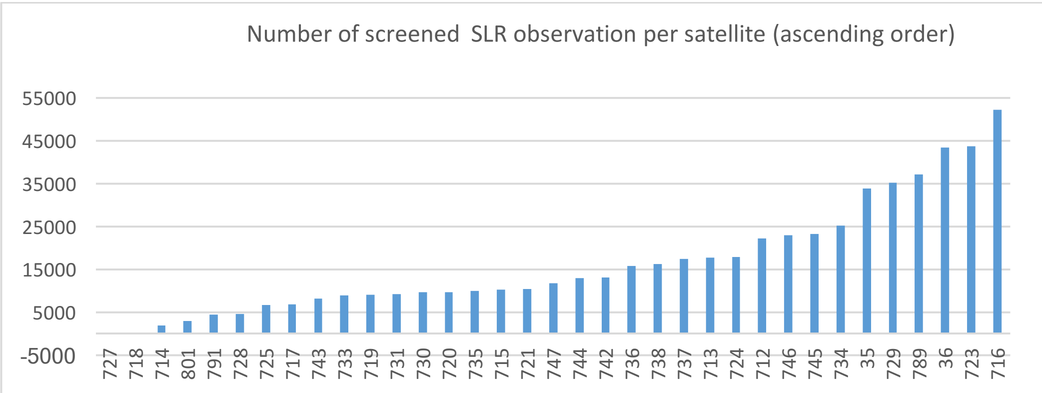

Fig. 3: The number of SLR observations (after screening) per satellite (in ascending order of observations).

Table 1 refers to the median of the bias and the rms of the DSRC per station. For the case of stations statistics, we separated the results with respect to the three satellite combinations, in particular: (a) using only GLONASS, (b) using only GPS and (c) using both constellations.

Table 1: The median of the bias and the rms per station (in mm)

	bias	rms
GLONASS	-24.5	42.7
GPS	-13.6	22.6
both	-19.8	41.4

The median bias and rms of the DSRC per satellite is -22.0 mm and 43.0 mm, respectively. Figures 4 and 5 depict the bias per station and satellite group, respectively. It is also worth to mention that the estimated mean biases for the majority of the cases, especially for the satellites show negative sign. This practically means that the observed ranges are mainly larger than the distances computed from the orbits and the ground stations, respectively.

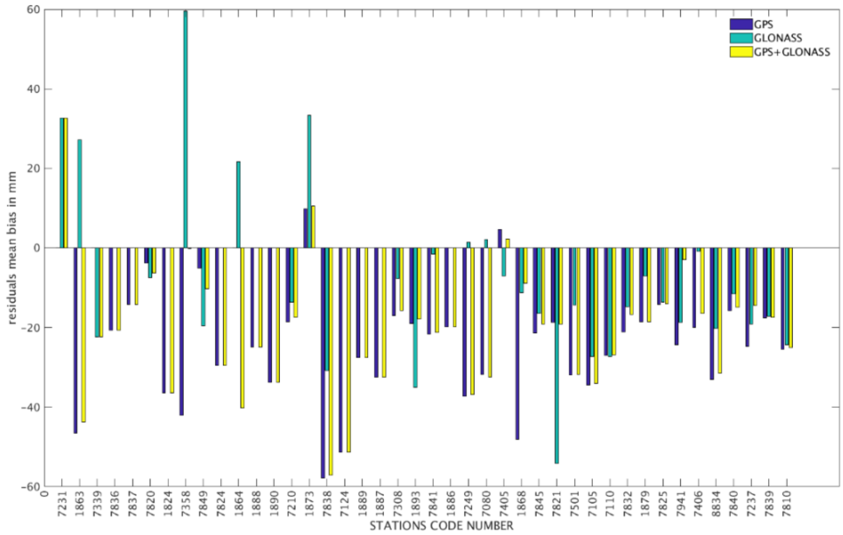

Fig. 4: The bias of the DSRC per station. The stations in x-axis have ascending order with respect to their final screened observations.

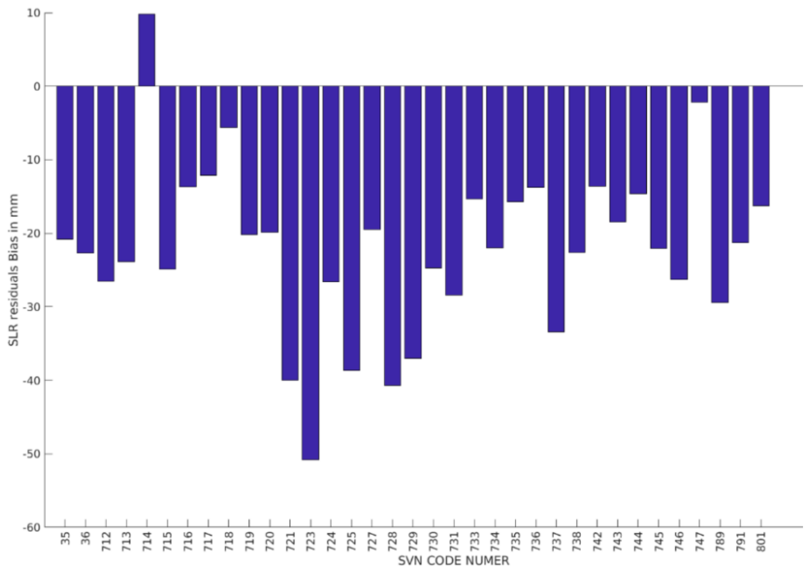

Fig. 5: The bias of the DSRC per satellite (after screening).

Compared to earlier studies, these results show similar biases for GPS and GLONASS satellites, which is a good indication that the underlying orbit modelling and estimation is more consistent between GPS and GLONASS. We should note for Fig. 4 that in some stations there were no GPS observations (the mean bias for these stations is not zero). The results indicate differences regarding the bias performance between the GPS and GLONASS satellites: The GPS satellites show smaller rms than the GLONASS satellites.

Some interesting cases

The Simosato station in Japan (number 7838) which shows relatively large bias (-57.1 mm only GLONASS observations, no GPS, Fig. 6).

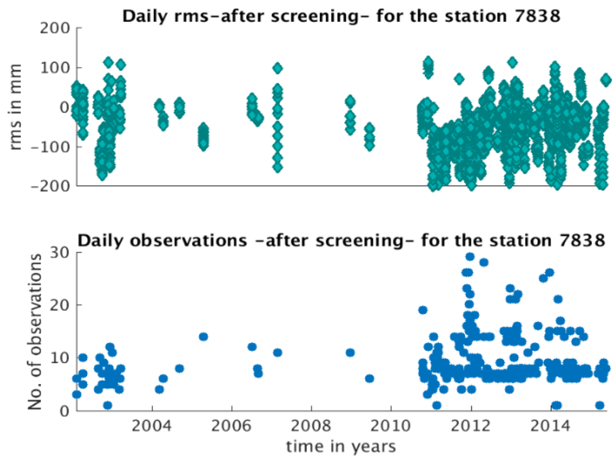

Fig. 6: The daily rms and the number of daily observations for Simosato Station using both GLONASS satellites (no GPS observations).

We can observe that from the year 2011, the daily rms is improved. This is an indicator for the better performance of this particular station. The total number of the screened observations is 2643.

Additionally, the Tanegashima station in Japan (7358) presents a quite peculiar behaviour: While there is a significant dispersion of the daily rms (100.2 mm for GLONASS and 106.5 mm for GPS, respectively) , the bias of the residuals is found -0.1 mm. The number of the screened observations is rather poor (260 for GPS and 3370 for GLONASS observations, respectively). Figure 7 illustrates the DSRC for the Tanegashima station.

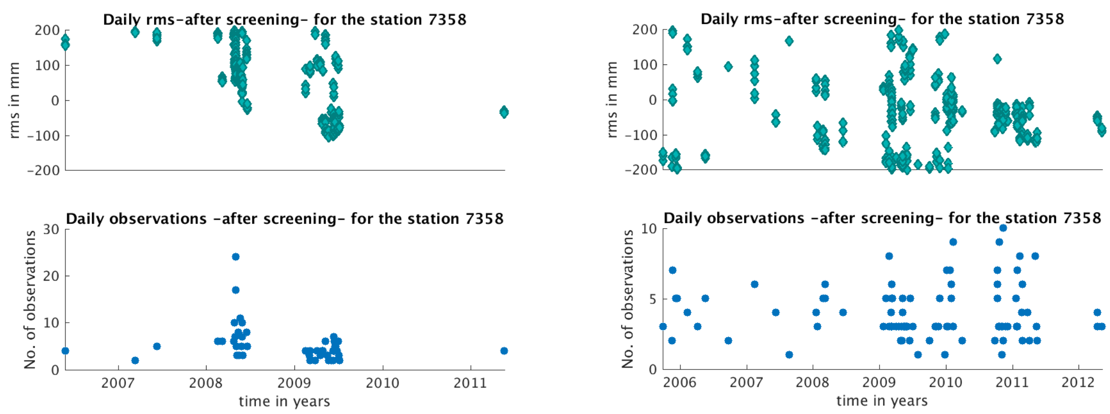

Fig. 7: The daily rms and the number of daily observations for Tanegashima station (left: GPS observations and right: GLONASS observations).

4. Conclusions and further investigations

The site-specific DSRC reveals a median bias of 25 mm for the GLONASS and -13.6 mm for the GPS and -19.8 mm using both constellations. On the other hand, the median of the satellite-specific bias is found to be -22.0 mm (-22.3 mm for GLONASS only and -21.8 mm for GPS only observations, respectively). The aforementioned results should be thoroughly investigated using GNSS and classic SLR observations to spherical satellites, i.e., mainly LAGEOS, under a rigorous combination scheme. We observe that the quality of the results is strongly dependent on the number of the observations. The DSRCs are the first indicators of the quality of the measurements and they are absolutely necessary for a reliable data screening. The next steps of the project will include all the necessary methodologies for the rigorous combination of SLR and GNSS, and thereof the derivation of the range biases estimation, along with other parameters such as stations coordinates, satellites orbits, geocenter motion and ERPs.

5. References

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