Orbit validation using Satellite Laser Ranging

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Introduction

Satellite Laser Ranging (SLR) allows the precise measurement of long distances by determining the round-trip travel time of a light pulse between a ground station and a satellite. SLR plays a key role in several fields of Earth and space science. Indeed, orbit measurements are used to better understand the distribution of Earth's mass, tectonic plate motion or ocean circulation patterns. This poster focuses on the use of SLR for satellite orbit control, illustrating how laser measurements can be used to validate the theoretical trajectory of a satellite.

Orbit validation: main ideas of the implementation

This study was carried for the satellite missions Grace-FO 1/2 and Swarm A/B/C. The developed program aims to calculate the theoretical distance d_{th} between the ground station and the satellite, and to compare it with the distance d_{slr} measured via SLR.

Normal point data format

The SLR measurements are collected in a specific file format called *Normal Point*, or NP in short. This format corresponds to a condensed set of observations generated from a large number of *full-rate* (i.e. single) observations collected over a specified time interval called bin. In particular, this file includes the precise laser emission timestamp t_{emit} and the distance d_{slr}. In this study, the NPs were already given preprocessed in the GROOPS format.

Ground station coordinates

Since the calculations are done in the inertial frame, ground station coordinates must be transformed in to the celestial frame. Given a timestamp t, a certain rotary matrix $R(t)$ and the ground station position $u(t)$ in the Terrestrial Reference Frame, the ground station position $x(t)$ in the Celestial Reference Frame can basically be computed with:

$$x(t) = R(t)^T u(t)$$

Satellite coordinates

In practice, the position of the satellite y is not directly known at the time of the laser reflection t_{bounce} and must be estimated. To do so, interpolation is performed using nearby known positions with the Neville-Aitken method.

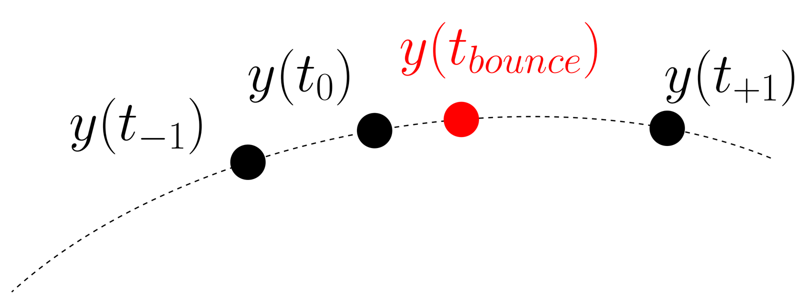

Figure 1: Neighboring positions of $y(t_{bounce})$ used for interpolation

SLR residuals

With t_{emit} being the timestamp of laser emission read from an NP

$$d_{th} = \|y(t_{bounce}) - x(t_{emit})\|$$

Hence, the residual is:

$$r = d_{slr} - d_{th}$$

where d_{slr} is the measured range from the NP.

Correction and Numerical Results

The main limiting factor of SLR accuracy is the atmosphere. The two common wavelengths used for SLR are 532 nm (green light) and 1064 nm (infrared light). These wavelengths are not affected by the ionosphere but solely by the troposphere. Hence stations constantly measure weather conditions (temperature, air pressure, humidity), which are assigned to every NP and used for the correction. The currently adopted model by the SLR community to correct for the atmosphere is given in [1] and [2].
The correction increases rapidly with low elevations as seen in Figure 2. Also the accuracy of the model decreases with the low elevation, making low elevation measurements less accurate.

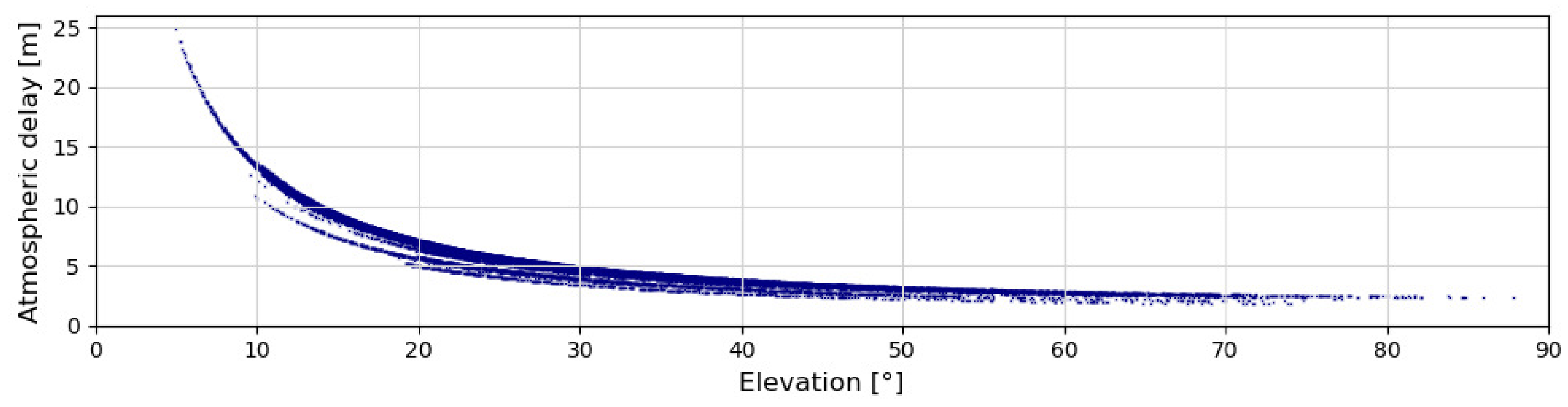

Figure 2: Atmospheric delay modeled for all the NPs in the month of 2021-01

The resulting SLR residuals without any corrections are seen on the left side of Figure 3. The residuals are mostly positive, as the measured distance is too long because of the atmospheric delay. After applying the atmospheric correction the results on the right side of Figure 3 are obtained. The residuals are now shifted towards Zero.

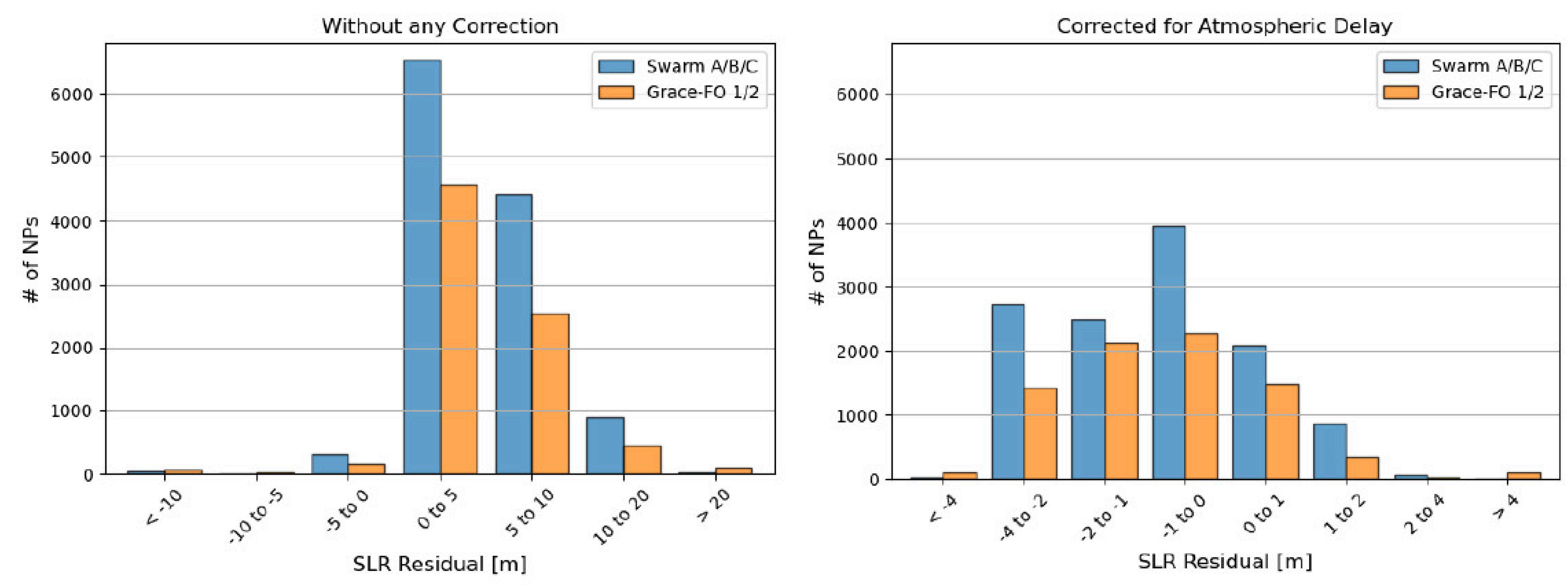

Figure 3: SLR Residuals in the month of 2021-01 grouped for the missions Grace-FO and Swarm

Conclusions

Residuals in the range of some meters are still remaining after the atmospheric correction. An analysis of e.g. station performance is therefore not sensible.
Eccentricity of the Laser Retro Reflector should be the next biggest influence on the SLR Residual. An implementation of satellite orientations and eccentricity vectors was tried but did not yield the expected results.
Some outliers in the residuals due to the implementation have to be detected. They originate for example from NPs close to midnight, where orbit information from two different days is used.

References

[1] Mendes V.B and Pavlis E.C. High-accuracy zenith delay prediction at optical wavelengths. *Geophysical Research Letters*, 31(14), 2004.

[2] Mendes V.B., Prates G., and Pavlis E.C. et al. Improved mapping functions for atmospheric refraction correction in slr. *Geophysical Research Letters*, 29(10), 2002.