SLR long-term range biases for non spherical LEOs

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1. Satellite Laser Ranging (SLR)

SLR is performed by ground stations with ultra-short pulse lasers, optical receivers, and timers to measure two-way ranges to satellites equipped with passive retro-reflectors. The range observations are subject to station-specific Range Bias (RGB) and satellite-specific Center of Mass (COM) corrections. Due to specific laser-pulse reflection properties, detector characteristics and post-processing strategies, the RGB and COM corrections are subject to station/satellite-correlations. Due to diverse technical and environmental conditions, the performance of the stations of the International Laser Ranging Service (ILRS), providing observations of the Sentinel satellites, is not very homogeneous over time (Fig. 1).

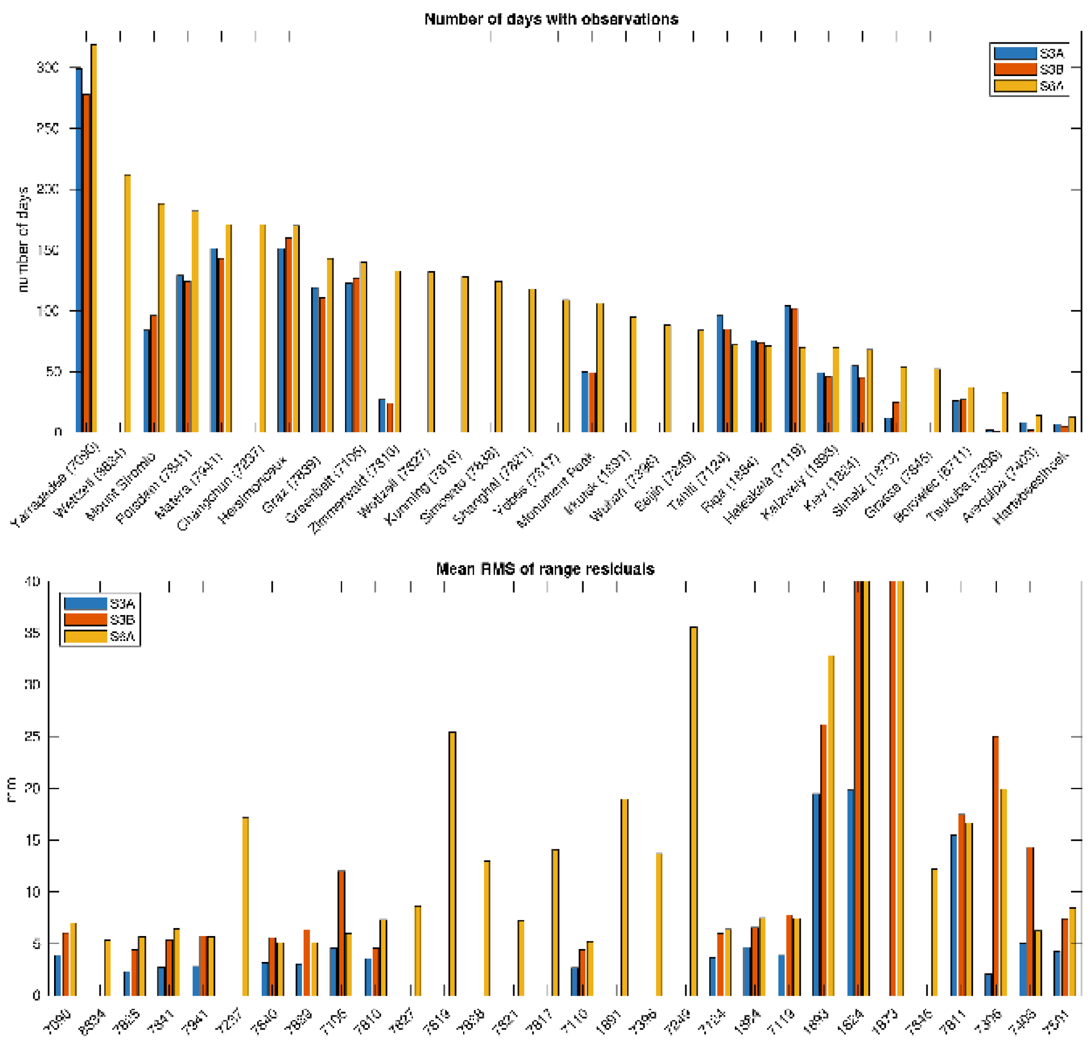

Figure 1: Observation coverage during the year 2025 (top) and scatter of the SLR range residuals (bottom) for ILRS stations which observed the Sentinel-3A/B or -6A satellites in 2025.

2. Sentinel Orbit Determination using GNSS

At the Astronomical Institute of the University of Bern (AIUB) daily GNSS-based satellite orbits are routinely generated in the frame of the Quality Working Group of the Copernicus POD Service (CPOD) for the Sentinel-1, -2, -3 and -6 satellites with the in-house Bernese GNSS Software. The orbit quality is validated independently by SLR observations (Arnold et al., 2019) of selected high-performance stations (Fig. 2). The RMS of the SLR range residuals 2025 to the Sentinel-3A/B and -6A satellites evaluated for this study is below the 1 cm-level (Fig. 3, see legend for annual mean per satellite).

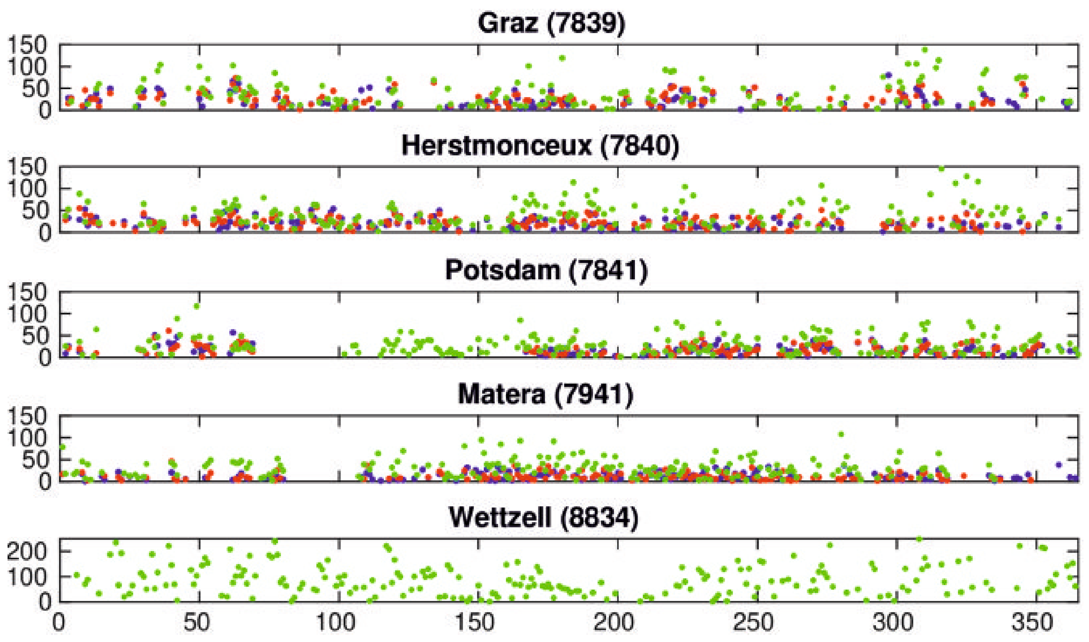

Figure 2: Daily number of observations for a subset of selected stations and satellites (S3A: blue, S3B: red, S6A: green).

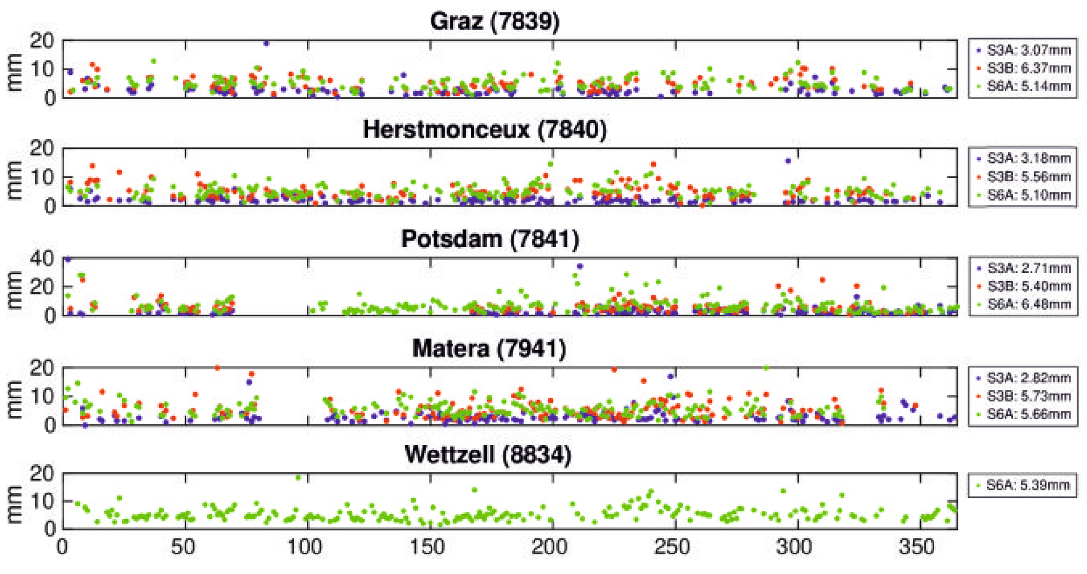

Figure 3: Daily RMS of SLR range residuals per station and satellite (S3A: blue, S3B: red, S6A: green), arc-wise (i.e., daily) range-biases are estimated and reduced from the observation.

3. Range Bias Determination

The SLR contribution to the ITRF2020 reference frame was generated by applying RGB and COM corrections, determined for the spherical LAGEOS and ETALON satellites beforehand by long-term analysis of the Italian Space Agency (ASI, Luceri et al., 2019). For the correct evaluation of SLR measurements, e.g. to altimetry satellites, at least station-specific range biases should be applied. Recent analysis revealed that satellite-specific long-term range bias estimates improve the observation quality, while due to the sparse SLR observation coverage a co-estimation of short-term (i.e., arc-wise) station and satellite specific range biases weakens the geophysical signal content of the observations (Rudenko et al, 2025).

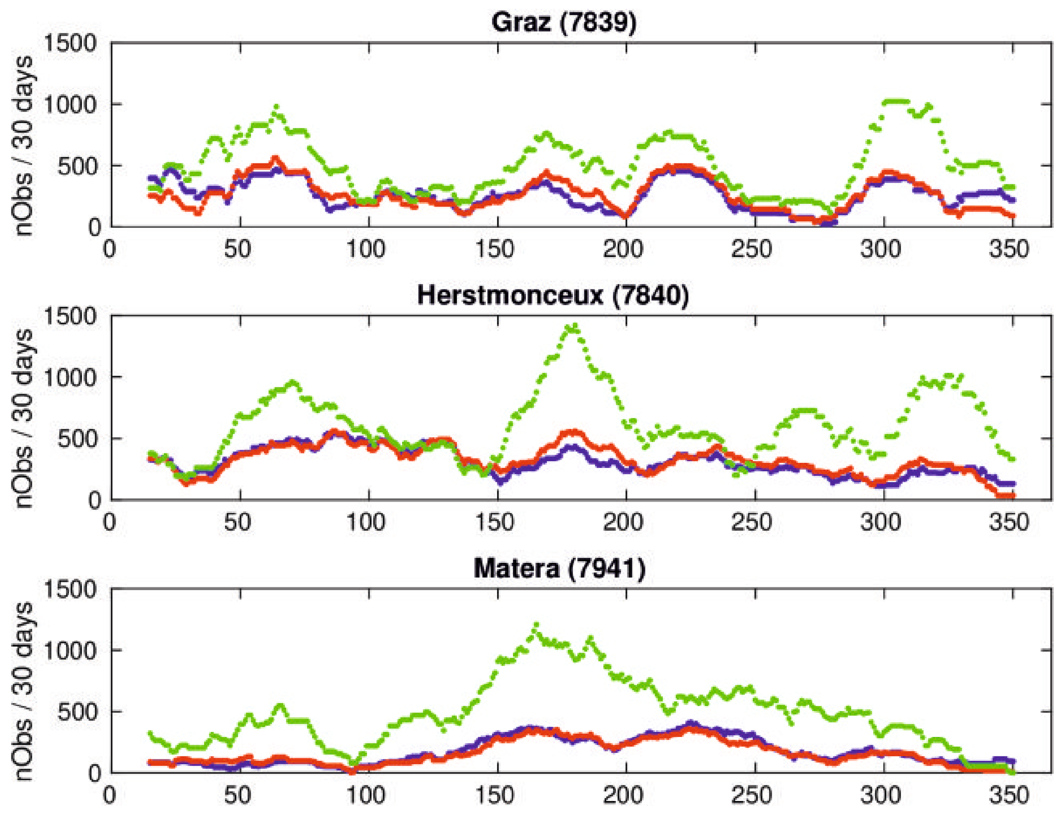

Figure 4: Accumulated number of observations per 30 d sliding window (S3A: blue, S3B: red, S6A: green) for selected stations.

To study the long-term stability of the RGBs, 30 d sliding mean values have been determined based on reduced dynamic GNSS-derived satellite orbits of the Sentinel-3A/B, and -6A satellites in 2025 (Figs. 4, 5).

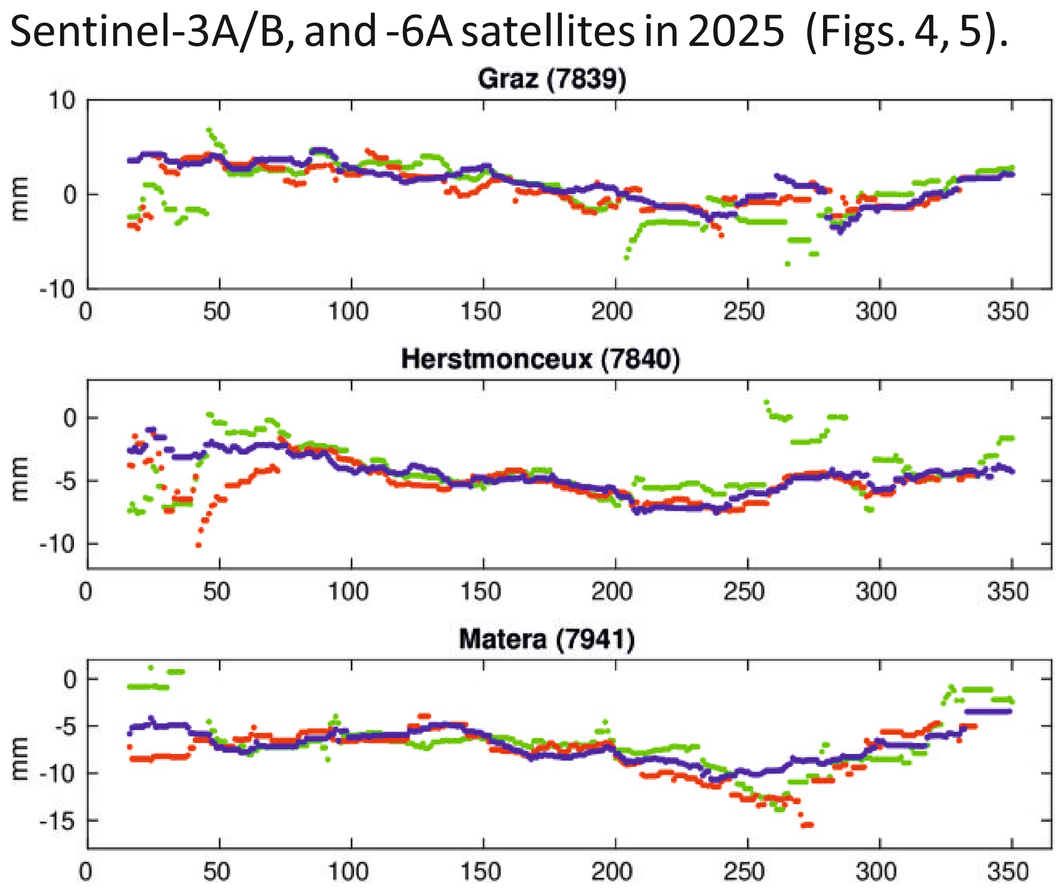

Figure 5: 30 d sliding mean range bias estimates (S3A: blue, S3B: red, S6A: green) for selected stations.

To assess the correlation with station displacements, e.g. related to loading-effects, the 30 d sliding mean RGBs of the Sentinel-3A satellites are compared to coordinate corrections derived by 7 day network solutions of LAGEOS/ETALON observations (Fig. 6). Compared to the RGB estimates, the station coordinates show dominating seasonal variations.

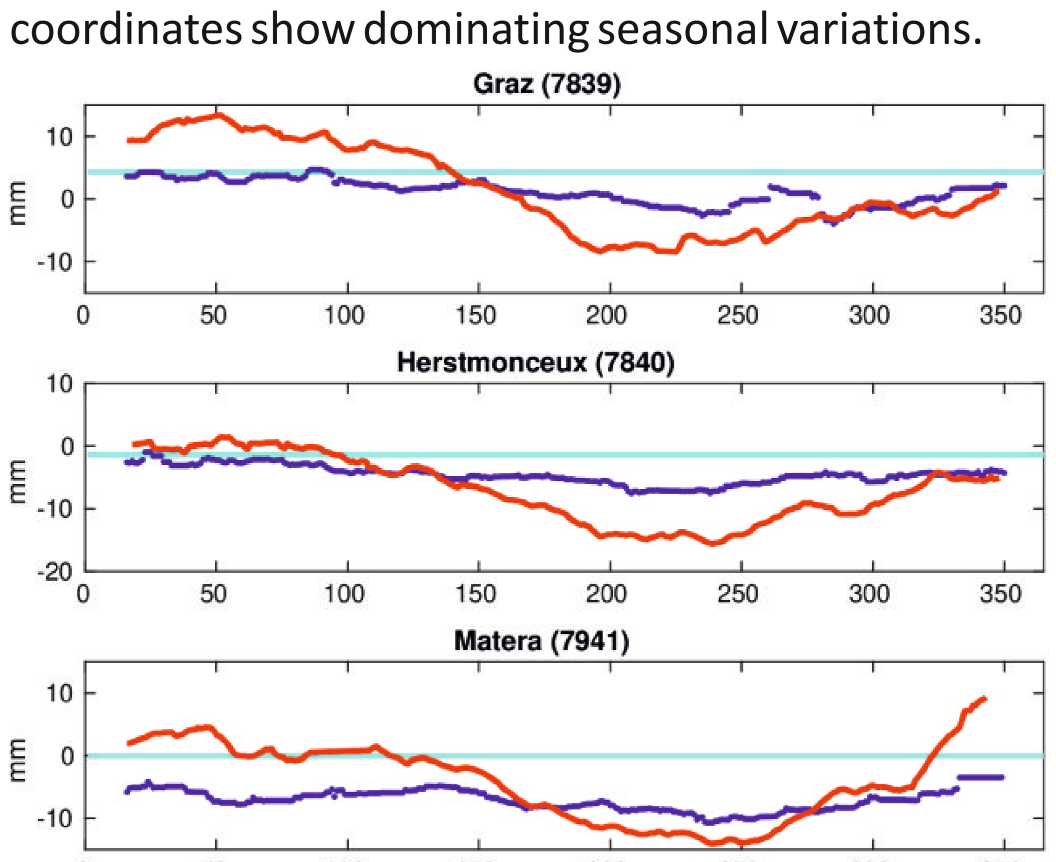

Figure 6: S3A 30 d range biases (blue), inverse station corrections in Up-direction (red), and static apriori range biases (cyan) provided by the ILRS for the spherical LAGEOS satellites.

4. Impact of Screening Strategy

In preparation for the multi-observation technique co-location satellite mission Genesis, combined GNSS/SLR orbit and geophysical parameter estimation is being performed with Low Earth Orbiters equipped with GNSS receivers and SLR retro-reflectors, like the Sentinel-3 and -6 satellites. To support the signal-separation, static range-biases have been determined for the year 2025, based on the GNSS-derived satellite orbits. In the following, the impact of the screening strategy of the SLR range observations on the RGB estimates is studied.

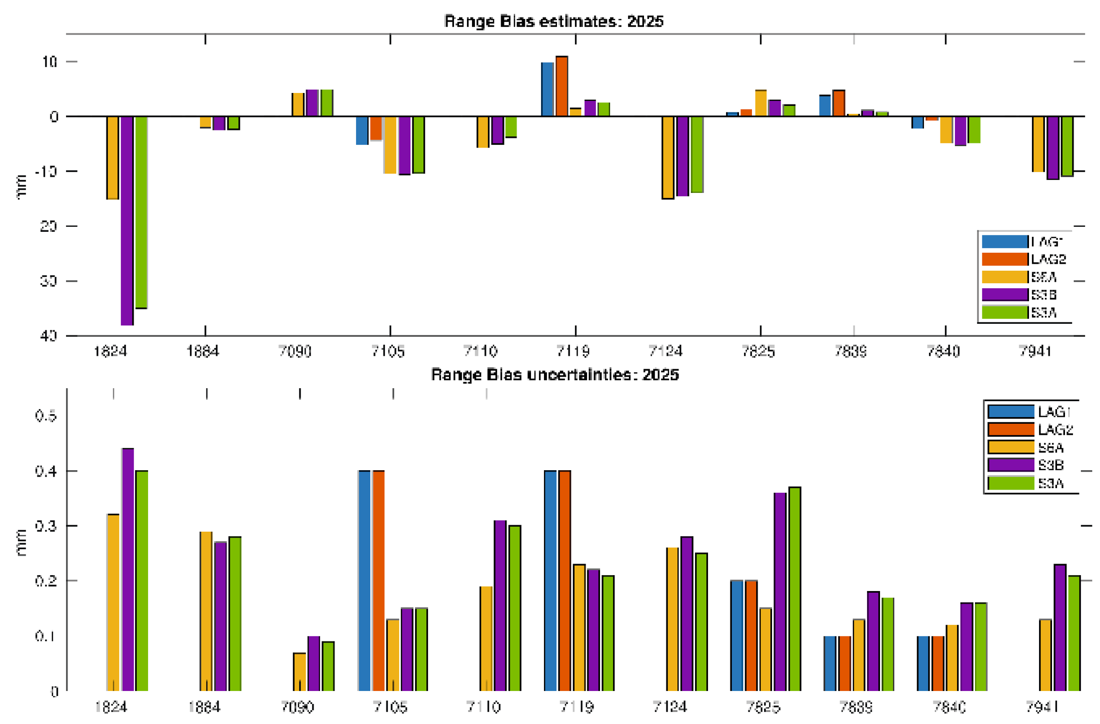

Figure 7: Static range bias estimates 2025 per station and satellite (top), and corresponding uncertainties (bottom); a fixed 12 cm threshold for the SLR range observation screening has been applied.

For the screening of the residuals of the SLR range observations with respect to the GNSS-derived satellite orbits, either a fixed threshold of 12 cm (Fig. 7), or in addition an overall 3*sigma criterion for the outlier detection has been applied (Fig. 8). No elevation cut-off angle has been used to remove low-elevation observations. The subset of high-performance SLR stations of the ILRS network evaluated for this study is shown in Fig. 9.

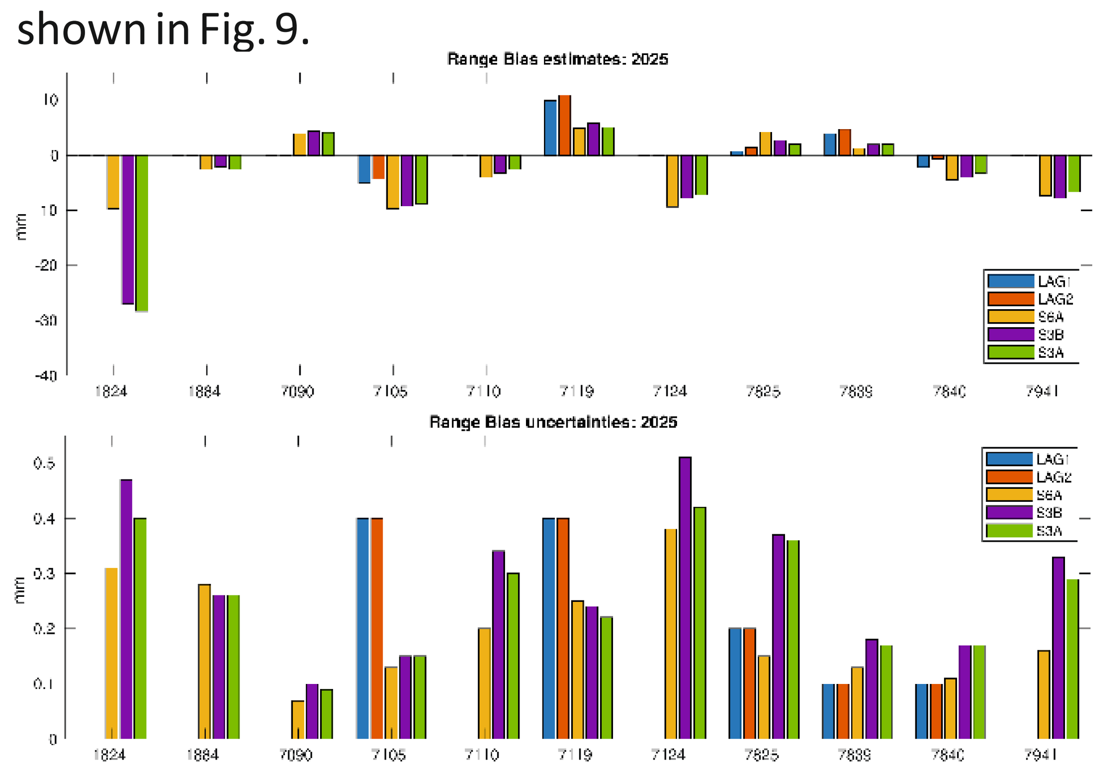

Figure 8: Static range bias estimates 2025 per station and satellite (top), and corresponding uncertainties (bottom); additionally to Fig. 7, a 3*sigma SLR range outlier detection has been applied.

5. Summary

For most of the high-performance SLR stations the annual RGB estimates for the Sentinel-3A/B, and -6A satellites agree at the 1 mm-level and are more consistent than the apriori RGBs for the LAGEOS satellites provided by the ILRS. For individual stations the RGB estimates are sensitive to the screening strategy applied (e.g., 1824, 7119, 7124, and 7941).

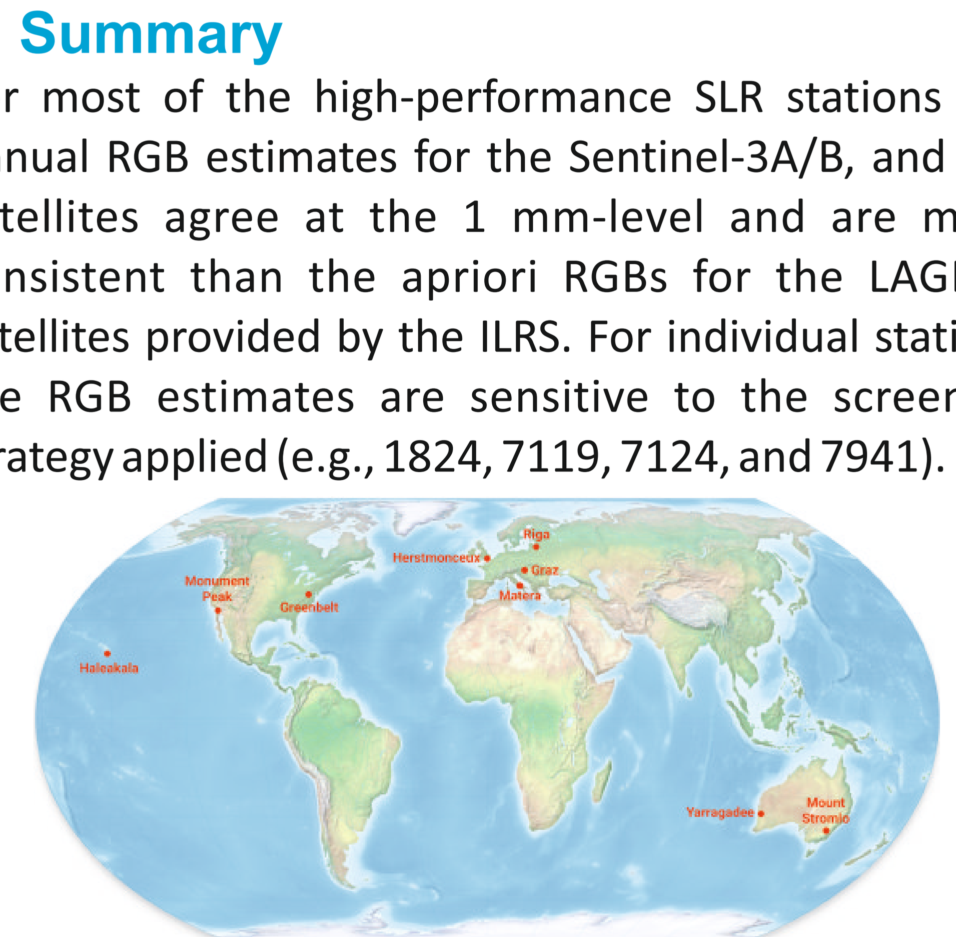

Figure 9: High-performance stations selected for detailed data analysis and range bias determination.

References

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