Modeling range corrections from SLR residuals to active Low Earth Orbiters – insights from study based on over 10 satellites and 20 years of data

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Numerous active low Earth orbiters (LEOs) used to observe the Earth system are equipped with GNSS receivers and SLR retroreflectors, e.g., Jason, Swarm, GRACE, and Sentinel-3 satellites. The GNSS technique onboard LEOs is commonly employed for precise orbit determination (POD), whereas the SLR technique is typically used to validate the POD products based on GNSS. Effective SLR validation of LEO POD requires accounting for systematic effects, such as range biases, time biases, station coordinates' corrections, and tropospheric delay biases to mitigate systematic errors embedded in SLR observations.

Currently, the International Laser Ranging Service (ILRS) does not provide official range correction products for active LEOs, as it does for spherical geodetic satellites, such as LAGEOS-1/2. As a result, SLR-based validation approaches for LEO POD vary across different analysis centers, depending on factors such as bias time resolution, correction type, station/satellite grouping, or outlier rejection strategies.

In this study, we perform SLR validation of LEO POD products provided by the ESA Copernicus Service and the Technical University of Graz, covering almost the full duration of the missions. We use data from more than 10 satellites including CHAMP, Swarm-A/B/C, Sentinel-3A/B, GRACE-A/B/C/D, Jason-1/2/3, TanDEM-X, and TerraSAR-X missions for the period of 2002.01-2023.6. Our investigation focuses on errors in SLR residuals that could affect derived geodetic and orbital parameters, such as range biases and tropospheric corrections.

We test different processing approaches including the ILRS recommendations for non-spherical satellites, application of a priori LAGEOS-based range biases, exploring different time resolutions for LEO biases, and grouping stations and satellites depending on the retroreflector types. We also compare LEO bias corrections with LAGEOS-based estimates from the ILRS and assess the dependency of SLR residuals on observation geometry parameters, such as station azimuth angle, Sun-satellite-Earth reference frame parameters, and satellite nadir angle. Our results demonstrate a high, less than 10-mm level of consistency between SLR measurements and GNSS-based LEO orbit products when systematic effects are properly modeled.