GNSS orbit validation using SLR observations at CODE

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Introduction

Orbits from Global Navigation Satellite Systems (GNSS) are typically based on microwave observations. Satellite Laser Ranging (SLR) is therefore a fully independent technique to validate these orbits. All GLONASS, Galileo, BeiDou, and QZSS spacecraft carry retroreflectors and can thus be tracked by SLR. The two GPS satellites equipped with reflectors are meanwhile decommissioned. The Center for Orbit Determination in Europe (CODE) operationally computes SLR residuals w.r.t. CODE's rapid and MGEX orbits and provides daily reports to the laser stations. At the same time, the residuals are used for internal orbit validation purposes.

Principle of SLR validation

The SLR observations ('observed') are directly compared to the geometry based on the SLR station coordinates and the microwave-based orbit ('computed') without estimating any parameter. The residuals ('observed minus computed') therefore contain potential range biases, reflector offset uncertainties, and other potential systematic effects as, for example, reported by Sośnica et al. (2015).

Validation of reprocessed GPS and GLONASS orbits

The most recent reprocessing campaign at CODE is called Repro15 (Sušnik et al. 2016). The main difference w.r.t. previous product series is the extension of the Empirical CODE Orbit Model (ECOM) by periodic terms (Arnold et al., 2015) as described in Table 1. These terms are in particular important for satellites with elongated bodies such as GLONASS.

Table 1: Empirical parameters estimated in D (satellite-Sun direction), Y (direction along the satellite's solar panels axes), and B (completes the orthogonal right-handed system) for the original ECOM and the extended ECOM (cycle-per-revolution is denoted as cpr).

		Parameters estimated in		
ECOM	Sol.	D	Y	B
original	D0B1	constant	constant	constant, 1-cpr
extended	D2B1	constant, 2-cpr	constant	constant, 1-cpr
extended	D4B1	constant, 2-cpr, 4-cpr	constant	constant, 1-cpr

The influence of the extended ECOM is demonstrated in Fig. 1. The dependency of the residuals on the elongation angle of the Sun (i.e., the angle between Sun and satellite as seen from the geocenter) is significantly reduced in case of D4B1 (cf. Fig. 1, middle left panel) compared to D0B1 (cf. Fig. 1, top left panel). At the same time, however, the scatter of the residuals is larger for D4B1. Ongoing tests revealed that the larger residuals for small solar beta angles (i.e., the elevation of the Sun above the orbital plane) using D4B1 (cf. Fig. 1, middle right panel) can be reduced by omitting the 4-cpr terms (D2B1, cf. Fig. 1, bottom right panel). That is why the 4-cpr terms were switched off in the operational product generation.

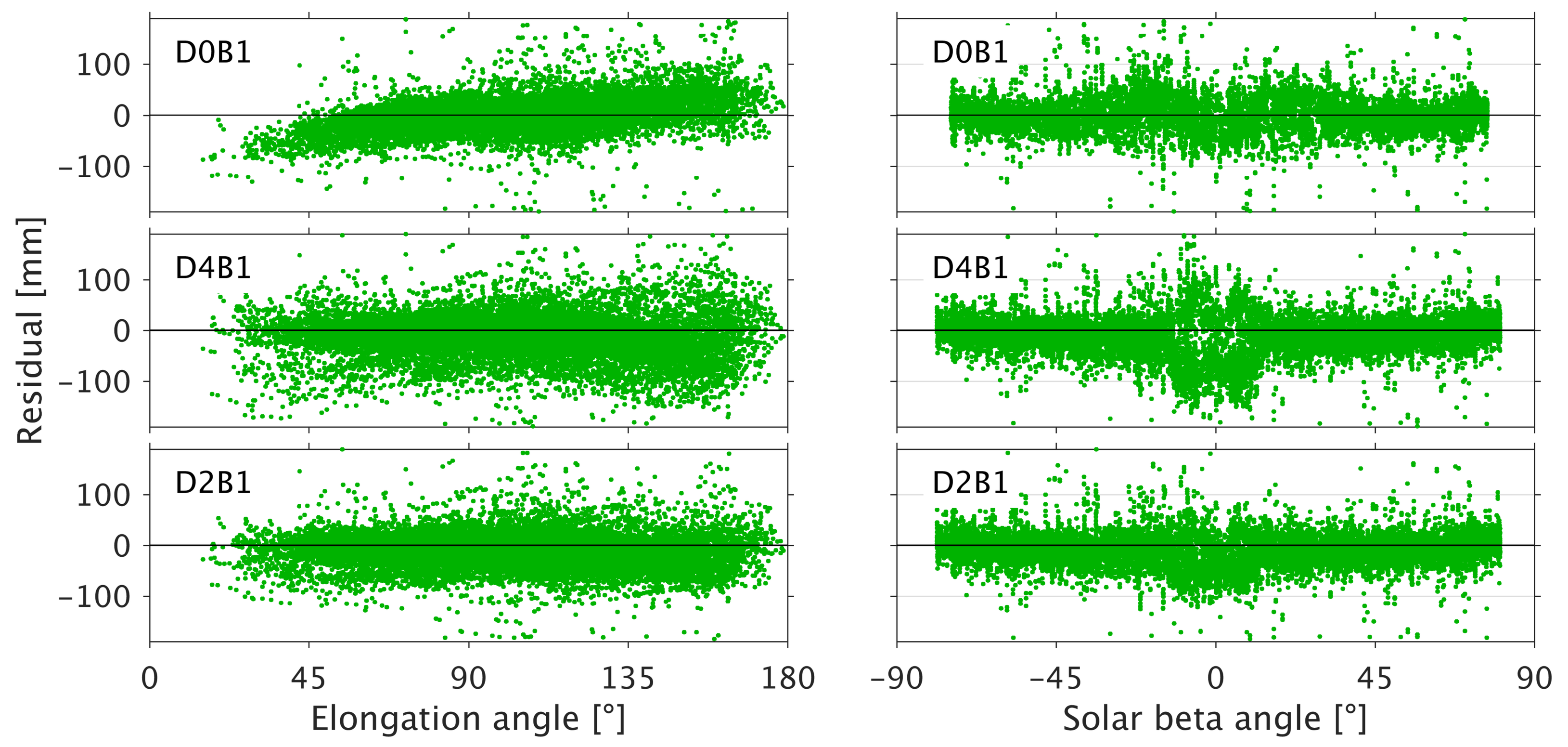

Figure 1: SLR residuals for 3-day GLONASS orbits (SVN 746) between Jan 2012 and Dec 2014 using D0B1 (top panels), D4B1 (middle panels), and D2B1 (bottom panels). Left and right panel: residuals as a function of the elongation angle and solar beta angle, respectively.

Validation example concerning CODE MGEX orbits

The residual reports generated at CODE (cf. Introduction) may be used to visualize the impact of model changes on the CODE orbital products. Figure 2 shows the impact of an improved ambiguity resolution scheme for Galileo, BeiDou, and QZSS.

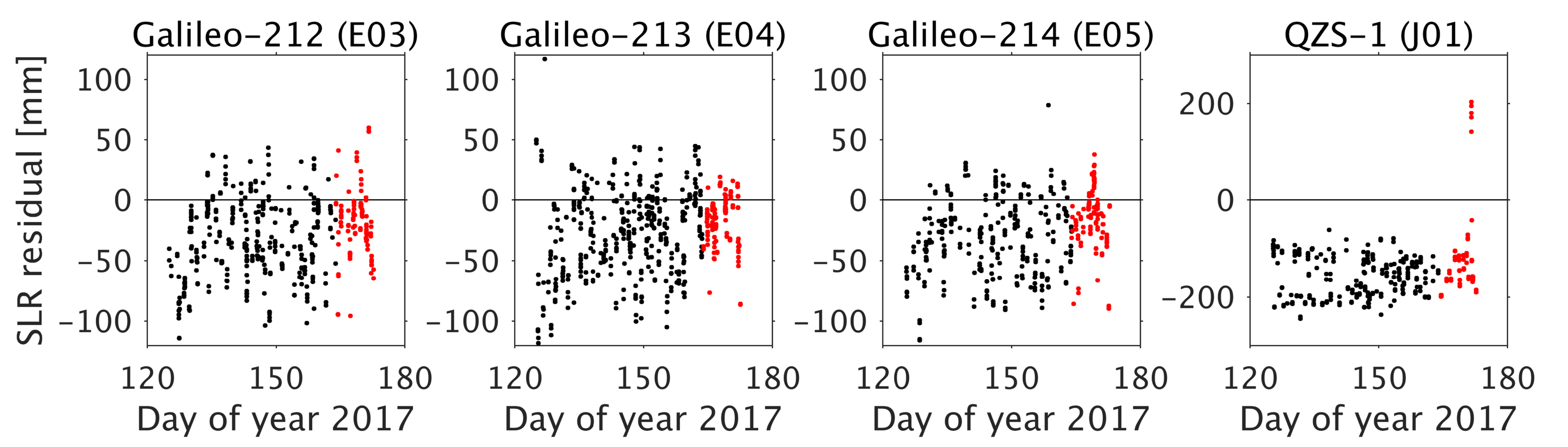

Figure 2: SLR residuals over two months w.r.t. CODE orbits for three Galileo satellites and QZS-1. The red dots indicate the residuals after the wide-lane/narrow-lane ambiguity resolution was extended from GPS to Galileo, BeiDou, and QZSS (day 164 of year 2017).

Validation of MGEX orbits from different ACs

The quality assessment of the IGS MGEX product series can also be assessed by SLR data. Because of its independence, it might be used to adjust the weights for future multi-GNSS orbit combination. To demonstrate this, we downloaded the MGEX orbits that were computed by six analysis centers (ACs), see Table 2.

Table 2: ACs providing MGEX products at `ftp://cddis.gsfc.nasa.gov/pub/gps/products/mgex`. **com**: Center for Orbit Determination in Europe, **gbm**: Deutsches GeoForschungsZentrum Potsdam, **grm**: CNES/CLS, **qzf**: Japan Aerospace Exploration Agency, **tum**: Technische Universität München, **wum**: Wuhan University.

GNSS/AC	com	gbm	grm	qzf	tum	wum
GLONASS	√	√	√	×	×	√
Galileo	√	√	√	×	√	√
BeiDou	√	√	×	×	×	√
QZSS	√	√	×	√	√	√

GPS is not listed since SLR validation is not possible.

During the investigated time span, i.e. January 2015 to December 2016, 58 100, 10 800, and 2700 SLR observations are available to Galileo satellites, BeiDou satellites, and QZS-1, respectively. Figure 3 gives an impression to which extent these satellites are tracked by the SLR stations.

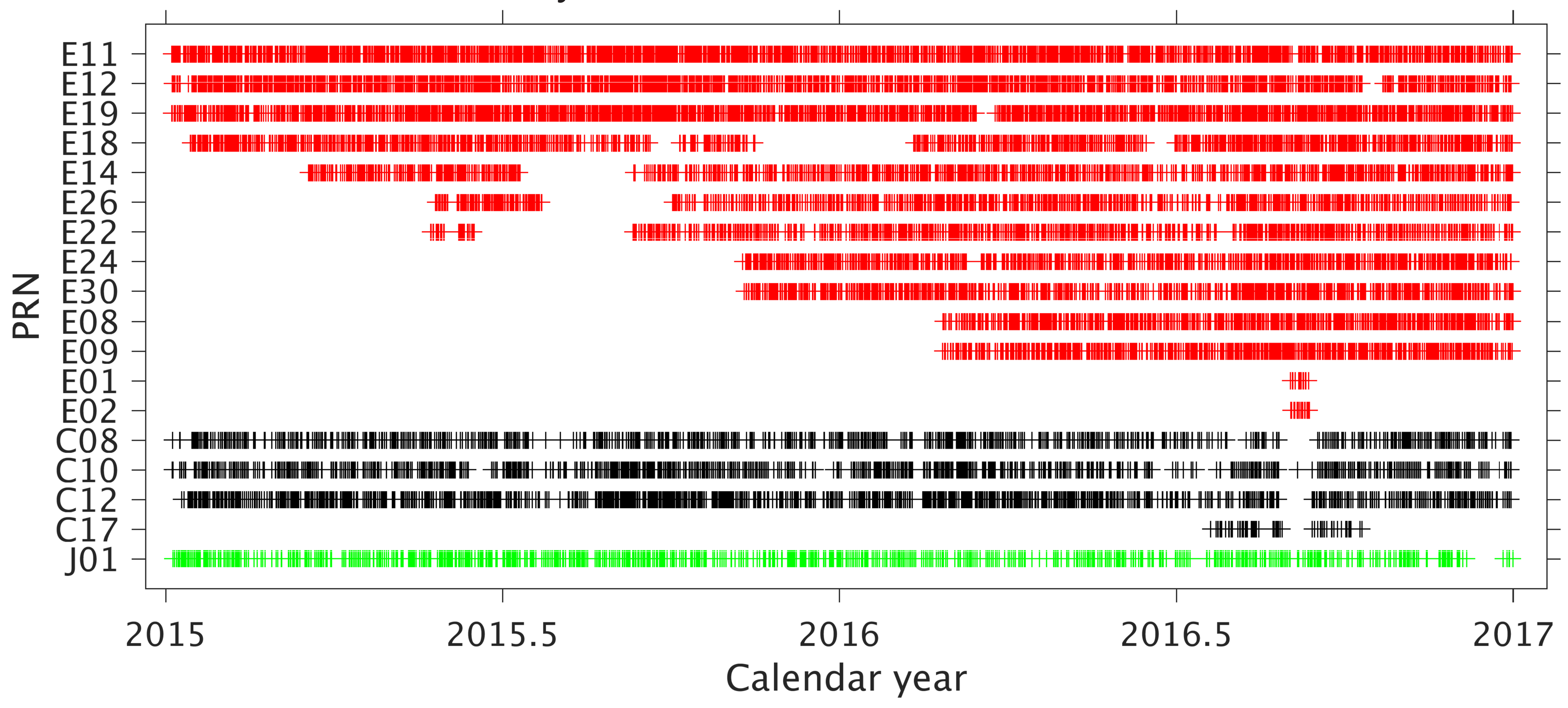

Figure 3: SLR observations to Galileo satellites (red color), BeiDou satellites (black color), and QZS-1 (green color) from January 2015 to December 2016.

Figure 4 shows mean value and standard deviation of SLR residuals for each satellite system and MGEX AC. In general, the residuals agree very well among the ACs. For QZS-1 the discrepancy of both the mean values and the respective standard deviations is largest. The standard deviation is smallest for the com orbits.

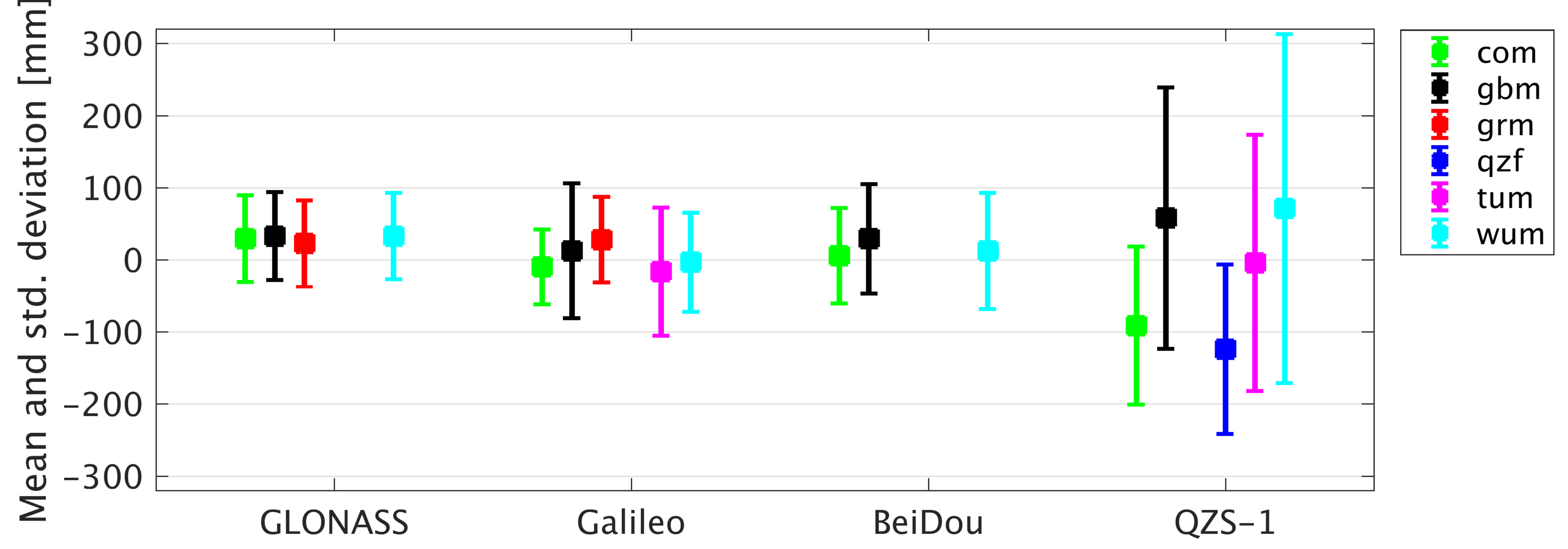

Figure 4: For each AC, mean value and standard deviation [mm] of SLR residuals with respect to GLONASS, Galileo, BeiDou, and QZS-1 satellites is shown. Note that all residuals larger than 300 mm (GLONASS), 500 mm (Galileo), 300 mm (BeiDou), and 1500 mm (QZS-1) were regarded as outliers. In addition, SLR observations during eclipses for GLONASS and during intervals with solar beta angle smaller than 20° for QZS-1 were not taken into account. For the description of acronyms see caption of Table 2.

Summary

The validation of the reprocessed GLONASS orbits showed that the elongation-dependency of the SLR residuals could be significantly decreased by using the extended ECOM including 2-cpr and 4-cpr terms in the satellite-Sun direction. At the same time, however, the residuals increased for small solar beta angles. First tests showed that this drawback can be avoided by omitting the 4-cpr parameters. We also demonstrated that SLR is a valuable tool to visualize the impact of changes in the parametrization on in-house computed GNSS orbits. SLR might serve as a quality parameter for adjusting the weights in future GNSS orbit combination procedures.

References

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