GNSS orbit validation activities at the Astronomical Institute in Bern

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Abstract

This contribution gives an overview of activities taking place at the Astronomical Institute of the University of Bern (AIUB) that are related to global navigation satellite system (GNSS) orbit validation. After explaining briefly the principle of validating microwave-based GNSS orbits by means of satellite laser ranging (SLR) data, we demonstrate the advantages of using the extended version of the classical empirical orbit model when it comes to GLONASS orbit determination. The SLR residuals show significantly smaller systematic patterns when the extended model is used. Further, the residuals of four GLONASS satellites are shown in detail giving evidence to some orbit degradation over time. The second part of this proceeding focuses on the validation of Multi-GNSS Extension (MGEX) orbits computed by six different analysis centers. For a time span of about 18 months, the SLR residuals to MGEX orbits are statistically evaluated and compared among the analysis centers. The standard deviation is smallest for the orbits provided by the Center for Orbit Determination in Europe (CODE).

Introduction

Satellite laser ranging (SLR) is a powerful tool to validate microwave-based orbits of GNSS satellites that are equipped with laser retroreflector arrays. We compare the SLR observations directly to the computed distance between laser station coordinates and the GNSS orbit without estimating any parameter. Thus, the residuals contain potential range biases, inconsistencies between the GNSS and SLR reference frame coordinates, and reflector offset uncertainties. Nevertheless, SLR residuals are fully capable to indicate the quality of the orbits. Speaking of quality, SLR data are mainly sensitive to the radial component of the GNSS orbits since the maximum angle of incidence of a laser pulse to a GNSS satellite does not exceed 14 degrees. The Bernese Software (Dach et al., 2015) is used for the validation procedure.

Validation of reprocessed GPS and GLONASS orbits

The SLR validation of microwave-based GNSS orbits, which were computed at the Center for Orbit Determination in Europe (CODE) operated by AIUB, revealed systematic effects when representing the range residuals as a function of the elongation angle (i.e., the angle between Sun and satellite as seen from the geocenter). As a consequence, the orbit modelling within the Bernese Software was revisited and extended by periodic terms in the satellite-Sun direction (see Arnold et al., 2015 for more details). It is mainly the GLONASS satellites with their elongated shape that profit from setting up these additional terms. The most recent reprocessing campaign at CODE, Repro15 (Sušnik et al. 2016), makes use of the extended empirical CODE model (ECOM). Figure 1 shows the range residuals with respect to GLONASS-M orbits resulting from the Repro15 campaign compared to the orbits from an older reprocessing campaign where the classical orbit model was used. The dependency on the elongation angle could be significantly reduced.

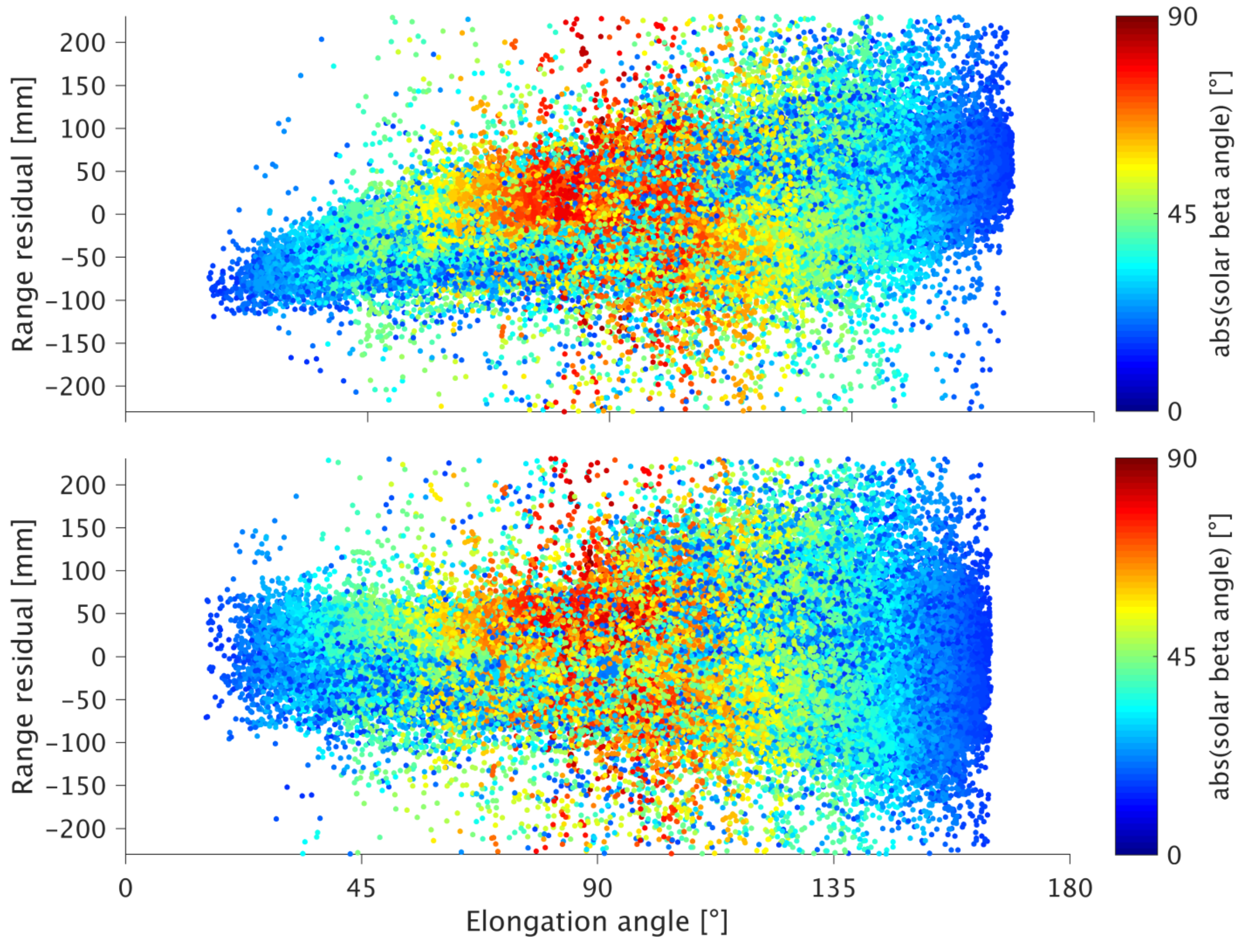

Figure 1: SLR residuals for 3-day GLONASS-M orbits between January 2003 and December 2014 using the classical ECOM (top) and the extended ECOM (bottom). The residuals are shown as a function of the elongation angle and of the solar beta angle. Furthermore, all residuals having an absolute beta angle smaller than 15 degrees (eclipse) have not been taken into account.

In Figure 1 the SLR residuals to the orbits of four GLONASS satellites (SVN 723, 725, 736, 737) are excluded due to their anomalous behavior. The residuals of these satellites increase after a certain time after launch (cf. Figure 2). All of them belong to the same orbital plane. Other satellites in the same orbital plane (e.g, SVN 716, 724, 729), however, do not show this effect. The reason for this abnormal behavior is not yet understood.

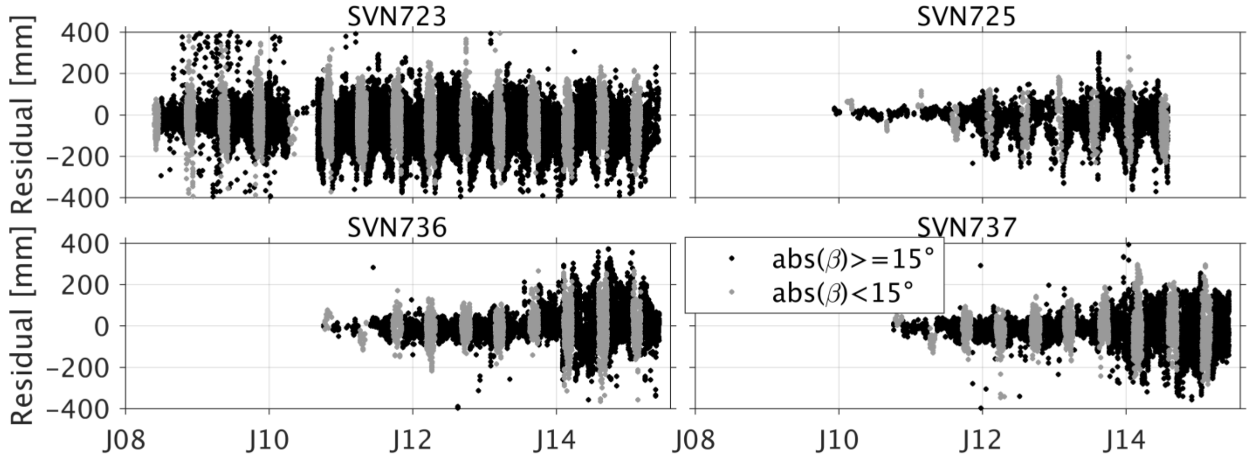

Figure 2: SLR residuals w.r.t. 3-day GLONASS orbits between January 2008 and May 2015 using the extended ECOM. Observations during satellite eclipses (solar beta angle smaller than 15 degrees) are depicted in gray.

Validation of MGEX orbits

CODE has been contributing to the Multi-GNSS Extension (MGEX) of the International GNSS Service (IGS) since the beginning of MGEX in 2012 (Prange et al., 2016). The quality assessment of this product series is essential because new signals to a new fleet of GNSS satellites become available. Within the IGS a comparison of different orbit products is the currently used practice. No quality parameter is considered. Instead, a majority voting approach is used. Since all new GNSS satellites (apart from GPS) are equipped with retroreflector arrays, SLR provides an independent quality control. We downloaded the MGEX orbits from six analysis centers (ACs) from ftp://cddis.gsfc.nasa.gov/gnss/products/mgex/, see Table 1. From the beginning of 2015 to mid of 2016, 38000, 8400, and 2200 normal points are available to Galileo satellites, BeiDou satellites, and QZS-1, respectively. Figure 3 gives an impression how well these satellites are tracked by laser stations.

Table 1: ACs providing MGEX products (**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)

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

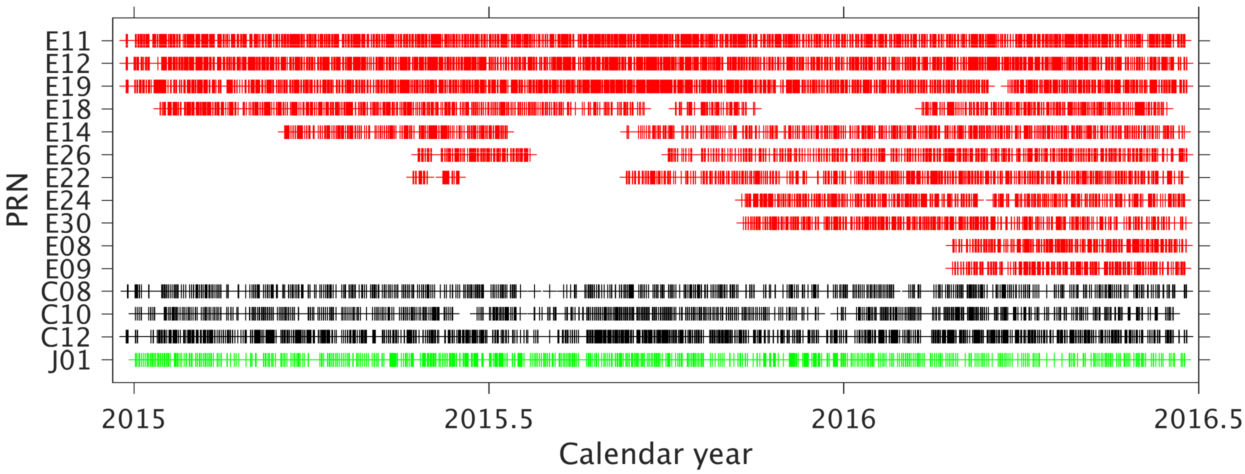

Figure 3: SLR observations to Galileo satellites (red color), BeiDou satellites (black color), and QZS-1 (green color).

Fig. 4 shows the mean value and the standard deviation of SLR residuals w.r.t. MGEX orbits for each AC. In general, the SLR residuals for the MGEX ACs agree very well. 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.

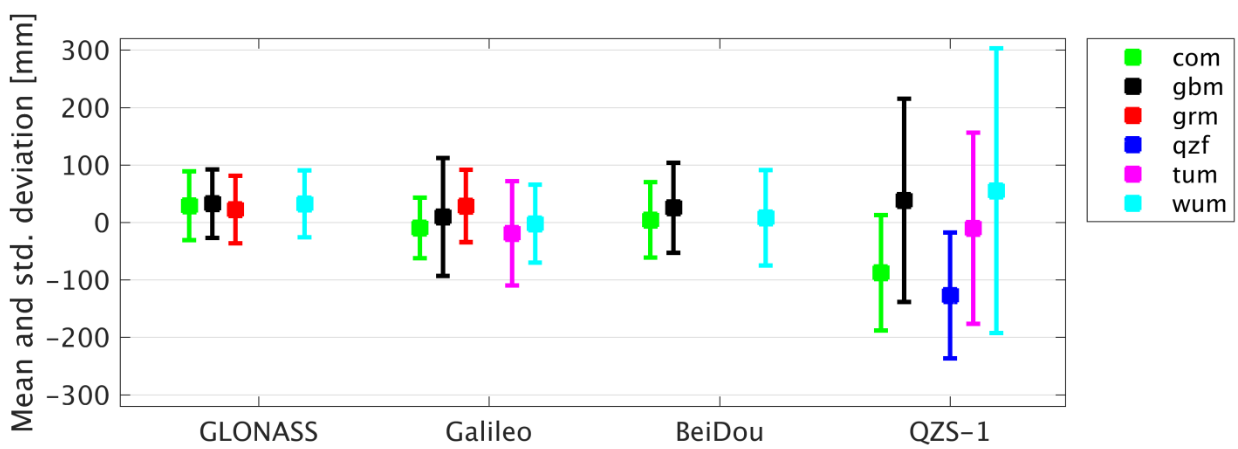

Figure 4: For each AC, mean value and standard deviation [mm] of SLR residuals with respect to GLONASS, Galileo, BeiDou, and QZS-1 satellites is shown. Note that all residuals larger than 300mm (GLONASS), 500mm (Galileo), 300mm (BeiDou), and 1500mm (QZS-1) were regarded as outliers. In addition, SLR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

Summary

The validation of the reprocessed GLONASS-M orbits showed that the elongation dependency of the SLR residuals is significantly smaller when using the extended ECOM. For all GNSS spacecraft that are equipped with laser retroreflector arrays, SLR can provide an independent quality measure for GNSS orbits that were computed from microwave data only. This information could potentially be used by the IGS for the orbit combination. We also compared the SLR residuals w.r.t. MGEX orbits computed from different ACs over a time span of about 16 months. GLONASS, Galileo, and BeiDou orbits agree very well among the different ACs. The discrepancy is larger for the QZS-1 satellite. The standard deviation of the SLR residuals is smallest for orbits computed at CODE.

References

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