GNSS orbit validation using SLR at CODE

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Abstact

We process SLR observations to code-referenced (CR) and GLONASS satellites in order to validate the 1-day and 3-day CODE solutions of 2014. The mean bias of CO2 residuals is 2.4 ± 0.3 mm for GPS and 4.1 ± 0.1 mm for GLONASS. The mean RMS of CO2 residuals is 10.1 ± 0.1 mm for GPS and 12.4 ± 0.3 mm for GLONASS. The results are in agreement with the analysis of 2013. The RMS of SLR residuals is 5.9 ± 0.1 mm for GPS and 7.9 ± 0.2 mm for GLONASS. The results are in agreement with the analysis of 2013.

Introduction

Satellite Ranging (SLR) observations to GNSS satellites provide an independent validation of the orbits determined from microwave observations, thus, allow us to assess the quality of the GNSS orbits. This includes, e.g., deficiencies in the solar radiation pressure modeling for GNSS orbits.

The 10th International Workshop on Laser Ranging, which was held in Bari (Italy) in November 2013, recognized the increasing importance of SLR to the improvement of GNSS performance. The Laser Ranging to GNSS was Experiment (LARGE) group was established in the aftermath of this workshop. The resolution of the workshop paid special attention to "the necessity of the SLRF technique to the improvement of time, frequency, and ephemera-data products from GNSS" and to "the significant contribution of GGOS to the development of GNSS measurement accuracy through co-location with SLR and other measurement techniques". Today, all active GLONASS satellites are tracked by many SLR stations, which gives us a very good tracking record of different GNSS satellites (see Fig. 1), and allows us to combine SLR and GNSS techniques using the co-location in space (see Fig. 2).

We validate the GNSS orbits from CODE repro2 campaign: the median number of registered full-rate observations per character of returning photons, e.g., in the Zimmerwald observation (7810), a detector change in 2006 can be easily recognized. Figure 4 shows the comparison of CODE 3-day solutions (CO2) and 1-day solutions (CF2). The RMS of residual solutions is typically smaller for CO2 solution, on average by 4%. The differences between CO2 and CF2 are largest in 1994 and in the period 1999-2003. After 2004 CO2 and CF2 seem to show a similar performance. After 2008, as well, the RMS of residuals increases in both solutions possibly due to worse quality of GPS orbits or new SLR stations and SLR stations affected by earthquakes without well-established coordinates in ITRF2008. Table 2 shows that CF2 solution should be used for the GNSS-SLR drag correction terms from the SLR observation residuals before the CF2 solution.

SLR validation of GPS orbits

We process the SLR observations to GNSS satellites collected in 1994-2014 by the ILRS stations. Table 1 shows that the mean SLR residuals for both GPS satellites are about ~13 mm with the RMS at a level of 23 mm. The SLR residuals are, however, station-, satellite- and time-dependent. Figure 3 shows that, for Yarragadee (7090), Graz (7893) and Herstmonceux (7840) the mean residuals were positive in early nineties, whereas they were negative for the remaining time span. For Zimmerwald (7810), a detector change in 2006 can be easily recognized. Figure 4 shows the comparison of CODE 3-day solutions (CO2) and 1-day solutions (CF2). The RMS of residual solutions is typically smaller for CO2 solution, on average by 4%. The differences between CO2 and CF2 are largest in 1994 and in the period 1999-2003. After 2004 CO2 and CF2 seem to show a similar performance. After 2008, as well, the RMS of residuals increases in both solutions possibly due to worse quality of GPS orbits or new SLR stations and SLR stations affected by earthquakes without well-established coordinates in ITRF2008. Table 2 shows that CO2 solution should be used for the GNSS-SLR drag correction terms from the SLR observation residuals before the CF2 solution.

SLR validation of GLONASS orbits

Although all GLONASS satellites are equipped with laser retroreflector arrays (LRAs), only three GLONASS satellites were recommended for tracking by the ILRS in the period of 2002-2010 (typical one per plane). In 2010 the ILRS decided to increase the number of tracked GLONASS satellites to six - two s/c per plane. Despite the ILRS recommendations, several SLR stations started tracking in 2010 and 2011 the full constellation of GLONASS satellites. The first station which initiated the tracking of the remaining GLONASS constellation was Herstmonceux, followed by Zimmerwald, Graz, Yarragadee, Potsdam, Changchun, Shanghai, Simrad, Sapporo, and some other ILRS stations.

GLONASS satellites are equipped with LRAs of different types (rectangular regular arrays, regular hollow circular arrays, or irregular shape covering the front side of the satellites). GLONASS LRAs consist of 112, 124, 132 or 396 corner corners. The older-class GLONASS satellites are typically equipped with aluminium coated corner corners, whereas the recently launched satellites have typically uncoated corner coated retroreflectors (see Table 3). Table 4 shows that the RMS of residual solutions is 42.0, 34.9, and 36.3 mm for old-class GLONASS satellites, GLONASS-M, and GLONASS-K, respectively. This shows that the RMS of residual solutions to GLONASS-124 is still about 30% larger than the corresponding value for GPS. Figure 6 shows, however, that the GLONASS satellites launched after 2007 have in general smaller RMS of residuals than the GLONASS satellites launched before 2007. GLONASS-M satellites with uncoated LRAs have a slightly smaller value of the mean residuals (5.5 mm on average) than the GLONASS satellites with coated LRAs (+2.1 mm, see Table 4). The RMS of residuals for recently launched GLONASS without coating is also smaller (31.8 mm on average) than for GLONASS with coating (36.3 mm on average, see Figure 6). Coated GLONASS LRAs have different characteristics of returning photons, e.g., in the Zimmerwald observation the median number of registered full-rate observations per one SLR normal point is 500 and 300 for uncoated and coated LRAs, respectively with the mean RMS is 0.52 and 1.15 mm, respectively (Ploner et al., 2014). Thus, the station- and satellite-specific range biases have to be considered when processing SLR data to GNSS derivatives. Figure 6 shows that the RMS of SLR residuals for the GLONASS is smaller for CO2 solution, in particular before 2010. For some satellites there is also a dependence of mean residuals w.r.t. the time of observation, e.g., for GLONASS-124, see Fig. 7.

Summary

SLR observations to GNSS satellites yield a remarkable important tool in a sense of validation of GNSS orbits and the assessment of deficiencies in solar radiation pressure modeling (see Fig. 8). The mean SLR residuals to GPS s/c are at a level of 23 and 35 mm for GPS and GLONASS, respectively. The CO2 CODE repro2 solution shows a better performance than the CF2 solution, in particular in early years of reprocessing when the global coverage of GNSS stations was limited. The SLR residuals depend on many constituents, e.g., on:

- GNSS satellite type/block (see Tab. 3);
- LRA coating (see Tab. 4, Fig. 5);
- Shape and size of LRA and number of corner cubes in LRAs (see Fig. 2);
- LRA coating (see Tab. 4, Fig. 5).

The mean SLR residuals to GPS satellites are higher than to GLONASS satellites (see Tab. 4). The mean RMS of SLR residuals to GPS satellites is 10.1 ± 0.1 mm for GPS and 12.4 ± 0.3 mm for GLONASS. The results are in agreement with the analysis of 2013.

Fig. 1: Number of SLR observations to GPS and GLONASS in 2013 collected by ILRS stations.
Areas of the circles are proportional to the number of collected observations.

Fig. 2: Validation of GNSS orbits using SLR data.

Fig. 3: Mean SLR residuals to GPS-36 satellites (CO2) for high-performing SLR stations.

Fig. 4: RMS of SLR residuals to GPS satellites for solutions (based on 3-day arcs) and CF2 solutions (based on 1-day arcs).

Fig. 5: RMS of SLR residuals to GPS satellites as a function of orbital plane, satellite type, coating, and LRA shape. Values in mm.

Fig. 6: RMS of SLR residuals to GLONASS satellites for solutions and CF2 solutions [mm].

Tab. 1: SLR residuals to GPS satellites from CO2 solution [mm].

Tab. 2: Amplitudes of draconitic harmonics from SLR validation of GPS-35 orbit [mm].

Tab. 3: RMS of residuals and mean offsets of SLR observations to GLONASS from CO2 as a function of orbital plane, satellite type, coating, and LRA shape. Values in mm.

Tab. 4: Validation of GNSS orbits using SLR data.

References


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Fig. 8: Relationship between the SLR residuals, argument of satellite latitude Δα, and the Sun elevation angle over orbital plane β for GPS (left) and GLONASS (right) from CO2. Small variations of mean biases can be observed for different arguments of satellite latitude w.r.t. the Sun. E.g., for GPS when Δα between 120° and 240°, the mean bias reaches ~20 mm, whereas the mean bias is close to 0 mm. An opposite picture is for GLONASS, indicating some deficiencies in solar radiation pressure modeling.