GNSS satellites as co-locations for a combined GNSS and SLR analysis

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ABSTRACT

GNSS microwave data were analyzed together with SLR observations to GPS, GLONASS, LAGEOS and ETALON satellites for a time span of five years. The GNSS satellites are used for connecting GNSS microwave and SLR range data. Consistently estimated SLR-GNSS range biases, offsets for the satellite microwave antenna as well as for the laser reflector array are derived. Corrections to the official values of about 3.3 cm are seen for the laser reflector array. The corrections for the microwave antenna differ between the GPS and GLONASS satellites and are in average about 2.5 cm and –140 cm, respectively.

1 Introduction

SLR range observations to satellites of Global Navigation Satellite Systems (GNSS) are taken since a long time, especially satellites of the Global Positioning System (GPS) or the Russian GLONASS. The ILRS stations are tracking both GPS satellites equipped with a Laser Reflector Array (LRA), i.e., GPS-05 and GPS-06, as well as a sub-set of the active GLONASS satellites, i.e., for most of the time three satellites in parallel, and since August 2010 the number was increased to six GLONASS satellites. Additionally, Herstmonceux is tracking the full GLONASS constellation since December 2009.

It is well known from the daily Quicklook reports sent out by AIUB (see ftp://ftp.unibe.ch/aiub/slr/gnss_report.txt for the latest report), that the biases seen in the pure SLR range residuals to given GNSS orbits (based on microwave data only) are at the level of a few centimeters. The possible reasons for the biases present in the pure SLR range residuals are manifold:

- bad SLR station coordinates (fixed to SLRF2005),
- discrepancies in the underlying terrestrial reference frames of GNSS (used for the satellite orbits) and SLR (used for the station coordinates), mainly regarding scale and geocenter,
- deficiencies in the modeling of the orbits of the GNSS satellites (problematic issues here are, e.g., solar radiation pressure and Earth albedo),
- errors in the phase center model of the GNSS microwave antenna (offsets and variations),
- errors in the offsets of the LRA,
- unknown SLR range biases for GNSS satellites.

2 Combined analysis of microwave and range data

In order to overcome the deficiencies with the pure range residuals mentioned above, we performed a combined analysis of SLR range data to the GPS and GLONASS satellites together with the microwave data of a global GNSS network of about 240 stations. The time span 2006 till beginning of 2011 has been considered, i.e., five years altogether. The analysis of the microwave data as well as the SLR data has been done using the Bernese Software (Dach et al., 2007). This guarantees that identical models and parameterizations are used for the analysis of all data.

The analysis of the GNSS microwave data was done in the framework of a combined GPS-GLONASS reprocessing performed by Dach et al. (2011). The phase center model igs05.atx (Schmid et al., 2007) has been used for modeling the antenna phase center offsets and variations. Daily normal equations (NEQs) including station coordinates, Earth rotation parameters (ERP), geocenter coordinates, GNSS orbit parameters and satellite antenna offsets (SAO) were generated.

The SLR data to GNSS satellites have been analyzed using the same orbit modeling for the GNSS satellites as in the analysis of the microwave data. For the time span considered, SLR observations from all stations are available for two GPS satellites and altogether ten GLONASS satellites. SLR data to all GLONASS satellites taken by the station Herstmonceux since December 2009 have been considered additionally. Daily NEQs were generated containing station coordinates, ERPs, geocenter coordinates, GNSS orbit parameters, LRA offset parameters, and range biases for all stations.

As a result from both steps, combined daily NEQs have been generated with the GNSS orbits determined by both, i.e., microwave and SLR data.

As a third step, SLR data to LAGEOS and ETALON have been analyzed and weekly NEQs were generated. The inclusion of these data should mainly stabilize the estimation of the SLR station coordinates as the amount of SLR data to the GNSS satellites is comparably small (i.e., in average 10-20 observations per day per satellite).

All NEQs described above have been accumulated for the entire time span of five years. Finally, a combined multi-year solution has been generated, with station coordinates and velocities estimated (amongst other parameters). The station network is aligned to the official TRF by applying no-net-rotation conditions with respect to IGS05 using a sub-set of GNSS stations. Local ties have not been applied. This implies, that the two space-geodetic techniques GNSS and SLR are connected only at the GNSS satellites tracked by SLR.

The focus of this contribution is on three different parameter types: SLR-GNSS biases (parameterized as a range bias), Satellite Antenna Offsets (SAO) for the GNSS microwave antenna, and offsets for the LRA. In order to study these parameters and their correlation, four different solutions have been generated. The characteristics of the solutions are summarized in Table 1. GNSS-SLR bias parameters are estimated as one range bias per station in all solution types. In the case of fixing the SAO parameters to the official values given by igs05.atx (Schmid et al., 2007) it is clear that any errors in the microwave phase center model might show up in the SLR-related parameters, e.g., the SLR-GNSS biases. The same holds for the solutions with LRA offsets fixed to their official values. These considerations lead to the conclusion that the GNSS-SLR bias parameters resulting from solution types 1-3 cannot be considered to represent real SLR range biases. Only the bias parameters resulting from solution type 4 represent real SLR range biases. The question arises, however, whether the three parameter types estimated in solution type 4 can be de-correlated.

	Solution 1	Solution 2	Solution 3	Solution 4
GNSS-SLR "range" bias parameter	1 bias per station estimated	1 bias per station estimated	1 bias per station estimated	1 bias per station estimated
LRA offset	Fixed to official values	Fixed to official values	Correction for the z-component estimated	Correction for the z-component estimated
Microwave SAO	Fixed to values of igs05.atx	Correction for the z-component estimated	Fixed to values of igs05.atx	Correction for the z-component estimated

Table 1: Types of combined GNSS-SLR solutions.

3 Results

1.1 SLR-GNSS bias parameters

The estimated SLR-GNSS bias parameters per station are shown in Figure 1 for different solution types.

In the first solution, i.e., assuming the LRA as well as the SAO to be correct, the estimated bias parameters are at the centimeter level and quite systematic (nearly all negative). This leads to the conclusion that several effects are accumulated in these parameters so that they cannot be considered to be an SLR "range bias".

When estimating corrections for the SAO (solution 2, not shown in Figure 1), the bias parameters do not change significantly: the median of the differences compared to the first solution is 0.4 mm. Therefore we can conclude that errors in the SAO values do not map into the SLR-GNSS range bias parameters. On the other hand, the resulting bias parameters cannot be considered to be an SLR "range bias", as already stated for solution 1.

In the case of the third solution (i.e., estimating corrections to the LRA offsets), the resulting bias parameters clearly change (see Figure 1). In general the values are smaller than in the solutions discussed before, and they are less systematic with positive as well as negative values. The differences compared to solution 1, however, are rather systematic, i.e., about 25 mm for nearly all stations. From this behavior we may conclude that the biases we see in the pure SLR range residuals might be due to an error in the LRA offset.

Compared to the third solution, the estimated bias parameters do not change significantly for the fourth solution (median difference compared to solution 3 is 0.0). This is a good indication that all parameter types can be estimated together.

The resulting SLR-GNSS bias parameters may represent real SLR range biases only in the case of solution types 3 and 4.

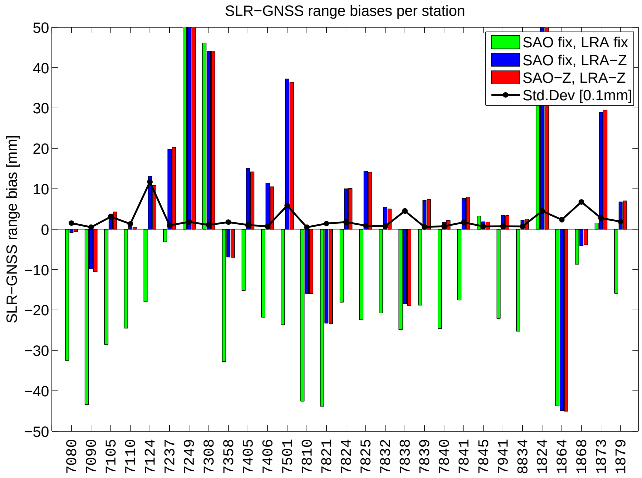

Figure 1: Station-specific SLR-GNSS bias parameters including their formal errors.

1.2 Z-Offsets for Laser Reflector Array

Independently of estimating corrections for the microwave SAO or fixing them to igs05.atx values, the corrections to the LRA z-offset are in the order of about 3 cm. The estimates are shown in Fig. 2a for the two GPS satellites tracked by the ILRS sites and all GLONASS satellites. The mean corrections for the GPS and GLONASS constellation for solution types 3 and 4 are given in Table 2. We can see that the impact of additionally estimating corrections for the microwave SAO is negligible for GPS and only at the level of a few millimeters for GLONASS. This can be explained by the fact that the SAO for GLONASS given in igs05.atx are obviously not correct (see e.g. Dach et al., 2011).

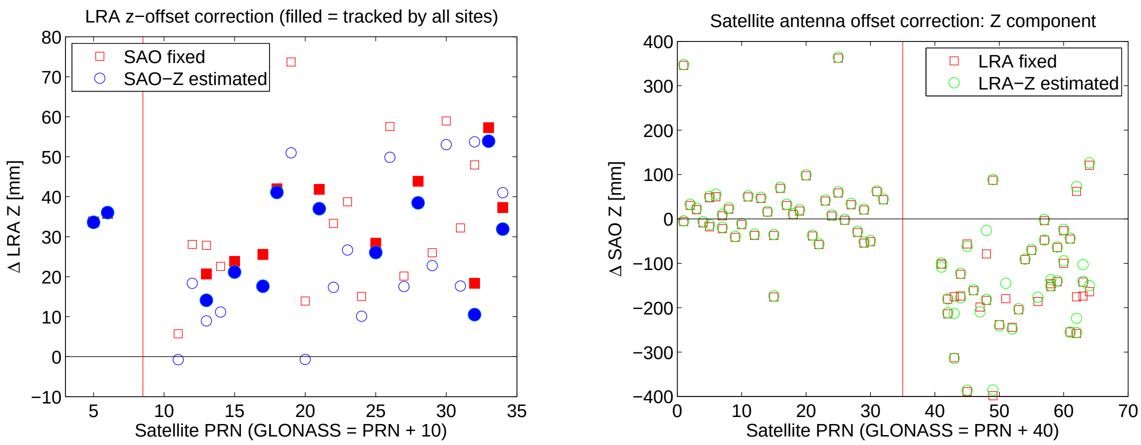

Figure 2: a) Corrections to the LRA offsets in z-direction (filled signatures: satellites tracked by all SLR stations; open signatures: satellites tracked only by Herstmonceux since Dec. 2009); b) Corrections to the microwave SAO in z-direction.

1.3 Z-Offsets for GNSS microwave antenna

The estimated corrections to the SAO in z-direction are shown in Figure 2b for the full GPS and GLONASS constellations. The corrections are quite different for both constellations: only about 25 mm in average for GPS (see Table 2), whereas about 140 mm for GLONASS and even with opposite sign. This confirms the assumption made already in Sec. 3.2 that the igs05.atx values for GLONASS are wrong, and it confirms earlier studies by Dach et al. (2011) and Thaller et al. (2011). The differences between solution types 2 and 4 (i.e., additionally estimating LRA corrections or not) are about 3 mm, thus, they are negligible. This behavior confirms that the three parameter types range bias, LRA offset and SAO can be estimated together.

	Mean correction for LRA z-offset [mm]		Mean SAO correction in z [mm]	
	GPS	**GLONASS**	**GPS**	**GLONASS**
Solution 2	-	-	23.3	-142.4
Solution 3	34.8	33.6	-	-
Solution 4	34.8	26.5	25.9	-138.8

Table 2: Estimated corrections to the offsets of the LRA and the microwave antenna: Mean corrections for the GPS and GLONASS constellations.

4 Conclusions

Combined solutions based on GNSS microwave data, SLR observations to GNSS satellites, LAGEOS and ETALON allow to estimate the relevant geodetic parameters consistently, i.e., station coordinates, satellite orbits, ERPs, SLR range biases as well as offsets at the GNSS satellites to the microwave antenna and the LRA. The accurate knowledge of the latter two parameter types is essential for combining both observation types, i.e., microwave and range data. Our studies revealed that the offsets provided by igs05.atx as well as the official LRA offsets do not fit together and do not fit to the observations. Corrections to both offsets are estimated at the centimeter level. Improvements may arise if the newly provided ITRF2008 and the corresponding SAO values of igs08.atx are used. Furthermore, the studies revealed that the three parameter types range bias, offsets for the LRA and microwave SAO can be estimated together. When estimating only range bias parameters, the resulting values do not represent a real SLR "range bias", but accumulates as well errors in the two offsets.

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