Space tie and local tie for combined GNSS-SLR analysis

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INTRODUCTION

The combination of space-geodetic techniques needs common parameters. Earth Rotation Parameters (ERP) and geocenter coordinates can be directly combined. For combining station coordinates, the position differences between the reference points of co-located sites must be known, i.e., the so-called «local ties» (LT). The LT and the coordinate differences from space-geodetic observations often mismatch. The error sources for the mismatch are difficult to be identified unambiguously in the classical combination approach (e.g. for ITRF) as only the ERPs are available as common parameters and LTs have to be used.
We present an alternative approach that allows us to validate the LTs: a combined analysis using the co-location in space. The procedure is illustrated in **Fig. 1**. The key issue of this procedure is that the GNSS orbits are determined from microwave and SLR observations together, thus, linking both space-geodetic techniques at the satellites instead of linking them on the ground. The application of LTs is not necessary.
We computed combined weekly GNSS-SLR solutions according to the procedure illustrated in **Fig. 1** for the time span 2000-2010, i.e., altogether eleven years.
The weekly NEQs were accumulated to a multi-year solution with estimating station coordinates and velocities, ERPs, SLR range biases and corrections to the space ties. The space tie between GNSS and SLR at GPS and GLONASS satellites consists of two components that relate the Center-of-Mass (COM) of the satellite (to which the orbits refer) with the reference points of the measurements (**Fig. 2**):

- the satellite antenna offset (SAO) of the phase center of the microwave transmitting antenna w.r.t. the COM;
- the offset of the center of the Laser Retro-reflector Array (LRA) w.r.t. the COM.

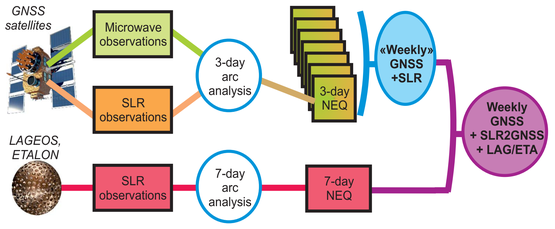

Figure 1: *Procedure for GNSS-SLR combination using satellite co-locations at GPS and GLONASS satellites.*

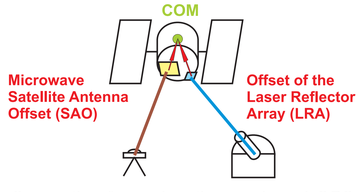

Figure 2: *Space ties for co-locations onboard GPS and GLONASS satellites. The common orbit refers to the Center-of-Mass (COM) of the satellite.*

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VALIDATION OF THE SPACE TIES

The official values of the SAOs are provided in igs08.atx, of the LRA offsets on the ILRS website. We estimated corrections to both space tie components (*z*-direction = nadir) within an 11-year combined SLR-GNSS solution.
The scale is defined by SLR as the observations to the LAGEOS and Etalon satellites are assumed to be unbiased. The estimation of SAO and LRA parameters is thus possible without fixing the scale of the station network.
Fig. 3 and **Fig. 4** show the corrections for the LRA offsets and the SAOs, respectively. The corrections for the LRA offsets are clearly smaller than the corrections to the SAOs. This indicates that the official igs08 SAOs do not fit to the scale given by SLR. According to the relationship *Zhu et al. (2003)*

$$\Delta \text{ scale [ppb]} = -7.8 * \Delta \text{ SAOz [m]}$$

the scale difference is **0.67 ppb** and **0.86 ppb** for the GPS and GLONASS satellites, respectively.
Fig. 5 shows the scale of the combined solution when using the corrected SAOs and LRA offsets (in comparison with single-technique solutions and the official reference frames). The SLR sub-network keeps the scale of a LAGEOS-only solution, but the scale of the GNSS sub-network is shifted by **-0.67 ppb**. This underlines the necessity of updating the space ties (mainly the SAOs) in order to increase the consistency between GNSS and SLR.

Figure 3: *Corrections for the official LRA offsets estimated from an 11-year combined GNSS-SLR solution. The mean corrections are:*
-1.4 mm *for GPS and*
-16.1 mm *for GLONASS.*

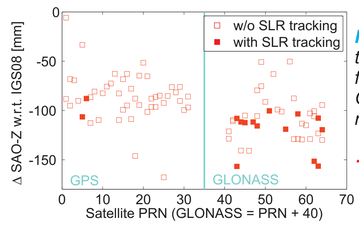

Figure 4: *Corrections for the official SAOs estimated from an 11-year combined GNSS-SLR solution. The mean corrections are:*
-86.1 mm *for GPS and*
-110.4 mm *for GLONASS.*

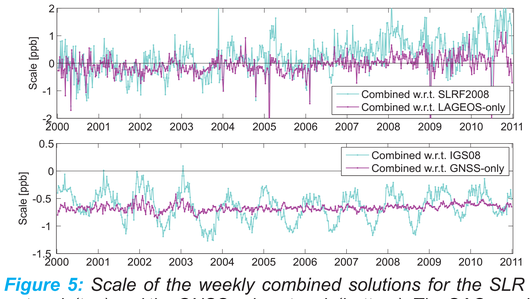

Figure 5: *Scale of the weekly combined solutions for the SLR sub-network (top) and the GNSS sub-network (bottom). The SAOs and LRA offsets are used from the 11-year combined solution (see **Figs. 3+4**).*

VALIDATION OF THE LOCAL TIES

We do not use the LTs in the combination, but connect both techniques only via satellite co-locations (in addition to ERPs and geocenter coordinates). This implies that the station coordinates of GNSS and SLR sites are estimated independently of the LTs. Therefore, this procedure allows us to validate the LT values from terrestrial measurements by comparing them with the differences of the estimated station coordinates at co-located GNSS and SLR sites.
Fig. 6 shows the discrepancies between terrestrial-measured LTs and the computed space-geodetic coordinate differences.
The agreement for the horizontal components is better than 1 cm for almost all co-locations. The height component is usually more critical, and the discrepancies in LTs are clearly bigger for the height: Only 27 co-locations agree better than 1 cm in height, whereas the 2-dimensional discrepancies are smaller than 1 cm for 41 co-locations.

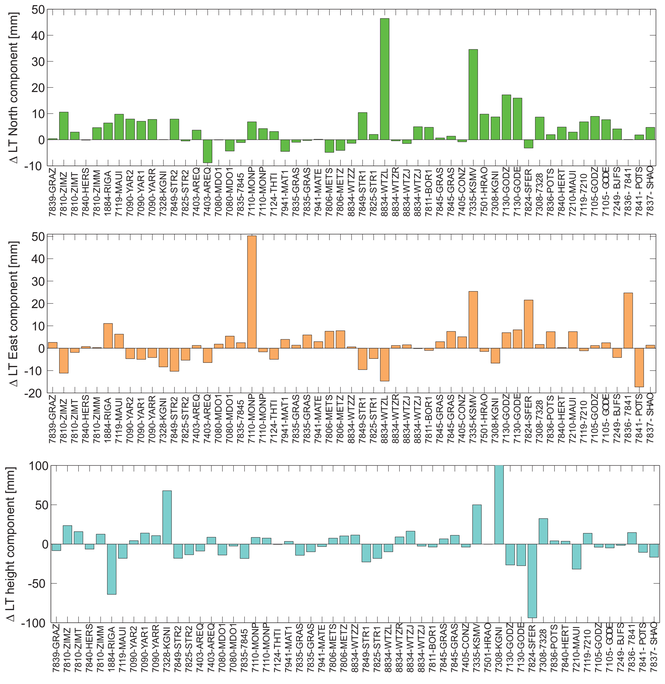

Figure 6: *Differences between LT values (from terrestrial measurements) and space-geodetic coordinates estimated from an 11-year combined GNSS-SLR solution using satellite co-locations. The site co-locations are sorted according to their distance and co-locations separated by more than 1 km are omitted.*

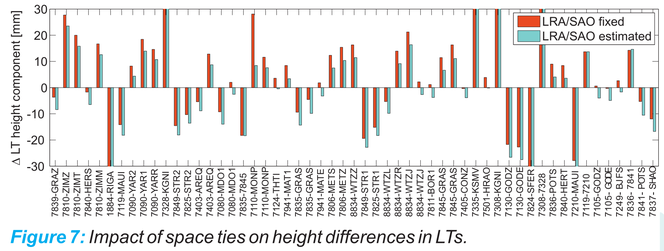

Figure 7: *Impact of space ties on height differences in LTs.*

IMPACT ON OTHER PARAMETERS

Neglecting the discrepancies in LTs and space ties leads to a degradation of all estimated parameters.
Fig. 7 shows the discrepancies in height of the LTs for two solution types: one solution without estimating corrections to the space ties (i.e., LRA offsets and SAOs) and the second solution with corrections estimated (see **Fig. 3+4**). It can be clearly seen that the agreement between GNSS and SLR station heights is improved if corrections to LRA offsets and SAOs are estimated. This fact confirms that the official values for SAOs and LRA offsets need to be updated in order to achieve a better consistency between GNSS and SLR.
The station height is highly correlated with the scale. **Fig. 5** shows that the scale of the combined solution is determined by SLR only - as desired because of phase center problems for GNSS.
Fig. 8 shows that the geocenter coordinates of the weekly combined solutions are shifted in average by 0.7 mm, 0.1 mm, and 1.8 mm in the *x*-, *y*-, and *z*-component, respectively, if the space ties are wrong at the level shown in **Figs. 3+4**. With discrepancies larger than 1 mm (mainly for the *z*-component), the goal of GGOS cannot be reached. It requires an update of the space ties in order to increase the consistency between GNSS and SLR.

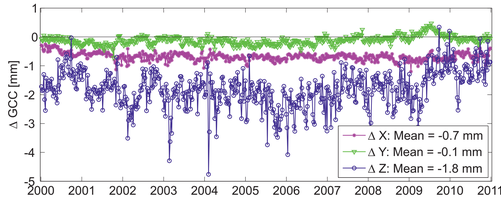

Figure 8: *Impact of using wrong SAOs and LRA offsets on the weekly combined geocenter coordinates. The differences between two solution types are shown:*
- using the official SAOs and LRA offsets,
*- using the improved SAOs and LRA offsets shown in **Figs. 3+4**.*

References

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