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Reconstructing local ties via co-location in space onboard GNSS and LEO satellites

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INTRODUCTION

Currently, the integration of all geodetic techniques, e.g., Global Navigation Satellite Systems (GNSS), Satellite Laser Ranging (SLR) is realized using local ties, i.e., the vectors which link the reference points of co-located geodetic technique telescopes and antennas, are derived based on in situ measurements, such as tachymetry and precise leveling. Satellite missions incorporating more than one space geodetic technique onboard the spacecraft, e.g., GNSS and SLR, allow for co-location in space. All Galileo satellites are equipped with the laser retroreflectors used for SLR, whereas many low Earth orbiters (LEOs) are equipped with GNSS receivers and SLR retroreflectors used mainly for their precise orbit determination (POD) and validation. In this study, we reconstruct the tie between SLR telescopes and GNSS receiver antenna, and the tie between two SLR telescopes, all co-located in Wettzell observatory (**Fig. 2**). We use the SLR observations to Galileo satellites and a global network of stations tracking the microwave GNSS signals in a combined SLR+GNSS solution for estimating the GNSS-SLR local tie (**Fig. 1 left**). For the SLR-SLR tie we use SLR observations to LEO, spherical geodetic, and Galileo satellites (**Fig. 1 right**).

METHODOLOGY AND DATA

The GNSS-SLR ties are calculated between GNSS station (WTZZ) and two SLR stations 8834 (WLRS) and 7827 (SOSW) based on the SLR+GNSS combination. We generate 1-day solution combining SLR-to-GNSS and GNSS normal equation systems (NEQ) with estimating the SLR and GNSS station coordinates with network constraining, global geodetic parameters, and GNSS orbits. For more details please follow Bury et al. 2021. The SLR-SLR tie between two telescopes, i.e., 8834 and 7827 are calculated using SLR observations to 24 satellites, i.e., Galileo, LARES, LAGEOS-1/2, and eight LEOs (Sentinel-3A, Swarm-A/B/C, Jason-2, GRACE-A/B, TerraSAR-X). We generate 7-day solutions combining SLR data to particular satellites with estimating global geodetic parameters and station coordinates with network constraining (ALL+W and LEO-only based solution), and with estimating only SLR station coordinates without network constraining (ALL+W+PPP). SLR to multi-satellite combination includes weighting of NEQs and range bias calibration. The processing follows the description of *LEO, ALL+W,* and *ALL+W+PPP* solutions in Strugarek et al. 2021. The calculated local ties are referenced to the a priori coordinates/distances from ITRF2014 and SLRF2014, and in situ local tie measurements from campaign of Kodet et al. (2018), and station site logs. **Table 1** shows processing summary for the local tie reconstruction.

	SLR+GNSS combination	SLR to multi satellites
Local ties (Wettzell)	WTZZ(GNSS)-8834(SLR), WTZZ(GNSS)-7827(SLR)	8834(SLR)-7827(SLR)
Observation type	microwaves and laser ranges NEQ combination: SLR-to-GNSS and GNSS	laser ranges to 9 LEOs or 24 LEO+MEO sats., weighted NEQs to each satellite (POD products as a priori)
Period	2017.0-2019.0	2016.0-2017.0
Estimated parameters	XYZ geocenter and XY pole coordinates, length-of-day, GNSS and SLR station coordinates (NNT+NNR constraining), GNSS orbit: 6 Keplerian, 5 ECOM, and pseudo-stochastic pulses in RSW	*ALL+W, LEO:* XYZ geocenter and XY pole coordinates, length-of-day, station coordinates (NNT+NNR constraining) *ALL+W+PPP:* station coordinates (free sol. – no constraints used) – SLR-PPP approach
Solution length	1-day	7-day (except for pole and length-of-day)
Range bias	a priori long term values resubstituted from SLR-to-GNSS, SLR-to-LAGEOS NEQs	a priori long term values resubstituted from SLR to multi-satellite NEQs combination

TAB. 1. Processing summary for local tie reconstruction.

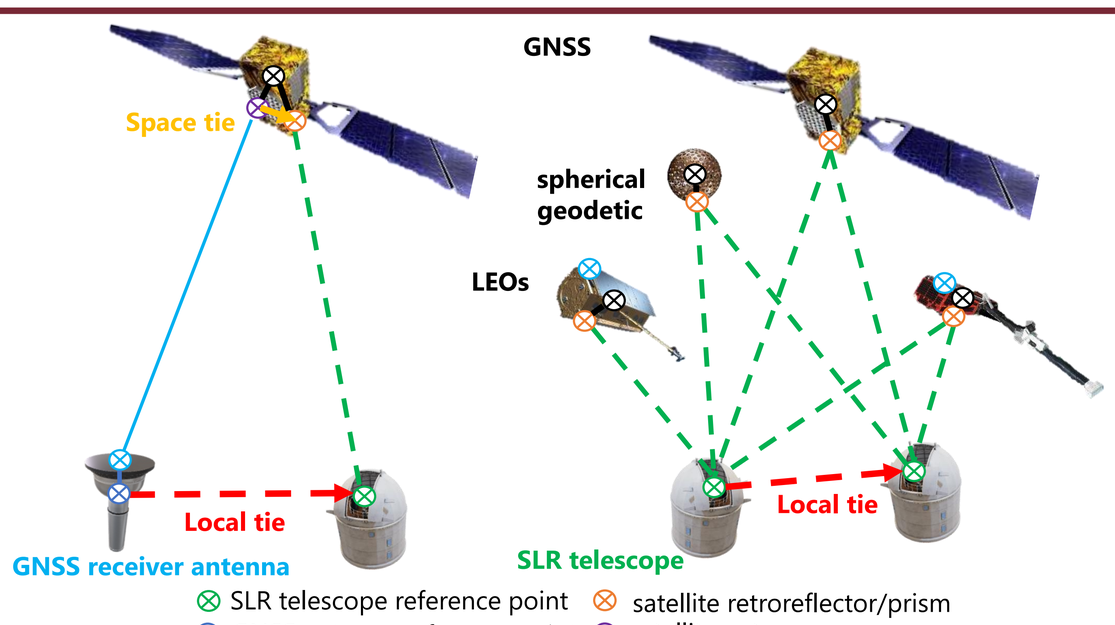


FIG. 1. Schematic view of GNSS-SLR local ties reconstruction based on GNSS+SLR combination (left), and local ties between two SLR telescopes based on SLR to multi-satellite solution (right).

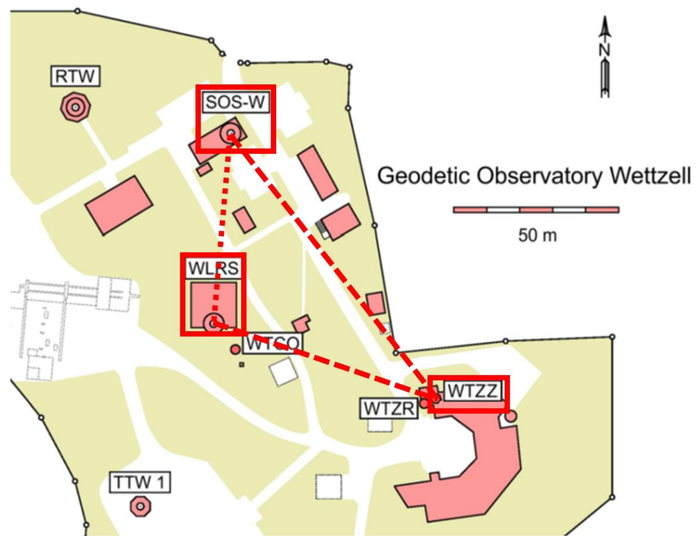


FIG. 2. Map of co-located instruments in Wettzell observatory. The investigated local ties in red. Based on Fig. 1 from Kodet et al. (2018).

LOCAL TIES FROM SLR+GNSS COMBINATION

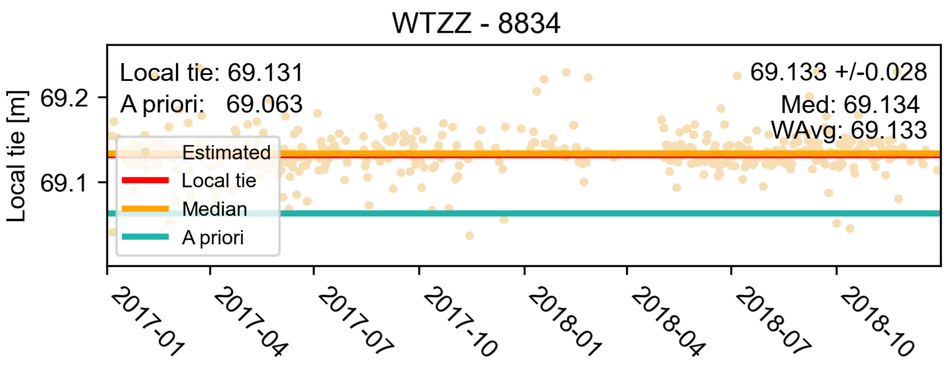


FIG. 3. 3D local ties for GNSS-SLR co-located stations in Wettzell. The red, orange, and turquoise lines denote the local tie measured in situ, the median of the local tie from the SLR-GNSS co-location in space, and the local tie calculated from ITRF2014 and SLRF2014, respectively. Dots illustrate single solution results.

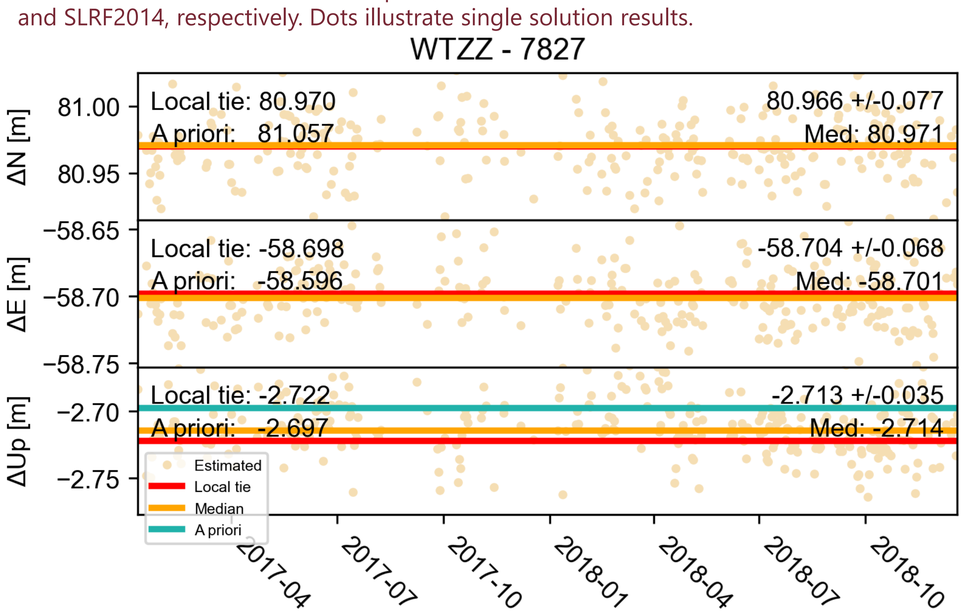
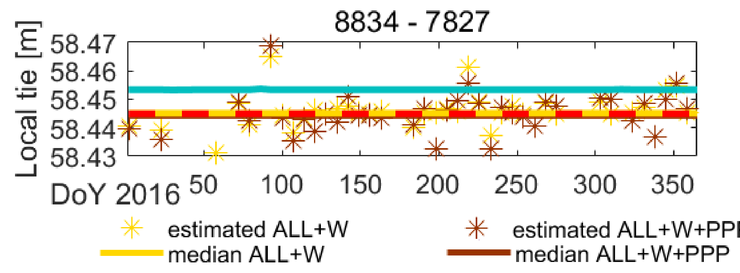


FIG. 5. Local ties for WTZZ-7827 decomposed into the North, East, and Up, component. The description of the figure is consistent with the Figure 3.

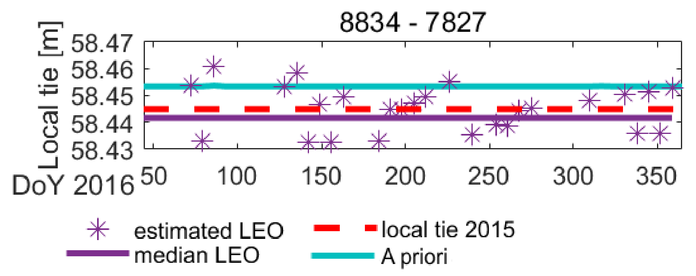
Figure 3 and 4 illustrate the 3D local ties for WTZZ-8834 and 8834-7827 stations based on SLR+GNSS combination and SLR to multi-satellite solutions, respectively, w.r.t the local ties measured in situ and local ties based on a priori coordinates from SLRF2014 and ITRF2014. The calculated WTZZ-8834 tie (orange) shows an agreement with the in situ measurements (red lines) at the level of 4 mm. In the case of 8834-7827 tie, the agreement with in situ measurements is even greater and reach the level of 0.2, 0.4, and 3.8 mm for ALL+W, ALL+W+PPP, and LEO solutions, respectively. The distances from a priori station coordinates are more deteriorated w.r.t. in situ measurements and reach even 10 mm.

LOCAL TIES FROM SLR TO MULTI-SATELLITES



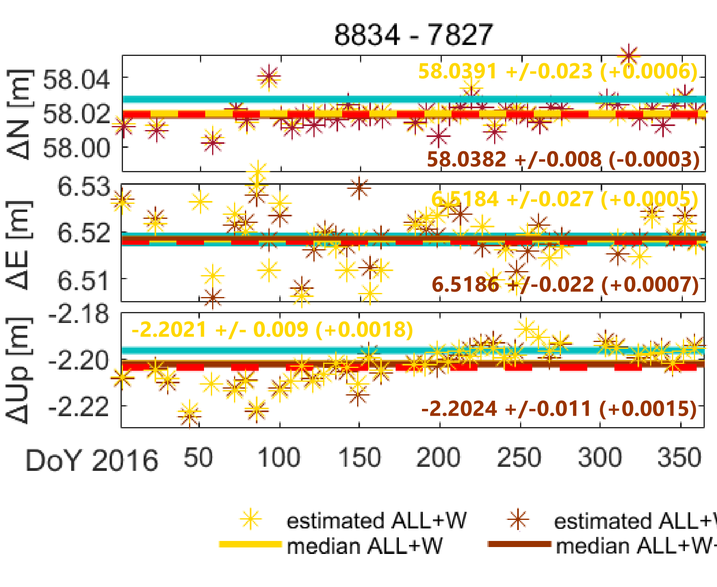
Local tie: 58.4449 | A priori: 58.4451 (+0.0082) | Med. ALL+W 58.4449 +/- 0.031 (+0.0002) | Med. ALL+W+PPP 58.4451 +/- 0.023 (-0.0004)

LOCAL TIES FROM SLR TO LEO



Med. LEO 58.4417 +/- 0.063 (-0.0003)

FIG. 4. 3D local ties for 8834-7827 SLR telescopes in Wettzell. The red and turquoise lines (left, right) denote the local tie measured in situ and the local tie calculated from SLRF2014 (a priori), respectively. The yellow and brown lines (left) denote the median of the local tie from the SLR to multi-satellite ALL+W and ALL+W+PPP solutions, respectively. The purple line (right) denotes the median of the local tie from the SLR to LEO-only solution. Stars illustrate 7-day solution results. The median difference w.r.t. the measured local ties are shown in parentheses.



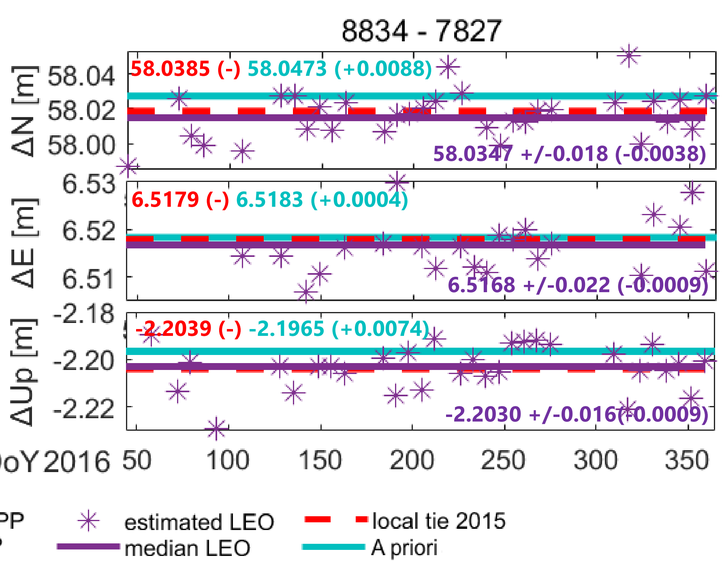


FIG. 6. Local ties for 8834-7827 decomposed into the North, East, and Up, component. The description of the figure is consistent with the Figure 4.

Figure 5 and 6 illustrate the local ties for WTZZ-7827 and 8834-7827 stations decomposed into the North, East, and Up components and analogical tested solutions. The WTZZ-7827 local ties from SLR-GNSS combination (orange) show a great agreement with the in situ measurements (red lines) at the level of 1, 3, and 8 mm for the North, East and Up components, respectively. The median of 8834-7827 local tie from SLR to multi-satellite solution show the agreement with the in situ measurements at the level of 0.6 (0.3), 0.5 (0.7), and 1.8 (1.5) mm for the North, East and Up components, respectively and ALL+W (ALL+W+PPP) solution. In the case of SLR to LEO-only combination, the estimated 8834-7827 tie is consistent with in situ measurements at the level of 3.8, 0.9, and 0.9 mm for the North, East, and Up components, respectively. The component differences from a priori station coordinates w.r.t. in situ measurements vary within the ranges of 0.4-8.8 and 8.7-102 mm for WTZZ-7827 and 8834-7827 ties, respectively, depending on solution and component (**Fig. 5, 6**).

CONCLUSIONS

- Co-location of SLR and GNSS space techniques onboard navigation and LEO satellites allows reconstructing the local ties between GNSS antenna and SLR telescopes
- The GNSS-SLR local ties in Wettzell (WTZZ-8834, WTZZ-7827) derived from long-term SLR+GNSS combined solution indicate 4 mm consistency with in situ measurements
- The SLR-SLR local ties in Wettzell (8834-7827) derived from long-term SLR to LEO-only and multi-satellite solutions indicate ~1 mm consistency with in situ measurements

References

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