WROCŁAW UNIVERSITY OF ENVIRONMENTAL AND LIFE SCIENCES

EGU General Assembly 2020

UNIVERSITÄT BERN

Determination of global geodetic parameters based on integrated SLR measurements to LEO, geodetic, and Galileo satellites

Dariusz Strugarek[1,*], Krzysztof Sośnica[1], Daniel Arnold[2], Adrian Jäggi[2], Grzegorz Bury[1], Radosław Zajdel[1]

[1] Institute of Geodesy and Geoinformatics, Wrocław University of Environmental and Life Sciences, Poland; [2] Astronomical Institute, University of Bern, Switzerland; *dariusz.strugarek@upwr.edu.pl

INTRODUCTION

Numerous of active low Earth orbiters (LEOs) and Global Navigation Satellite System (GNSS) satellites, including the Galileo constellation, are equipped with laser retroreflectors used for Satellite Laser Ranging (SLR). SLR measurements to LEOs, GNSS, and geodetic satellites vary in terms of the number of registered normal points (NPs) or satellite passes. In 2016-2018, SLR measurements to LEOs constituted 81% of all NPs, whereas 10% of NPs were assigned to GNSS (Fig.1). The remaining 9% of NPs were completed by geodetic satellites, including LAGEOS-1/2. Thus, the question arises whether those 91% of SLR data can be used for other purposes than just orbit validation. In this study, we show that the SLR observations to Galileo, passive geodetic and active LEO satellites together with precise GNSS-based orbits of LEOs and Galileo can be used for the determination of global geodetic parameters: Earth rotation parameters (ERPs) and geocenter coordinates (Fig.2). Here, we use SLR observations to Galileo, LARES, LAGEOS-1/2, eight LEO satellites (Sentinel-3A, Swarm-A/B/C, Jason-2, Grace-A/B, TerraSAR-X).

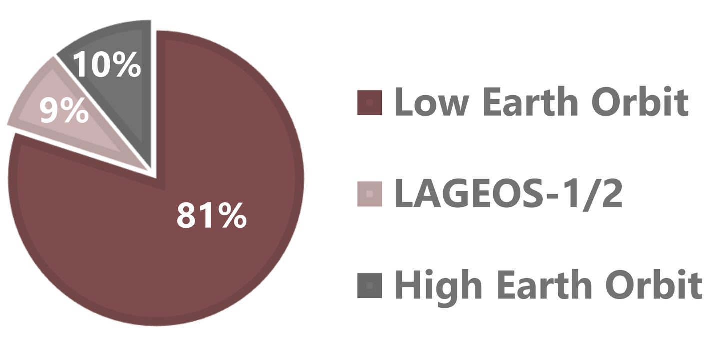


Fig.1. Percentage of SLR observations (normal points) to particular satellite types in 2016-2018

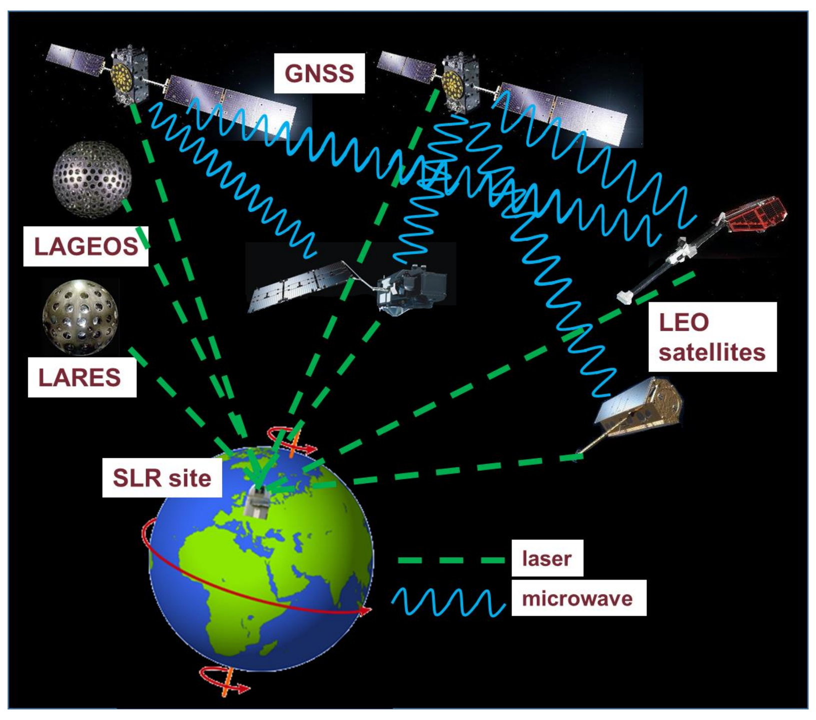


Fig.2. Observation principle for the reference frame realization and global geodetic parameters determination

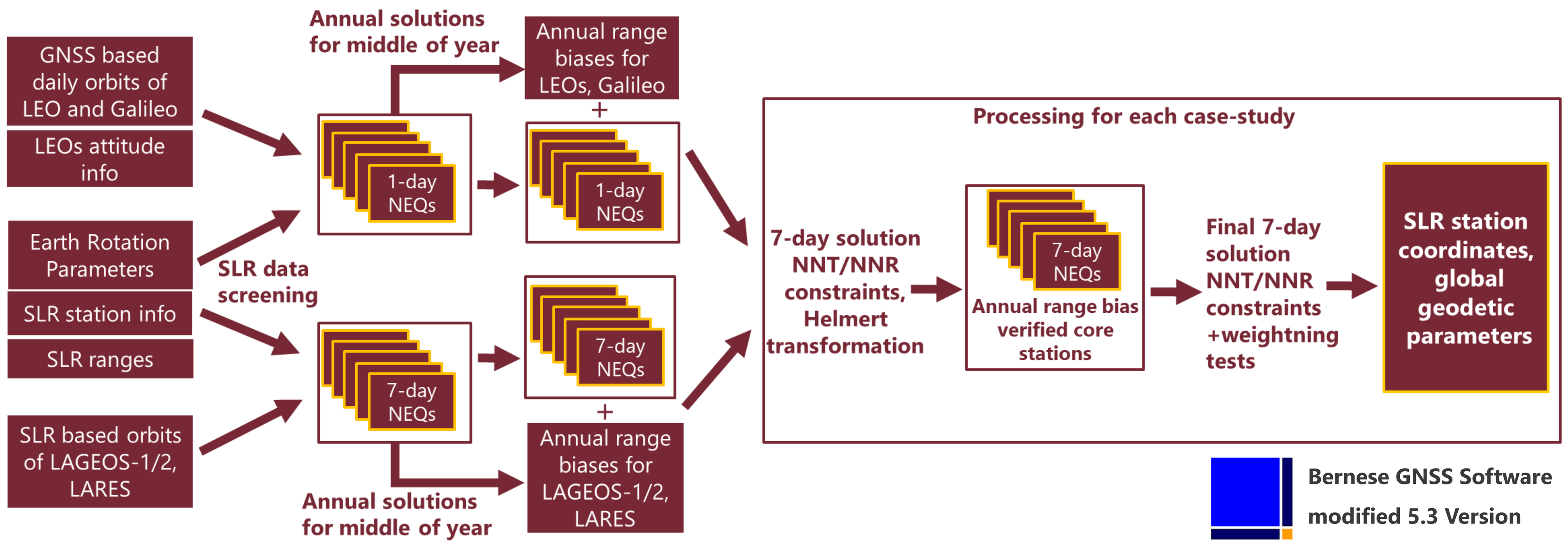
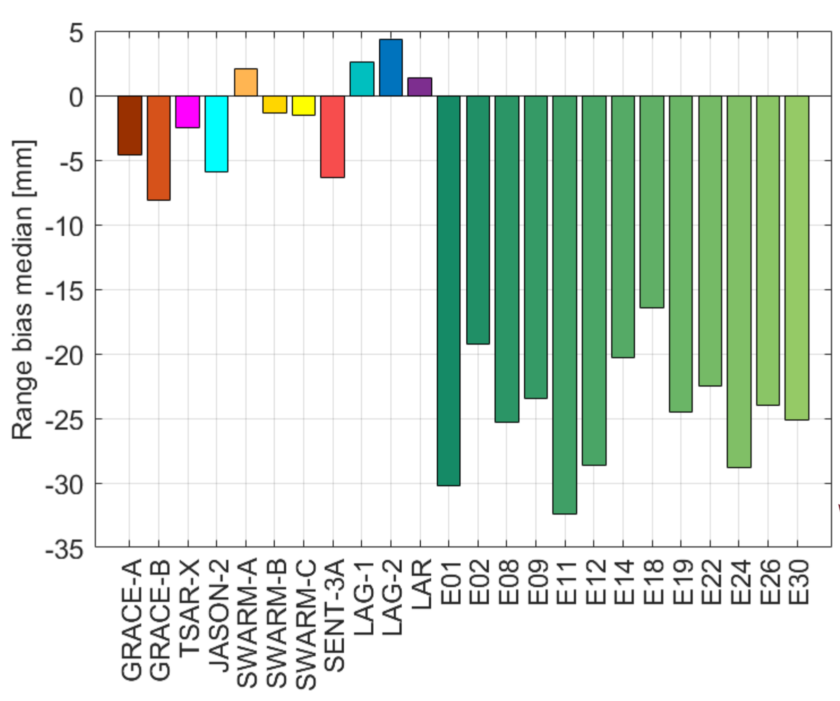


Fig.3. Scheme of the reference frame realization and global geodetic parameters determination processing

METHODOLOGY AND DATA

We combine 1-day normal equations (NEQs) based on SLR range observations, a priori station coordinates from SLRF2014, the 1-day precise GNSS-based orbits of LEOs and Galileo provided by the Astronomical Institute, University of Bern (AIUB), German Aerospace Center (DLR), and Center for Orbit Determination in Europe (CODE). The LAGEOS-1/2 and LARES orbits were estimated in the calculation process based on SLR data. We used LEO satellite attitude data, and ERP with minimum constraints for SLR station coordinates determination. The geocenter coordinates, X, Y pole coordinates, and the UT1-UTC rates, i.e., length-of-day (LoD) were estimated (see Fig. 2. and Fig. 3.). In our solution, we introduced annual mean range biases for each SLR station to particular LEO, geodetic and Galileo satellites. We generated the 7-day solutions with no-net-rotation (NNR) and no-net-translation (NNT) constraints with estimation of additional parameters. Next, we used the Helmert transformation between obtained coordinates of core stations and the SLRF2014 for the verification of core stations (for details see scheme in the Fig. 3.). After selection of a stable set of core stations, we calculated final solutions, with combination of data at NEQ level and with different weighting strategies. In the processing, we used the modified version of the Bernese GNSS Software for the 2016.0-2017.0 period.

ANNUAL RANGE BIAS CORRECTIONS



In the calculation process it is important to introduce range bias corrections for SLR stations. In our study, we applied annual range biases for each station-satellite pair. Mean annual range bias values (Fig. 4.) show that the largest corrections, at the level of -16 to -33 mm, occur for Galileo. In the case of geodetic, and LEOs, the range bias values do not exceed 8 mm and have different signs, depending on the satellite.

Fig.4. Annual median range bias values (for all stations) to particular satellites in 2016 (E01-E30 names refer to Galileo PRNs)

Fig.5. Applied annual range biases on selected SLR stations to particular satellites in 2016 (E01-E30 names refer to Galileo PRNs)

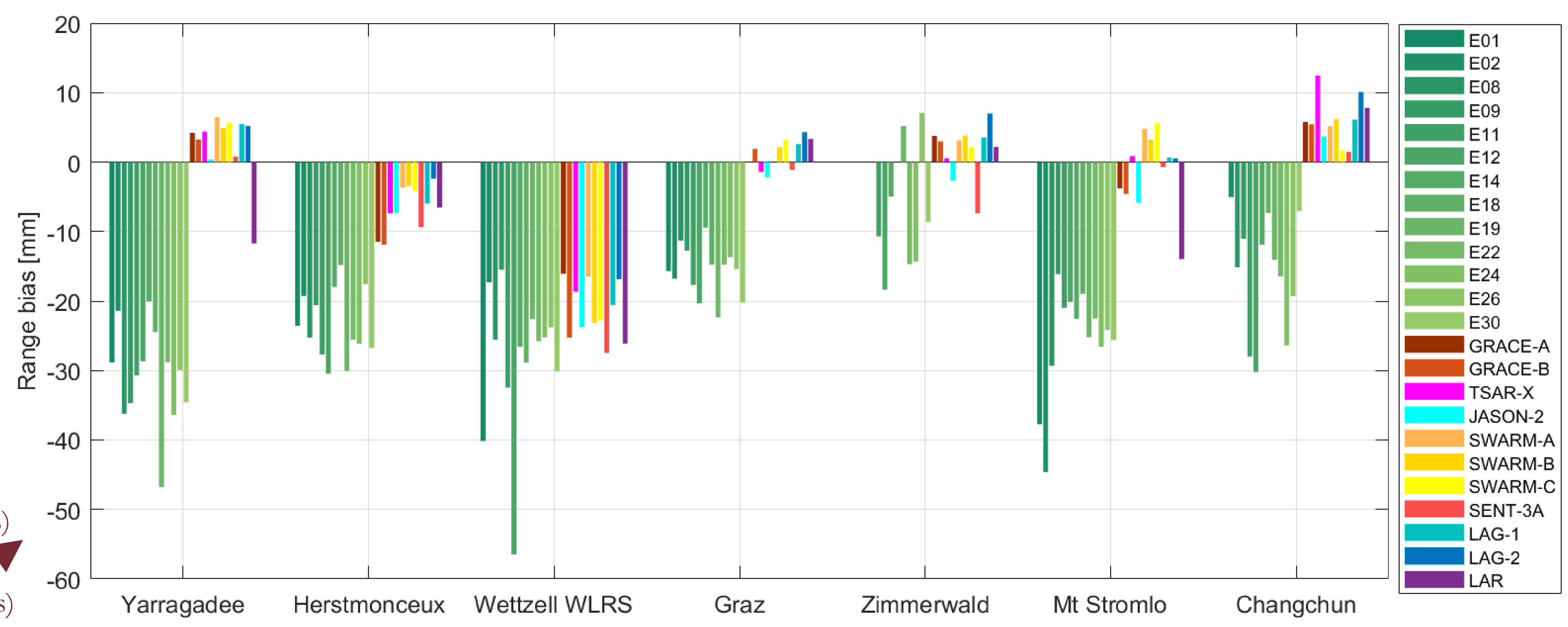
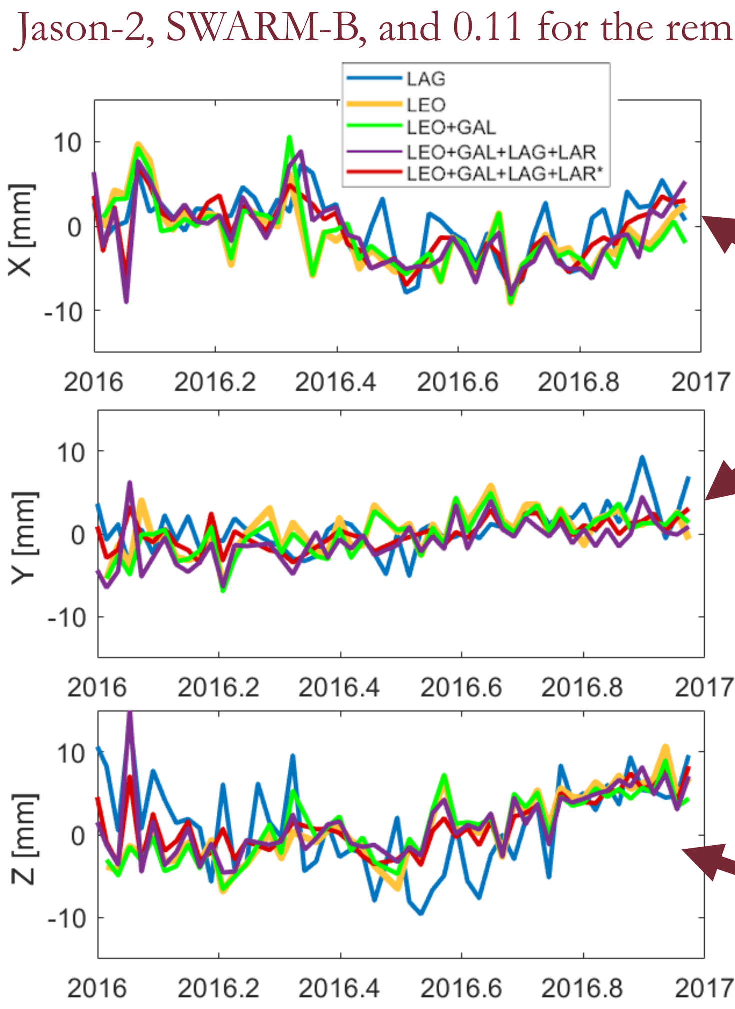


Figure 5 shows applied range biases for seven SLR stations to LEO, geodetic, and Galileo satellites. For Galileo, the largest corrections are applied to the Mt Stromlo, Wettzell, and Yarragadee stations (even -55 mm). In the case of geodetic, and LEO satellites, the highest corrections are obtained to the Wettzell and Herstmonceux, and are at the level of -25 and -10 mm respectively. For some stations (e.g. Changchun, Yarragadee), LEO range biases have positive signs and do not exceed 12 mm.

GLOBAL GEODETIC PARAMETERS & COMBINED SOLUTIONS

For the determination of geocenter coordinates, pole coordinates, and LoD, we used different case studies. We generated LAGEOS-only solution (LAG), and combinations, i.e., eight LEOs (LEO), eight LEO and thirteen Galileo satellites (LEO+GAL), LEO, Galileo, LAGEOS-1/2 and LARES satellites (LEO+GAL+LAG+LAR). For improving the estimation of parameters and reducing the influence of the satellites with the poorest orbit quality, we employed the weighting of observations in combined solutions. We changed the weighting schemes of the SLR observations in the NEQ processing for each data type, which resulted in scaling factors 1.00 for LAG, 0.25 for Sentinel-3A, Jason-2, SWARM-B, and 0.11 for the remaining satellites, namely LEO+GAL+LAG+LAR*.



Combinations consistent with LAGEOS

Three times improvement of combinations

Combinations less scattered

Fig.6. Comparison of geocenter coordinates

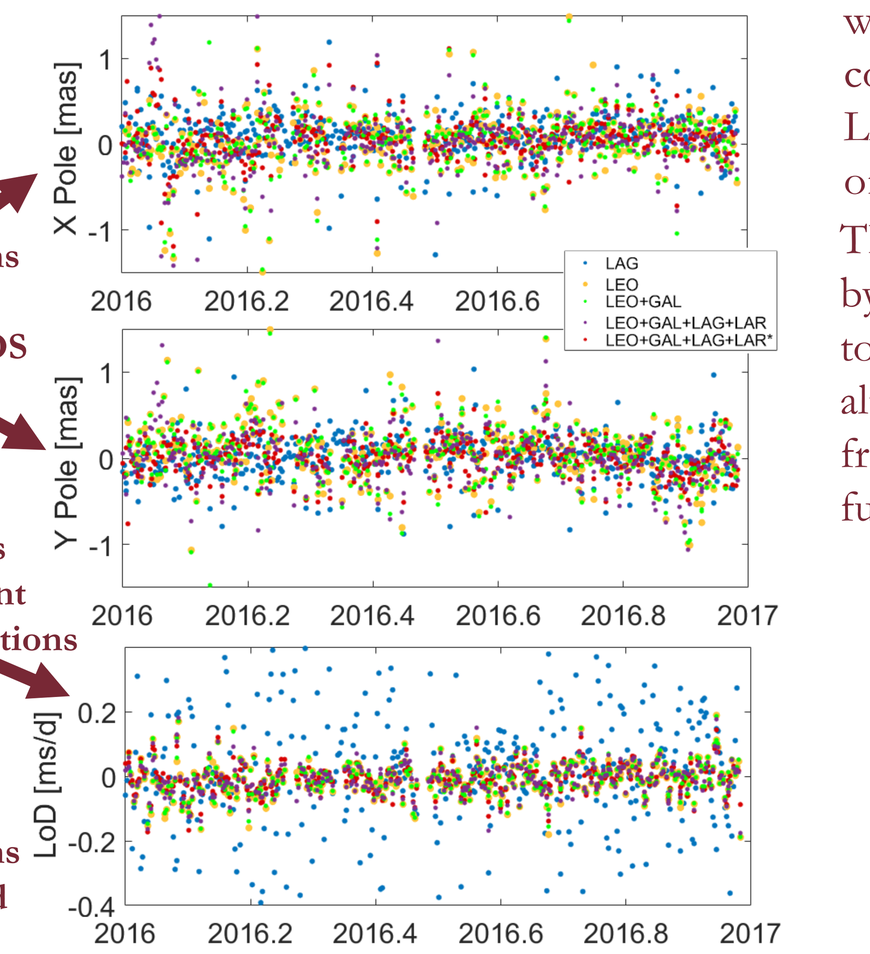


Fig.7. Differences of pole coordinates and LoD, w.r.t IERS-14-C04

Results for the geocenter coordinate determination are depicted in Fig. 6 and Tab. 1. The LEO+GAL+LAG+LAR* solutions show consistent results with LAG solutions and are characterized by superior root-mean-square (RMS) values at the level of 3.7 mm, 1.7 mm and 3.4 mm for the X, Y, and Z components, respectively. Also, LEO and LEO+GAL combinations show smaller RMS values, w.r.t LAG, especially for the Y and Z components. The Z geocenter coordinates for LEO, LEO+GAL, and LEO+GAL+LAG+LAR* are significantly less scattered than the LAG solution until the 3rd quarter of 2016, and then became consistent with LAG as well. Results for pole coordinates and LoD referenced to the IERS-C04-14 are provided in Fig 7 and Tab. 2. The LEO+GAL+LAG+LAR* solutions show slightly better results when compared to LAG only solutions with the RMS of 0.166, and 0.174 mas for the X, and Y pole coordinates, respectively. The other combinations show similar or slightly better results when compared to LAG solutions. The comparison for the LoD show even more than three times lower RMS values, at the level of 0.050 ms/d, w.r.t IERS-C04-14, for all combinations, when compared to the LAG solution.

The multi-satellite combinations are inessentially influenced by LAGEOS observations, which may be affected by the correlation of the Z component of geocenter with LAG orbit empirical parameters. SLR observations to LEO, and Galileo improve the determination of LoD, due to introducing data from satellites at different altitudes, with fixed microwave orbits, which stabilizes the relative orientation between terrestrial and celestial frames. Due to a relatively short period of observations of just one year, this aspect should be taken under further investigations.

Solution	X		Y		Z	
	mean	RMS	mean	RMS	mean	RMS
LAG	0.2	3.7	0.7	2.7	0.9	5.4
LEO	-1.3	3.9	0.3	2.6	0.9	4.2
LEO+GAL	-1.2	4.0	0.2	2.5	0.8	3.8
LEO+GAL+LAG+LAR	-0.8	4.2	-1.0	2.5	1.2	4.1
LEO+GAL+LAG+LAR*	-0.5	3.7	0.0	1.7	1.1	3.5

Tab.1. Mean offsets and RMS values of the estimated X, Y, and Z geocenter coordinates, w.r.t. SLRF2014 (in mm)

Solution	X pole		Y pole		LoD	
	mean	RMS	mean	RMS	mean	RMS
LAG	0.109	0.191	0.036	0.175	0.015	0.169
LEO	0.028	0.191	0.034	0.194	-0.011	0.053
LEO+GAL	0.044	0.191	0.038	0.194	-0.010	0.051
LEO+GAL+LAG+LAR	0.013	0.174	0.013	0.181	-0.008	0.050
LEO+GAL+LAG+LAR*	0.055	0.155	0.018	0.167	-0.004	0.049

Tab.2. Mean offsets and RMS values of the estimated X, Y pole coordinates and LoD, w.r.t. IERS-C04-14 series (pole coordinates in microarcseconds (mas), LoD in miliseconds/day (ms/d))

CONCLUSIONS

- SLR stations have been providing observations to a large number of new LEO and Galileo satellites.
- Each SLR site requires different bias correction individually for a particular satellite.
- SLR observations to LEO+Galileo+LAGEOS+LARES with proper weighting of observations allow for the determination of geocenter coordinates with the variability of 3.7, 1.7, and 3.5 mm for the X, Y, and Z component, respectively, whereas the LoD shows three times smaller RMS in the combined than in LAGEOS solutions, with the RMS of 0.05 ms, w.r.t. the IERS-14-C04.

In 2016, Galileo did not have the status of the fully operational system. Further improvement may be expected!

Acknowledgments: The authors gratefully acknowledge the International Satellite Laser Ranging Service for their effort to collect and provide SLR observations of LEO and LAGEOS satellites and CODE, AIUB, and DLR for providing LEO and Galileo orbits. D. Strugarek, K. Sośnica, R. Zajdel, G. Bury, are supported by the Polish National Science Centre (NCN), Grant No. 552 UMO-2018/29/B /ST10/00382.

For the related study of Sentinel-3A/B and LAGEOS combinations please see:

DOI: 10.3390/rs11192282 URL: https://www.mdpi.com/2072-4292/11/19/2282