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UNIVERSITÄT BERN

WROCŁAW UNIVERSITY OF ENVIRONMENTAL AND LIFE SCIENCES

Low Earth Orbiter

LAGEOS 1/2

Realization of reference frames based on integrated SLR measurements to LEO and LAGEOS satellites

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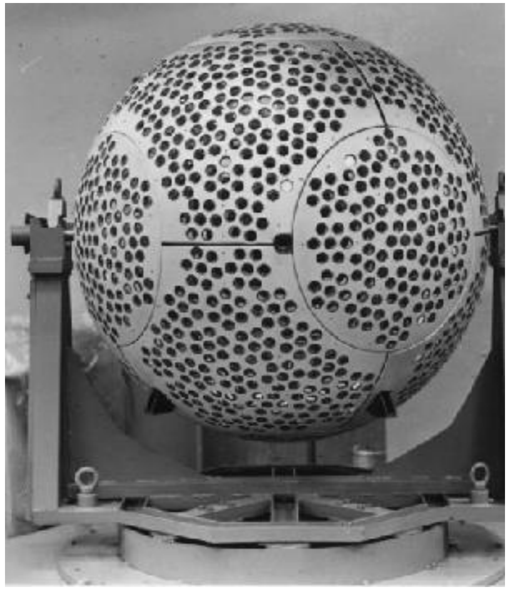
Motivation

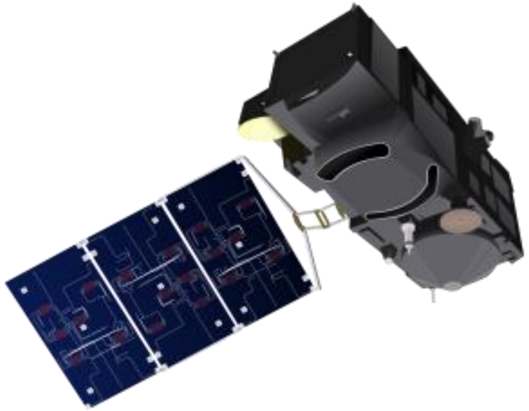
LAGEOS1/2

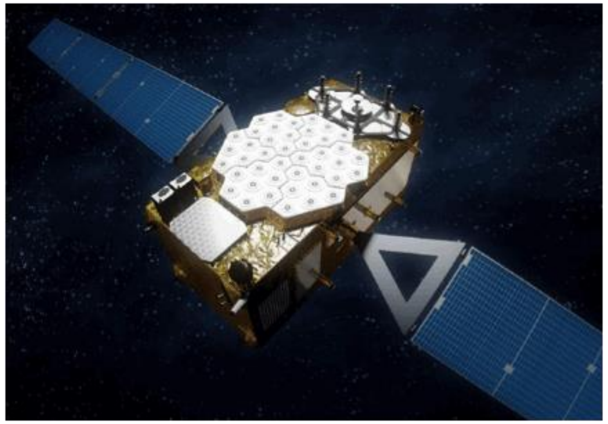


Etalon 1/2

Satellite Laser Ranging (SLR) measurements to passive geodetic satellites (LAGEOS & Etalon) are used for the realization of reference frames (e.g. ITRF2014)

Motivation





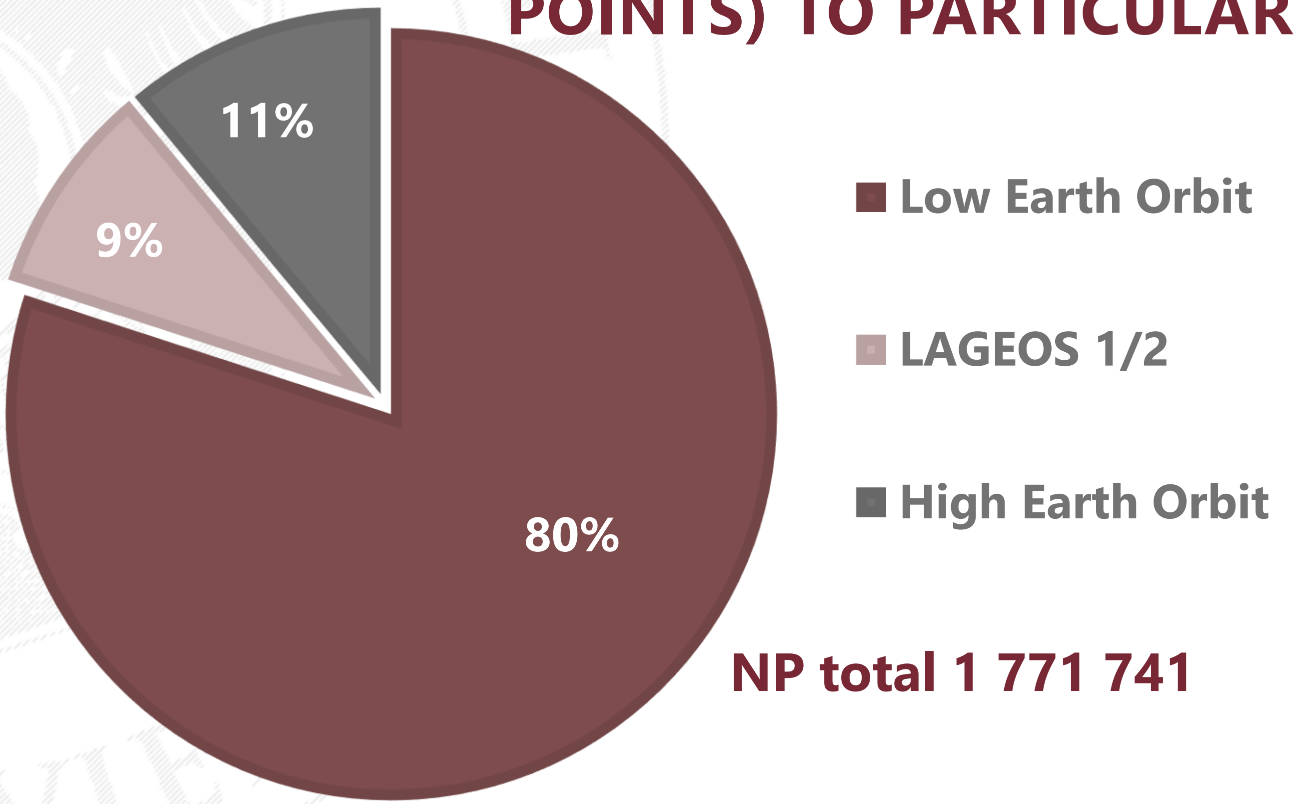
retroreflectors

GNSS or active Low Earth orbit (LEO) satellites are equipped with retroreflctors, which allow for SLR measurements

Motivation

International Laser Ranging Service (ILRS) initiates a series of intense tracking campaigns for GNSS and LEO satellites

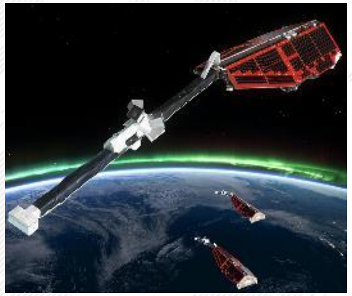
PERCENTAGE OF SLR OBSERVATIONS (NORMAL POINTS) TO PARTICULAR SATELLITE TYPES IN 2017



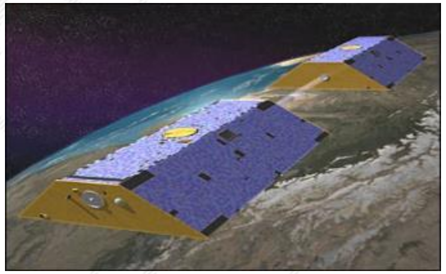
NP total 1 771 741

Only 9% of all SLR measurements are used currently for the reference frames realization, determination of Earth rotation parameters (ERP), and geocenter coordinates

SLR measurements



SWARM-A/B/C



GRACE-A/B

Jason-2

TerraSAR-X

SENTINEL-3A

- *ESA, NASA, EUMETSAT, GFZ DLR, CNES*
- *active Low Earth Orbit satellites*
- *GNSS receivers onboard*
- *satellites with different weight, shape, equipment, orbit parameters*
- *precise GPS-based orbits and attitude data*

Active satellites → SLR → orbit validation

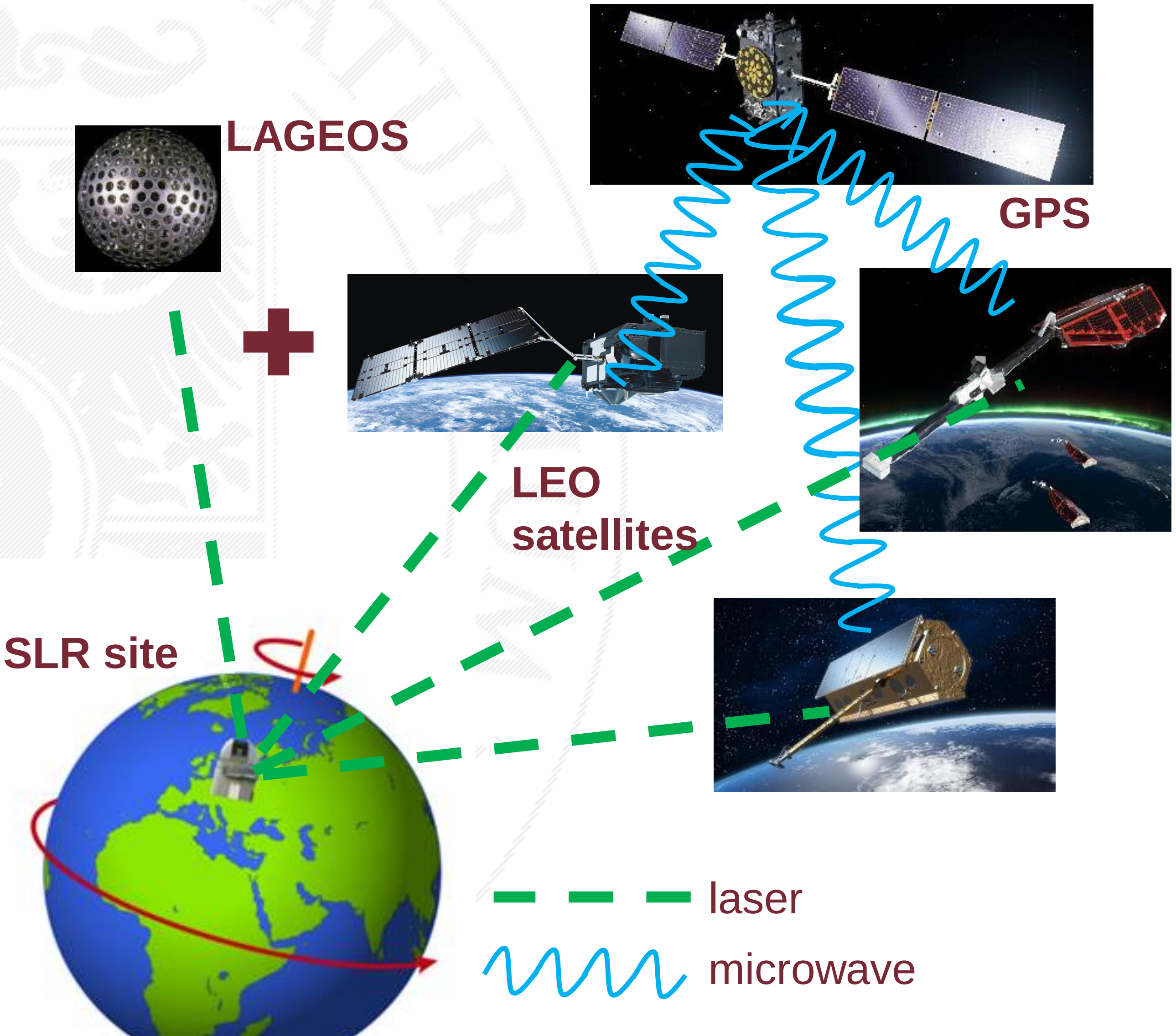
LAGEOS-1, LAGEOS-2

- *NASA and ASI*
- *used for relativistic effects, gravity field, geodynamics, ERP, geocenter coordinates research by SLR measurements*

- *passive, spherical, geodetic satellites, with low area-to-mass ratio*
- *eqiupped with 426 retroreflectors dedicated for SLR technique*

Passive satellites → SLR → station coordinates, geocenter coordinates, ERP, scale, relativistic effects validation

LEOs GNSS- and SLR- based analysis



SLR normal points + High-quality GPS-based LEO satellites orbit and orientation data

geodetic satellites likewise approach

Station coordinates

Station SLR biases

Geocenter

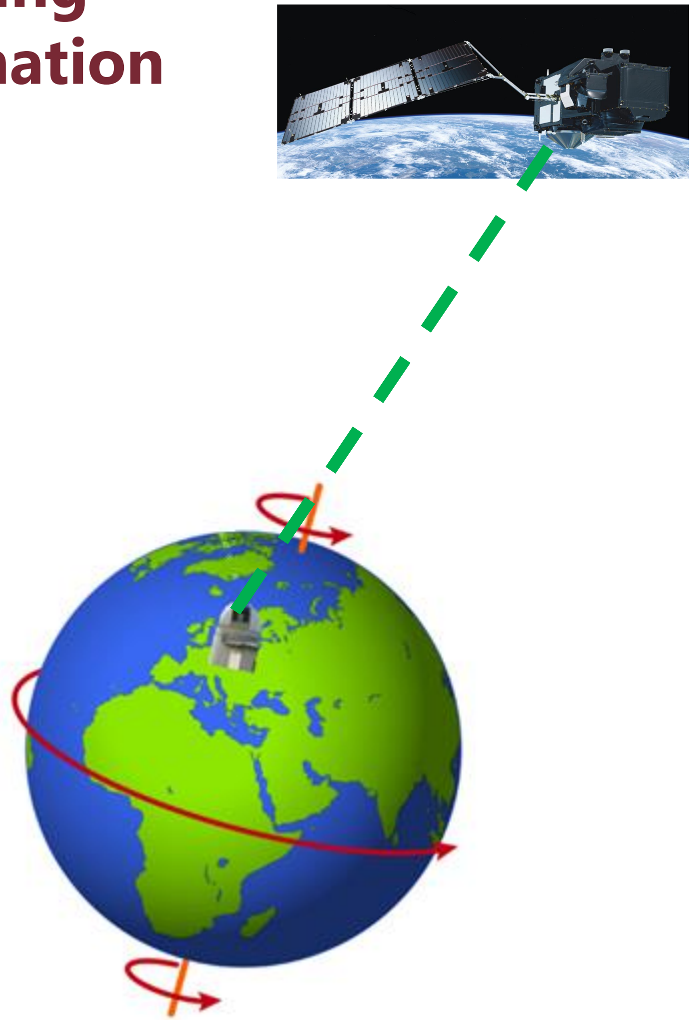
ERPs

LEOs-only and Combined LEOs + LAGEOS solutions

Bernese GNSS Software modified 5.3 Version

Solution tests– SLR to LEOs

LEO satellites
(fixed GPS-based orbits)



Solution tests: different network and parameters constraining and a different number of accumulated 1-day orbit combination

Test1: network constraining: no-net-translation (NNT) no-net-rotation (NNR) with estimation of parameters → SLR station coordinates, geocenter, ERPs

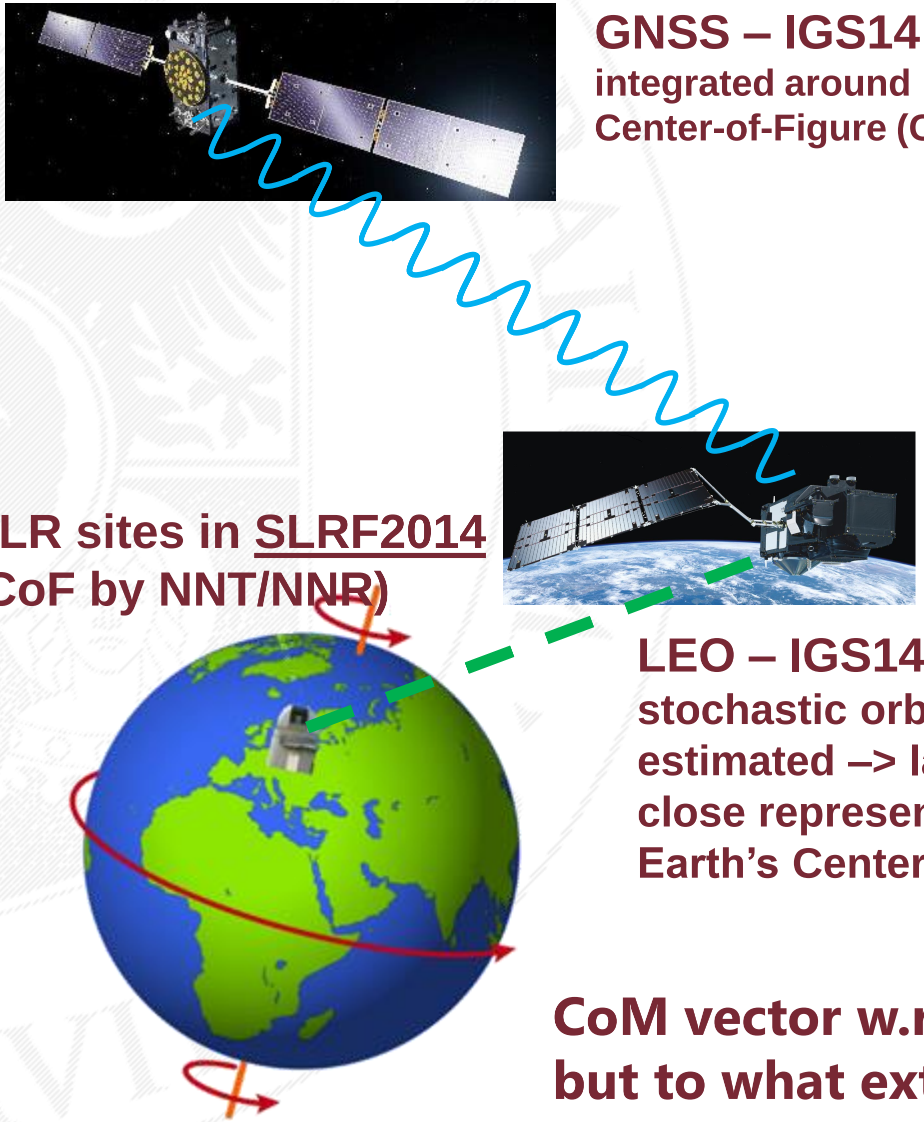
Test2: network constraining: no-net-translation (NNT) no-net-rotation (NNR) without estimation of parameters → SLR station coordinates

Test3: no network constraining and without estimation of parameters → SLR station coordinates

Time span: 2016-2017

The issue of the reference frame differences

Test 1 with NNT/NNR constraints

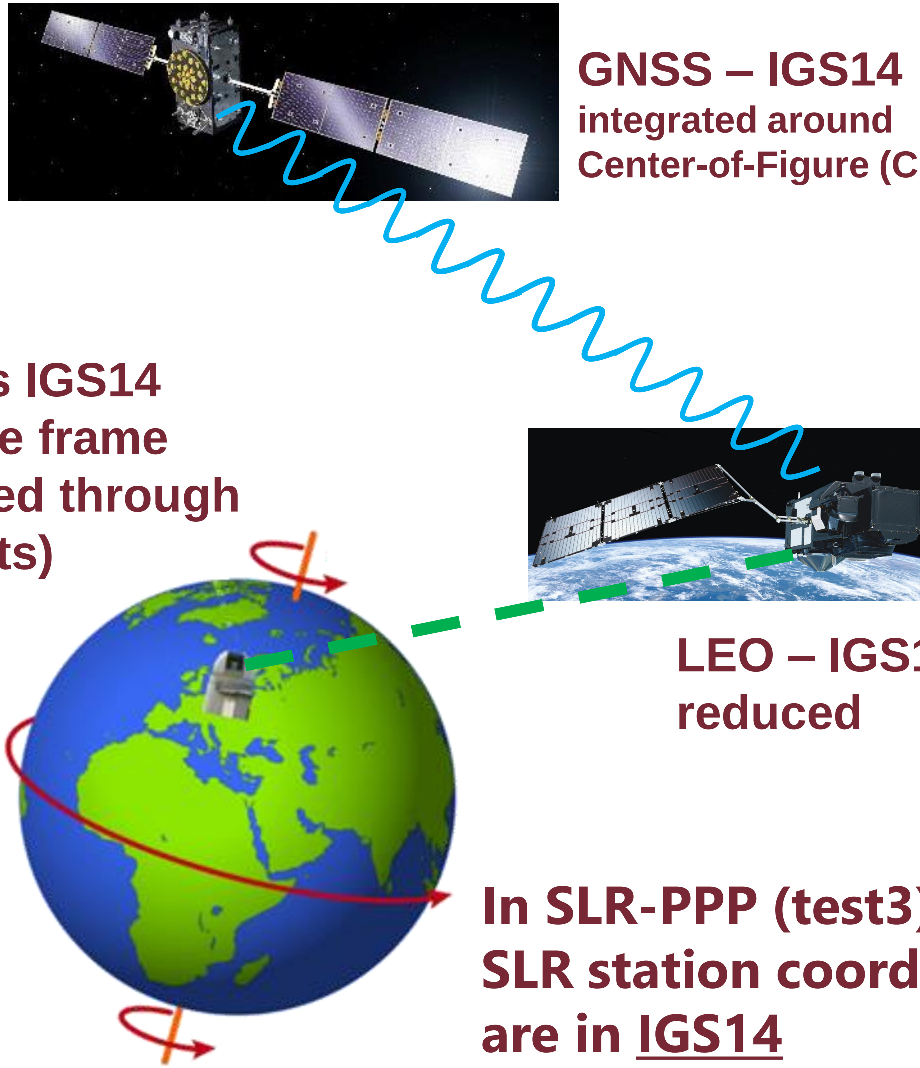


GNSS – IGS14
integrated around Center-of-Figure (CoF)

SLR sites in <u>SLRF2014</u> (CoF by NNT/NNR)

LEO – IGS14, but pseudo-stochastic orbit parameters are estimated –> larger flexibility, close representation of the Earth's Center-of-Mass (CoM)

Test 3 no network constraints



GNSS – IGS14
integrated around Center-of-Figure (CoF)

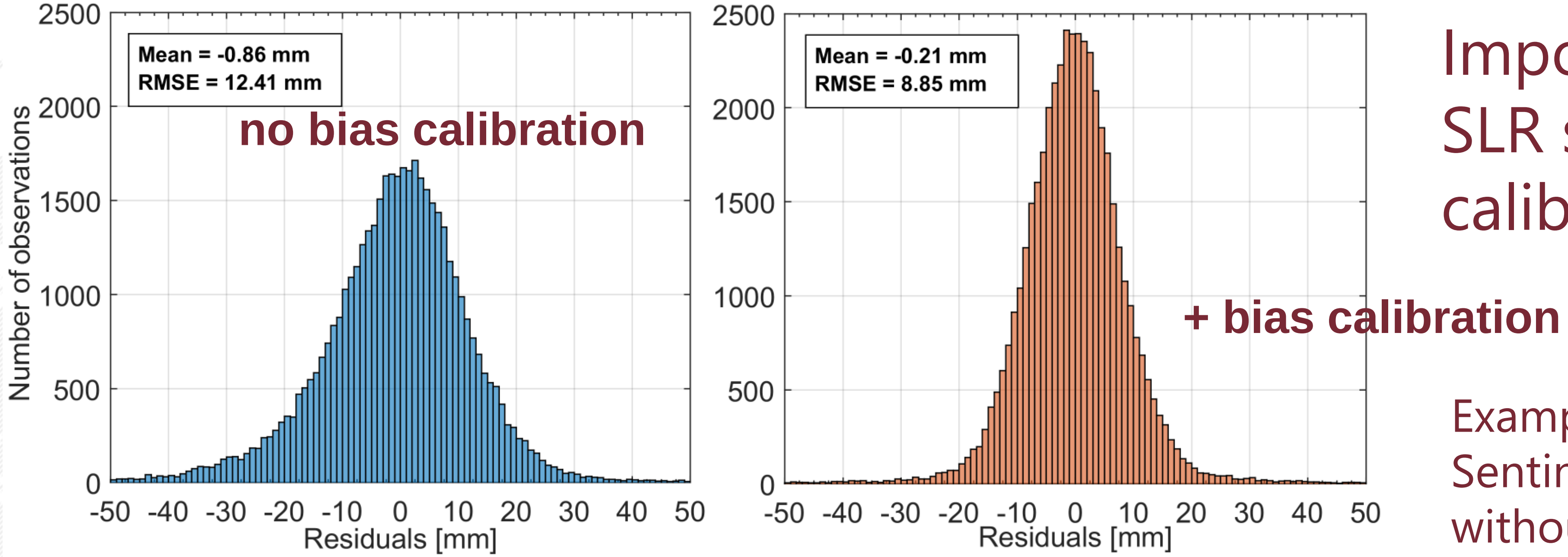
SLR sites IGS14 (reference frame transferred through LEO orbits)

LEO – IGS14, reduced

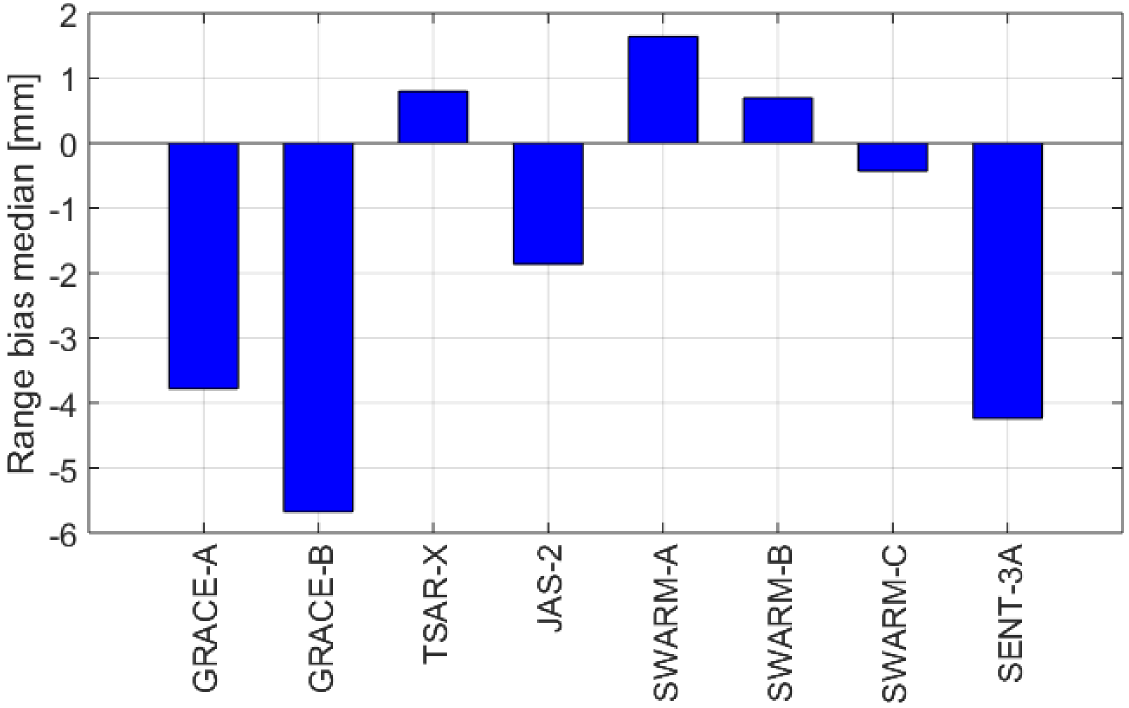
In SLR-PPP (test3) SLR station coord. are in <u>IGS14</u>

CoM vector w.r.t. CoF represents geocenter motion, but to what extent IGS14 and SLRF2014 are consistent

Importance of proper SLR station bias calibration for LEOs



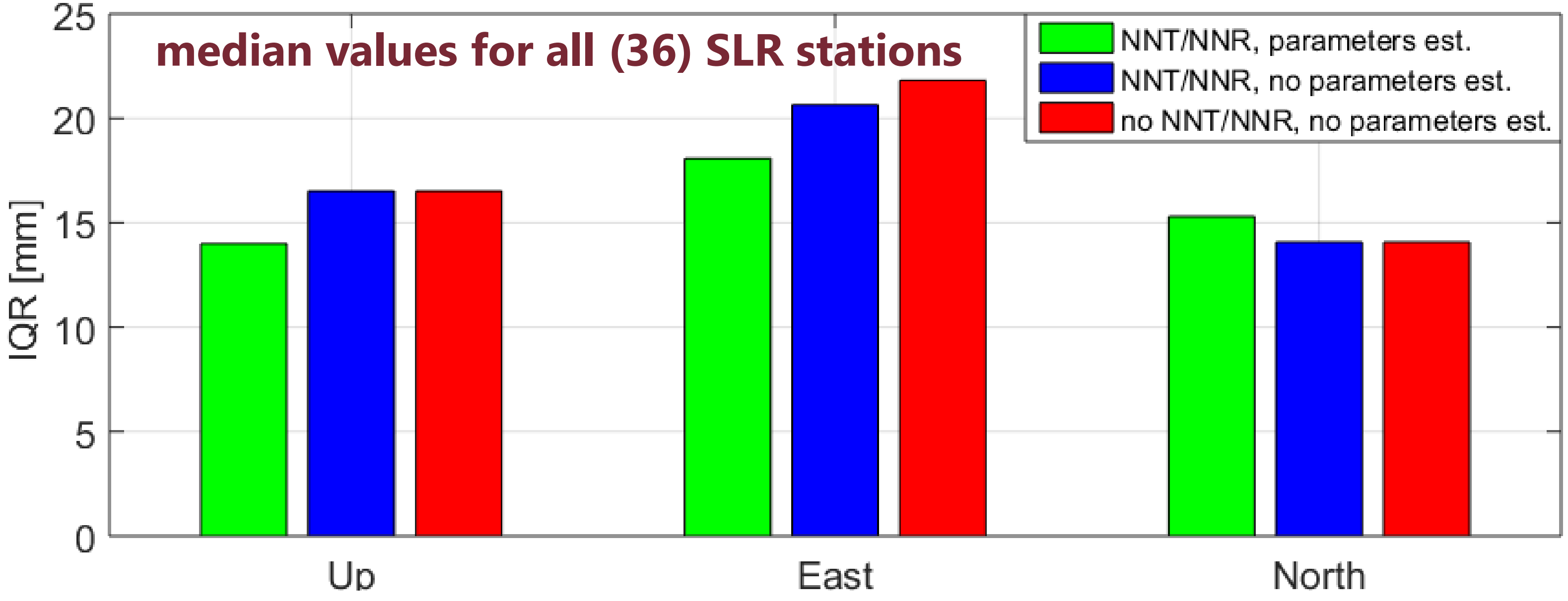
Example of SLR residuals to Sentinel-3A GPS based orbits without and with bias calibration



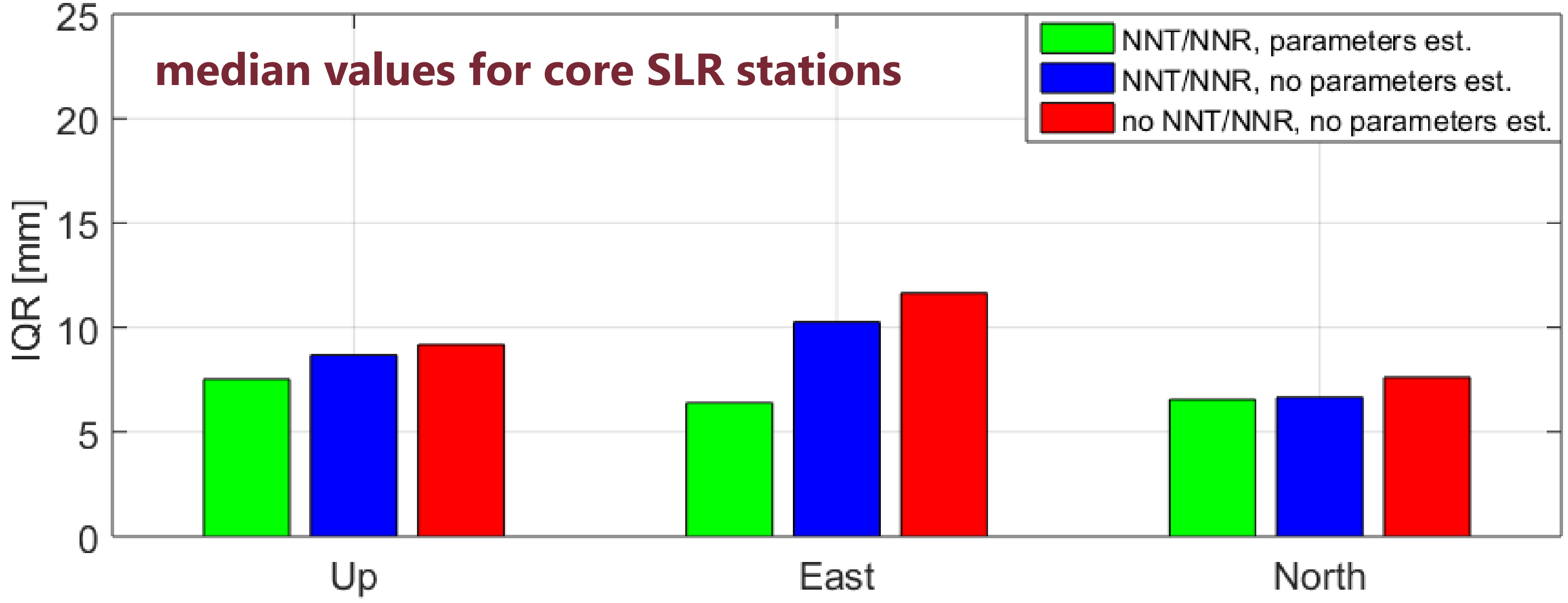
Each satellite requires different bias correction

RESULTS

TEST 1: A different constraining for LEOs



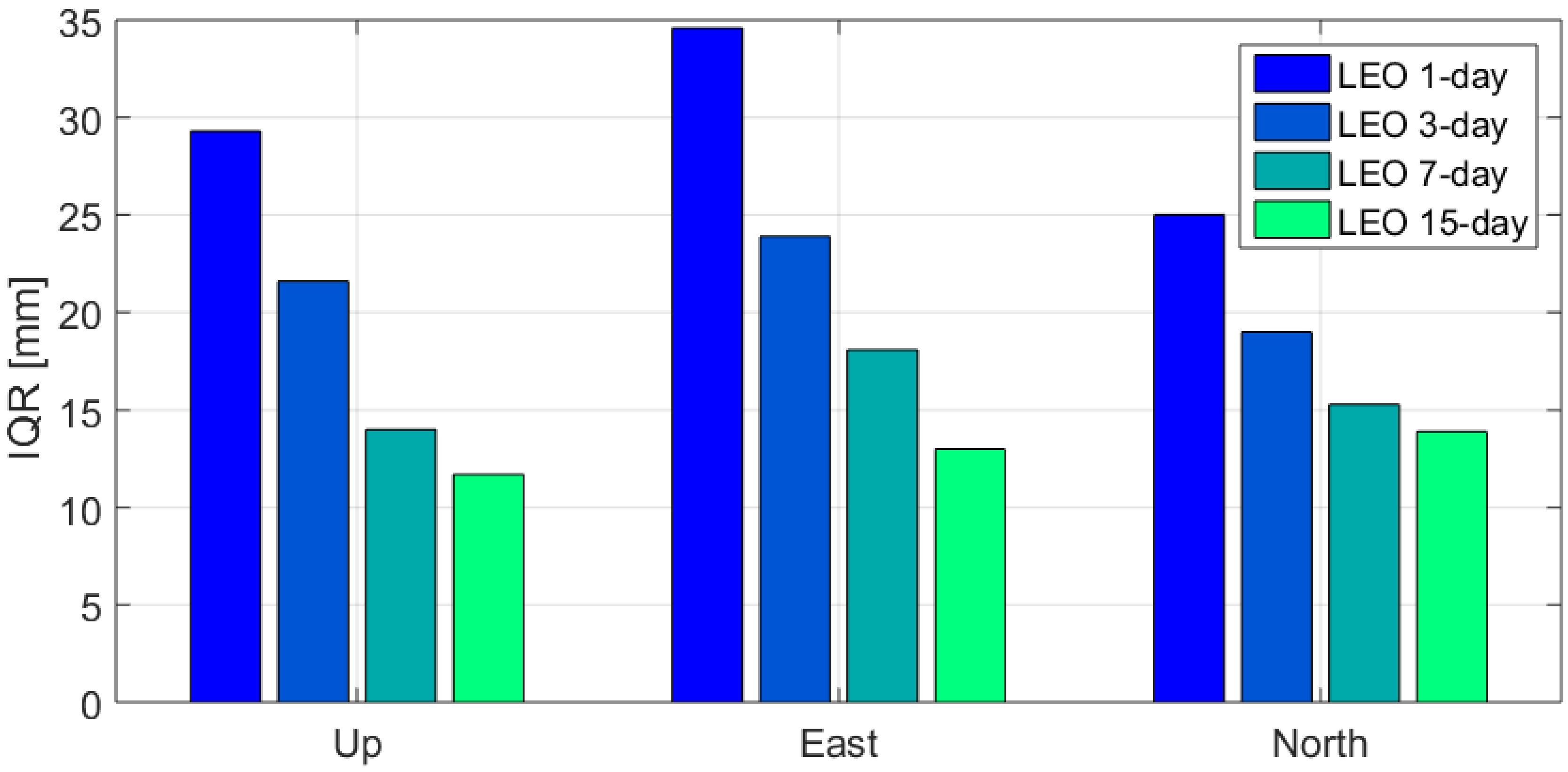
The positioning of **all SLR stations** with the accuracy at the level of **less than 22 mm,** even without network constraining



The positioning of **core SLR stations** with the accuracy at the level of **10 mm is possible!**
Even without network constraining (blue) provides proper station coordinates (8-12mm-top sites)

Core stations: Yarragadee, Greenbelt, Matera, Hartebeesthoek, Haleakala, Zimmerwald, Mt Stromlo, Graz, Herstmonceux, Potsdam

TEST 2: A different number of accumulated 1-day orbits- LEO



Different number of accumulated orbits median values for all (36) stations

Statistics for all SLR sites

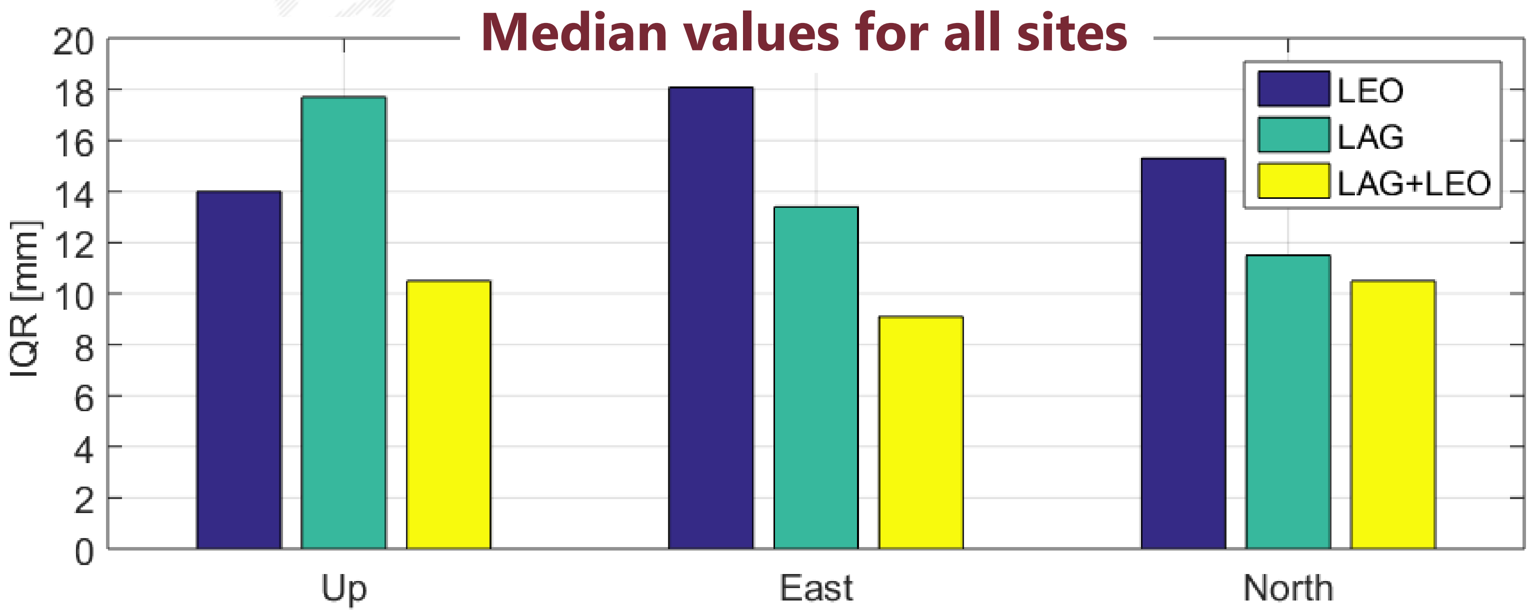
1-day, 3-day LEO solutions are insufficient for high-quality coordinates

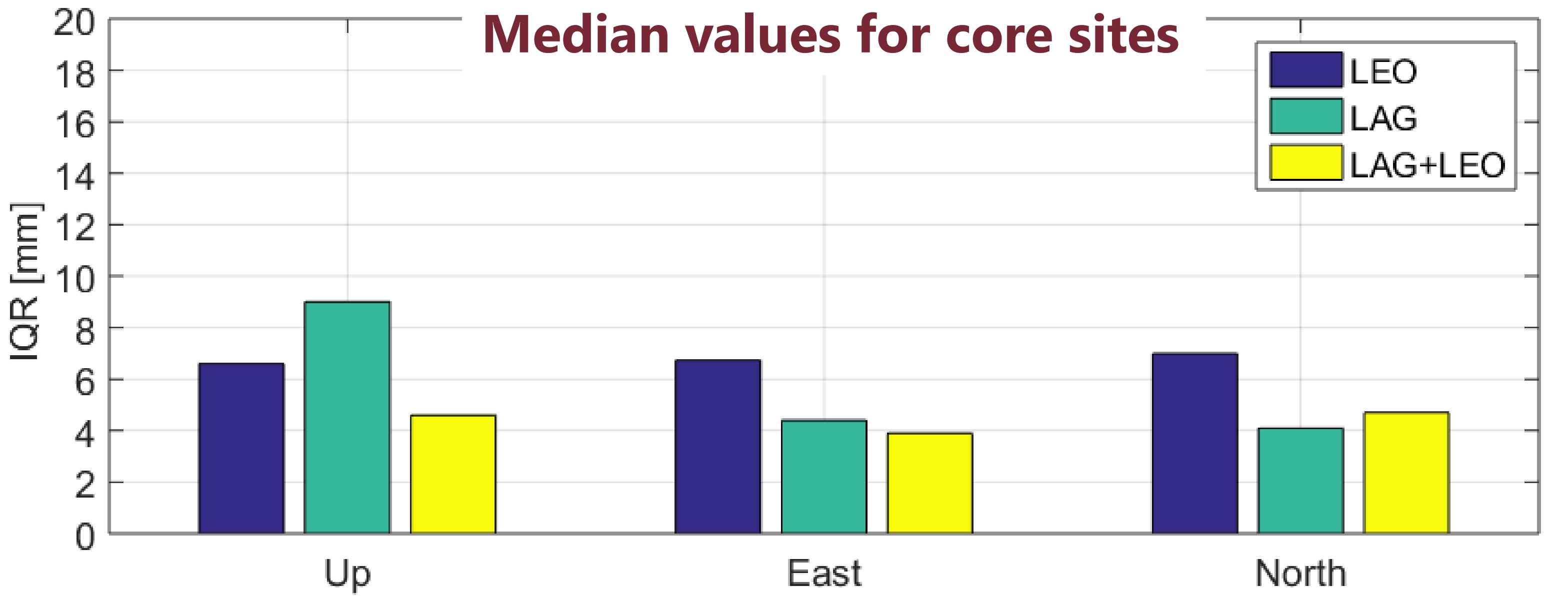
Good global coverage can be achieved in **7-day solutions**

Station coordinates (w.r.t ITRF2014)

Combined solution results and comparision

Station coordinates
(w.r.t ITRF2014)





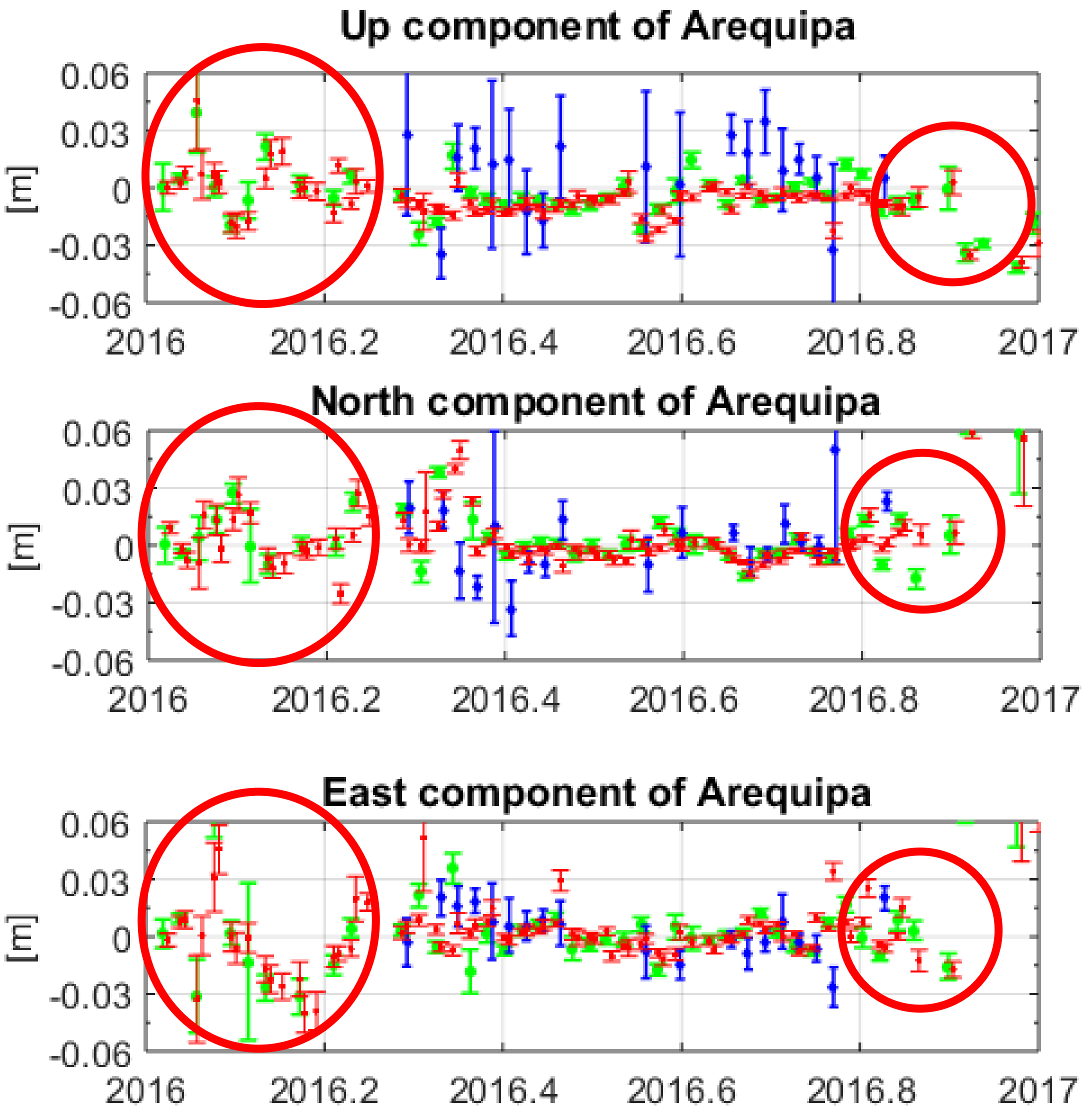
Determination strategy:

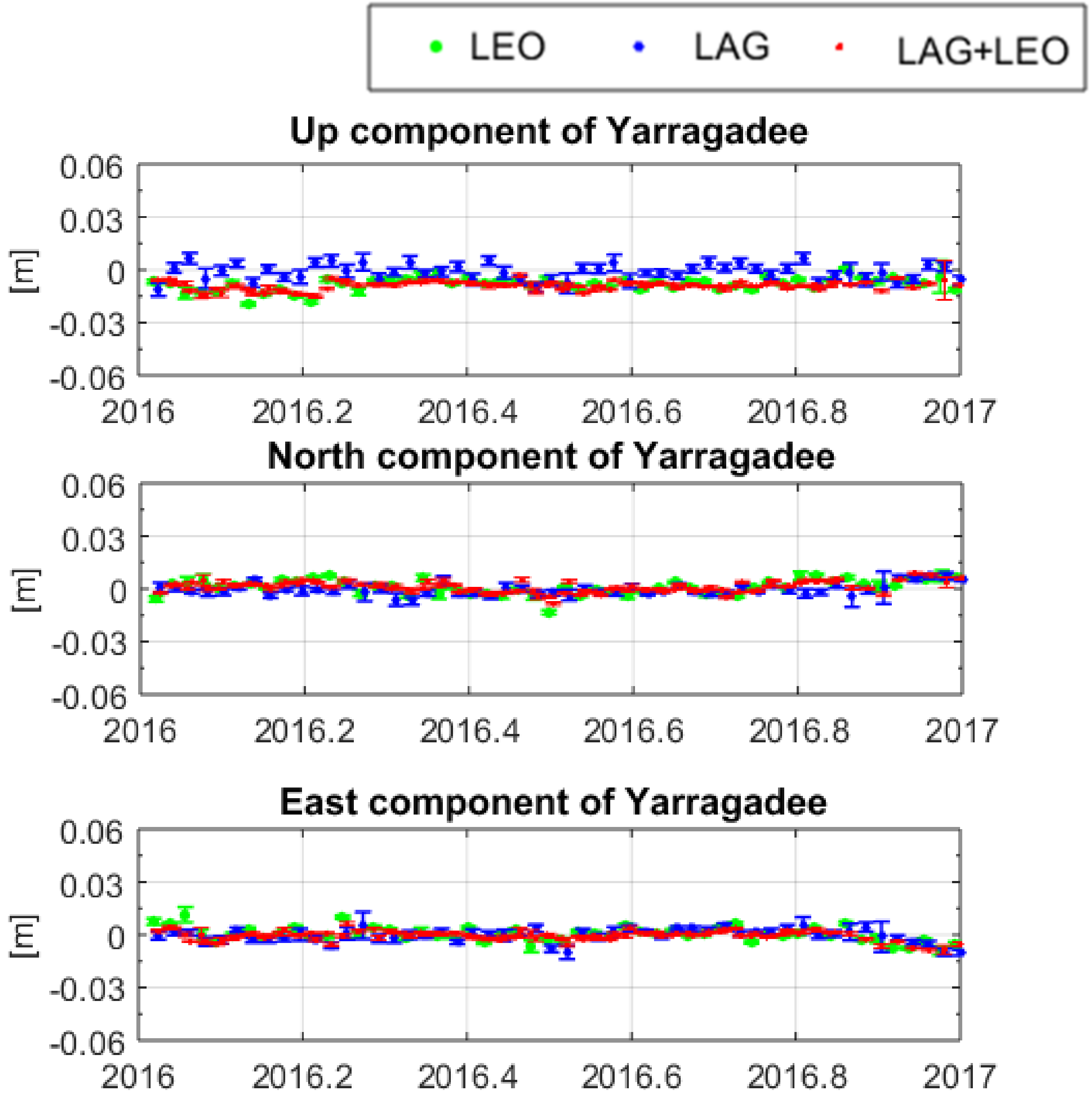
- NNT/NNR with estimation of parameters
- 7-day accumulated orbits
- Introduction of annual range bias for LEOs in all solutions
- Weighting of observations in LAG+LEO solution (σ=10mm for LAG, σ=20mm for LEOs)

SLR sites statistics

- LEOs are slightly better for the Up component
- LAGEOS is better for the horizontal components
- **Best results** for all components in the **combined solution**

Number of obs. increase





LEOs-only solutions when LAGEOS not tracked- number of obs. increase

Station coordinate repeatability for Yarragadee falls between 5 and 11 (IQR) mm for individual components.

Summary

SLR stations have been providing **observations to a large number** of new active **LEOs and GNSS**

SLR observations to active LEO satellite require a **proper station bias calibration**

SLR data and high-quality GPS-based orbits of LEOs allow for the determination of **station coordinates with the accuracy of 10 mm** (core sites), even without network constraining

Reference frame realization based on SLR measurements to LEOs is possible

Best results are obtained from the combined LAGEOS+LEOs solution

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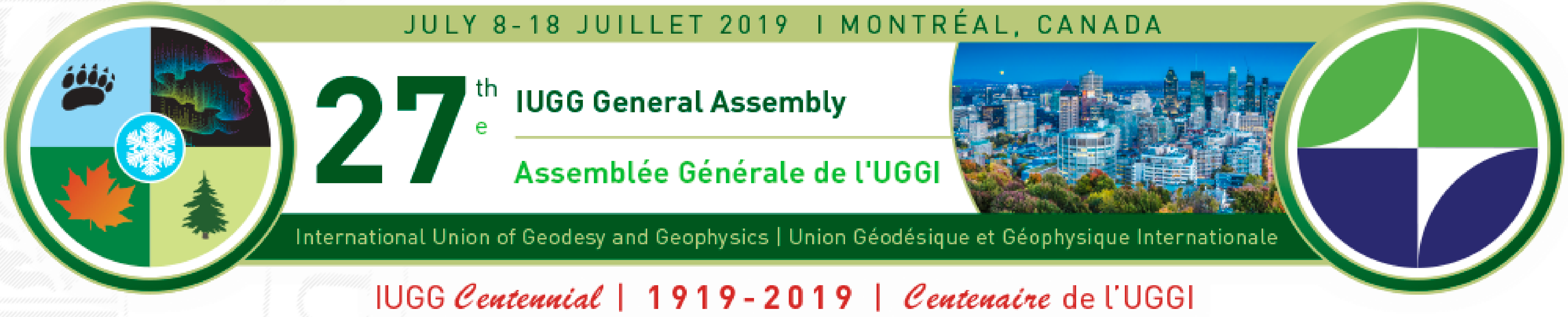

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