Tracking of GNSS satellites – usage in the GNSS community

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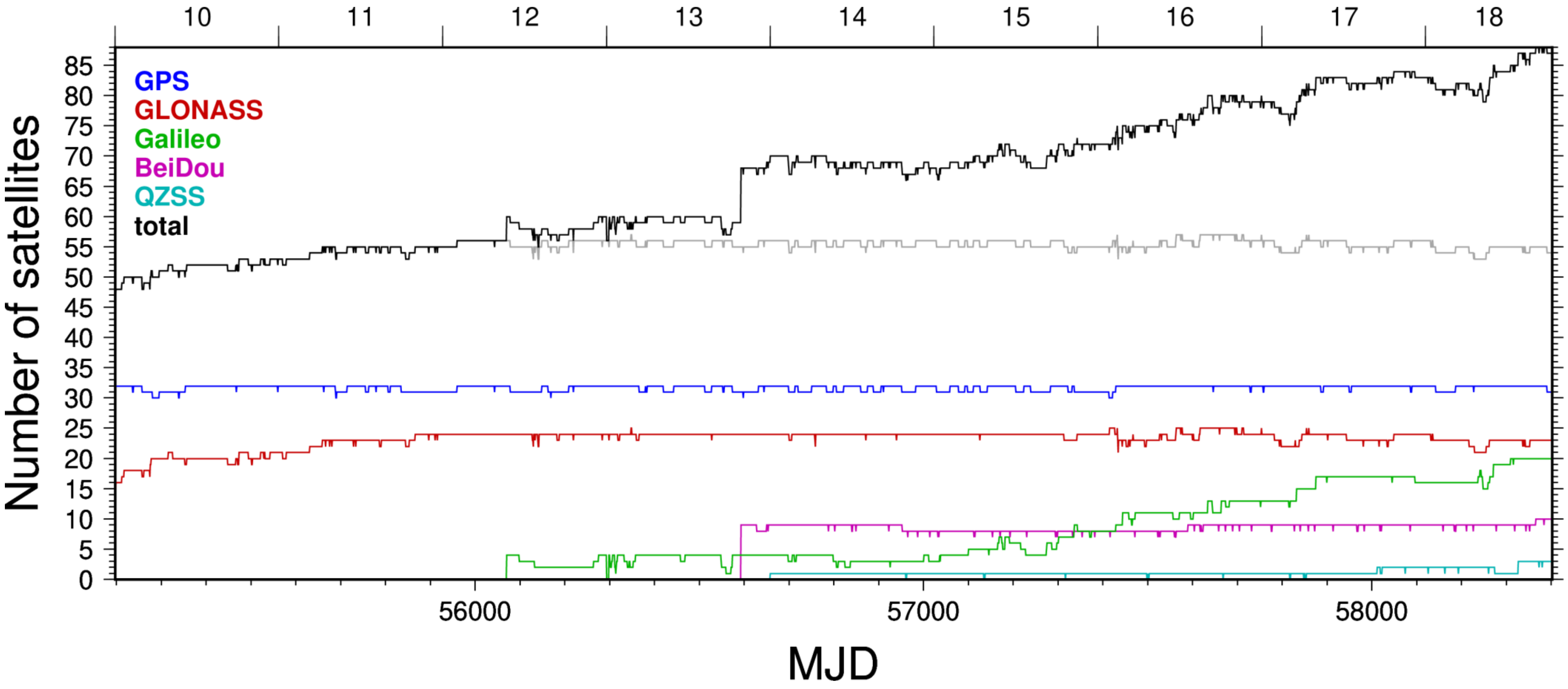
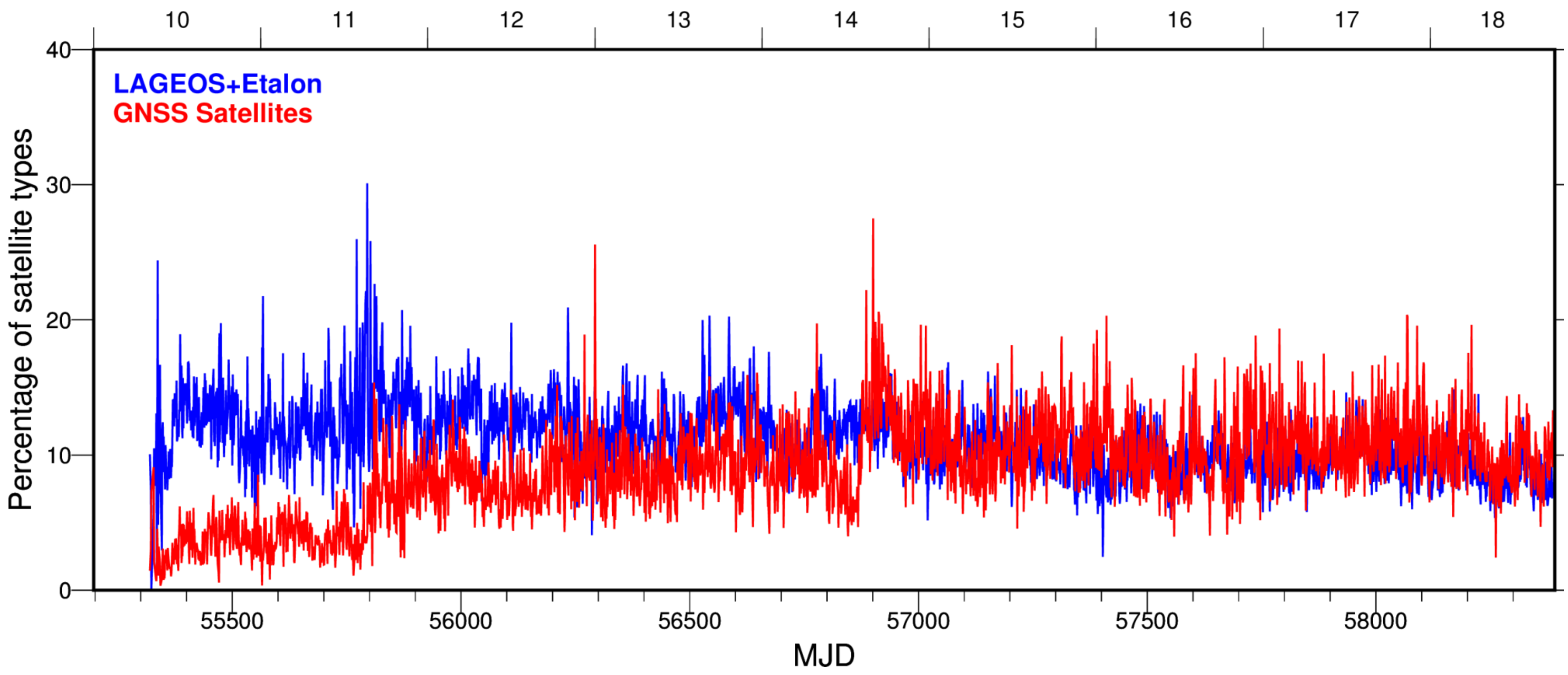
Development of the GNSS constellations



Number of satellites extracted from the CODE final/CODE-MGEX solution

ILRS tracking to GNSS satellites



Statistics extracted from the CRD-NP records as provided by CDDIS.

Usage of GNSS-Measurements to GNSS satellites

IGS INTERNATIONAL GNSS SERVICE

The ILRS takes a big effort to track GNSS satellites. Currently **about 10%** of the measurements (same amount as for LAGEOS+Etalon).

Current and potential future applications for these measurements:

1. Validation of microwave derived orbits of GNSS satellites
   Focus of this presentation
2. Combined processing of GNSS- and SLR-measurements on observation level
   Andritsch et al.: The effect of SLR tracking scenarios to GNSS satellites in a combined solution
3. Potential future applications:
   - Improvements of orbits in GEO (IGSO?) by combined analysis of SLR and MW data

Long time series for GPS35 & GPS36

For the two GPS satellites long time series of SLR measurements exists.

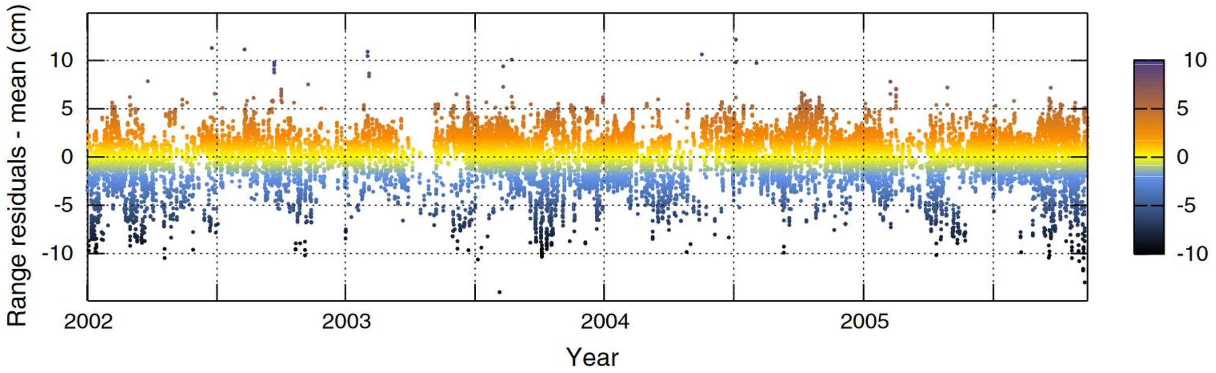


Fig. 3. Color-coded SLR range residuals (cm) minus mean value derived from CODE final orbits for GPS satellites PRN G05 and G06. (For interpretation of the references in color in this figure legend, the reader is referred to the web version of this article.)

Urschl, C., G. Beutler, W. Gurtner, U. Hugentobler, S. Schaer; 2007: **Contribution of SLR tracking data to GNSS orbit determination.** Advances in Space Research, vol. 39(10), pp. 1515-1523, DOI 10.1016/j.asr.2007.01.038.

Long time series for GPS35 & GPS36

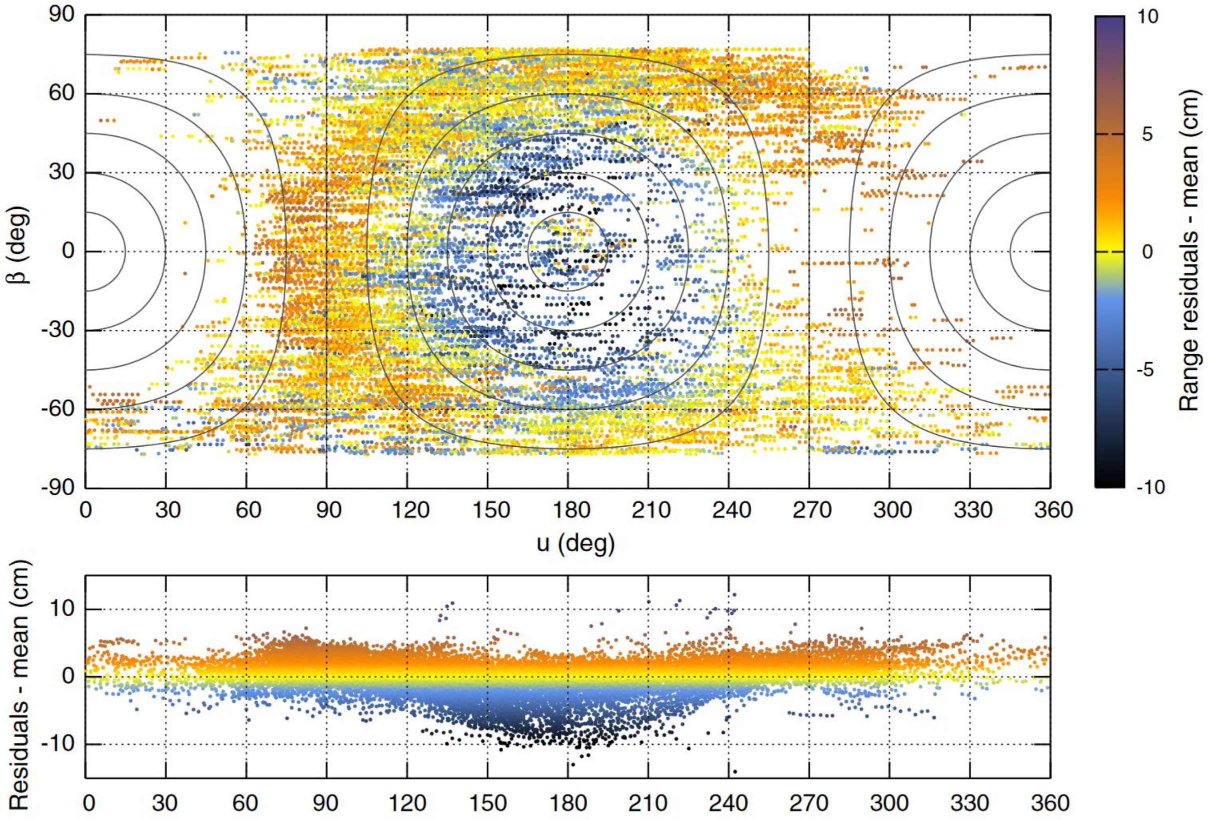
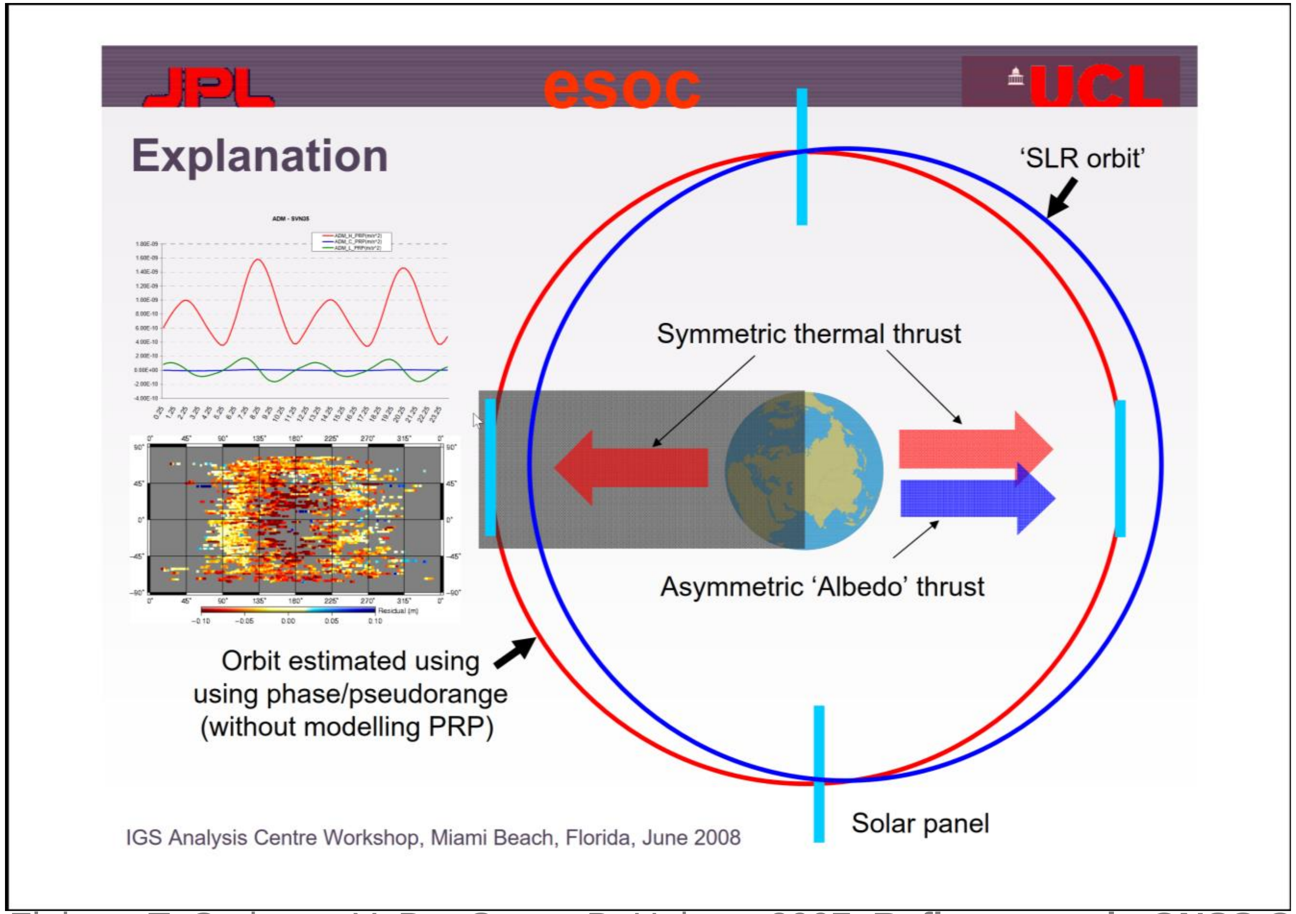


Fig. 4. Color-coded SLR range residuals (cm) minus mean value derived from CODE final orbits for the GPS satellites PRN G05 and G06 in the (u, β)-coordinate system; *bottom*: projection onto *u*-axis; circles represent phase angle E, 15° spacing, 0° at center, 180° at edges. (For interpretation of the references in color in this figure legend, the reader is referred to the web version of this article.)

Urschl, C., G. Beutler, W. Gurtner, U. Hugentobler, S. Schaer; 2007: **Contribution of SLR tracking data to GNSS orbit determination.** Advances in Space Research, vol. 39(10), pp. 1515-1523, DOI 10.1016/j.asr.2007.01.038.

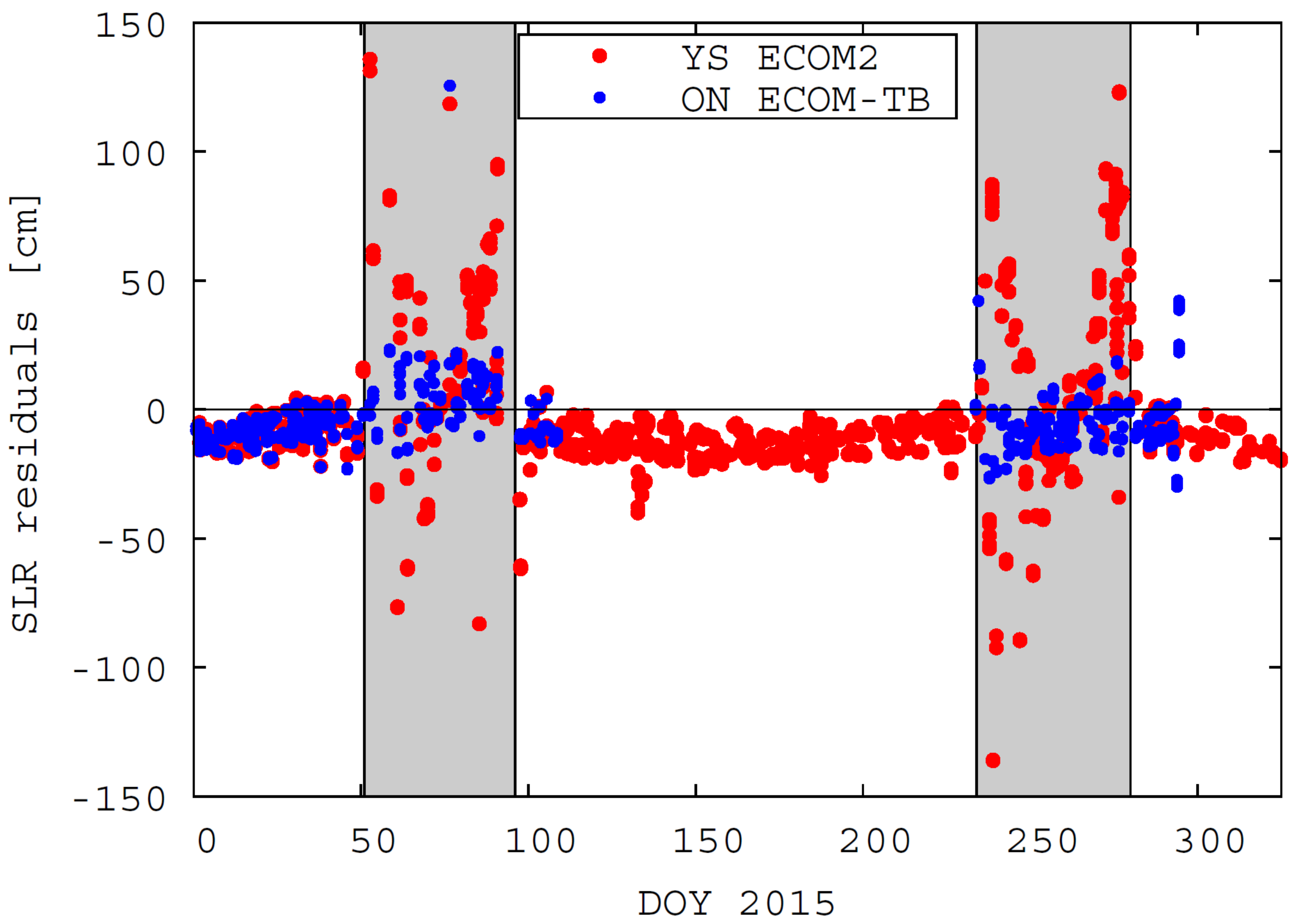
Long time series for GPS35 & GPS36



Ziebart, M., A. Sibthorpe, C. Flohrer, T. Springer, Y. Bar-Sever, B. Haines; 2007: **Refinements in GNSS Orbit Modelling.** International GNSS Service Analysis Center workshop 2008, Miami Beach, FL, USA, June 2-6, 2008.

SLR measurements in the frame of MGEX

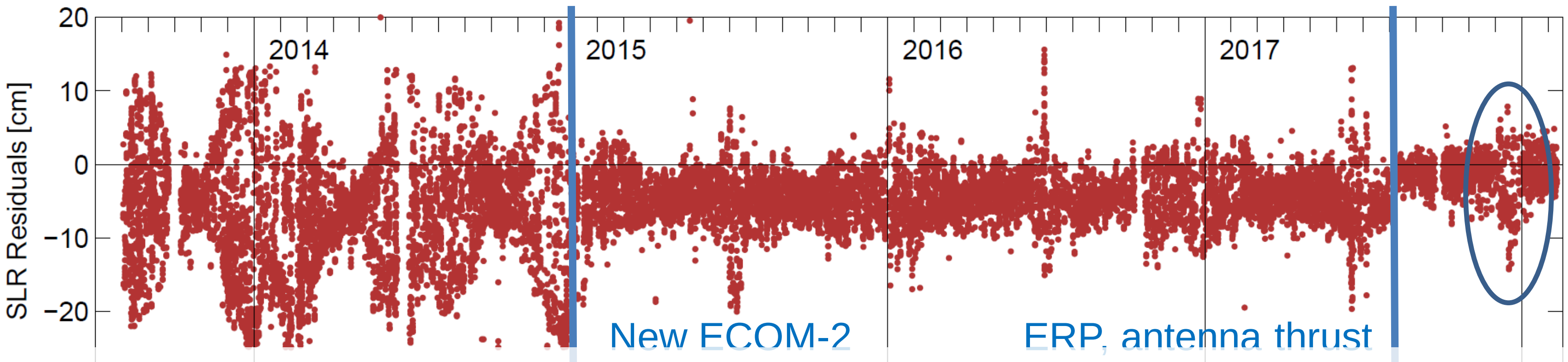
- SLR residuals to orbits are an essential tool when developing new orbit models
- Development of a new empirical orbit model for GNSS satellites during orbit normal mode



Example from Prange et al.: An Empirical SRP Model for the Orbit Normal Mode
Presented at the IGS Workshop 2018 in Wuhan.

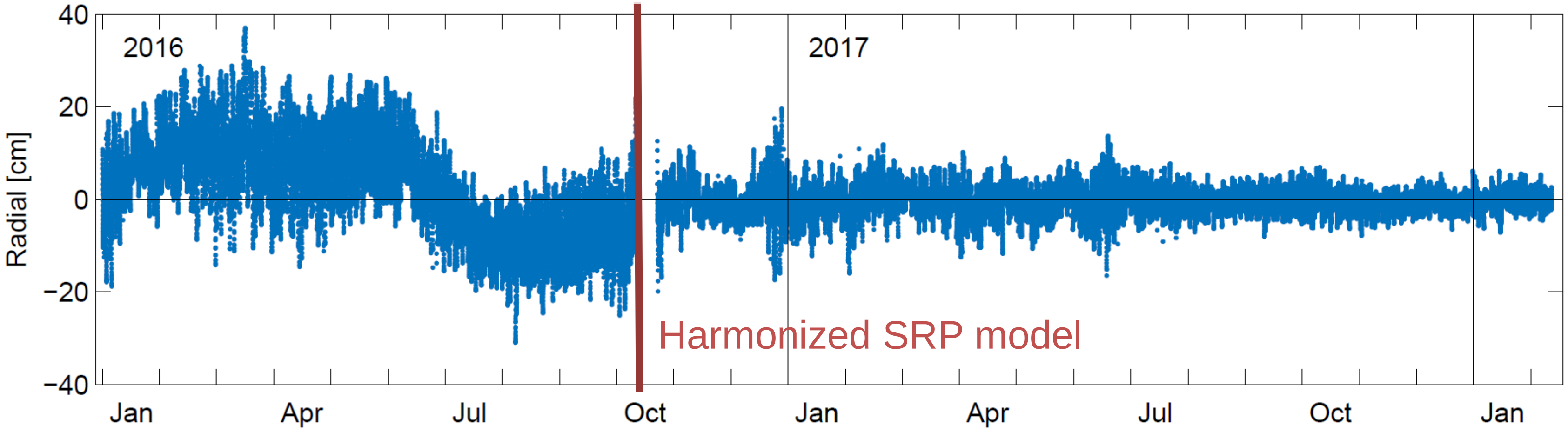
SLR measurements in the frame of MGEX

SLR Residuals CODE MGEX product for Galileo E102



These graphics are regularly produced and published at the MGEX-page as a feedback to the analysis centers (http://www.igs.org/mgex).

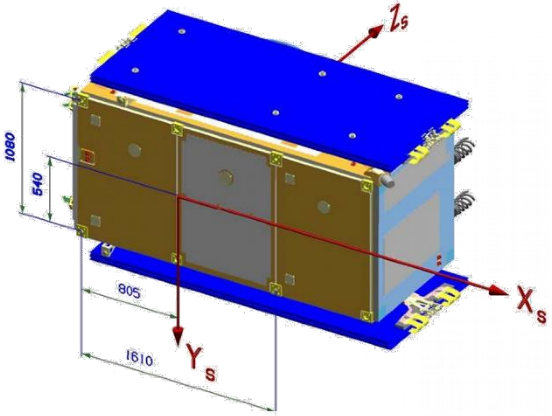
Radial orbit difference CODE-GFZ MGEX products



Thermal radiation forces for Galileo satellites

IOV

FOC



Galileo satellites (Galileo Satellite Metadata, URL: https://www.gsc-europa.eu).

The resulting forces are asking for additional parameters in an empirical force model. For the selection of the model components and their impact on the orbit the SLR measurements are very helpful.

Radiators are installed on

- IOV satellites: +X, +Y, -Y
- FOC satellites: +X, +Y, -Y and -Z

D. Sidorov, R. Dach, L. Prange, A. Jäggi: Improved orbit modelling of Galileo satellites during eclipse seasons. Presented at IGS workshop, Wuhan, China, 29 Oct. - 02 Nov. 2018.

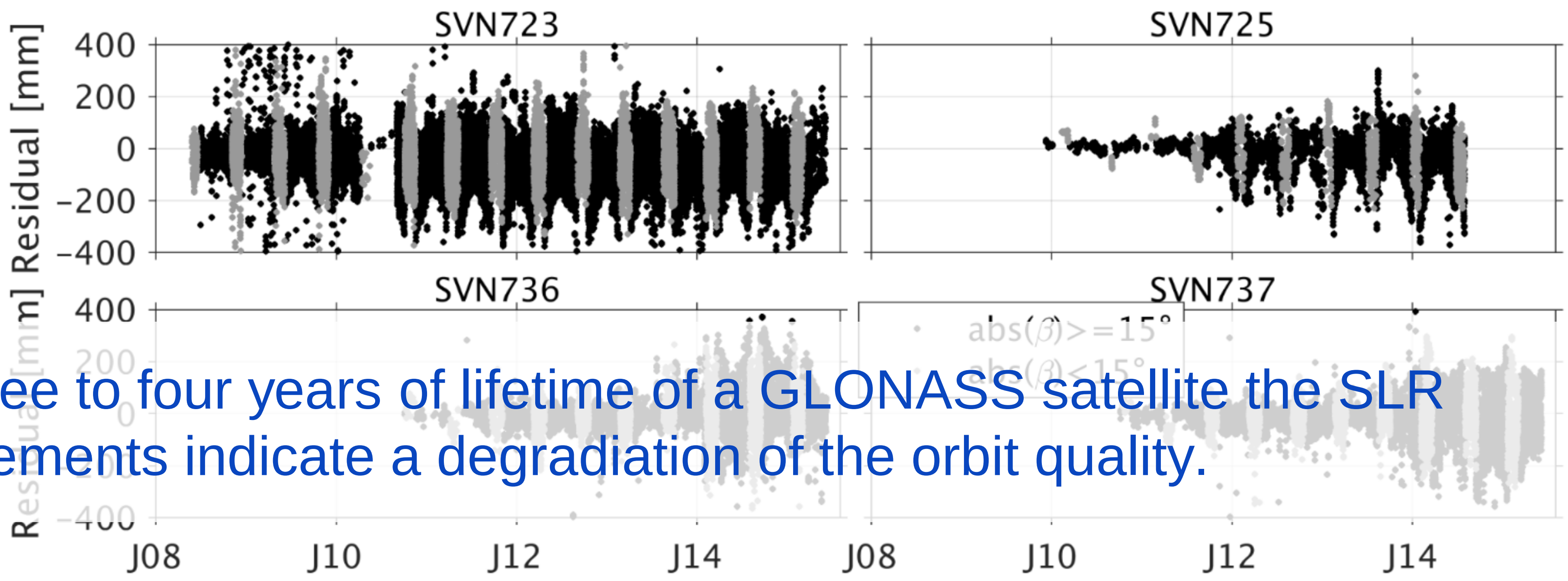
Optimal tracking for «SLR validation»

It is not difficult to derive the optimal tracking scenario for this purpose:

- QZSS in orbit normal mode
- Galileo thermal radiation effects during eclipse
- MGEX monitoring

In particular the Galileo example was triggered by the SLR-residuals in the MGEX monitoring.

The GLONASS-issue



After three to four years of lifetime of a GLONASS satellite the SLR measurements indicate a degradiation of the orbit quality.

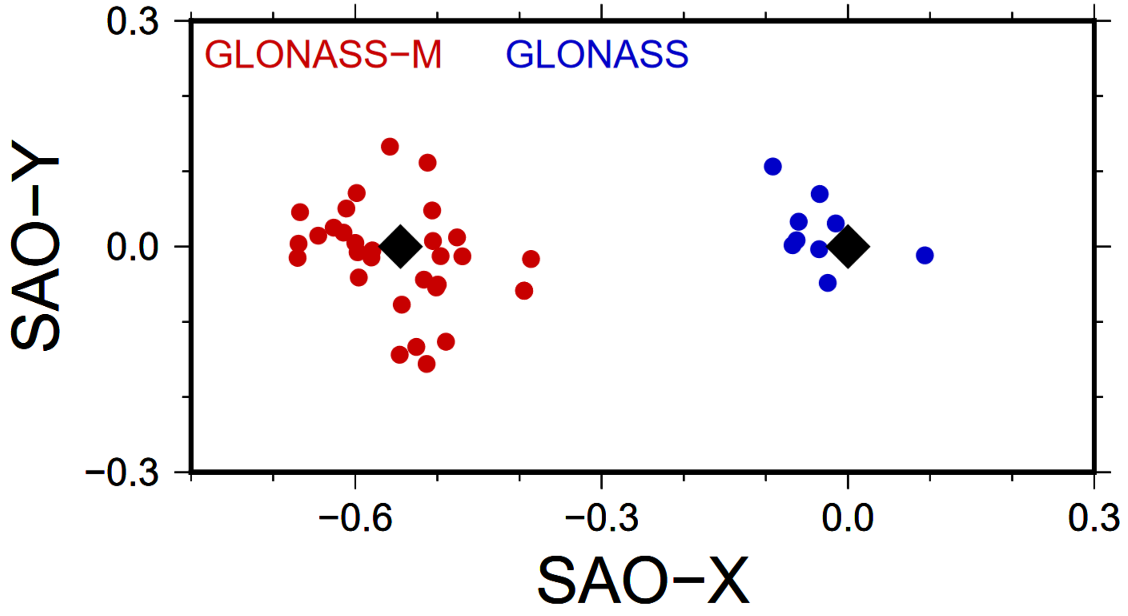
Figure 2: SLR residuals w.r.t. 3-day GLONASS orbits between January 2008 and May 2015 using the extended ECOM. Observations during satellite eclipses (solar beta angle smaller than 15°) are depicted in gray.

Grahsl, A., A. Sušnik, L. Prange, D. Arnold, R.Dach, A. Jäggi; 2016: GNSS orbit validation activities at the Astronomical Institute in Bern. ILRS Workshop 2016, Potsdam, Germany, 9 14 October, 2016.

The GLONASS-issue

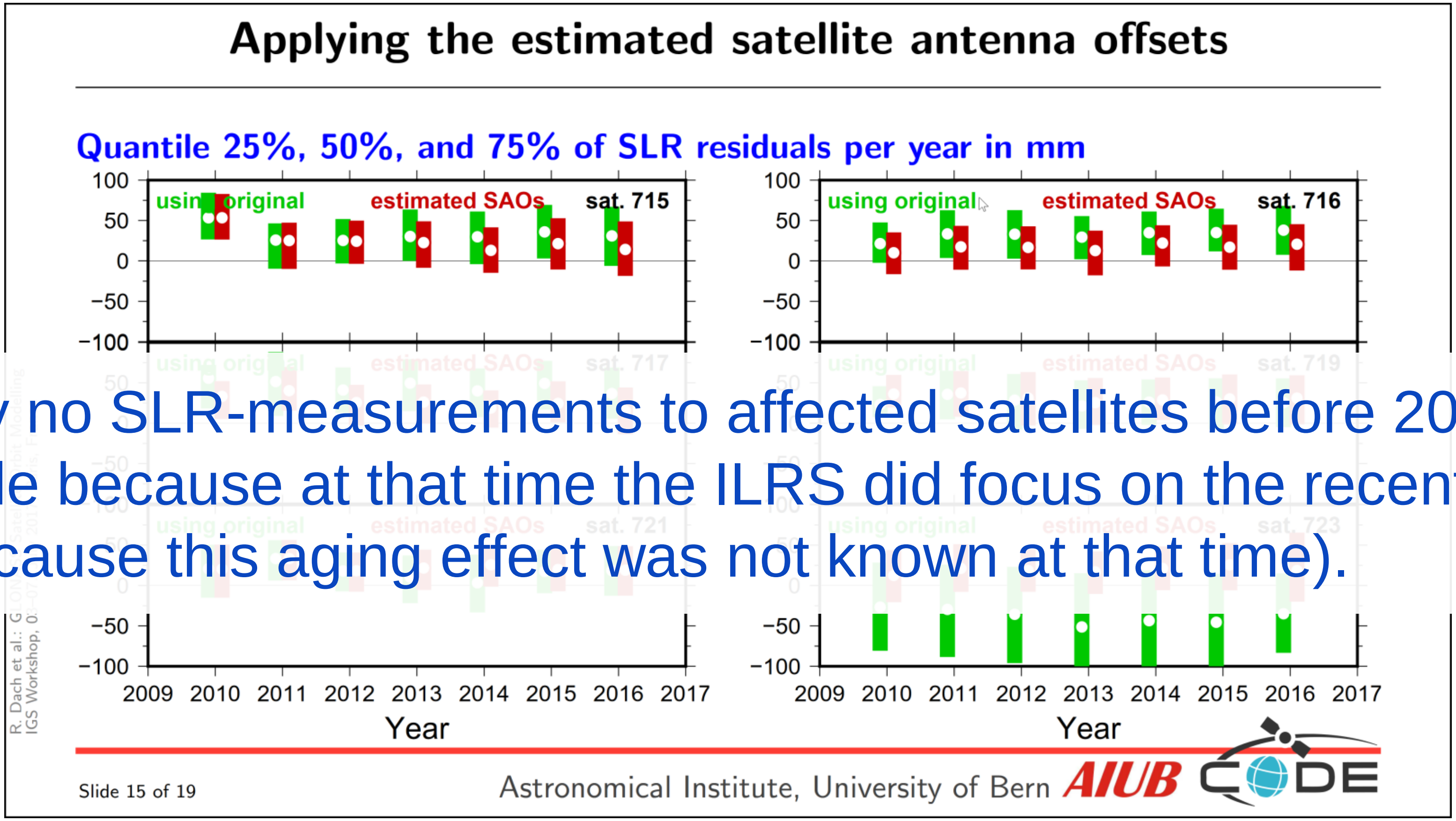
- A significant change in the horizontal satellite antenna offsets was detected at the epochs with the increase of the SLR residuals.

- Even if it is not clear what really happens at these satellites the use of the alternative satellite antenna offsets helps to improve the orbits.



Dach, R., A. Sušnik, A. Grahsl, A. Villiger, D. Arnold, L. Prange, S. Schaer, A. Jäggi; 2017: GLONASS Satellite Orbit Modelling. International GNSS Service (IGS) Workshop 2017, Paris, France, July 3-7, 2017.

The GLONASS-issue



Unfortunately no SLR-measurements to affected satellites before 2010 have been available because at that time the ILRS did focus on the recently launched satellites (because this aging effect was not known at that time).

Dach, R., A. Sušnik, A. Grahsl, A. Villiger, D. Arnold, L. Prange, S. Schaer, A. Jäggi; 2017: GLONASS Satellite Orbit Modelling. International GNSS Service (IGS) Workshop 2017, Paris, France, July 3-7, 2017.

Station-dependent effects when tracking GNSS-sat.

- Also the SLR-stations show systematic effects when tracking GNSS satellites.

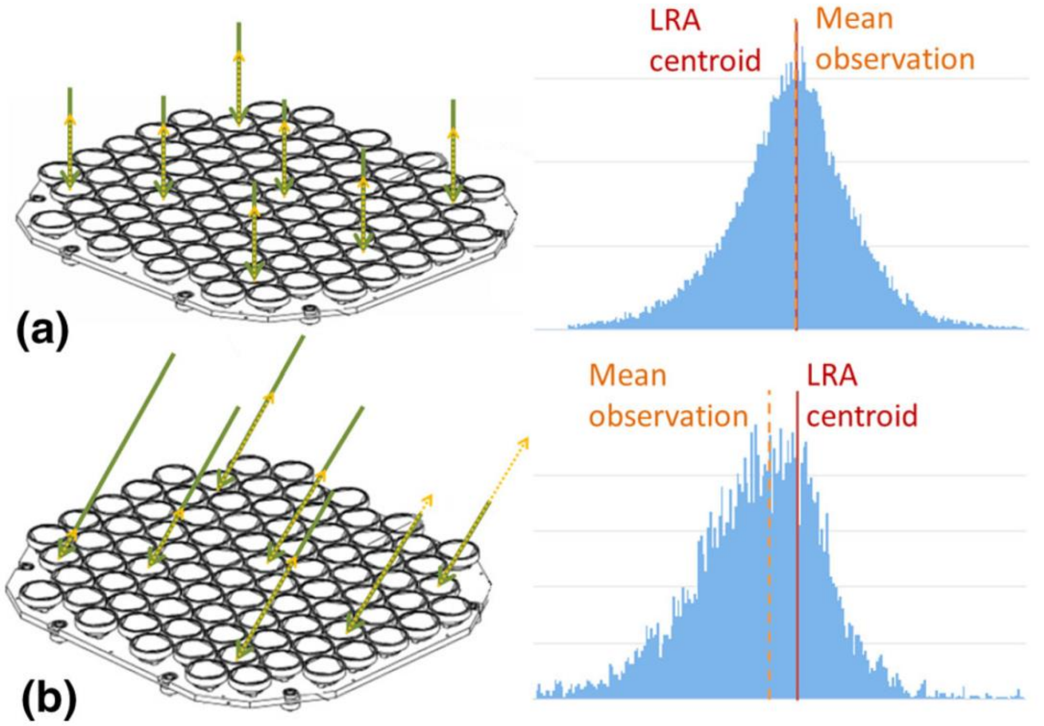


Fig. 7 Satellite signature effect for multi-photon detectors: **a** the nadir angle is 0 and the LRA centroid coincides with the mean observation, **b** the LRA is inclined and the detection timing is defined at some threshold level at the leading edge of the return pulse; as a result, the mean registered range is shorter than the actual one

Sośnica, K., L. Prange, K. Kaźmierski, G. Bury, M. Drożdżewski, R. Zajdel, T. Hadaś; 2017: Validation of Galileo orbits using SLR with a focus on satellites launched into incorrect orbital planes. Journal of Geodesy, vol. 92(2), pp 131-148. DOI 10.1007/s00190-017-1050-x.

Station-dependent effects when tracking GNSS-sat.

- Also the SLR-stations show systematic effects when tracking GNSS satellites.
- The used detector type
  - Micro-Channel Plate (MCP),
  - Photo-Multiplier Tube (PMT),
  - Compensated Single-Photon Avalanche Diode (C-SPAD),

  has a systematic effect on the obtained measurement.

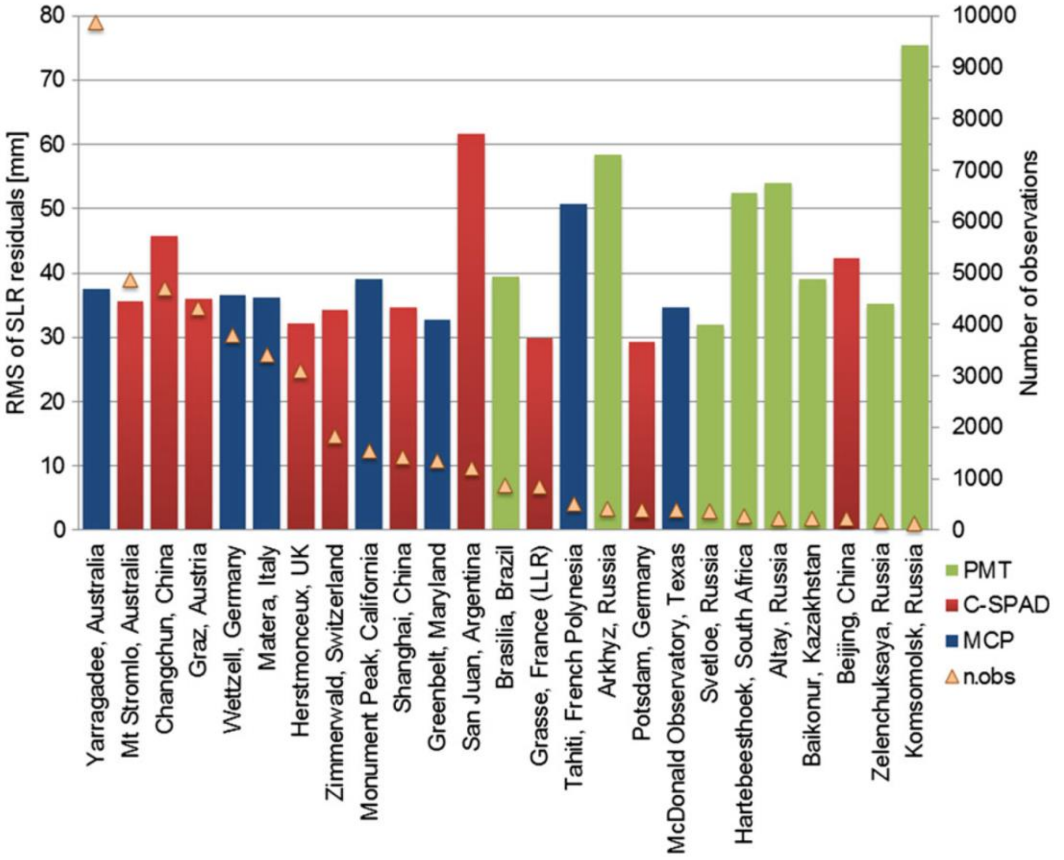


Fig. 8 RMS of SLR residuals and the number of observations to Galileo collected by different SLR stations

Sośnica, K., L. Prange, K. Kaźmierski, G. Bury, M. Drożdżewski, R. Zajdel, T. Hadaś; 2017: Validation of Galileo orbits using SLR with a focus on satellites launched into incorrect orbital planes. Journal of Geodesy, vol. 92(2), pp 131-148. DOI 10.1007/s00190-017-1050-x.

Summary

Requirements (wishes) regarding the tracking scenarios from the different applications:

- Track the same satellite for a long time in order to find and reduce systematic effects and to detect (so far) unknown effects that should be considered when developing orbit models.
- Track a certain group of satellites during dedicated periods.
- All stations should track one and the same satellite at one arc in order to detect/monitor also systematics in the SLR tracking stations.

These requirements contradict each other. With the current tracking scheme a reasonable compromise is achieved.

Summary

- The different examples of using SLR-measurements for GNSS-orbit validation have shown the huge potential and the importance of these measurements.
- The bigger the number of SLR measurements is the better systematic effects can be detected in the GNSS orbit modelling.
  Otherwise it takes longer until such deficiencies become detectable.
- Each measurement counts! **Thank you for the effort taken so far!**
- That's why the IGS on behalf of the scientific GNSS community asks the ILRS workshop to adopt the following recommendations:

IGS Recommendation to the ILRS

Recognizing

the increasing load on ILRS stations caused by the increasing number of GNSS satellites equipped with laser retroreflectors

and

the priority of geodetic laser satellites and as well as the needs from other missions;

considering, furthermore,

the importance of SLR tracking for orbit validation and analysis of GNSS satellites

as well as

the need to achieve a homogeneous coverage of all GNSS constellations, satellite types, orbital planes and individual spacecraft;

the IGS recommends that the ILRS

retains the general prioritization of geodetic laser satellites before GNSS satellites and satellites from other missions

and

on request by the GNSS providers or the GNSS user community gives priority to dedicated campaigns for tracking of selected GNSS satellites at the expense of a reduced background tracking activity

and

uses remaining tracking resources to select and track the remaining GNSS satellites in a randomized manner, where each station can freely select a set of GNSS satellites for tracking on a weekly basis.

IGS Recommendation to the ILRS

Considering

the increasing number of GNSS satellites in geosynchronous and geostationary orbit and the special challenges for determination and validation of the respective orbits

the IGS encourages

the extension of SLR stations supporting high-altitude tracking, specifically in the Asia-Pacific region, and the transition to kHz laser systems enabling shorter normal point duration.