

Satellite co-locations for combined GNSS and SLR analyses

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Overview

1. **Co-locations** at stations and satellites
2. **SLR tracking of GNSS** satellites (GPS and GLONASS)
3. **Results** from combining:
 - GNSS and SLR@GNSS
 - GNSS and SLR@GNSS and SLR@Lageos
- Conclusions and outlook

Co-locations for GNSS and SLR

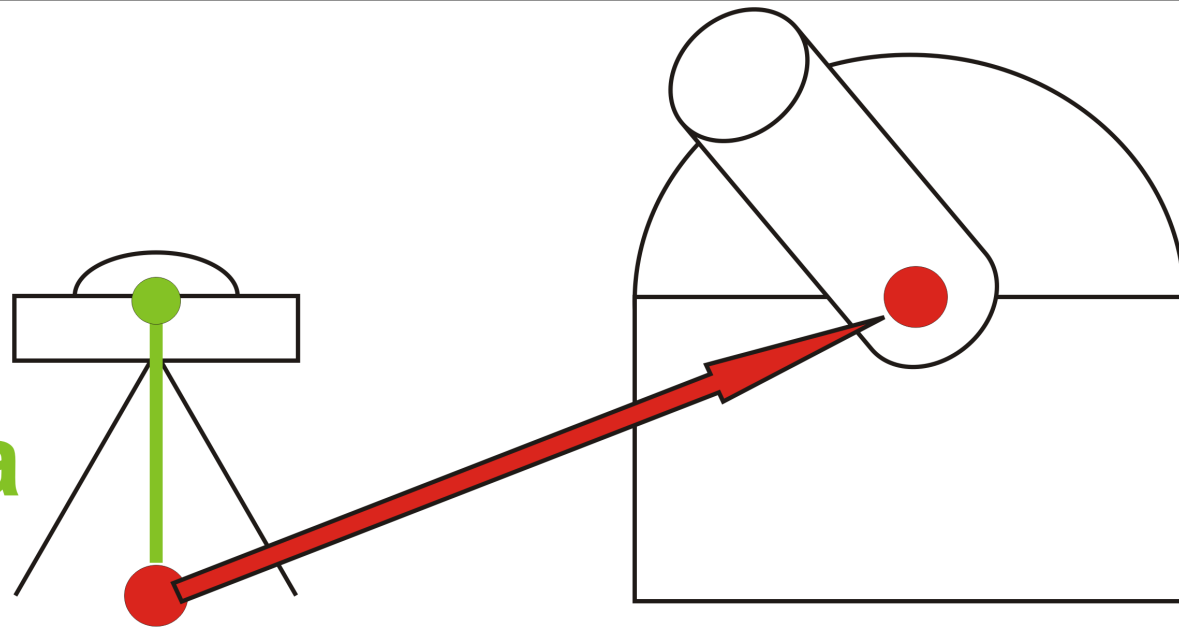
Co-location at stations (e.g., for actual ITRF computation):

- Application of known **local tie** values
- GNSS observations of ground network; SLR observations to Lageos

Problems:

- **Phase center** modelling of GNSS antenna
- **Local ties** (accuracy, transformation local → geocentric)
- **Number** (and distribution) of **co-located GNSS-SLR stations**

Phase
Center
+
Antenna
Height



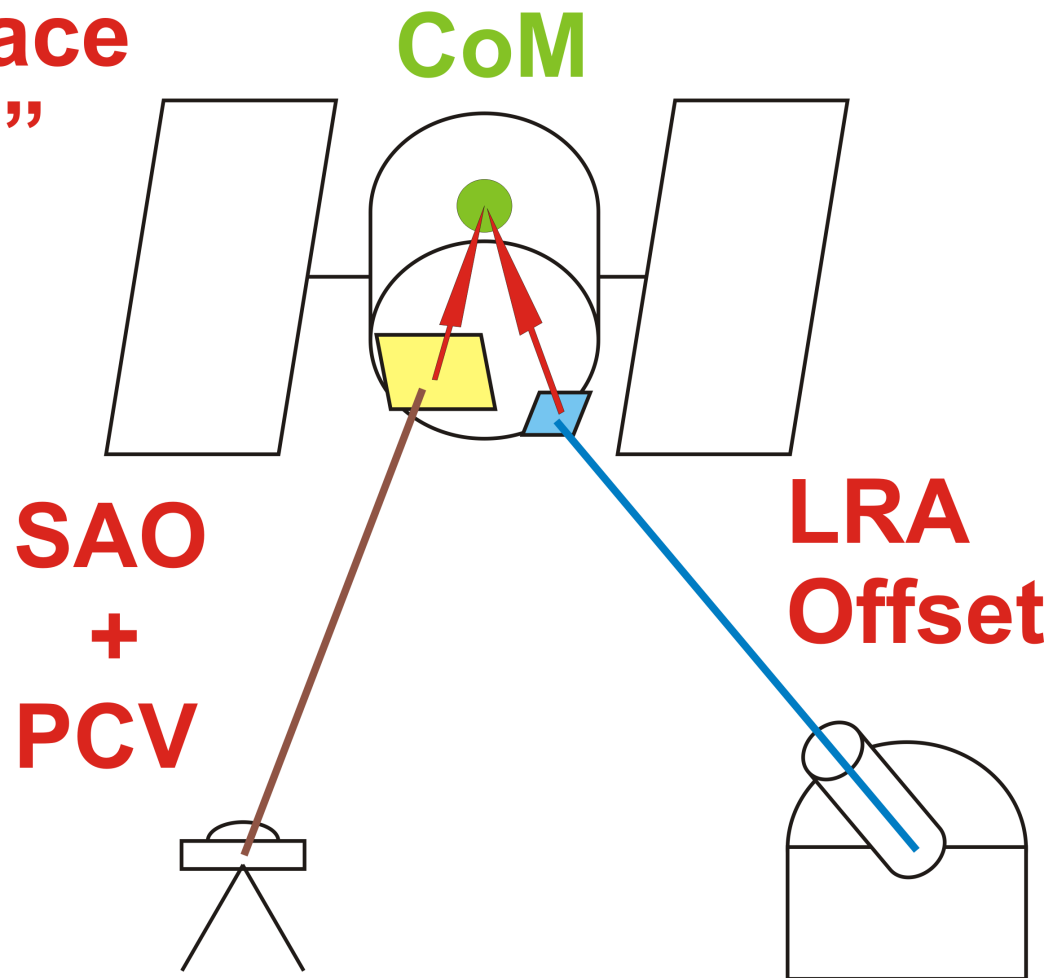
Local Tie

Co-locations for GNSS and SLR

Co-location at GNSS satellites = Transmitting point for GNSS
Reflecting point for SLR (target)

→ **Vectors** of GNSS and SLR reference points **w.r.t. satellite CoM** needed

“Space Tie”



Space Tie =

1. GNSS Satellite Antenna Offsets (**SAO**)
2. GNSS Phase Center Variations (**PCV**)
3. Offsets for Laser Retroreflector Array (**LRA**)

SLR tracking of GNSS satellites

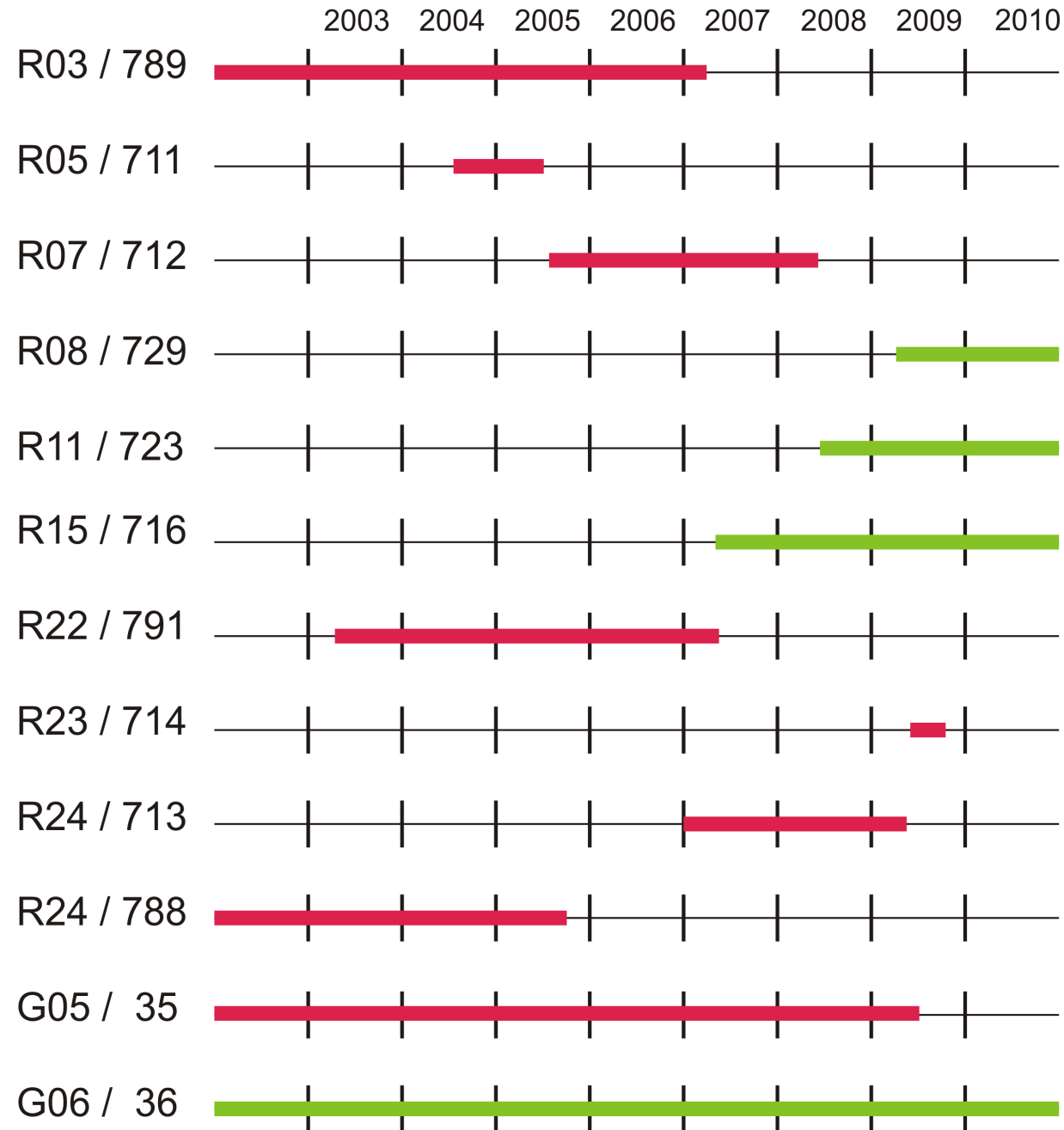
→ Only **2 GPS satellites** are equipped with retro-reflector arrays (G05, G06)

→ **All GLONASS satellites** are equipped with retro-reflector arrays

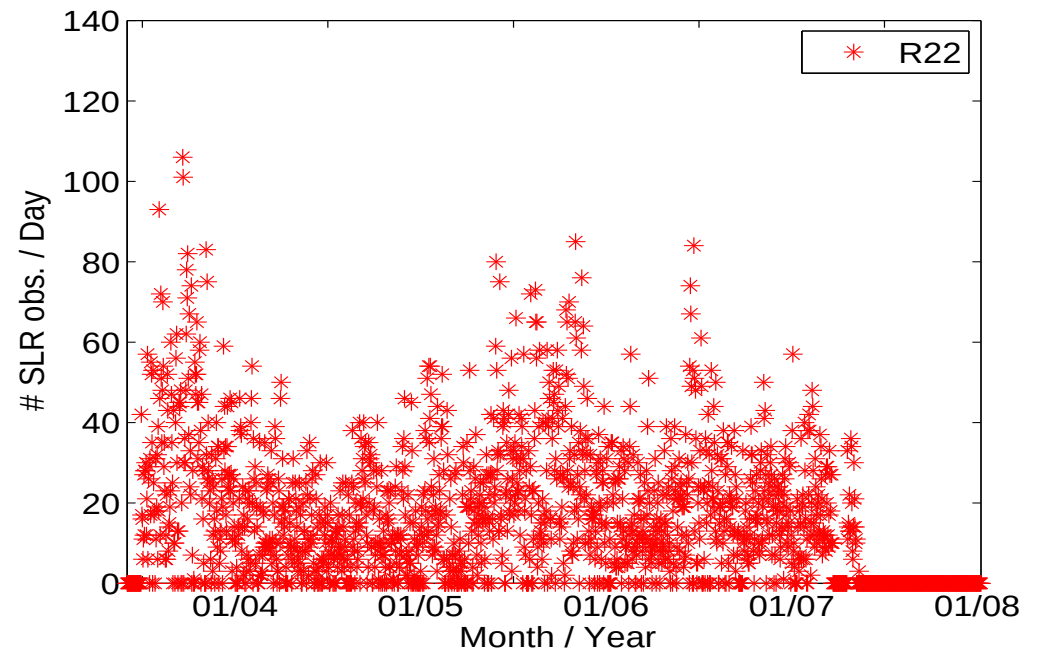
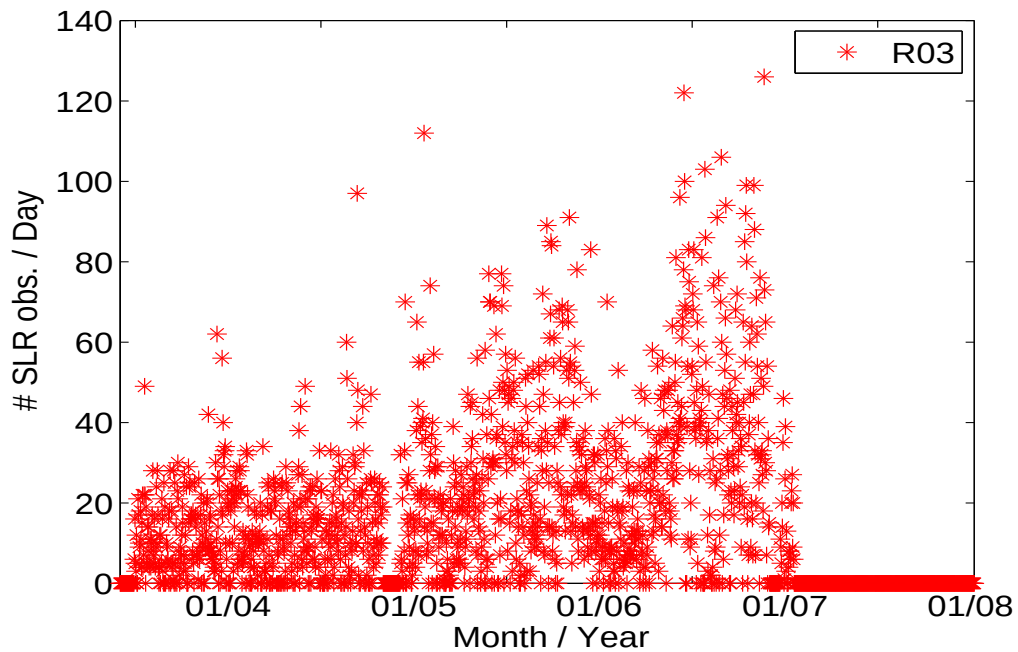
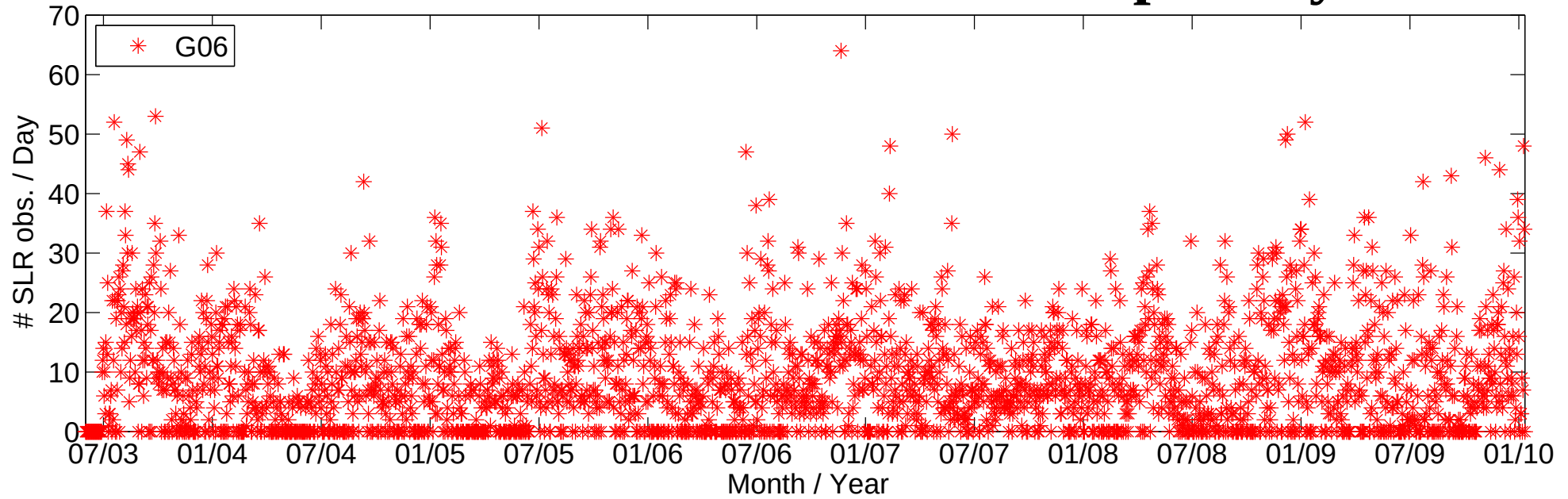
→ SLR tracking for selected GNSS satellites:

2 (1) GPS

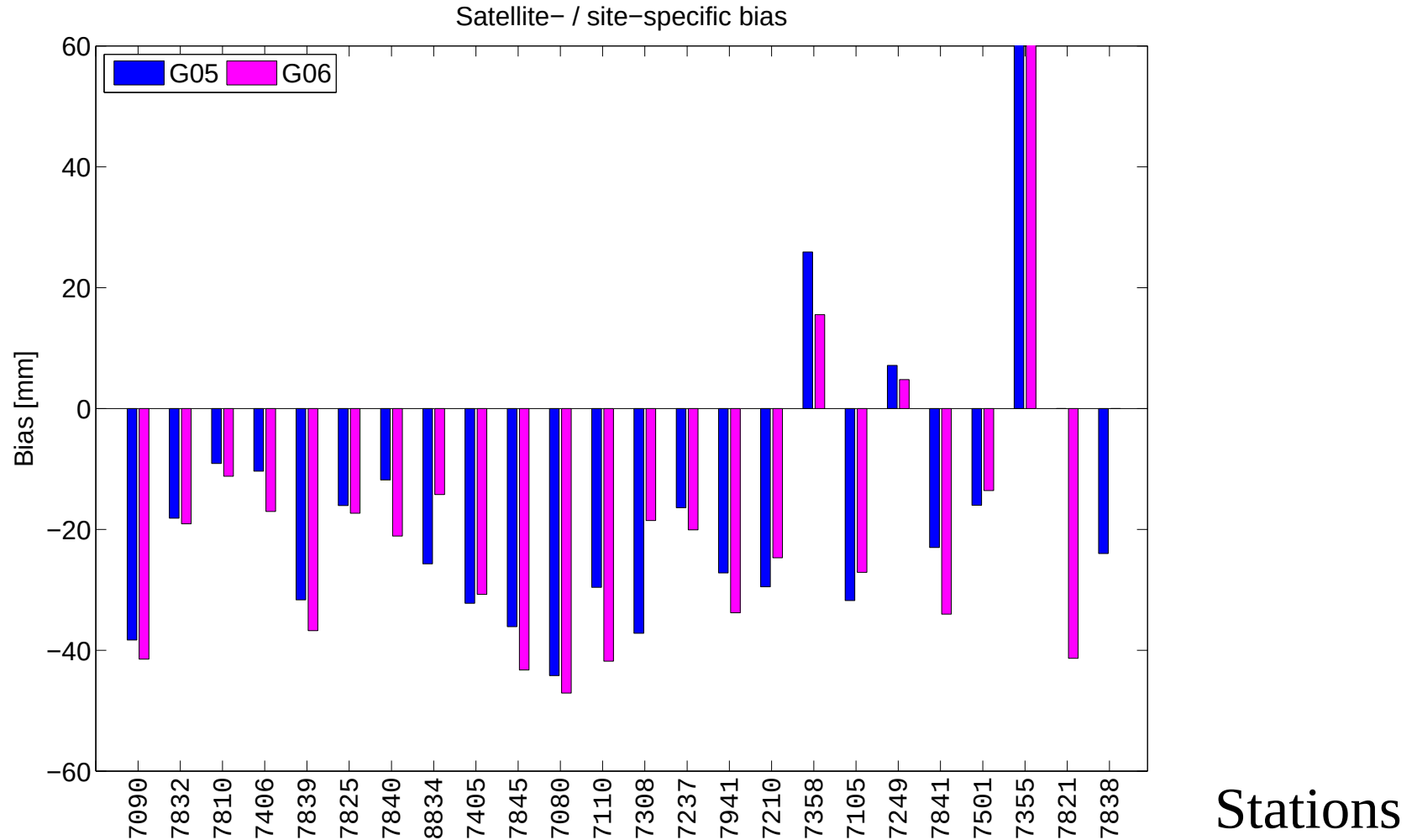
3 GLONASS



Number of SLR observations per day



SLR residuals: Mean bias



Mean bias for all stations
for 2003 – 2009 [mm]:

G05	G06
-24.0	-26.4

R03	R07	R11	R15	R22	R24a	R24b
-13.5	-8.6	-19.5	-2.6	-14.1	-17.9	-16.0

Combined analysis of GNSS and SLR

Questions:

Are satellite co-locations strong enough to fully replace co-locations on ground?

(**space ties** instead of **local ties**)

Which values do the site-specific **SLR range biases** for GNSS satellites have?

Is an estimation of **GNSS SAO** together with **SLR range biases** possible or does this cause a rank deficiency for the **scale**?

Combined analysis of GNSS and SLR

Analysis and combination with the *Bernese GPS Software*

→ *GNSS-only NEQs (daily):*

- Combined GPS+GLONASS analysis performed at CODE
- Re-analysis for 2003 – 2008, routine IGS analysis for 2009

→ *SLR-only NEQs for SLR@GNSS (daily):*

- SLR data to GPS and GLONASS satellites
- Parameterization identical to GNSS analysis (orbits, ERP, geocenter)
- Range biases for all sites

→ *Combination on normal equation level:*

- Use of “space ties” only, no “local ties”!

→ *SLR-NEQs for Lageos (weekly; 2007 - 2009):*

- Range biases only for selected sites

→ *Combination on normal equation level:*

- Weekly combination and accumulation to long-term solution

Combined analysis of GNSS and SLR

SLR station network

- not included in the datum definition (no-net-rotation, no-net-translation)
- no local ties applied
- solely appended via the „space ties“ (common orbit parameters)

Verification of SLR station coordinates: Helmert transformation

RMS	SLRF2005		Lageos-only	
	Comb: SLR@GNSS	54.40	54.22	[mm]
	Comb: + Lageos	6.70	2.95	[mm]
	SLRF2005		7.49	[mm]

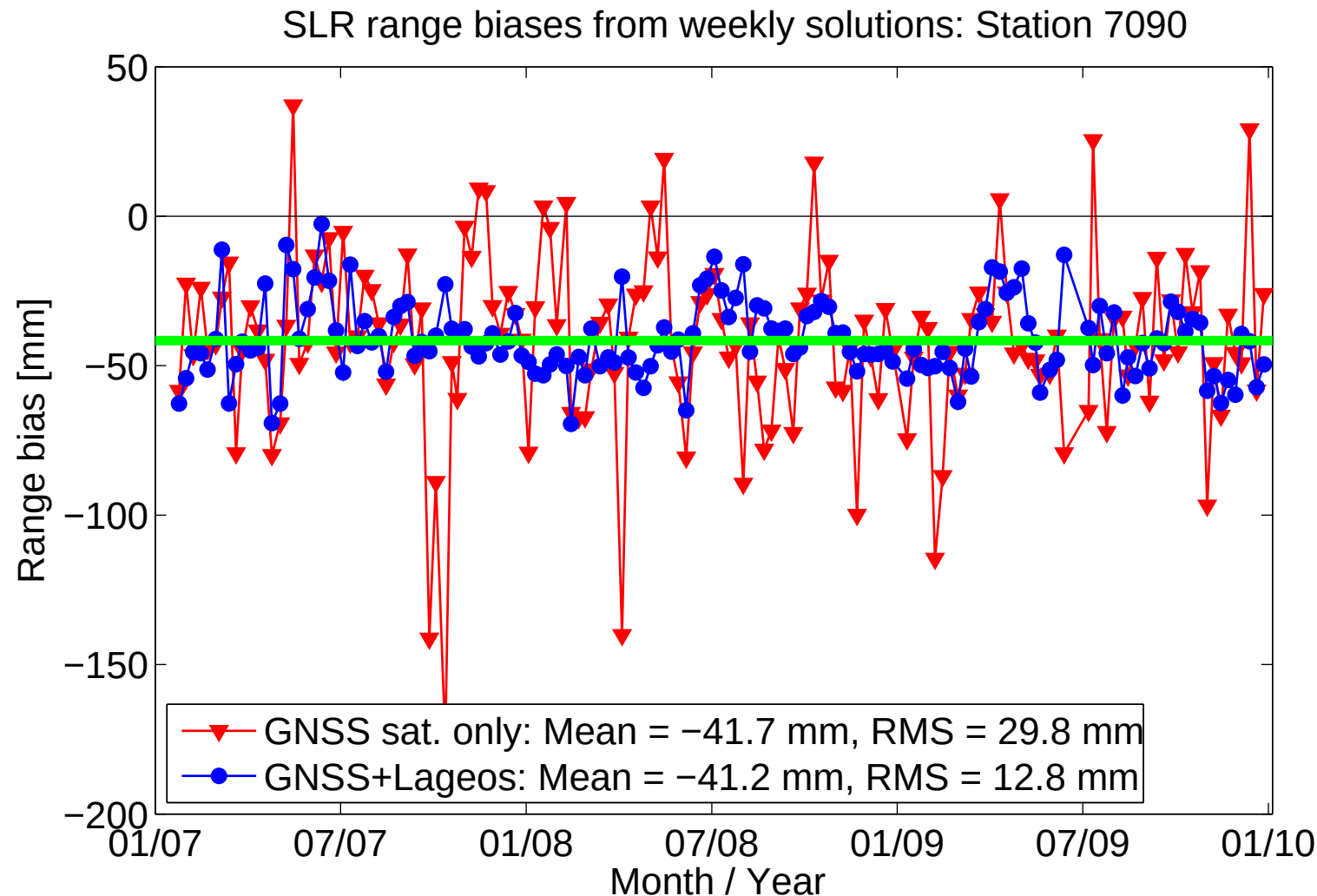
- Agreement is at the **cm-level**
- **Inclusion of Lageos** improves the coordinate estimates
- Connection by using space ties only is possible

Problems:

1. Values for GNSS satellites are not available
 - But: Biases are seen in SLR residual analysis
 - Estimation of **range biases for all stations** needed
 - Definition of the scale?

2. Number of observations (10 – 20 per day)
 - **Daily** estimation is not possible

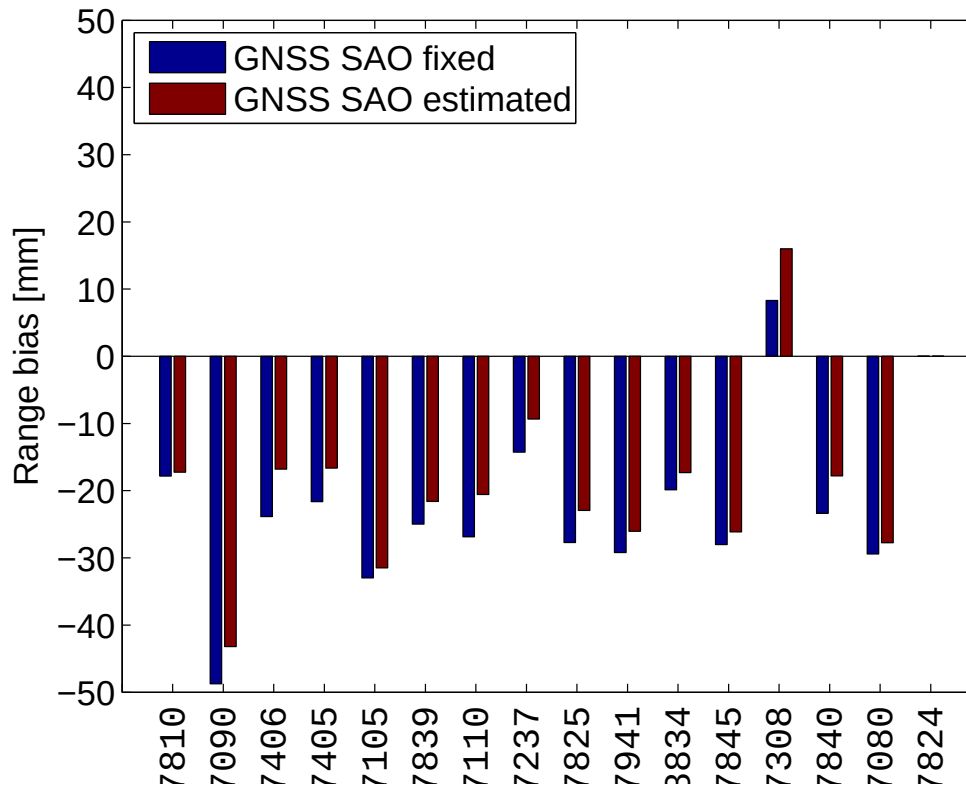
SLR range biases



- **Weekly** estimation from **SLR@GNSS** data only: possible in few cases
- Inclusion of **Lageos** data improves weekly solutions
- **Yearly (or multi-year)** solutions needed for reliable values

SLR range biases and GNSS SAO

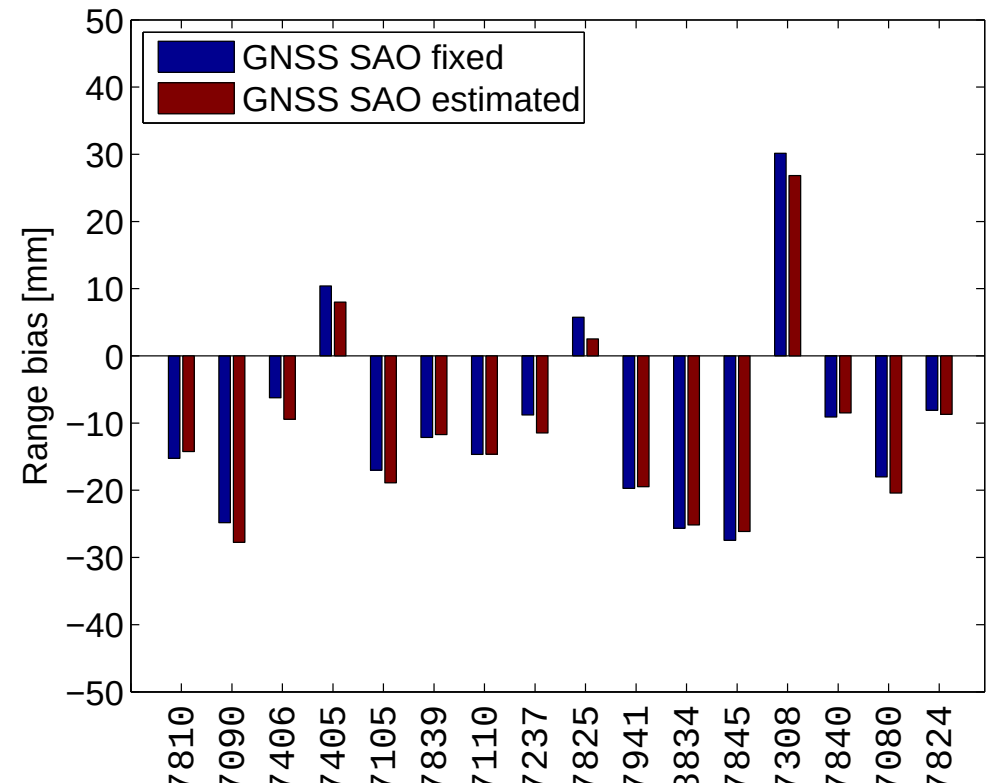
SLR range biases for satellite G06



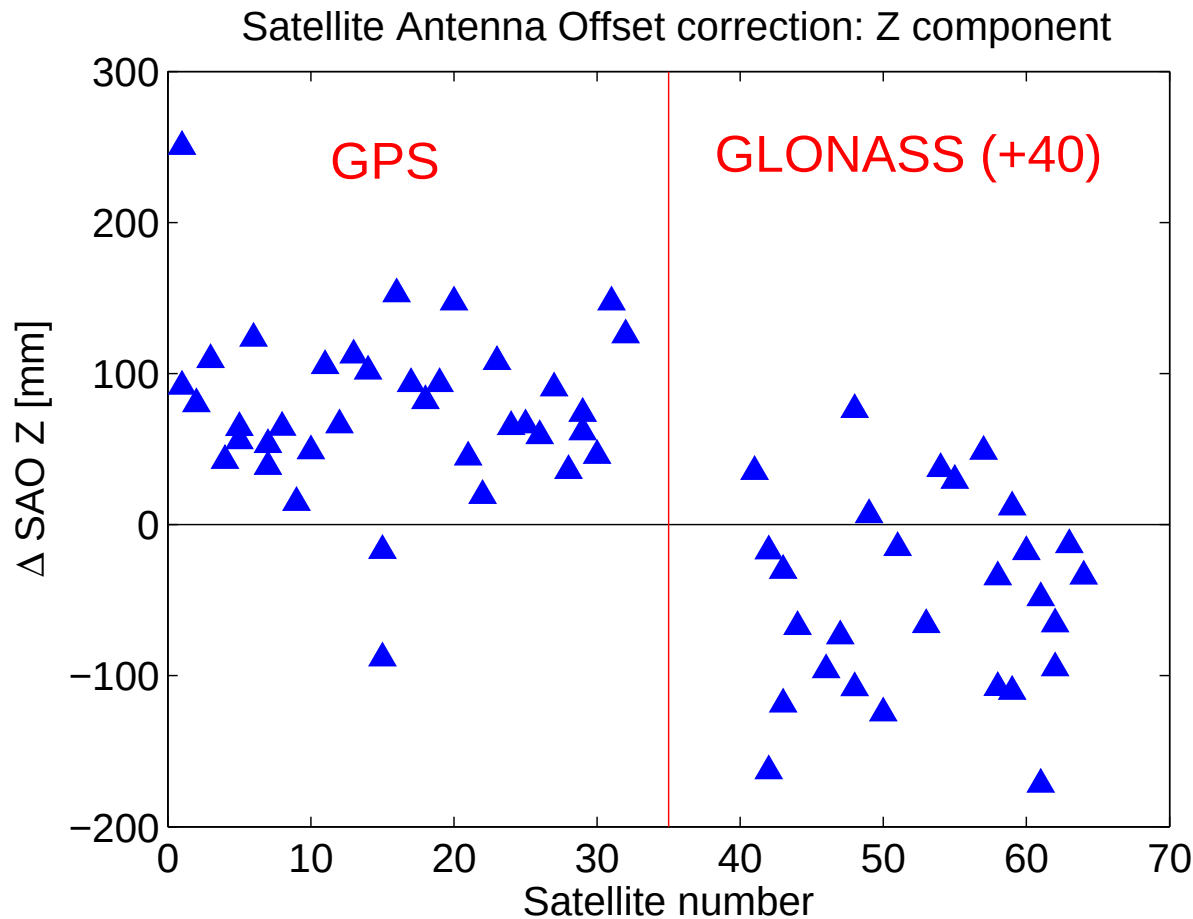
Impact of GNSS-SAO estimation
on SLR range biases:
< 5 mm

Using NEQs of 2007-2009
Including Lageos data

SLR range biases for satellite R15



SLR range biases and GNSS SAO



Mean ΔZ for GPS:
76.4 mm

Mean ΔZ for GLONASS:
-47.7 mm

Δ Scale for GNSS network:
0.59 ppb

Δ Scale for SLR network:
0.00 ppb

No general shift of SAO estimates
=> Scale of SLR is transferred properly to GNSS

Conclusions and outlook

- Inclusion of SLR@GNSS works properly
- Connection via „*space ties*“ is possible (without local ties)
BUT:
Accurate ties (in space and on sites) required for combination
- *Scale from SLR* can be transferred to GNSS
→ Estimation of GNSS satellite antenna offsets possible
- *SLR range biases* to GNSS satellites can be determined reasonably only from long observation time spans