Combined analysis of GNSS and SLR data using satellite co-locations

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Overview

1. Combination of GNSS and SLR: **General considerations**
2. **Expectation** from a combined analysis of GNSS and SLR@GNSS
3. **Results** from one year of combining GNSS and SLR@GNSS
4. Conclusions and outlook

Combination of GNSS and SLR

Co-location at stations:

→ Application of known **local tie** values

→ GNSS observations of ground network; SLR observations to Lageos

Problem:

→ Phase center modelling of GNSS antenna

→ Local ties

Co-location at satellites:

1.) **GNSS satellite**: Transmitting point for GNSS
Reflecting point for SLR (target)

2.) **LEO satellite**: Receiving point for GNSS ("kinematic station")
Reflecting point for SLR (target)

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

Co-location at GNSS satellites

SLR to GNSS satellites:

1. **Validation** of microwave-only GNSS orbits by SLR range residuals
   ⇒ control of a priori models (e.g., radiation pressure)

2. **Combined orbit determination**
   ⇒ only few SLR normal points per day (~ 10-20 per satellite)
   ⇒ problematic on daily basis

Strength of ***SLR to geodetic satellites*** (Lageos,...):

Reference frame: mainly **scale** and **geocenter**

⇒ **Applicable as well for SLR @ GNSS?**

Expectation from combined analysis

	GNSS @GNSS	SLR @GNSS	SLR @Lageos
Radiation pressure ↔ **Geocenter**	Problems in RPR modelling	Problems in RPR modelling	RPR well modelled
GNSS satellite antenna phase center ↔ **Scale**	Problems in phase center modelling	independent	-
Range biases ↔ **Scale**	-	Decorrelated if different elevation angles	For a few sites only

SLR @ GNSS: ⇒ Geocenter is affected as well
⇒ **Scale** is transferred directly to GNSS

⇒ **Independent** control of **local ties**

Combined analysis of GNSS and SLR

- Studies using one year of data: 2008
- Analysis and combination with the *Bernese GPS Software*

→ ***GNSS-only NEQs (daily):***

- Combined GPS+Glonass analysis performed at CODE

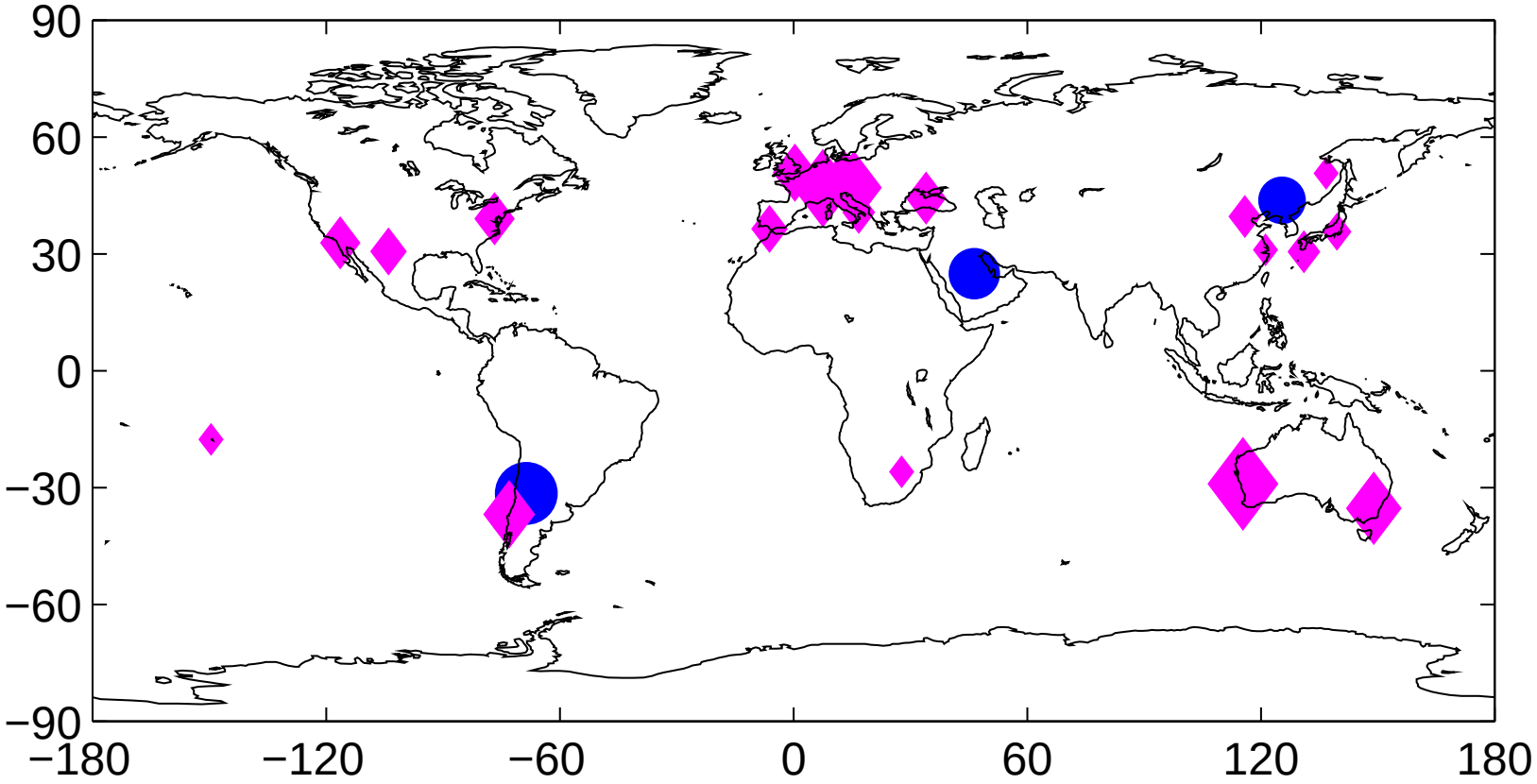
→ ***SLR-only NEQs (daily):***

- SLR data to GPS and Glonass satellites
- Parameterization identical to GNSS analysis (orbits, ERP, geocenter)
- In addition: Range biases

→ ***Combination:***

- Daily combination
- Accumulation to annual solution
- Use of “space ties” only, no “local ties”!

Network in 2008



Satellites tracked:

GPS: G05
G06

GLONASS:
R15
R24
R07
R11

Altogether:
25 SLR sites
31855 normal points (NP)

8 sites with > 1000 NP
5 sites with > 500 NP
6 sites with > 100 NP
6 sites with < 100 NP

Northern hemisphere:
16804 NP
Southern hemisphere:
15051 NP

Combined analysis of GNSS and SLR

Questions to be answered:

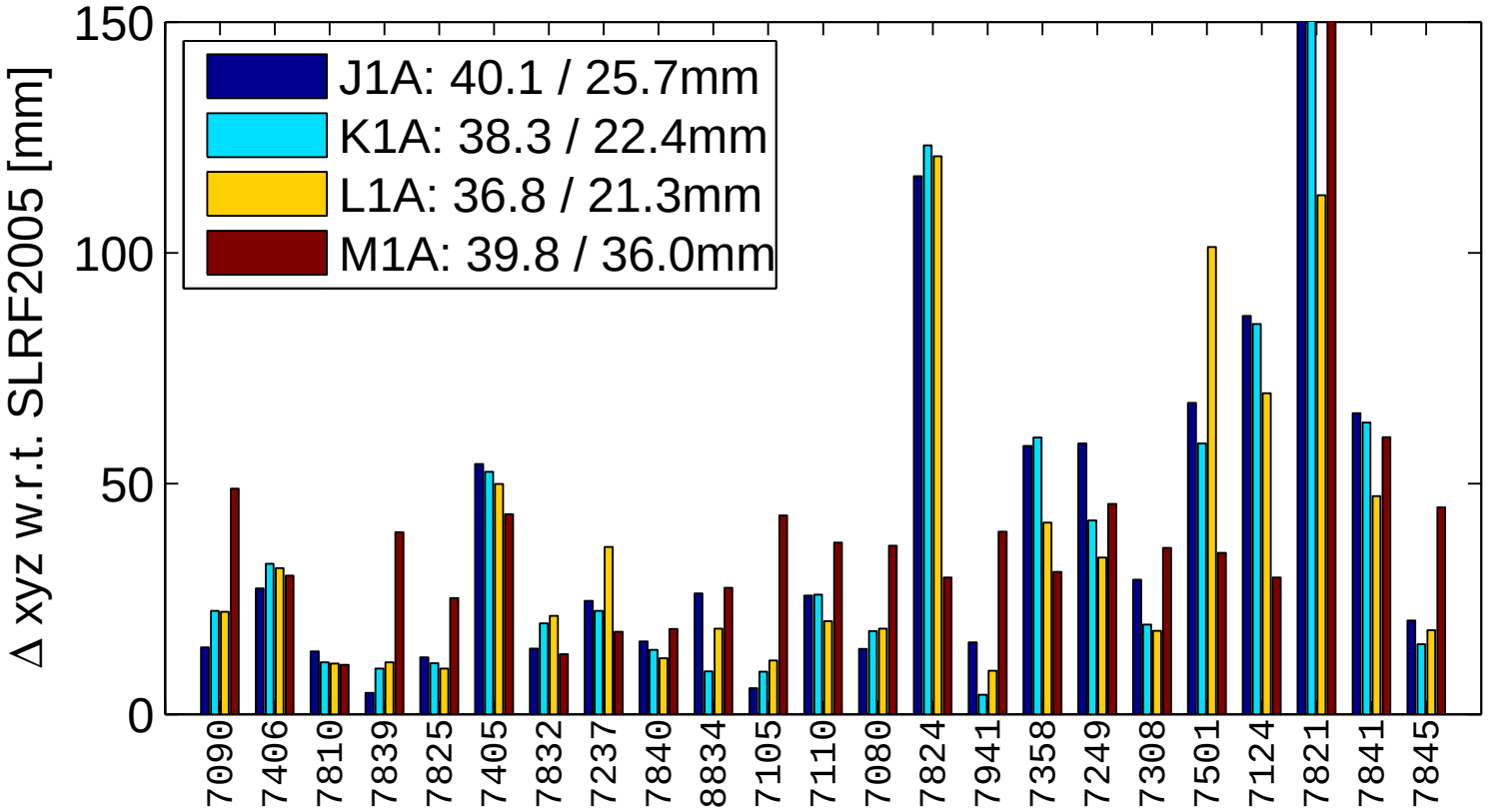
Are satellite co-locations strong enough to fully replace co-locations at ground?
(**space ties** instead of **local ties**)

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

		GNSS SAO fixed on igs05.atx	**GNSS SAO** corrections **estimated**
M	***No*** SLR range bias	SLR and GNSS deliver information on the scale ⇓ Scale of combined solution is a **weighted mean of the GNSS and SLR scale** (GNSS will dominate)	SLR delivers information on the scale GNSS has a rank deficiency w.r.t. the scale ⇓ Scale of combined solution comes **only from SLR**
L	SLR range bias ***per satellite*** (G05, G06, R15, R24, ...)		
K	SLR range bias ***per system*** (GPS, GLONASS)		
J	SLR range bias ***per station***		

Comparison with SLRF2005



Stations sorted according to number of SLR observations (descending order)

SLR station coordinates are well determined by using solely “space ties” (no local ties to GNSS sites; not included in datum definition)

Prerequisite: sufficient number of SLR observations (~ 200-300 NP)

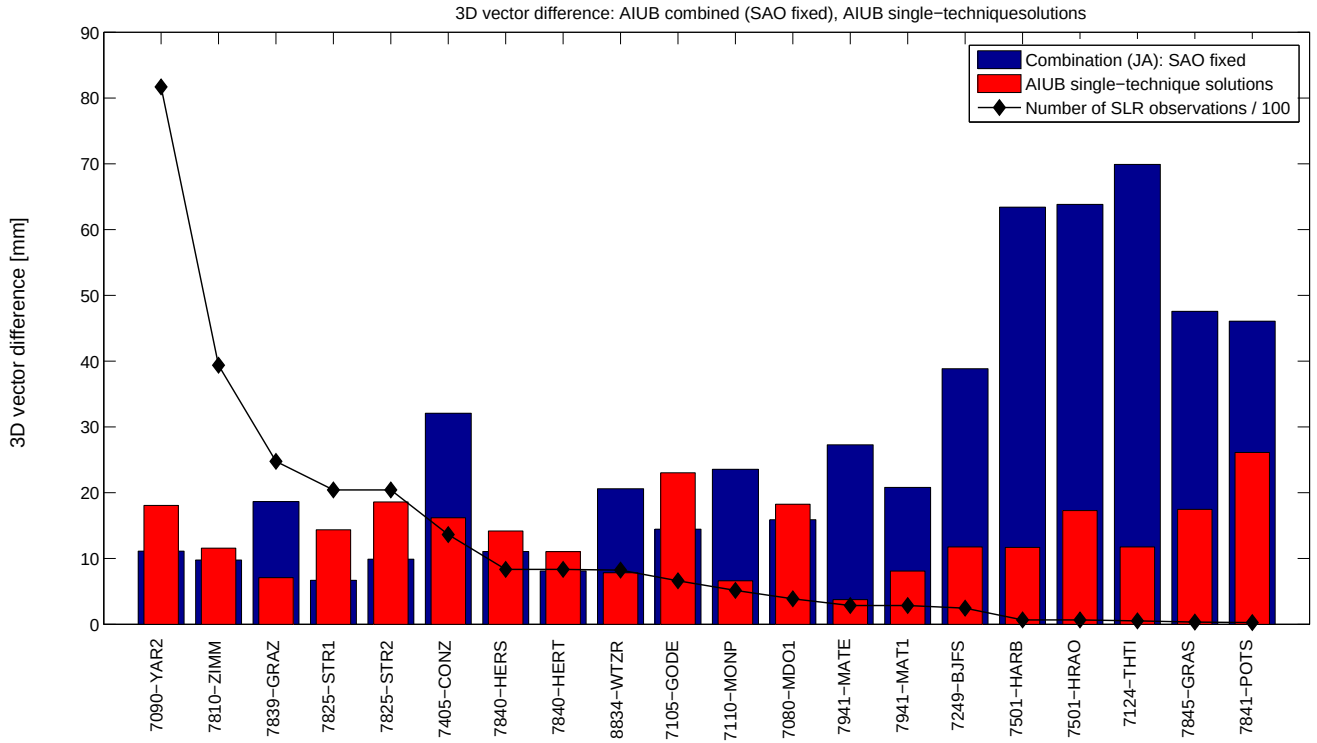
Comparison with local ties

Combining GNSS and SLR@GNSS using „space ties“ only

→ Combined yearly GNSS+SLR solution

→ Datum definition: NNR+NNT (GNSS core sites), **no Local ties**

→ **GNSS antenna phase center (SAO) fixed = Scale defined by GNSS and SLR**



Red:
From annual single-technique solutions

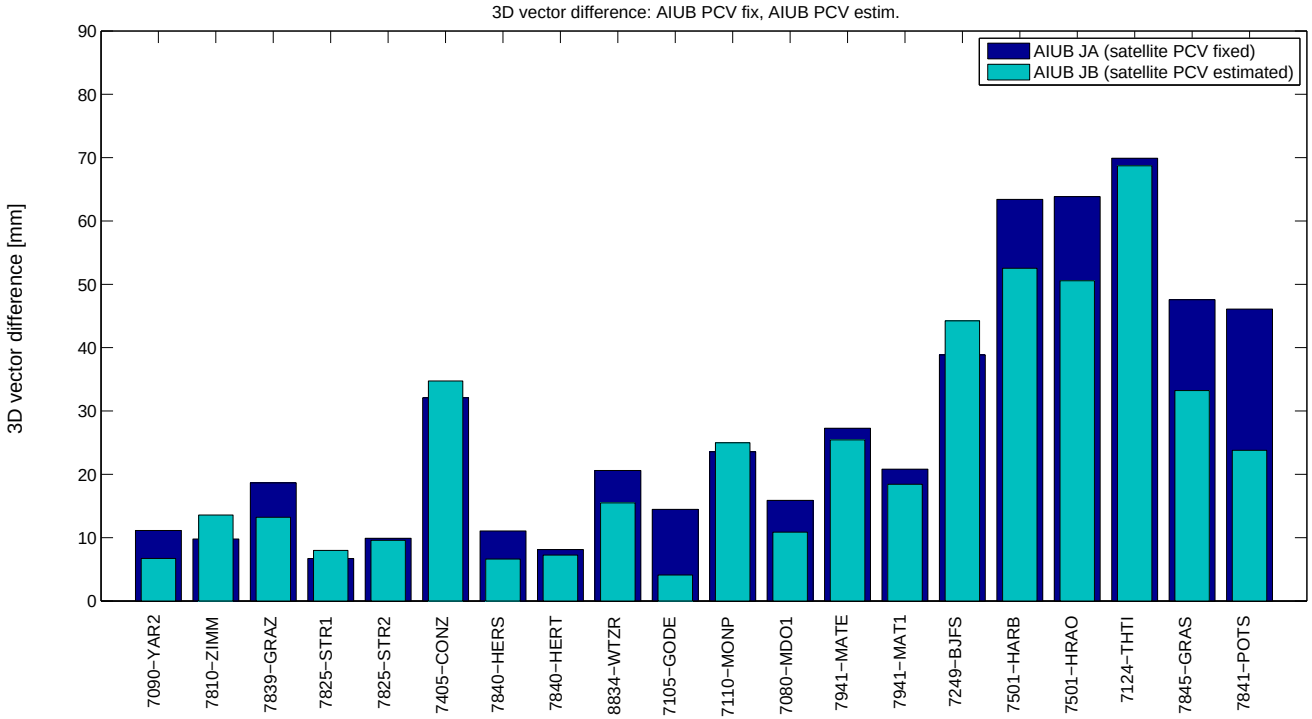
Blue:
Combined solution, GNSS SAO fixed

Comparison with local ties

Impact of GNSS antenna phase center (SAO) estimation:

→ No big differences ⇒ Estimation of SAO is possible

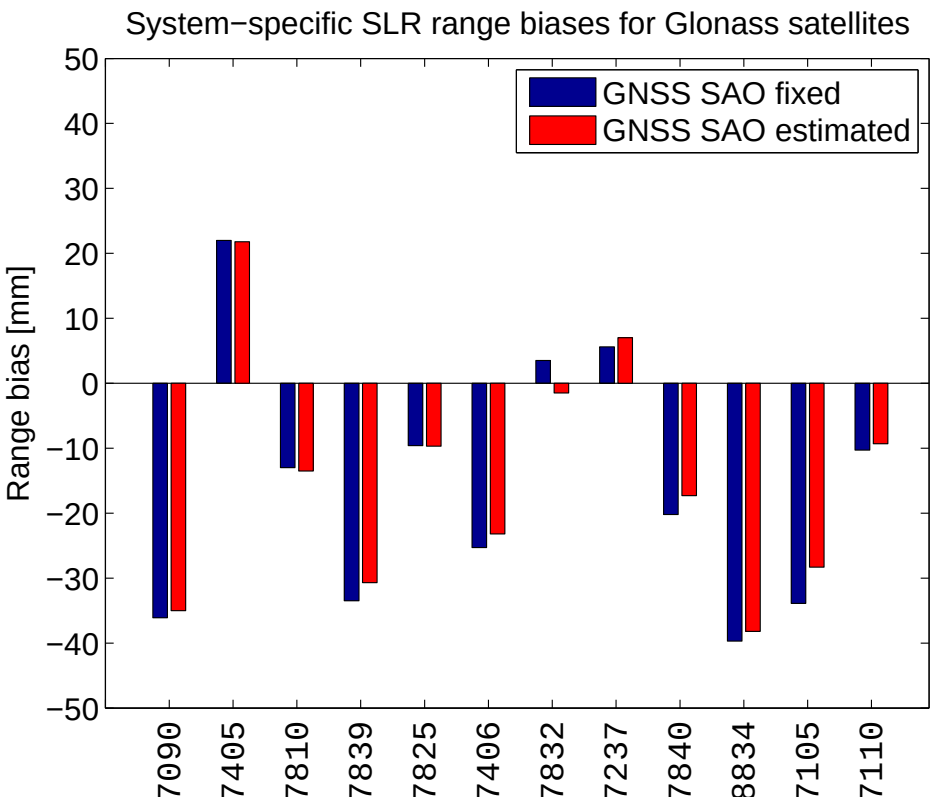
→ Slightly better agreement with local ties if scale is NOT defined by GNSS (has to be verified using longer time span of data!)



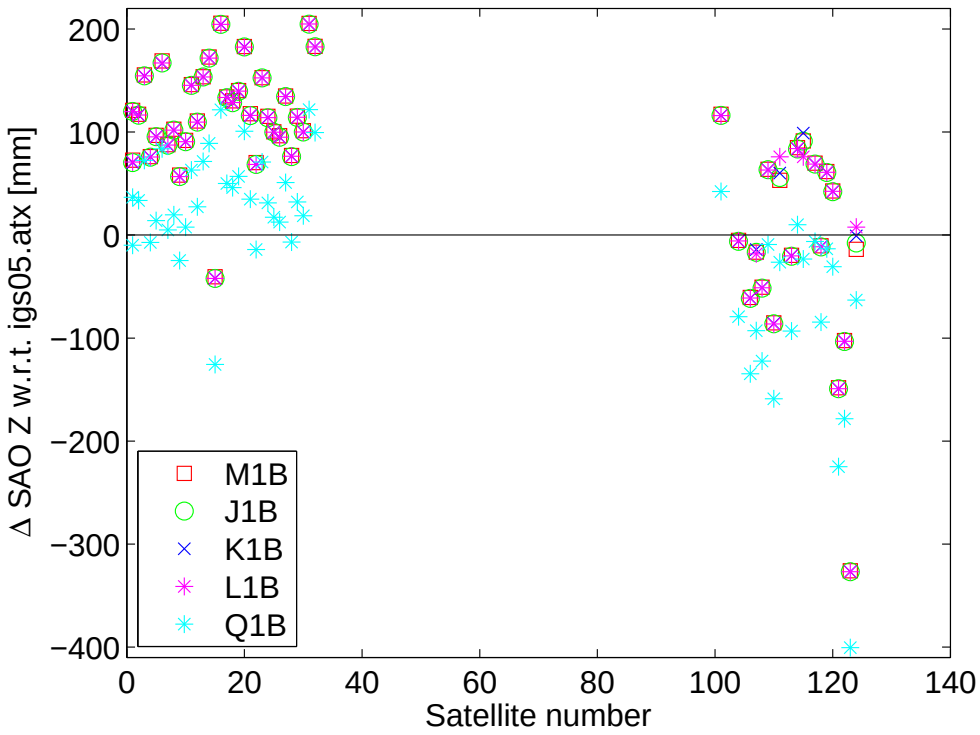
Blue:
Combined solution,
GNSS SAO fixed

Green:
Combined solution,
GNSS SAO estimated

SLR range biases and GNSS SAO



GPS **GLONASS**



Simultaneous estimation of GNSS antenna phase center offsets and SLR range biases is possible

⇒ Scale of SLR can be transferred into GNSS network

Conclusions and outlook

- Combination using ***SLR@GNSS*** works fine
  ⇒ most direct way to combine GNSS and SLR

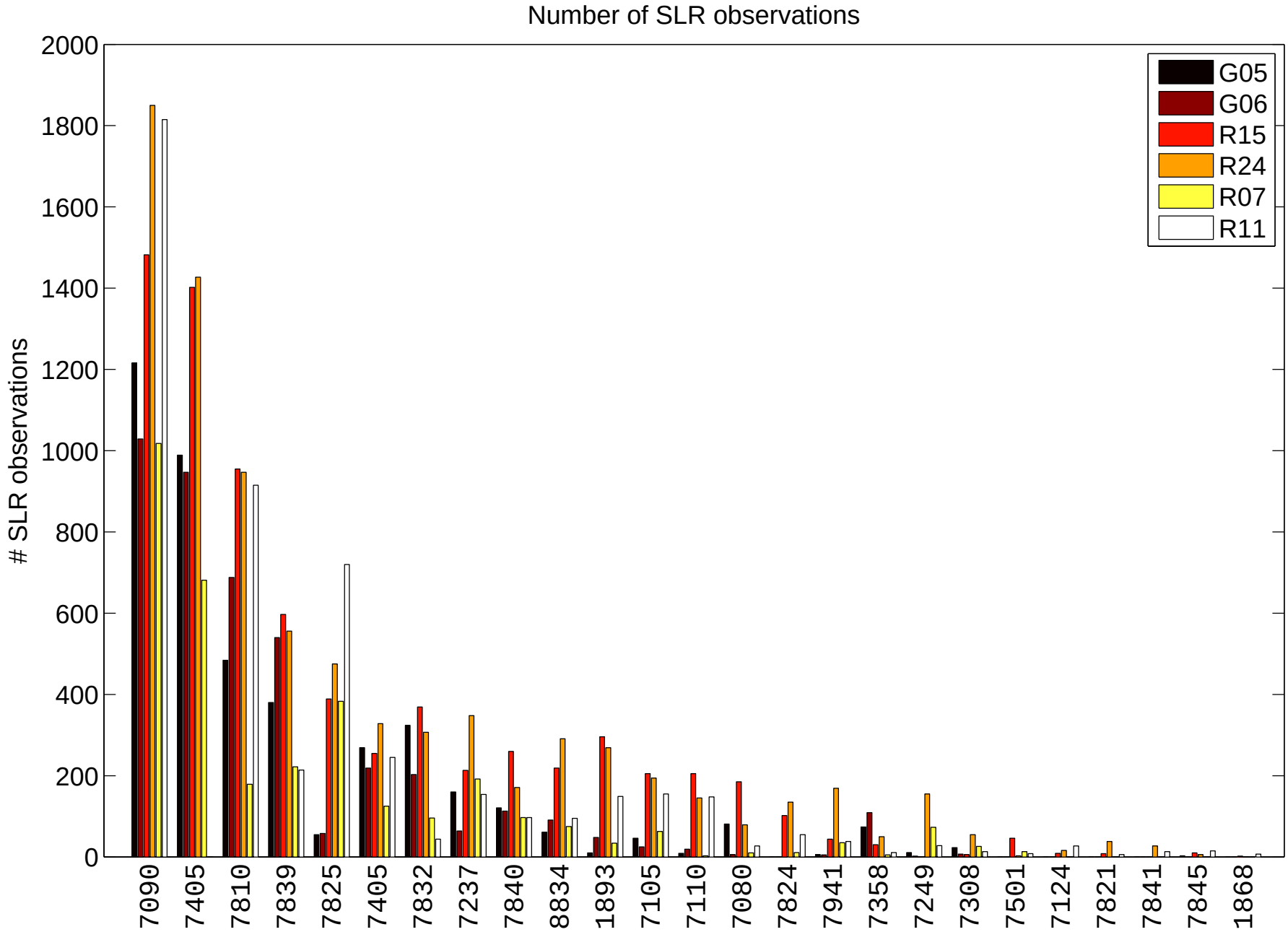
- Connection via „***space ties***“ only is possible (without local ties)
  ⇒ Independent control of local ties
  BUT:
  Accurate ties (in space and on sites) required for combination
  Number of SLR observations critical (not possible on a daily basis)

- ***Scale from SLR*** is transferred to GNSS ***directly*** (not via local ties)
  ⇒ Estimation of GNSS SAO consistent to SLR scale

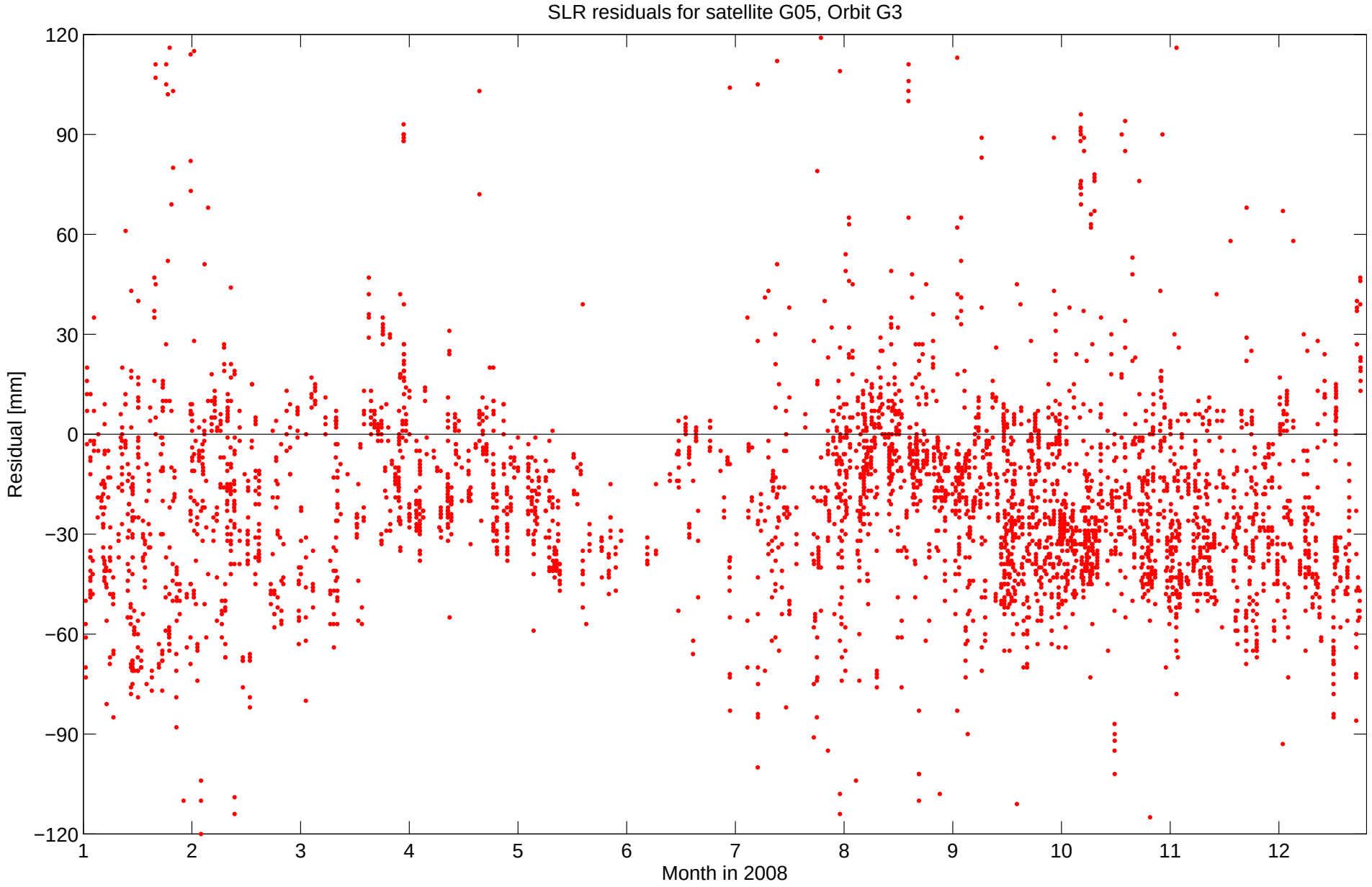
- Orbit overlap error is slightly improved (mainly GLONASS)

- Studies have to be extended to ***longer time span***
- ***Inclusion of Lageos***: Geocenter; more stable SLR station coordinates

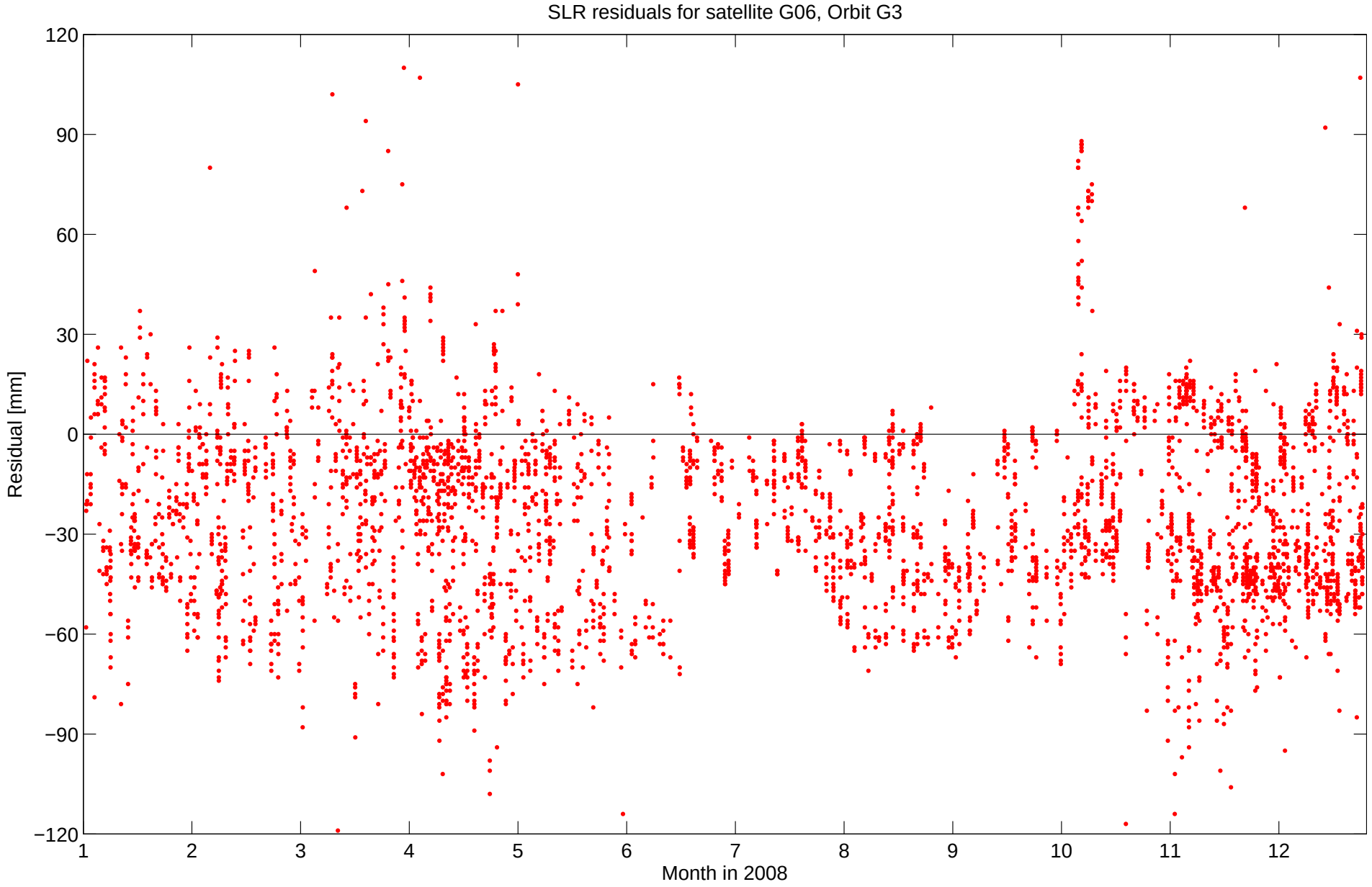
Number of observations in 2008



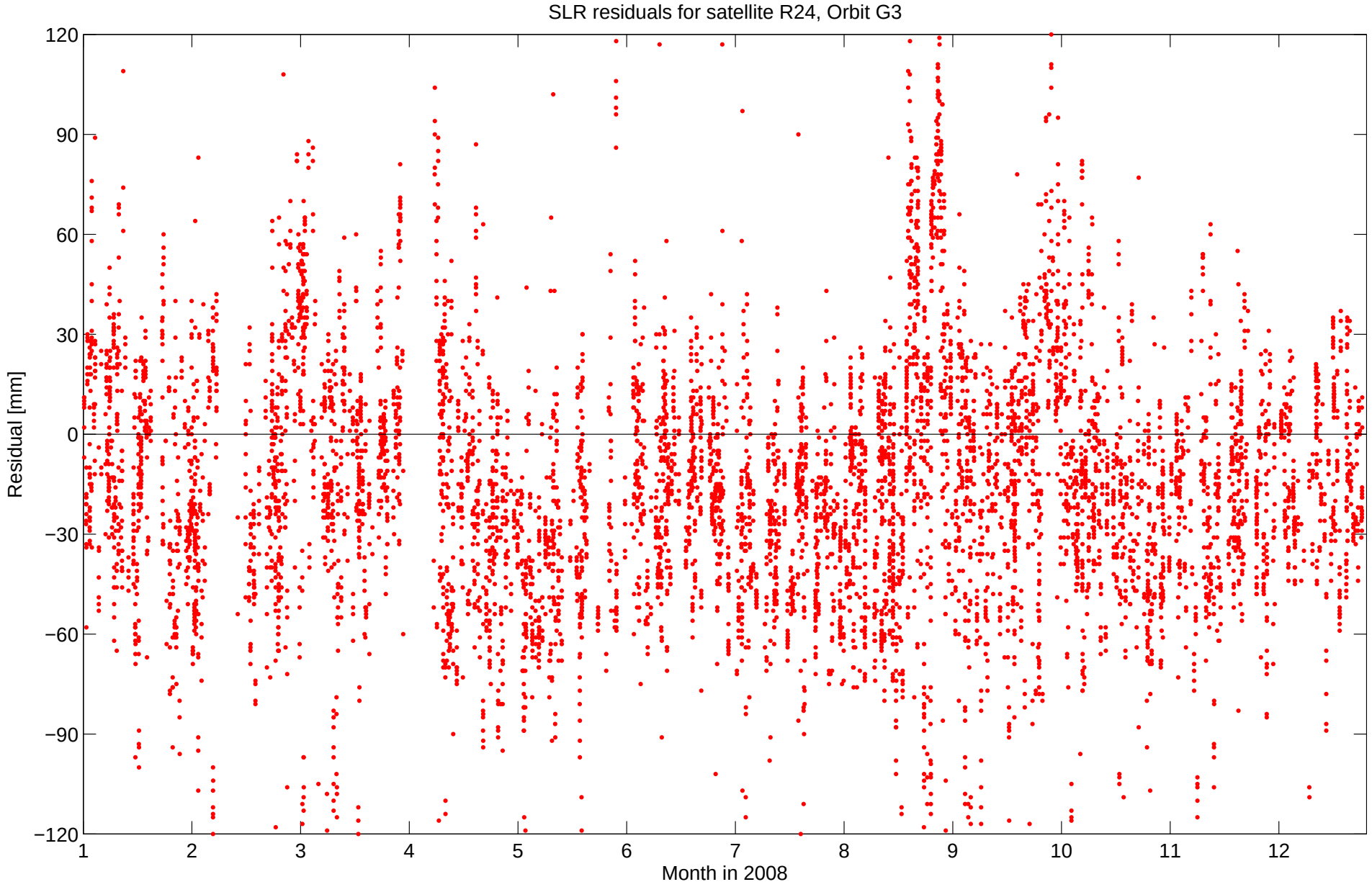
SLR residuals



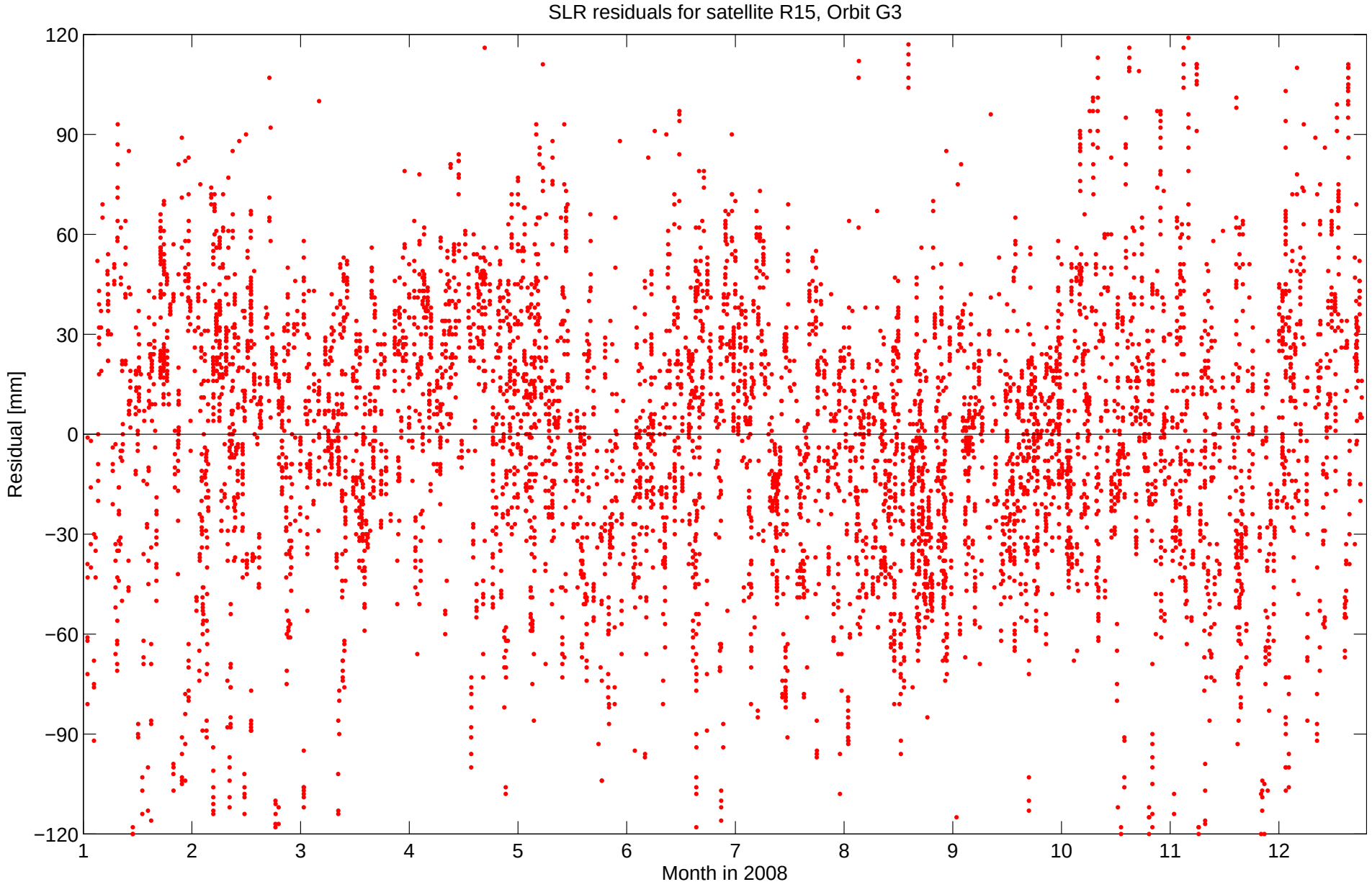
SLR residuals



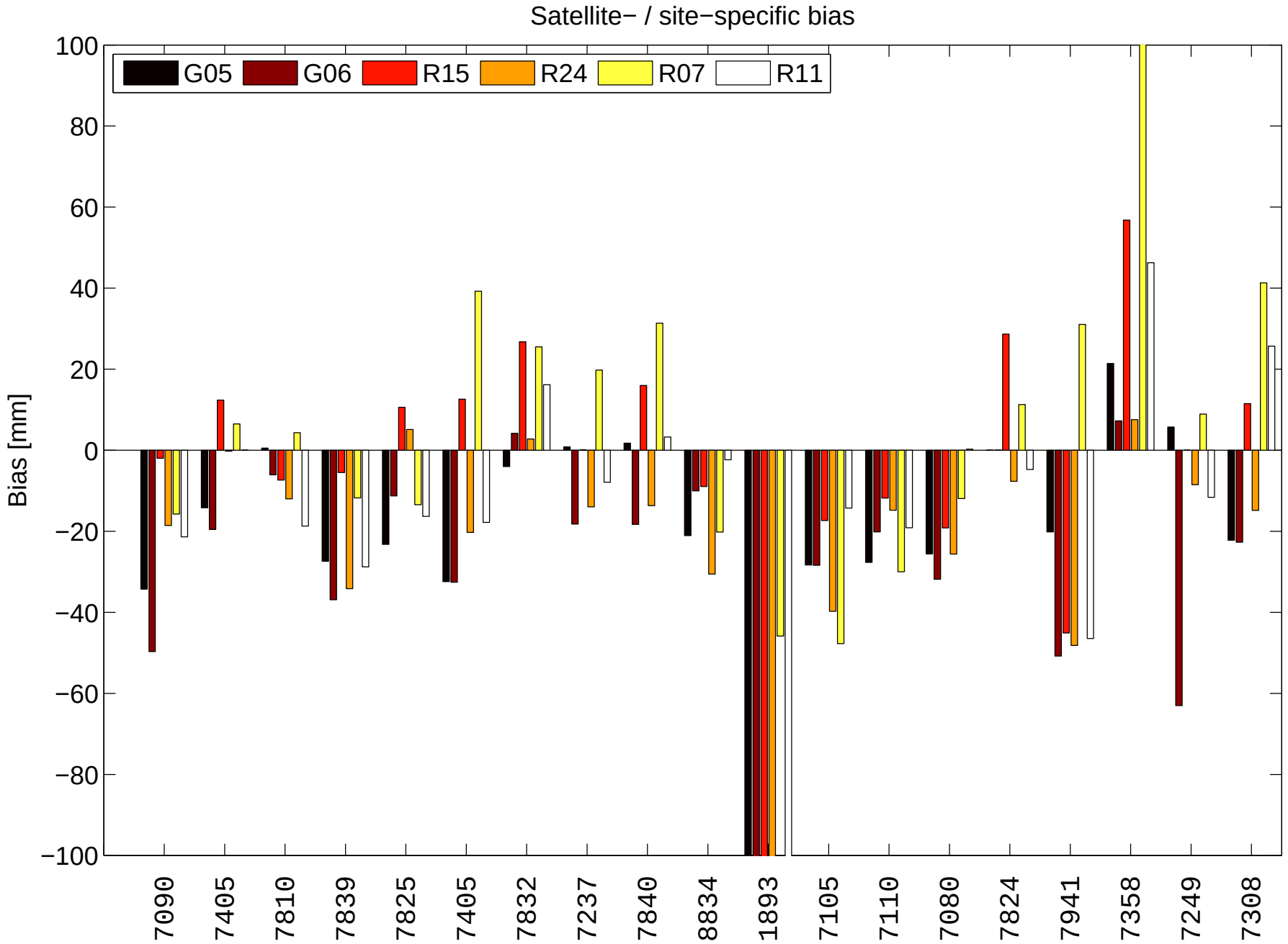
SLR residuals



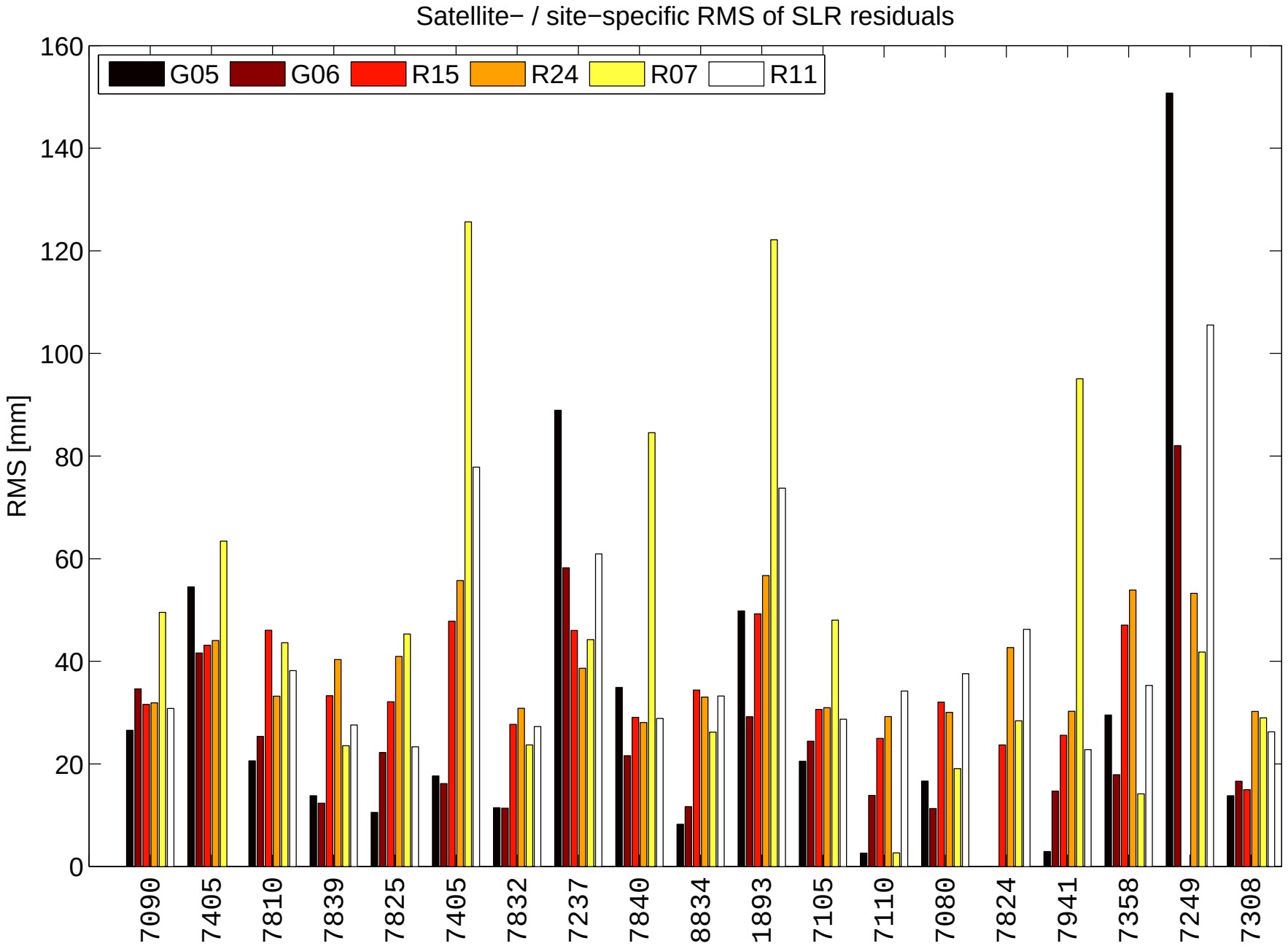
SLR residuals



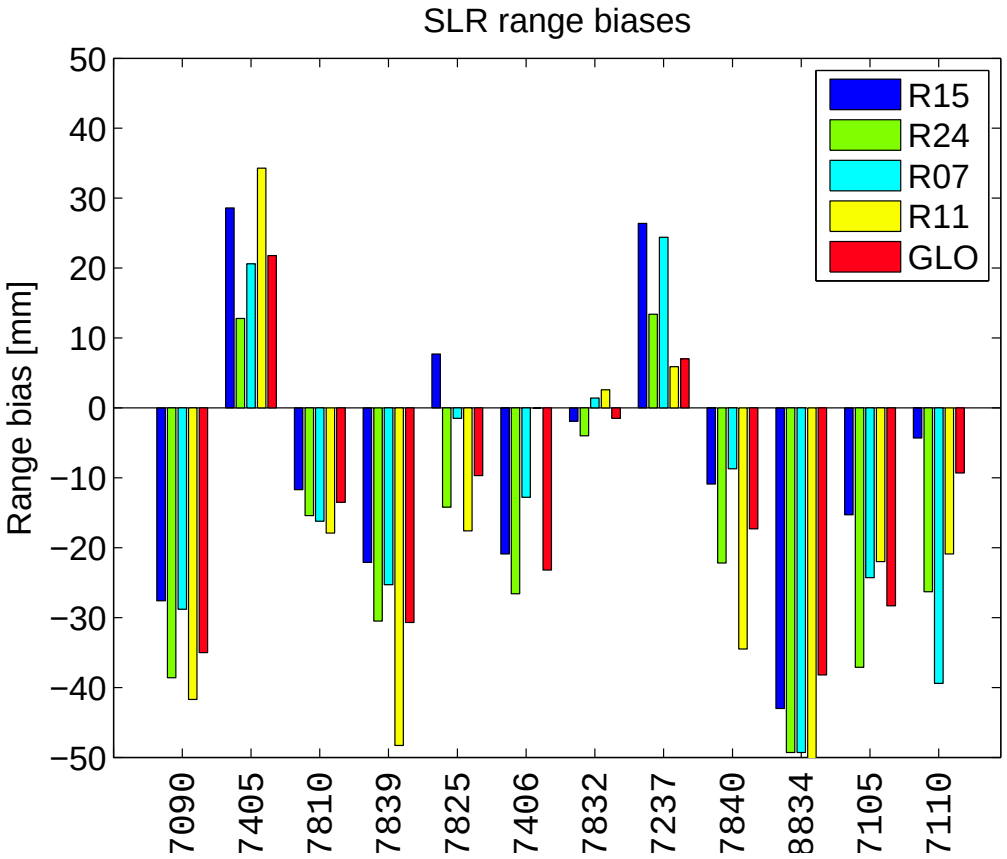
SLR residuals: Mean Bias



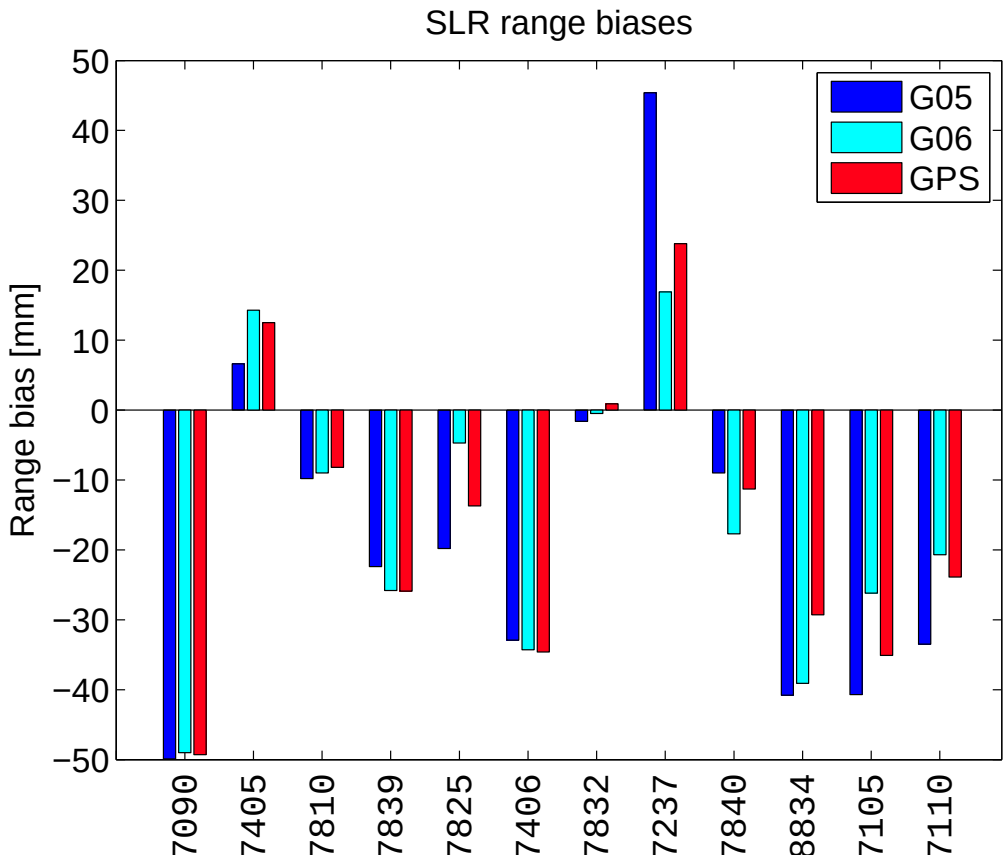
SLR residuals: RMS



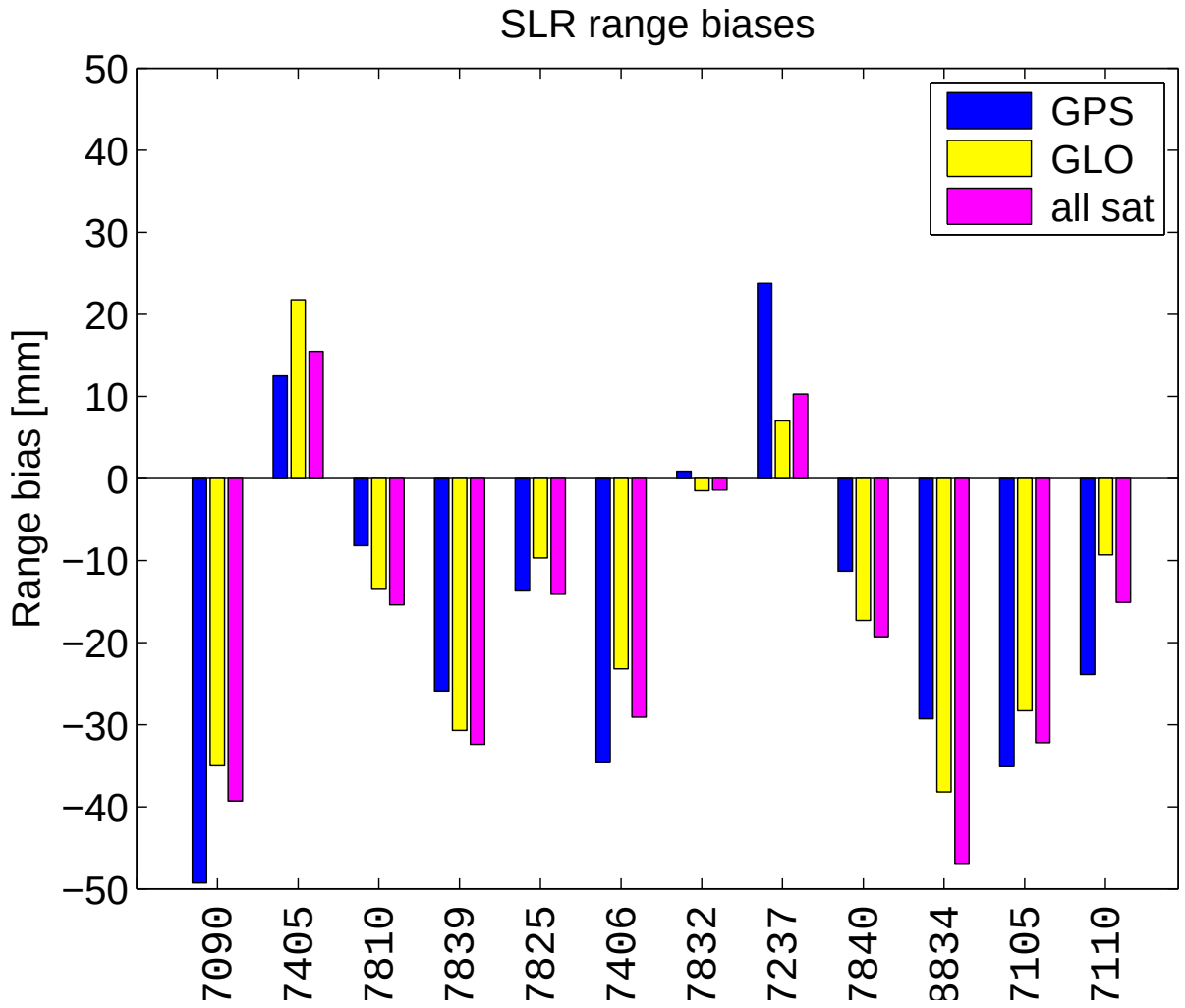
SLR range biases



System-specific range biases seem to be sufficient for most sites



SLR range biases



Station-specific range biases seem to be sufficient

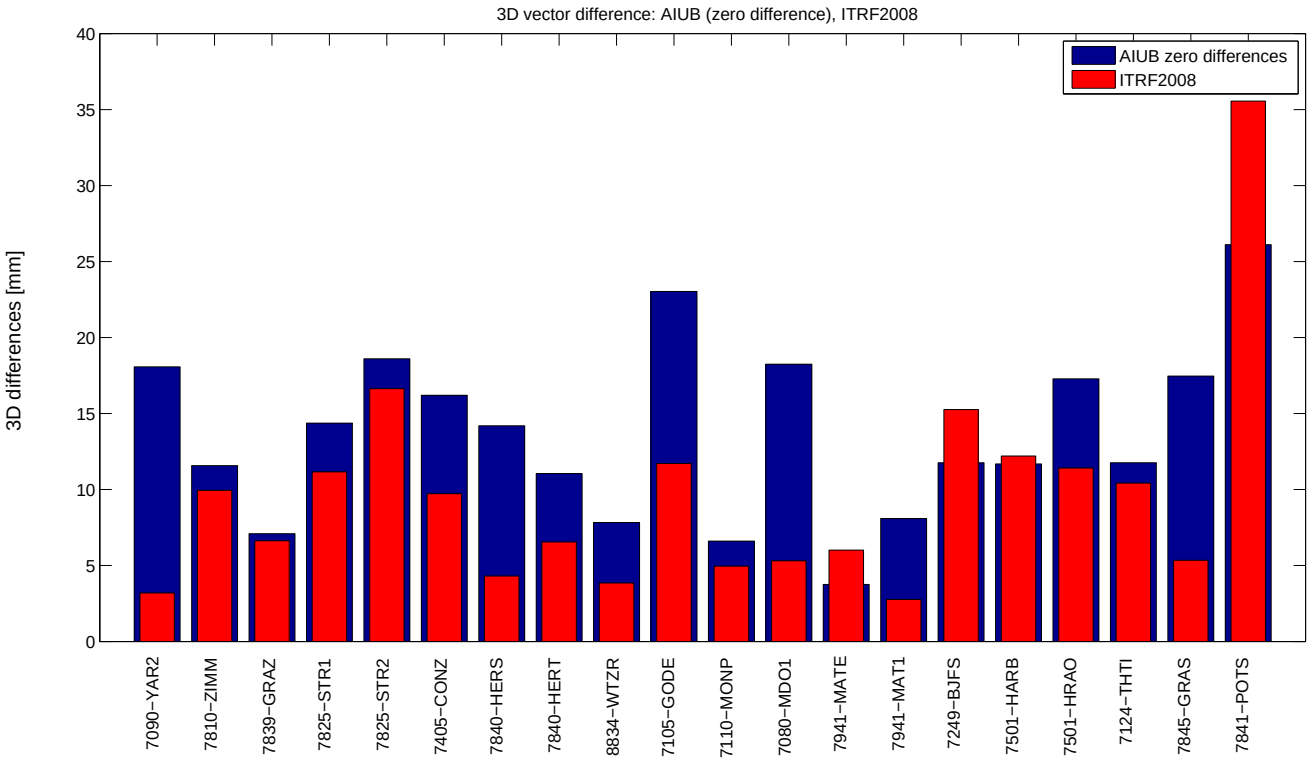
Comparison with local ties

Level of agreement when using one year of data only

→ Coordinate differences from GNSS-only and SLR-only solutions (1 year)

→ Datum definition for both solutions using NNR+NNT (core sites)

→ Velocities from ITRF2005



Red:
ITRF2008 (prelim.)

Blue:
From annual single-technique solutions

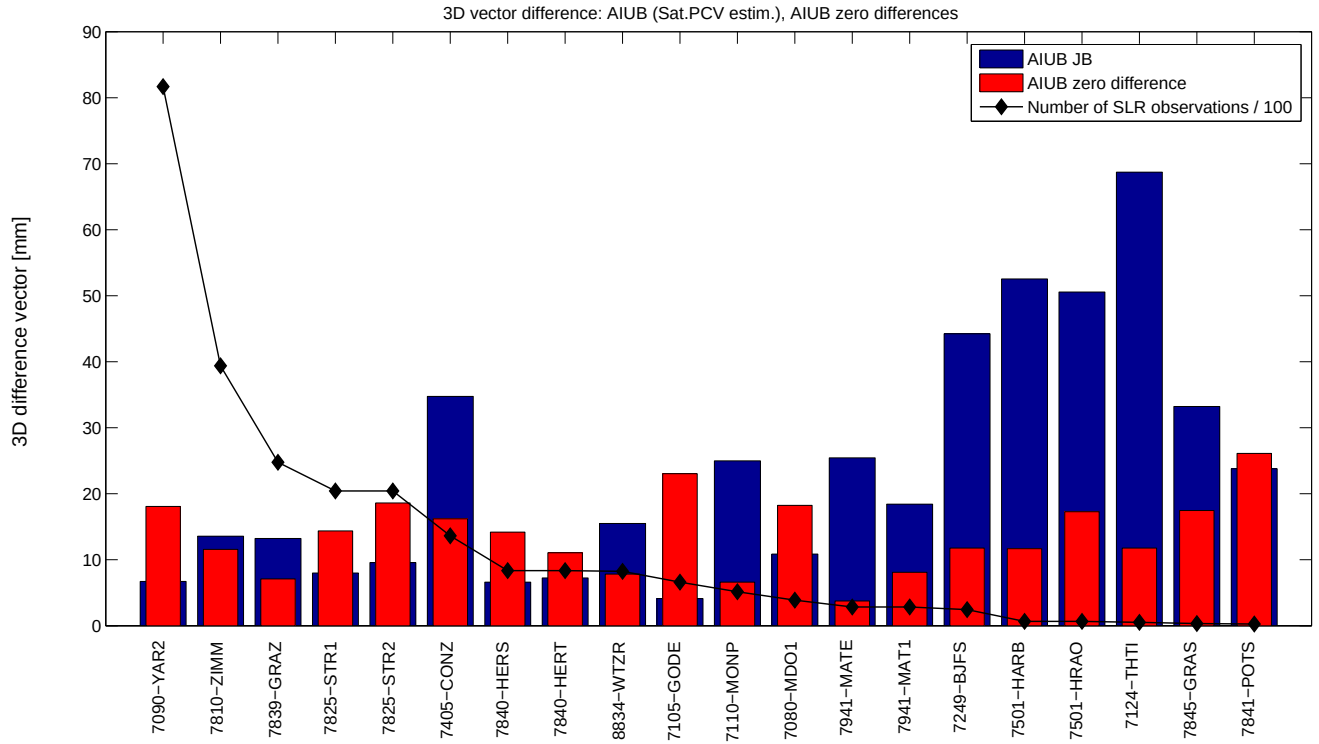
Comparison with local ties

Changes when combining GNSS and SLR@GNSS using „space ties“ only

→ Combined yearly GNSS+SLR solution

→ Datum definition: NNR+NNT (GNSS core sites), **no Local ties**

→ **GNSS antenna phase center (SAO) estimated = Scale defined by SLR only!**



Red:
From annual single-technique solutions

Blue:
Combined solution, GNSS SAO estimated

Scale between solutions (GNSS core sites)

L = Satellite-specific SLR range biases
K = System-specific SLR range biases
J = Station-specific SLR range biases

	L1A	**K1A**	**J1A**		**L1B**	**K1B**	**J1B**
GNSS-only	0.0	0.0	0.0		**0.9**	**0.9**	**0.9**
L1A		0.0	0.0		**0.9**	**0.9**	**0.9**
K1A			0.0		**0.9**	**0.9**	**0.9**
J1A					**0.9**	**0.9**	**0.9**
L1B						0.0	0.0
K1B							0.0
Lageos	0.0 ±0.9	-0.8 ±0.7	-0.4 ±0.7		0.3 ±1.0	-0.6 ±0.6	-0.3 ±0.7

[ppb]

„***A***“: GNSS Sat.ant. fixed
= Scale fixed

„***B***“: GNSS Sat.ant. estimated
= Scale free ⇒ from SLR