SLR observations to spherical and GNSS satellites and their combined analysis with GNSS microwave observations

Daniela Thaller

Astronomical Institute, University of Bern, Switzerland

Séminaires “Temps & Espace”

Observatoire de Paris, 4. June 2012

Overview

- SLR analysis for spherical satellites
- SLR residual analysis for GNSS satellite orbits
- Combined GNSS-SLR analysis

SLR analysis for spherical satellites

- ***Bernese GPS Software (BSW)*** has been extended:
  - Orbit modelling for spherical satellites
  - Handling / analysis of SLR observations

- **Cooperation with BKG** (Frankfurt/Main, Germany):
  - BKG is ILRS Analysis Center
  - Contribution of BKG to the ILRS is based on ***BSW*** since July 2010

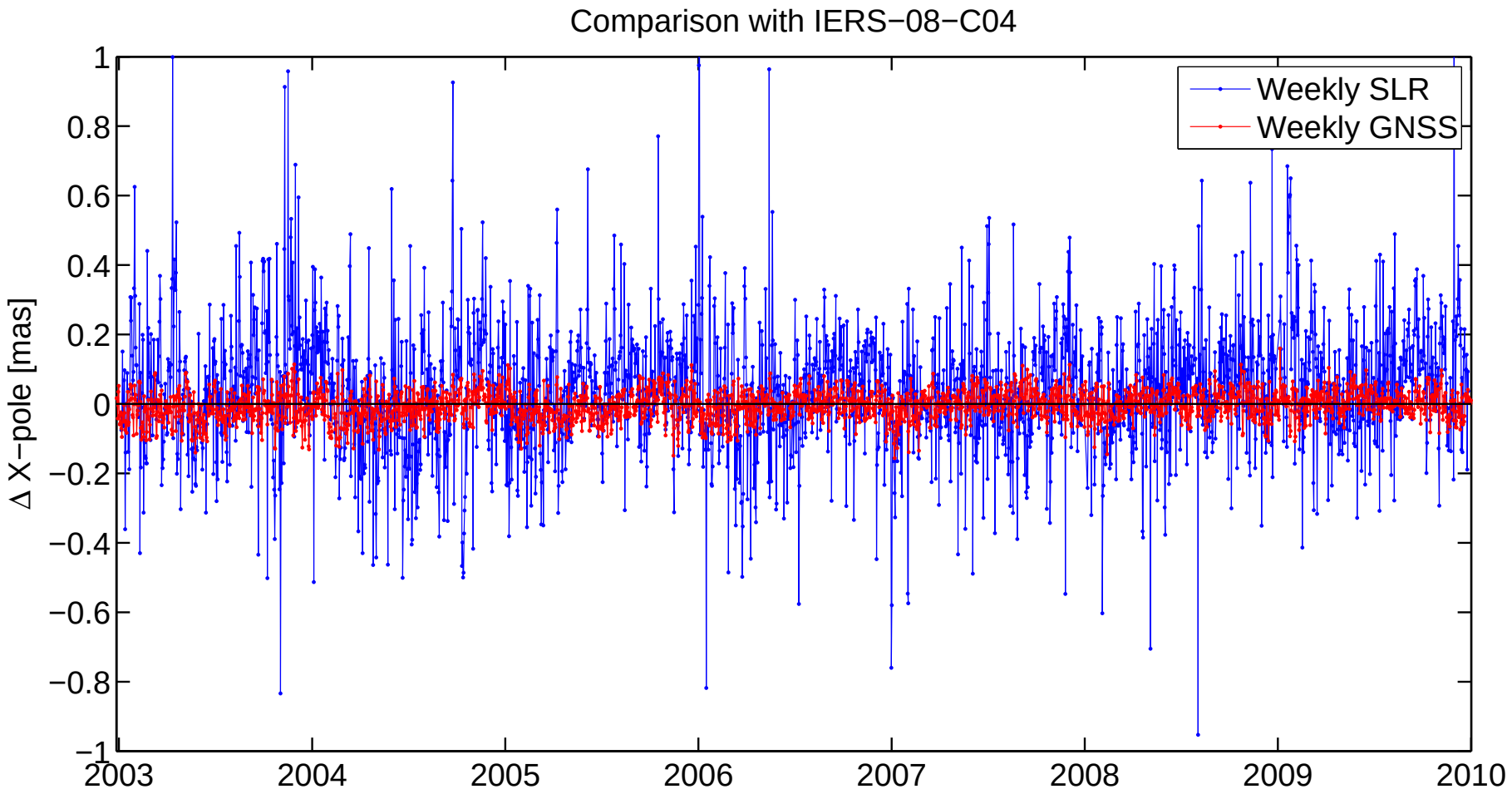
SLR analysis for spherical satellites

Typical parameter set-up in weekly SLR solutions:

- Station coordinates
- Earth Rotation Parameter:
  - Polar motion
  - Length of Day (LOD)
- Satellite orbits:
  - 6 Osculating elements
  - Empirical orbit parameters:
    - Constant along-track acceleration
    - Once-per-revolution along-track parameters
    - Once-per-revolution cross-track parameters
- Range biases (for selected sites)

~ 120 – 140 Parameters per week

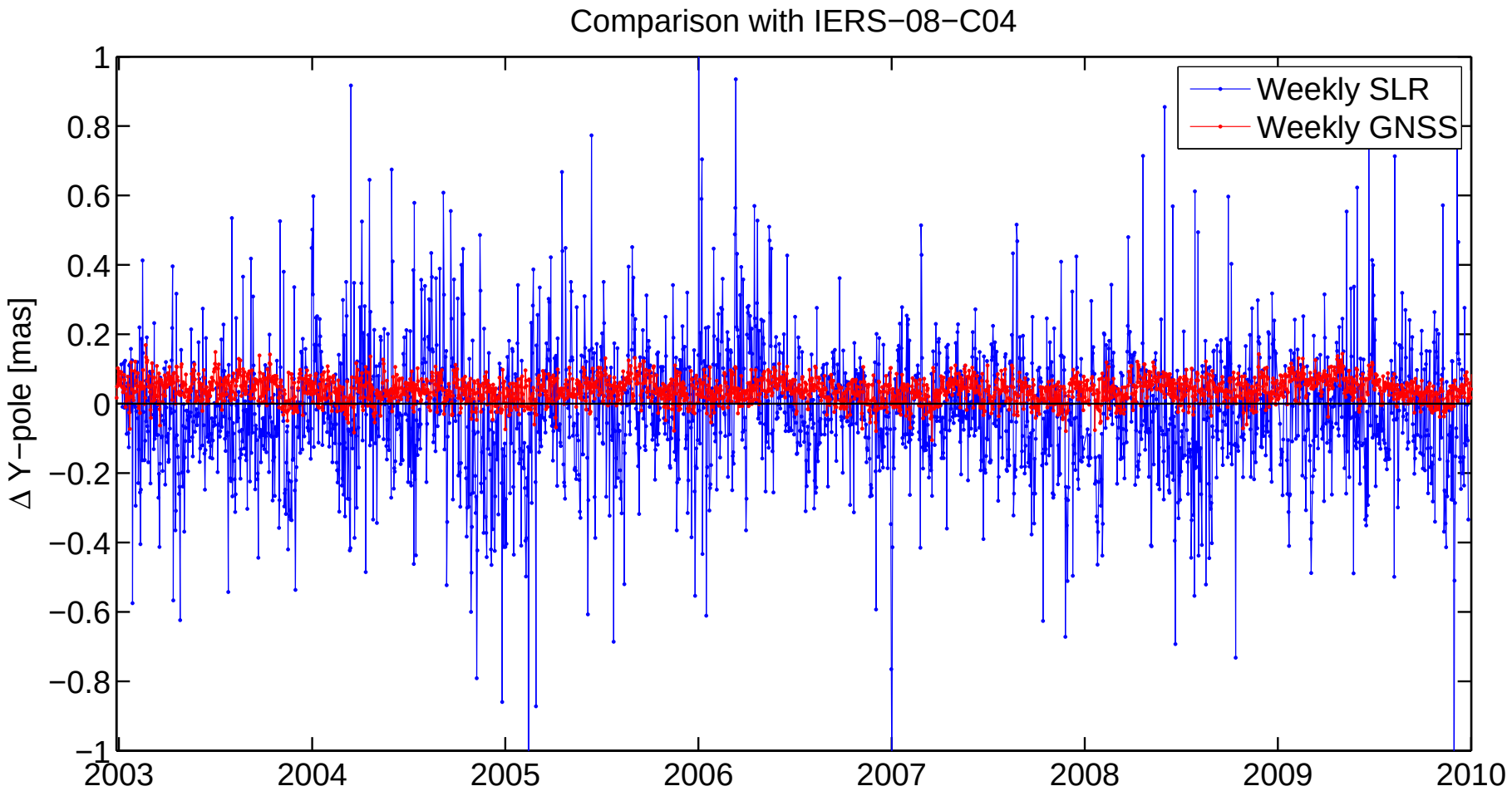
SLR analysis for spherical satellites: ERP



Mean Bias = 36 μas RMS = 141 μas

−6 μas 46 μas

SLR analysis for spherical satellites: ERP



Mean Bias = −21 µas **RMS** = 145 µas

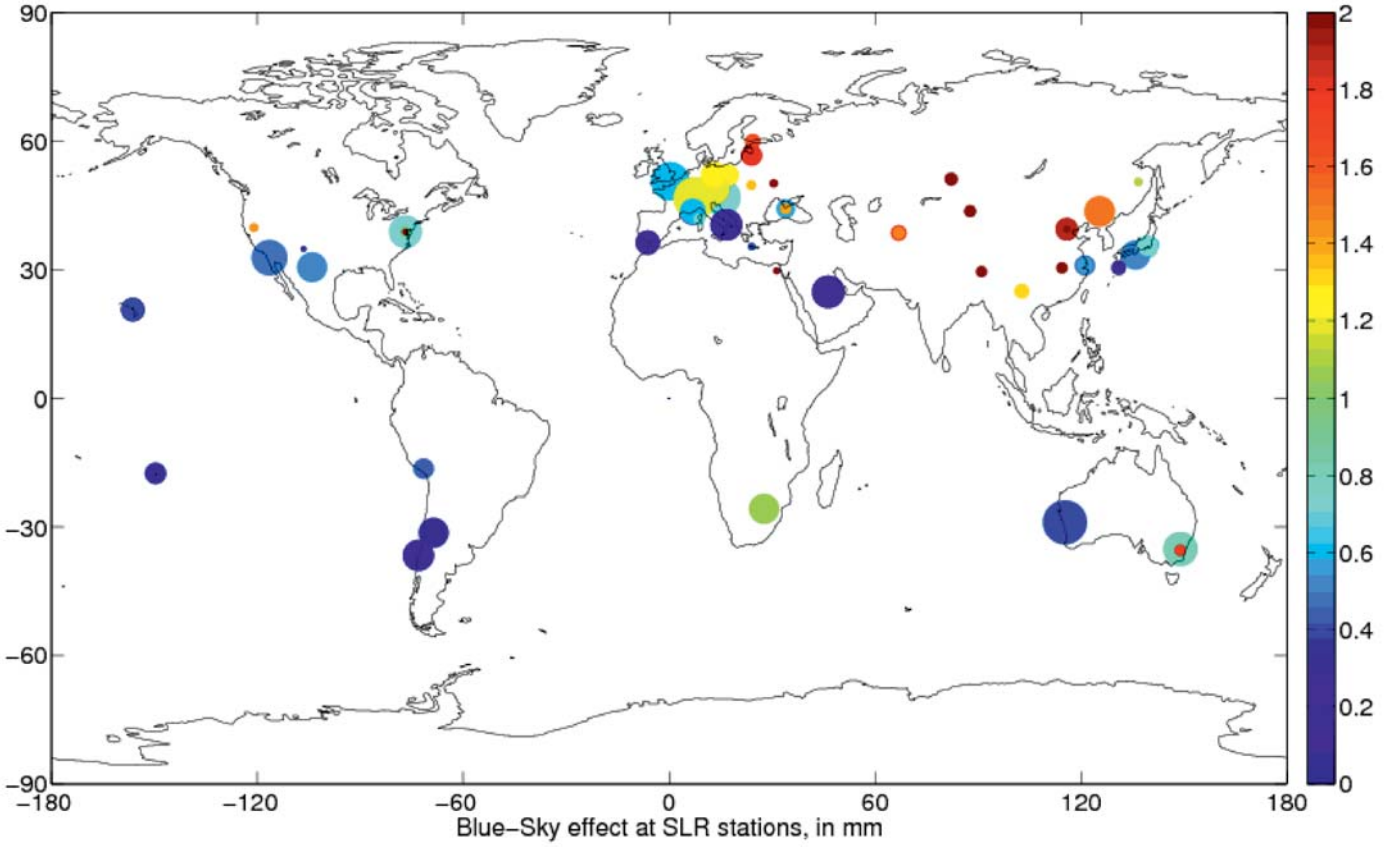
42 µas 40 µas

SLR analysis: «Blue-Sky Effect»

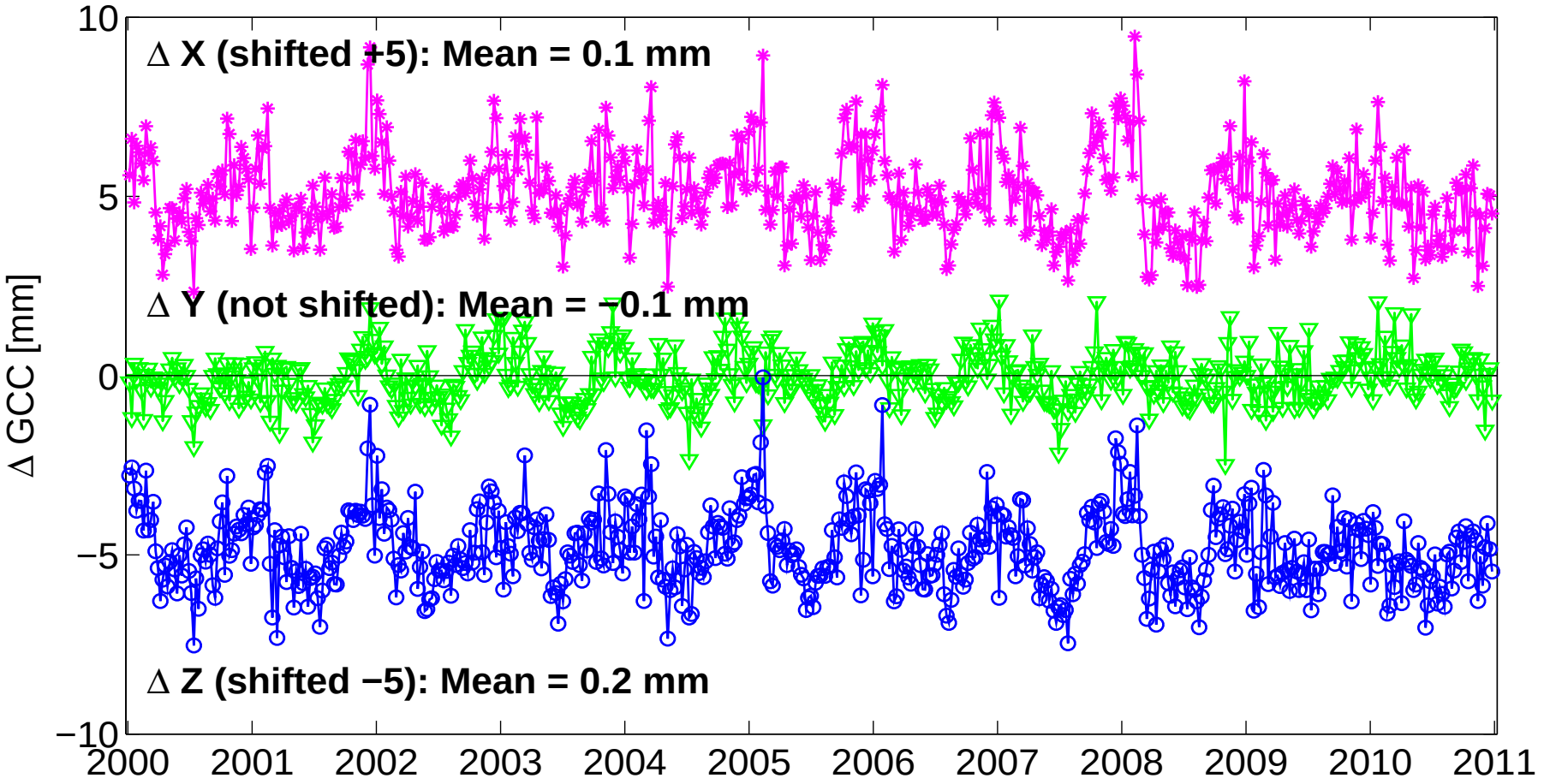
SLR observations are possible only at cloudless sky

= usually high pressure

⇒ Systematic **atmospheric loading** on SLR stations: up to **2 mm**



Impact of atmospheric loading

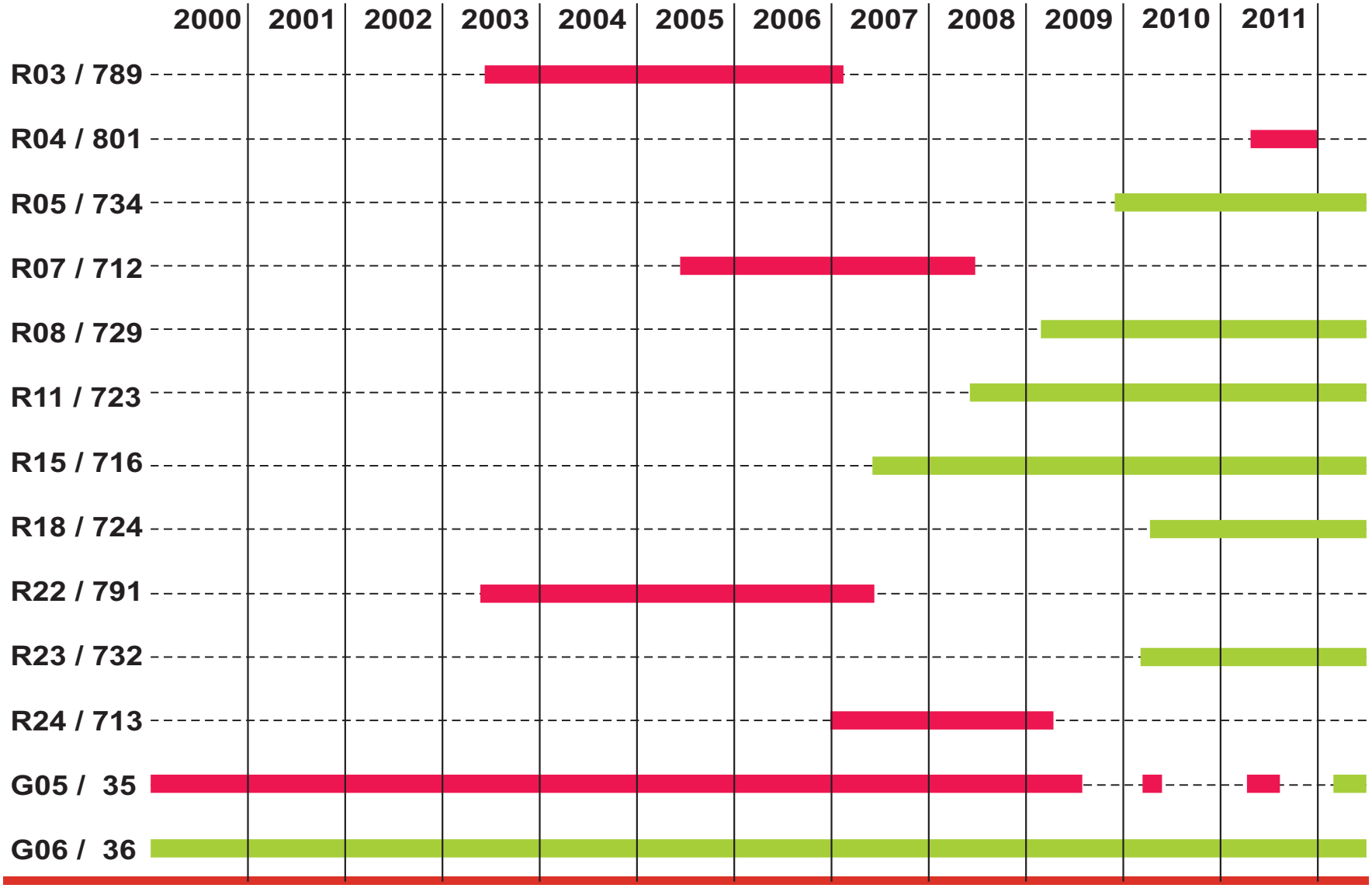


SLR tracking of GNSS satellites

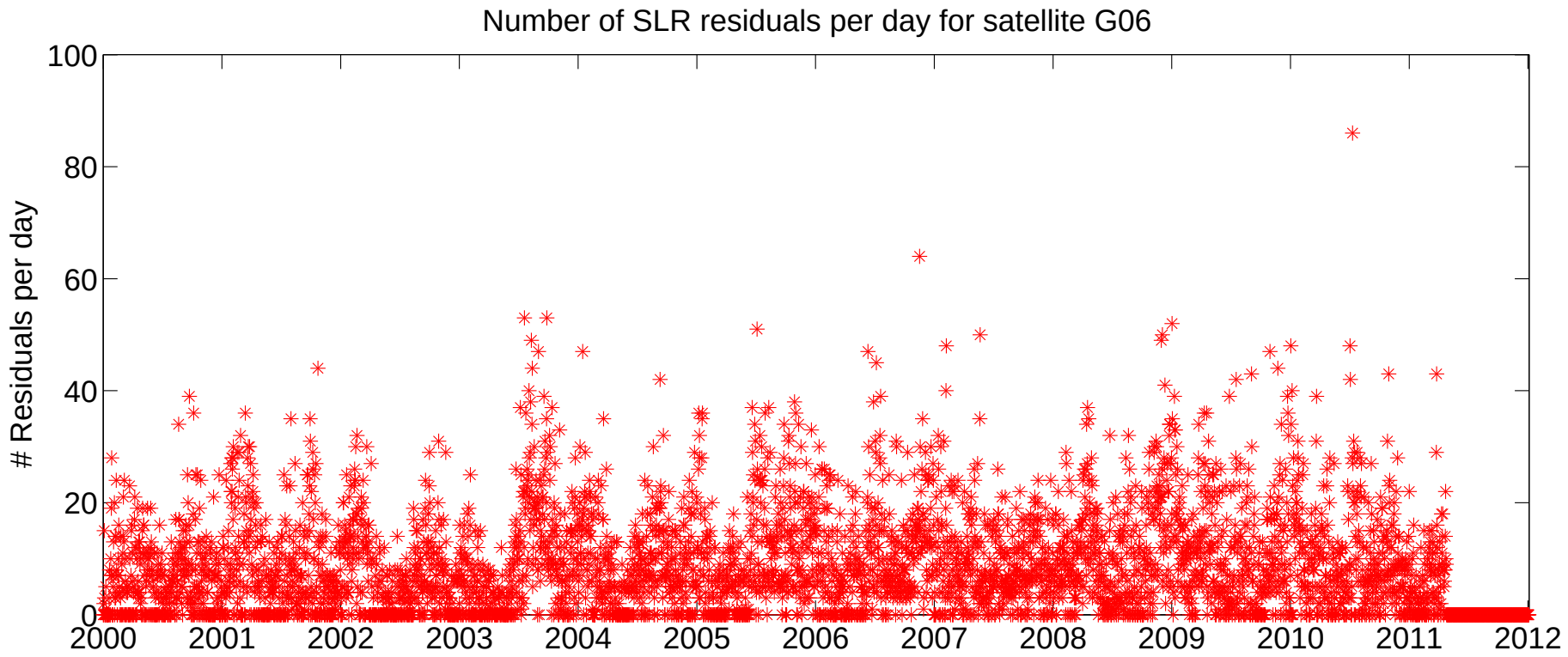
- **Several GNSS satellites are tracked by SLR:**
  - Independent validation of the orbit computation based on microwave data
  - Combined GNSS-SLR analysis (satellite co-location)

- **SLR residual computation at AIUB:**
  - GNSS satellite orbits (and ERPs) computed at the CODE Analysis Center of the IGS
  - SLRF2008 station coordinates
  - A daily report is sent to the ILRS

SLR tracking of GNSS satellites



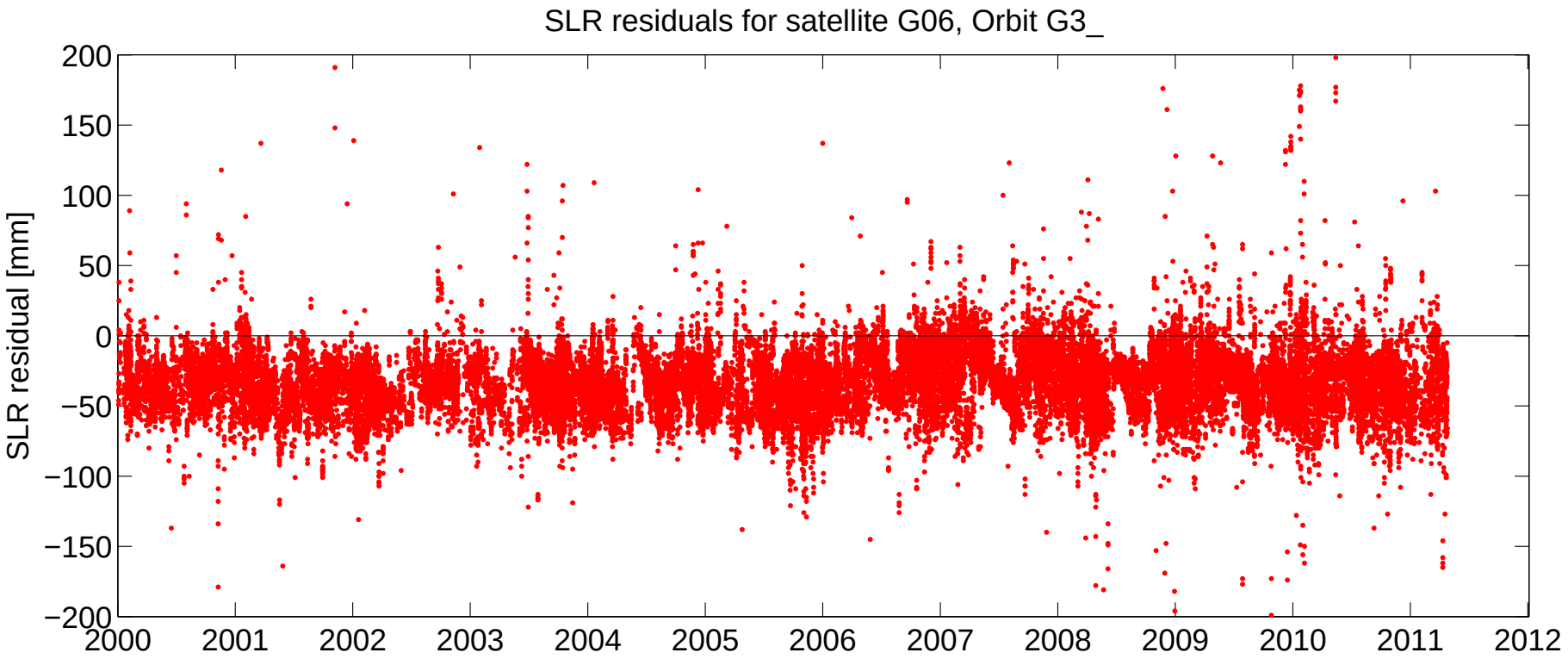
SLR tracking of GNSS satellites



Number of observations per day / per satellite is very small:

- GPS: ~ 10 – 15
- GLONASS: ~ 20 – 30

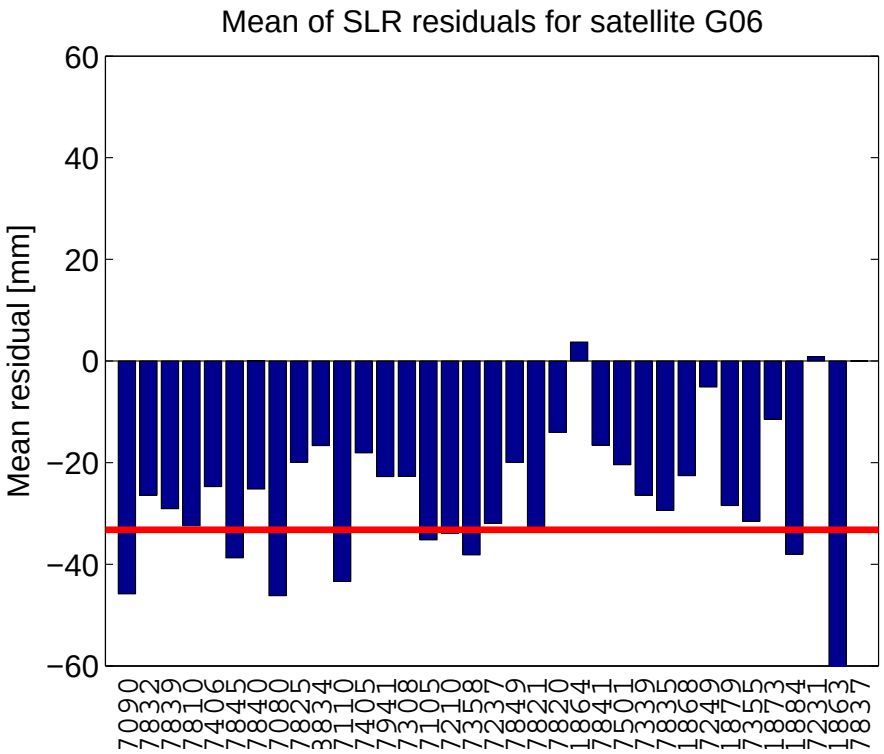
SLR residual analysis for GNSS orbits

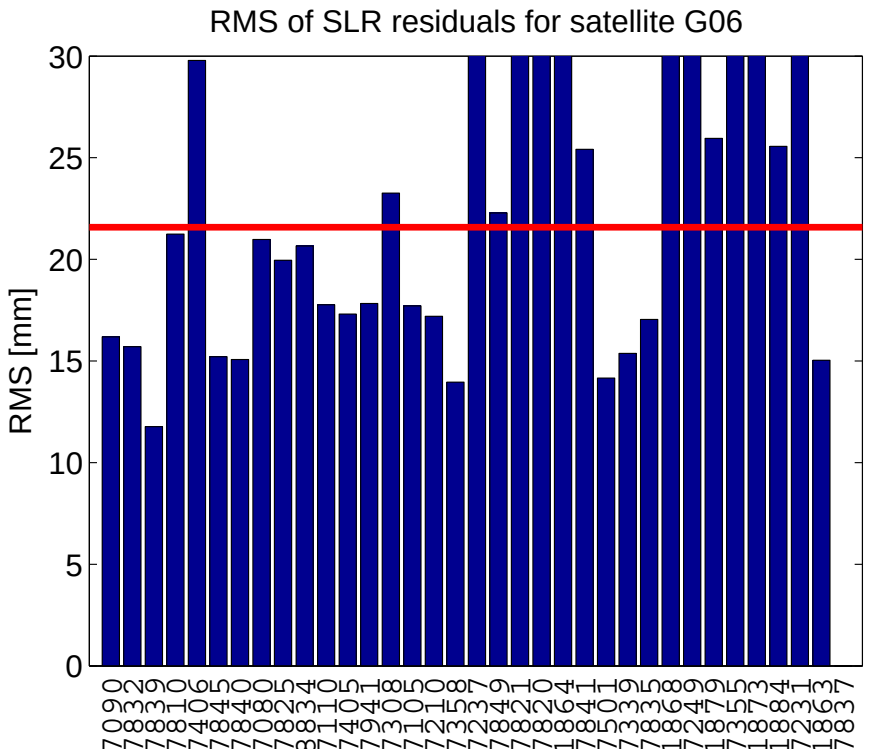


- Overall Mean Bias = -33.2 mm
- Overall RMS = 21.6 mm

But: Bias and RMS are station-dependent

SLR residual analysis for GNSS orbits

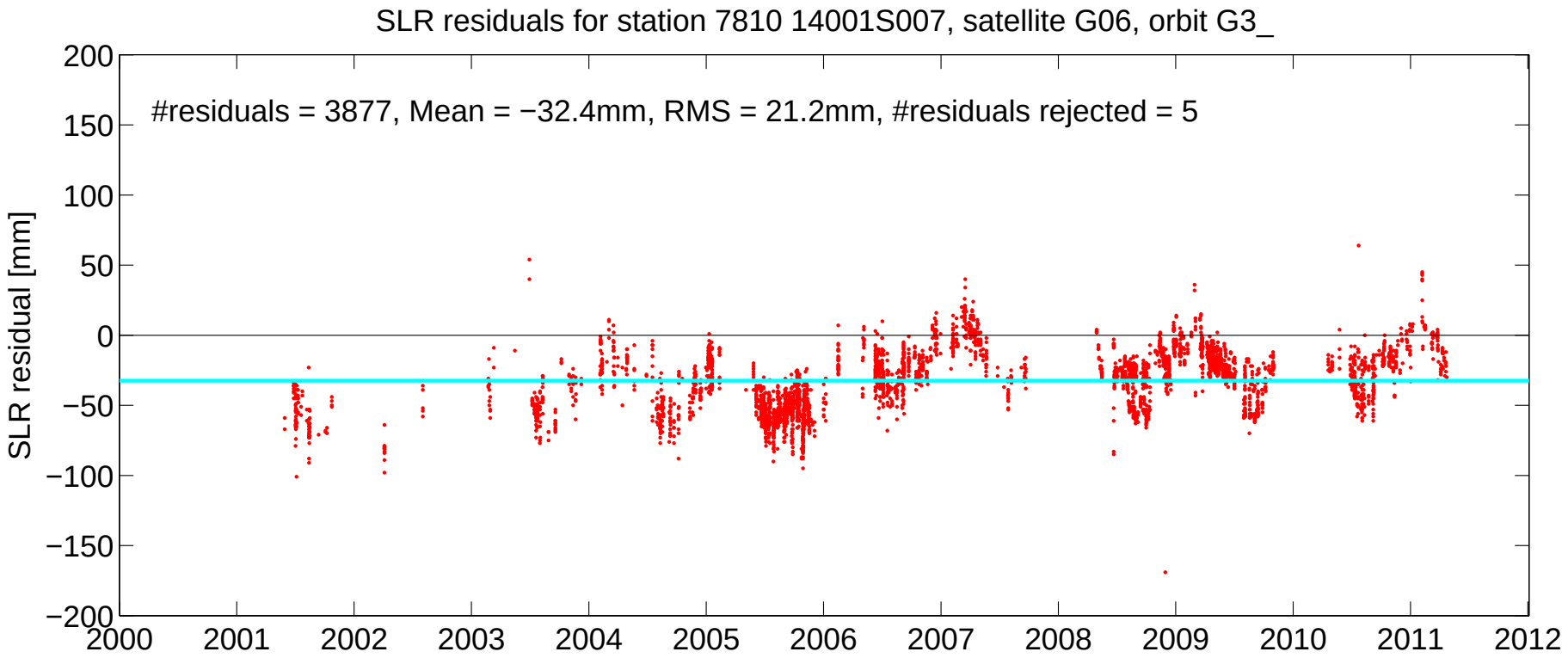




- Overall Mean Bias = -33.2 mm
- Overall RMS = 21.6 mm

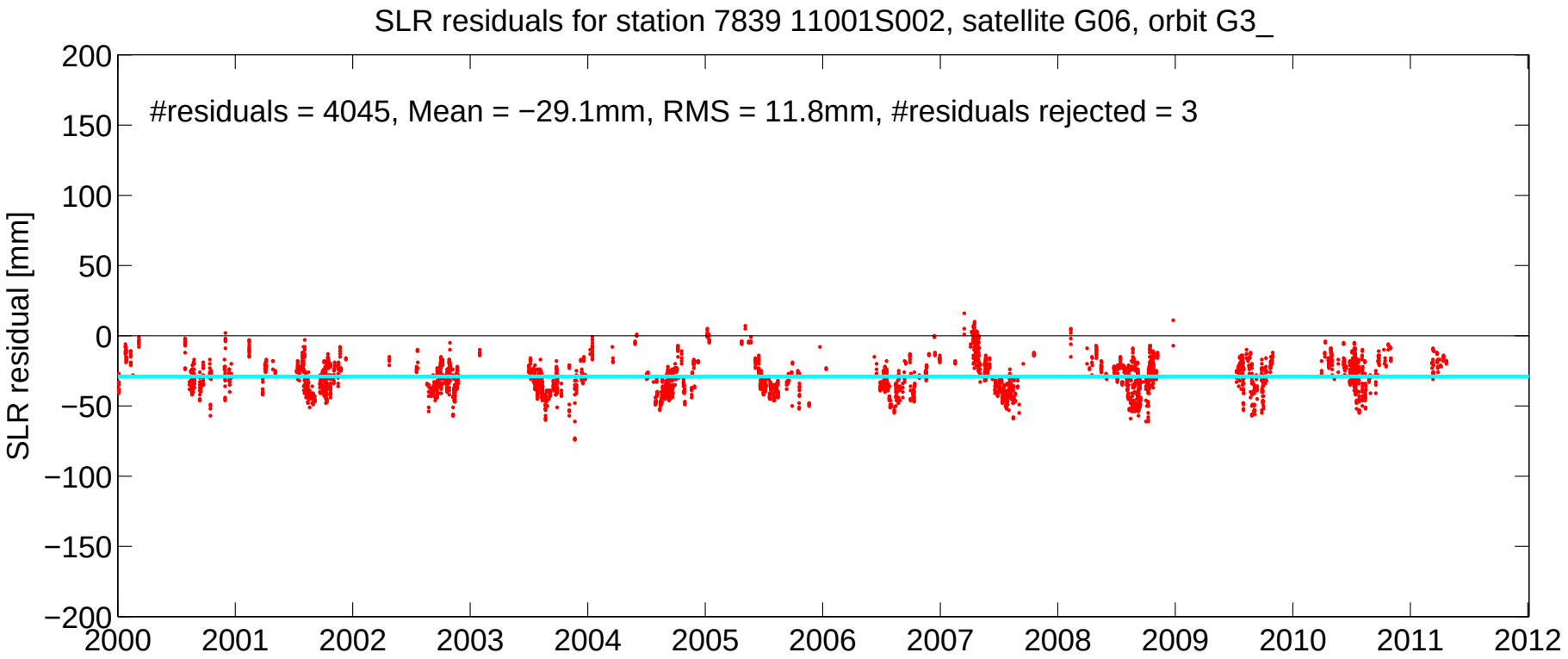
But: Bias and RMS are **station-dependent**

SLR residual analysis for GNSS orbits



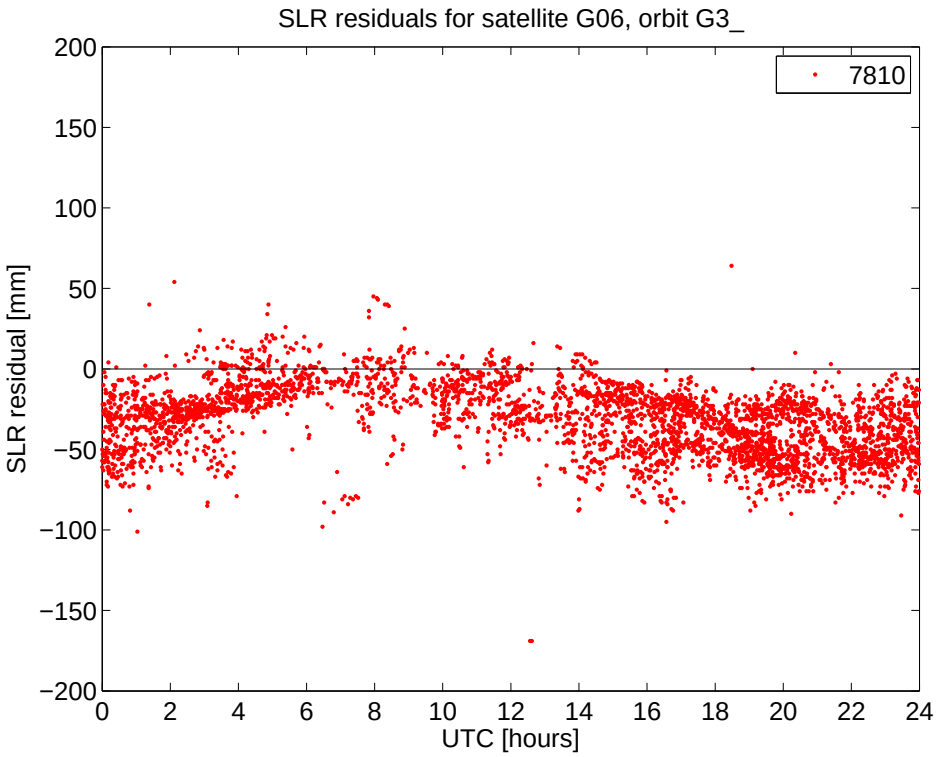
- Even time-dependent variations are visible:
  - Station upgrades
  - Seasonal

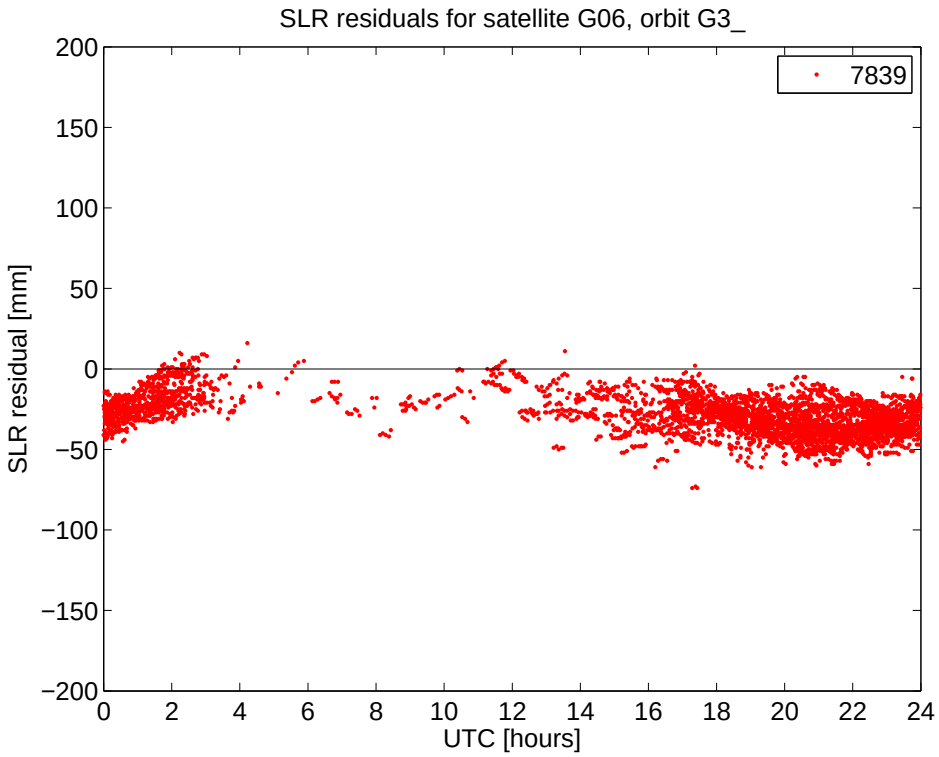
SLR residual analysis for GNSS orbits



- Even time-dependent variations are visible:
  - Seasonal

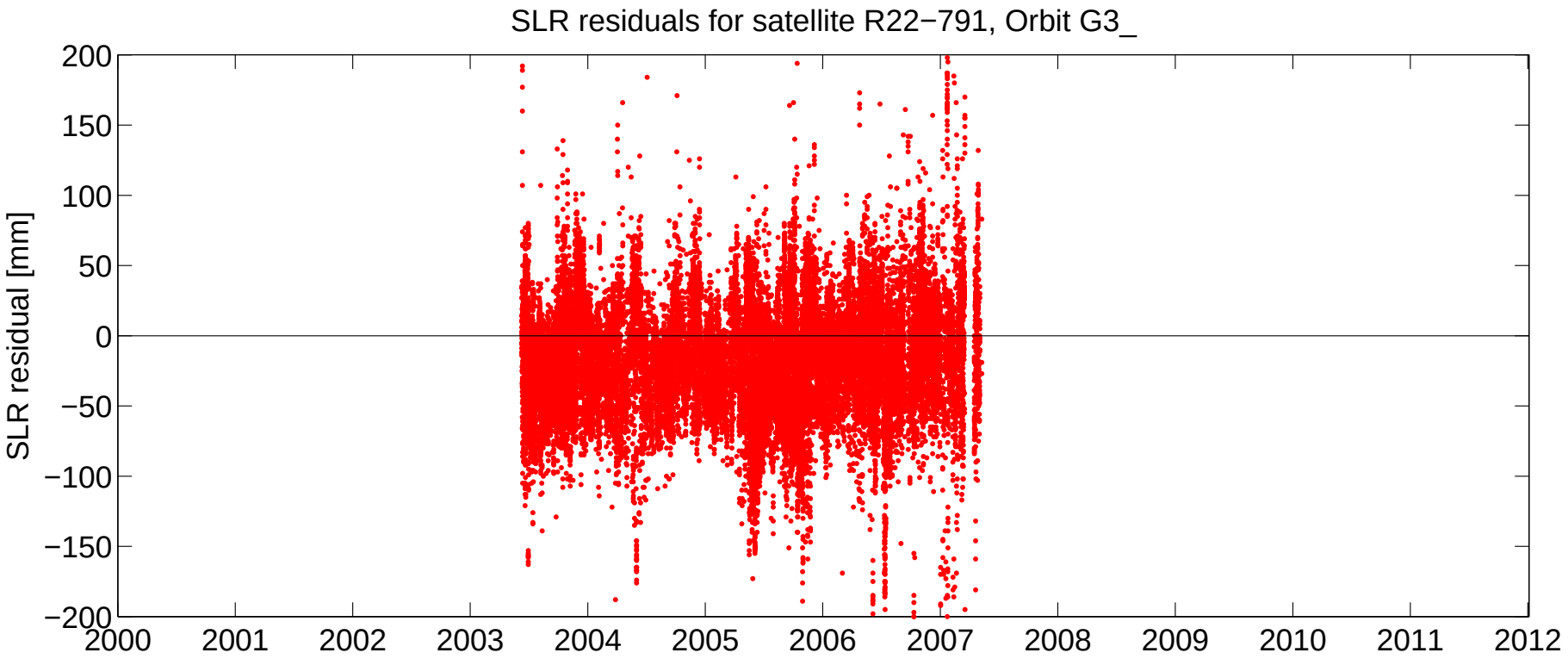
SLR residual analysis for GNSS orbits





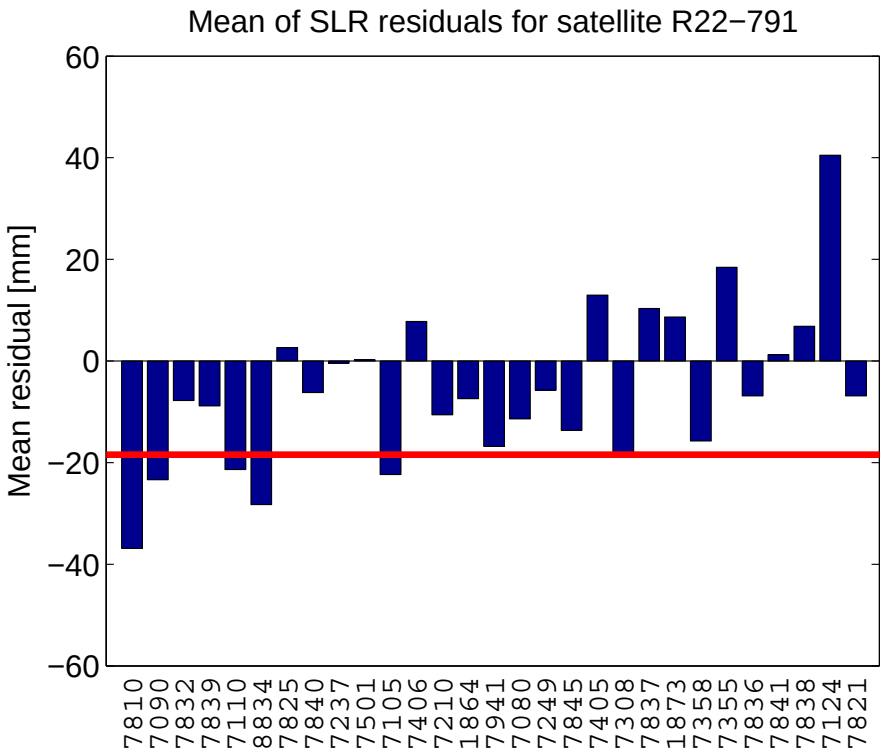
- Even time-dependent variations are visible:
  - Daily

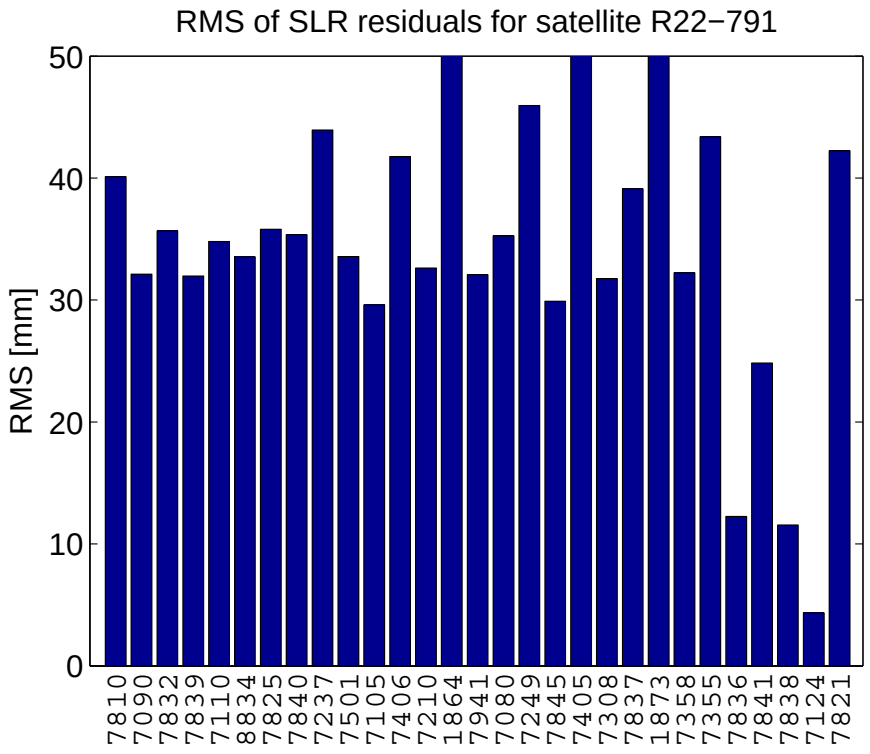
SLR residual analysis for GNSS orbits



- Overall Mean Bias = -18.4 mm
- Overall RMS = 38.9 mm

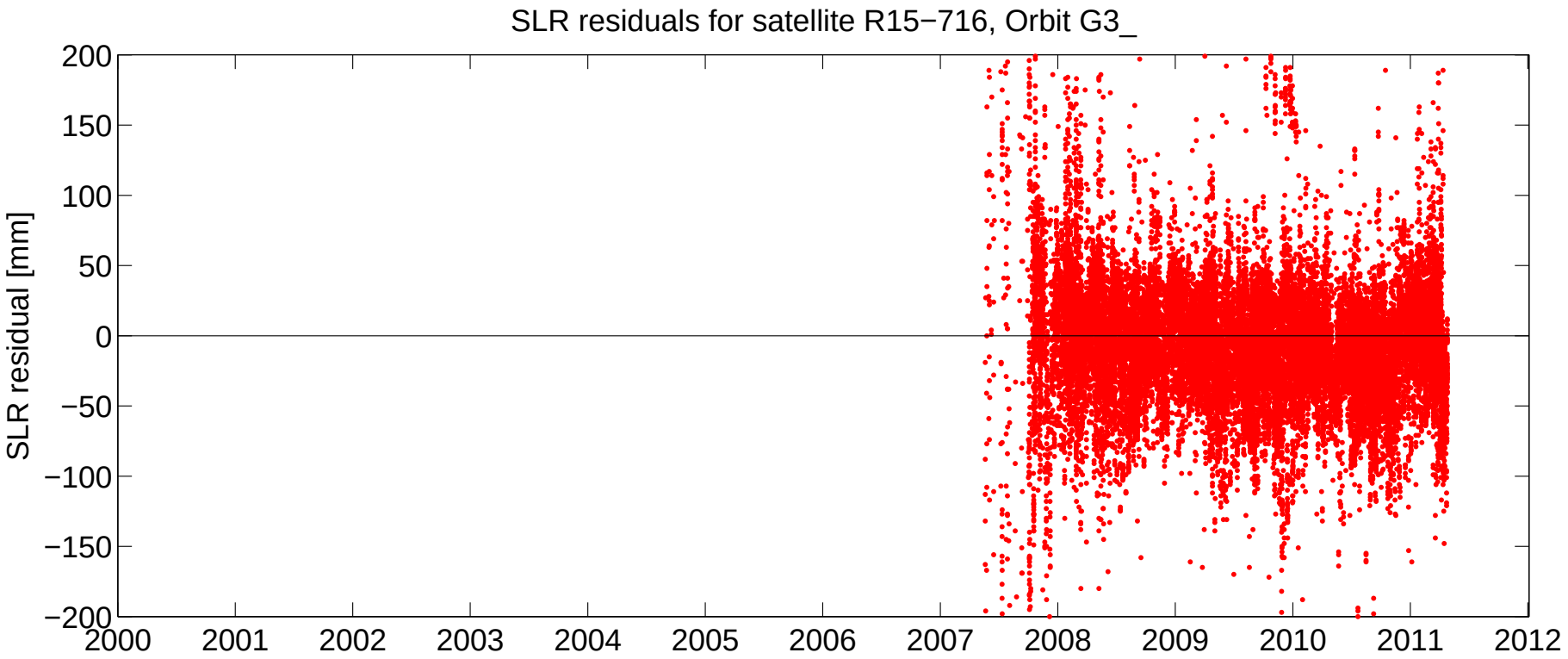
SLR residual analysis for GNSS orbits





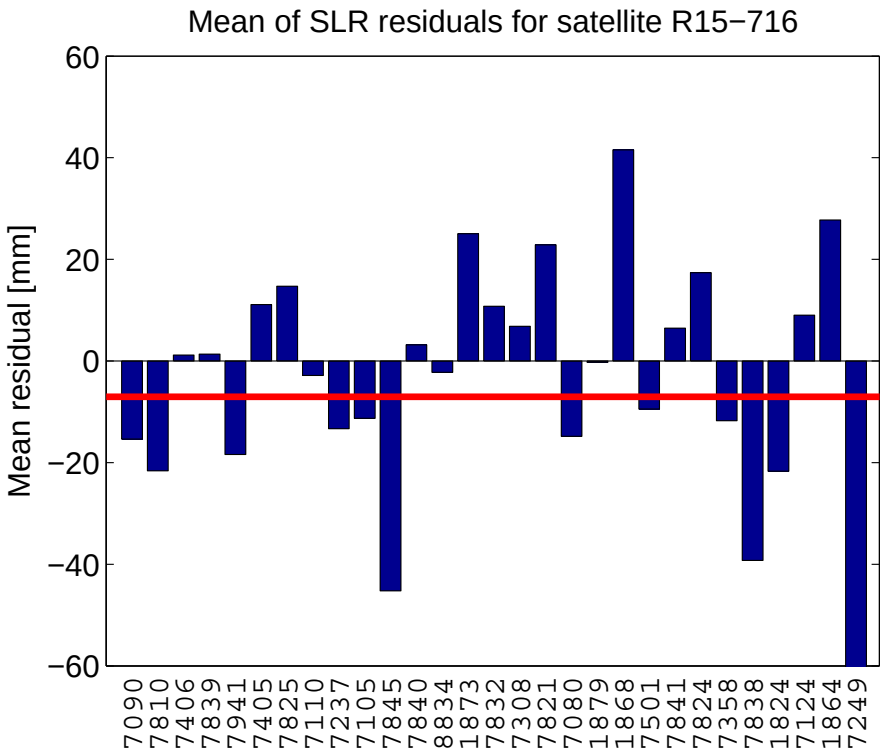
- Overall Mean Bias = -18.4 mm
- Overall RMS = 38.9 mm

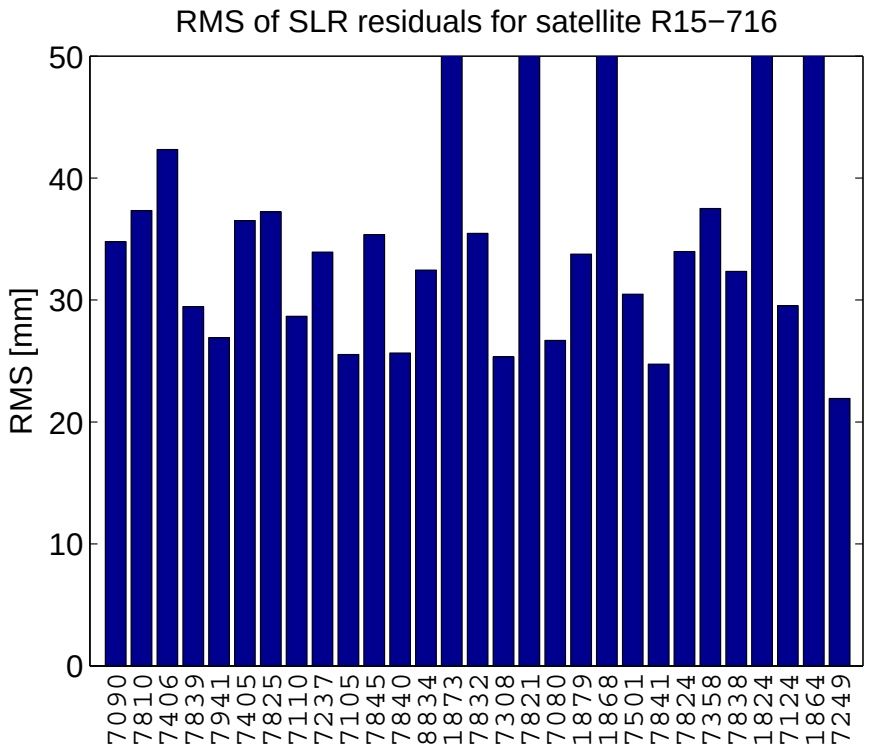
SLR residual analysis for GNSS orbits



- Overall Mean Bias = -7.0 mm
- Overall RMS = 40.3 mm

SLR residual analysis for GNSS orbits





- Overall Mean Bias = -7.0 mm
- Overall RMS = 40.3 mm

SLR residual analysis for GNSS orbits

Satellite PRN-SVN	# SLR observations	Overall mean bias [mm]	Overall RMS [mm]
G06- 36	37124	-33.21	21.58
G05- 35	32981	-31.53	20.03
R22-791	30047	-18.42	38.86
R15-716	29899	- 7.03	40.33
R03-789	29059	-17.79	41.89
R07-712	21317	-12.30	38.64
R11-723	20873	-28.01	37.23
R08-729	20273	-33.15	32.04
R24-713	17626	-19.72	43.59
R23-732	7006	-16.77	31.87
R05-734	4245	-12.92	28.63
R18-724	3412	-12.83	30.84

SLR residual analysis for GNSS orbits

What is influencing the SLR residuals?

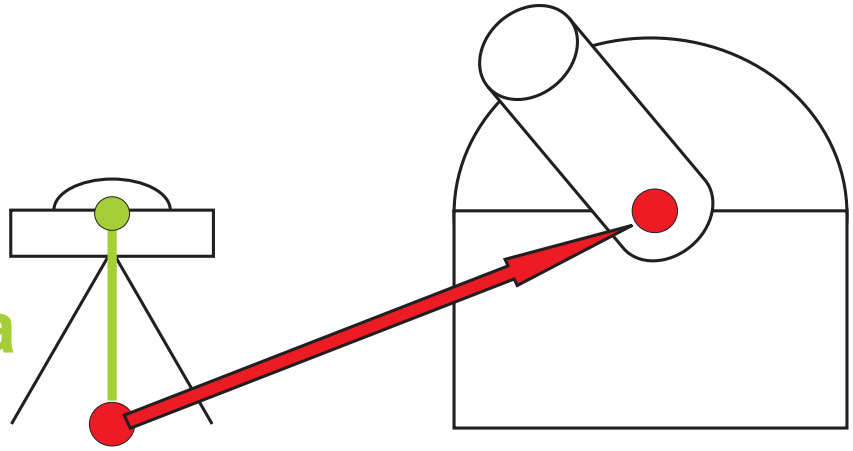
- Errors in SLR station coordinates
- Errors in offsets of the laser reflector array (LRA)
- Un-calibrated SLR range biases for high satellites
- Quality of GNSS orbits:
  - Problems in satellite orbit modelling
  - Satellite antenna offsets (and phase center variations)
  - Network used to determine orbits (⇒ GLONASS issue)
- Inconsistencies in GNSS and SLR reference frame

➢ Combined analysis including estimation of parameters for possible error sources

Combined GNSS-SLR analysis: Co-locations

Station co-location
vs.
Satellite co-location

Phase Center + Antenna Height



Local Tie

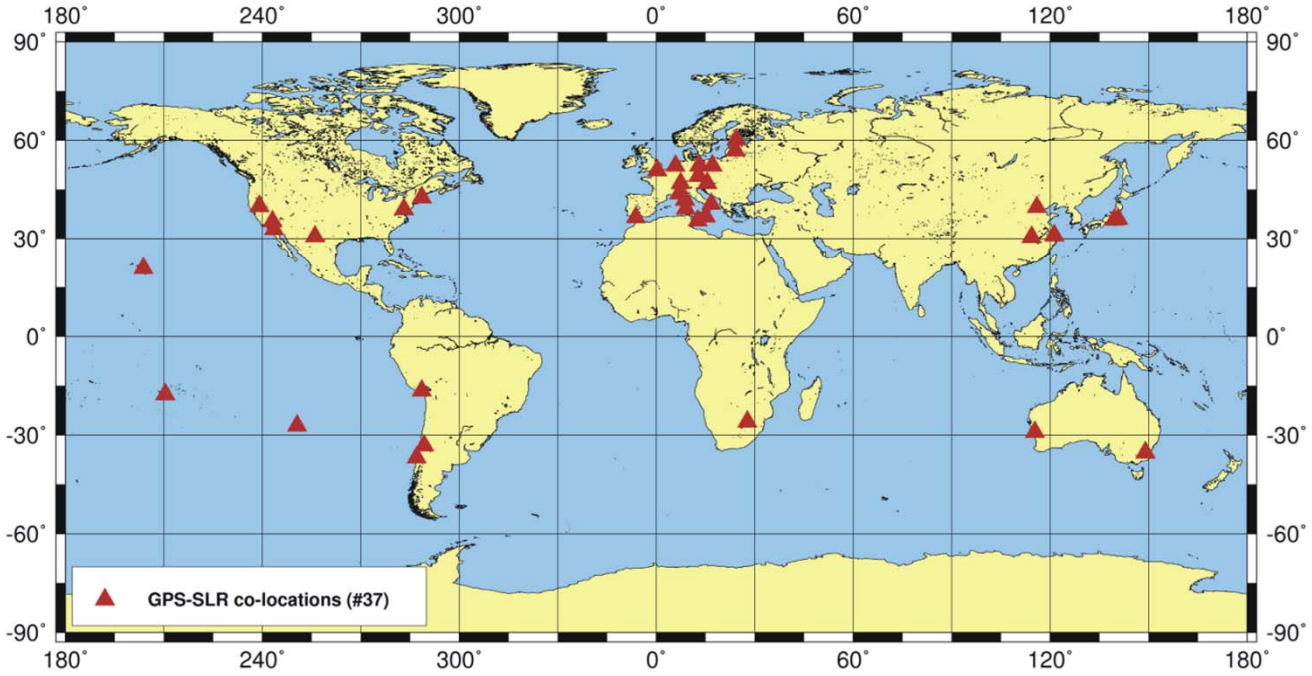
Co-location at stations (e.g., for actual ITRF computation):
→ Application of known local tie values
→ GNSS observations of ground network
→ SLR observations to LAGEOS etc.

→ Independent of satellite tracked
→ Local ties from terrestrial measurements

Combined GNSS-SLR analysis: Co-locations

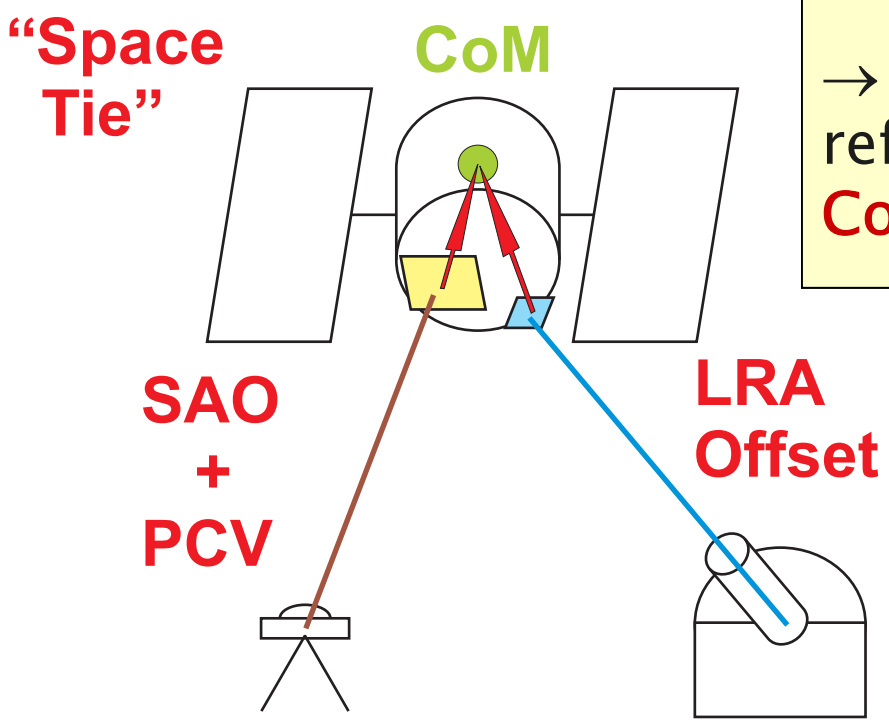
Station co-location
vs.
Satellite co-location

- bad **global distribution** of co-located sites
- only **few** co-locations (37)
- questions concerning **accuracy**, **transformation** local→global



Combined GNSS-SLR analysis: Co-locations

Station co-location
vs.
Satellite co-location



Co-location at GNSS satellites

=

Common orbit parameters from GNSS microwave and SLR range data

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

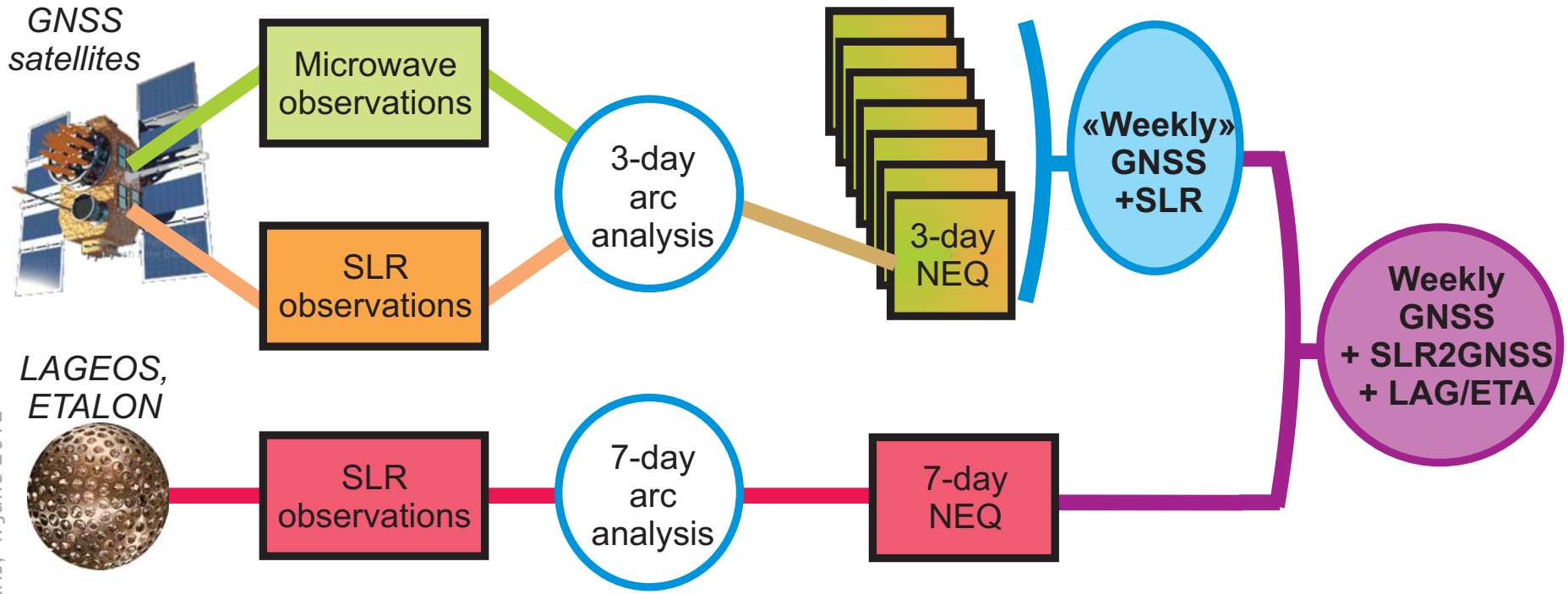
Combined GNSS-SLR analysis

Common parameters for combination:

- Direct combination
- Indirect combination by applying correction terms («Local ties»)

Parameter	GNSS microwave	SLR@GNSS	SLR spherical satellites
Station coordinates	GNSS	SLR	SLR
ERP	X	X	X
Orbits GNSS satellites	X	X	
Orbits spherical satellites			X
Geocenter	X	X	X
Microwave SAO	X		
LRA offsets		X	
Range biases		X	X

Combined GNSS-SLR analysis



- **Reprocessing 2000.0 – 2011.0**:
  - CODE GNSS reprocessing using IGS08 models
  - SLR reprocessing
- ***Bernese GNSS Software*** for all processing steps:
  - Equivalent to combination at observation level

Combined GNSS-SLR analysis

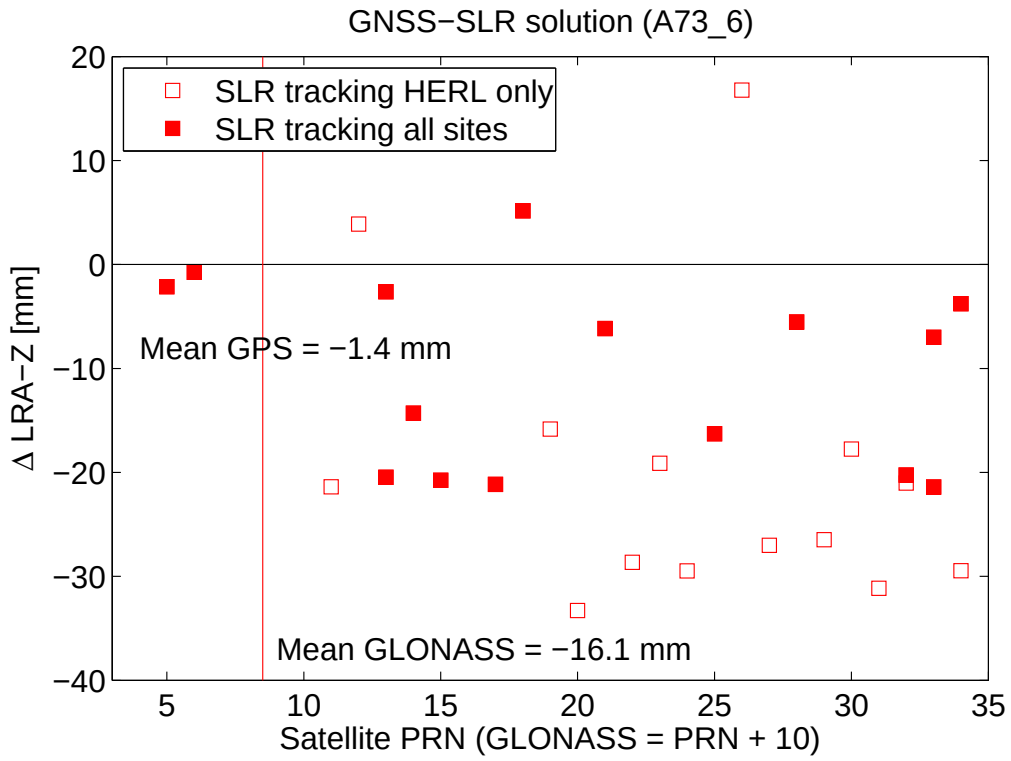
	MW @GNSS	SLR @GNSS	SLR @Lageos
Radiation pressure ↔ **Geocenter**	Problems in RPR modelling	Problems in RPR modelling	RPR well modelled
GNSS satellite antenna phase center ↔ **Scale**	Problems in phase center modelling	independent	-
Range biases ↔ **Scale**	-	Decorrelated if different elevation angles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

SLR @GNSS:

⇒ Geocenter is affected as well ⇒ LAGEOS needed

⇒ Scale is transferred to GNSS ⇒ LAGEOS helps for decorrelation

Combined GNSS-SLR analysis: LRA

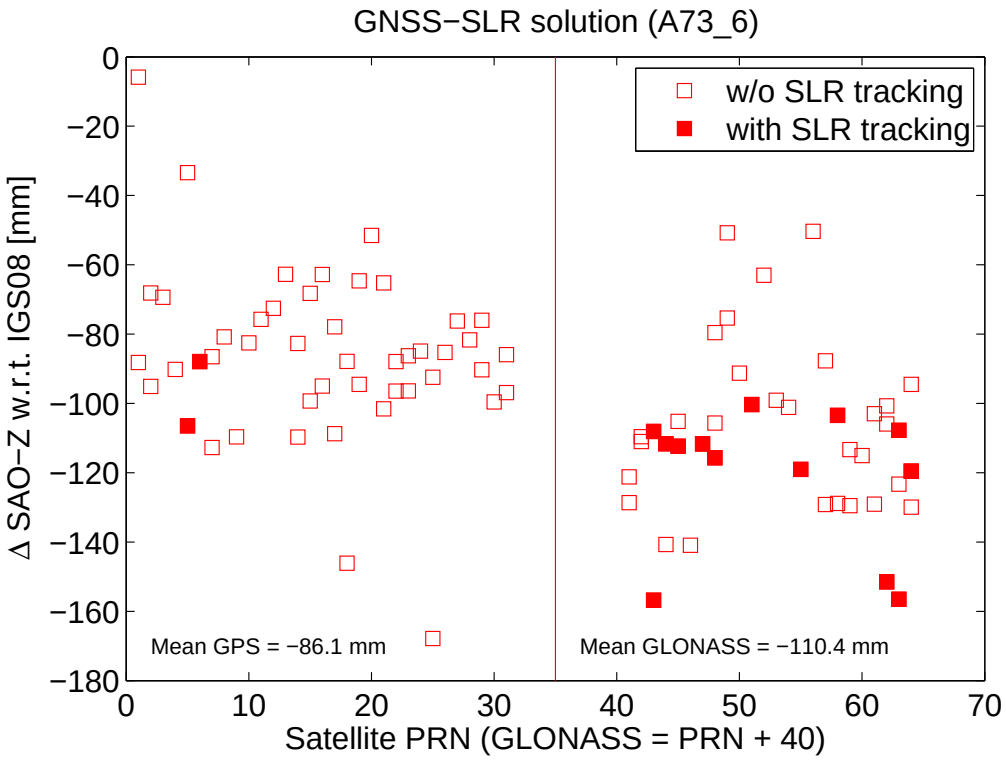


Corrections to ILRS values:

GPS: −1.4 mm

GLONASS: −16.1 mm

Combined GNSS-SLR analysis: SAO



Δscale [ppb] =

$-7.8 \times \Delta SAO_Z$ [m]

Corrections to IGS08 values:

GPS: -86.1 mm

GLONASS: -110.4 mm

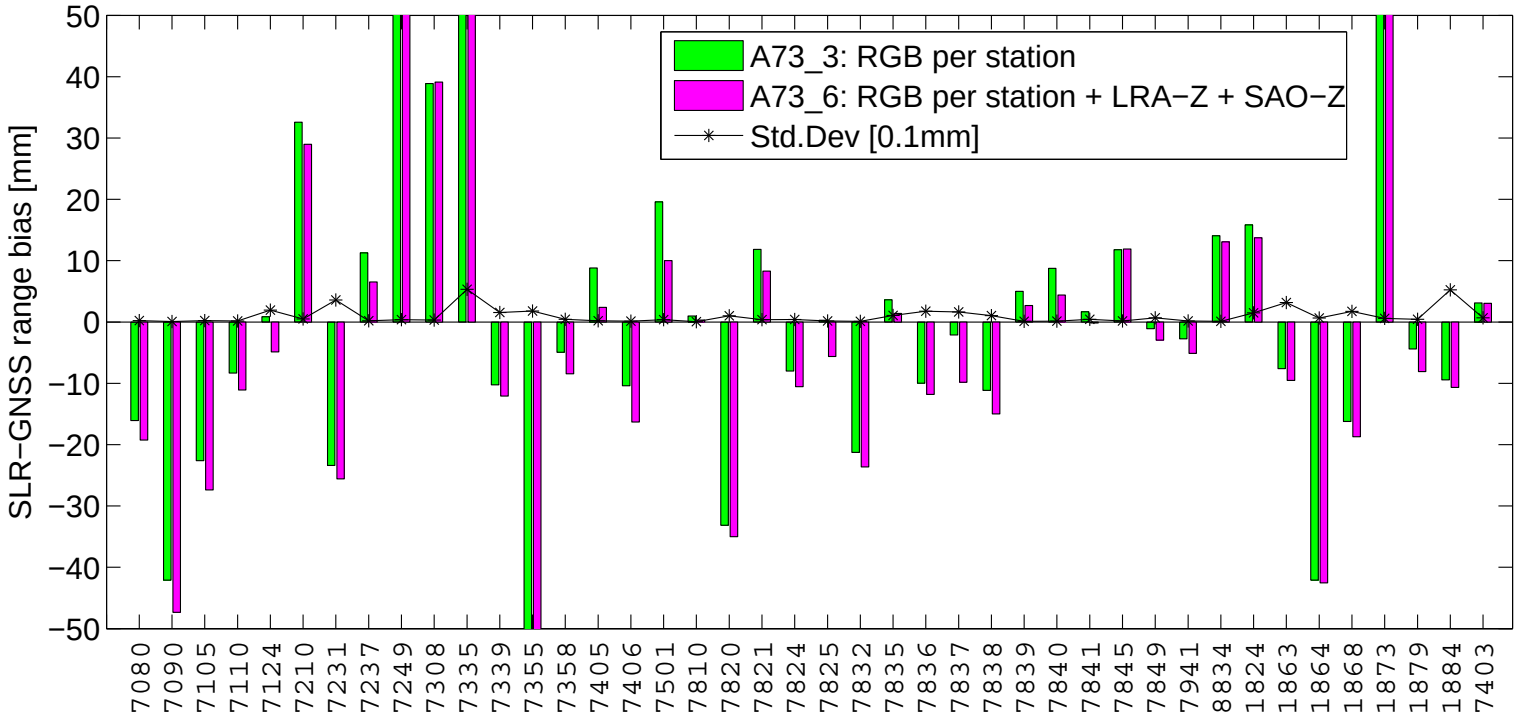
$\Rightarrow$ 0.67 ppb

$\Rightarrow$ 0.86 ppb

Combined GNSS-SLR analysis: Range biases

1 RGB per station (for all satellites) estimated:

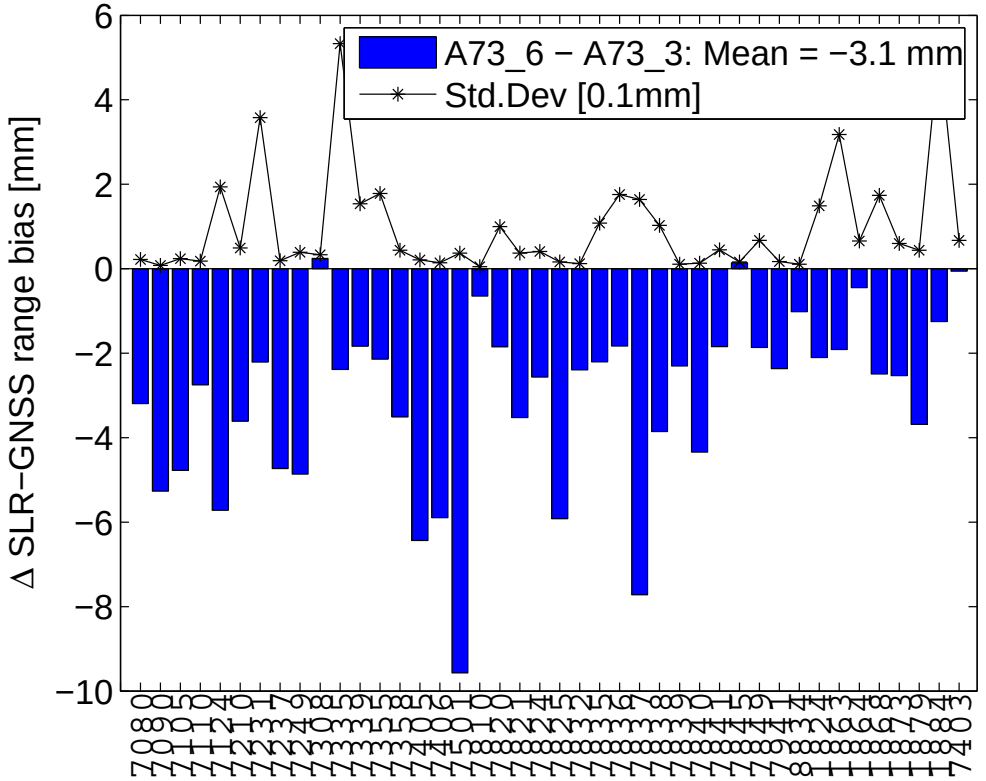
- Big differences between stations (+- few centimeters)
- Correlations with other parameters?



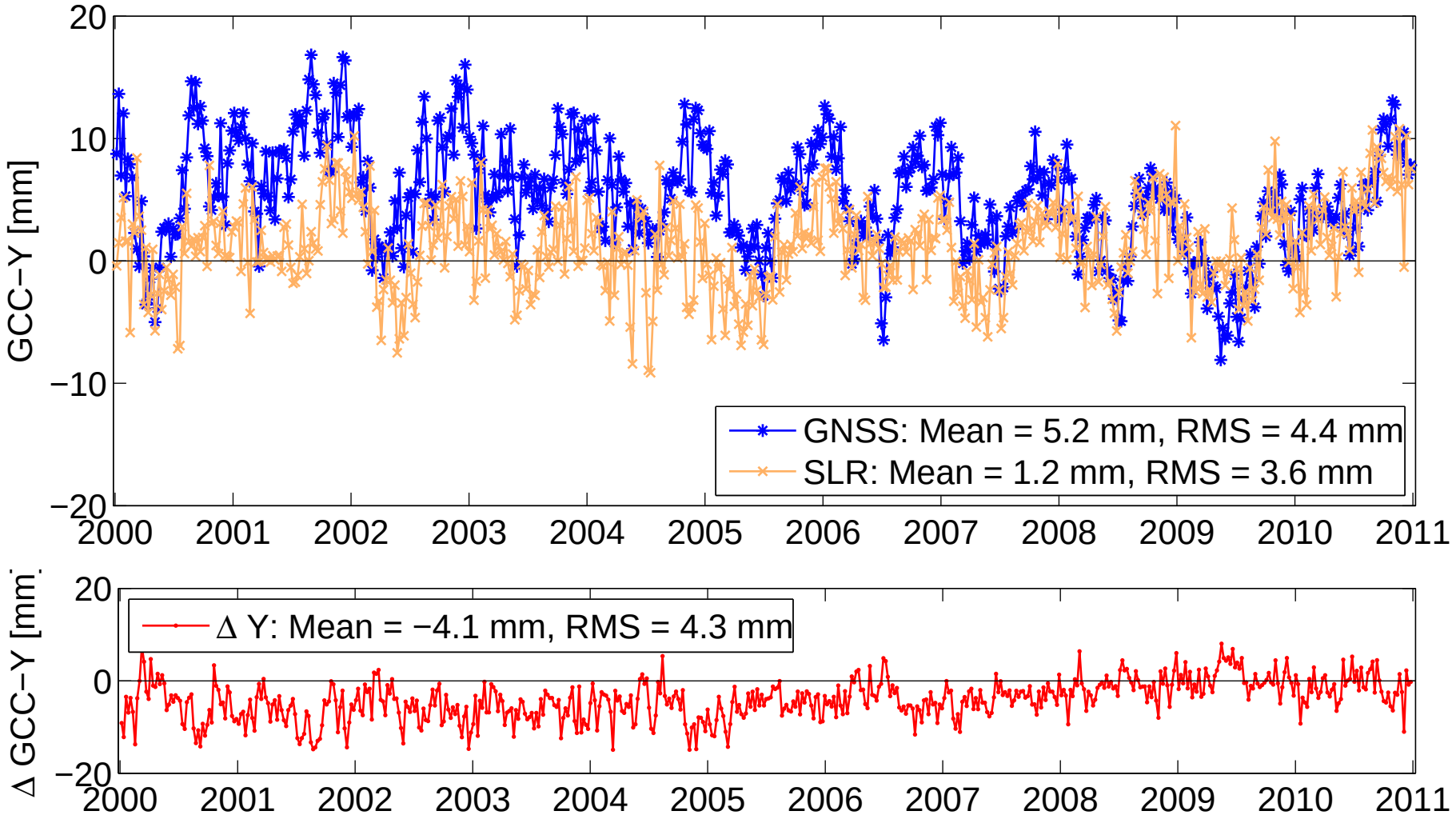
Combined GNSS-SLR analysis: Range biases

Correlations with other parameters?

- Additional estimation of SAO and LRA offset corrections causes differences in RGB estimates of a few mm only
- Not critical

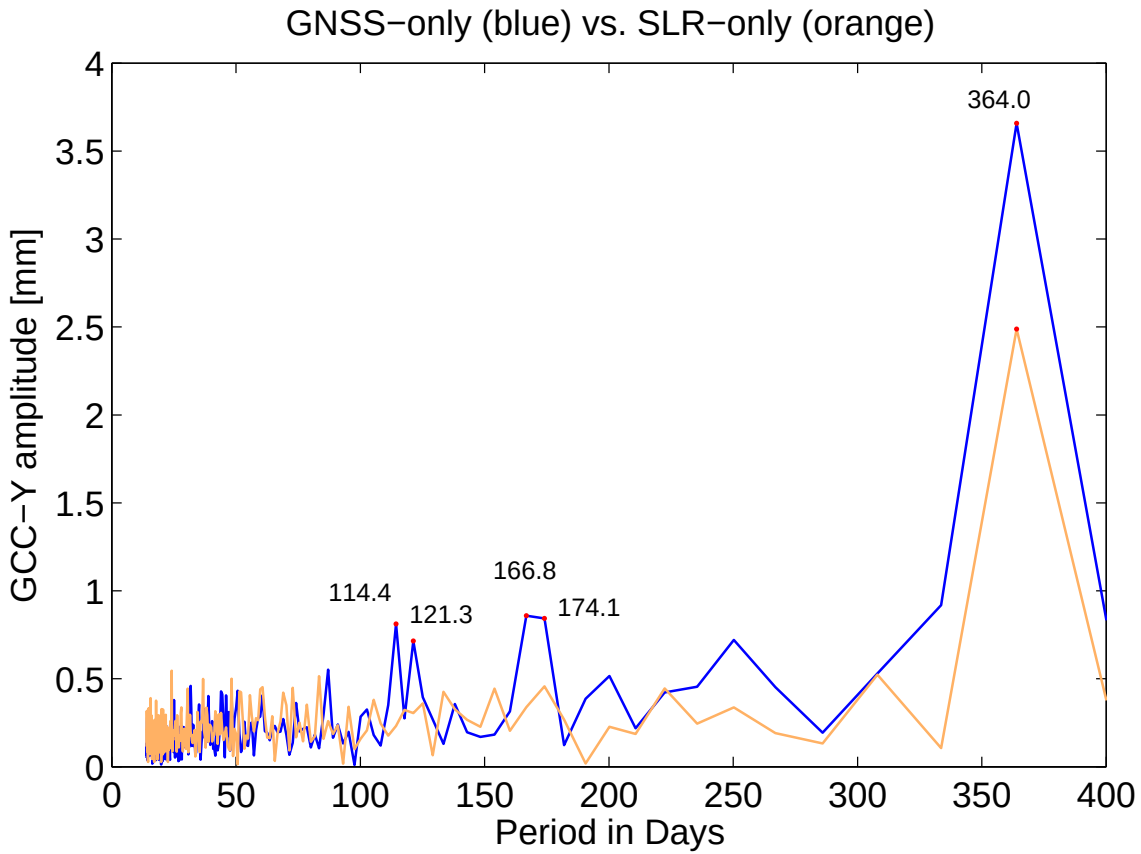


Geocenter: SLR-only and GNSS-only series



- Comparable series from GNSS and SLR (except for shift 4 mm)

Geocenter: SLR-only and GNSS-only series

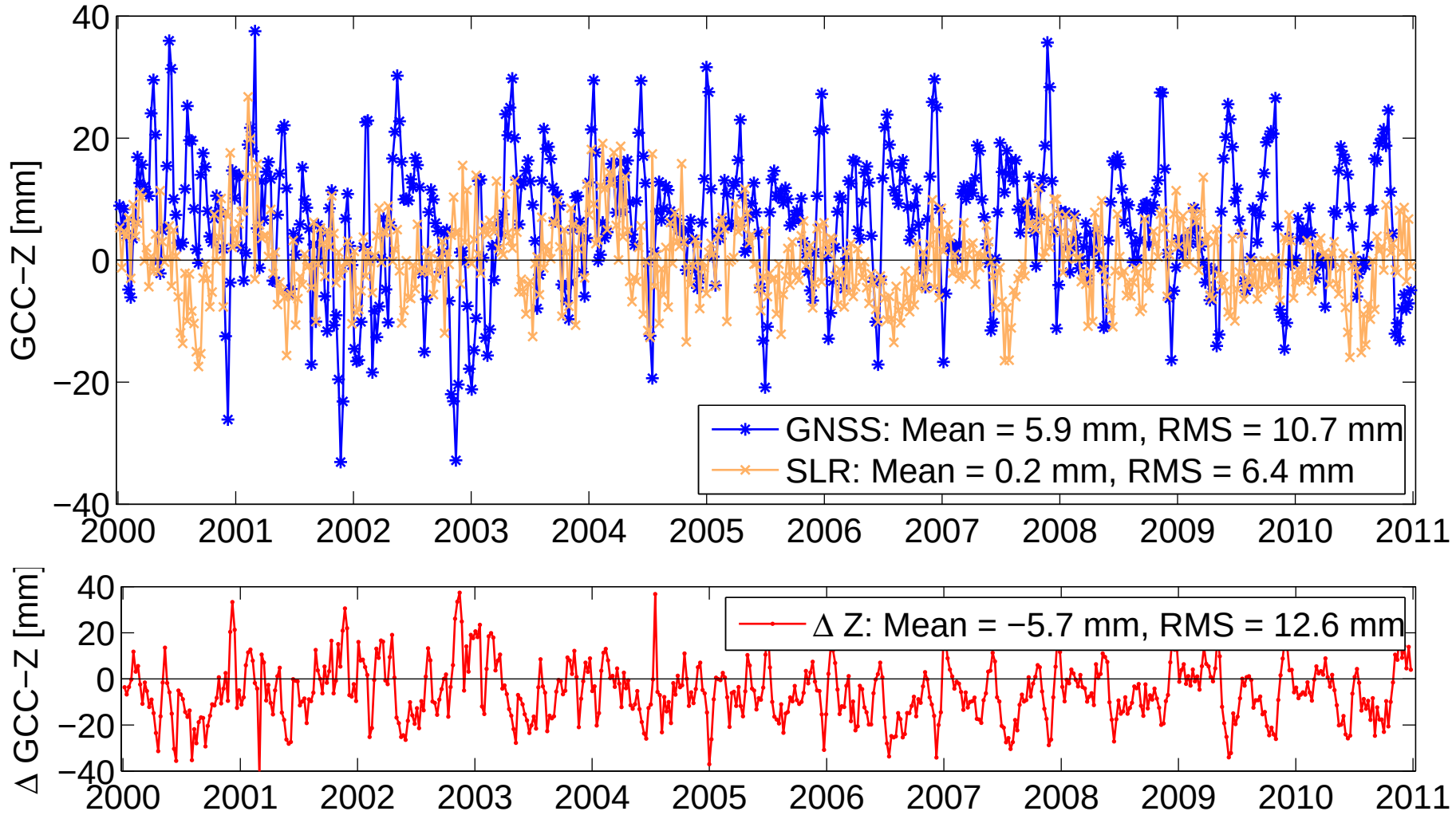


GNSS-only
7-day solutions

SLR-only
7-day solutions

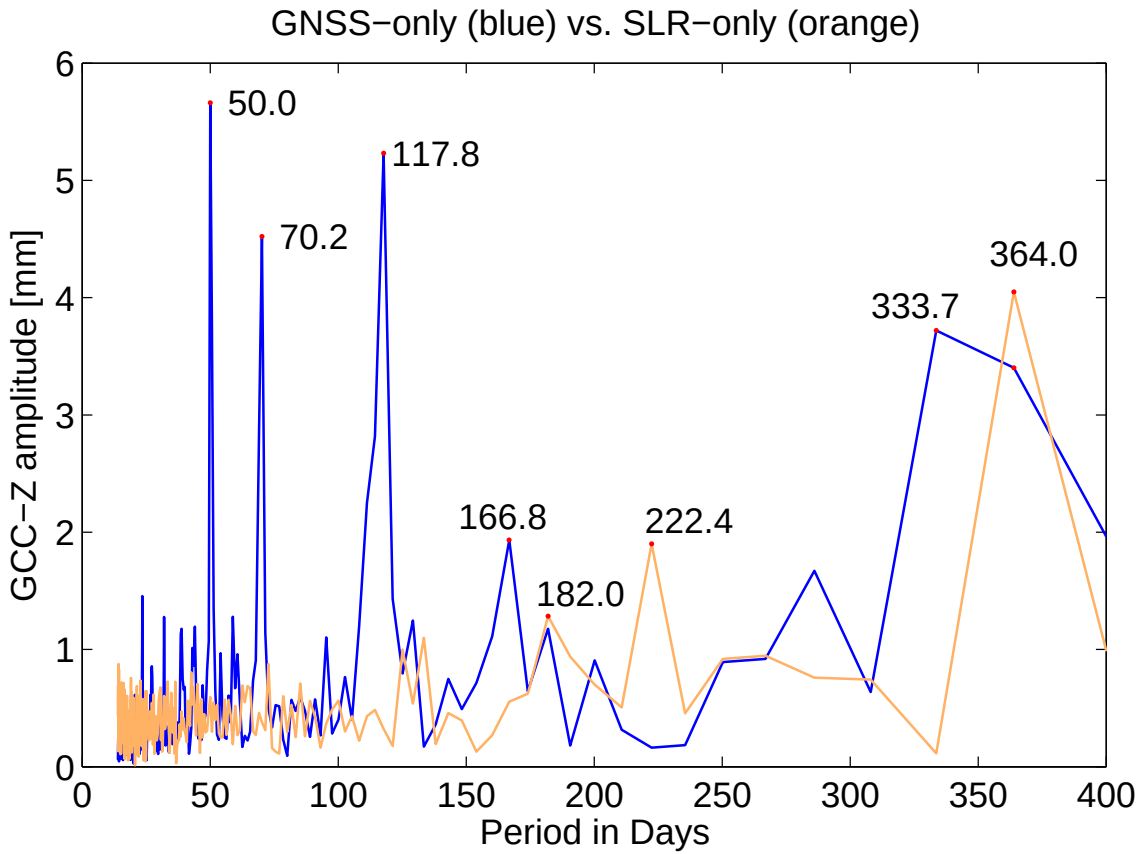
- Mainly annual signal visible
- Amplitudes are slightly different for GNSS and SLR series
- Few periods in GNSS series seem to be artifacts

Geocenter: SLR-only and GNSS-only series



- SLR shows clearly fewer variations than GNSS

Geocenter: SLR-only and GNSS-only series

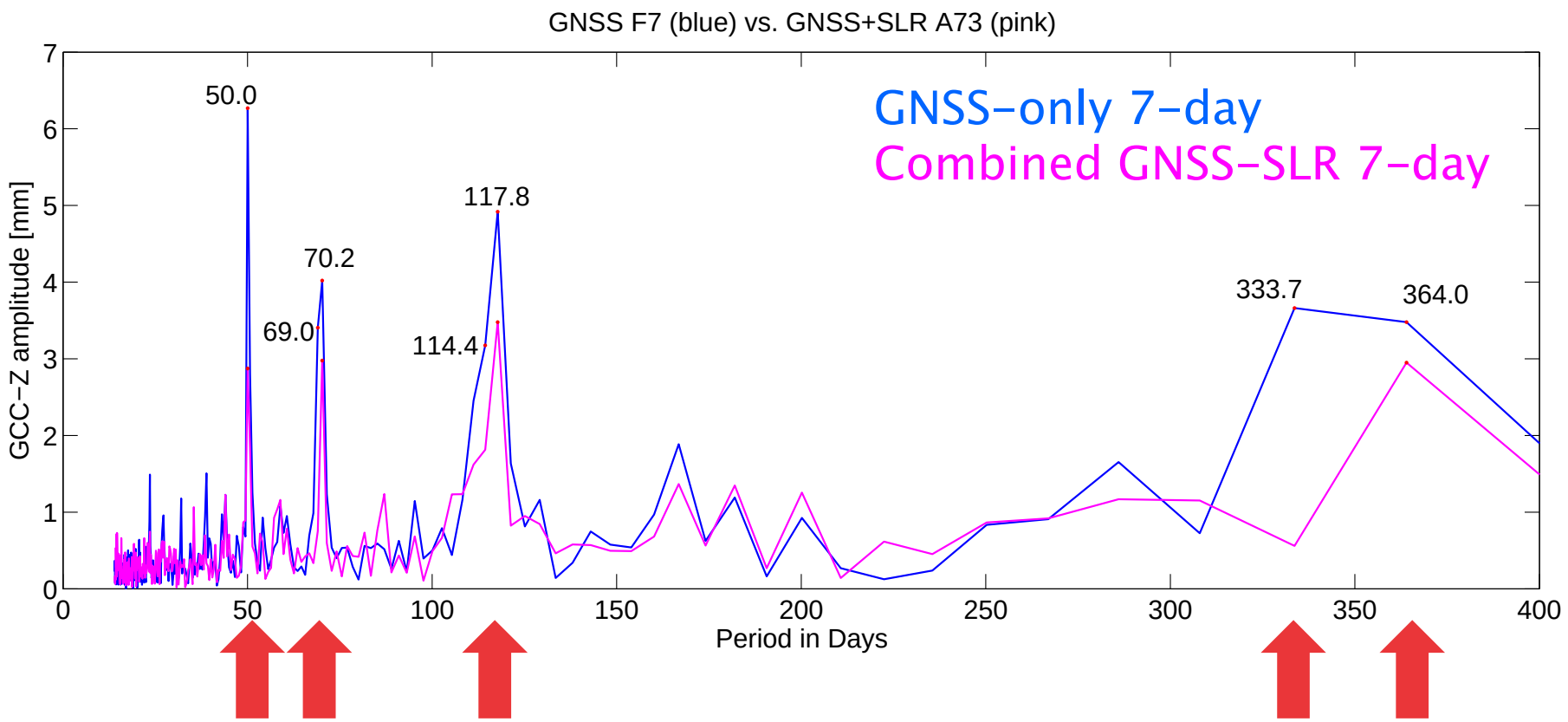


GNSS-only
7-day solutions

SLR-only
7-day solutions

- Draconitic year is clearly visible: GNSS = 352 d, LAG-2 = 222 d
- Annual and draconitic signal are not distinguishable for GNSS
- Big amplitudes at harmonics of draconitic year for GNSS

Geocenter: Combined SLR-GNSS series



- Annual signal remains; draconitic GNSS signal vanishes
- Harmonics of draconitic GNSS year are reduced but not eliminated

Summary

- GNSS and SLR analysis is done at AIUB
- Identical software package for the analysis and the combination

  $\Rightarrow$ Combination at observation level
- SLR data to GNSS satellites included in the combination

  $\Rightarrow$ «Space Tie»
- Components of the «Space Tie» can be evaluated:
  - Microwave antenna offsets (SAO)
  - Laser reflector array offsets (LRA)
- All parameters benefit from the combination (e.g. geocenter coordinates)

Acknowledgements

- Astronomical Institute, University of Bern (AIUB):
  - *Krzysztof Sośnica*
  - *Adrian Jäggi*
  - *Rolf Dach*
  - *Gerhard Beutler*
- Bundesamt für Kartographie und Geodäsie (BKG), Frankfurt/Main:
  - *Maria Mareyen*
  - *Bernd Richter*
- Technische Universität München:
  - *Peter Steigenberger*

Thanks for your attention !