Federal Agency for
Cartography and Geodesy

SLR and the Global Terrestrial Reference Frame

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With contributions by:

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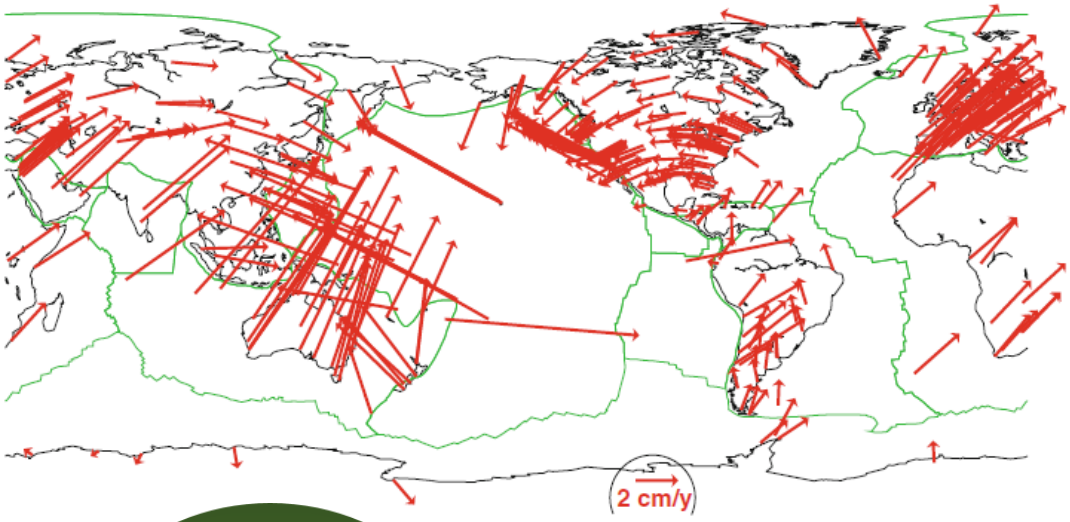
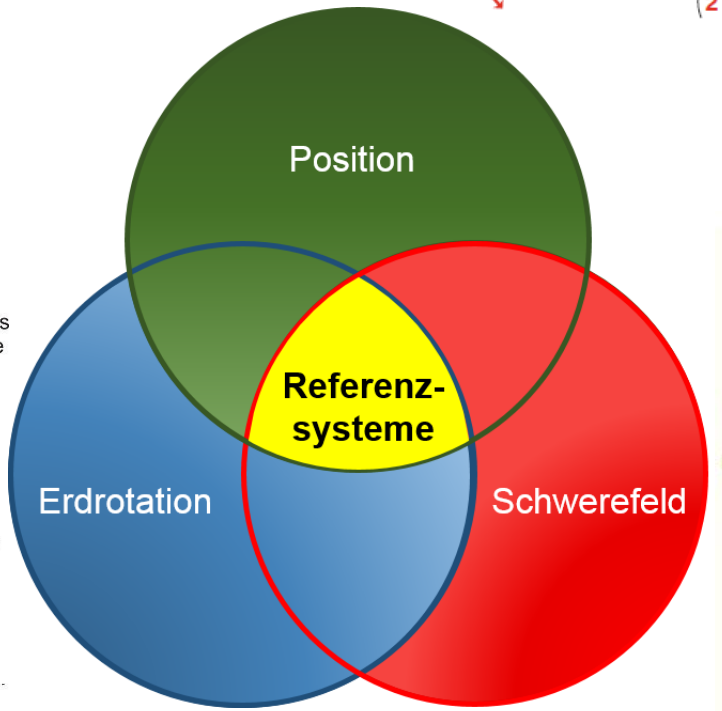
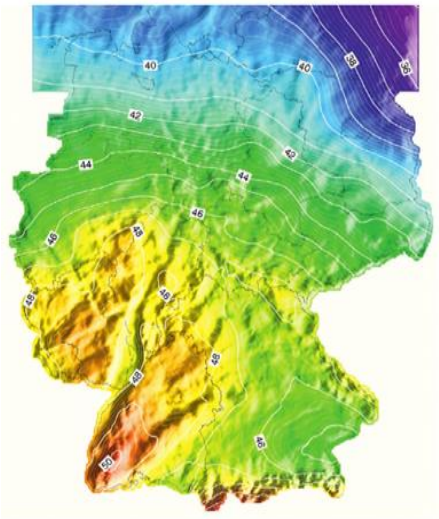
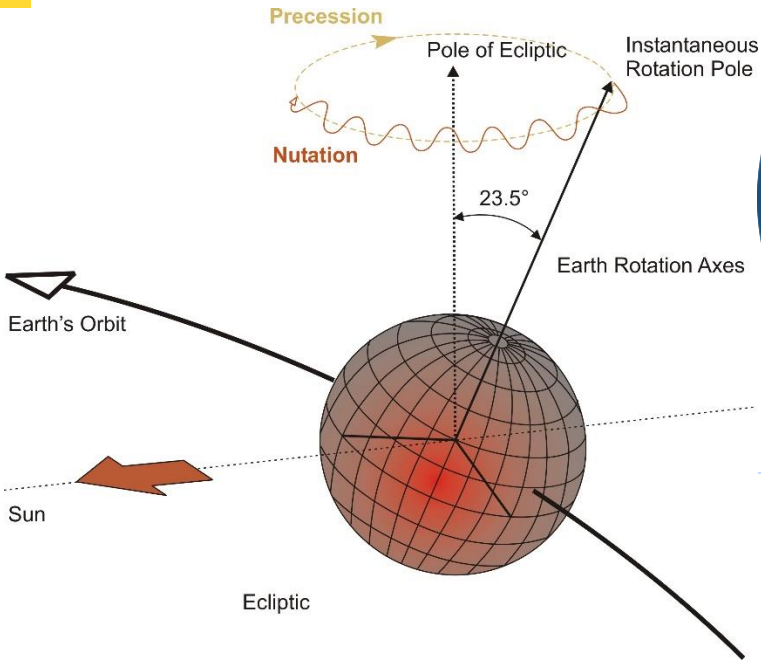
Cinzia Luceri (ASI, Italy; ILRS Combination Center)

The 3 Pillars of Geodesy









Parameter Space and actual ITRF computation

	GNSS	VLBI	SLR
Station coordinates + velocities	XG	XV	XS
Satellite orbits	X		X
Quasar coordinates		X	
Polar motion + rates	X	X	X
Universal Time (dUT)		X	
Length of Day (LOD)	X	X	X
Nutation (+ nutation rates)	(x)	X	(x)
Geocenter	(X)		X
Earth‘s gravity field	(x)		X
Troposphere	X	X	
Ionosphere	X	(x)	
Technique-specific parameters	xG	xV	xS

Parameter Space and actual ITRF computation:
⇒ only few parameter types are included

	GNSS	VLBI	SLR
Station coordinates + velocities	XG	XV	XS
Satellite orbits	-		-
Quasar coordinates		-	
Polar motion + rates	X	X	X
Universal Time (dUT)		X	
Length of Day (LOD)	X	X	X
Nutation (+ nutation rates)	-	X	-
Geocenter	*(X)*		*X*
Earth's gravity field	*(x)*		*X*
Troposphere	*X*	*X*	
Ionosphere	*X*	*(x)*	
Technique-specific parameters	*xG*	*xV*	*xS*

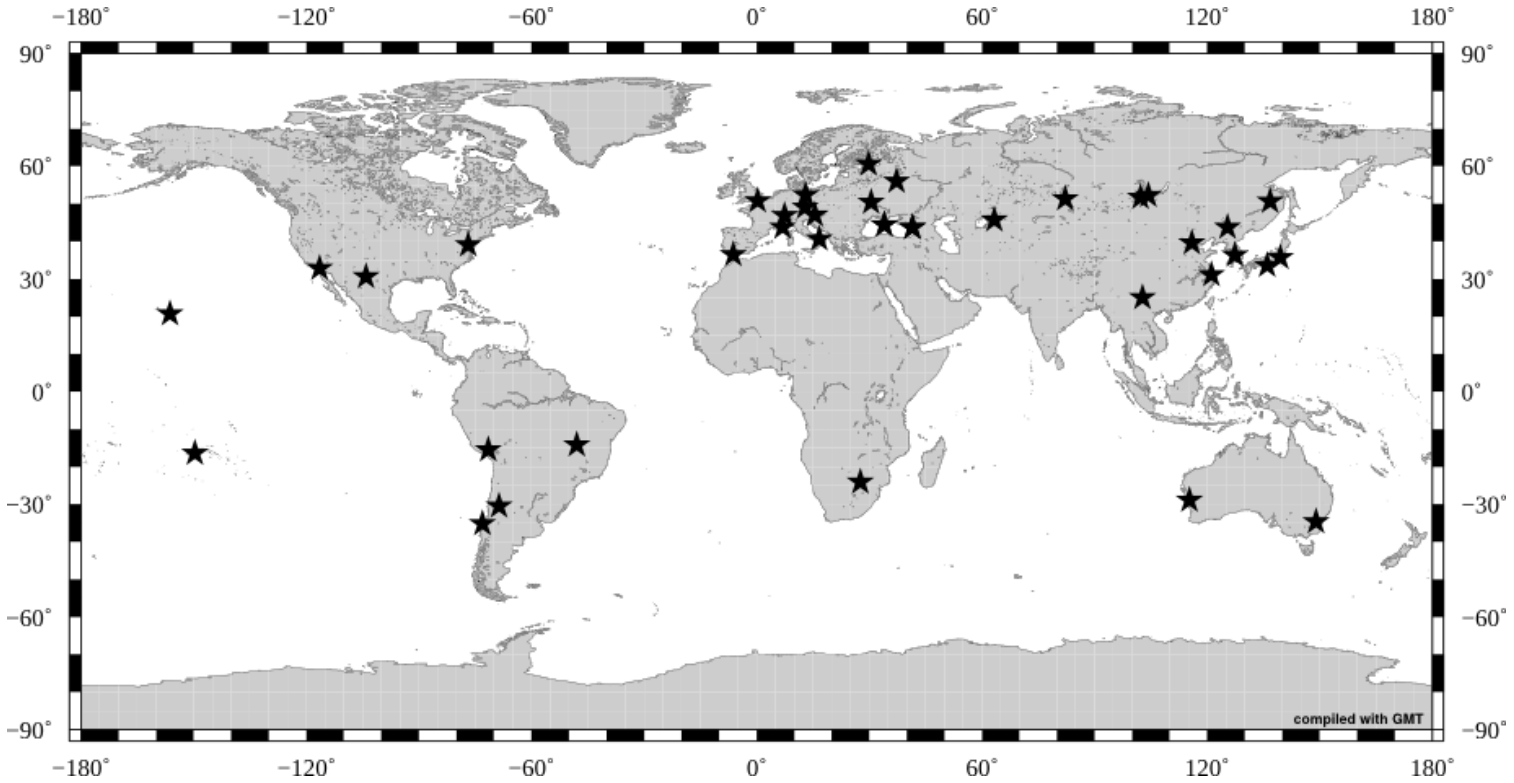
Parameter Space and actual ITRF computation

No Direct combination possible;
Co-location sites and Local Ties are needed

Station coordinates + velocities	XG	XV	XS
Satellite orbits	-		-
Quasar coordinates		-	
Polar motion + rates	X	X	X
Universal Time (dUT)		X	
Length of Day (LOD)	X	X	X
Nutation (+ nutation rates)	-	X	-
Geocenter			
Earth's gravity field	*(x)*		*X*
Troposphere	*X*	*X*	
Ionosphere	*X*	*(x)*	
Technique-specific parameters	*xG*	*xV*	*xS*

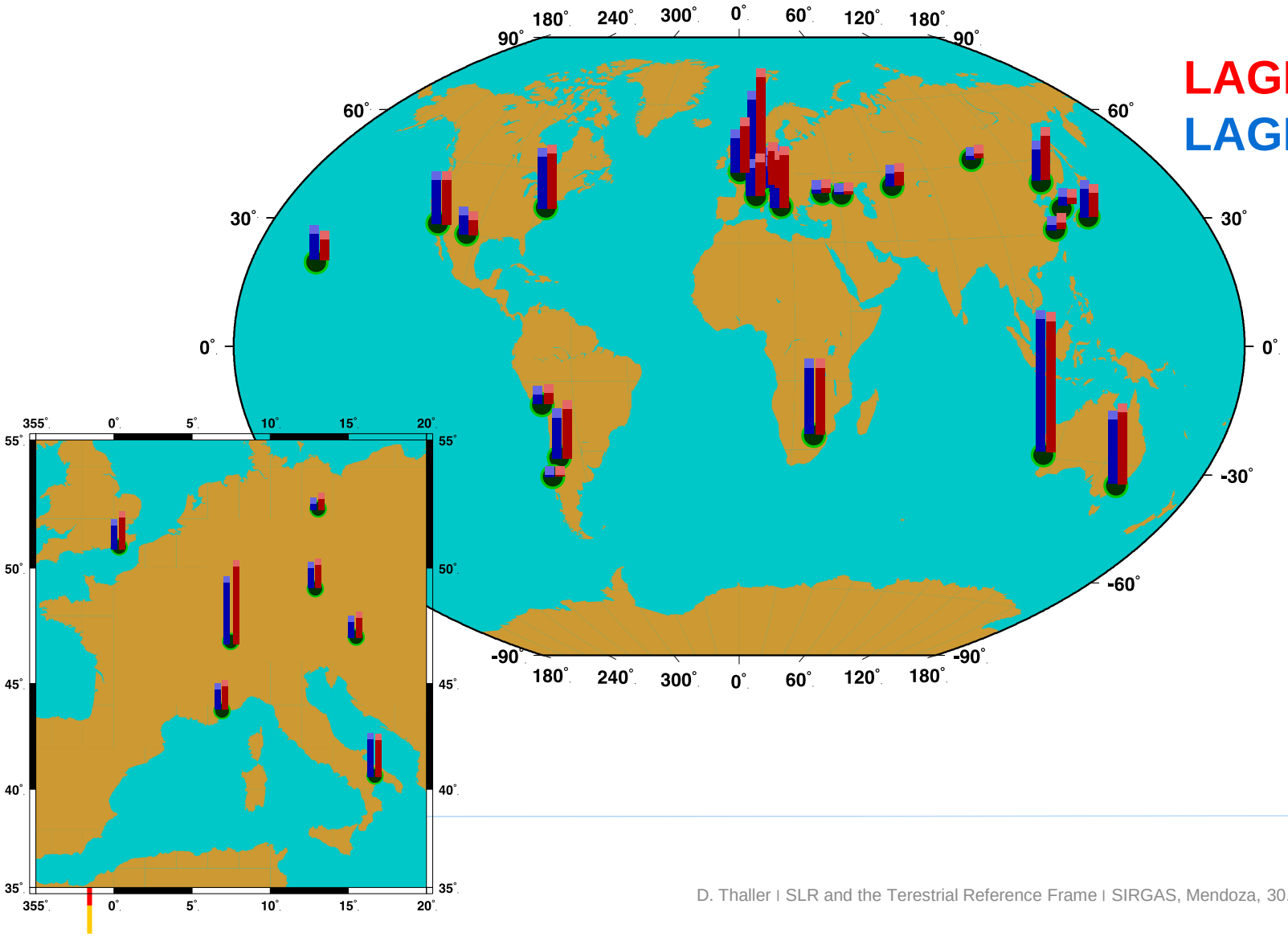
Direct combination is possible

SLR Station Network



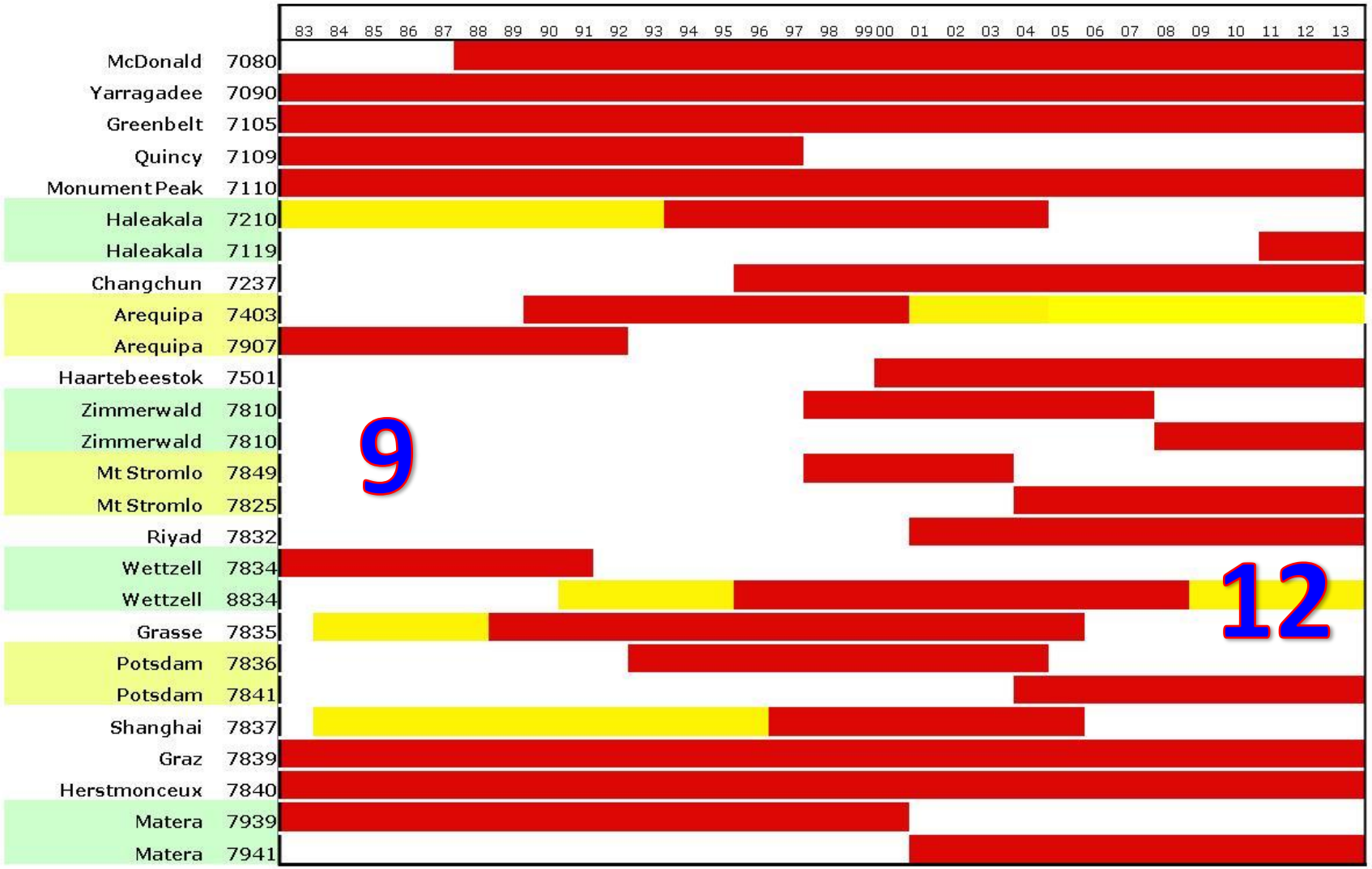
- Few sites only
- Bad global distribution (no high latitudes; few Southern sites)

SLR Station Network: Data Yield



SLR Station Network: Time Line

SLR Station Network: Core Sites



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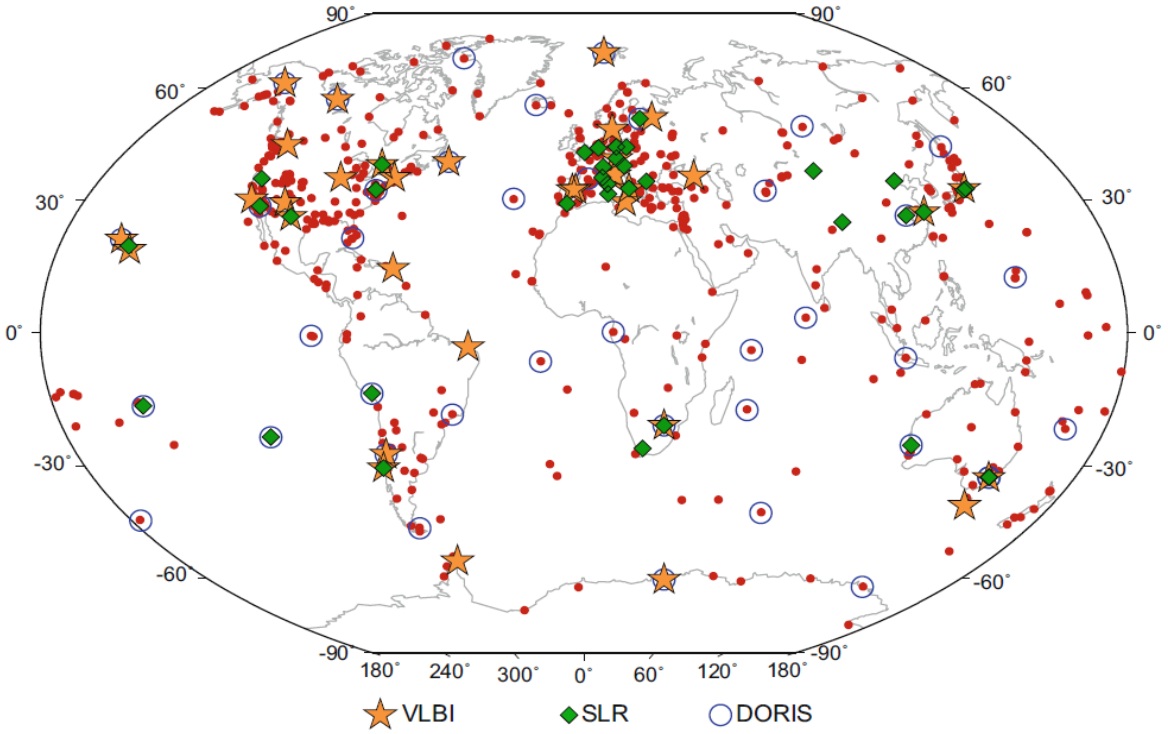
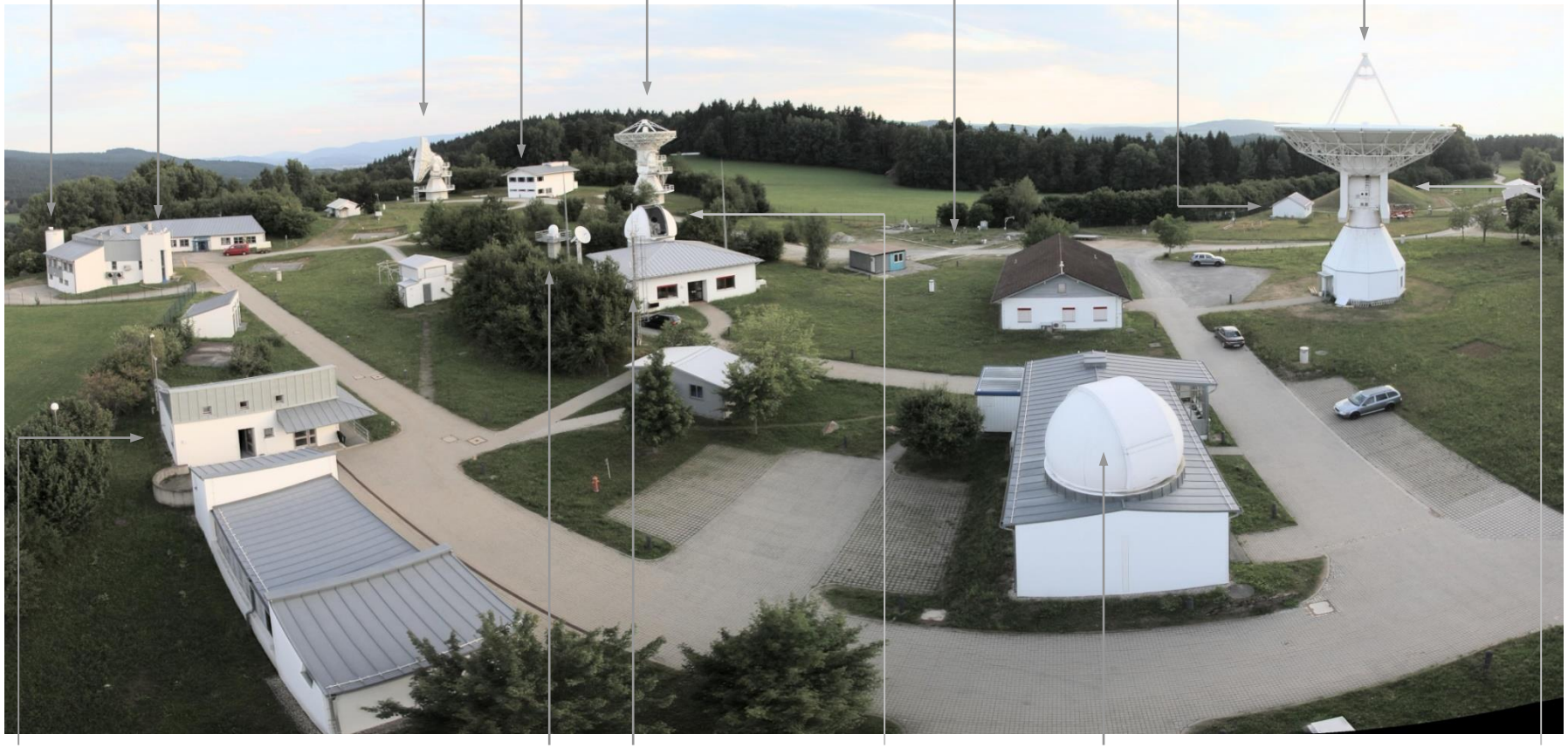
Network of Co-location Sites for ITRF



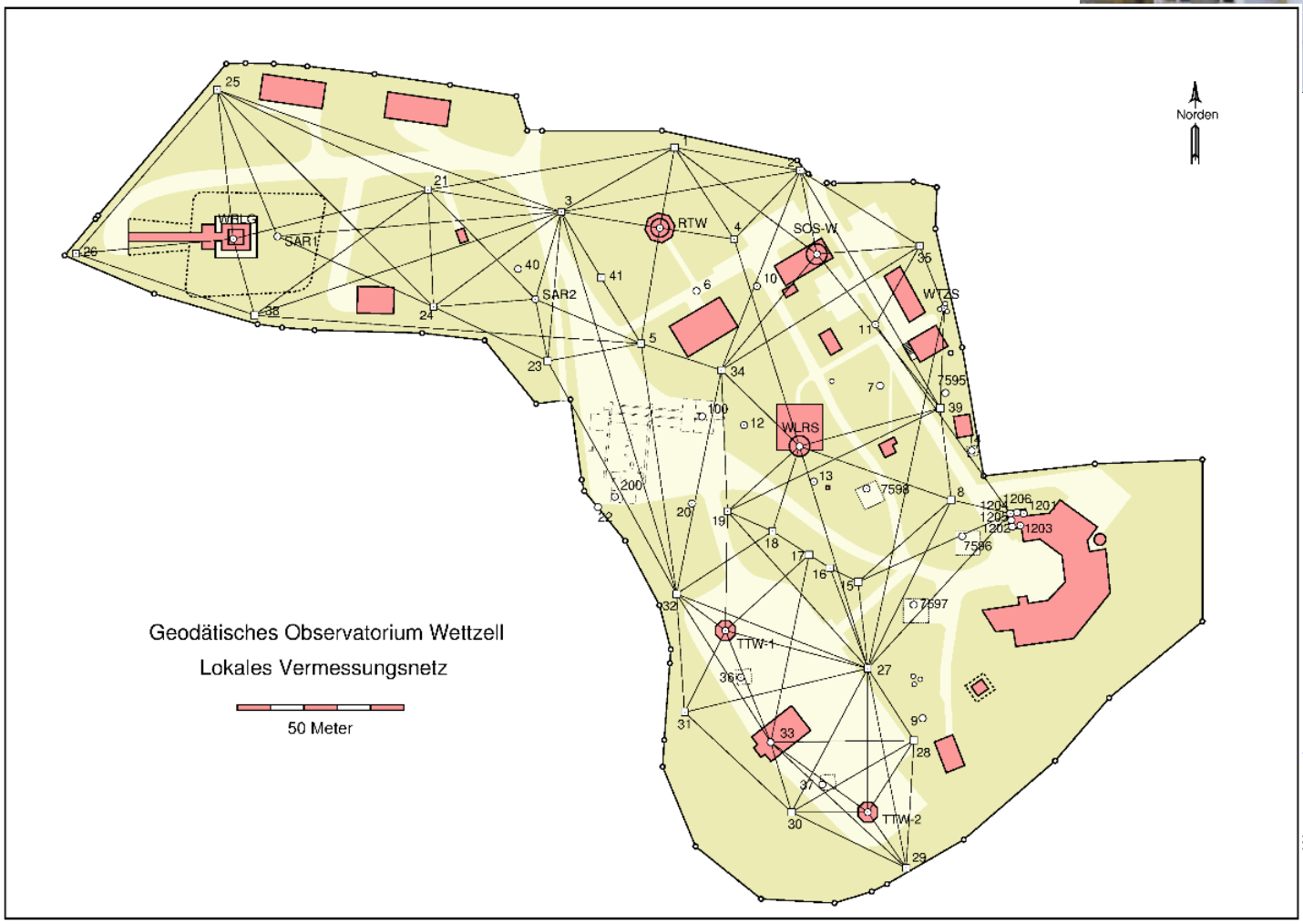
- Few sites only
- Bad global distribution
- Connection of SLR, VLBI and DORIS mainly **via GNSS**

Co-location Sites: Geodetic Observatory Wettzell



Co-location Sites: Local Tie

- Classical surveying
- Permanent + campaign GNSS



Current ITRF approach

IDS

IGS INTERNATIONAL GNSS SERVICE

International Laser Ranging Service

IVS

Combined SINEX DORIS

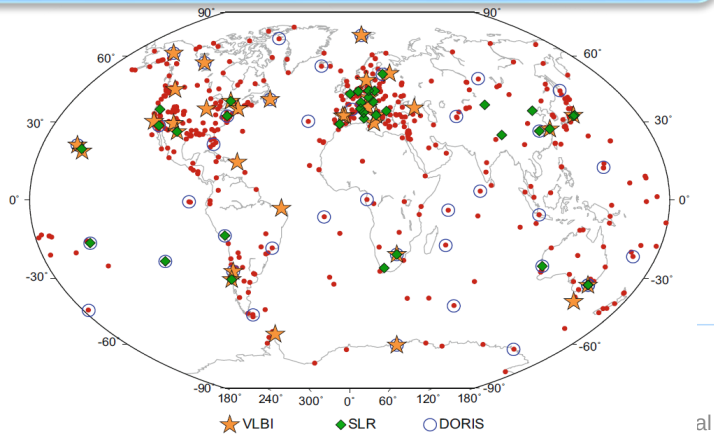
Combined SINEX GNSS

Combined SINEX SLR

Combined SINEX VLBI

Inter-technique Combination
DORIS + GNSS + SLR + VLBI

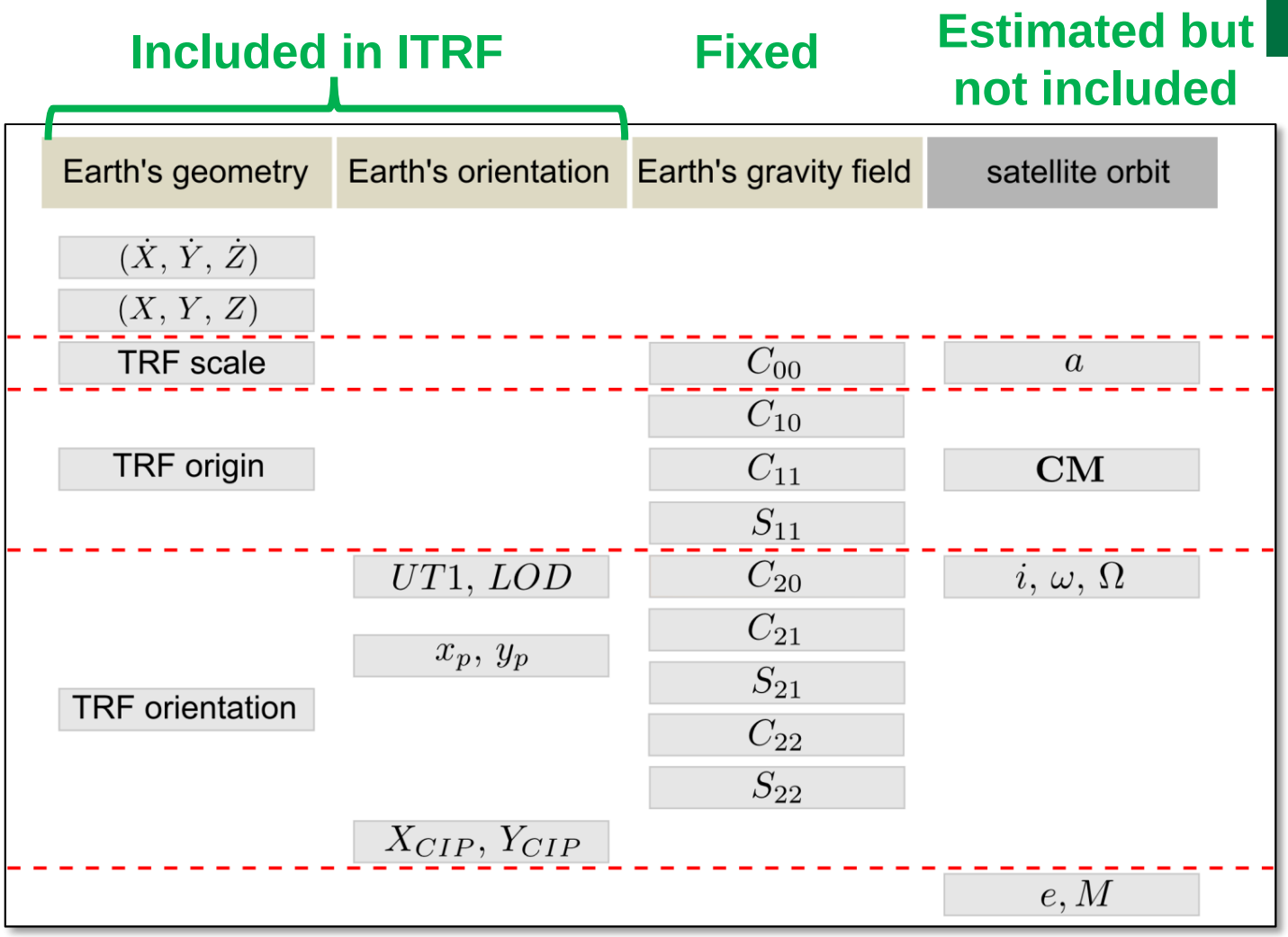
- IGN, Paris
- DGFI-TUM, München
- JPL, Pasadena



Current ITRF Approach: Geodetic Datum

Problem:

High correlation between parameter groups

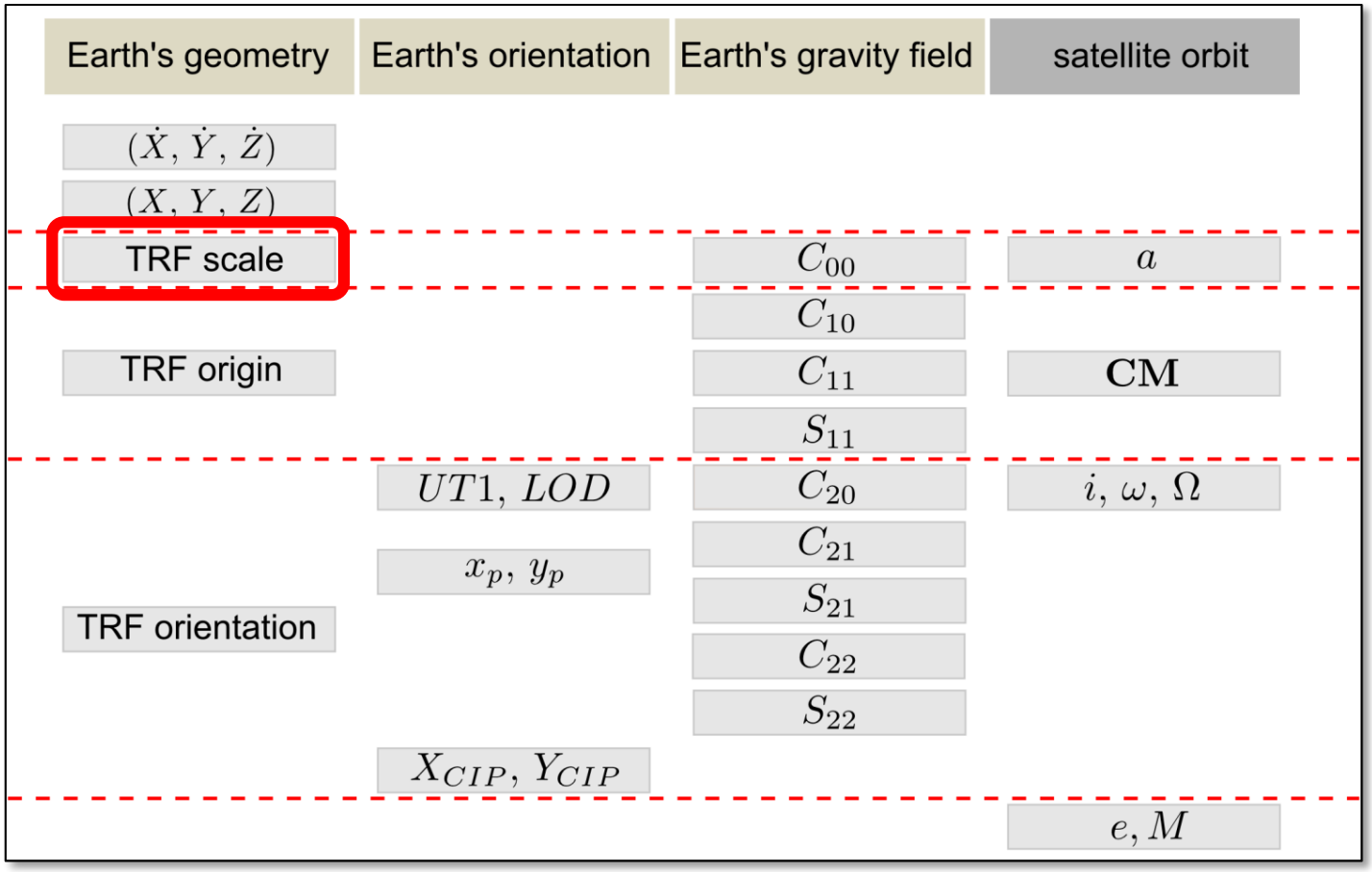


Current ITRF Approach: Geodetic Datum

Can be defined by SLR (as long as C_{00} is fix)

In ITRF: SLR+VLBI

GNSS/DORIS: Phase Centre Issues



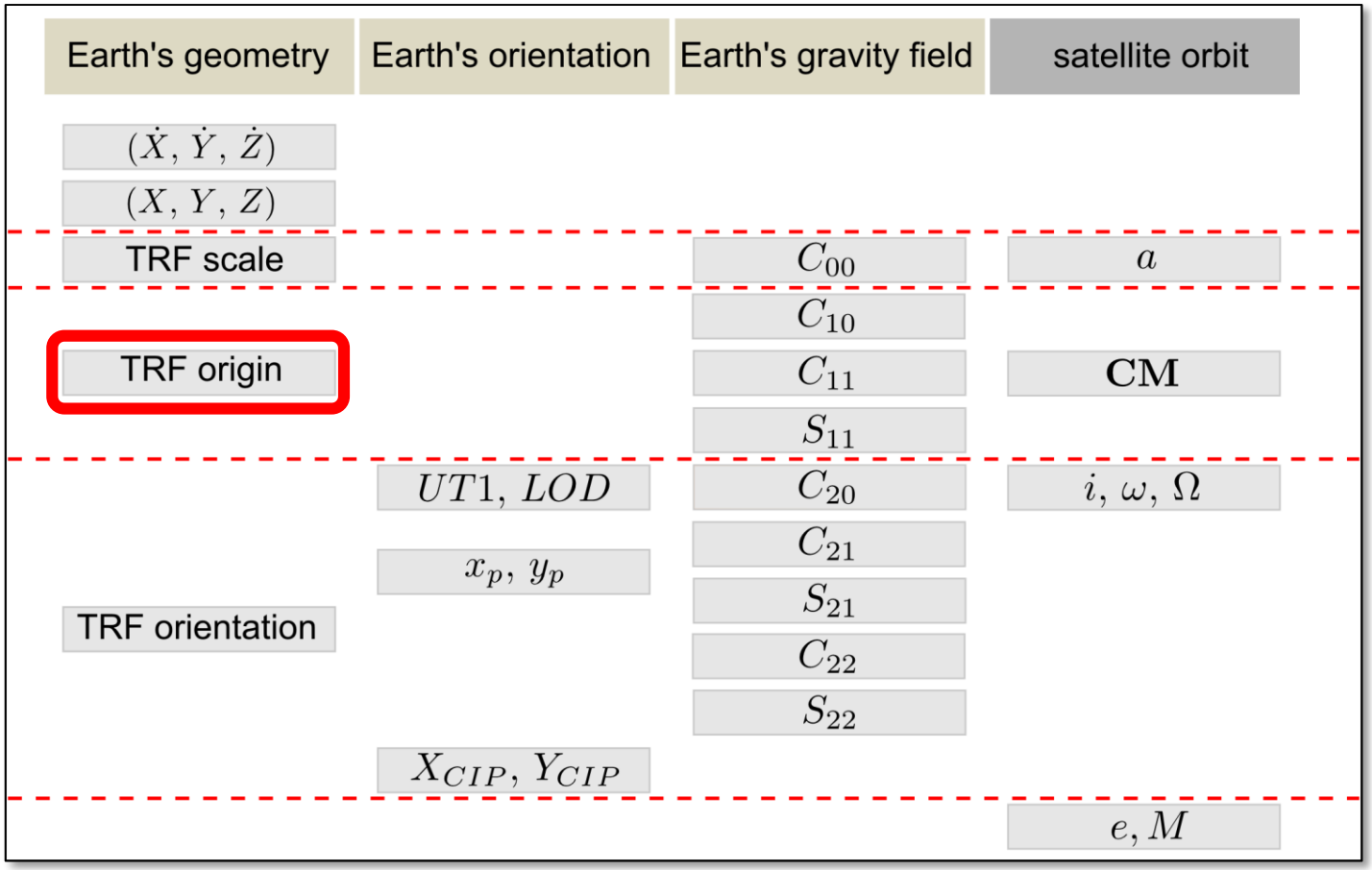
Current ITRF Approach: Geodetic Datum

Can be defined by SLR (as long as C_{1n} are fix)

In ITRF: SLR only !

GNSS/DORIS: Orbit Issues

VLBI: no access

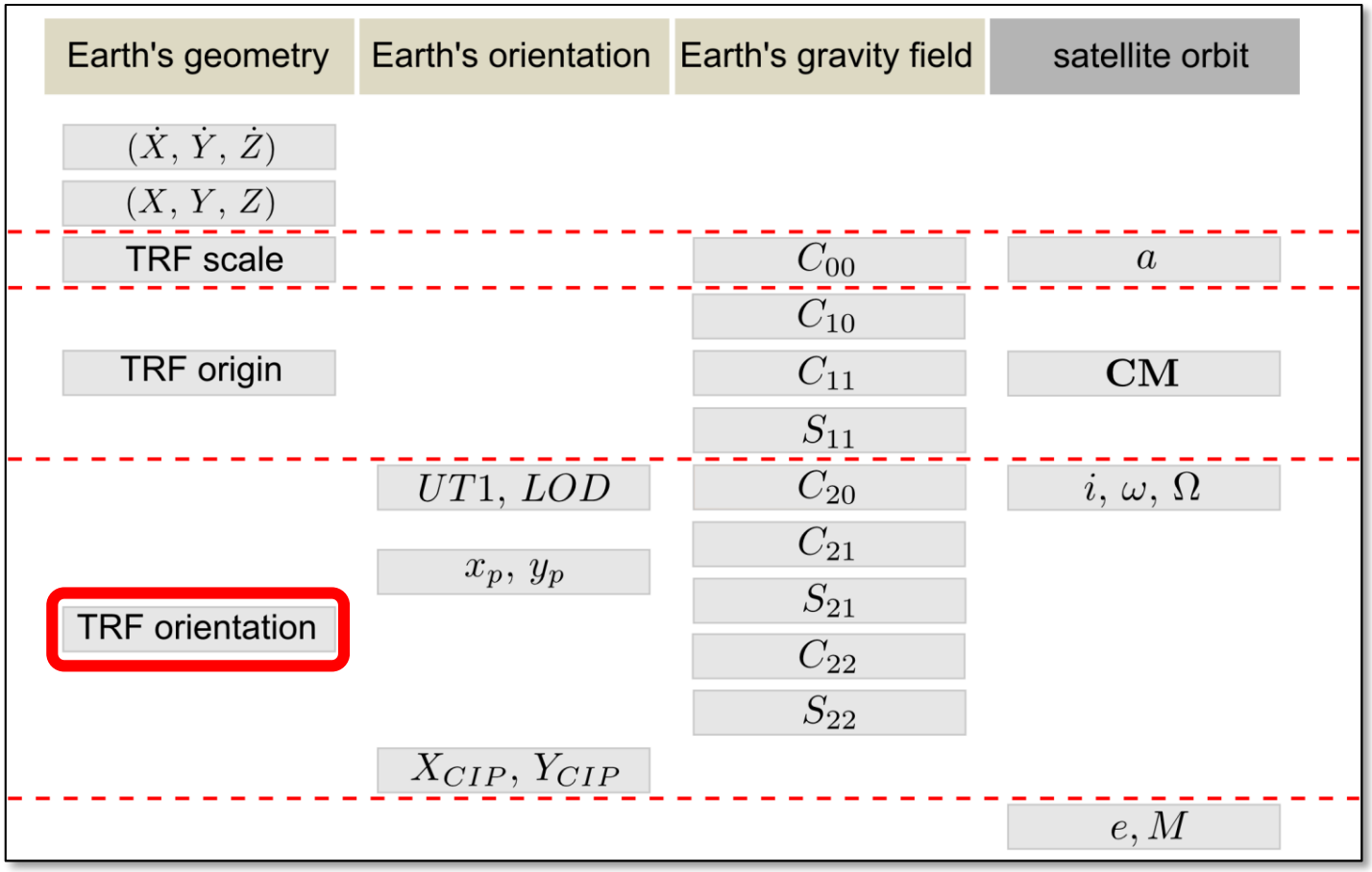


Current ITRF Approach: Geodetic Datum

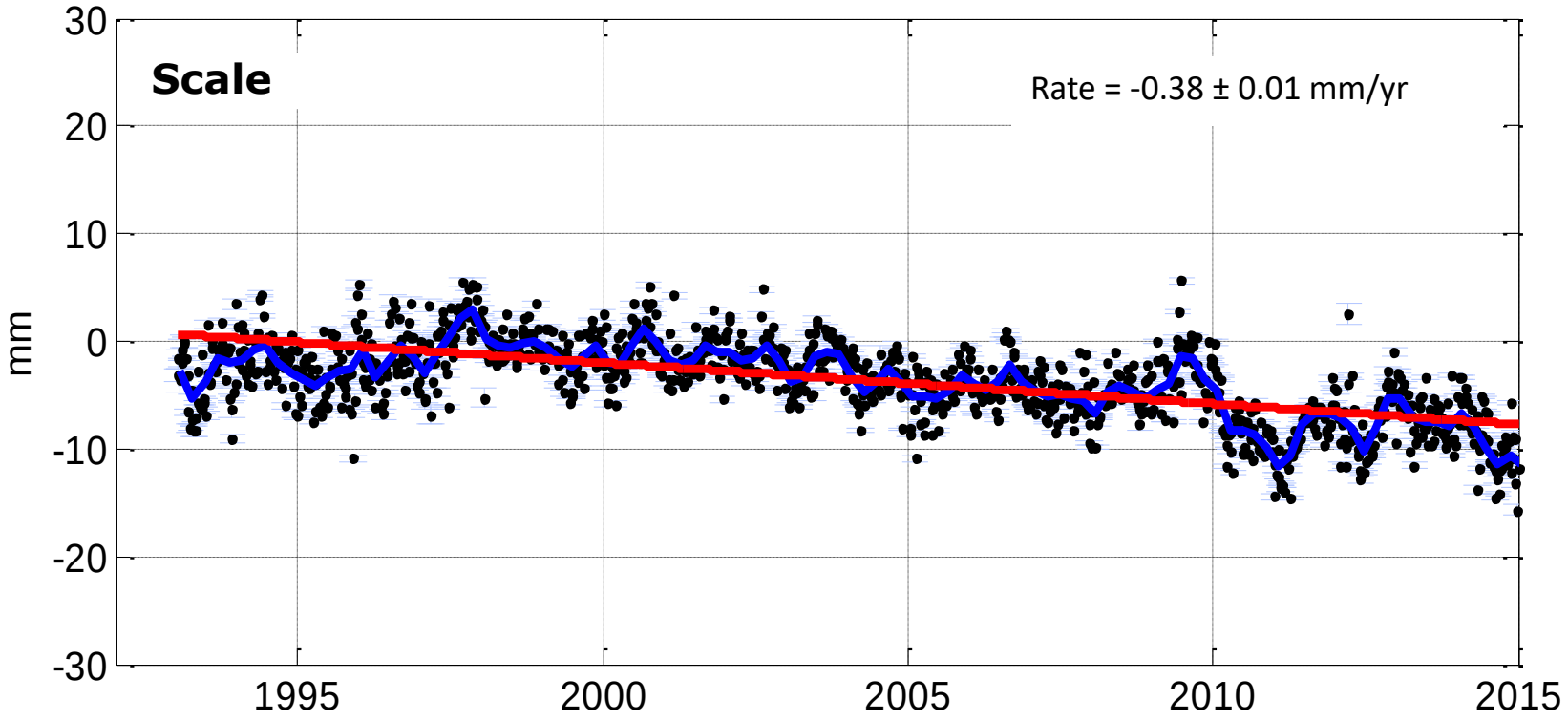
Satellite techniques and VLBI:

Not accessible if orbits and EOP are estimated

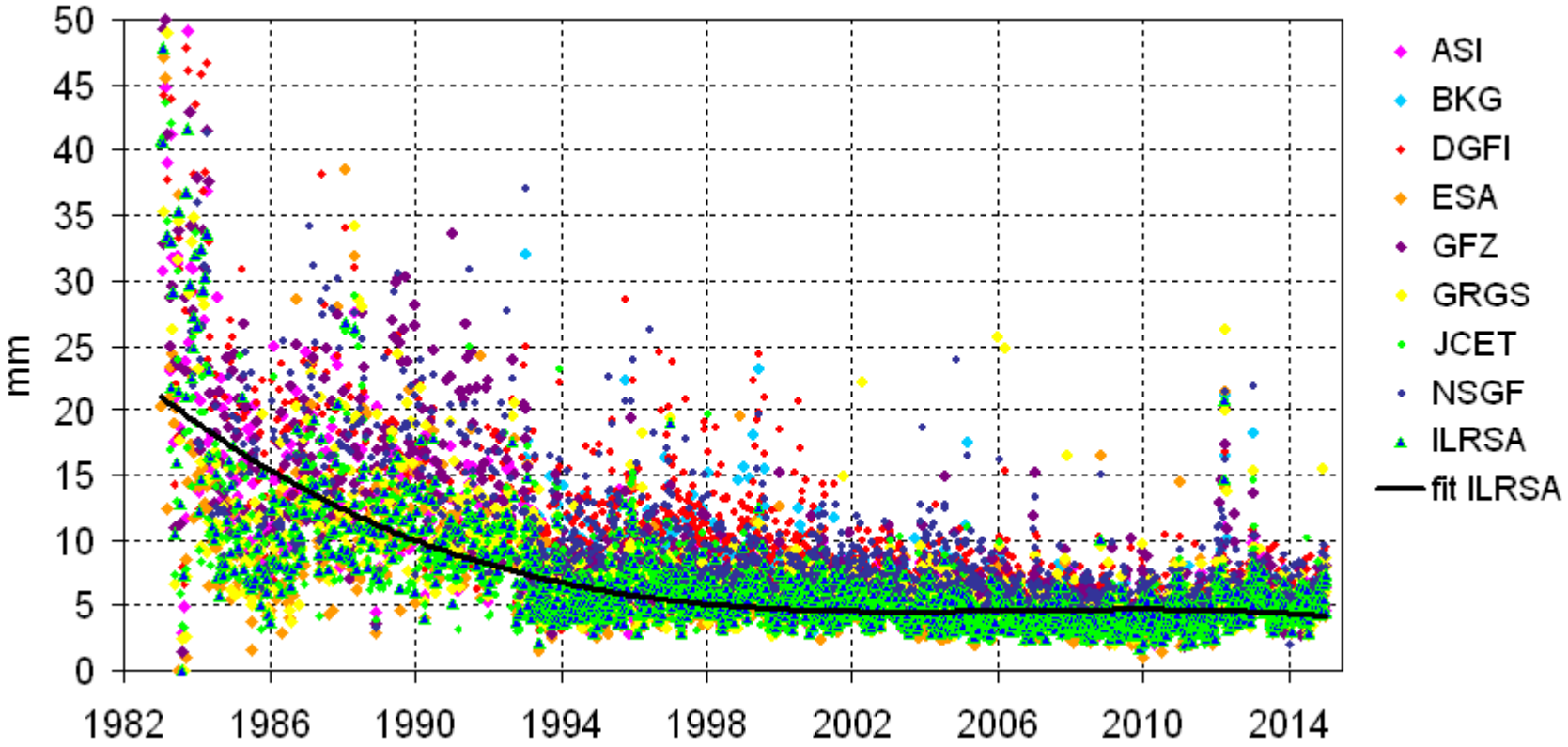
In ITRF: External information (NNR)



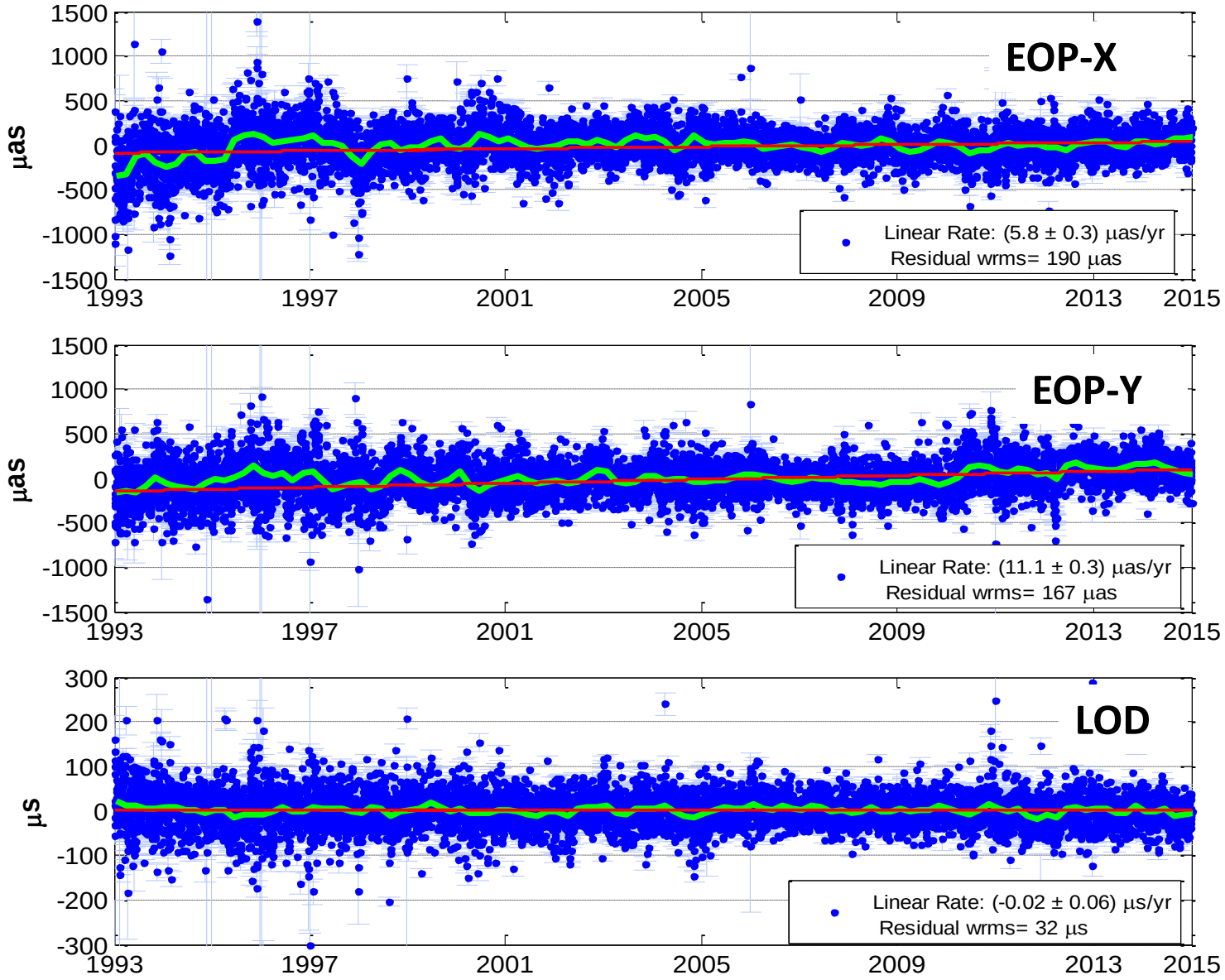
Scale w.r.t. ITRF2008:
From Re-analysis for ITRF2014 generation



Quality of Station Coordinates (from ILRS-A Combination)



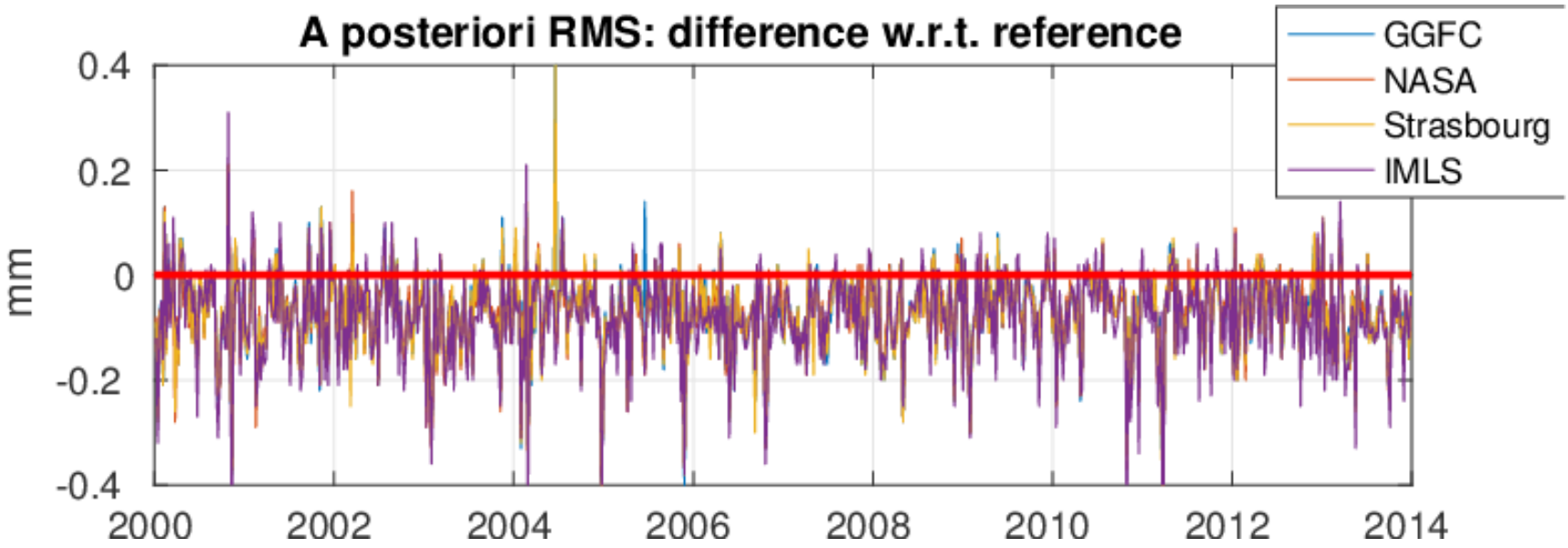
Polar Motion: ILRS-A vs. IERS-Bulletin-A



Possible Improvements

- Advanced modelling
- Make use of additional existing SLR data
  - Other spherical satellites:
    - Increase amount of data
    - Improve global coverage
  - Other satellites tracked by SLR, but operating also GNSS / DORIS instruments:
    - Increase amount of data and global coverage
    - Co-location of techniques via satellite orbits
    - Stations do not need to be co-located
- Improve SLR data yield
- Additional stations:
  - Increase amount of data and global coverage

Improved Modelling of Station Variations: Loading

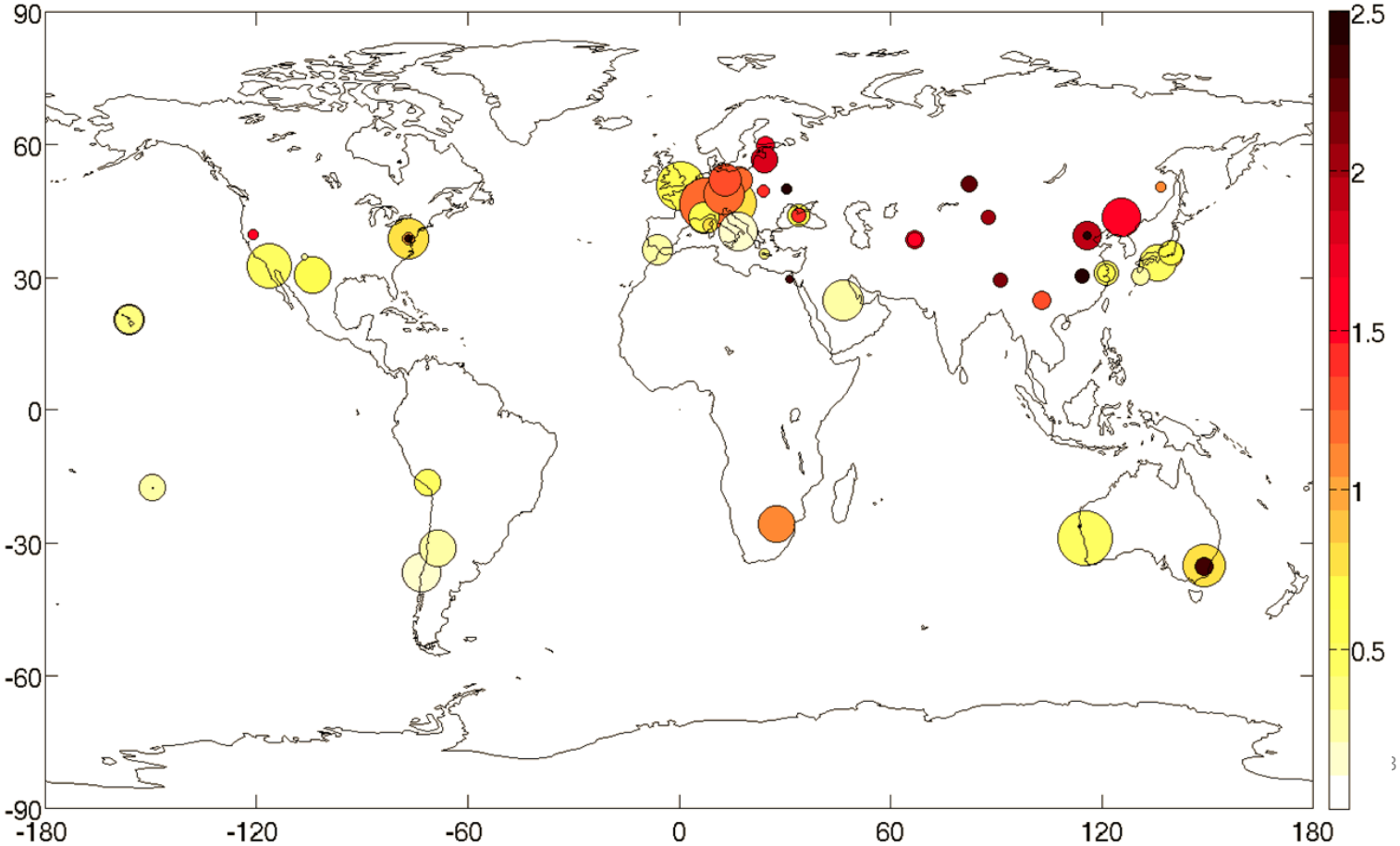


- Testing different sets of loading corrections (atmosphere, ocean, hydrology)
- Reference solution without any loading corrections

➢ Improvement of solutions if loading is applied

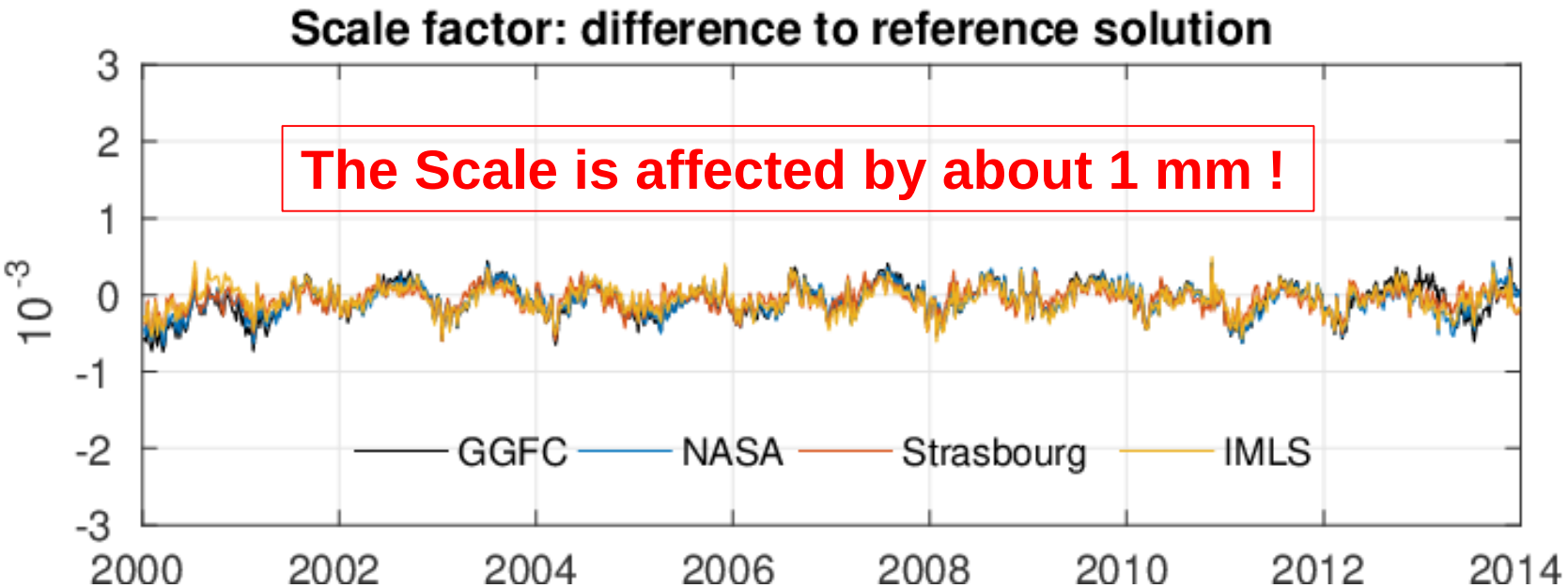
Improved Modelling of Station Variations: Loading

SLR observes only at good weather conditions (high pressure)
⇒ Atmospheric loading causes a systematic effect in SLR, i.e., the so-called **„Blue-Sky Effect“**



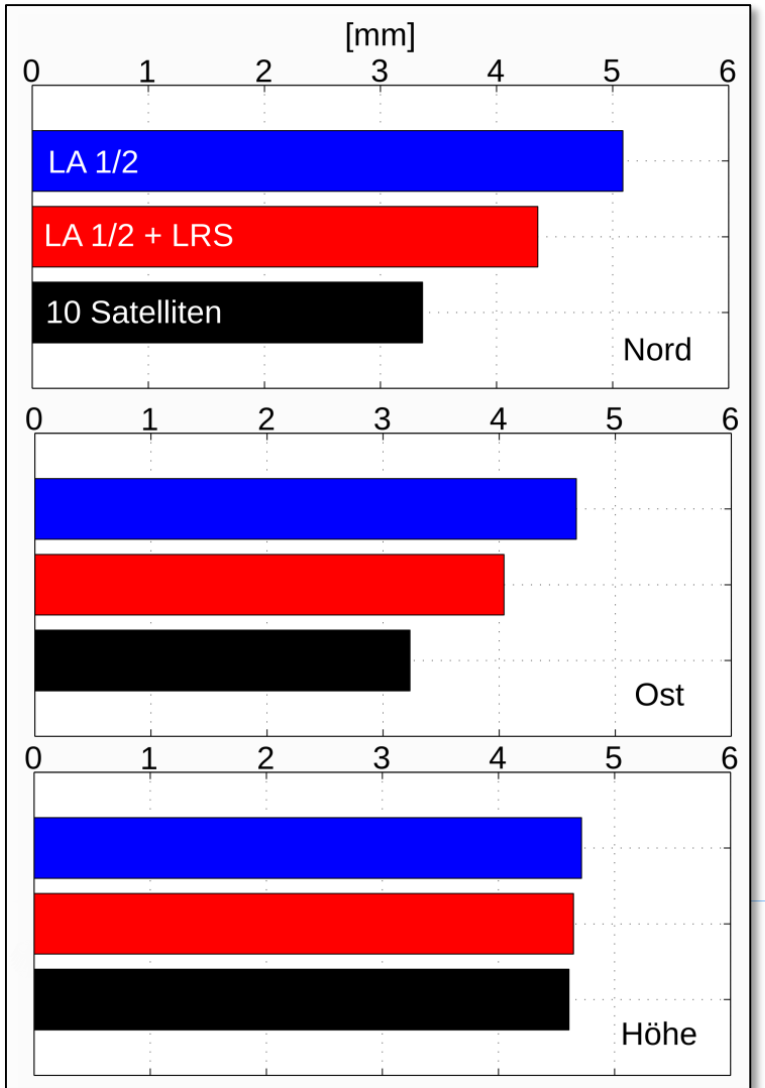
Improved Modelling of Station Variations: Loading

SLR station	Number of normal points (1999–2010)	Mean impact of Atmospheric Pressure Loading	Blue–Sky effect [mm]
Golosiv, Ukraine	330	6.6	4.4
Wuhan, China	1052	4.9	3.2
Beijing–A, China	189	2.7	2.5
Helwan, Egypt	223	3.2	2.4
Altay, Russia	1776	6.7	2.3



Possible Improvement: Other Geodetic Satellites

Scatter of station positions w.r.t. SLRF2008



Improvement in Horizontal:

ca. 14 % (LA 1/2 + LRS),

ca. 34 % (10 satellites)

- Due to better sky coverage with different satellite orbits

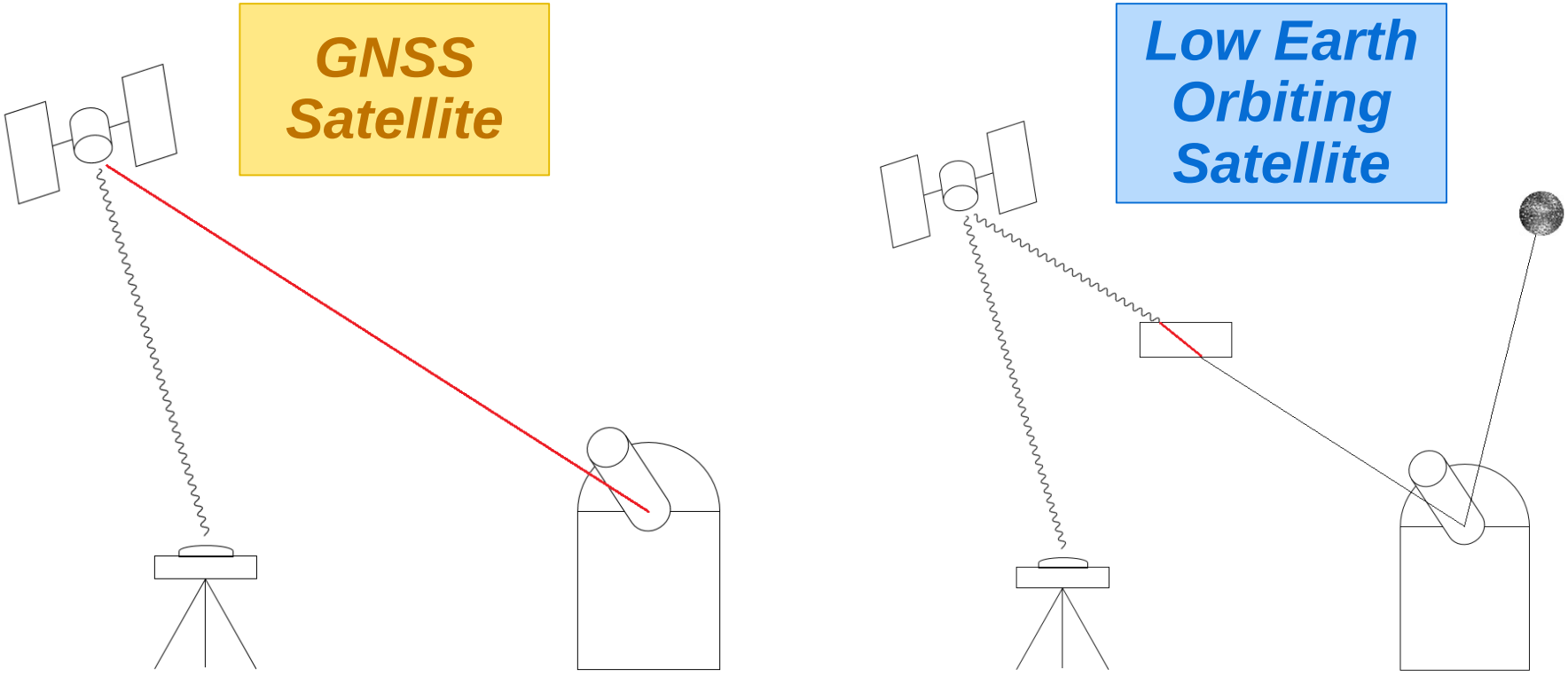
(almost) No Improvement in Height

- Given by the SLR range

Possible Improvement: Satellite Co-location

Use also non-passive satellites, that are not pure SLR satellites, but are equipped with retro-reflectors.

Satellite co-locations for SLR and other techniques (GNSS, DORIS)



SLR-GNSS Co-locations at GNSS satellites

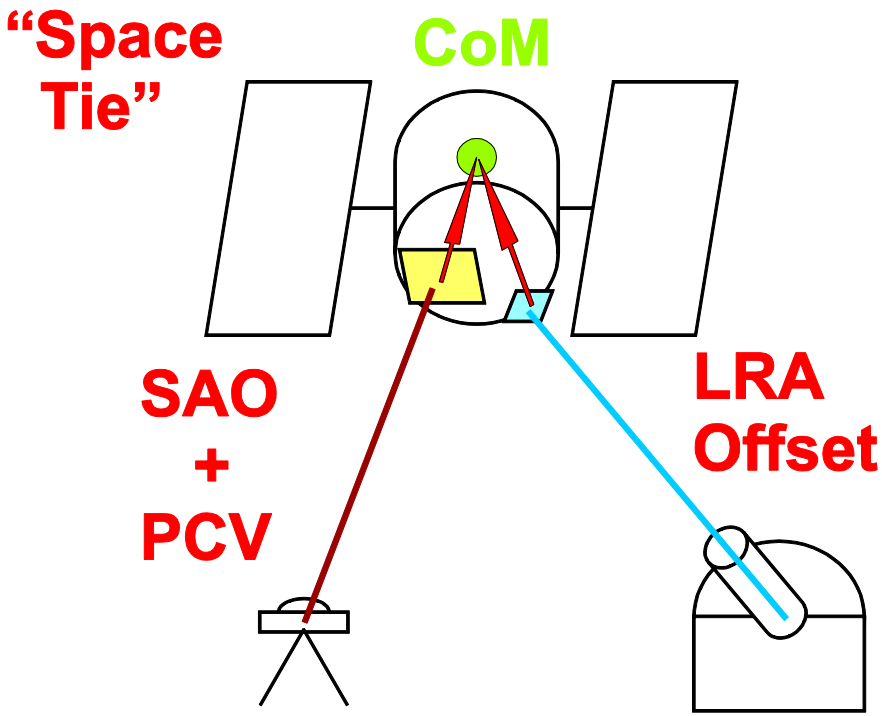
Co-location at GNSS satellites

=

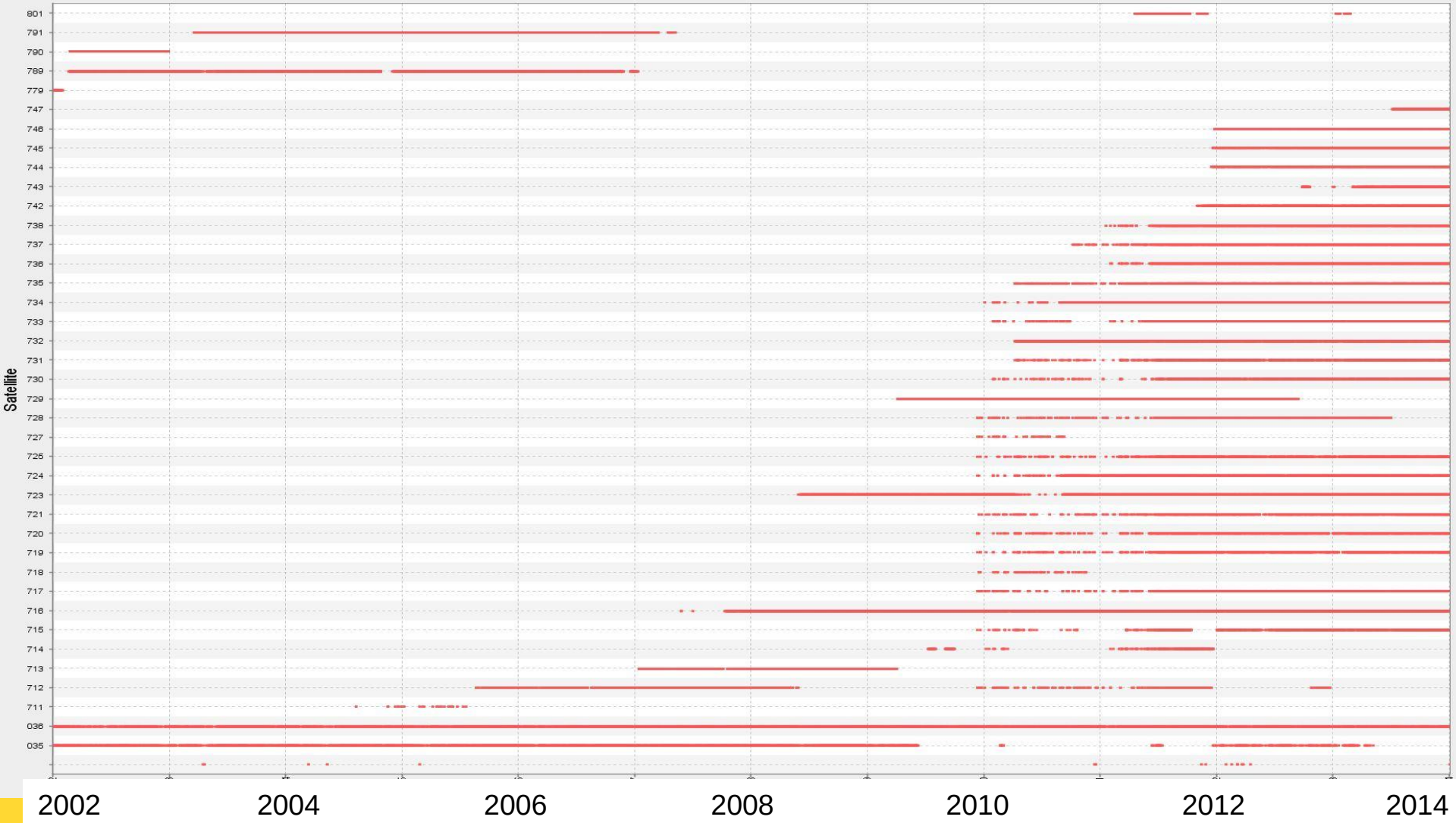
Common orbit parameters from GNSS microwave and SLR range data

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

- Satellite Antenna Offsets (SAO)
- Offset of Laser Retro-reflector Array (LRA)



SLR-GNSS Co-locations at GNSS satellites



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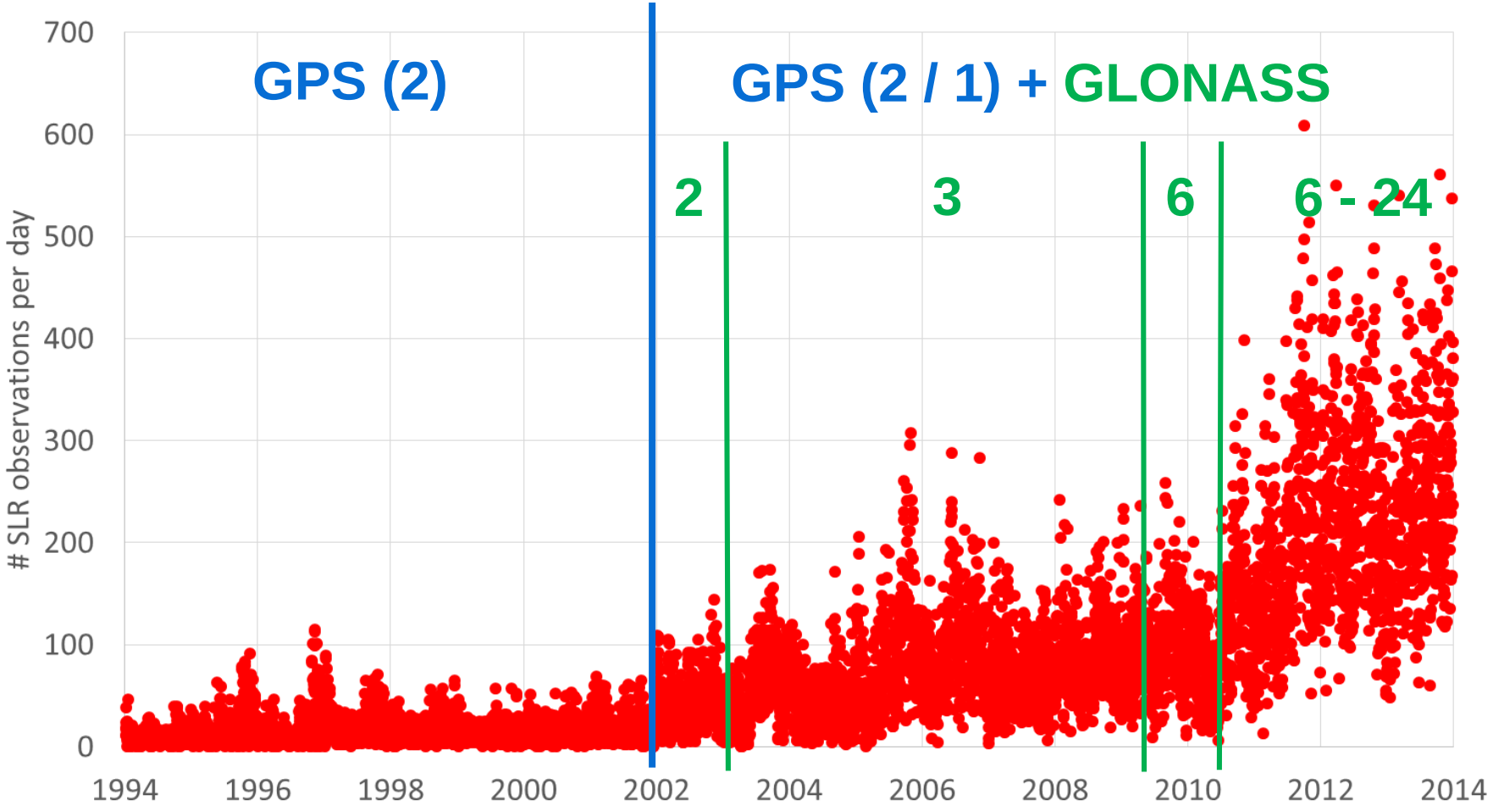
SLR-GNSS Co-locations at GNSS satellites



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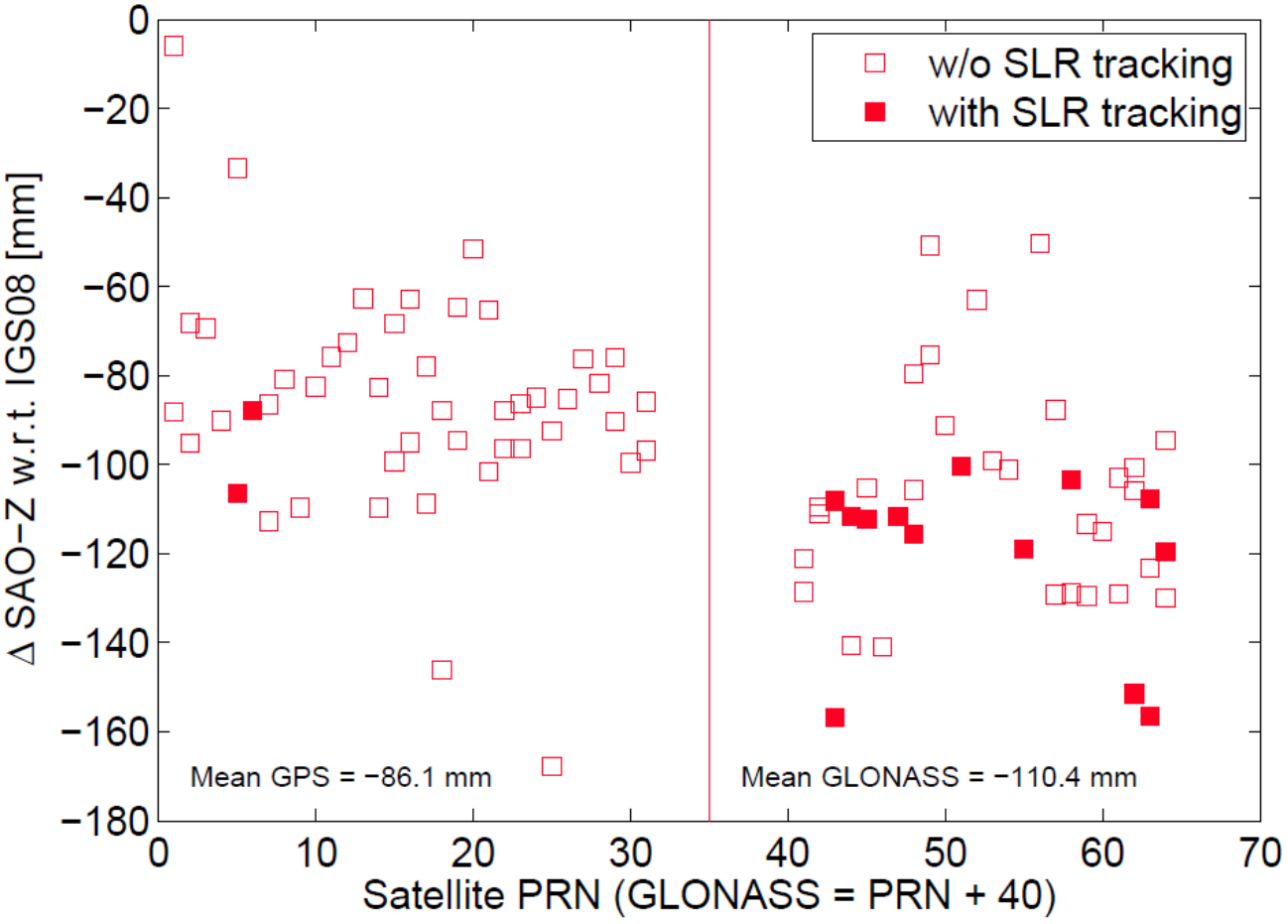
GNSS Satellite Antenna Offsets from Combined SLR-GNSS solutions



Mean GPS = -86.1 mm

Mean GLONASS = -110.4 mm

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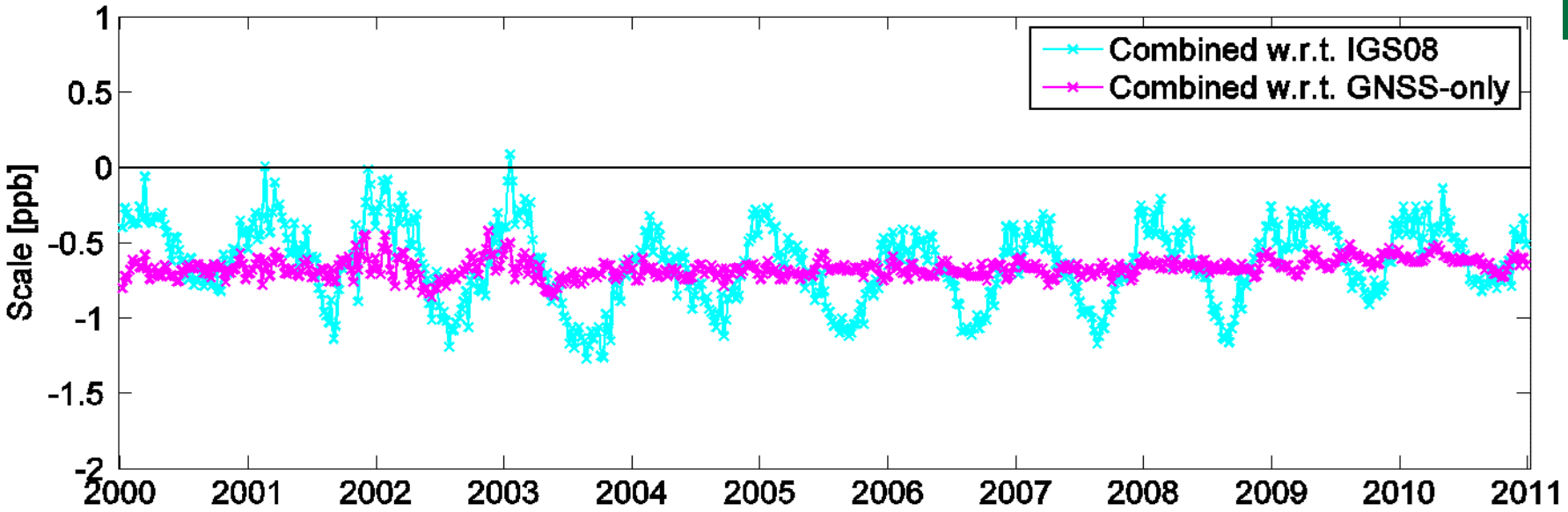
GNSS Satellite Antenna Offsets and **SCALE**



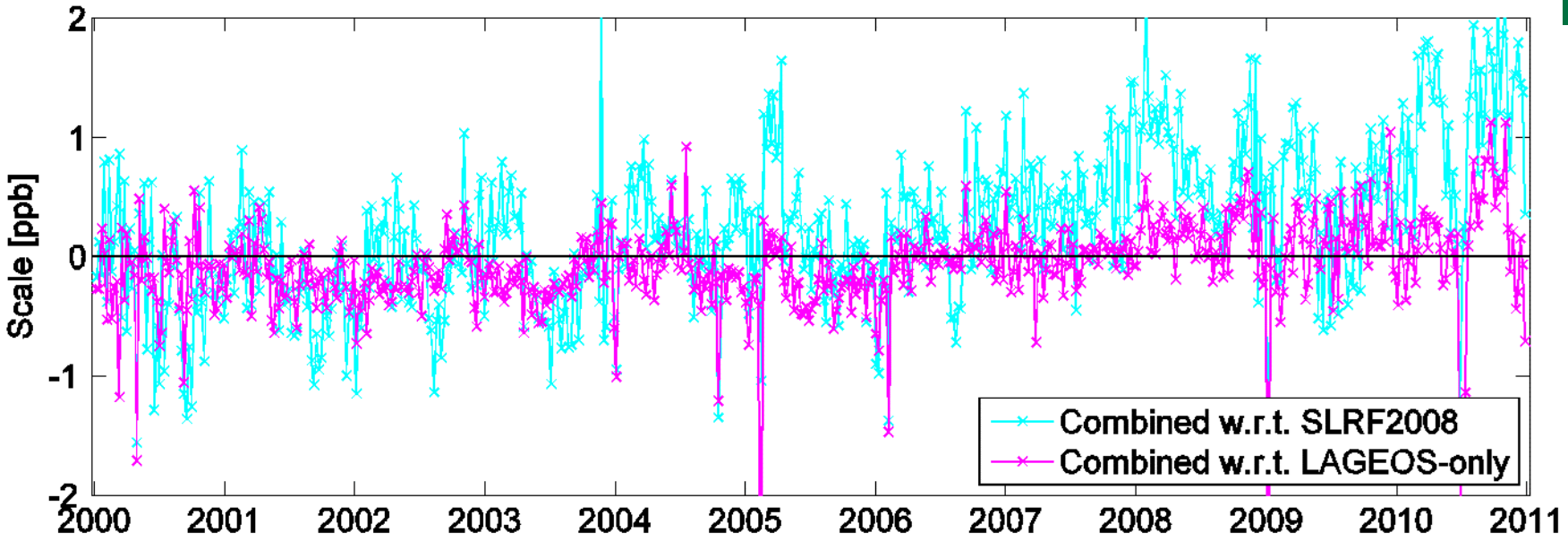
SAO-Z is correlated with scale: $\Delta Scale\ [ppb] = -7.8 \cdot \Delta SAOz\ [m]$

$\Delta SAOz\ (GPS) = -86.1\ mm \quad \Rightarrow \Delta scale = 0.67\ ppb$

$\Delta SAOz\ (GLONASS) = -110.4\ mm \quad \Rightarrow \Delta scale = 0.86\ ppb$

SAO corrections are absorbed by the GNSS network scale

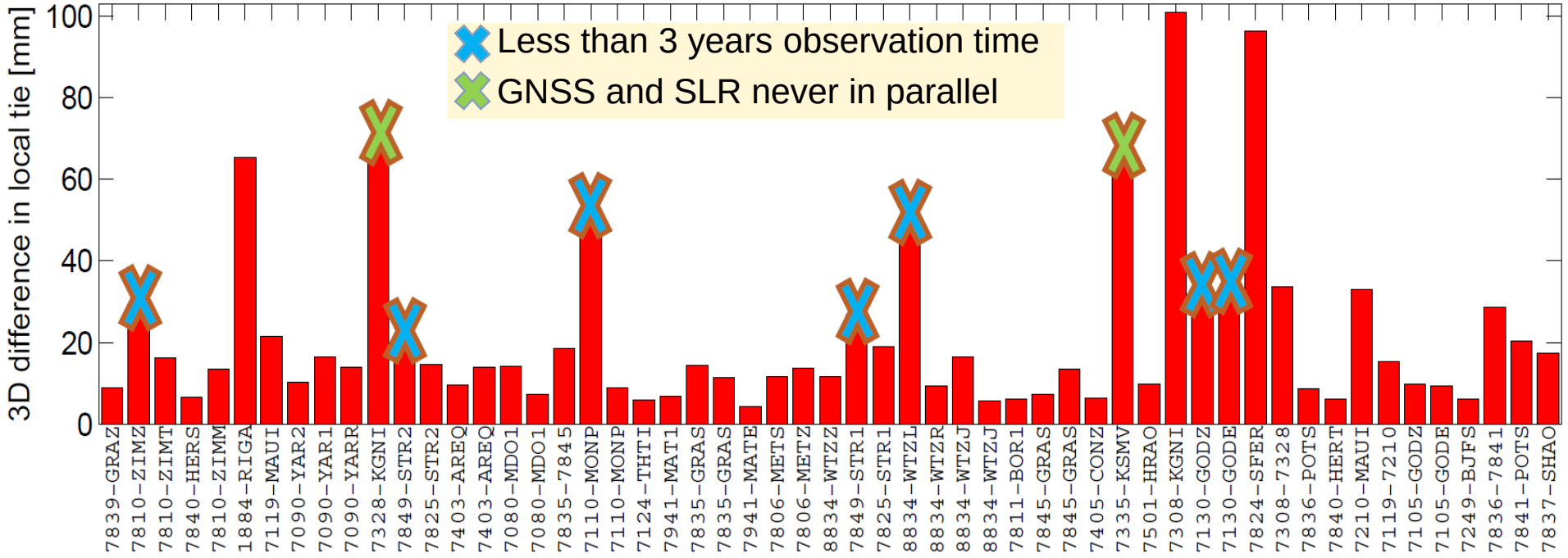
GNSS Satellite Antenna Offsets and **SCALE**



- No systematic scale difference for the SLR network
- Scale from SLR is transferred to the combined solution

SAO corrections are fully consistent to the SLR scale

Combined GNSS-SLR Solutions: Validation of Local Ties



3-D agreement:

$0 \text{ mm} < \Delta \leq 10 \text{ mm}$	17 co-locations
$10 \text{ mm} < \Delta \leq 20 \text{ mm}$	13 co-locations
$20 \text{ mm} < \Delta \leq 30 \text{ mm}$	5 co-locations
$30 \text{ mm} < \Delta$	15 co-locations

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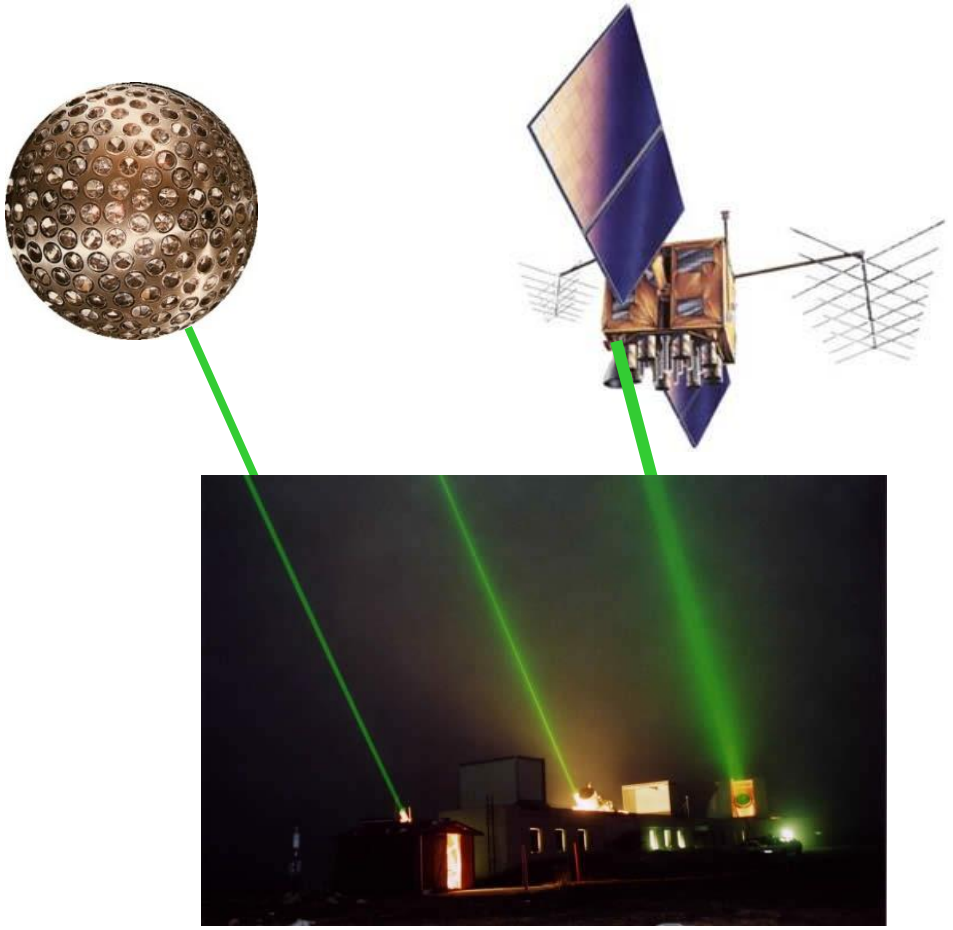
Thank you for your kind attention!



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Zusammenfassung der Ergebnisse

- Eine **Erhöhung der Stationsperformances** hat einen großen Einfluss
- Der Einfluss der verbesserten **Netzgeometrie** ist annähernd konstant

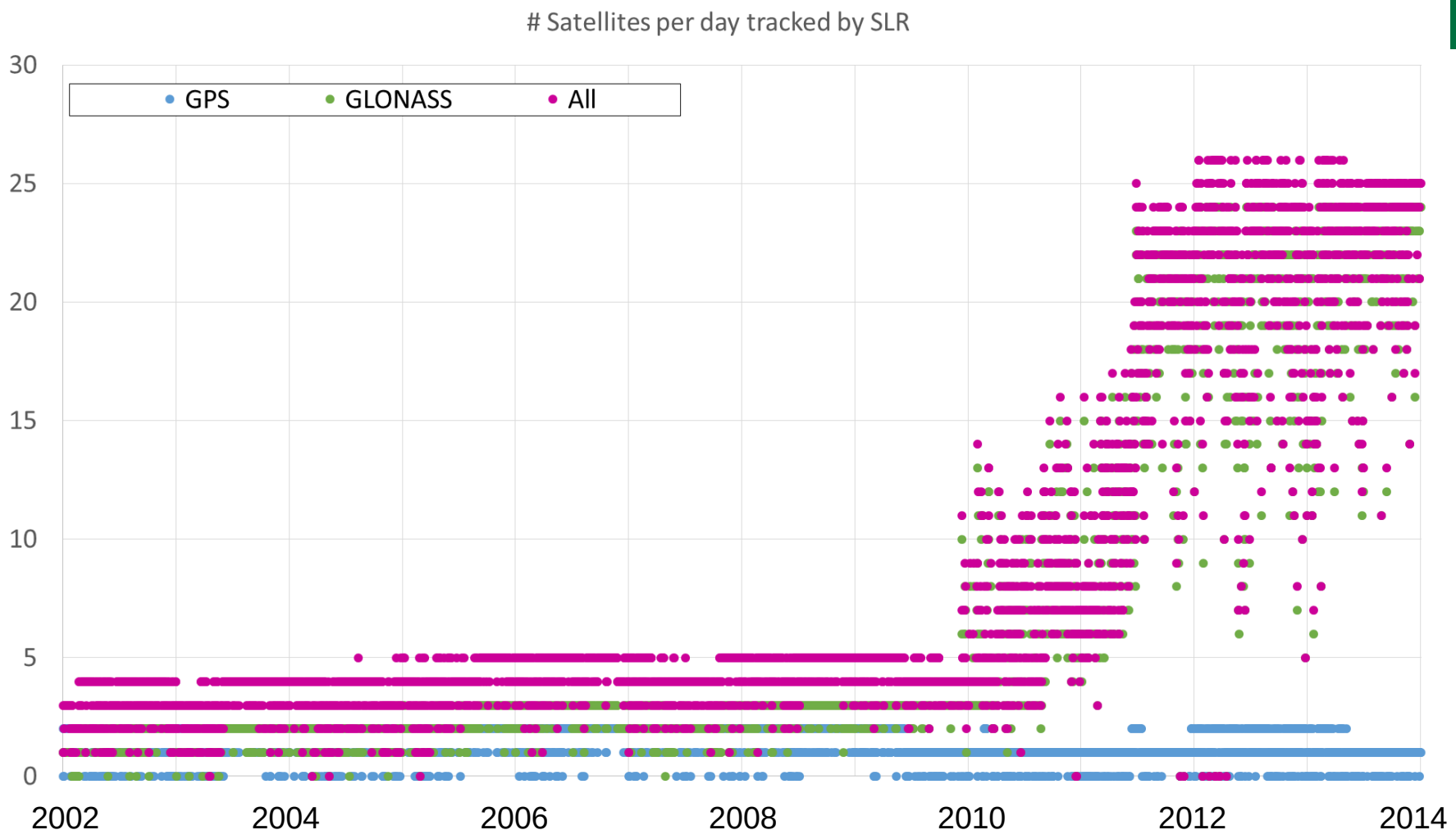
- Nimmt man eine Erhöhung der Stationsperformances auf ein Minimum von 20 % an, so ergibt sich:

	Helmert-Parameter					EOP		
	RMS	t_x	t_y	t_z	M	x_{Pol}	y_{Pol}	LoD
Techn.	44 %	10 %	27 %	14 %	49 %	10 %	10 %	4 %
Geom.	6 %	18 %	20 %	24 %	20 %	4 %	5 %	2 %
Komb.	48 %	26 %	41 %	35 %	59 %	13 %	15 %	6 %

- Der Einfluss einer **Verkleinerung des Messfehlers** ist geringer (unter der Annahme, dass es sich um Weißes Rauschen mit $\sigma \leq 1\ \mathrm{cm}$ handelt)

- **Eine Verbesserung der Netzgeometrie und eine technische Weiterentwicklung des bestehenden Stationsnetzes sind gleichermaßen wichtig!**

GNSS satellite co-locations



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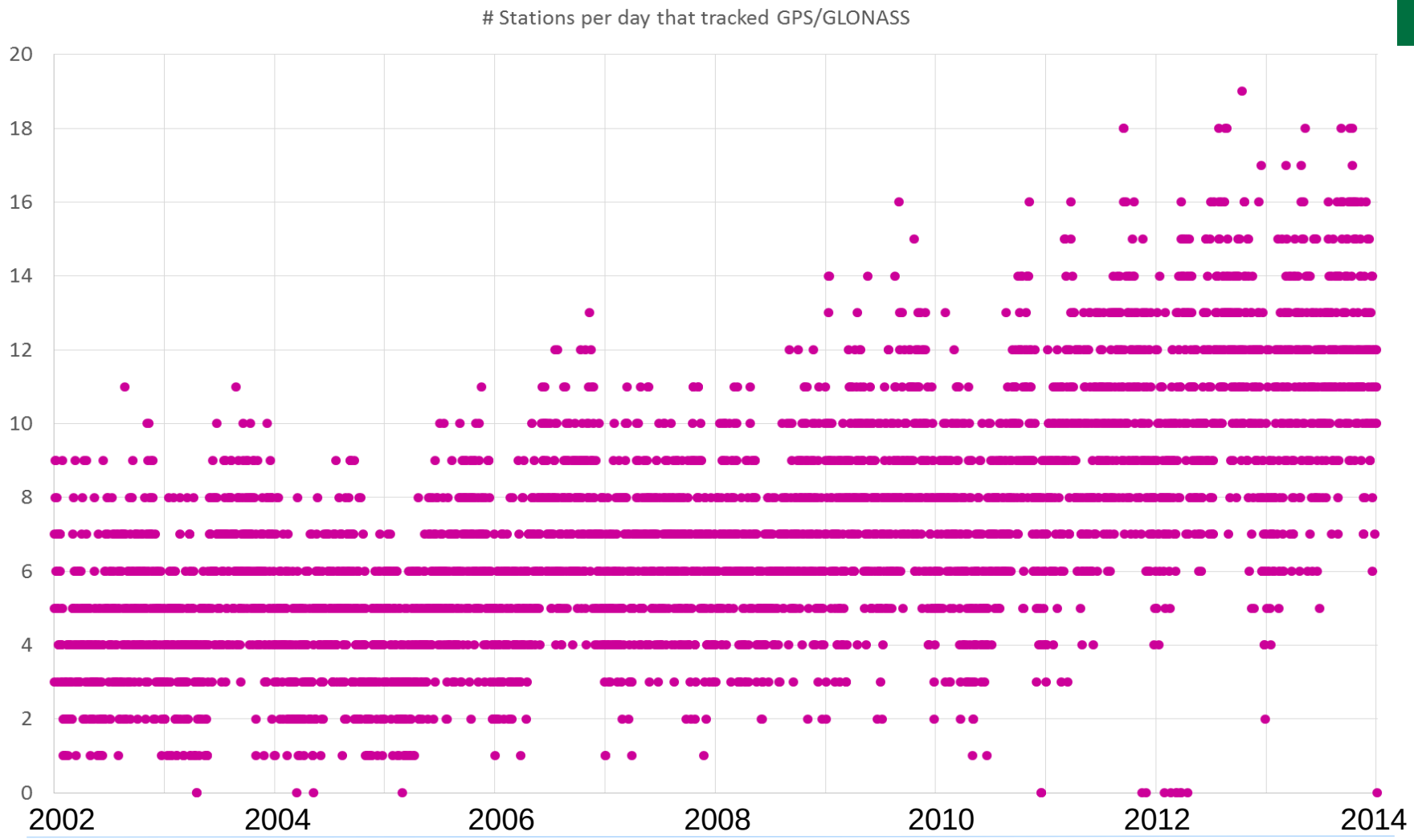
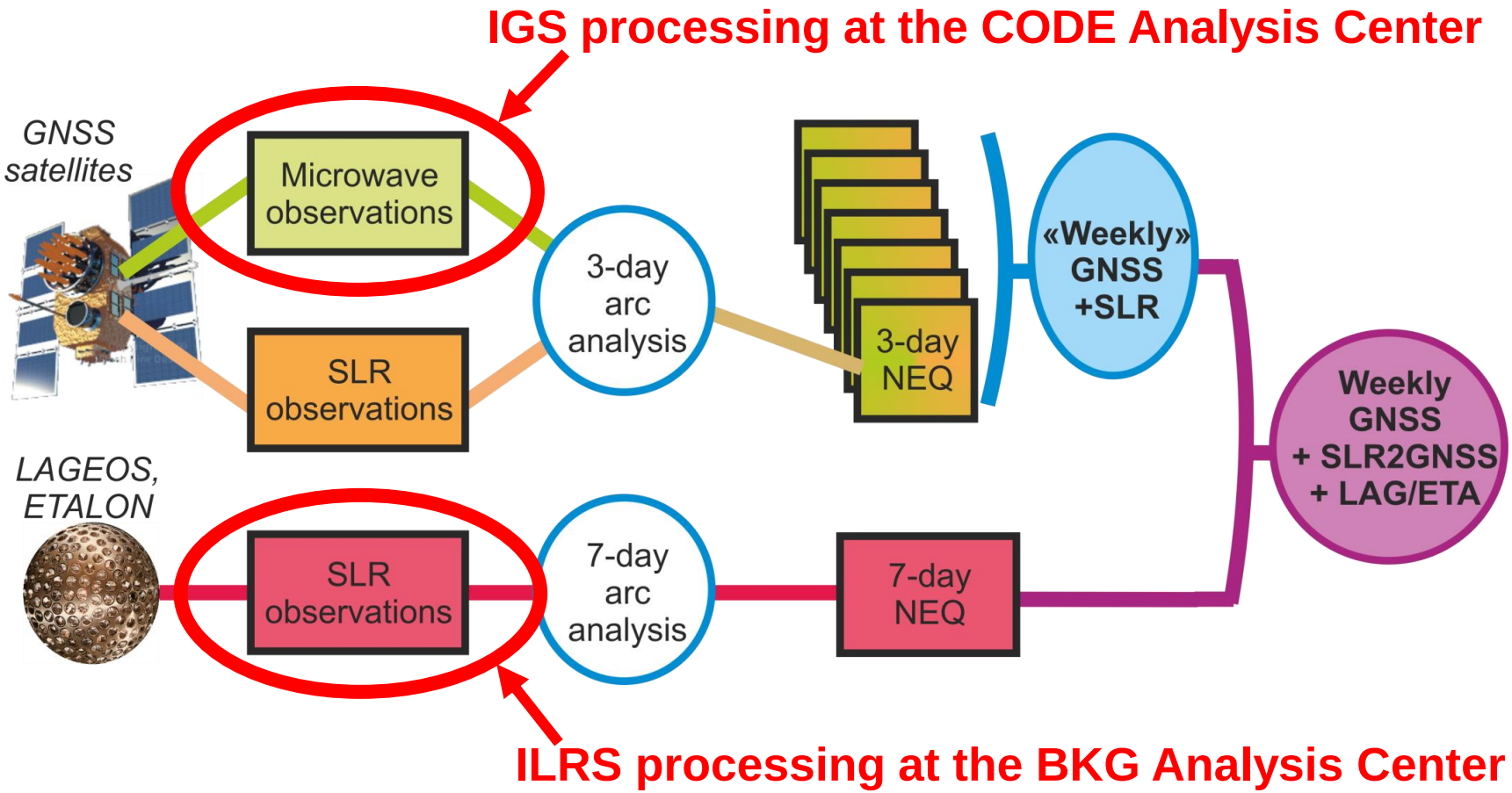
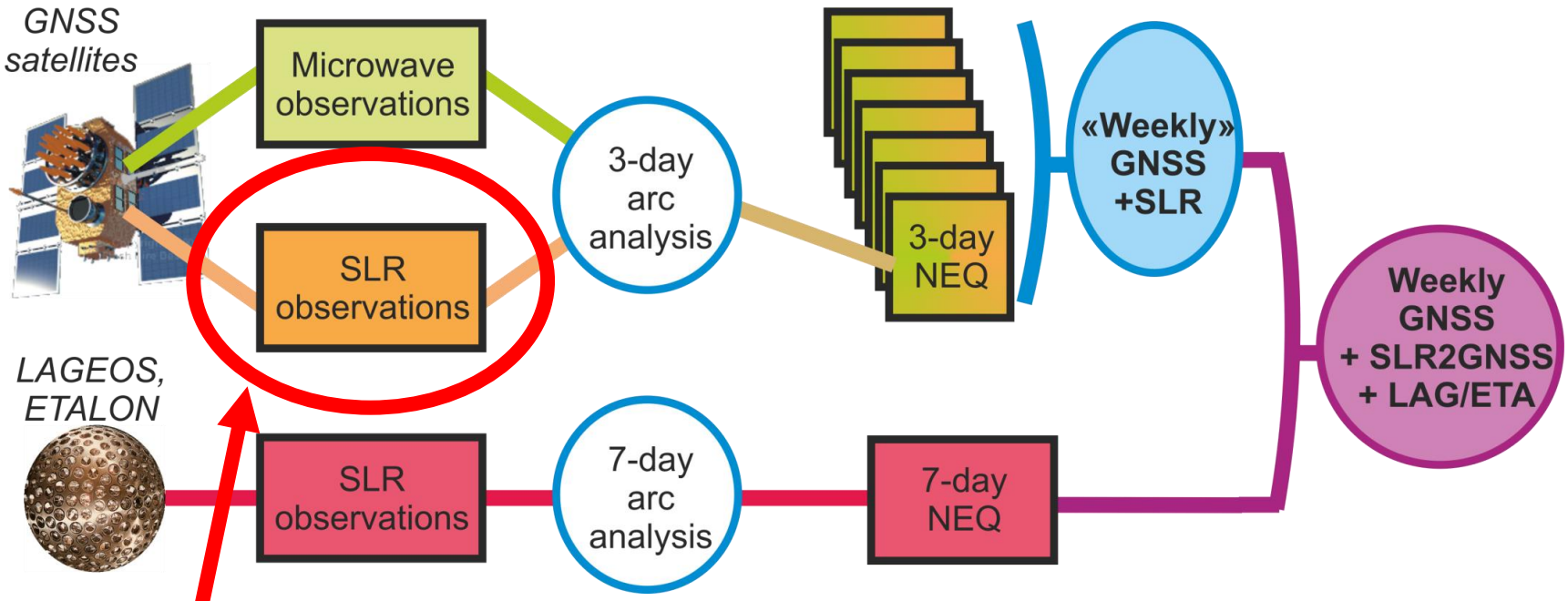
GNSS satellite co-locations



Pre-combined GNSS-SLR solutions from CODE

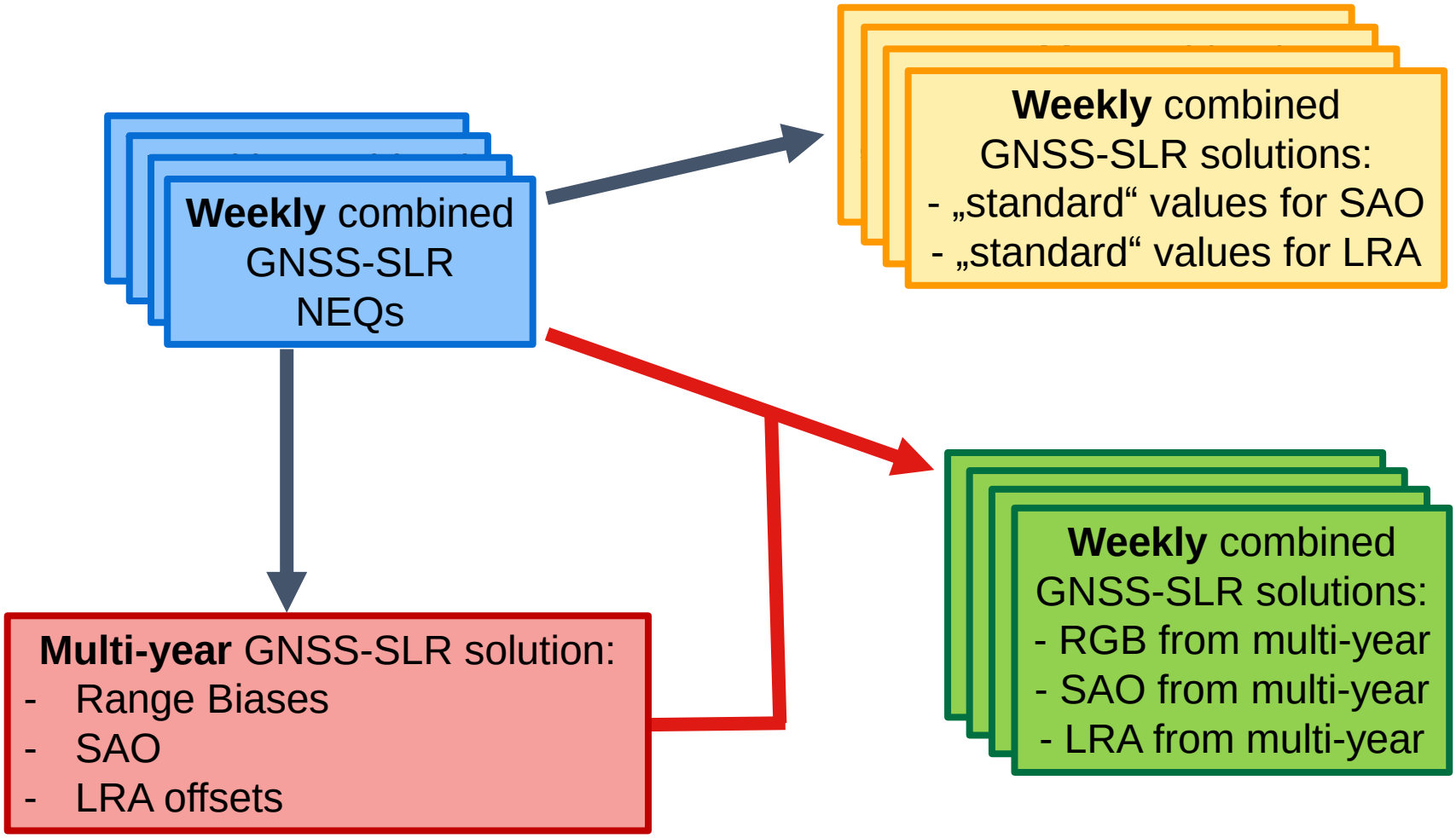


Pre-combined GNSS-SLR solutions from CODE

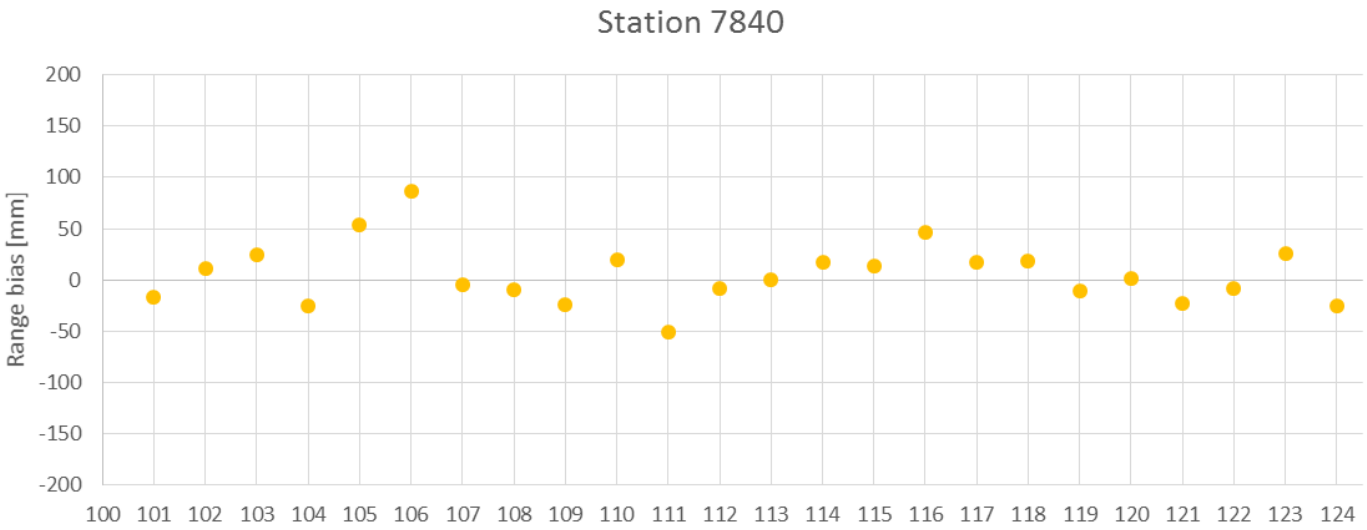


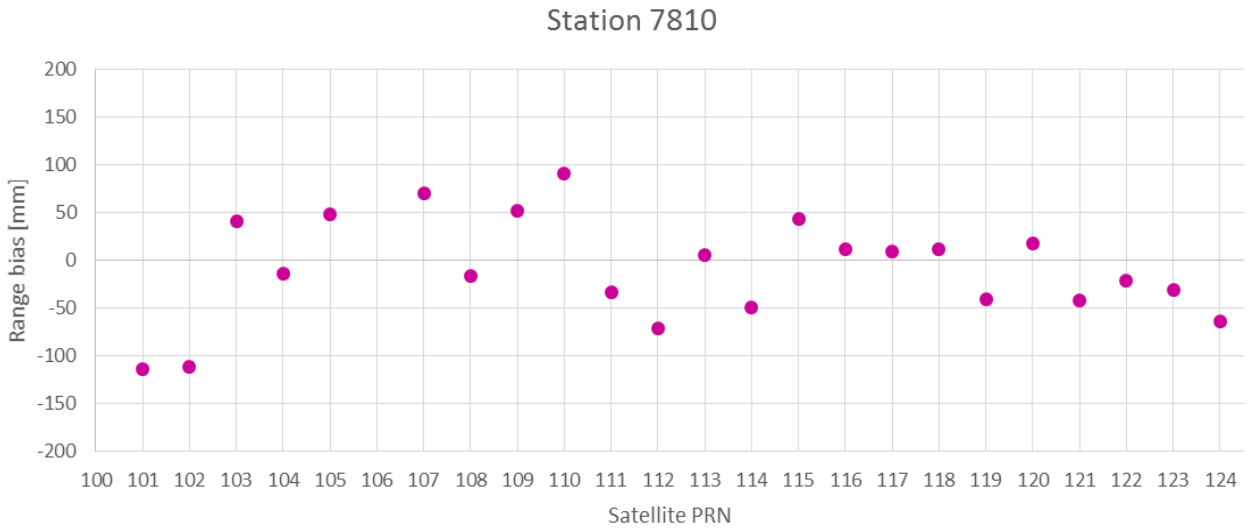
Using **co-locations at GNSS satellites** for connecting both techniques

Strategy for pre-combined solutions



Range biases





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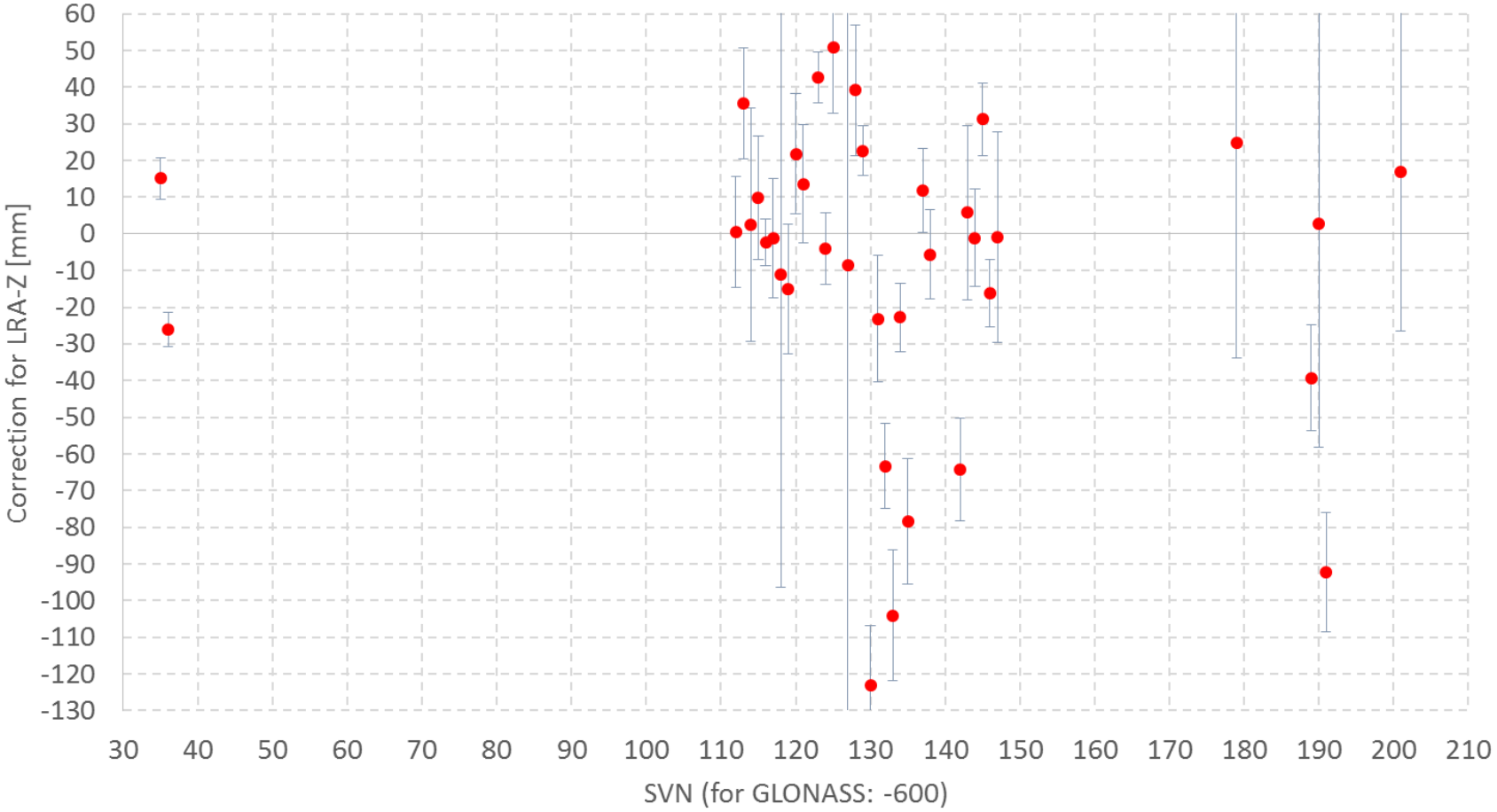
Laser retro-reflector array offsets



Mean GPS = -5.5 mm

Mean GLONASS = -6.6 mm

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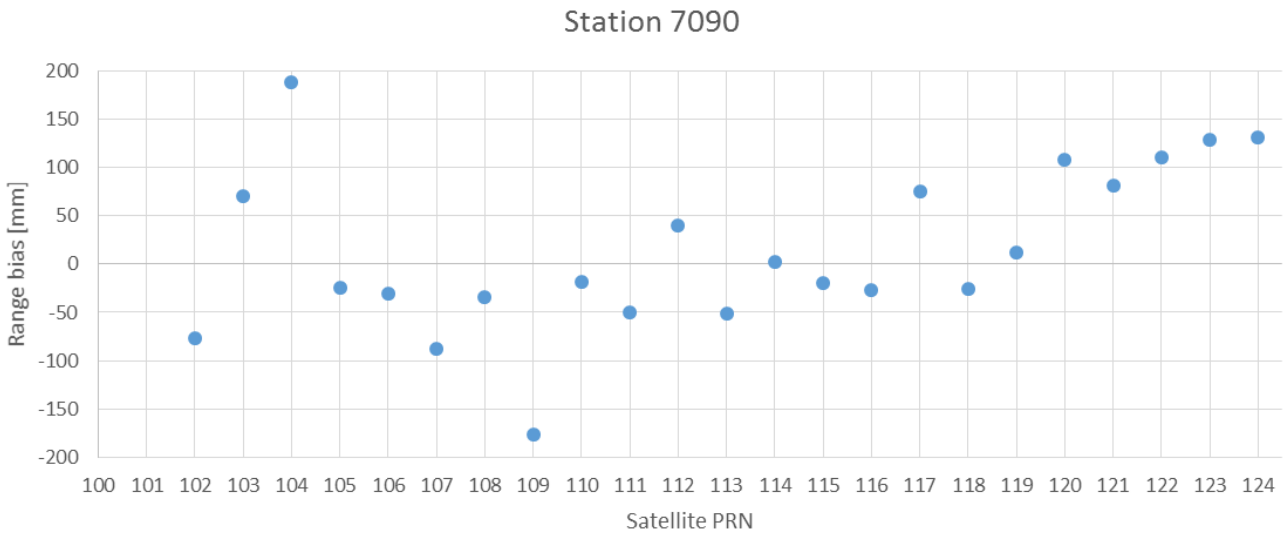
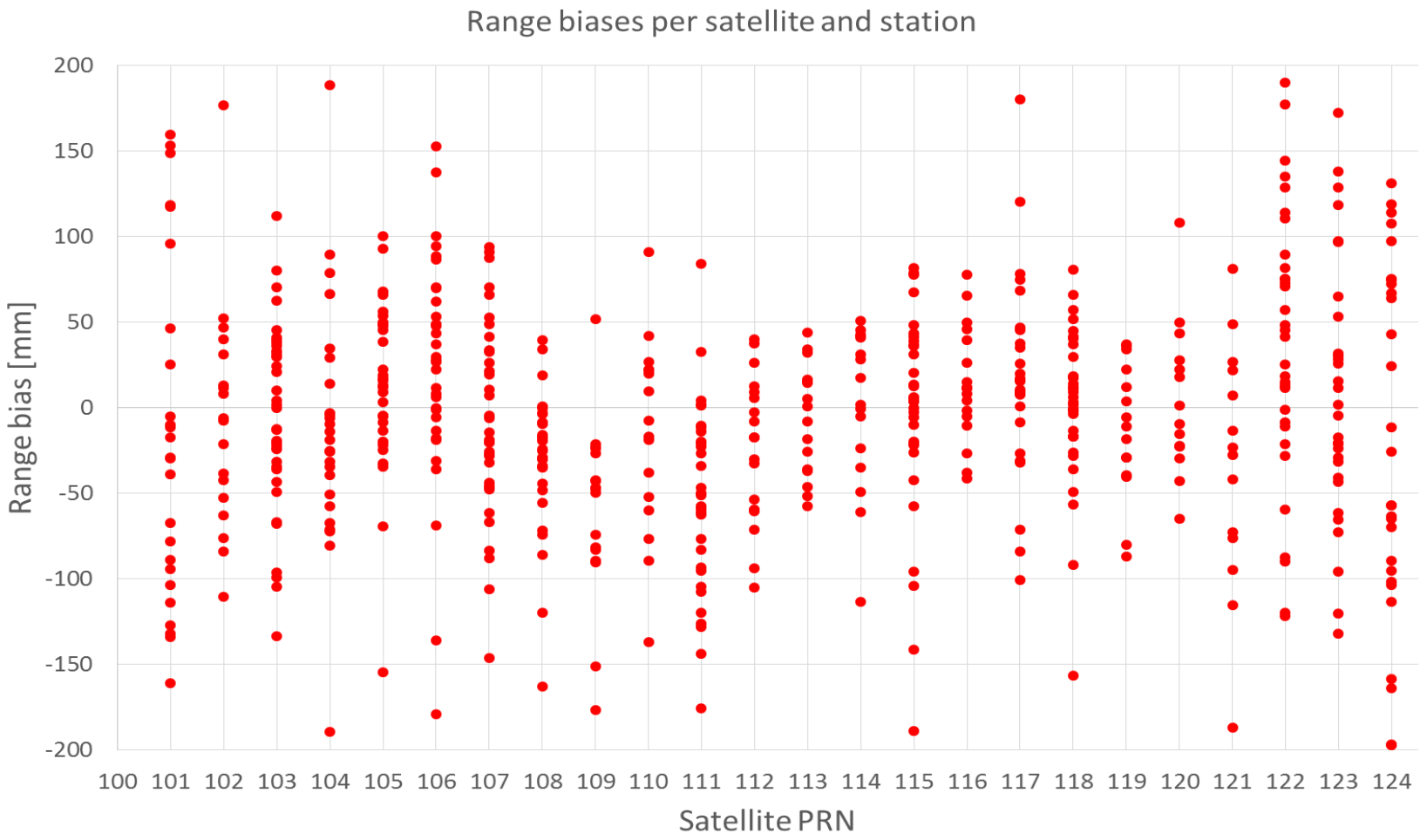
Range biases



Range biases



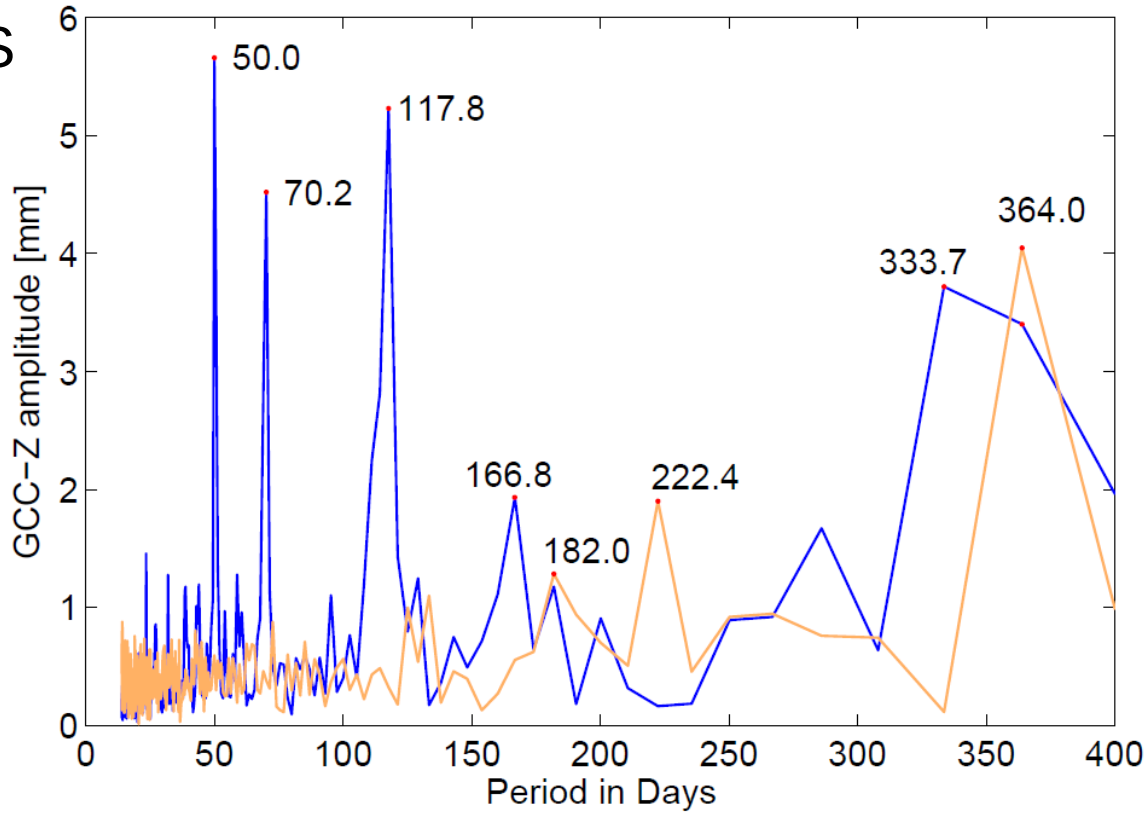
Geocenter: Single techniques

Draconitic year is visible: GNSS = 352d, LAG-2 = 222d

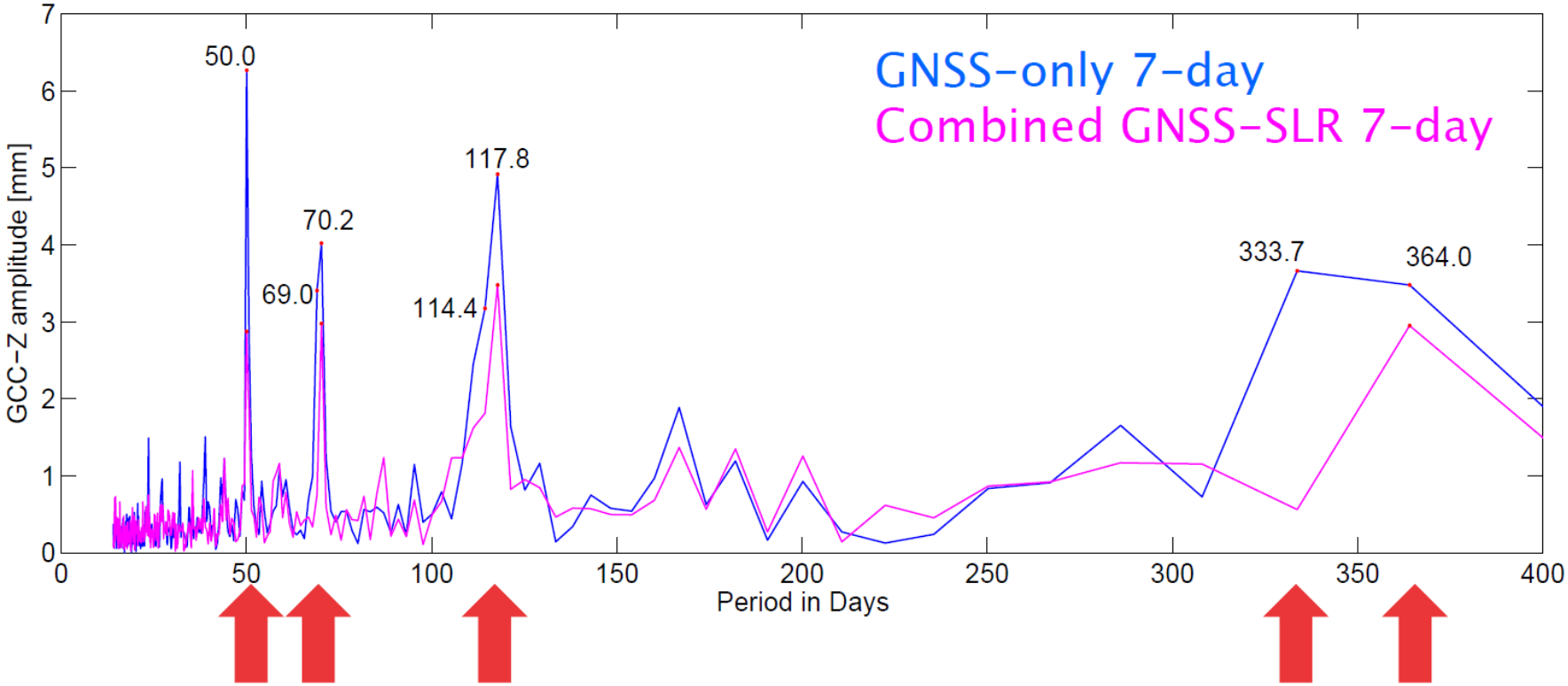
+ Harmonics for GNSS

GNSS-only

SLR-only



Geocenter: Combined solutions



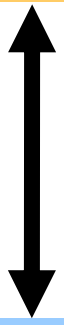
- Annual signal remains; draconitic signals disappear
- Harmonics of draconitic GNSS year are reduced, but not eliminated

Local ties: Validation

„Local Tie“:

3D vector between reference points of space geodetic instruments (GNSS antenna or SLR telescope or …) at co-located sites

From terrestrial measurements



Discrepancies have to be evaluated

Station coordinates from space techniques:

3D position of reference points of space geodetic instruments

From combined GNSS-SLR solutions using satellite co-locations,
without using Local Ties !!!