Can we improve LAGEOS solutions by combining with LEO satellites?

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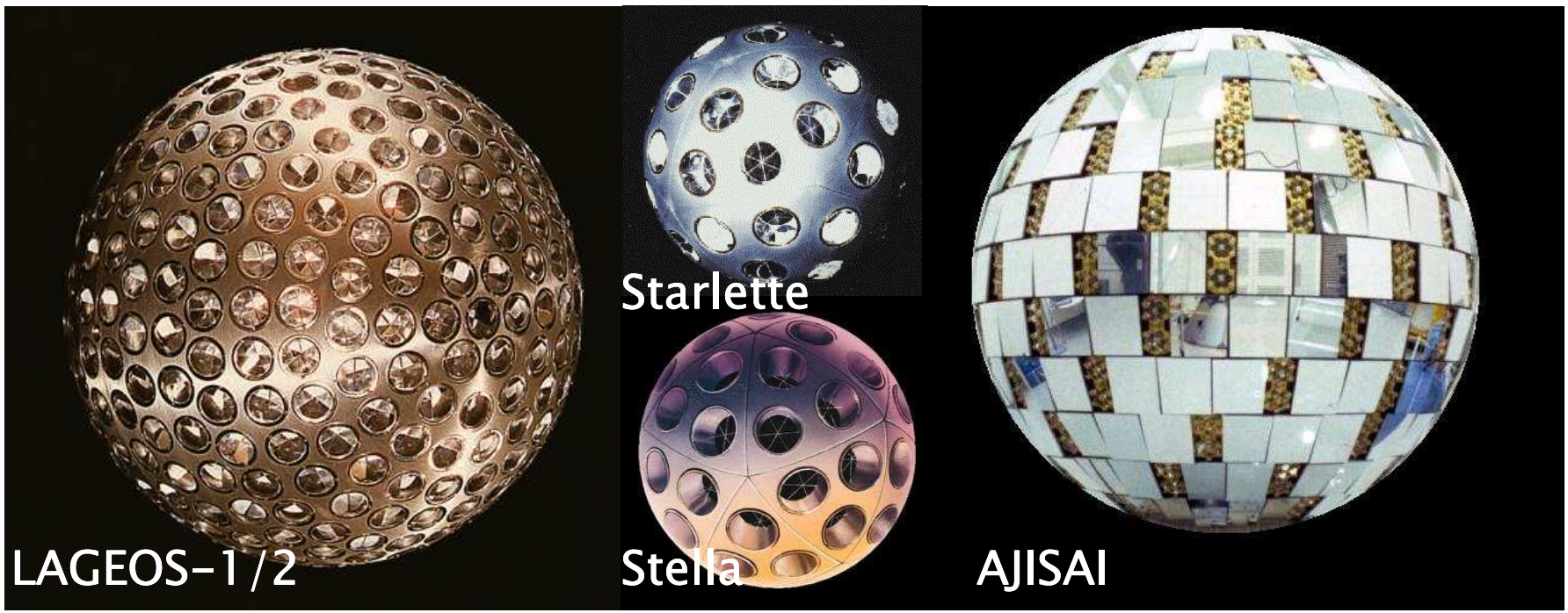
Motivation

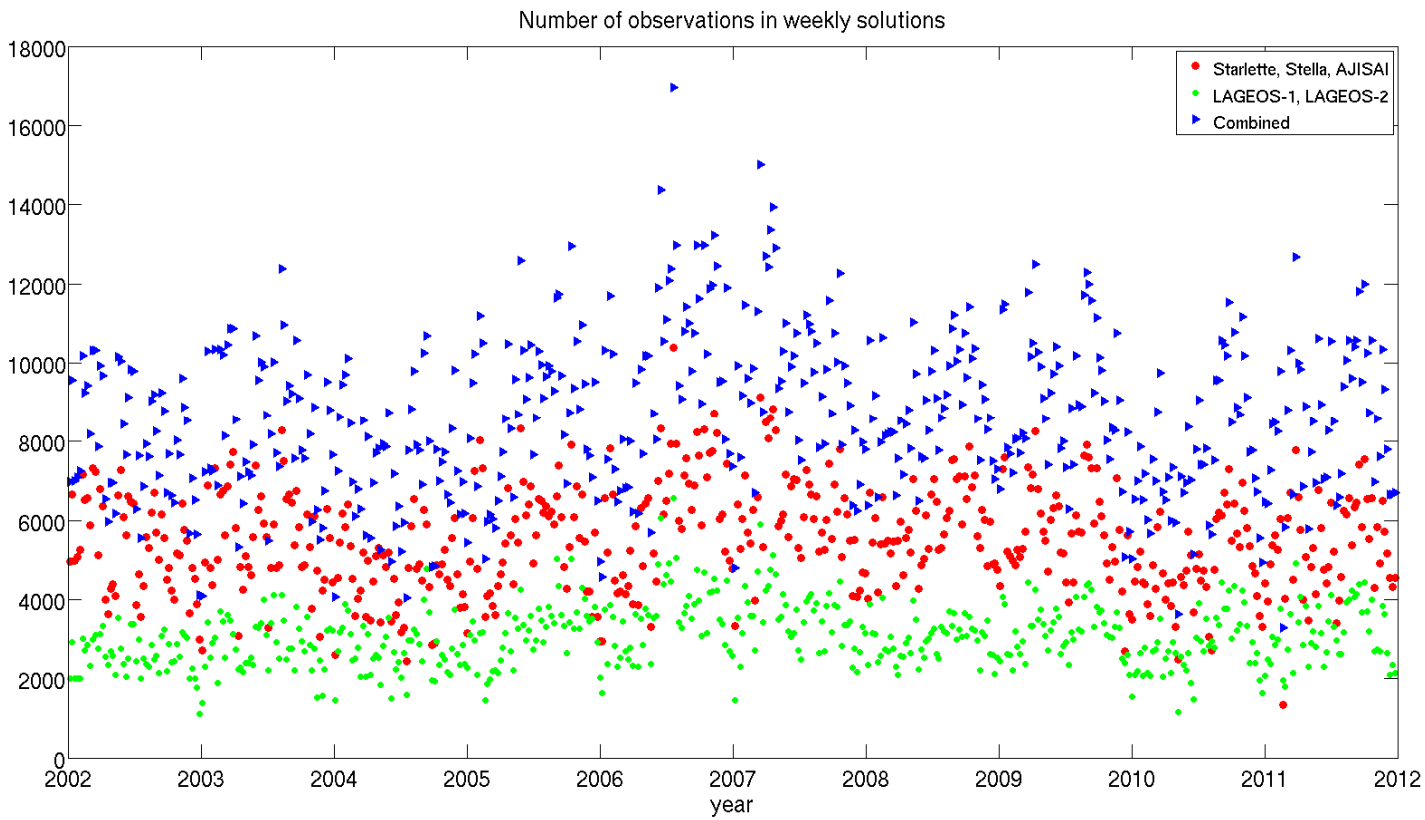
Current ILRS products:

- LAGEOS-1/2 & Etalon-1/2 solutions only,
- On average ~3000 normal points to LAGEOS-1/2 and ~300 normal points to Etalon-1/2 per week,
- The impact of Etalon-1/2 on the solution is virtually negligible



Motivation

- Some of the SLR stations do not observe LAGEOS, e.g., Helwan, Egypt (7831), Mendeleevo, Russia (1870)



	LAGEOS-1	LAGEOS-2	AJISAI	Starlette	Stella
No of normal points per week	1500	1500	3000	1600	800

	LAGEOS-1/2	LEO	Combined
No of stations per week	19.8	21.1	22.4

Why LEO satellites are neglected?

It is more difficult to model Starlette, Stella, AJISAI (LEO) orbits, because of:

- higher sensitivity to the Earth gravity field and to the temporal variations of the gravity field,
- uncertainties in air drag models and variations of air density in the high atmosphere,
- deficiencies of SLR station-specific Center-of-Mass corrections (CoM), due to different laser systems used in SLR stations.

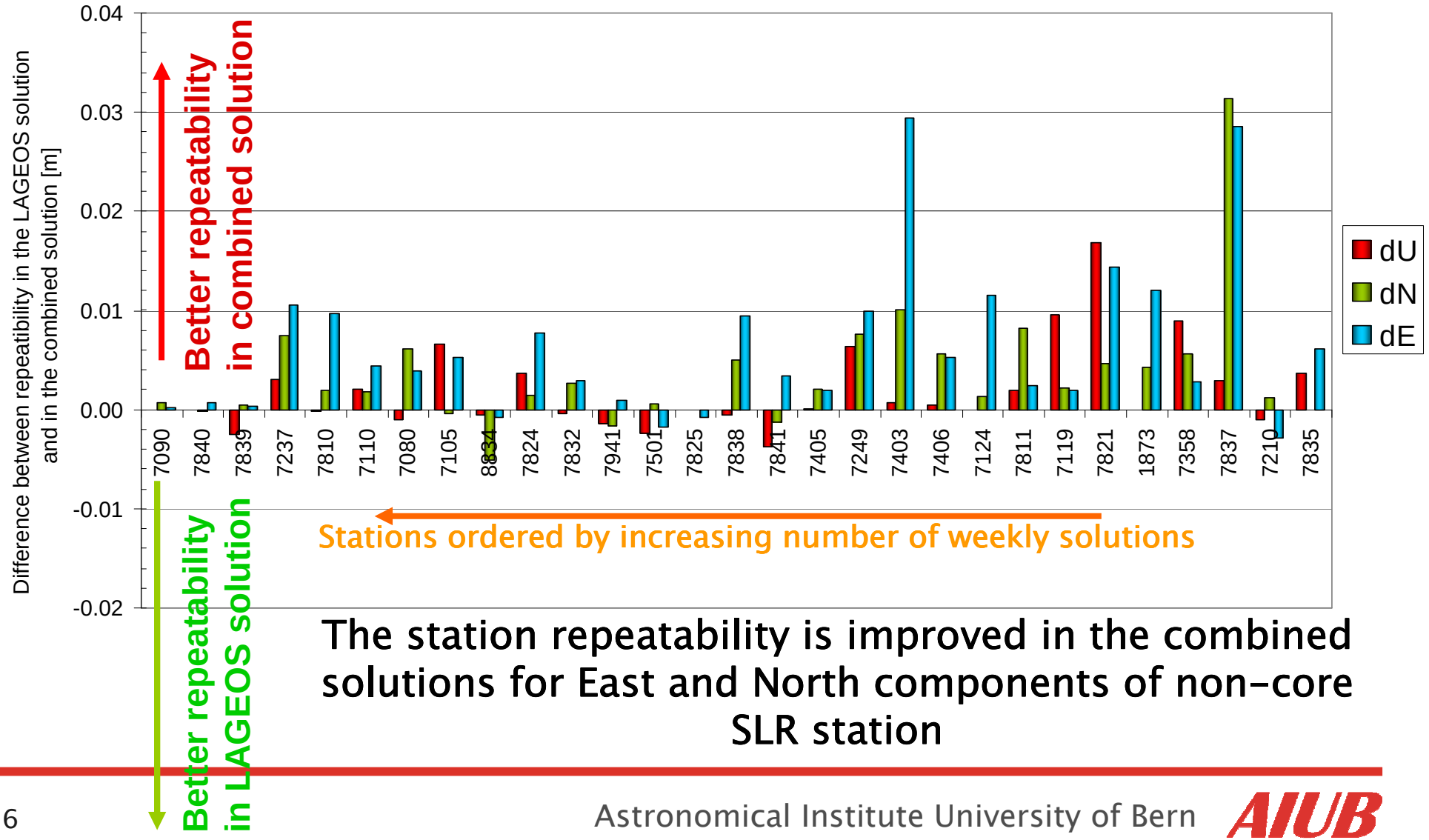
Solution set-up

In the Starlette, Stella, and AJISAI (LEO) 7-day solutions we apply the air drag NRLMSISE-00 model with fixed scaling factors and we estimate:

- Orbits:
  - six osculation elements (weekly)
  - constant (S0) and OPR sine and cosine terms (SS/SC) in along-track (daily),
  - OPR sine and cosine terms (WS/WC) in out-of-plane (daily),
  - pseudo-stochastic pulses in along-track (every revolution period) -> similar to CHAMP/GRACE/GOCE orbit solutions
- station coordinates (one set per 7-day arc),
- range biases (for all satellites and all stations, one set per 7-day arc),
- gravity field coefficients up to degree/order 3/3 (one set per 7-day arc),
- Piece Wise Linear (PWL) pole coordinates and Length-of-Day (one set at the daily boundary).

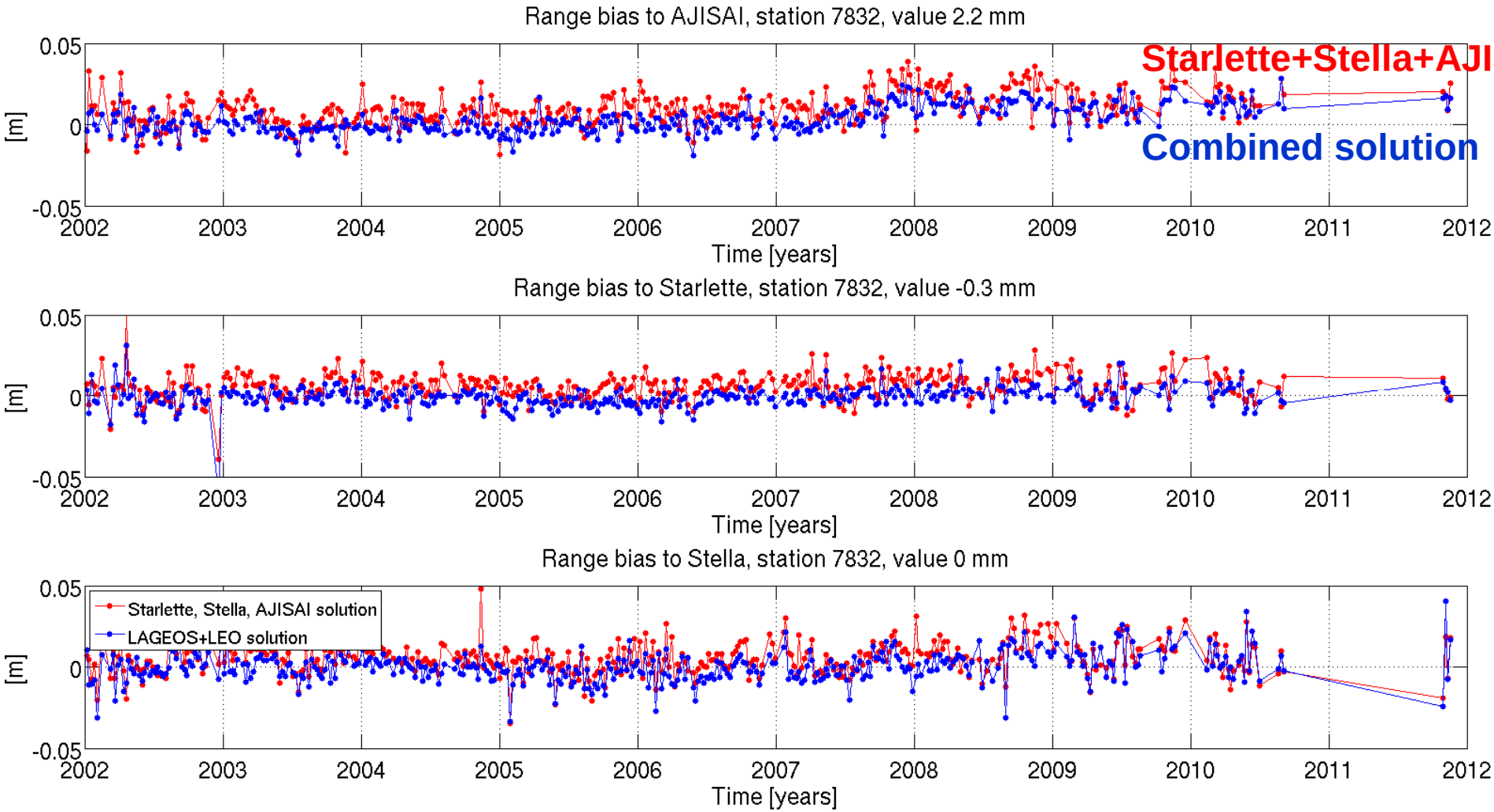
Results: Station coordinates

Station coordinate repeatability
in LAGEOS-1/2 and the combined solutions



The station repeatability is improved in the combined solutions for East and North components of non-core SLR station

Results: Range biases



Range biases in LEO-only solution are influenced by correlations with the network scale.

Estimation of CoM

Estimation of CoM corrections as a difference between:

- A priori CoM,
- Estimated range bias (from the combined solution with LAGEOS-1/2. The scale is defined by LAGEOS-1/2).

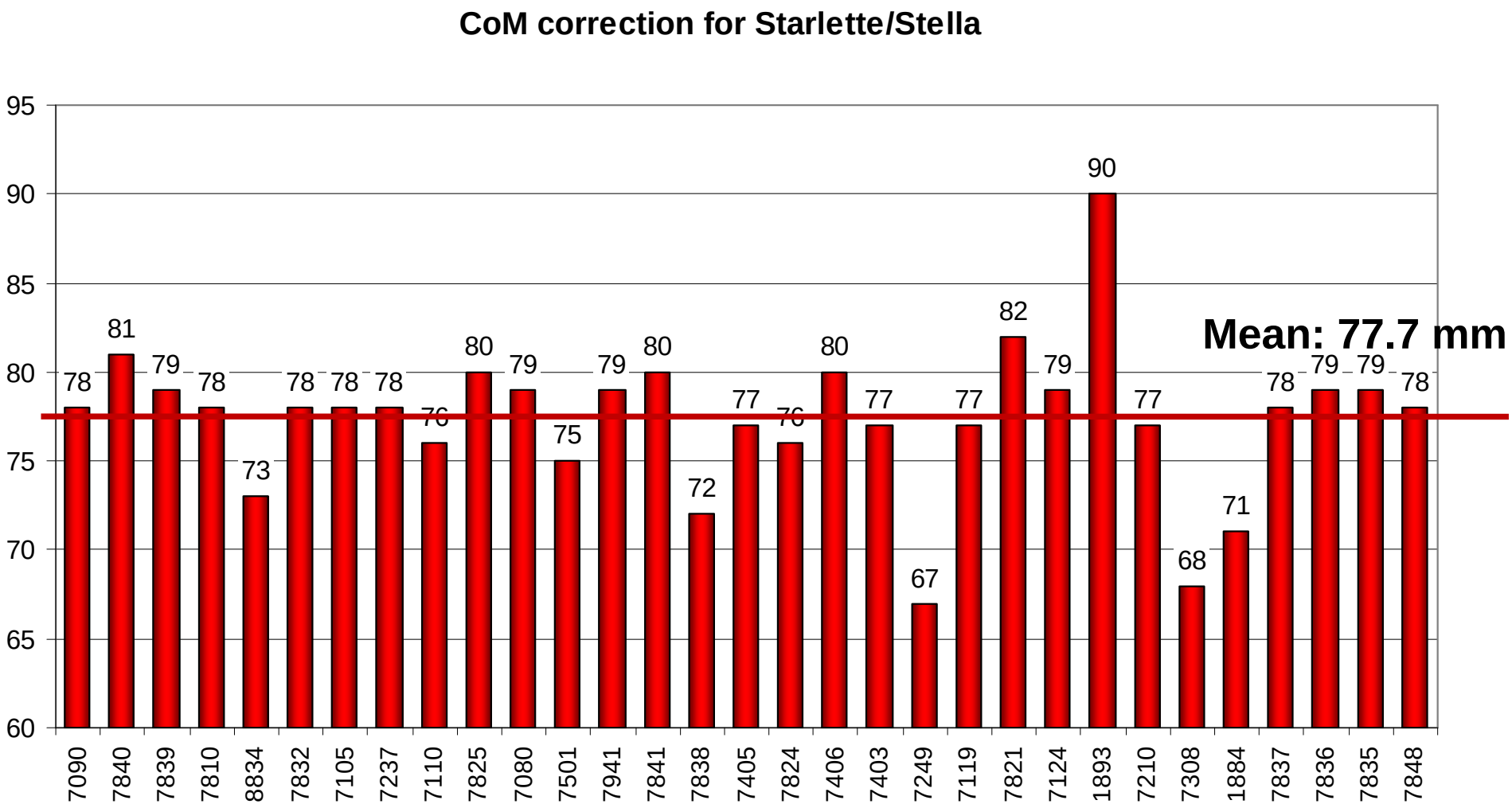
	LAGEOS-1/2	Starlette	Stella	AJISAI
A priori CoM	Time- and Station-specific (1)	78 mm (2)	78 mm (2)	1010 mm (3)

(1) Appleby G, Otsubo T, Pavlis EC, Luceri C, Sciarretta C (2012) Improvements in systematic effects in satellite laser ranging analyses - satellite centre-of-mass corrections. Geophysical Research Abstracts Vol. 14, EGU2012-11566, 2012, EGU General Assembly 2012

(2) Ries J (2008) SLR bias/CoM offset issues, impact on the TRF scale. GGOS Ground Networks and Communications Working Group Meeting, April 16, 2008, Vienna

(3) ILRS recommended value

Center-of-Mass corrections

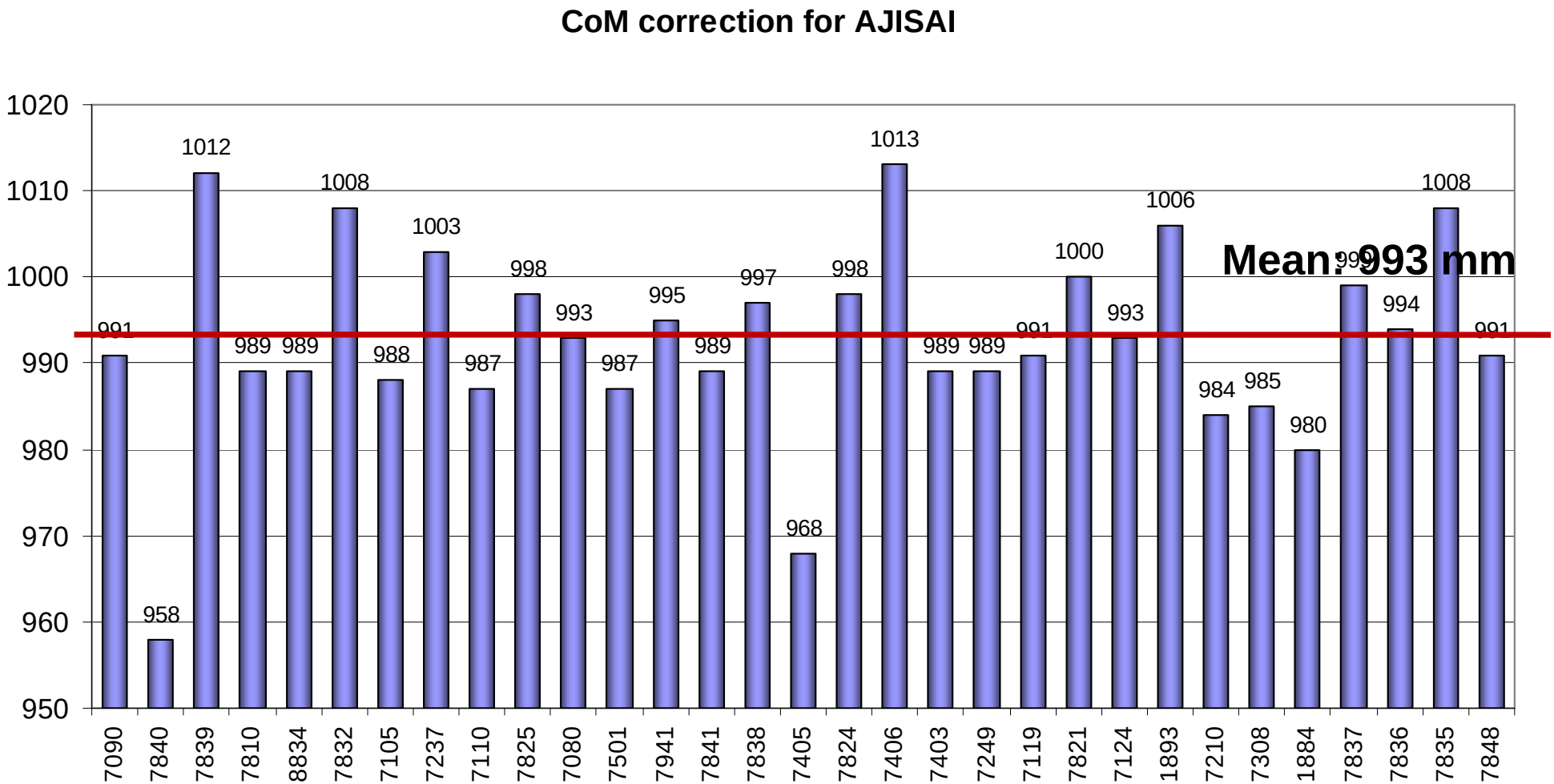


ILRS recommended value: 75 mm

Ries (2008) recommendes CoM 78-79 mm

Ries J (2008) SLR bias/CoM offset issues, impact on the TRF scale. GGOS Ground Networks and Communications Working Group Meeting, April 16, 2008, Vienna

Center-of-Mass corrections



ILRS recommended value: 1010 mm

Variations of CoM 45 mm for different SLR stations

One CoM for all SLR stations is insufficient

Center-of-Mass corrections

Center-of-Mass corrections in different periods (different laser systems):

	AJISAI	Starlette/Stella
Concepcion		
2001.0-2006.3	993	77
2006.3-2012.0	964	77
Zimmerwald		
2001.0-2006.2	1003	92
2006.2-2012.0	986	76

Difference of 29 mm for Concepcion (AJISAI only),
Difference of 16-17 mm for Zimmerwald (all LEO)

Summary

- **LAGEOS-1/2 solutions can be improved when including Starlette, Stella, AJISAI**
  - **Estimation of Z-geocenter coordinate is improved in the combined LAGEOS-LEO solution,**
  - **Station coordinates can be obtained for stations not observing LAGEOS-1/2**
  - **WRMS of Polar motion can be improved up to 10% in the combined solution w.r.t. LAGEOS-1/2 solution,**
- **Mean estimated Center-of-Mass correction for Starlette/Stella is 78 mm (ILRS recommended value is 75 mm),**
- **Mean estimated Center-of-Mass correction for AJISAI is 993 mm (ILRS recommended value is 1010 mm),**
- **Variations of CoM for AJISAI are large (45 mm) for different SLR stations (and different equipments)**

Thank you for your attention

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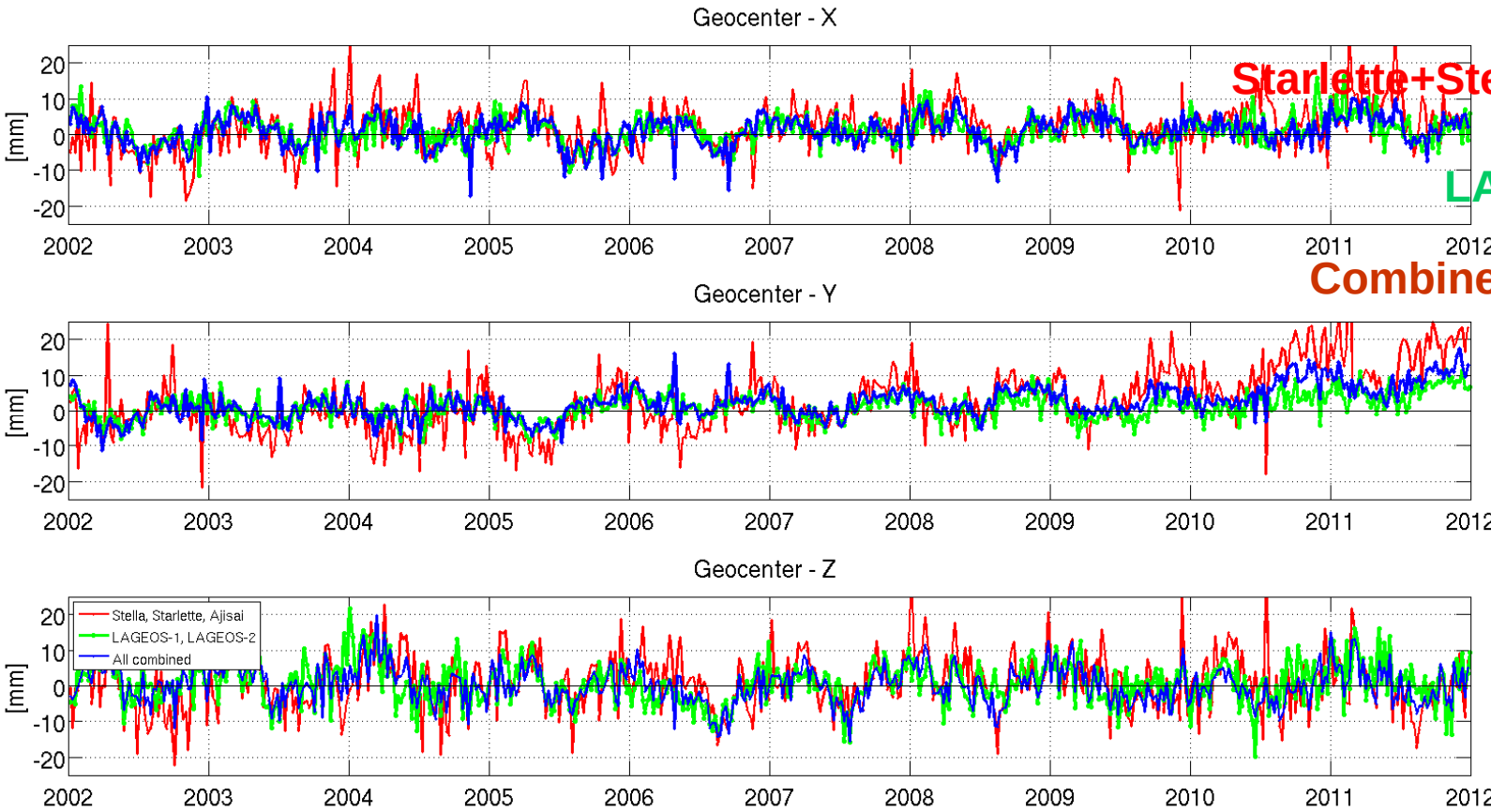
Results: Geocenter



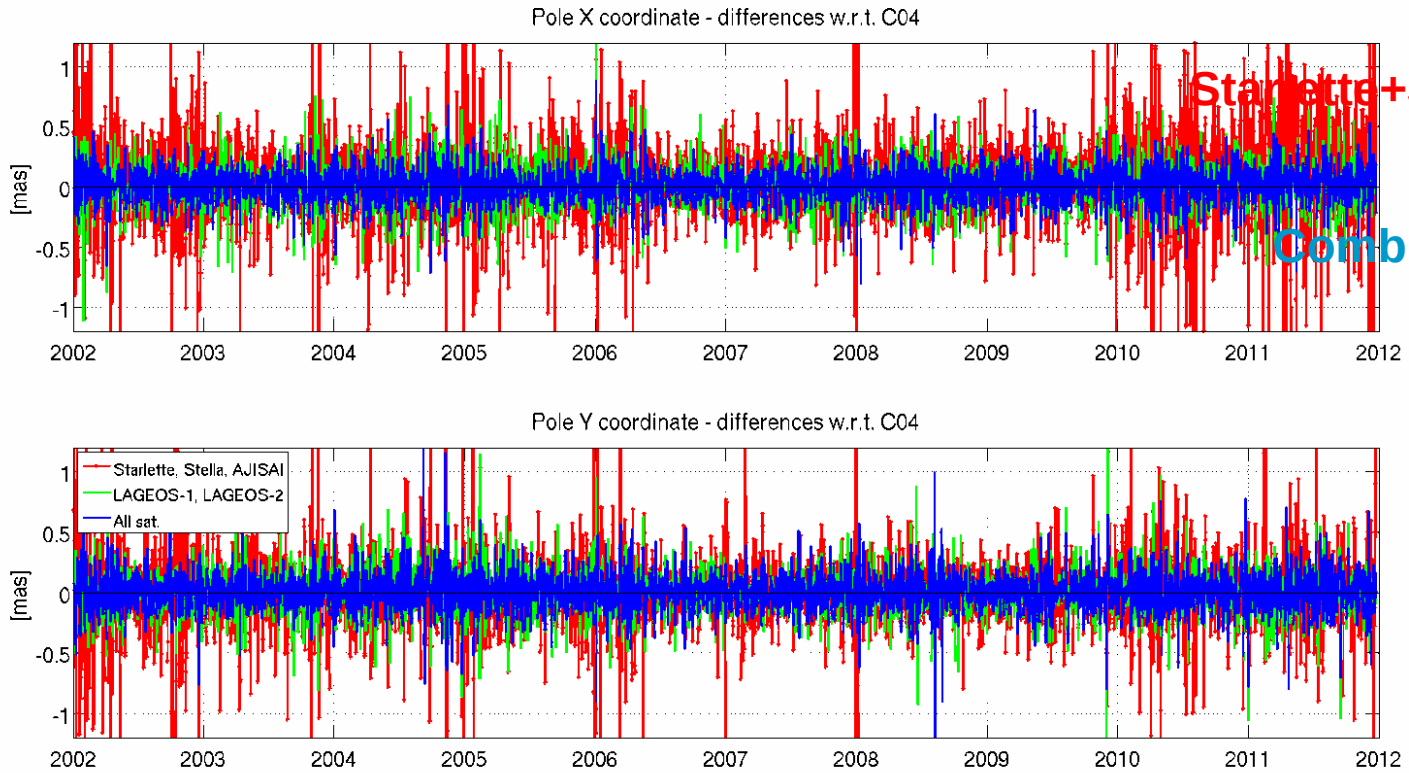
Starlette+Stella+AJISAI

LAGEOS-1/2

Combined solution

	X			Y			Z		
	LEO	LAGEOS	LEO+ LAGEOS	LEO	LAGEOS	LEO+ LAGEOS	LEO	LAGEOS	LEO+ LAGEOS
RMS	6.67	4.02	4.23	9.06	3.67	4.56	7.97	**5.99**	**5.33**
Amplitude of annual signal	2.97	2.99	3.40	5.28	2.49	2.94	4.68	3.64	4.13

Results: Earth Rotation Parameters (w.r.t. IERS C04)



Starlette+Stella+AJISAI

LAGEOS-1/2

Combined solution

		Starlette, Stella, Ajisai	Lageos -1/2	Combined solution
Mean bias	X pole	57.7 µas	4.1 µas	6.4 µas
	Y pole	-8.7 µas	-8.0 µas	-8.5 µas
	LOD	-3.6 µs	6.1 µs	6.3 µs
Weighted RMS	X pole	269.8 µas	160.0 µas	148.9 µas
	Y pole	218.1 µas	155.2 µas	140.3 µas
	LOD	106.5 µs	57.0 µs	56.3 µs

7% for X pole
10% for Y pole