SLR-derived terrestrial reference frame using observations to LAGEOS-1/2, Starlette, Stella, and AJISAI

Krzysztof Sośnica (1), Adrian Jäggi (1),
Daniela Thaller (2), Gerhard Beutler (1),
Rolf Dach (1), Christian Baumann (1)

(1) Astronomical Institute, University of Bern, Switzerland

(2) Bundesamt für Kartographie und Geodäsie, Frankfurt am Main, Germany

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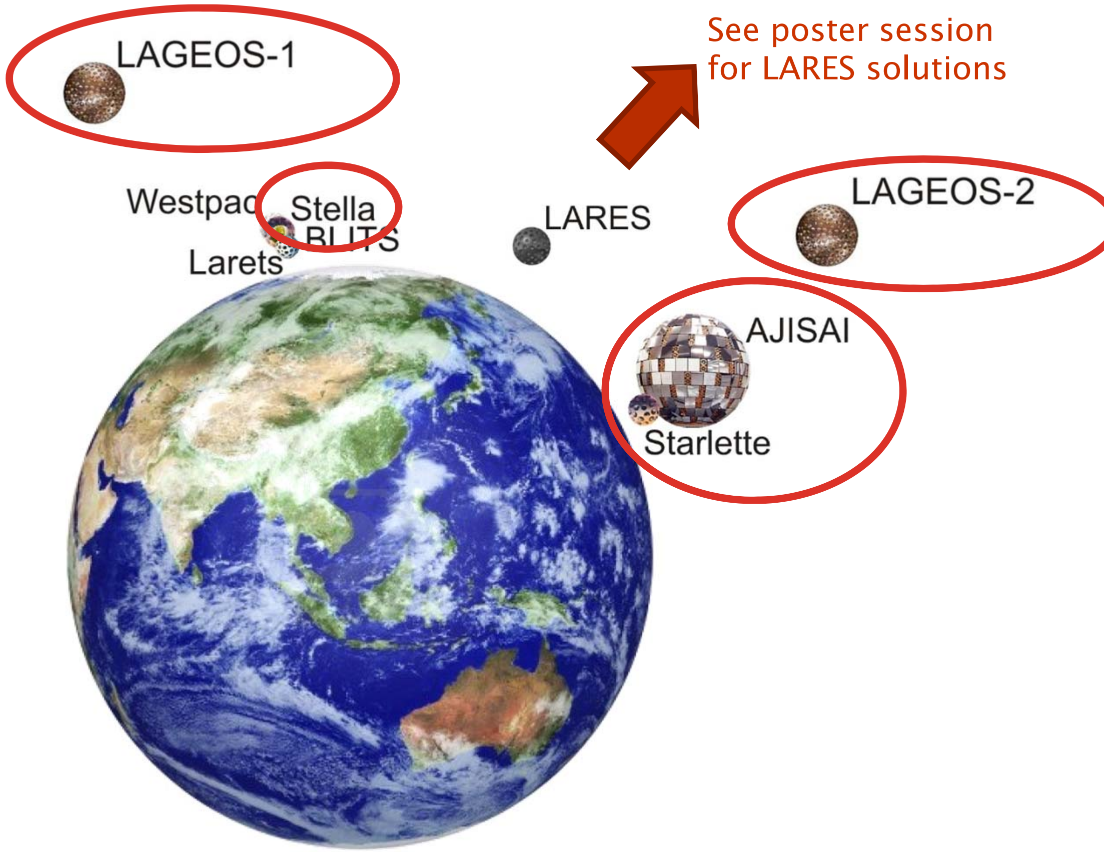
Motivation

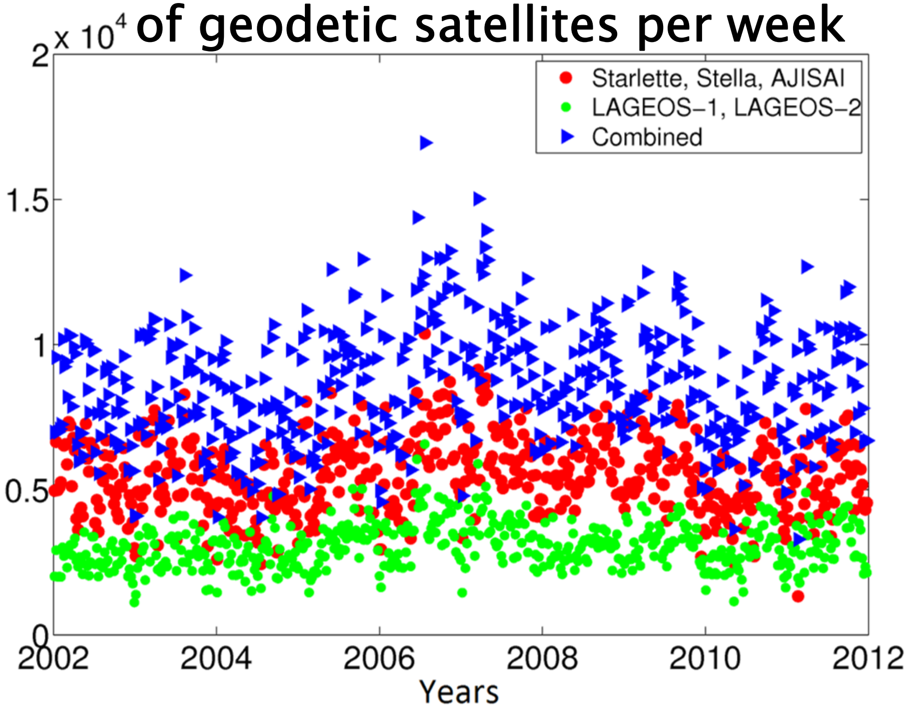
Current ILRS products:

- 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

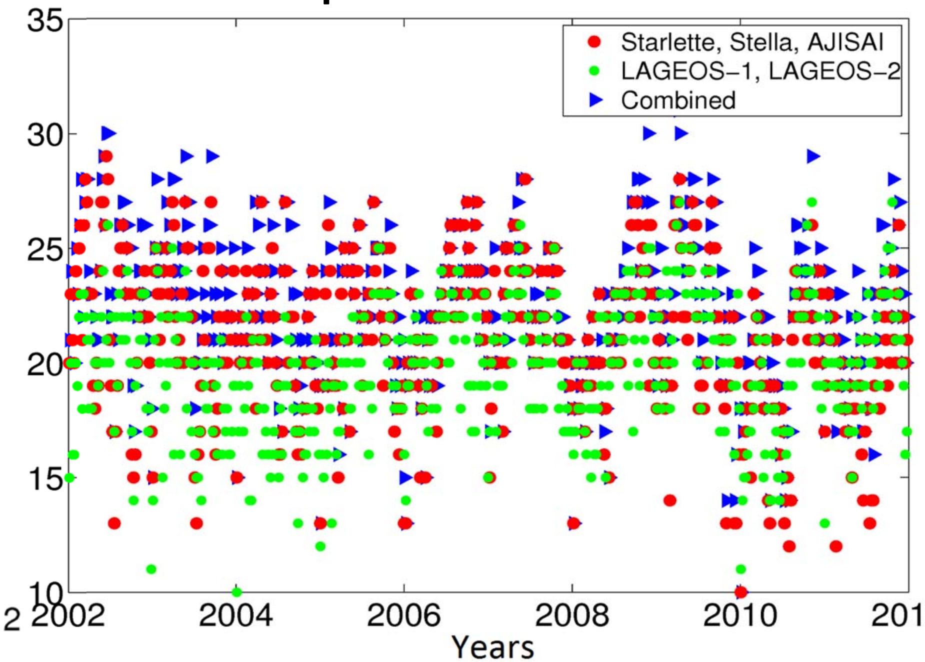


Motivation

Number of SLR observations of geodetic satellites per week



Number of SLR stations observing satellites per week



	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

SLR solutions in the Bernese GNSS Software

Parameter		LAGEOS	LEO
Station Coordinates		Weekly	Weekly
Earth Rotation Parameters		PWL daily	PWL daily
Geocenter Coordinates		Weekly	Weekly
Gravity field		Up to d/o 4	Up to d/o 4
Range Biases		**Selected stations**	**All stations**
Orbit	Osculating Elements	Weekly	Weekly
Orbit	Constant along-track S0	**Weekly**	-
Orbit	Air Drag Scaling Factor	-	**Daily**
Orbit	Once-per-rev SS, SC	**Weekly**	**Daily**
Orbit	Once-per-rev WS, WC	**Weekly** (when not estimating gravity field)	**Daily**
Orbit	Pseudo-Stochastic Pulses	-	**Once-per-rev in along-track**

Bernese GNSS Software, v.5.3

10 years of processed data (2002-2012)

Scale

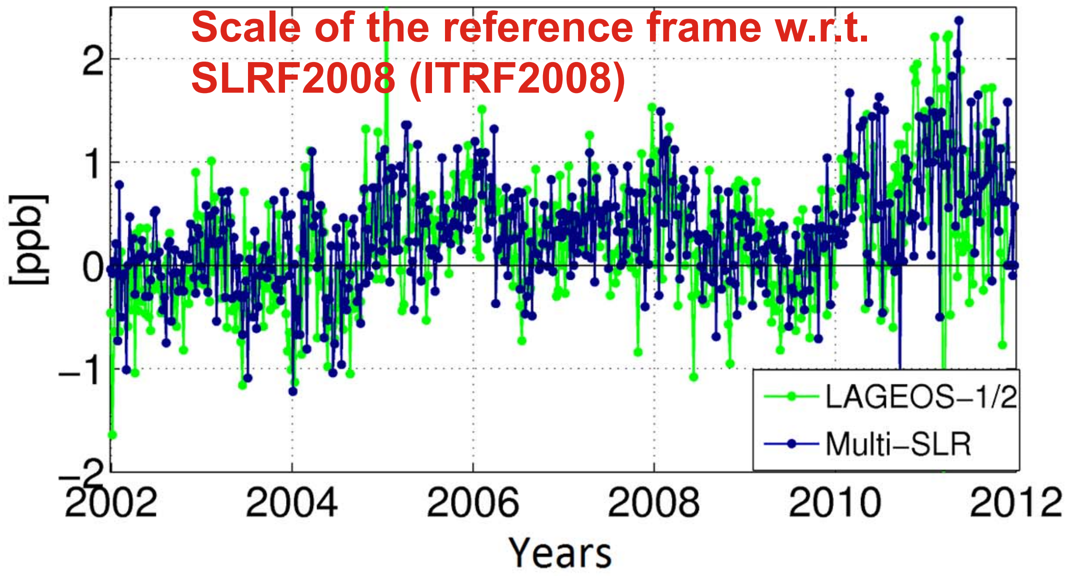
TRF scale estimated from the Helmert 7-parameter transformation of weekly SLR solutions

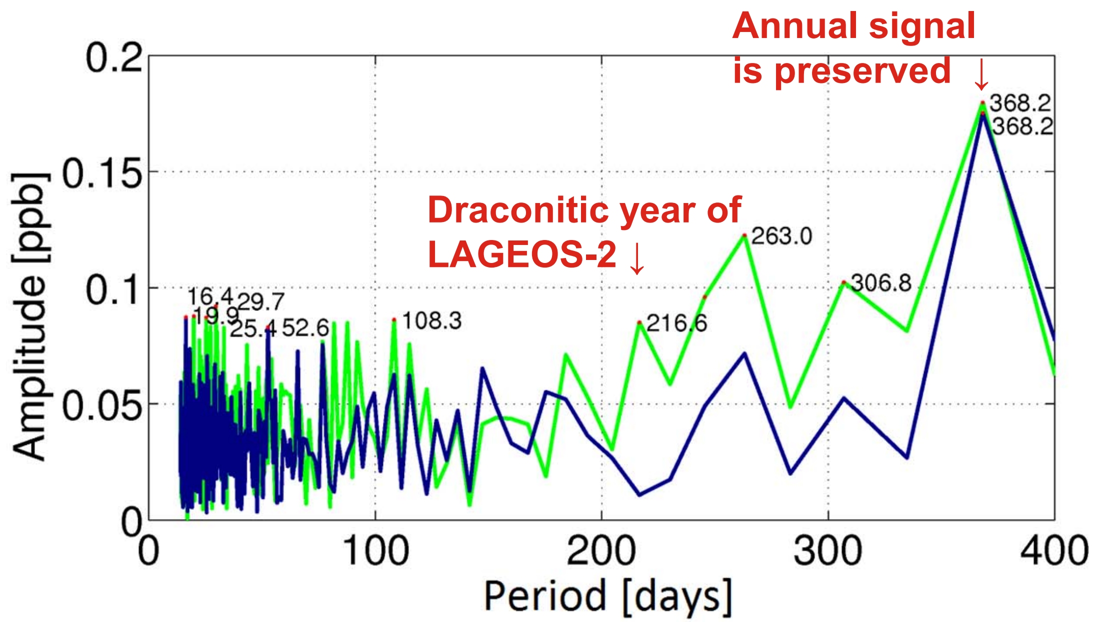
Orbit modeling deficiencies related to non-gravitational forces appear as the periods of the draconitic year.

Draconitic year is a time interval between two consecutive passes of the Sun through the orbital plane of a satellite (in the same direction).

Draconitic years of geodetic satellites:

- 222 days: LAGEOS-2,
- 560 days: LAGEOS-1,
- 89 days: AJISAI,
- 73 days: Starlette,
- 182 days: Stella.





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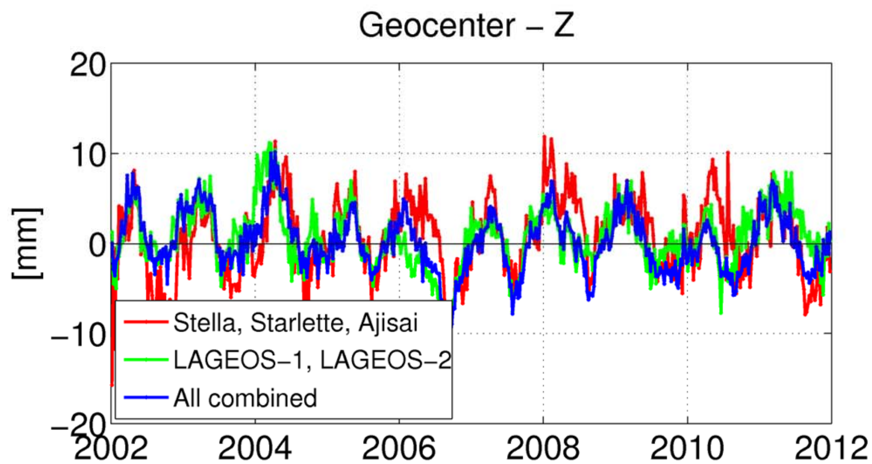
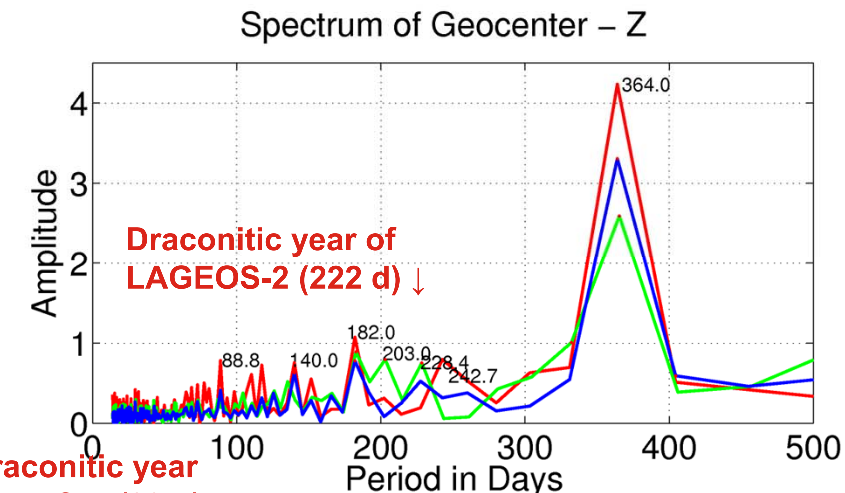
Geocenter coordinates





The origin of the reference frame (geocenter coordinates) are best defined by the SLR technique. The X and Y components can be also defined by other techniques, e.g., DORIS, GNSS, but the Z component is strongly affected by the deficiencies in the solar radiation pressure modeling, and thus, can only be established by the SLR solutions*.

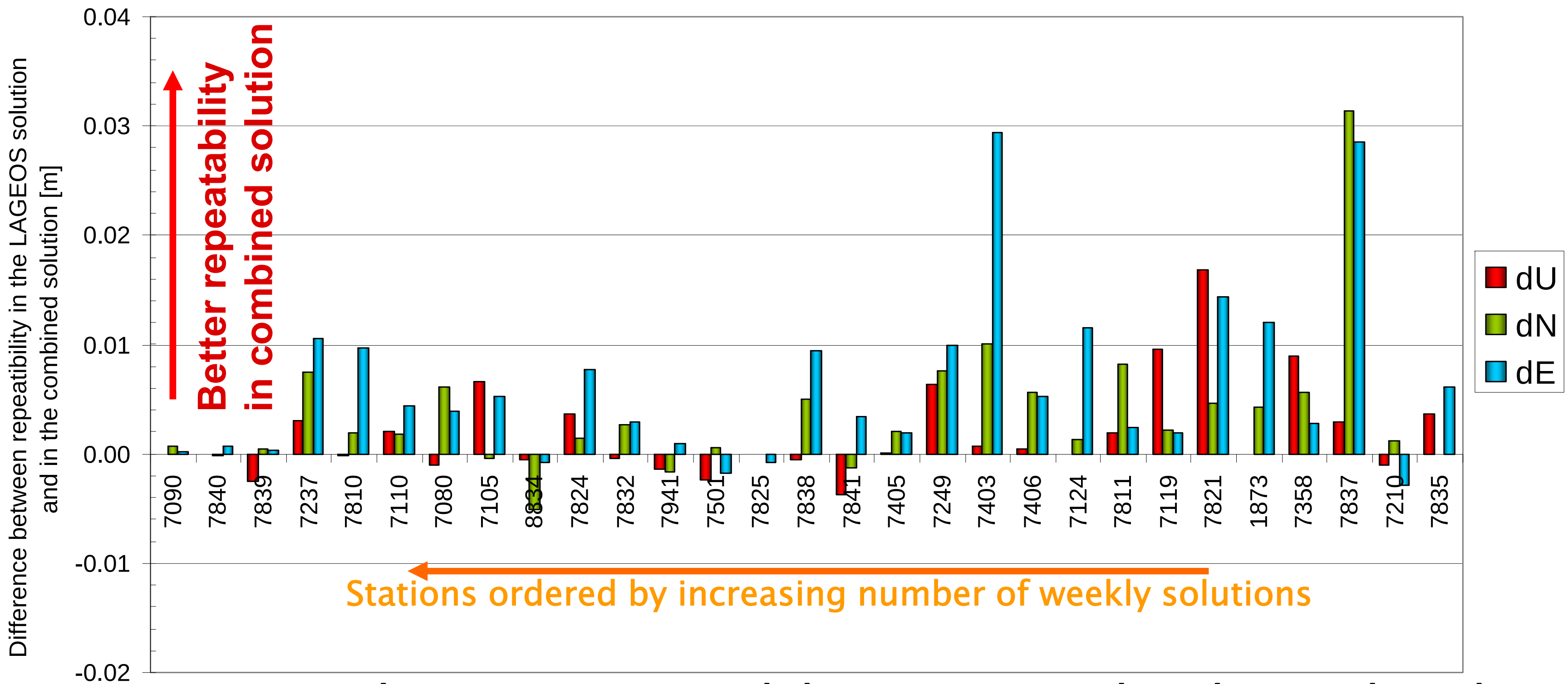
The LAGEOS–1/2 solutions or the Star+Ste+Aji solutions show very small orbit modeling deficiencies (draconitic year of LAGEOS–2 and Ajisai).

All amplitudes related to draconitic years are substantially reduced in the combined solutions.

* see Meindl et al. (2013) Geocenter coordinates estimated from GNSS data as viewed by perturbation theory. Advances in Space Research, Volume 51, Issue 7, p. 1047–1064

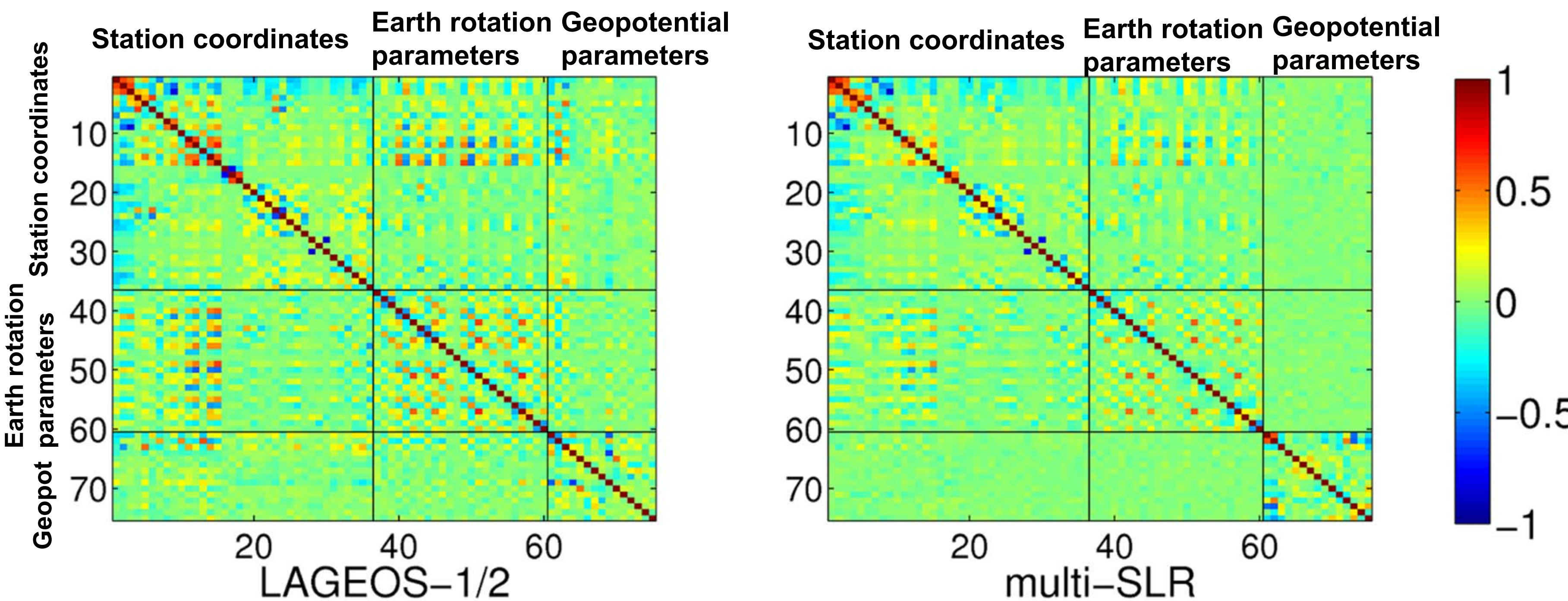
Weekly repeatabilities of station coordinates

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

Correlations

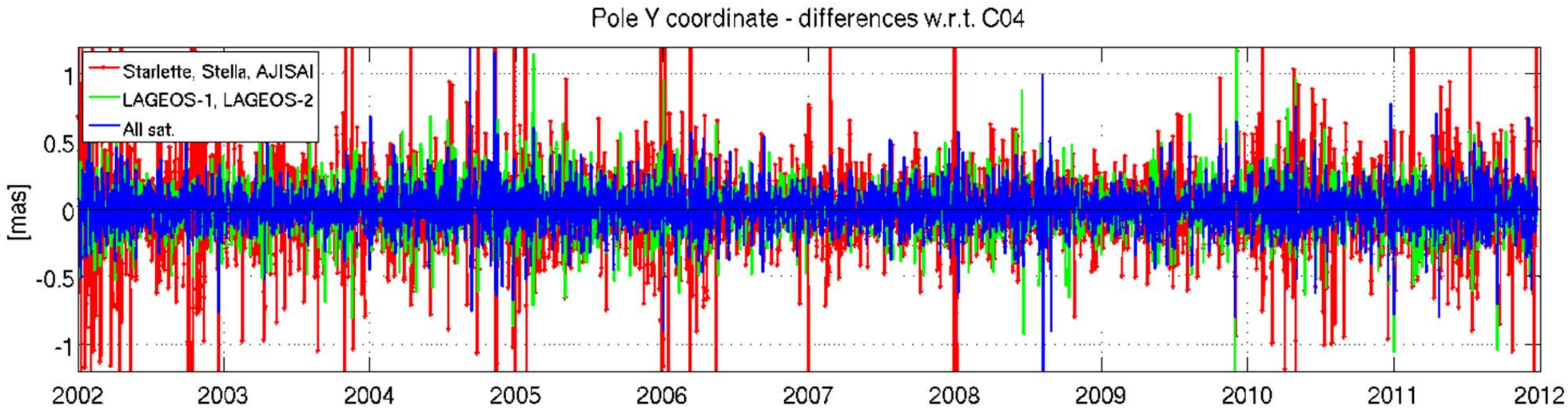


Correlation coefficients between selected parameters.

Estimated parameters (ERPs, geopotential, station coordinates) can be substantially decorrelated when using many SLR satellites, due to:

- better observation geometry,
- larger number of SLR observations,
- different orbital characteristics (altitudes, inclination angles, eccentricities).

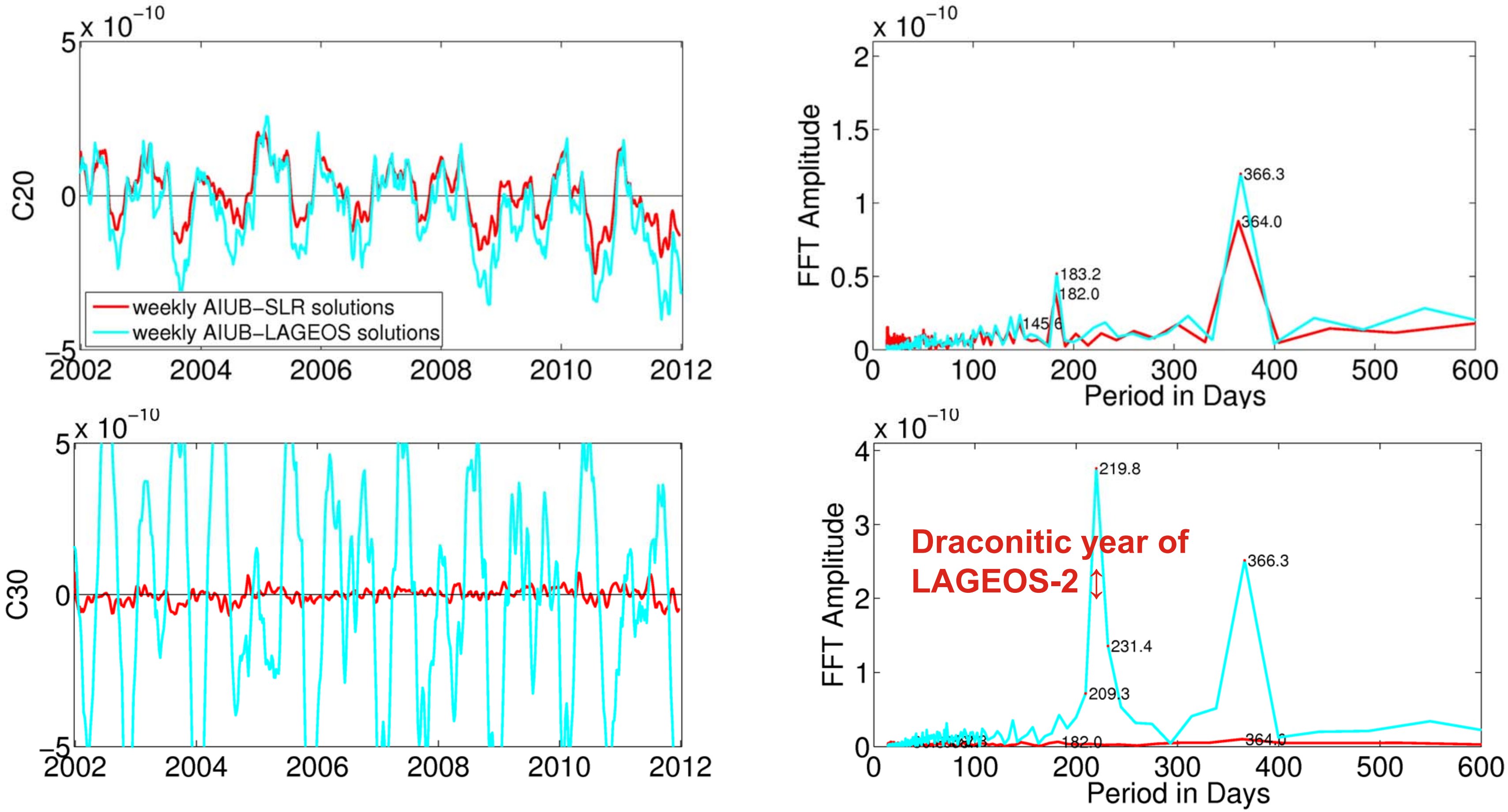
Earth Rotation Parameters (w.r.t. IERS-08-C04)



Solution type		X pole [μas] bias	X pole [μas] WRMS	Y pole [μas] bias	Y pole [μas] WRMS	LoD [μs] bias	LoD [μs] WRMS	Repeatability [mm] Up	Repeatability [mm] North	Repeatability [mm] East
LAGEOS-1/2	gravity up to 4/4	4.1	160.0	-8.0	155.2	6.1	57.0	11.1	10.2	12.3
LAGEOS-1/2	no gravity	45.8	168.5	-54.1	153.5	77.3	120.5	10.9	10.0	12.4
SLR-LEO	gravity up to 4/4	38.3	267.9	-7.8	217.6	-38.5	105.6	15.3	15.4	15.2
SLR-LEO	no gravity	190.1	437.5	-61.1	315.9	189.6	359.3	15.8	15.6	16.8
multi-SLR	gravity up to 4/4	6.4	148.9	8.5	140.3	6.3	56.3	11.3	11.2	11.7
multi-SLR	no gravity	83.7	153.1	63.3	156.7	75.8	121.7	11.1	11.3	11.8

Simultaneous estimation of all parameters
(gravity field+station coord+ERPs+orbits)
is beneficial for SLR solutions
(in particular for combined L1/L2/Sta/Ste/Aji solutions).

Gravity field parameters



C_{20} can be well-established from LAGEOS-1/2 solutions, but the amplitude of annual signal is by 20% larger than in the multi-SLR solutions.

C_{30} from LAGEOS-1/2 shows a clear alias period with draconitic year of LA-2.

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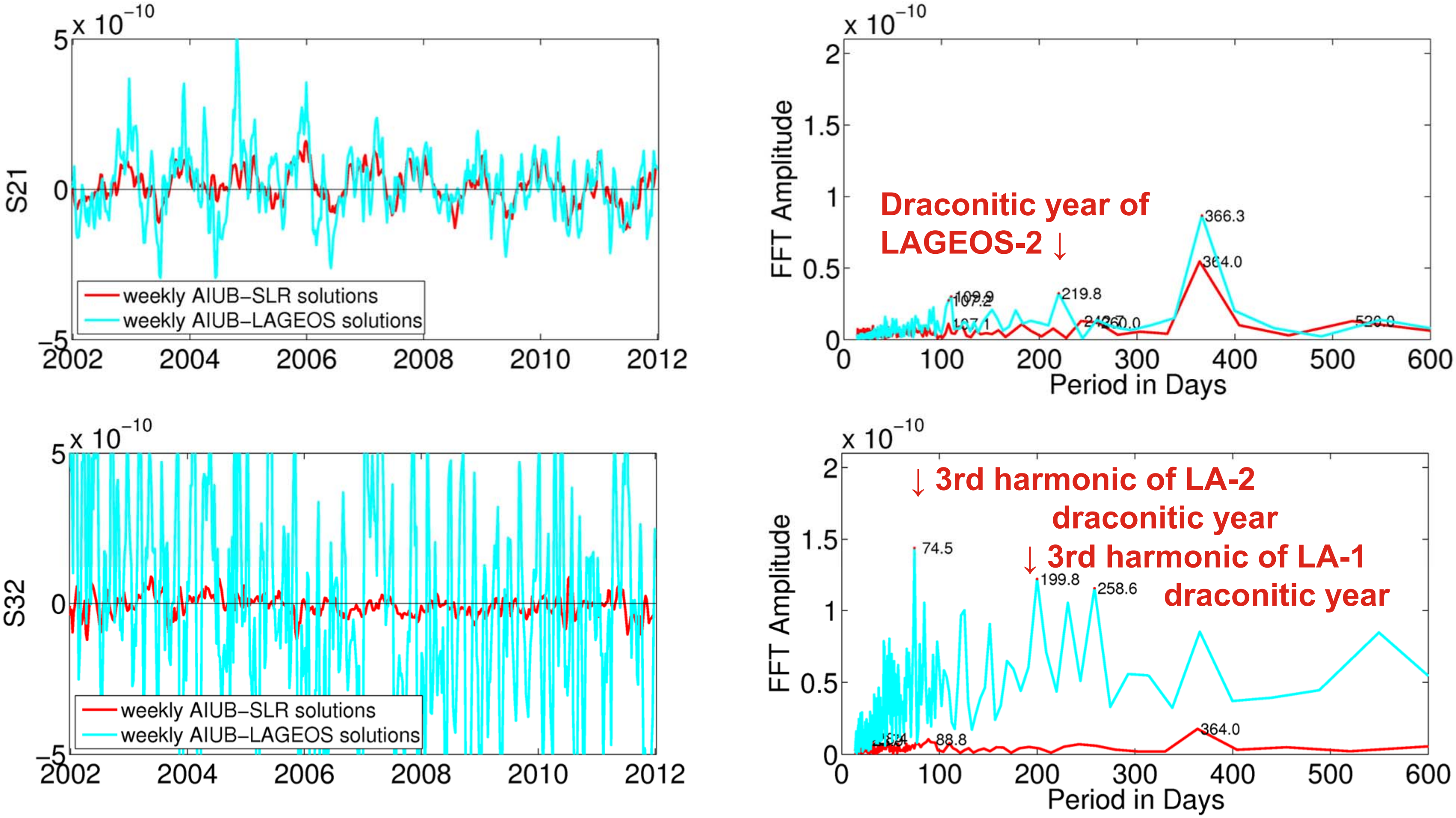
Gravity field parameters



Gravity field parameters (besides C20) can be much better established from the multi-SLR solutions (in particular for degree higher than 2). LAGEOS-1/2 solution reveals variations related to the draconitic years or their harmonics.

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Summary

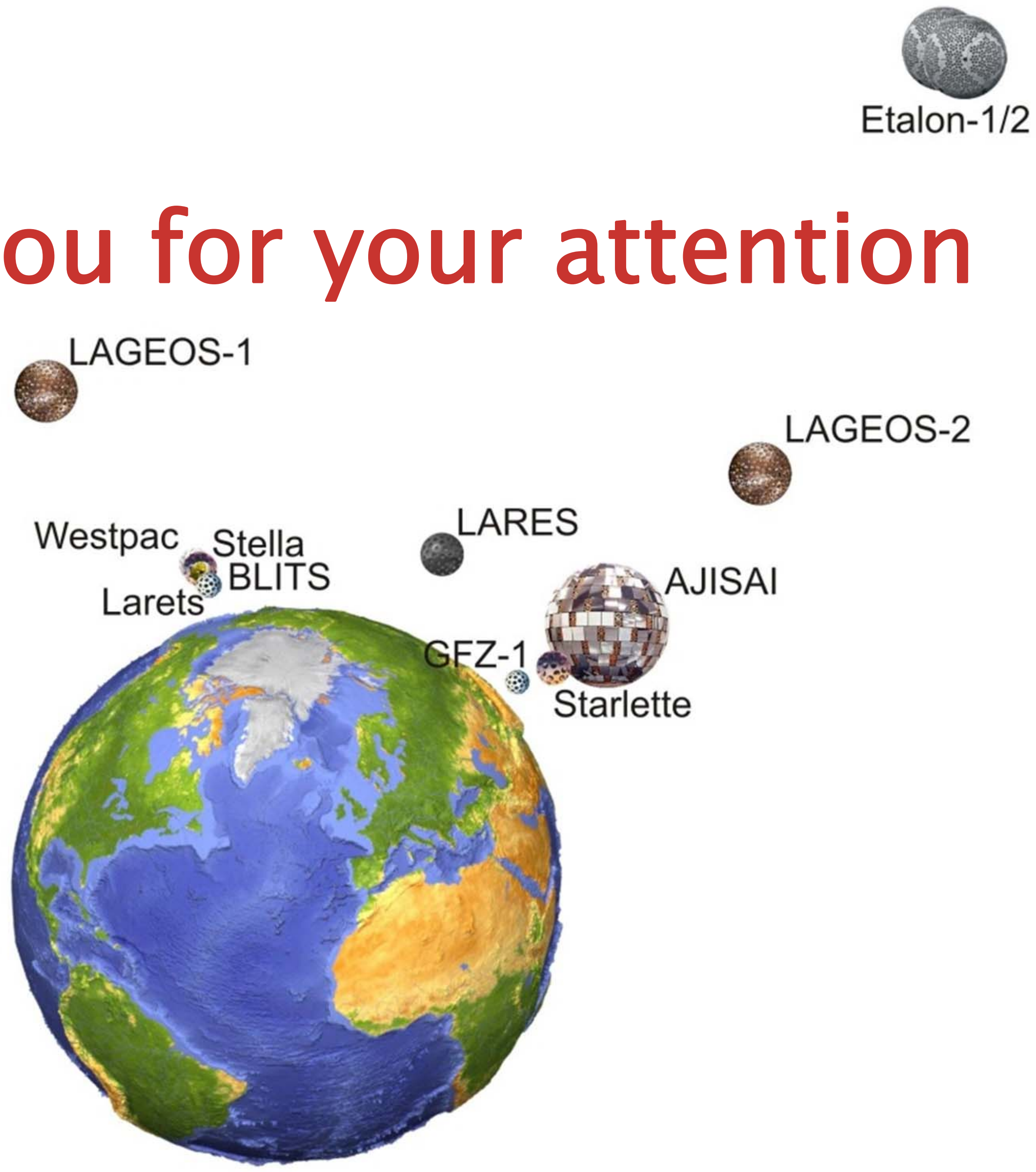
Advantages of the multi-SLR solutions :

- The estimated parameters can be substantially decorrelated.
- The observation geometry is improved.
- Orbit modeling deficiencies of non-gravitational forces (solar radiation pressure, albedo, Earth's infrared radiation, the Yarkovsky effect, the Yarkovsky-Schach effect, light aberration, etc.) can be reduced.
- As a result, the terrestrial reference frame parameters (scale, geocenter coordinates, ERPs) can be better established.
- The repeatability of some SLR station coordinates can be improved.

Disadvantages of the multi-SLR solutions:

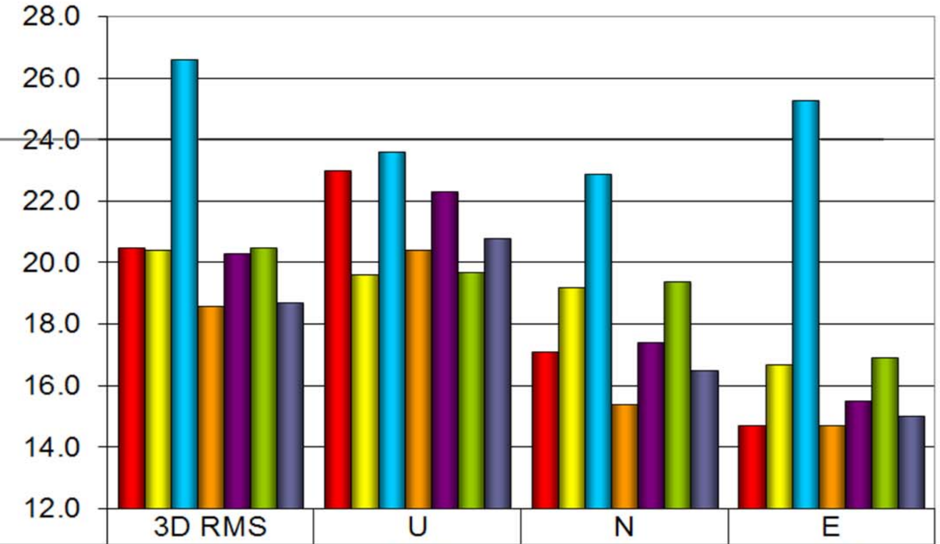
- The repeatability of some of best-performing SLR station coordinates is slightly worse w.r.t. the LAGEOS-1/2 solutions,
- High-quality solutions of low orbiting satellites require more user's attention (screening process and the orbit modeling optimization).

Thank you for your attention



Single-satellite solutions

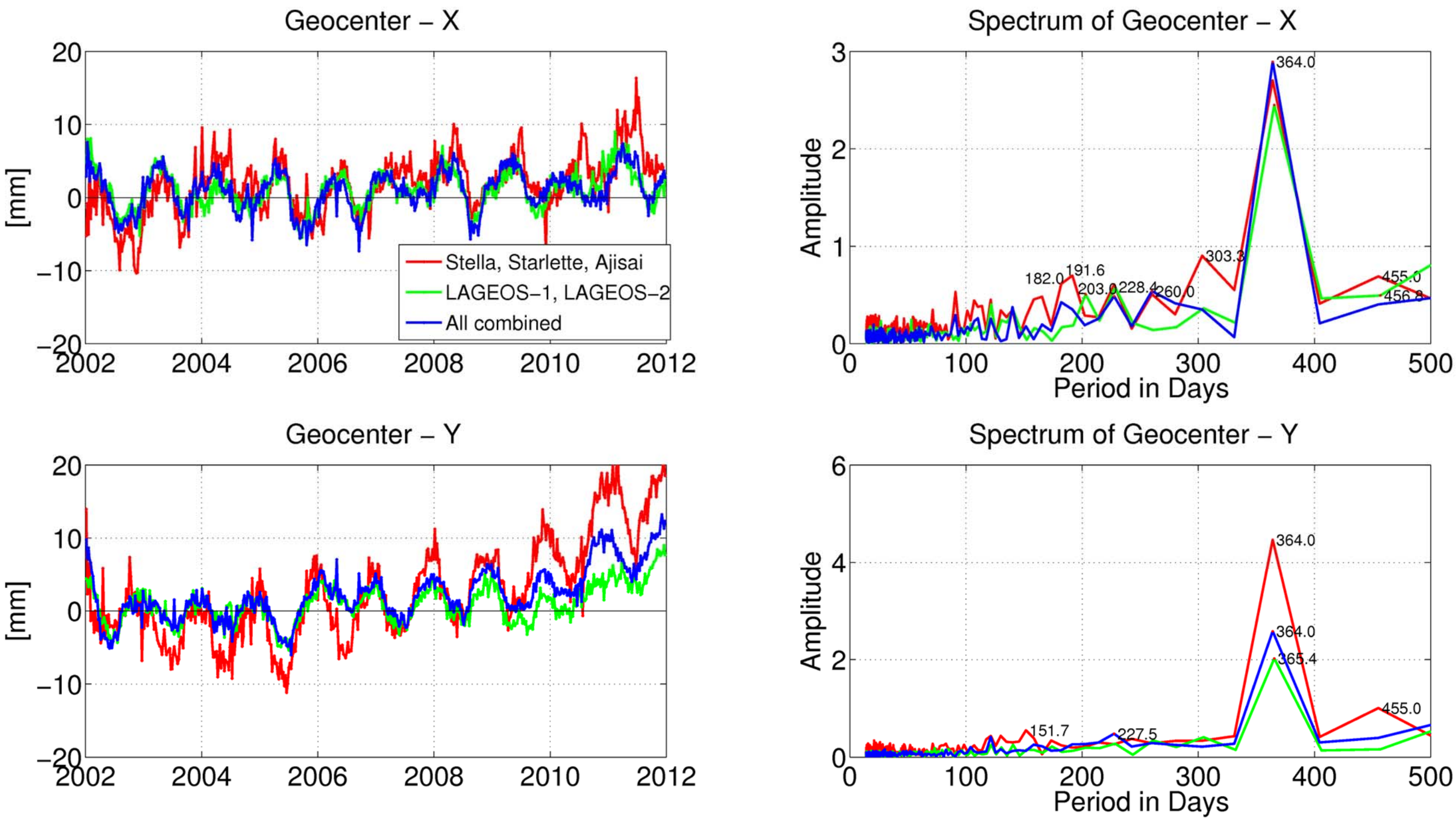
Stella leads to worse Coordinates, but LoD is improved



	3D RMS	U	N	E
AJISAI	20.5	23.0	17.1	14.7
Starlette	20.4	19.6	19.2	16.7
Stella	26.6	23.6	22.9	25.3
AJISAI+Starlette	18.6	20.4	15.4	14.7
AJISAI+Stella	20.3	22.3	17.4	15.5
Starlette+Stella	20.5	19.7	19.4	16.9
AJISAI+Starlette+Stella	18.7	20.8	16.5	15.0

	Aposteriori sigma of unit weight [mm]	Mean number of observation per week	X pole bias [µas]	X pole WRMS [µas]	Y pole bias [µas]	Y pole WRMS [µas]	LoD bias [µs]	LoD WRMS [µs]
AJISAI	6.31	3011	36.4	266.3	3.6	233.9	-17.3	108.5
Starlette	6.45	1697	21.8	339.5	-6.5	290.5	-18.0	133.0
Stella	6.03	813	120.0	901.6	-11.8	829.0	9.6	110.7
AJISAI+Starlette	6.85	4708	32.0	207.3	-3.0	184.4	-35.2	136.9
AJISAI+Stella	7.24	3824	71.8	304.4	-3.8	256.6	-1.0	93.1
Starlette+Stella	7.62	2510	75.2	365.2	-19.1	291.5	-3.7	99.4
All satellites	7.78	5521	57.7	269.8	-8.7	218.1	-3.6	106.5

Geocenter coordinates



The Y geocenter component from the multi-SLR solution shows large annual variations and a secular drift, whose origin remains unclear. Nevertheless, the combined solutions are slightly less noisy than the LAGEOS-1/2 solutions.

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