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

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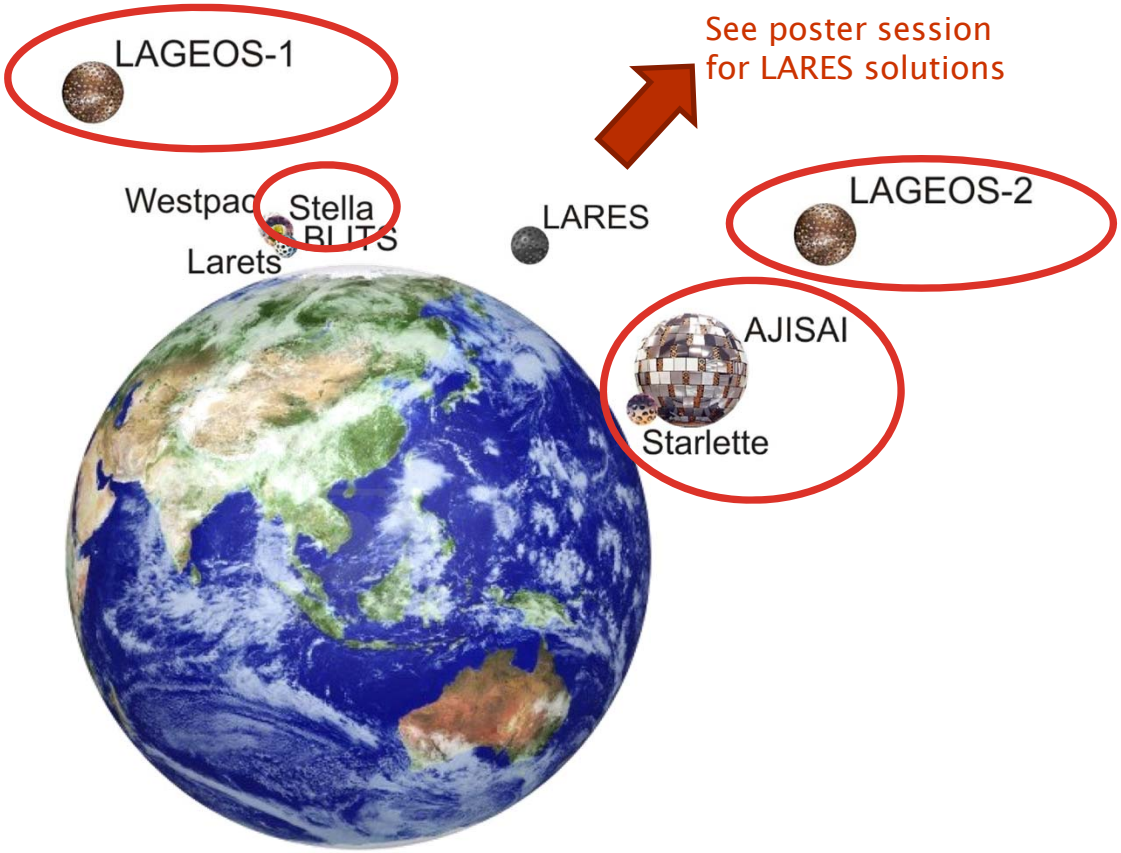
18th International Workshop on Laser Ranging

11-15 November 2013 Fujiyoshida, Japan

Motivation

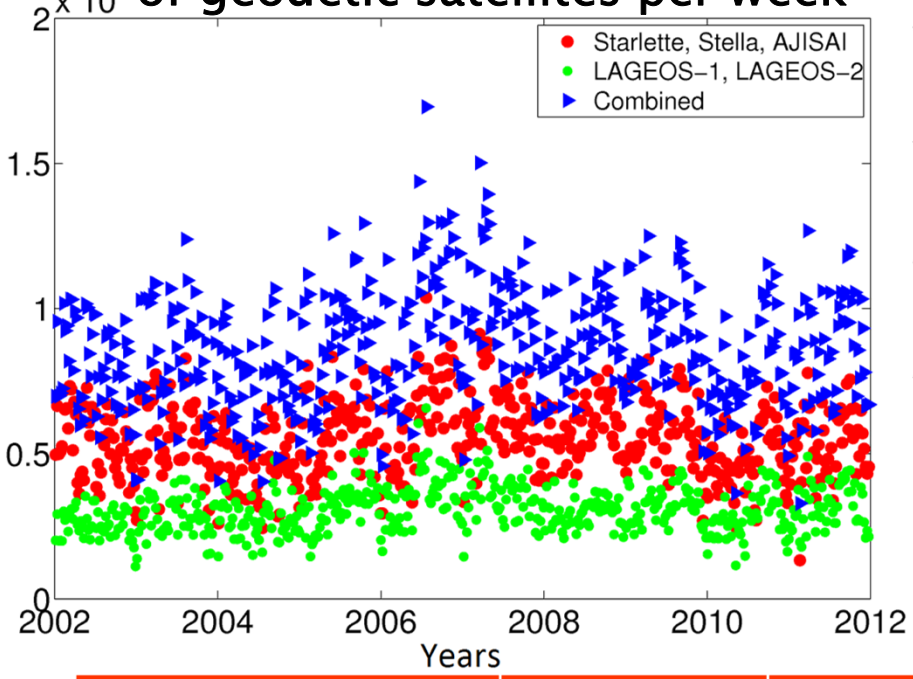
Current ILRS products:

- 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

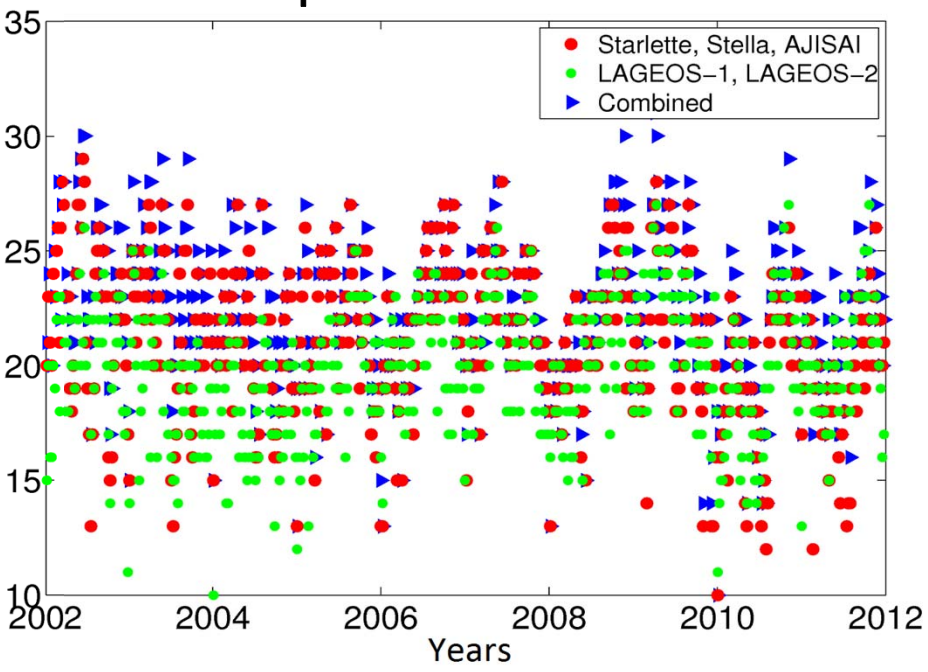


Motivation

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

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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
	Constant along-track S0	**Weekly**	-
	Air Drag Scaling Factor	-	**Daily**
	Once-per-rev SS, SC	**Weekly**	**Daily**
	Once-per-rev WS, WC	**Weekly** (when not estimating gravity field)	**Daily**
	Pseudo-Stochastic Pulses	-	**Once-per-rev in along-track**

Bernese GNSS Software, v.5.3

10 years of processed data (2002-2012)

Scale

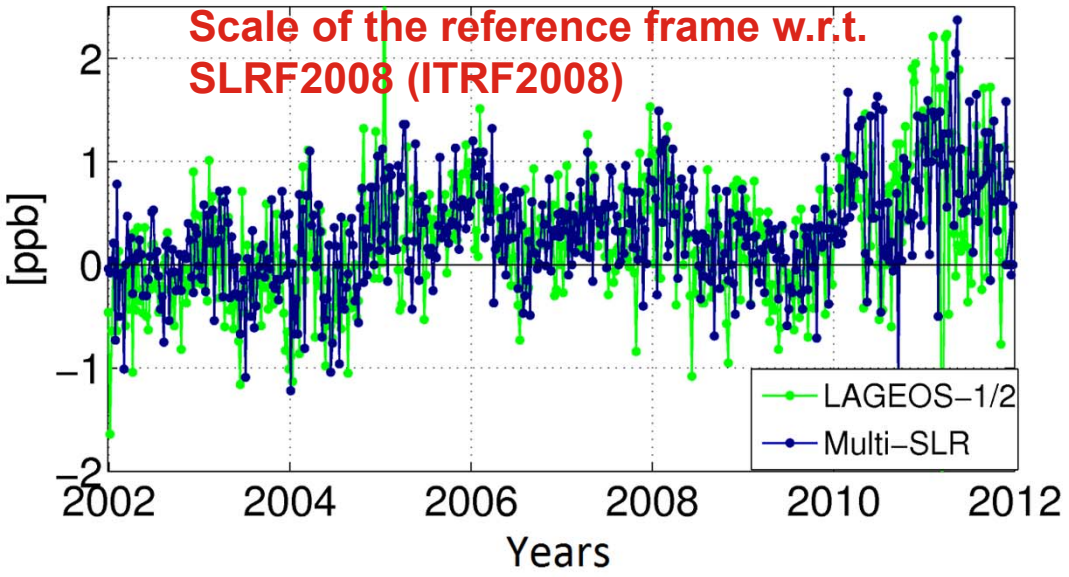
TRF scale estimated from the Helmert 7-parameter transformation of weekly SLR solutions

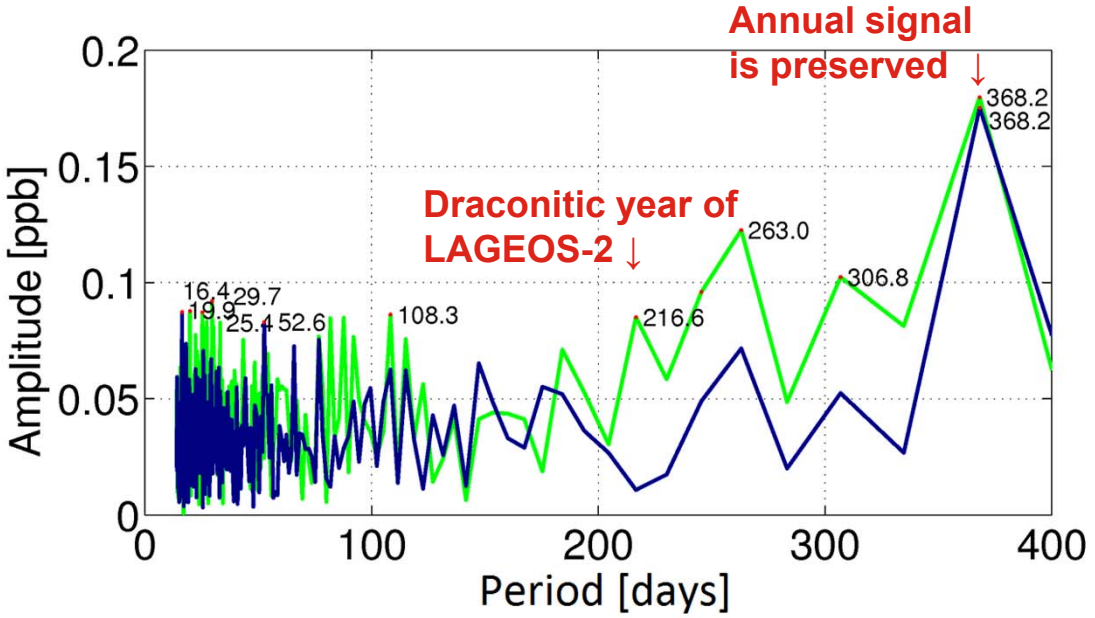
Orbit modeling deficiencies related to non-gravitational forces appear as the periods of the draconitic year.

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

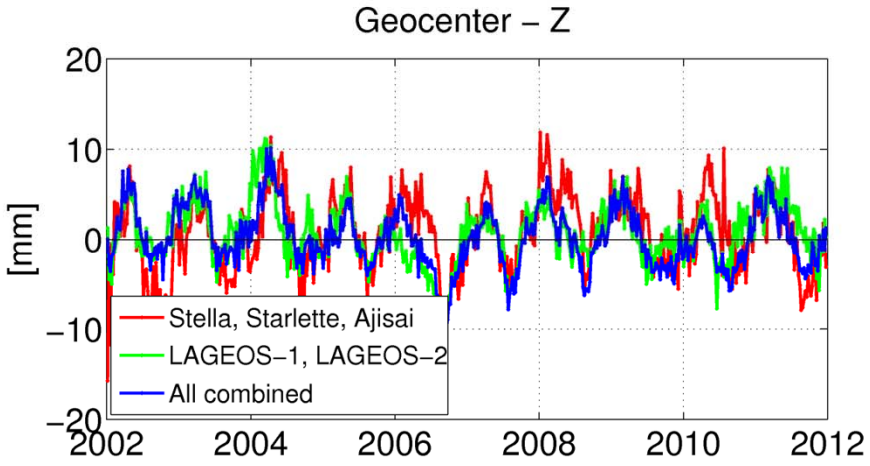
Draconitic years of geodetic satellites:

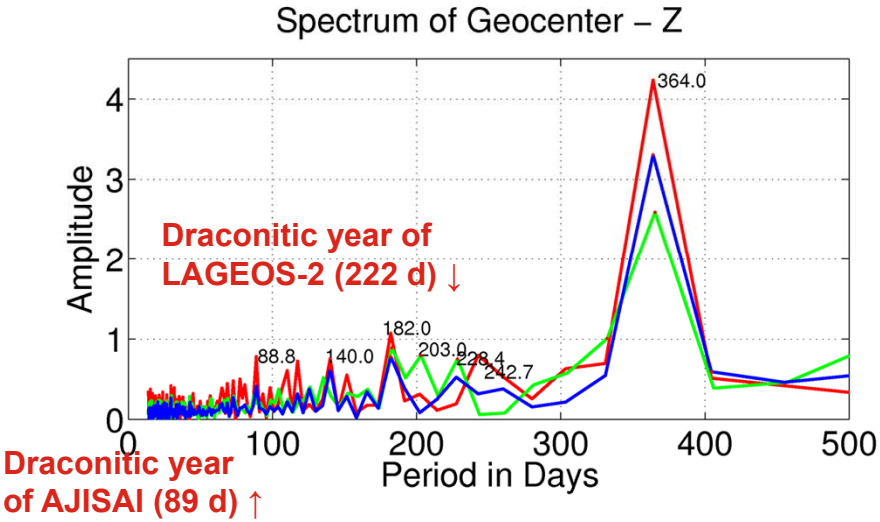
- 222 days: LAGEOS-2,
- 560 days: LAGEOS-1,
- 89 days: AJISAI,
- 73 days: Starlette,
- 182 days: Stella.





Geocenter coordinates





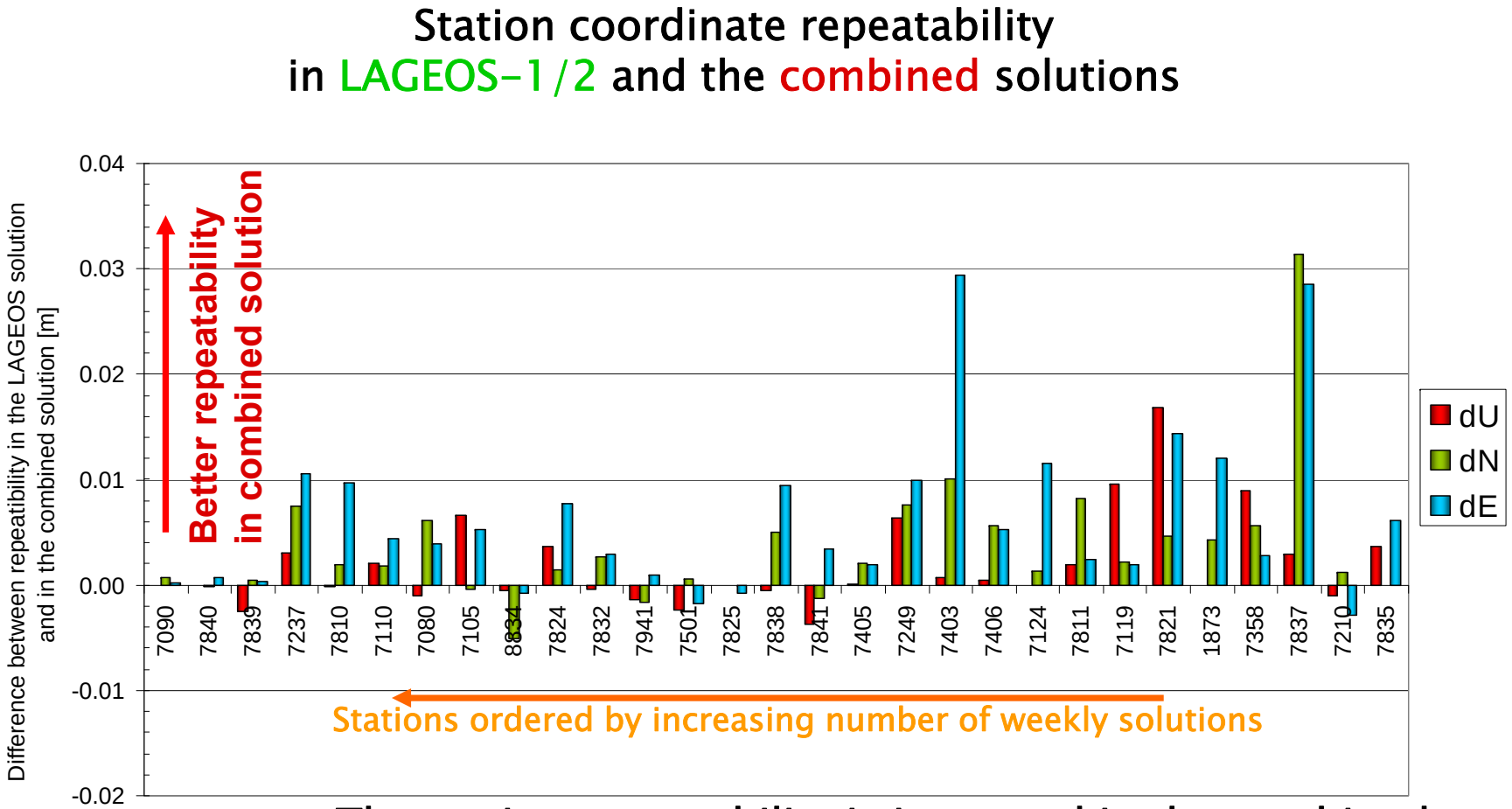
The origin of the reference frame (geocenter coordinates) are best defined by the SLR technique. The X and Y components can be also defined by other techniques, e.g., DORIS, GNSS, but the Z component is strongly affected by the deficiencies in the solar radiation pressure modeling, and thus, can only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

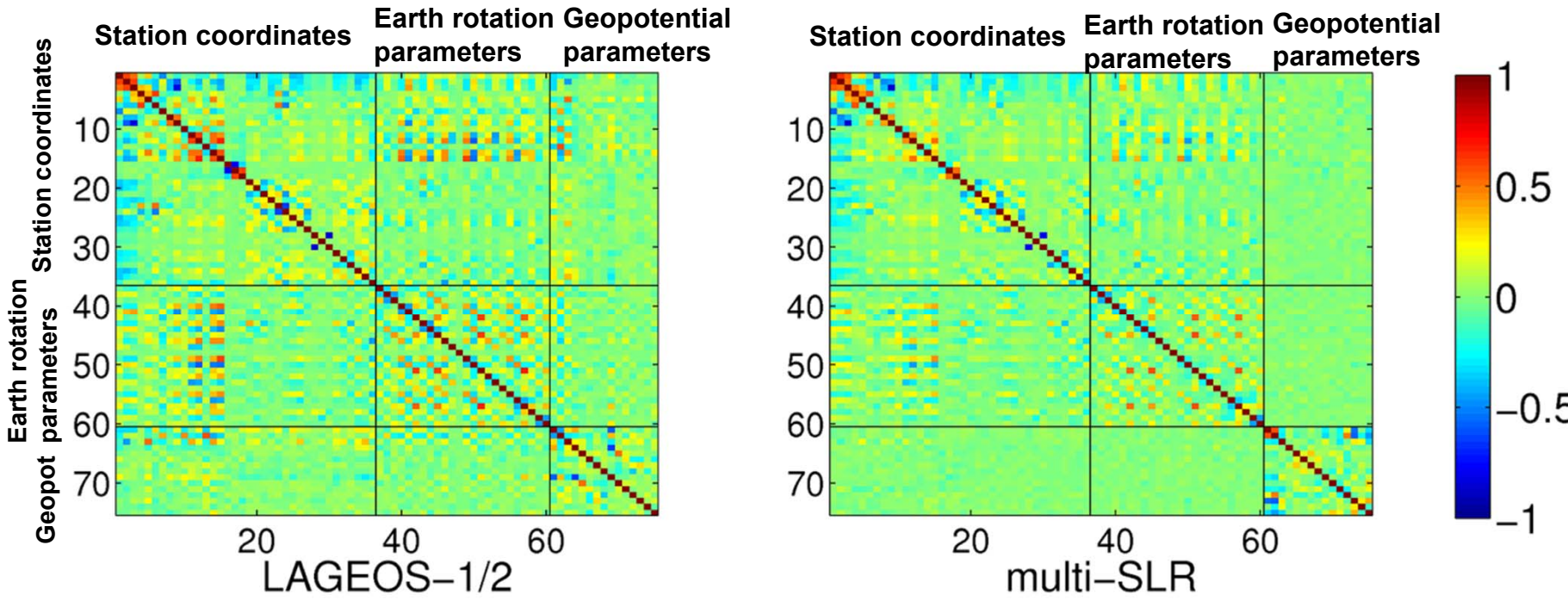
* see Meindl et al. (2013) Geocenter coordinates estimated from GNSS data as viewed by perturbation theory. Advances in Space Research, Volume 51, Issue 7, p. 1047-1064

Weekly repeatabilities of station coordinates



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

Correlations

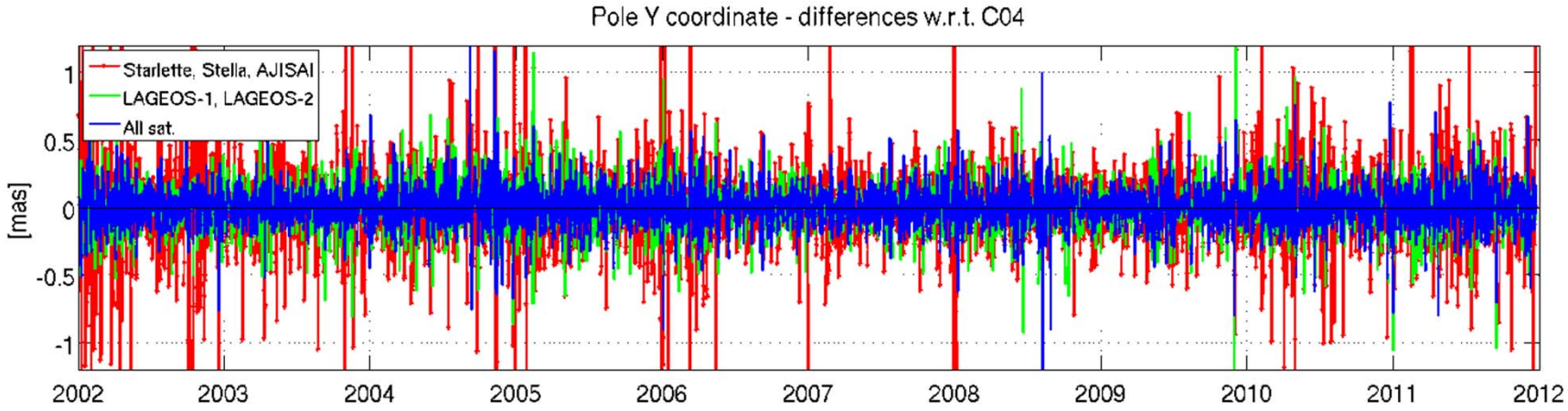


Correlation coefficients between selected parameters.

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).

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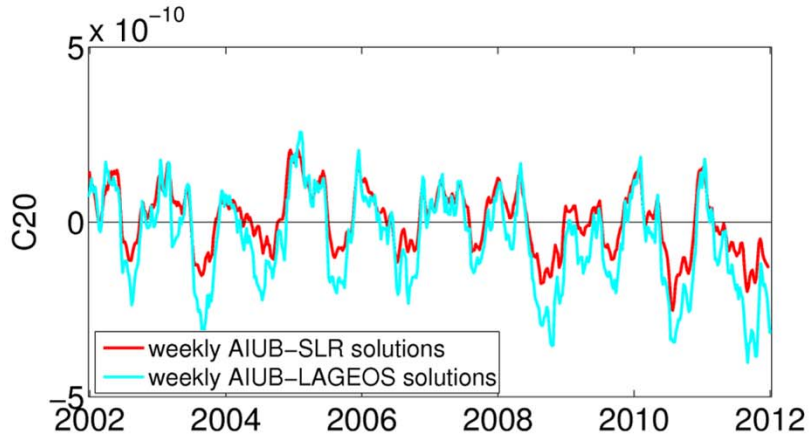
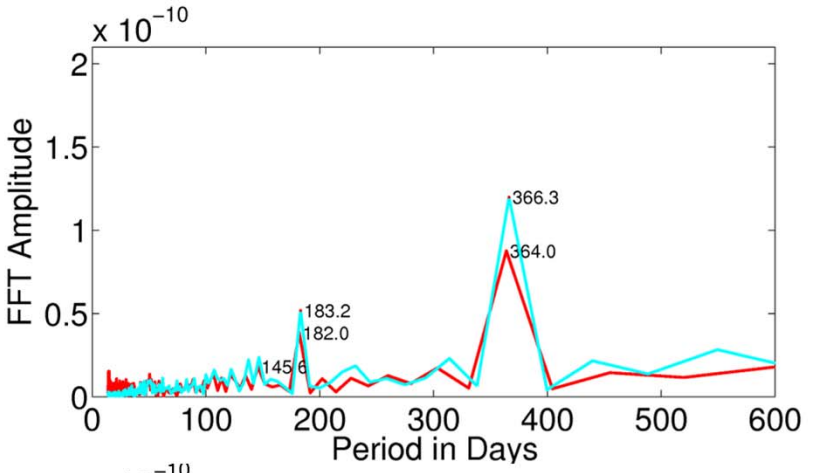
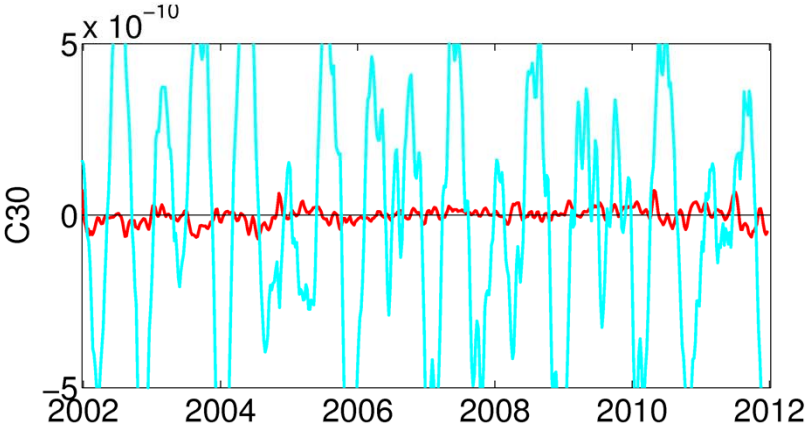
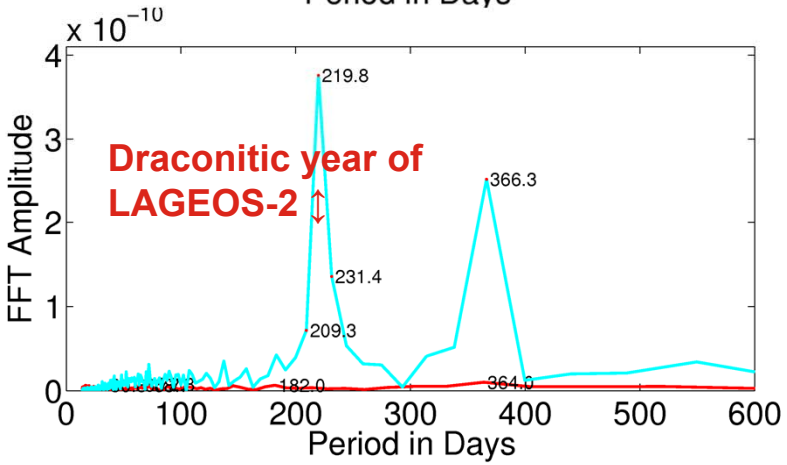
Gravity field parameters





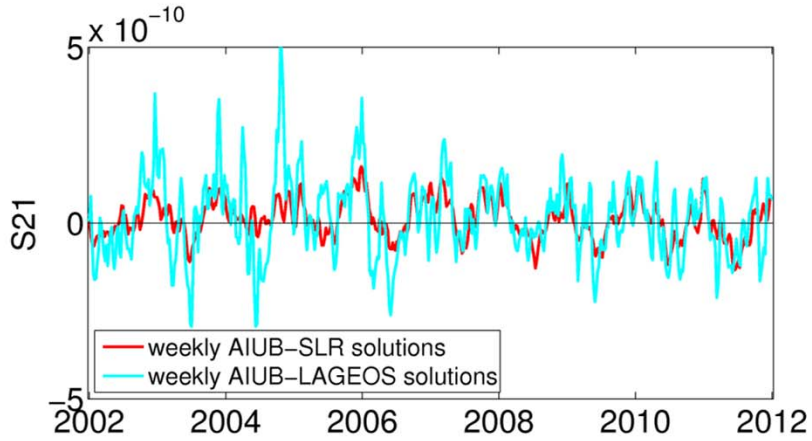


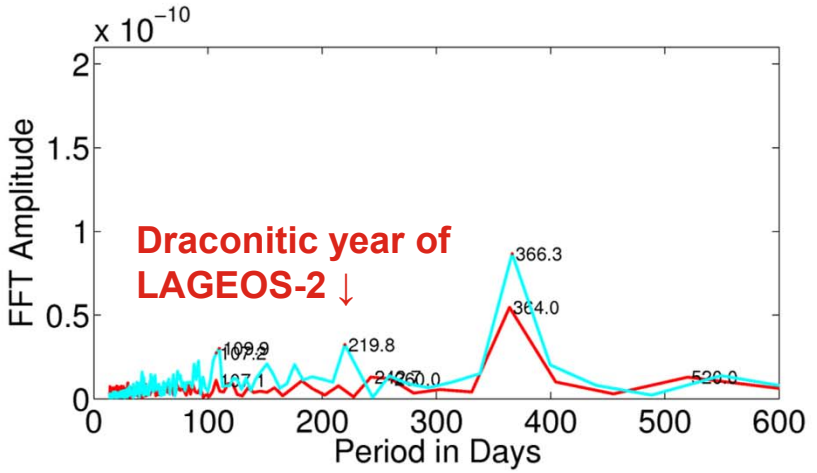


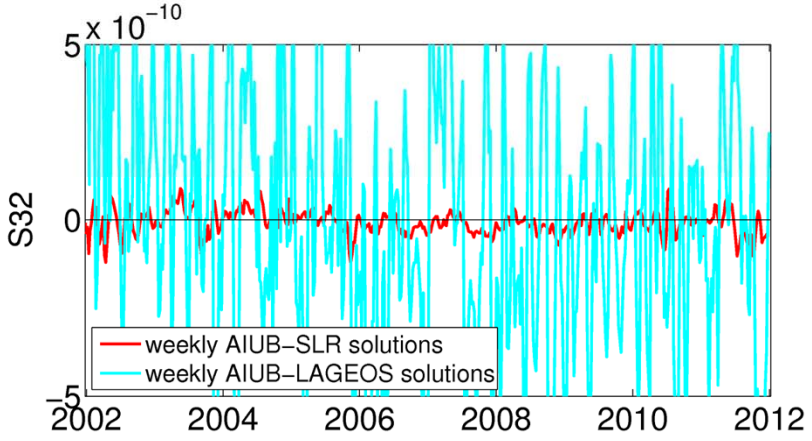
C_{20} can be well-established from LAGEOS-1/2 solutions, but the amplitude of annual signal is by 20% larger than in the multi-SLR solutions.

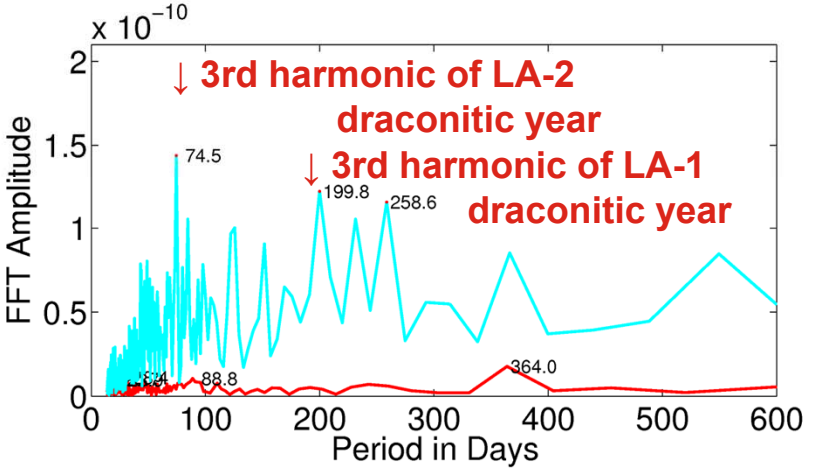
C_{30} from LAGEOS-1/2 shows a clear alias period with draconitic year of LA-2.

Gravity field parameters









Gravity field parameters (besides C_{20}) 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.

Summary

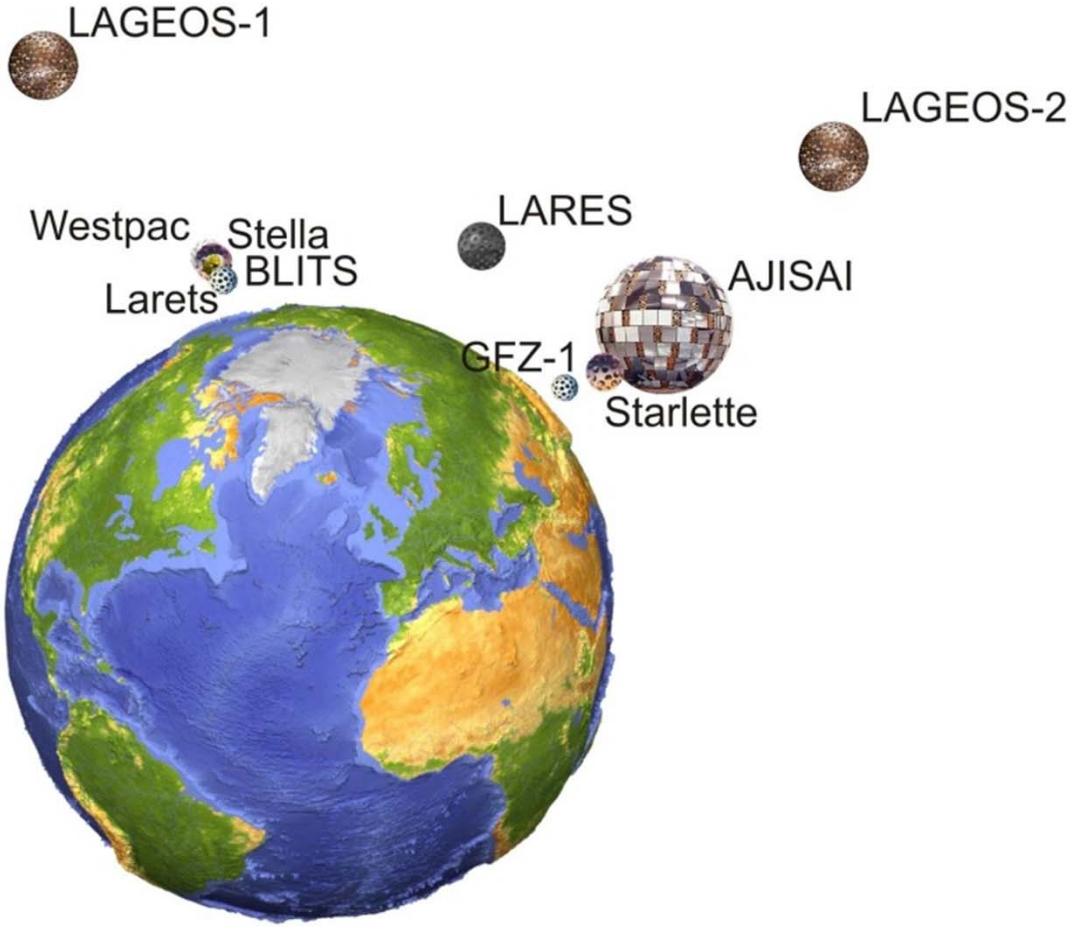
Advantages of the multi-SLR solutions :

- 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:

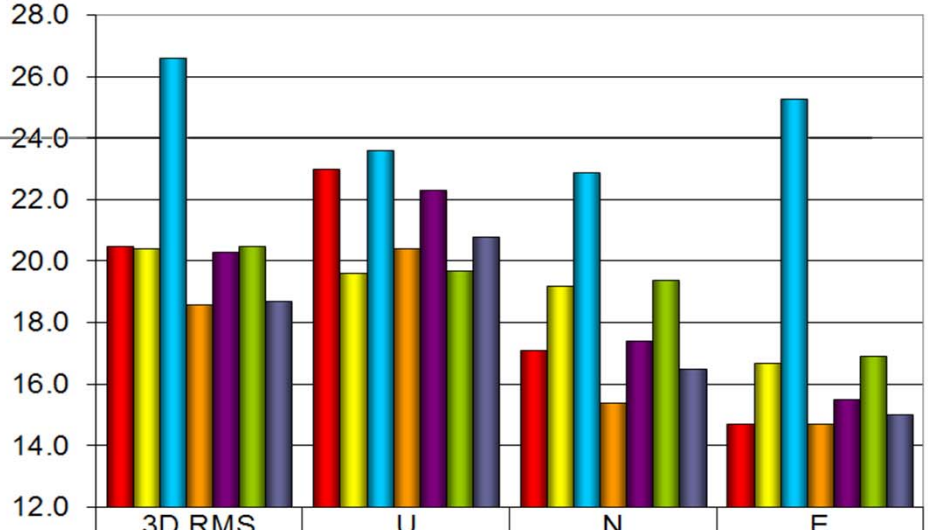
- The repeatability of some of best-performing SLR station coordinates is slightly worse w.r.t. the LAGEOS-1/2 solutions,
- High-quality solutions of low orbiting satellites require more user's attention (screening process and the orbit modeling optimization).

Thank you for your attention



Single-satellite solutions

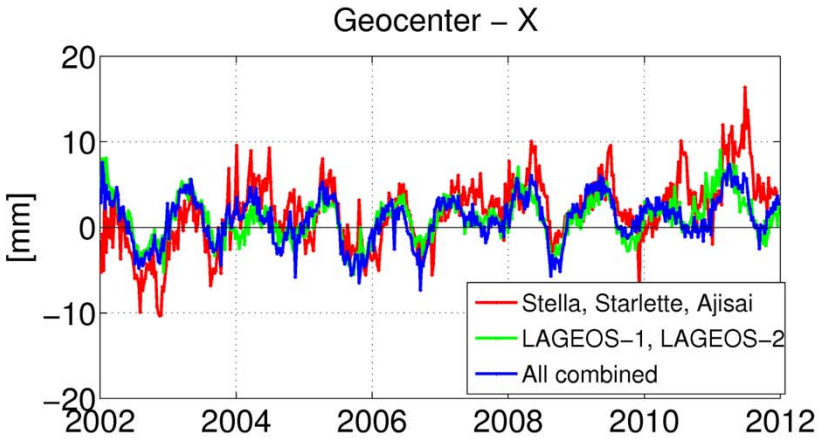
Stella leads to worse Coordinates, but LoD is improved

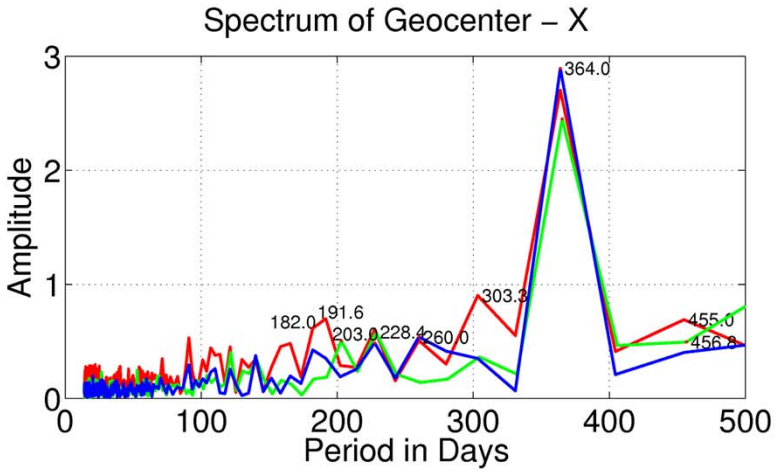


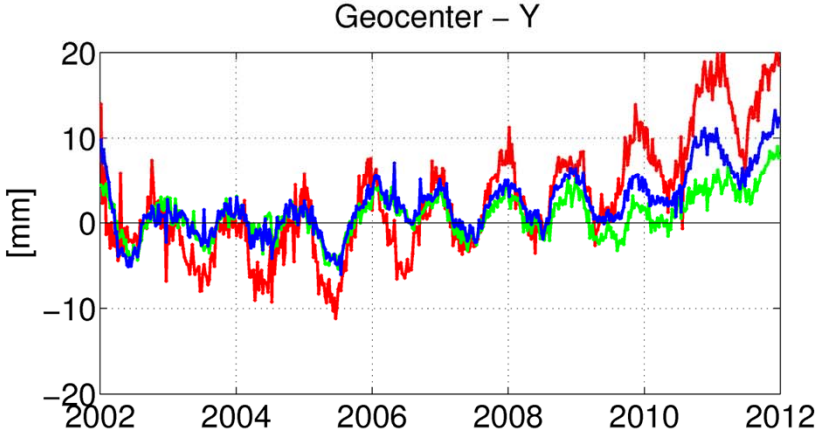
	3D RMS	U	N	E
AJISAI	20.5	23.0	17.1	14.7
Starlette	20.4	19.6	19.2	16.7
Stella	26.6	23.6	22.9	25.3
AJISAI+Starlette	18.6	20.4	15.4	14.7
AJISAI+Stella	20.3	22.3	17.4	15.5
Starlette+Stella	20.5	19.7	19.4	16.9
AJISAI+Starlette+Stella	18.7	20.8	16.5	15.0

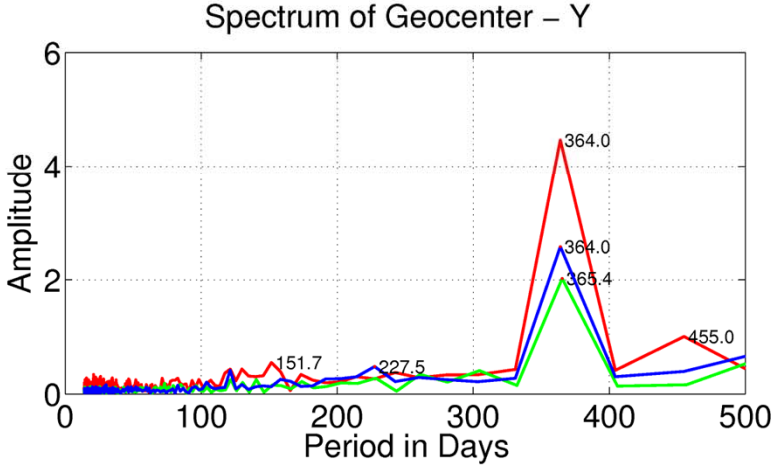
	Aposteriori sigma of unit weight [mm]	Mean number of observation per week	X pole bias [µas]	X pole WRMS [µas]	Y pole bias [µas]	Y pole WRMS [µas]	LoD bias [µs]	LoD WRMS [µs]
AJISAI	6.31	3011	36.4	266.3	3.6	233.9	-17.3	108.5
Starlette	6.45	1697	21.8	339.5	-6.5	290.5	-18.0	133.0
Stella	6.03	813	120.0	901.6	-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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