Estimation of geodetic parameters by combining SLR observations to LAGEOS, Starlette, Stella, and AJISAI

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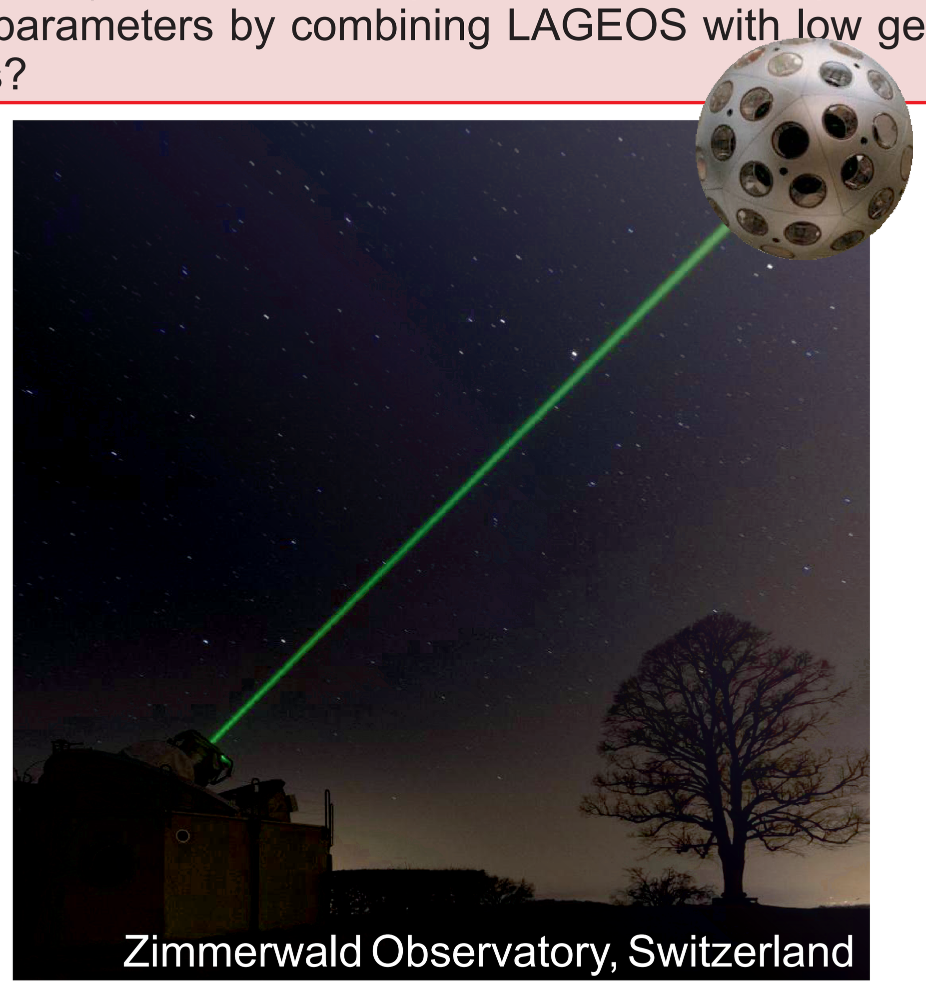
Introduction

Currently the definition of the SLR reference frame is based mainly on SLR observations to two LAGEOS satellites only, despite the availability of long time series of precise SLR observations to low geodetic satellites, i.e., Starlette, Stella, and AJISAI (LEO). It raises the question: Can we improve SLR-derived parameters by combining LAGEOS with low geodetic satellites?



	AJISAI	Starlette	Stella	LAGEOS-1	LAGEOS-2
Diameter [m]	2.15	0.24	0.24	0.60	0.60
Mass [kg]	685	47	48	407	405
Area-to-mass [m^2/kg]	58.0e-4	9.6e-4	9.4e-4	6.9e-4	7.0e-4
Radiation coeff. C_R	1.03	1.134	1.131	1.13	1.13
Semi-major axis [m]	7’866’500	7’334’700	7’176’100	12’274’000	12’158’000
Orbit altitude [m]	1’500’000	800'000 – 110’000	830’000	5’860’000	5’620’000
Eccentricity	0.0016	0.0205	0.0010	0.0039	0.0137
Inclination [deg]	50.04	49.84	98.57	109.90	52.67
Draconitic year [days]	89	73	57	560	222
A priori sigma of unit weight	25 mm	20 mm	20 mm	10 mm	10 mm

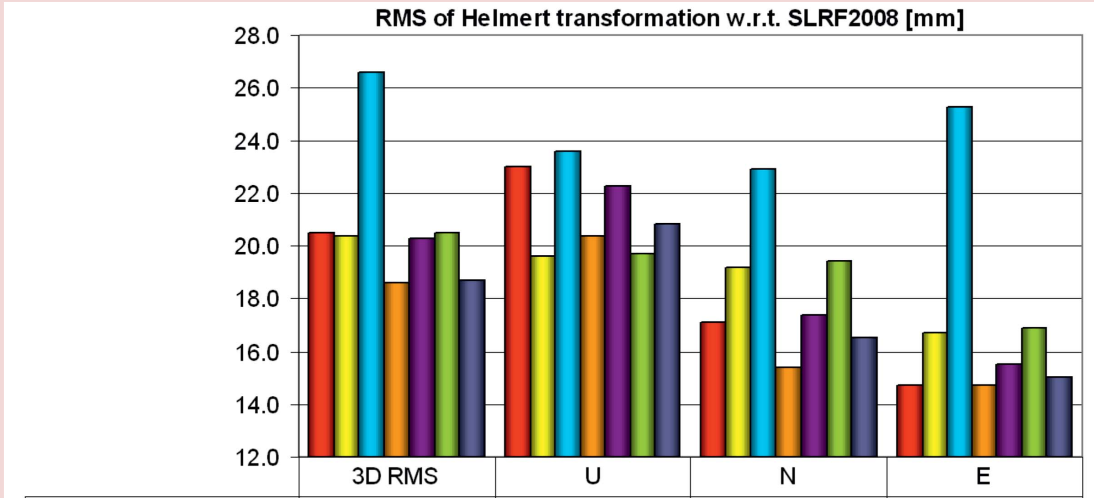
We processed 10 years of SLR observations to LAGEOS, Starlette, Stella, and AJISAI. We investigate the optimum orbit parameterization and the impact of low satellites on SLR-derived parameters. The SLR-derived Earth rotation parameters (pole coordinates and Length-of-Day LoD) are compared with GNSS results from the CODE reprocessing. Low spherical harmonics of the Earth's gravity field are compared with GRACE results from AIUB-monthly gravity field solutions.

In orbit modeling 'Test I' and 'Test II' we investigate the impact of different orbit parameterizations on:

- A posteriori sigma of unit weight,
- Differences of pole coordinates and LoD estimates w.r.t. the a priori IERS C04 series,
- Station coordinates (RMS of Helmert transformation w.r.t. SLR terrestial reference frame - SLRF2008).

For further analysis and comparisons with LAGEOS results we use the 7-day arcs (solution ‹A› in Test II) for Starlette, Stella, and AJISAI solutions. The IERS Conventions 2010 are applied, therefore the presented gravity field estimates refer to EGM2008. For low satellites we use NRLMSISE-00 air drag model and different weighting (see Table above).

Orbit modeling - Test I

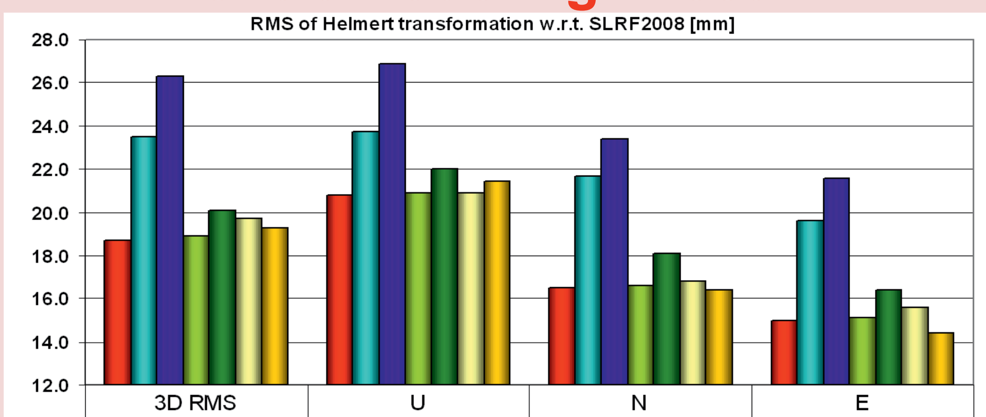


	3D RMS	U	N	E
AJISAI	20.5	23.0	17.1	14.7
Starlette	20.4	19.6	19.2	16.7
Stella	26.6	23.6	22.9	25.3
AJISAI+Starlette	18.6	20.4	15.4	14.7
AJISAI+Stella	20.3	22.3	17.4	15.5
Starlette+Stella	20.5	19.7	19.4	16.9
AJISAI+Starlette+Stella	18.7	20.8	16.5	15.0

	Aposteriori sigma of unit weight	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	0.631	3011	36.4	266.3	3.6	233.9	-17.3	108.5
Starlette	0.645	1697	21.8	339.5	-6.5	290.5	-18.0	133.0
Stella	0.603	813	120.0	901.6	-11.8	829.0	9.6	110.7
AJISAI+Starlette	0.685	4708	32.0	207.3	-3.0	184.4	-35.2	136.9
AJISAI+Stella	0.724	3824	71.8	304.4	-3.8	256.6	-1.0	93.1
Starlette+Stella	0.762	2510	75.2	365.2	-19.1	291.5	-3.7	99.4
All satellites	0.778	5521	57.7	269.8	-8.7	218.1	-3.6	106.5

In all combinations including Stella the station coordinates are of inferior quality due to Stella's orbit perturbations. Otherwise Stella decorrelates LoD and C_{20} estimates, because Stella's orbit has a different inclination than Starlette and AJISAI.

Orbit modeling - Test II

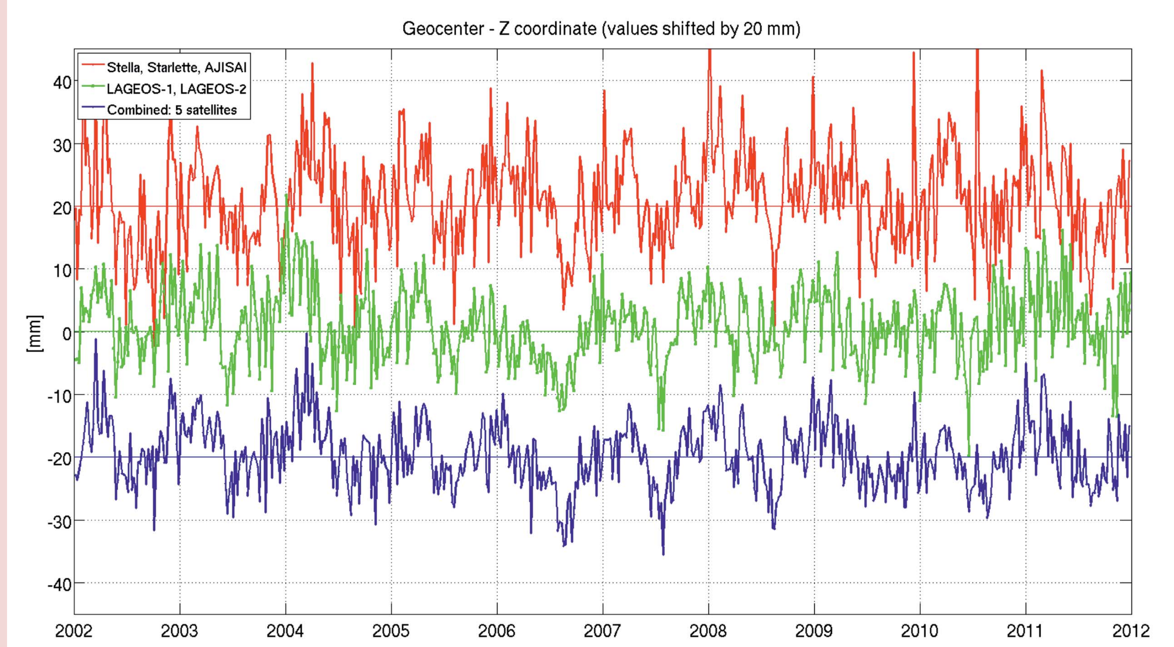


	3D RMS	U	N	E
A	18.7	20.8	16.5	15.0
B1	23.5	23.7	21.7	19.6
B2	26.3	26.9	23.4	21.6
C1	18.9	20.9	16.6	15.1
C2	20.1	22.0	18.1	16.4
D1	19.7	20.9	16.8	15.6
D2	19.3	21.4	16.4	14.4

Solution name	Length of solution [days]	Sets of osculating elements	Sets of dynamical parameters	Pseudo-stochastic pulses	Aposteriori sigma of unit weight	X pole bias [µas]	X pole WRMS [µas]	Y pole bias [µas]	Y pole WRMS [µas]	LoD bias [µs]	LoD WRMS [µs]
A	7	1	7	S	0.778	57.7	269.8	-8.7	218.1	-3.6	106.5
B1	7	1	1	S	1.350	38.6	508.7	-6.8	442.3	-15.0	102.2
B2	7	7	7	S	1.342	20.7	395.7	4.4	400.1	-2.2	120.0
C1	7	1	7	S,R,W	0.752	57.7	369.8	-8.7	218.1	-3.7	116.5
C2	7	1	7	-	0.781	85.5	350.2	0.1	275.7	-36.3	140.4
D1	5	1	5	S	0.714	35.8	258.0	-7.2	215.9	-34.5	111.4
D2	9	1	9	S	0.768	29.7	254.1	-3.2	213.1	-31.5	110.3

The most favorable solution is when estimating one set of osculating elements per arc, estimating dynamical orbit elements daily and stochastic pulses once-per-revolution in along-track (S). Stochastic pulses in other directions do not further improve the solution. The quality of the solution does not strongly depend on the length of the arc.

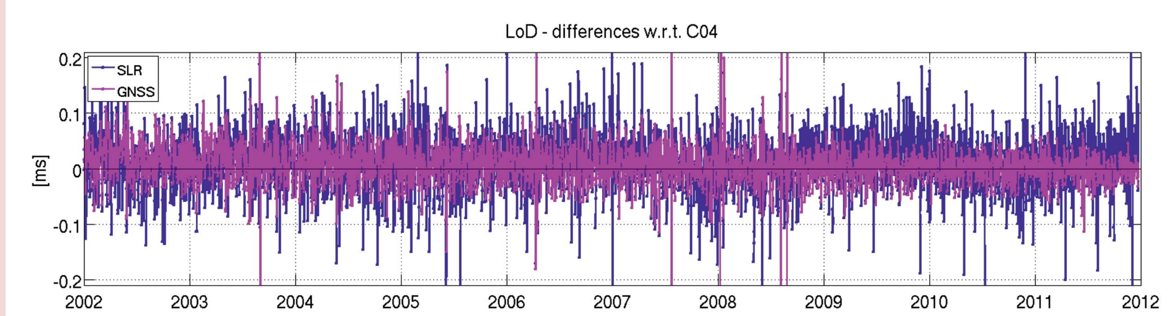
Geocenter coordinates

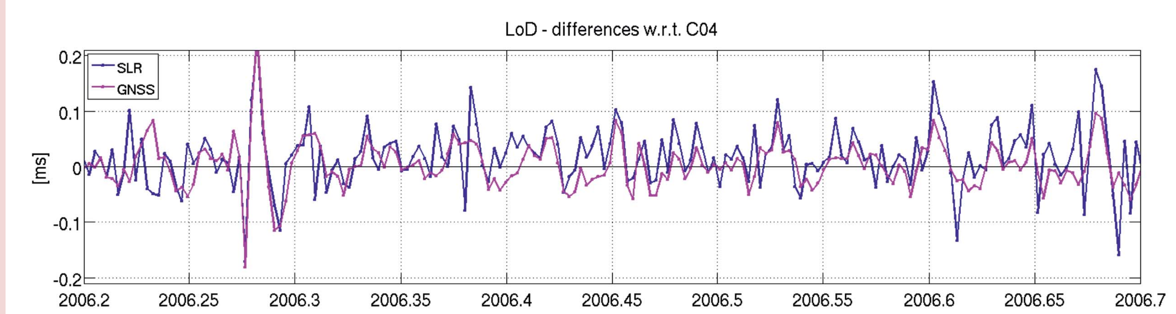


	X			Y			Z		
	LEO	LAGEOS	SLR combined	LEO	LAGEOS	SLR combined	LEO	LAGEOS	SLR combined
RMS [mm]	6.67	4.02	4.23	9.06	3.67	4.56	7.97	5.99	5.33
Amplitude of annual signl [mm]	2.97 ±0.20	2.99 ±0.18	3.40 ±0.17	5.28 ±0.22	2.49 ±0.16	2.94 ±0.16	4.68 ±0.30	3.64 ±0.27	4.13 ±0.25

In the combined SLR solution (2xLAGEOS+3xLEO) the amplitudes of annual signal of geocenter coordinates are increased for all geocenter components, because lower satellites are more sensitive to variations of geocenter. The RMS of the Z geocenter coordinate is smaller in a combined SLR solution by 11% w.r.t. LAGEOS-1/2 solution. The estimation of Z geocenter coordinate is crucial in SLR analyses, because reliable values of this parameter can be derived only from SLR observations of geodetic satellites, due to problems with the solar radiation pressure modeling.

Earth rotation parameters

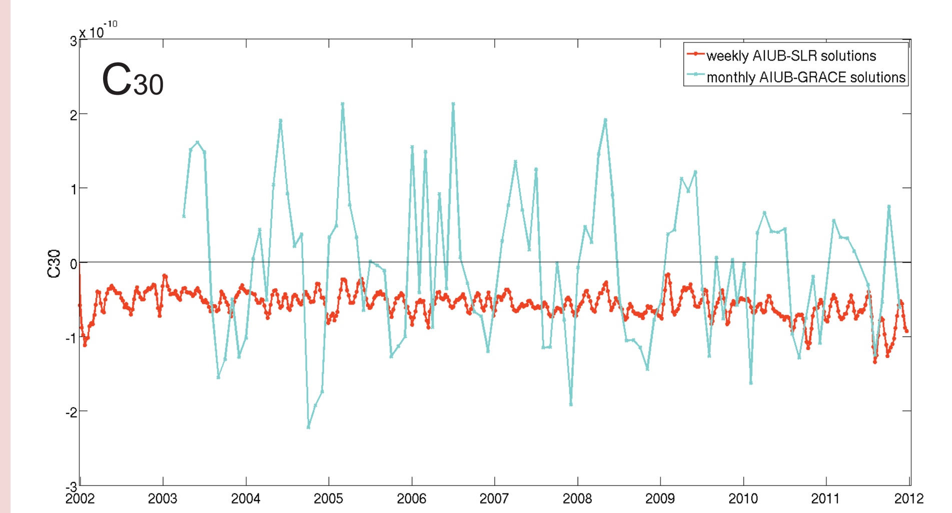


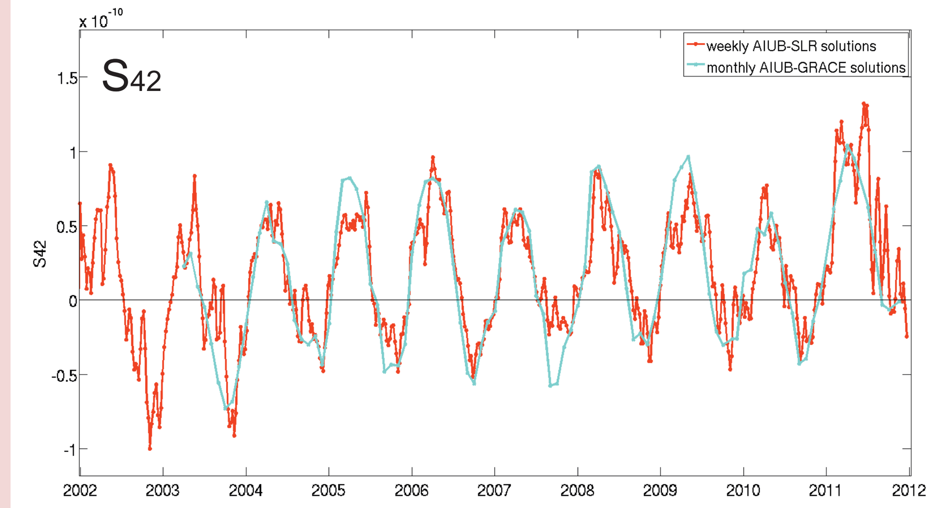


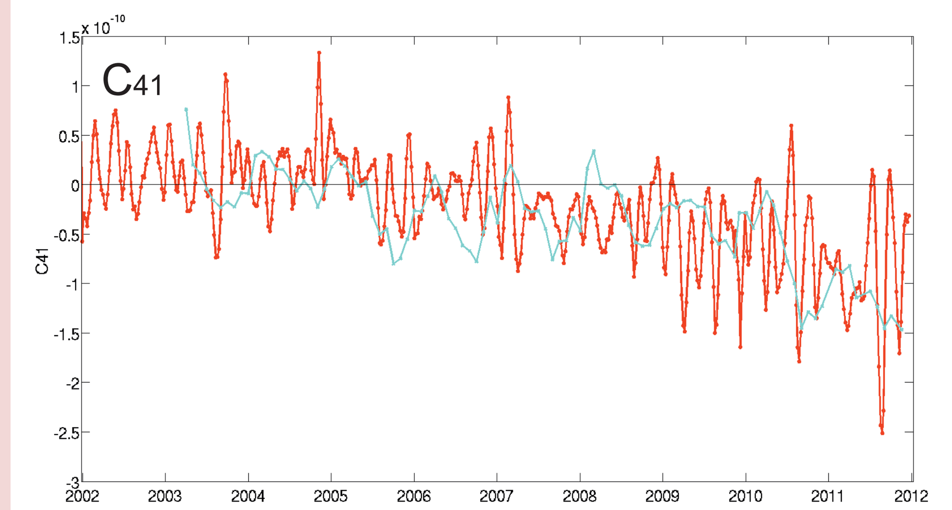
		Starlette, Stella, Ajisai	Lageos -1, -2	SLR combined solution	GNSS: GPS+GLONASS
Mean bias	X pole	57.7 µas	4.1 µas	6.4 µas	9.7 µas
	Y pole	-8.7 µas	-8.0 µas	-8.5 µas	29.0 µas
	LoD	-3.6 µs	6.1 µs	6.3 µs	4.8 µs
Weighted RMS	X pole	269.8 µas	160.0 µas	148.9 µas	45.3 µas
	Y pole	218.1 µas	155.2 µas	140.3 µas	41.6 µas
	LoD	106.5 µs	57.0 µs	55.1 µs	42.6 µs

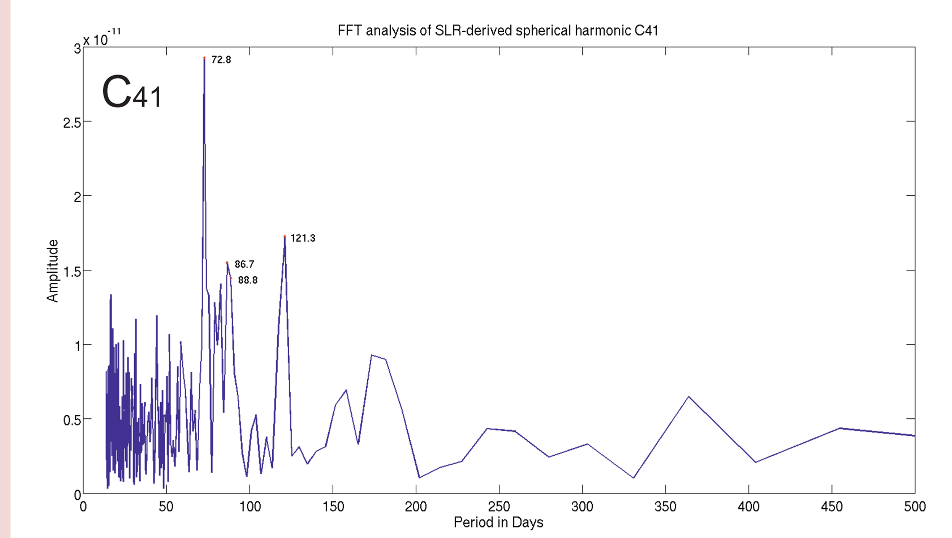
In the combined SLR solution the X pole and Y pole coordinates are improved by 7% and 10 %, respectively, w.r.t. LAGEOS-1/2 solutions in the comparison with IERS C04 series. The quality of SLR-derived LoD is only slightly worse than the GNSS solutions, even if the contribution of SLR to C04 is strongly downweighted.

Time variable Earth gravity field









SLR-derived time variable low gravity field coefficients are compared with GRACE-based results. Some of the coefficients are better determined in SLR analysis, e.g. C_{20} and C_{30}, whereas others agree very well in both solutions, e.g. S_{42}. There are, however, coefficients dominated by unmodeled forces acting on geodetic satellites, e.g. C_{41}. The spectral analysis of C_{41} clearly shows that the dominating periods are related to draconitic years of Starlette (73 days) and AJISAI (89 days).

Conclusions

The SLR-derived parameters can be improved when combining LAGEOS with Starlette, Stella, and AJISAI. The low geodetic satellites contribute to the determination of the Z geocenter coordinate (11% of improvement of RMS w.r.t. LAGEOS-only), pole coordinates (7-10% of improvement), and LoD. The SLR-derived LoD estimates are only slightly worse than those from GPS&GLONASS. Some of the low spherical harmonics of gravity field (C_{20}, C_{30}) are better determined in SLR solutions than in GRACE solutions, but the sparse SLR network and unmodeled thermal forces limit the quality of some other harmonics.

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