Earth gravity field recovery using GPS, GLONASS, and SLR satellites

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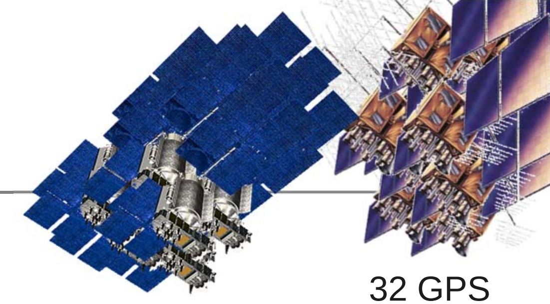
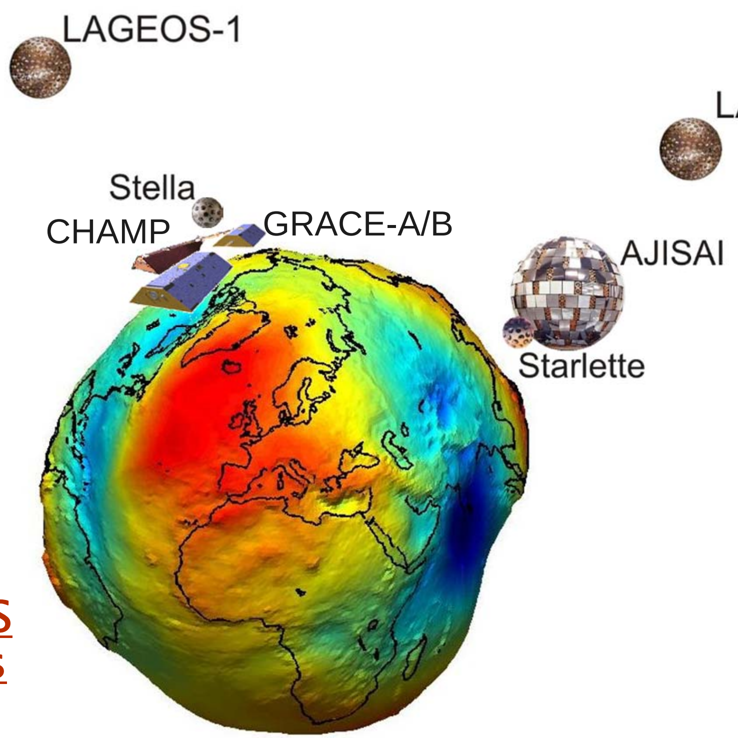
Motivation

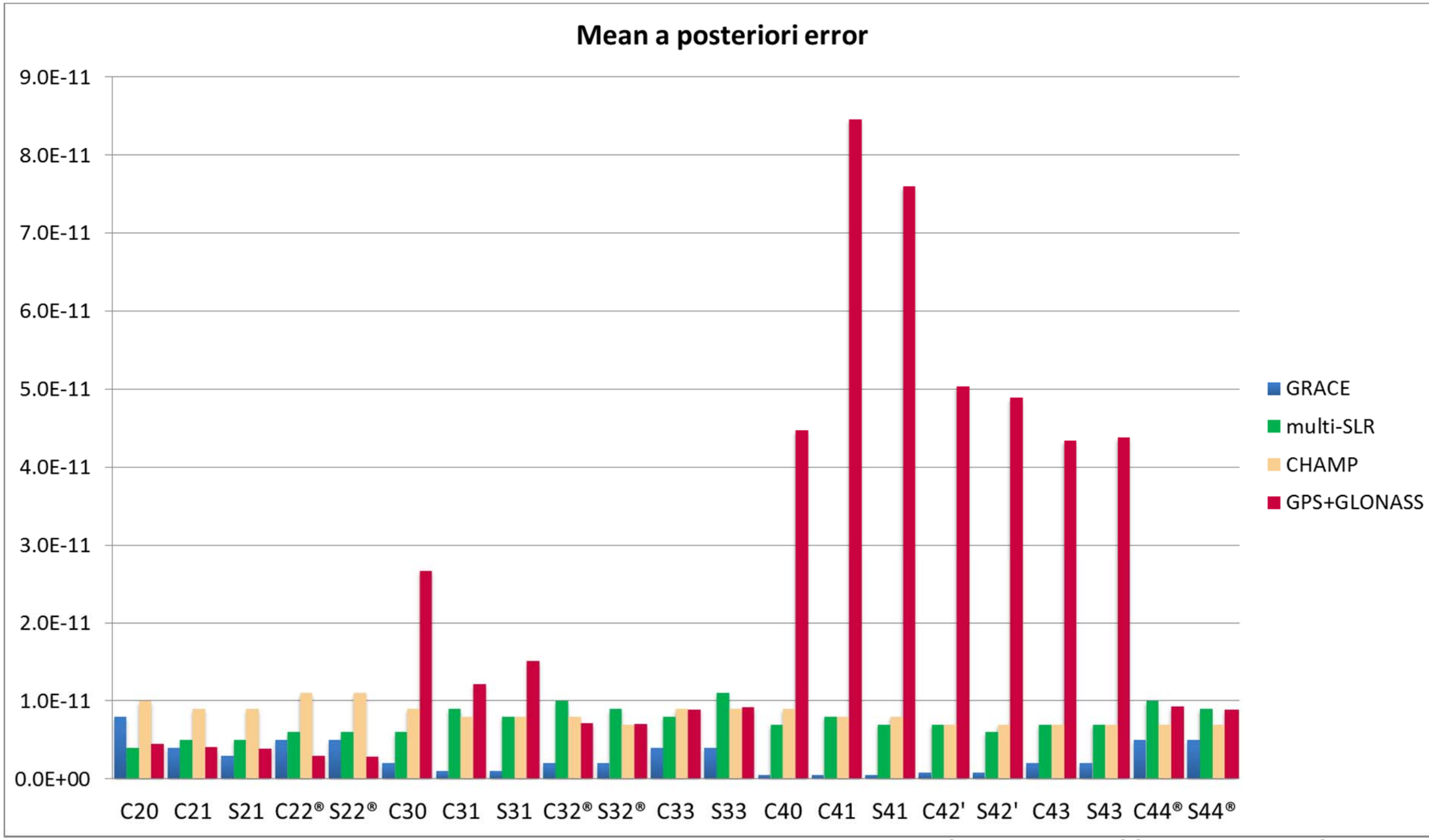


Time-variable Earth's gravity field can be determined from:

- GPS positions of satellites (CHAMP, GRACE-A/B, GOCE, SWARM; high-to-low),
- K-Band GRACE observations (low-to-low),
- Orbit perturbations:
  - using SLR to geodetic satellites,
  - using GPS and GLONASS microwave observations



Sensitivity of GPS resonant orbits



GNSS satellites are very sensitive to gravity field coefficients of degree 2. For coefficients above degree 3, GNSS are only sensitive to resonant gravity field parameters (®).

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Solution set-up

Estimated parameters		GNSS solutions	SLR solutions
		up to 32 GPS and 24 GLONASS satellites	LAGEOS-1/2, Starlette, Stella, Ajisai
Orbits	Osculating elements	A, e, i, Ω, ω, u_0 (1 set per 3 days)	A, e, i, Ω, ω, u_0 (1 set per 7 days)
Orbits	Dynamical parameters	D_0, Y_0, X_0, X_S, X_C (1 set per 3 days)	LAGEOS-1/2: S_0, S_C, S_S (1 set per 7 days) Sta/Ste/Aji: C_D, S_C, S_S, W_C, W_S (1 set per day)
Orbits	Pseudo-stochastic pulses	R, S, W (once per revolution)	LAGEOS-1/2: no pulses Sta/Ste/Aji: S (once per revolution)
Earth rotation parameters		X_P, Y_P, UT1-UTC (1 set per day)	X_P, Y_P, UT1-UTC (1 set per day)
Geocenter coordinates		1 set per 7 days	1 set per 7 days
Earth gravity field		**Estimated up to d/o 4/4** (1 set per 7 days)	**Estimated up to d/o 4/4** (1 set per 7 days)
Station coordinates		1 set per 7 days	1 set per 7 days
Other parameters		Troposphere ZD (2h), gradients (24h), GNSS-specific translations and ZTD biases	Range biases for selected stations

GNSS solutions are similar to the standard IGS solutions provided by CODE (Center for Orbit Determination in Europe), with some exceptions: Earth gravity field parameters are simultanously estimated and 7-day instead of 1-day solutions are generated.

SLR solutions are similar to the standard ILRS solutions provided by BKG, but more satellites are included (Sta/Ste/Aji) and Earth gravity field parameters are estimated.

GPS+GLONASS solutions

GNSS orbit modeling

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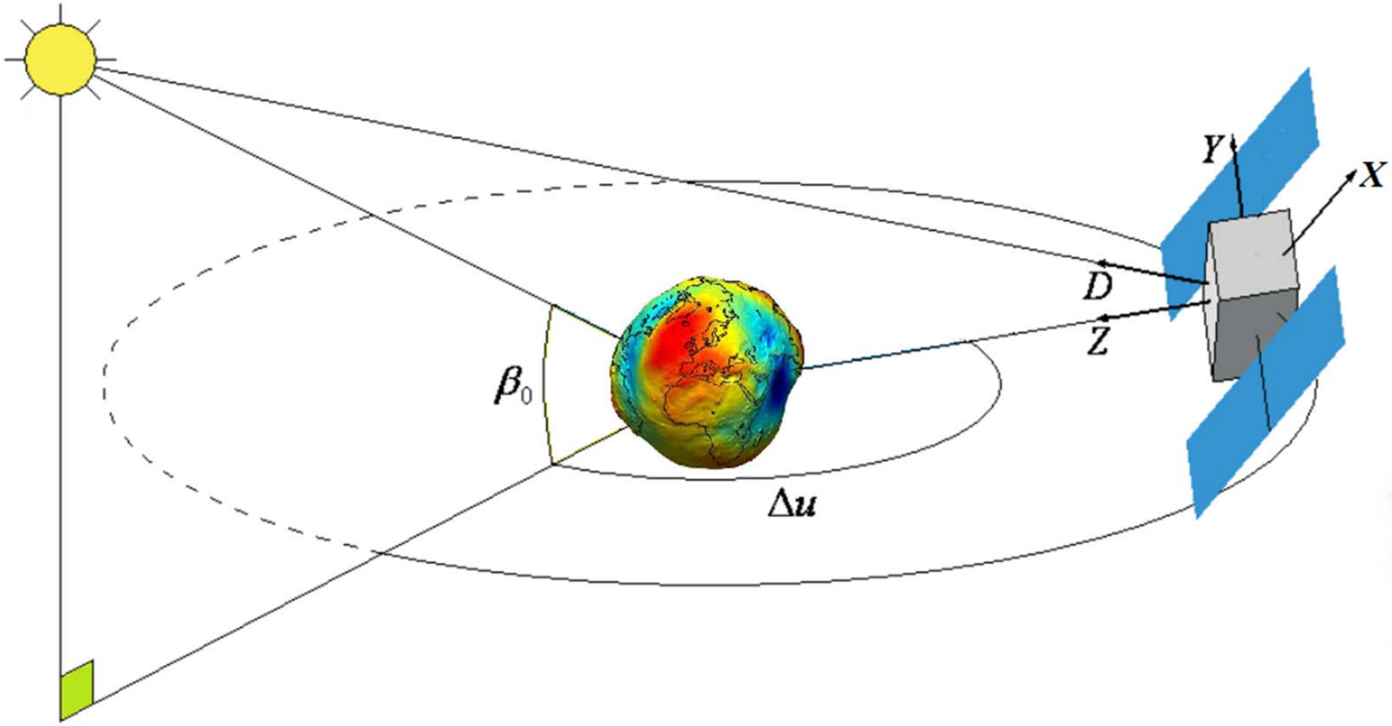


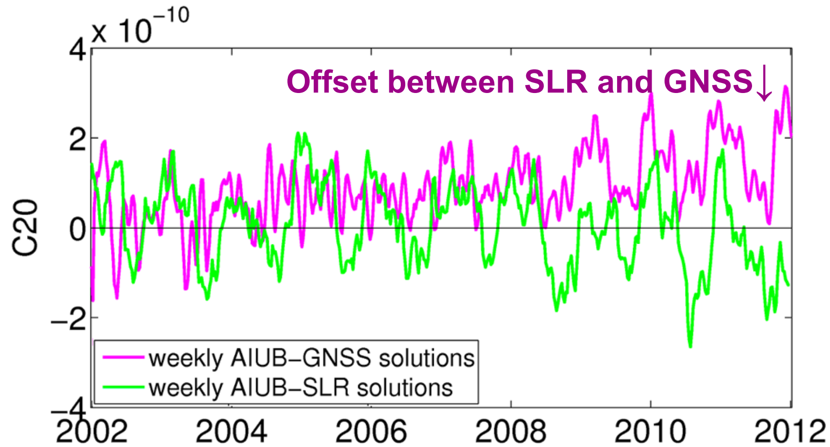
GNSS dynamic orbit parameters estimated in standard CODE solutions:

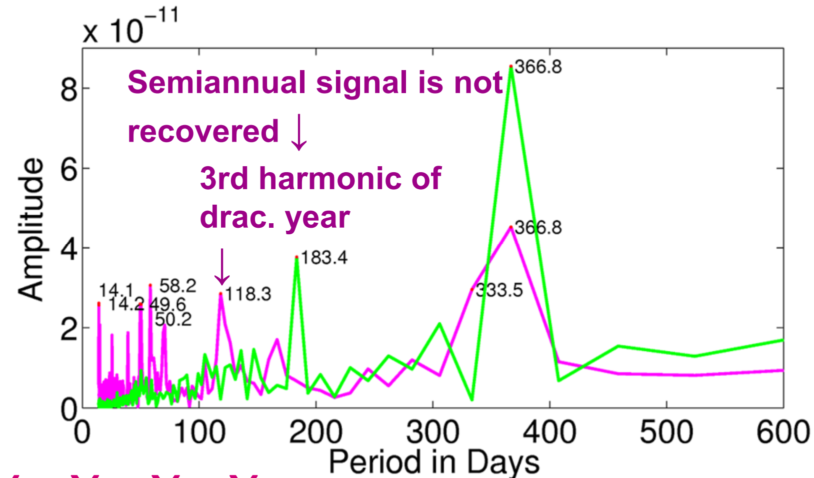
$D = D_0$

$Y = Y_0$

$X = X_0 + X_S \sin \Delta u + X_C \cos \Delta u$

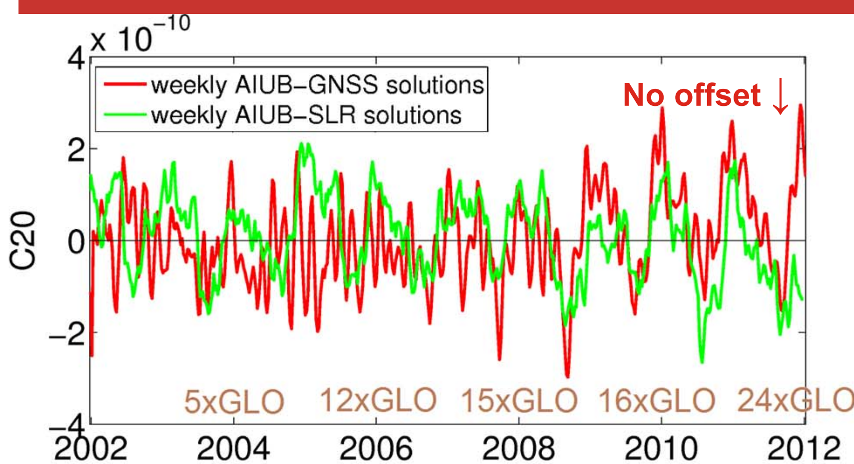
C_{20} from GPS and GLONASS

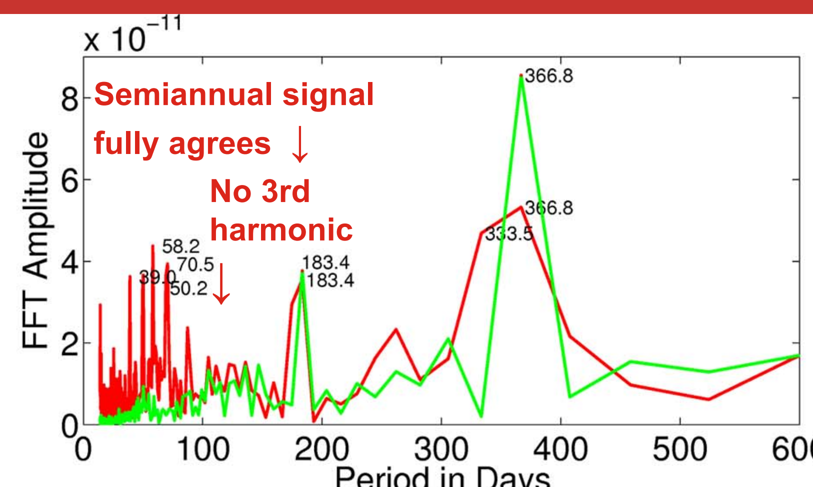




GNSS dynamic orbit parameters : D_0, Y_0, X_0, X_S, X_C

The constant and once-per-rev parameters in X are correlated with C_{20}





GNSS dynamic orbit parameters : D_0, Y_0 (no parameters in X)

These issues need further investigations

AIUB

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Zonal spherical harmonics from GPS and GLONASS

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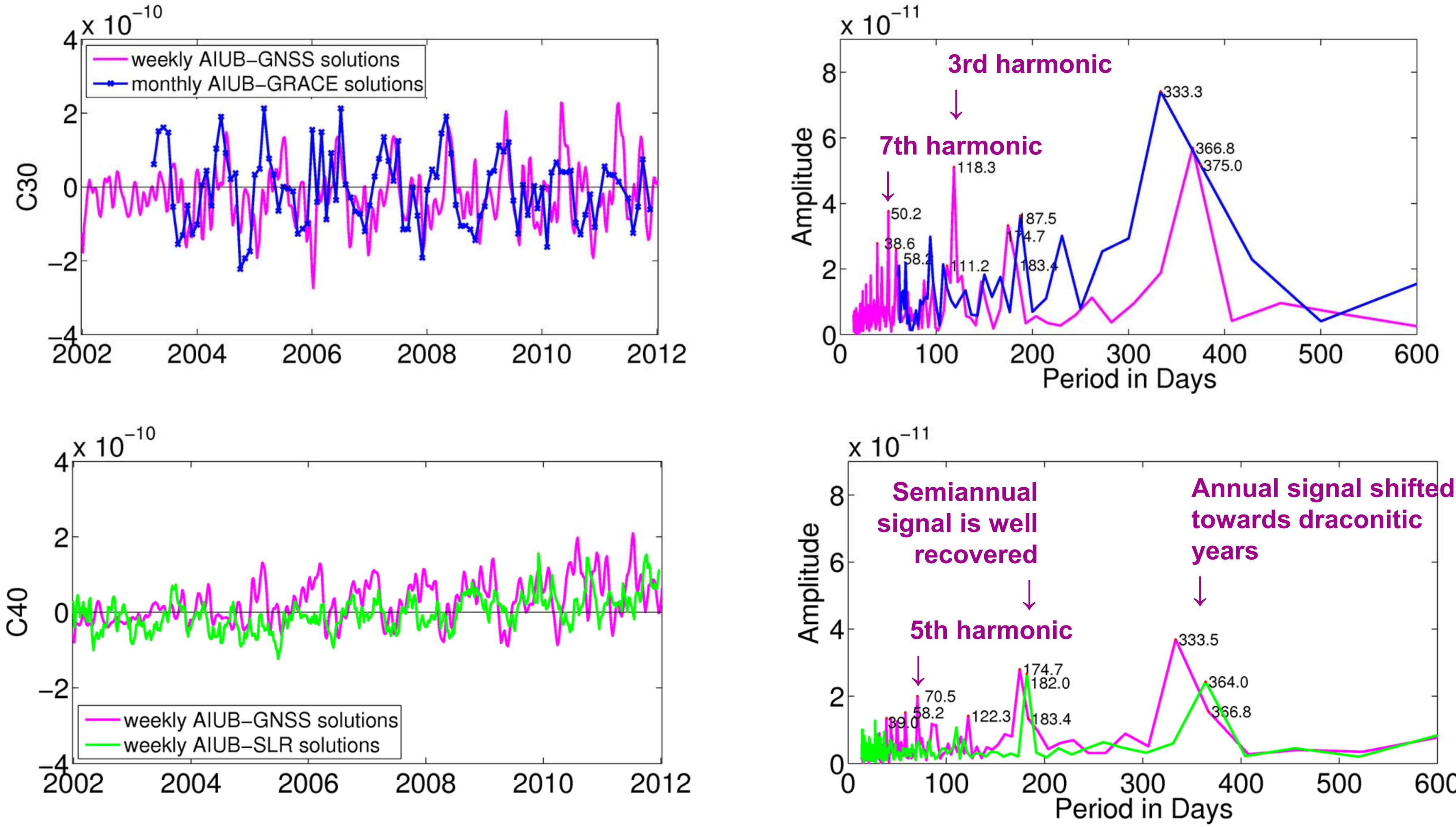
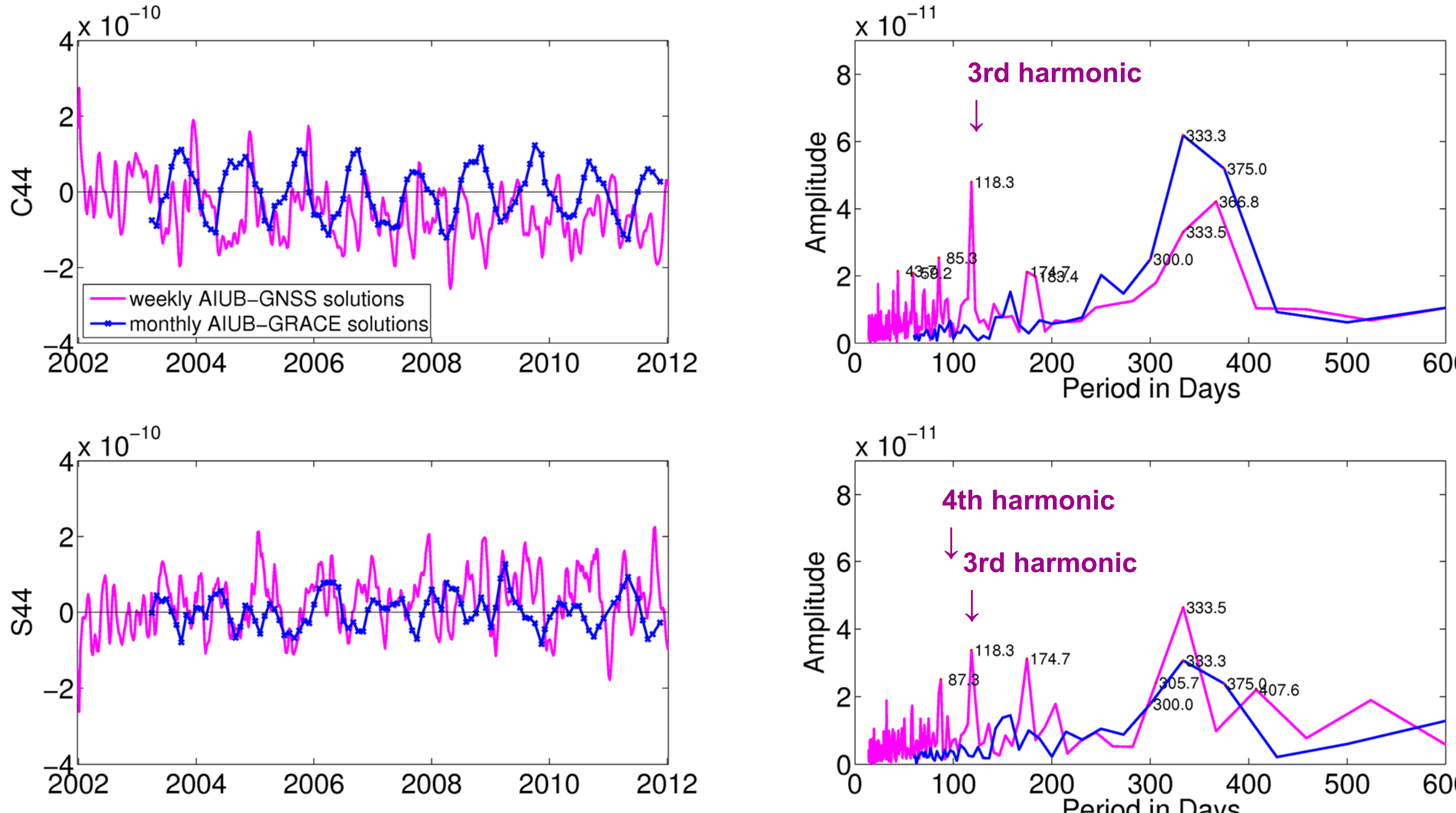


Zonal harmonics can be quite well recovered by GNSS

Resonant GPS harmonics



Resonant harmonics, despite a large sensitivity, cannot be fully recovered by GNSS, because of the correlations with D0.

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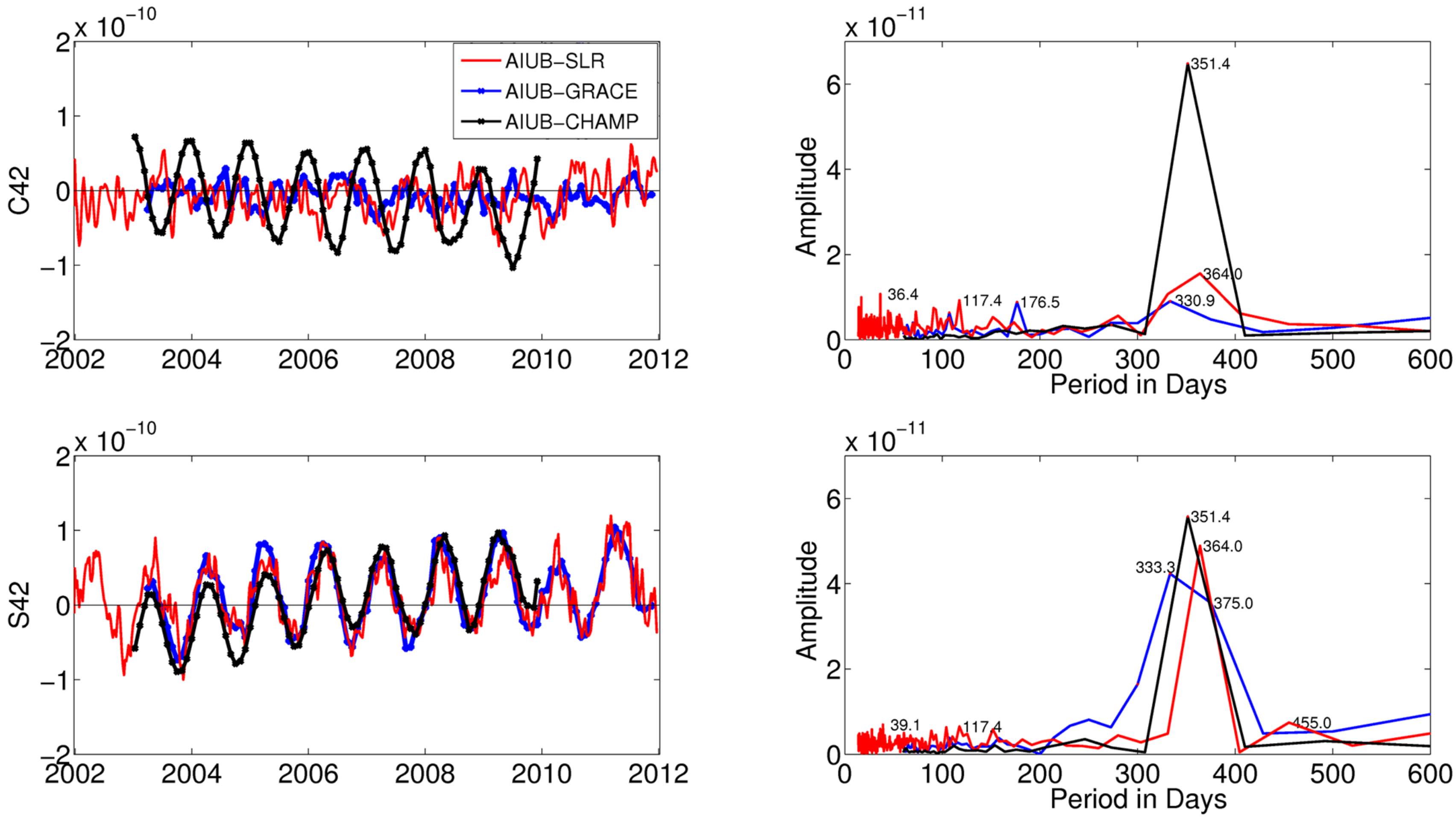
SLR solutions

SLR vs. CHAMP vs. GRACE



Some coefficients derived by SLR, CHAMP, and GRACE solutions agree very well. CHAMP solutions show typically larger amplitudes.

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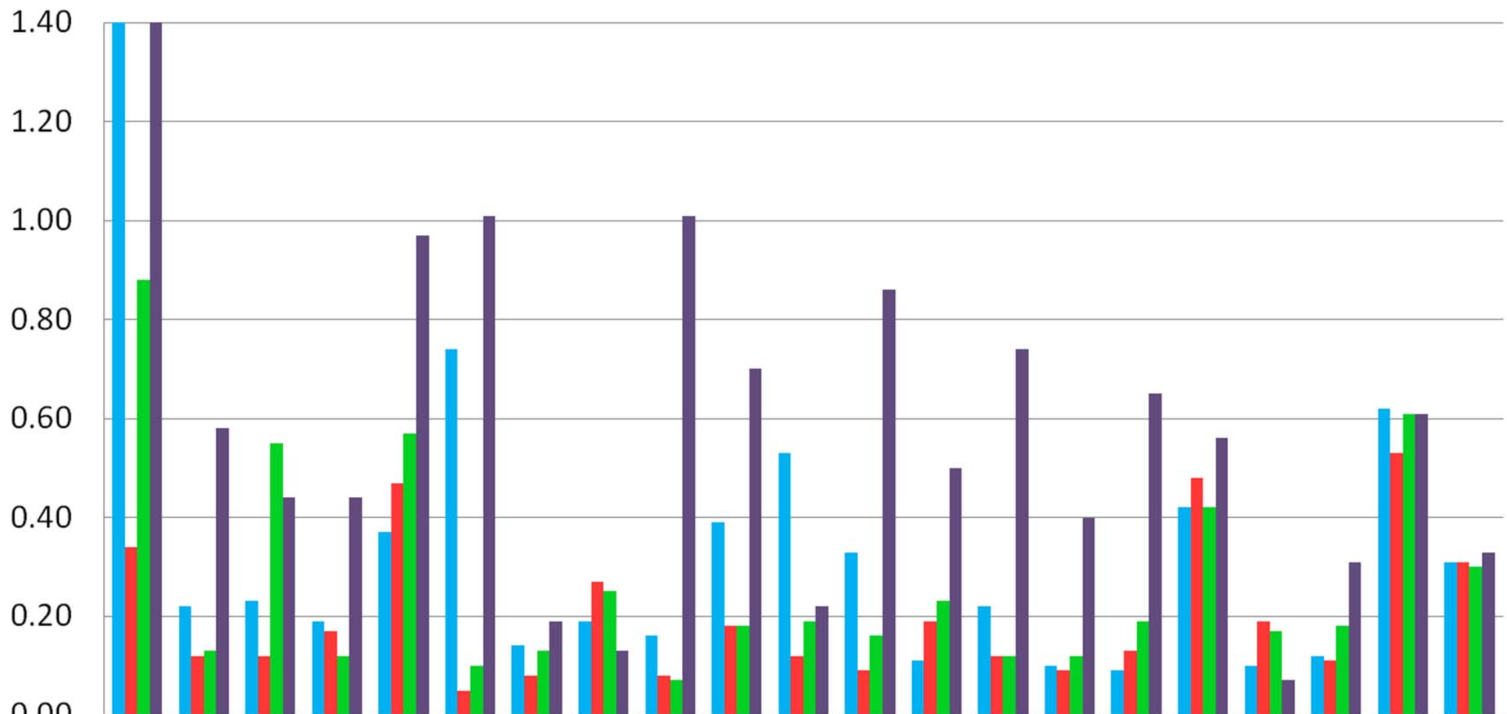
SLR vs. CHAMP vs. GRACE

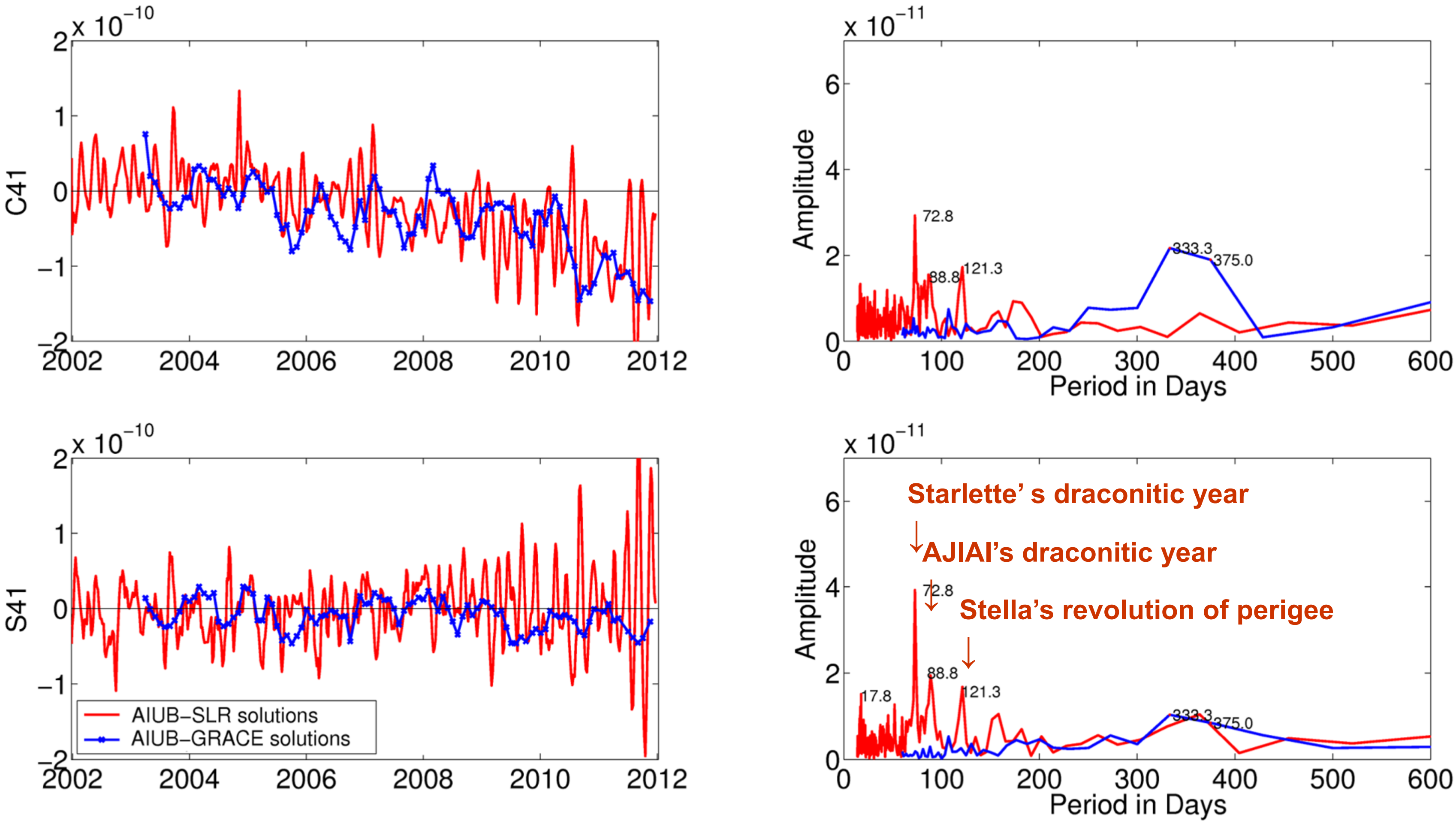
Amplitudes of annual signals of low gravity field coefficients (x1e-10)



	C20	C21	S21	C22	S22	C30	C31	S31	C32	S32	C33	S33	C40	C41	S41	C42	S42	C43	S43	C44	S44
GRACE	2.02	0.22	0.23	0.19	0.37	0.74	0.14	0.19	0.16	0.39	0.53	0.33	0.11	0.22	0.10	0.09	0.42	0.10	0.12	0.62	0.31
SLR with AOD	0.34	0.12	0.12	0.17	0.47	0.05	0.08	0.27	0.08	0.18	0.12	0.09	0.19	0.12	0.09	0.13	0.48	0.19	0.11	0.53	0.31
SLR w/o AOD	0.88	0.13	0.55	0.12	0.57	0.10	0.13	0.25	0.07	0.18	0.19	0.16	0.23	0.12	0.12	0.19	0.42	0.17	0.18	0.61	0.30
CHAMP (Kalman)	2.15	0.58	0.44	0.44	0.97	1.01	0.19	0.13	1.01	0.70	0.22	0.86	0.50	0.74	0.40	0.65	0.56	0.07	0.31	0.61	0.33

15 out of 21 (71%) coefficients up to d/o 4/4 are derived from SLR with a quality similar to GRACE's
13 out of 21 (62%) coefficients up to d/o 4/4 are derived from CHAMP with a qual. similar to GRACE's

SLR – specific issues



C_{41} derived by SLR shows similar secular trend to the GRACE results, but the high-frequency part is affected by correlations and modeling defficiencies

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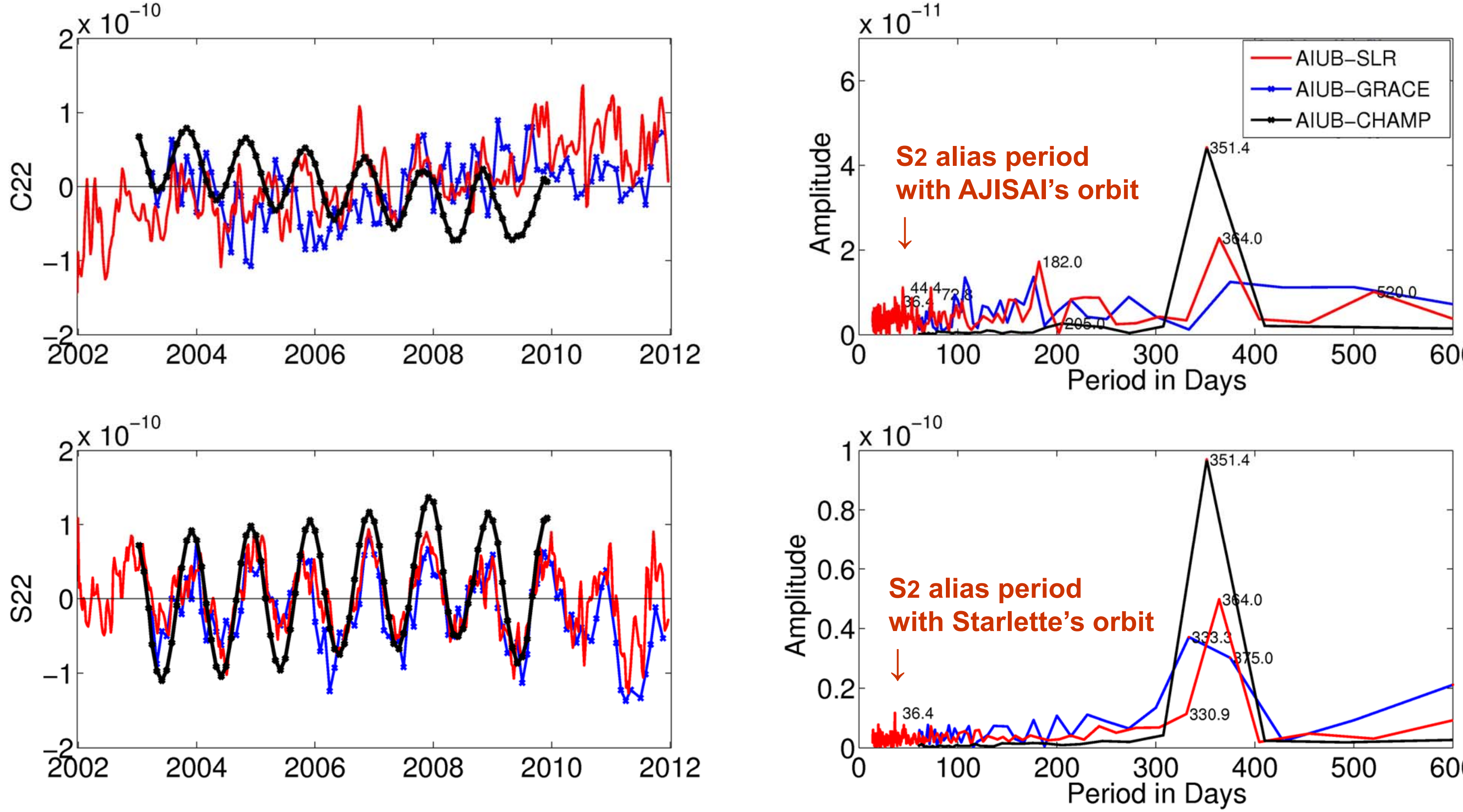
SLR – specific issues



Deficiencies in S2 tide (from the background models) affect not only the GRACE solutions, but also have a minor impact on the SLR solutions.

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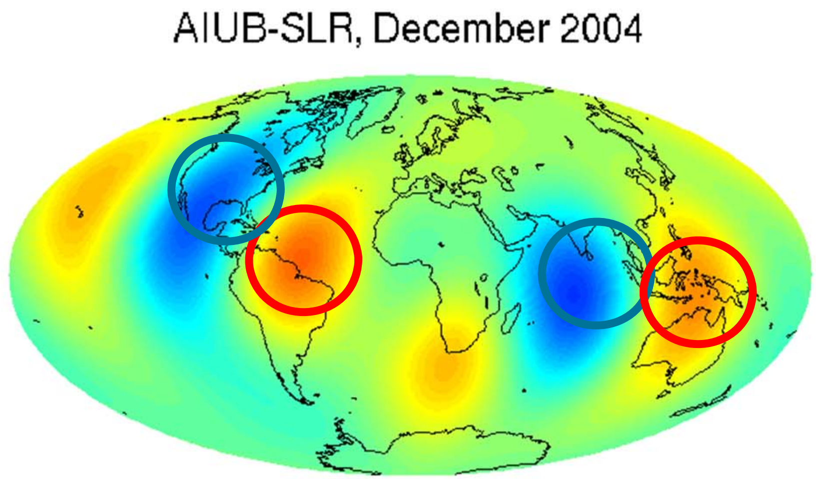
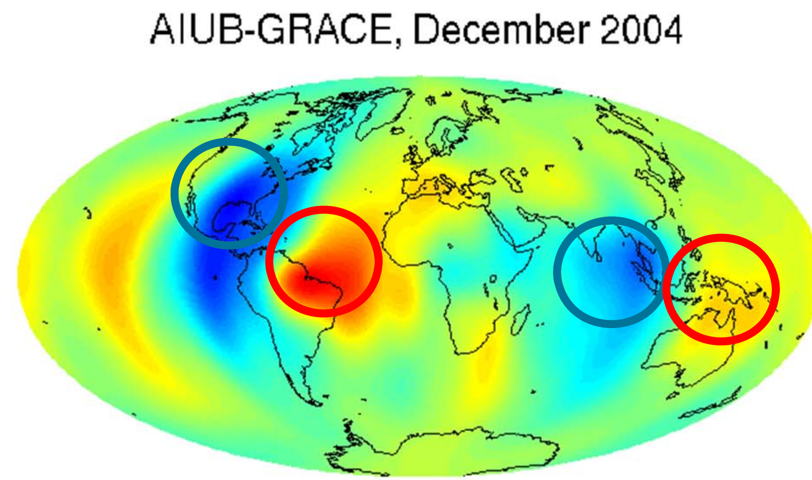
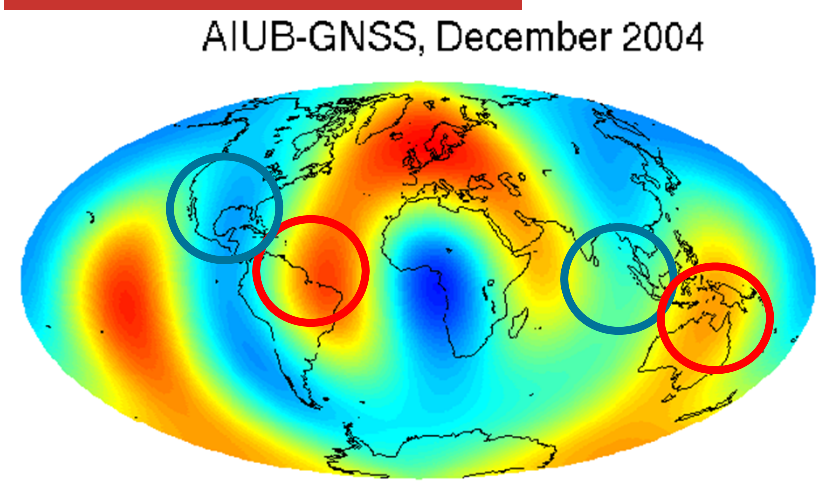
Low-degree geoid variations [mm]



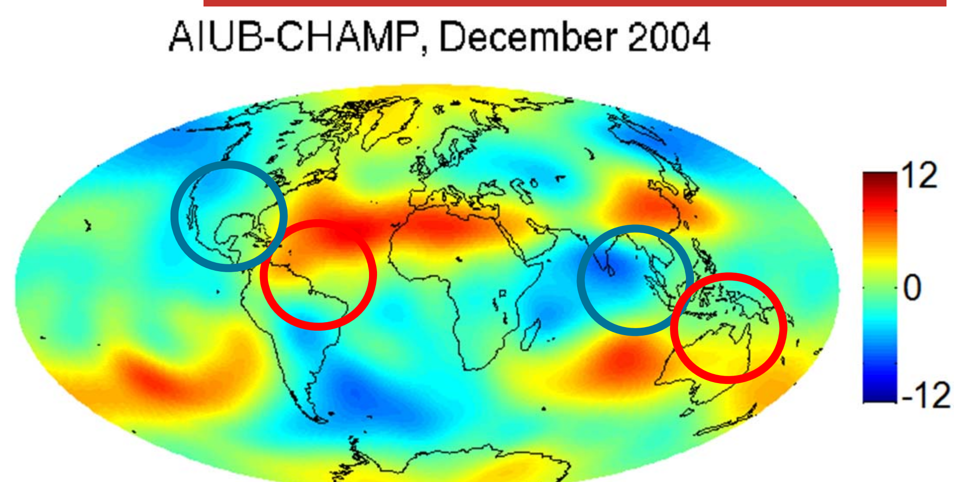
up to d/o 4/4, no filtering



up to d/o 60/45, 1000km Gauss filter



up to d/o 4/4, no filtering



up to d/o 60/60, 1000km Gauss filter

Low-degree gravity field parameters from SLR solutions fit well to the GRACE results.

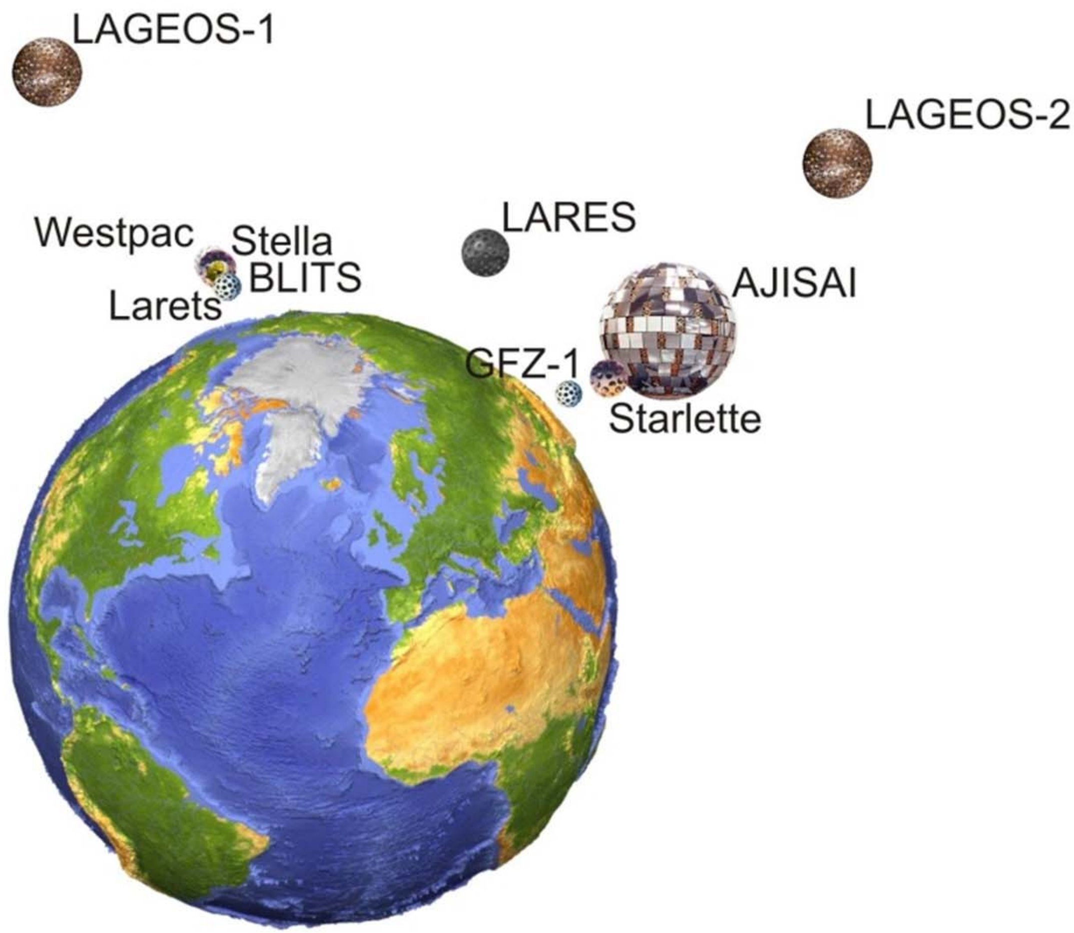
Summary

- The gravity field determination using GPS+GLONASS data is very promising, but requires further investigations.

- Most of the low-degree coefficients can be very well established by the observations of SLR geodetic satellites,

- Small issues related to SLR-derived gravity field coefficients originate from:
  - Deficiencies in background models, which are reflected, e.g., in the S_2 alias tide,
  - Deficiencies in the modeling of non-gravitational forces (solar radiation pressure, albedo, the Yarkovsky and Yarkovsky-Schach effects),
  - Correlations between gravity field parameters (e.g., C_{30} and C_{50}) and other parameters (e.g., orbits: perigee, ascending node, etc.).

Thank you for your attention



Geocenter coordinates from GNSS and SLR

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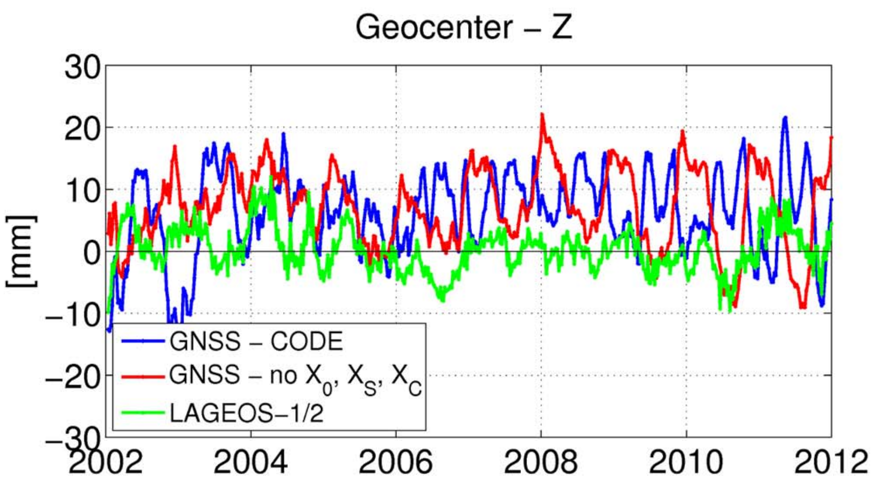
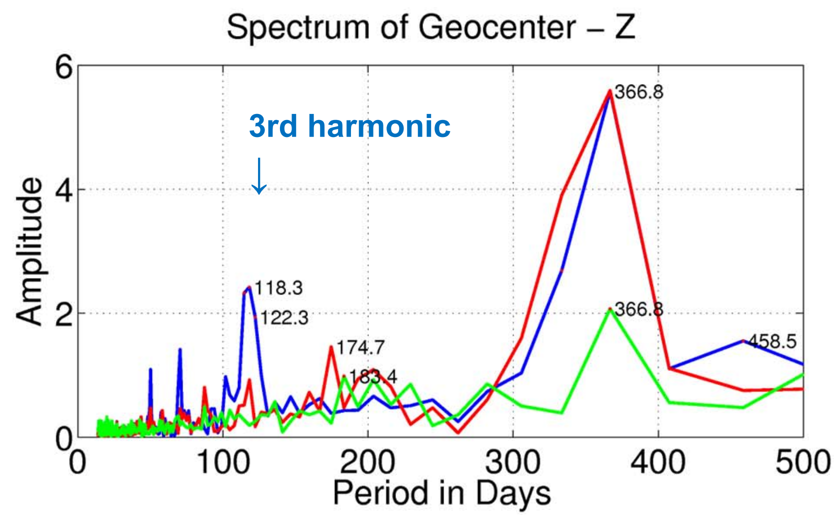
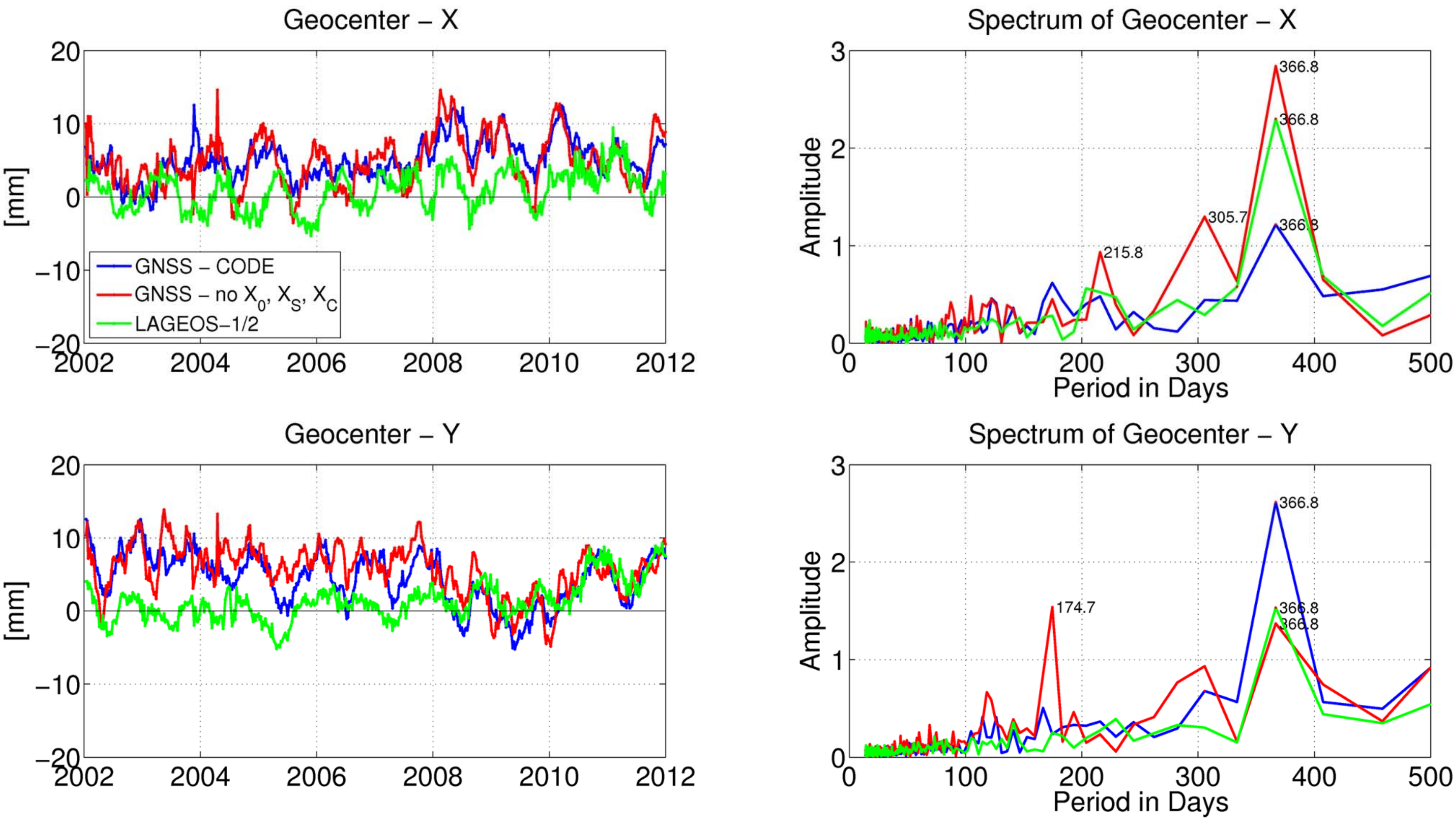




Z geocenter component from GNSS is extremely sensitive to orbit modeling; the exclusion of dynamic orbit parameters in the X direction entirely changes the signal!

Geocenter coordinates from GNSS and SLR



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