Earth's oblateness changes from GPS, GLONASS, and SLR data

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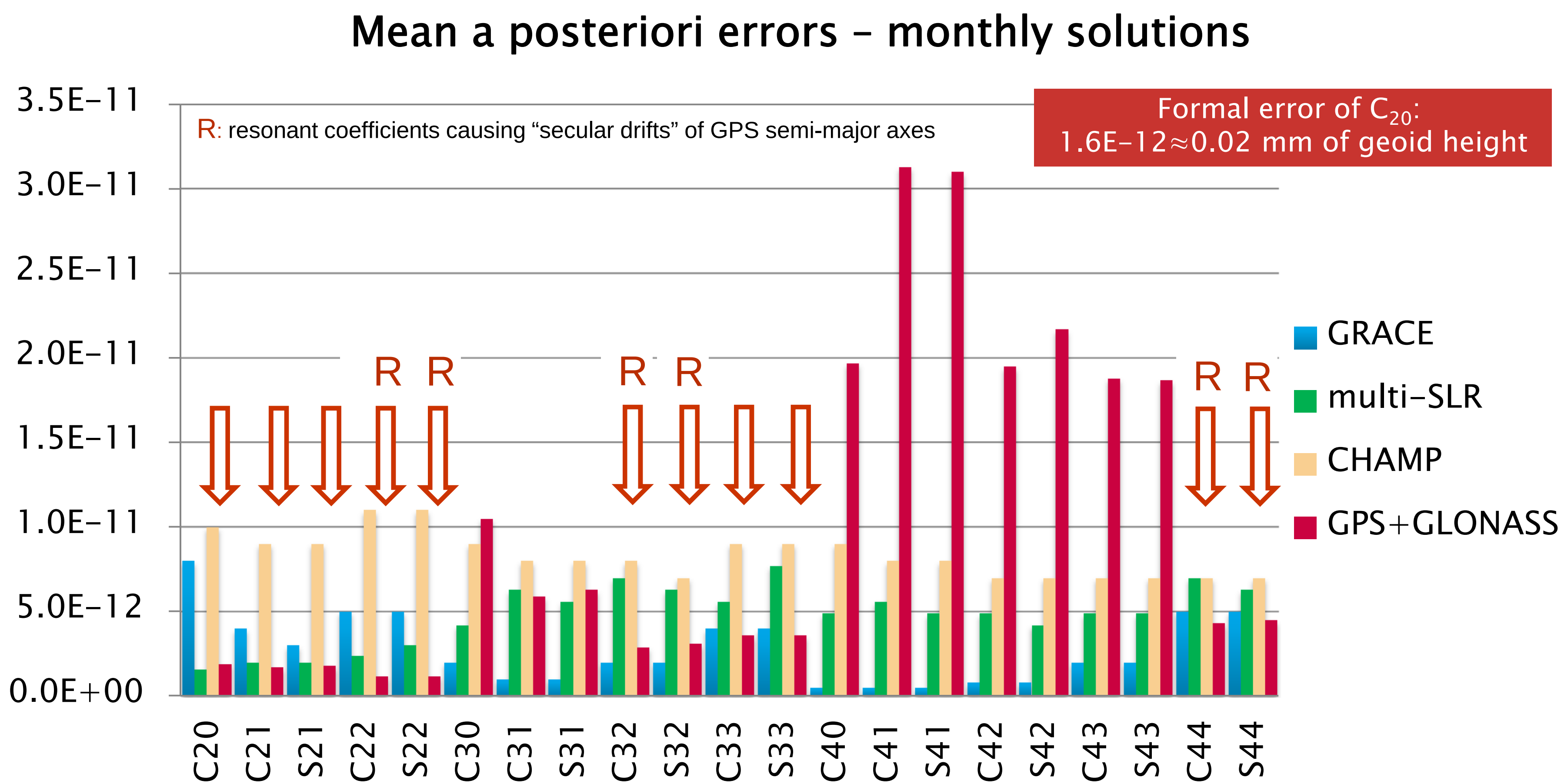
Sensitivity of GNSS solutions to low-degree gravity coeff.



GPS satellites are very sensitive to gravity field coefficients of degree 2. For coefficients above degree 3, GNSS are typically very sensitive only to resonant gravity field coefficients.

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GNSS solutions

List of estimated parameters & solution set-up

Estimated parameters		GNSS solutions
Estimated parameters		up to 32 GPS and 24 GLONASS satellites
Orbits	Osculating elements	a, e, i, Ω, ω, u_0 (1 set per 3 days)
Orbits	Dynamical parameters	D_0, Y_0, X_0, X_S, X_C – unconstrained D_S, D_C, Y_S, Y_C – constrained at 10^{-12} (1 set per 3 days)
Orbits	Pseudo-stochastic pulses	R, S, W (constrained, estimated every 12^h)
Earth rotation parameters		X_P, Y_P, UT1-UTC (Piecewise linear, 1 set per day)
Geocenter coordinates		1 set per 7 days
Earth gravity field		**Estimated up to d/o 4/4** (1 set per 7 days)
Station coordinates		1 set per 7 days
Other parameters		Troposphere ZD (2h), gradients (24h) and ZTD biases

We processed 10 years of GPS and GLONASS data using the standard orbit modeling as from CODE with two major exceptions:

- 7-day solutions are generated instead of the 3-day long-arc solutions as for the IGS.
- The Earth's gravity field coefficients up to degree/order 4/4 and geocenter coordinates are simultaneously estimated along with other parameters.

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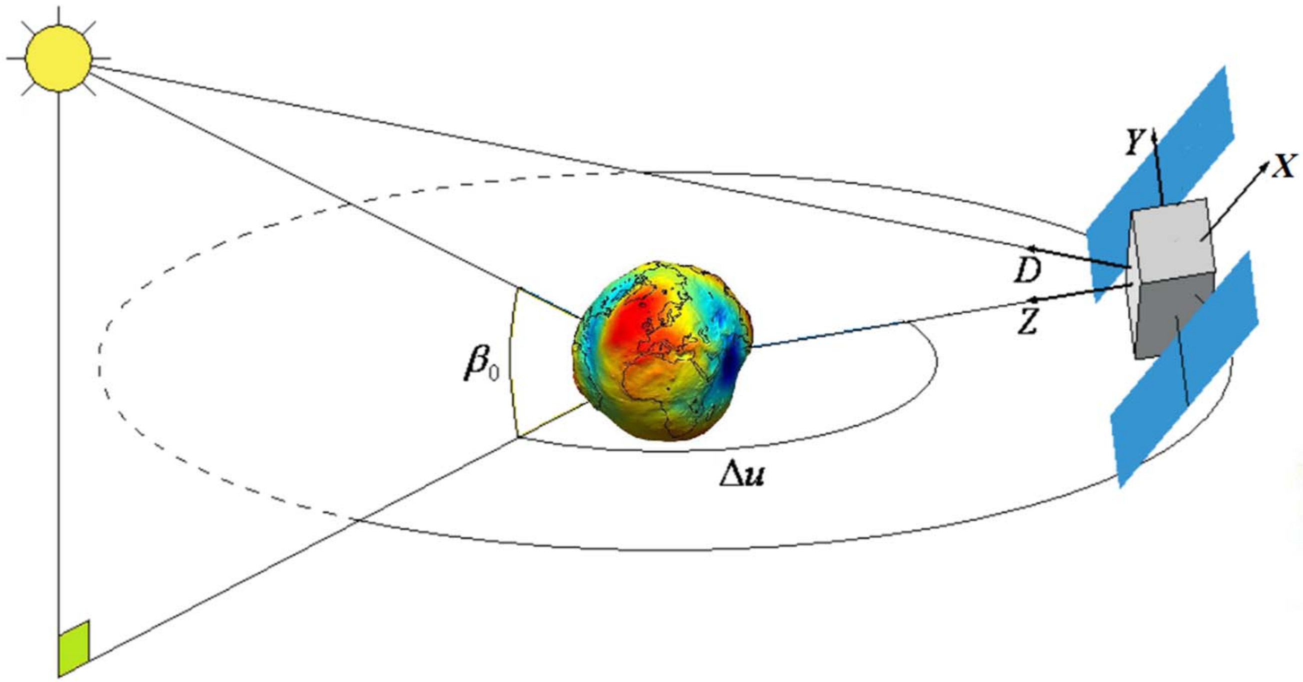
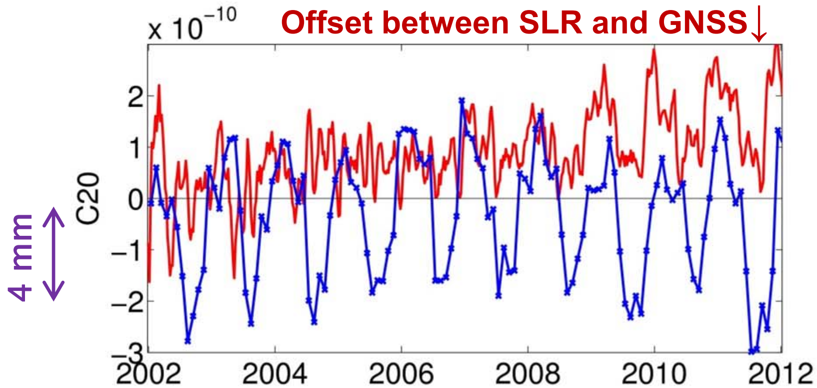
GNSS orbit modeling

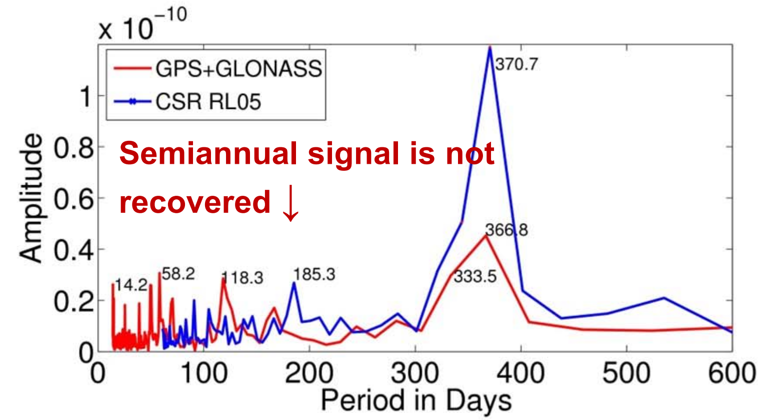


GNSS dynamic orbit parameters estimated in standard CODE solutions (reduced ECOM model):

$$\begin{pmatrix} D \\ Y \\ X \end{pmatrix} = \begin{pmatrix} D_0 \\ Y_0 \\ X_0 + X_S \sin u + X_C \cos u \end{pmatrix}$$

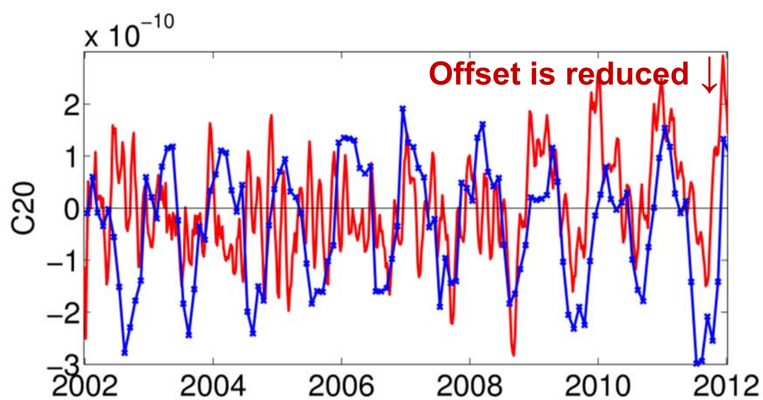
C_{20} from GPS+GLONASS

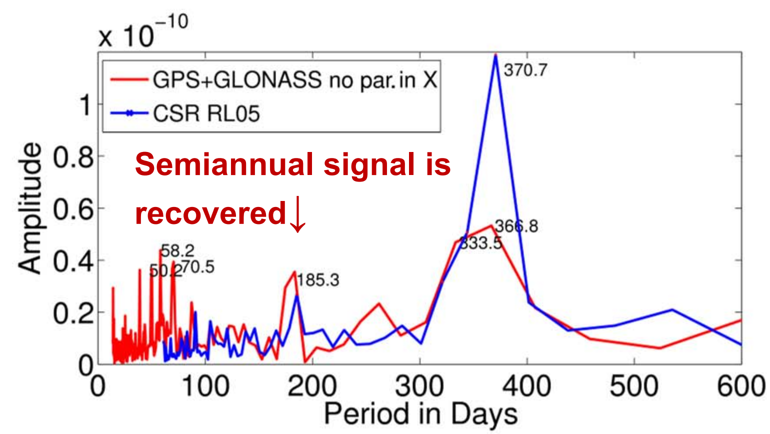




GNSS dynamic orbit parameters : D_0, Y_0, X_0, X_S, X_C

Orbit parameters in the X direction are correlated with C_{20}





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

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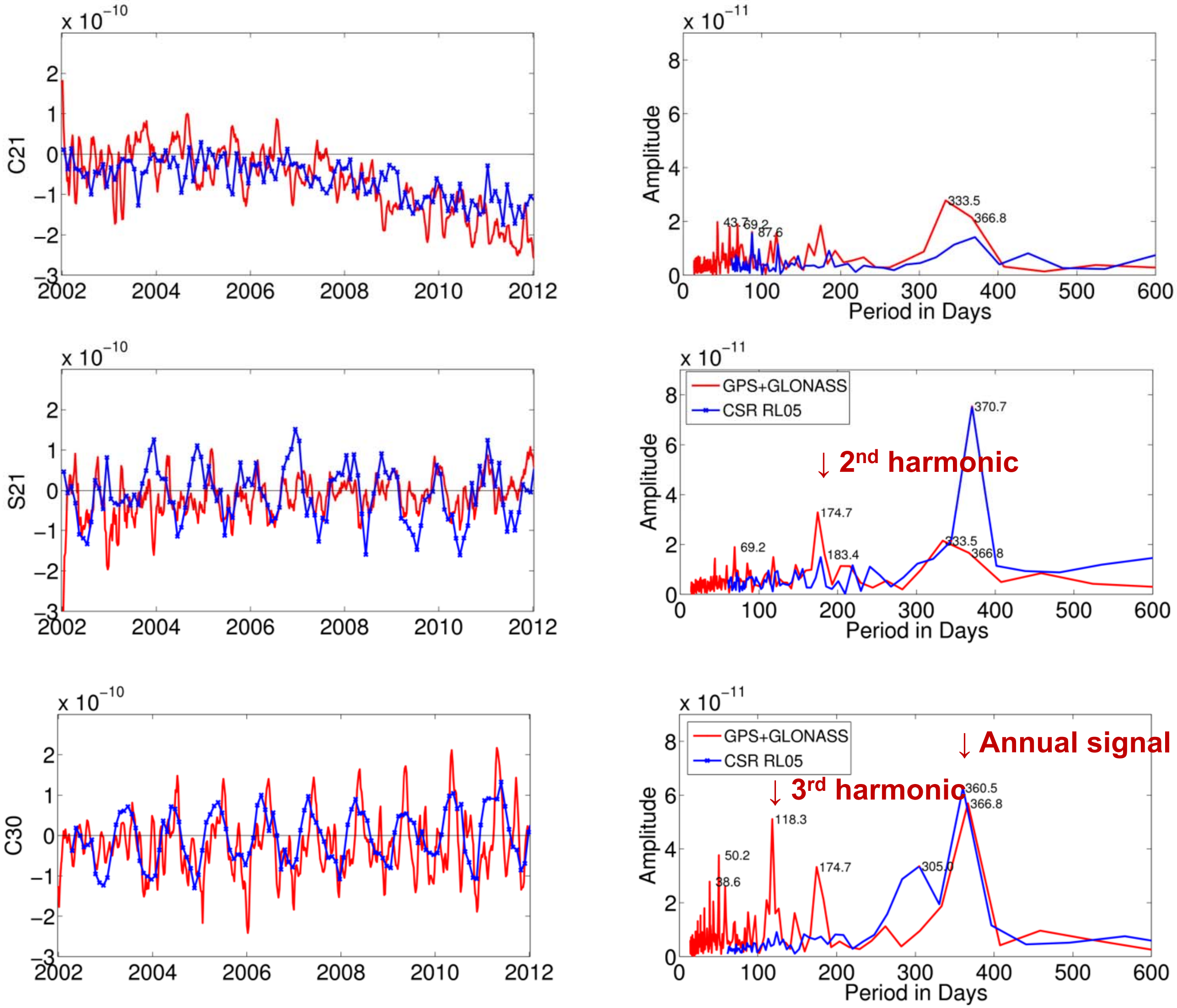
C_{21}, S_{21}, C_{30} from GPS+GLONASS



GNSS-derived gravity field parameters agree quite well with the CSR RL05 results (median difference of $8.2 \cdot 10^{-11}$), but:

- GNSS-derived parameters show both: the seasonal signals as well as draconitic periods,
- C_{20} is correlated with orbit parameters in the X direction.

Gravity coefficients benefit from the contribution of GLONASS (after 2008, when the station coverage improves).

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SLR solutions

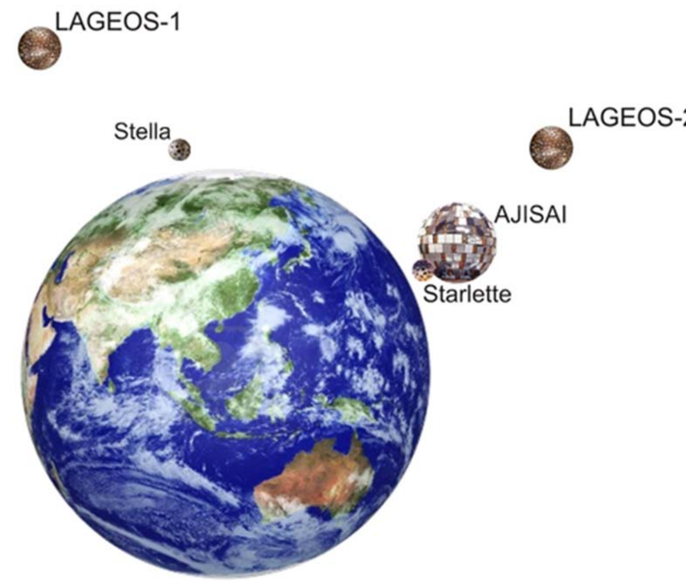
List of estimated parameters & solution set-up

Estimated parameters		SLR solutions
		LAGEOS-1/2, Starlette, Stella, AJISAI
Orbits	Osculating elements	a, e, i, Ω, ω, u_0 (1 set per 7 days)
	Dynamical parameters	LAGEOS-1/2 : S_0, S_S, S_C (1 set per 7 days) Sta/Ste/AJI : C_D, S_C, S_S, W_C, W_S (1 set per day)
	Pseudo-stochastic pulses	LAGEOS-1/2 : no pulses Sta/Ste/AJI : once-per-revolution in along-track only
Earth rotation parameters		X_P, Y_P, UT1-UTC (Piecewise linear, 1 set per day)
Geocenter coordinates		1 set per 7 days
Earth gravity field		**Estimated up to d/o 4/4** (1 set per 7 days)
Station coordinates		1 set per 7 days
Other parameters		Range biases for selected SLR stations

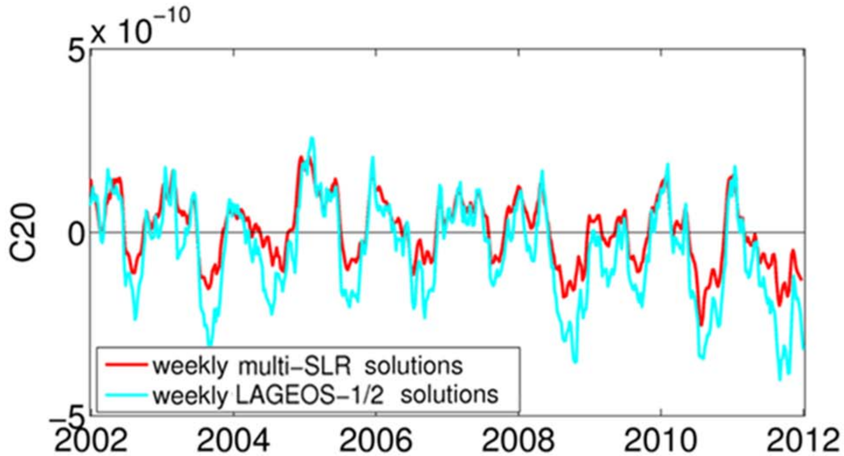
Once-per-revolution empirical parameters in out-of-plane are not estimated for LAGEOS, because they are directly correlated with C_{20}.

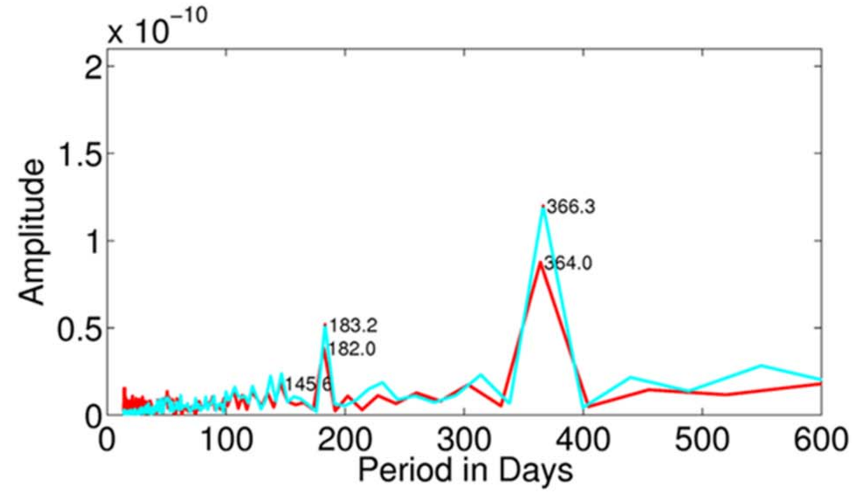
We processed 10 years of SLR data to 5 geodetic satellites: LAGEOS-1/2, Starlette, Stella, and AJISAI.

Orbit modeling of low orbiting satellites (LEO) comprises more estimated parameters due to their higher sensitivity to non-gravitational perturbations (atmospheric drag, albedo, direct radiation pressure).



C_{20} from LAGEOS-only and multi-SLR



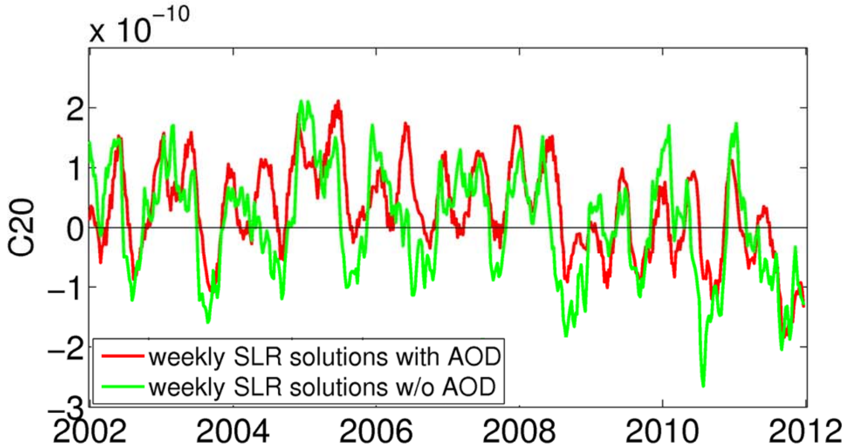


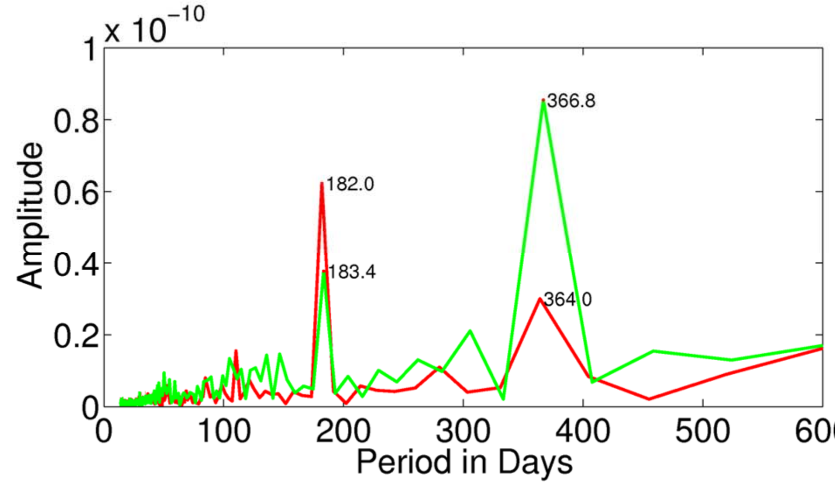
Variations of C_{20} from the LAGEOS-only solution are slightly overestimated due to correlations with other estimated parameters, e.g.:

- other gravity field coefficients (e.g., C_{40}),
- Length-of-day,
- Orbit parameters (e.g., ascending node),
- Empirical orbit parameters (S_0, S_C, S_S).

The multi-SLR solution with five high and low orbiting SLR satellites is thus more robust.

C_{20} from multi-SLR with and without AOD





When applying the time variable atmosphere and ocean gravity de-aliasing products (AOD), the estimated signal is changed, the annual signal is decreased, whereas the semiannual signal is increased w.r.t. the solution without AOD.

A full consistency between products must be kept when comparing different gravity field solutions (e.g., GRACE and SLR).

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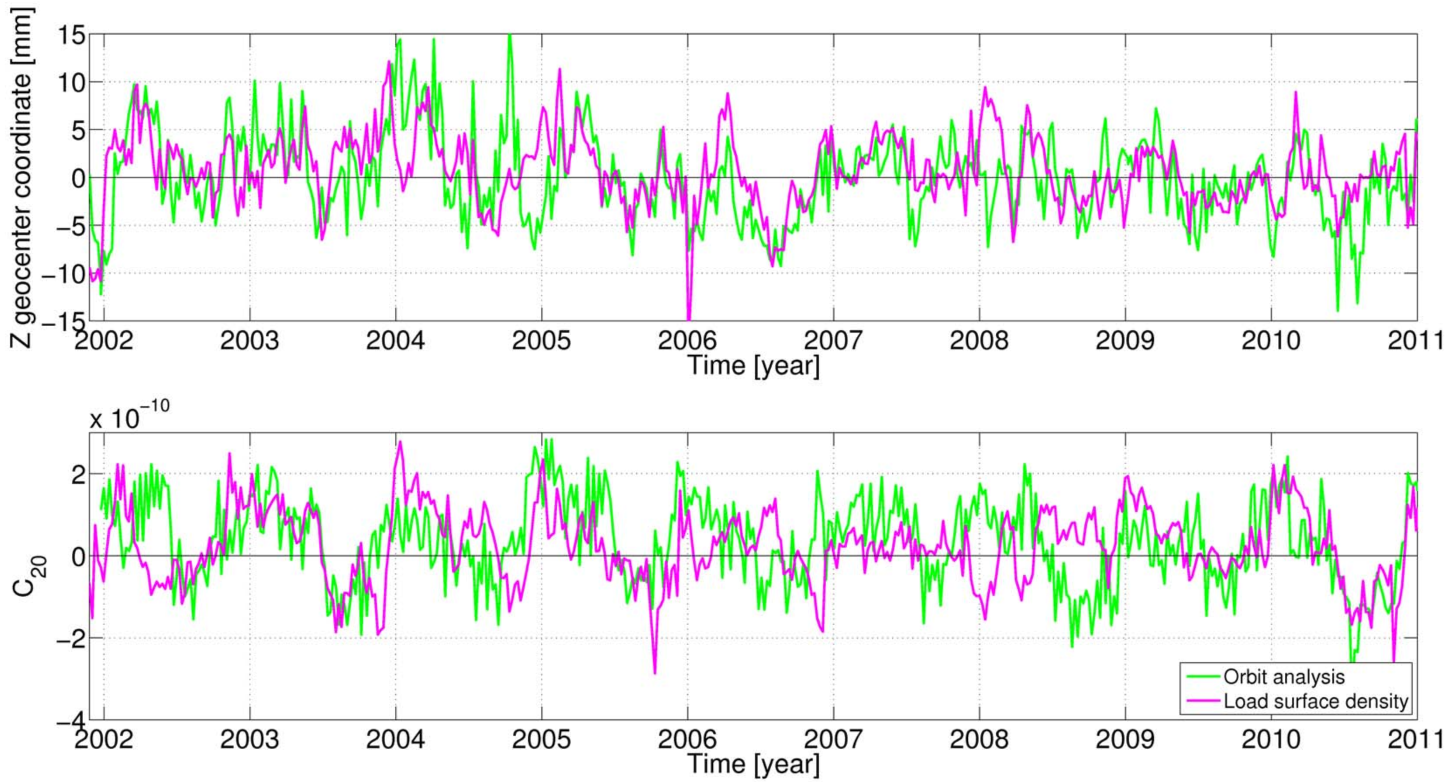
C_{20} from surface load



Variations of C_{20} can alternatively be recovered from surface load density variations, but this method is limited due to the inhomogeneous distribution of SLR stations. The correlation coefficients between “classical” C_{20} determination and C_{20} from station load displacements is 0.26 (and 0.53 for the Z geocenter coordinate).

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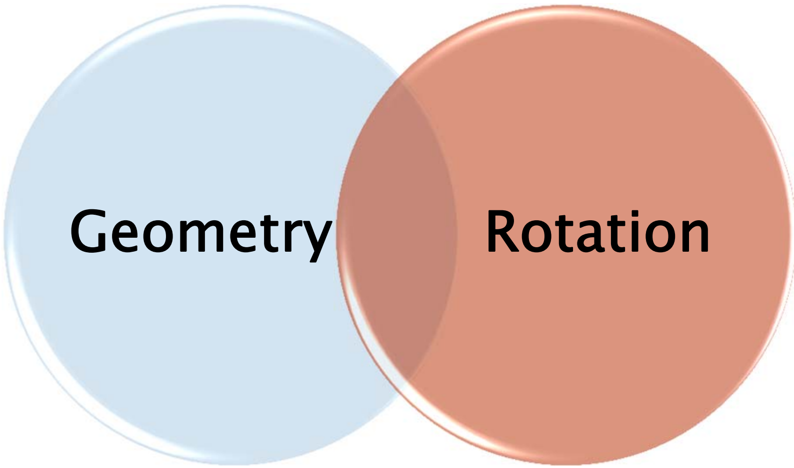
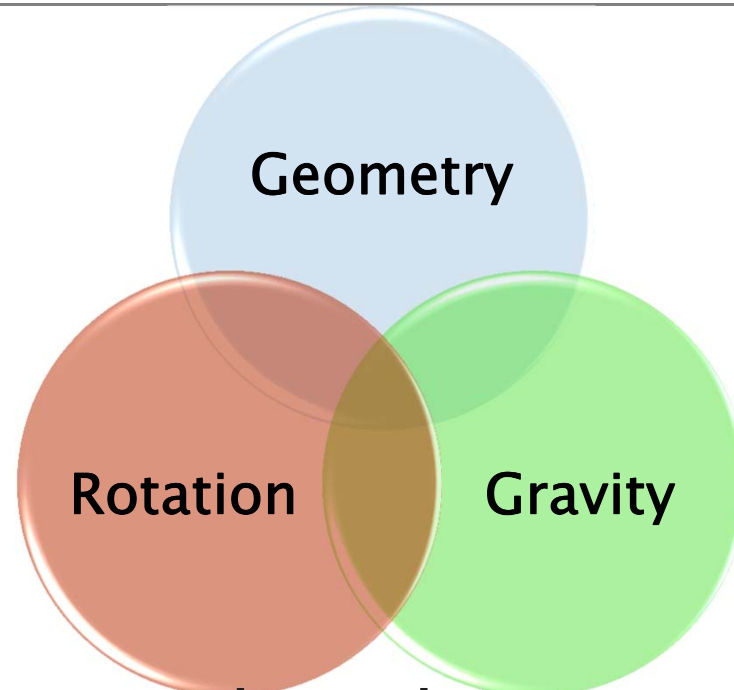
Earth Rotation Parameters

Three pillars of satellite geodesy





Current status:

IGS/ILRS provide products related to Geometry and Rotation, but not yet to temporal variations in the Earth's Gravity field.

This solution:

Parameters related to all three pillars are simultaneously estimated, because they are strongly dependent on each other.

How much affected are the GNSS/SLR-derived parameters by neglecting the temporal gravity field variations?

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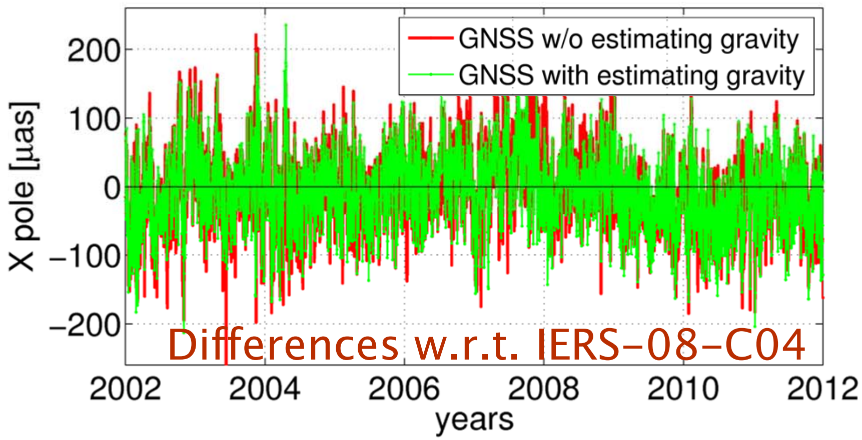
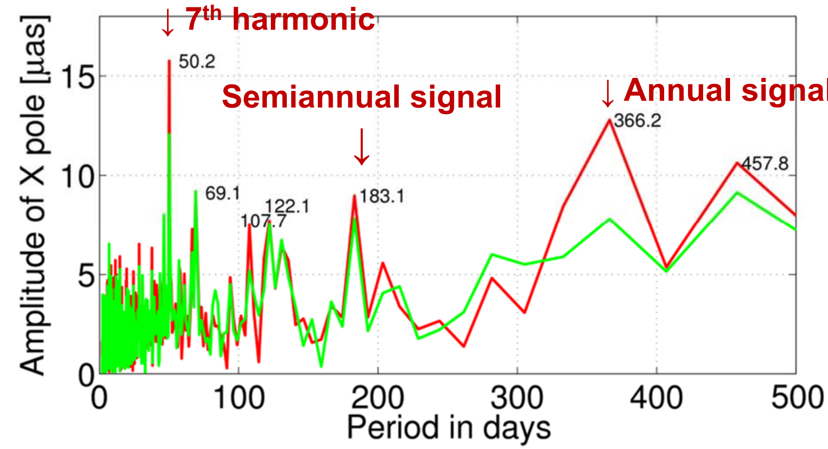
GNSS solutions – polar motion





For the X pole coordinate:

- the amplitude of the 7th harmonic is reduced from 15.9 to 12.2 µas,
- the amplitude of the annual signal is reduced from 12.8 to 6.9 µas,
- the mean offset w.r.t. IERS-08-C04 is reduced from -10.5 to -9.9 µas,

for the solutions without and with estimating gravity field parameters, respectively.

A priori static gravity field is insufficient for current high-accurate GNSS products.
Temporal variations in gravity field should be considered.

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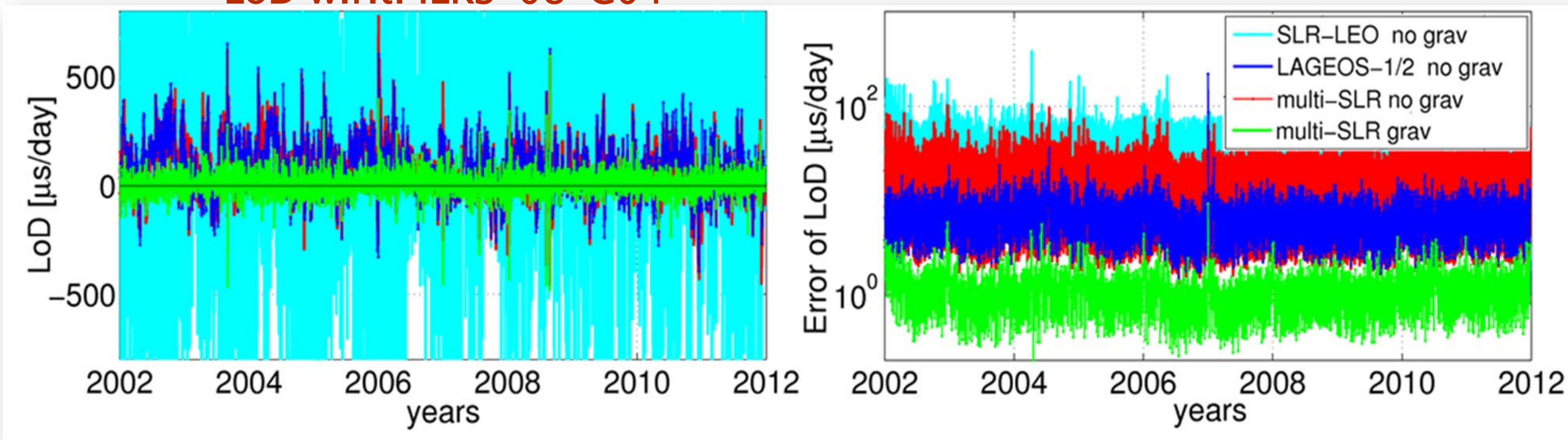
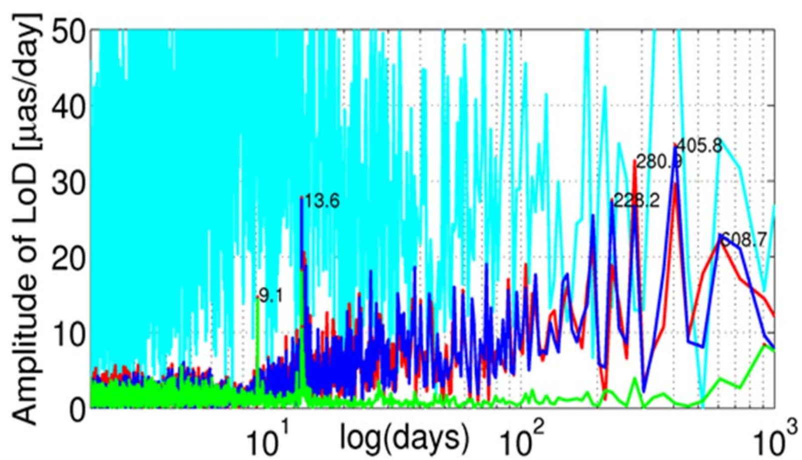
SLR solution with and without estimating gravity field

LoD w.r.t. IERS-08-C04





For LoD, the simultaneous estimation of the gravity field parameters:

- 1. reduces the offset of LoD estimates,
- 2. substantially reduces the a posteriori error of estimated LoD. The mean a posteriori error of LoD is 1.3, 16.9, 7.1, and 44.6 µs/day in the multi-SLR solution with gravity, multi-SLR solution without gravity, LAGEOS-1/2 solution without gravity, and SLR-LEO solution without gravity field parameters, respectively.
- 2. reduces peaks in the spectral analysis, which correspond, e.g., to orbit modeling deficiencies (peaks of 222 days, i.e., draconitic year of LAGEOS-2, 280 days, i.e., eclipsing period of LAGEOS-1),

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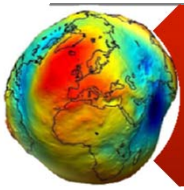
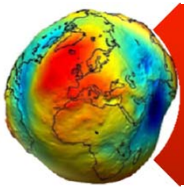
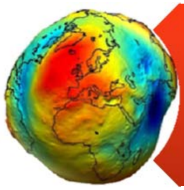
Summary



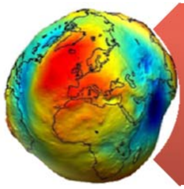
The GNSS satellites are sufficiently sensitive to low-degree gravity field parameters (including C_{20}), to recover the temporal gravity field variations.



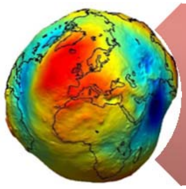
The empirical orbit parameters in the X direction are correlated with C_{20}, therefore the X-parameters partly absorb the C_{20} variations. However, not all the gravity variations are absorbed by empirical parameters.



Low orbiting SLR satellites improve the SLR solutions by reducing the correlations between estimated parameters. Mutli-SLR solutions with high and low orbiting SLR satellites is preferable as compared to LAGEOS-only.



The simultaneous estimation of gravity field parameters along with ERPs, station coordinates, and other parameters is feasible and it is beneficial, e.g., for estimated pole coordinates and length-of-day.



Temporal gravity field variations should be taken into account in both, the SLR and GNSS solutions.

Thank you for your attention

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