WROCŁAW UNIVERSITY OF ENVIRONMENTAL AND LIFE SCIENCES

Time-variable gravity field from SLR and combined GRACE-SLR solutions

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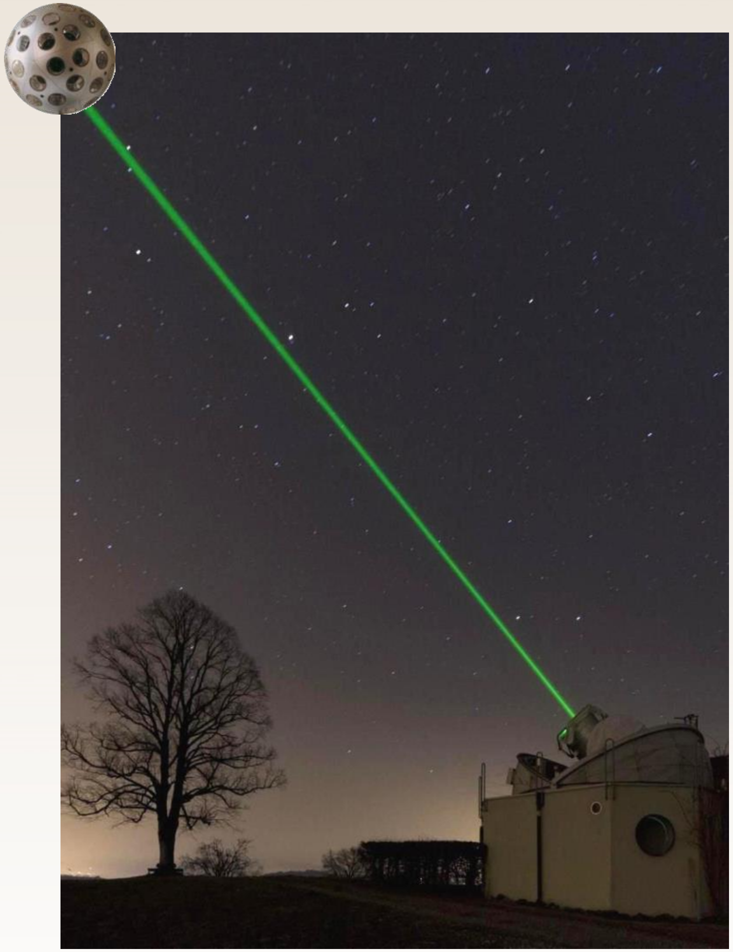
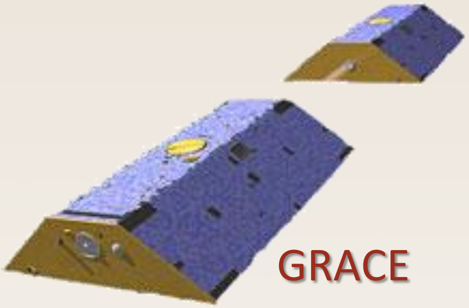
Satellite Laser Ranging (SLR)

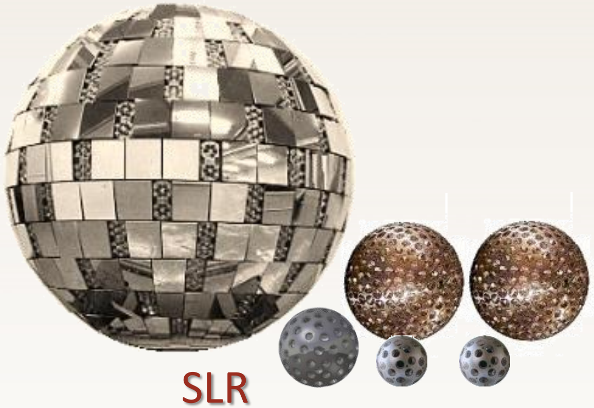
- SLR provides very accurate distance measurements (at a few mm-level) between ground stations and satellites.
- SLR geodetic satellites have a minimized area-to-mass ratio. They orbit the Earth at higher altitudes than the satellite gravity missions (e.g., GRACE, GOCE).
- SLR observations are typically used for deriving low-degree gravity field coefficients (degree 2) or zonal harmonics.
- The higher-degree monthly gravity field models can also be well derived from SLR observations using a combination of long and short arcs.



SLR station at Zimmerwald, Switzerland

GRACE vs. SLR





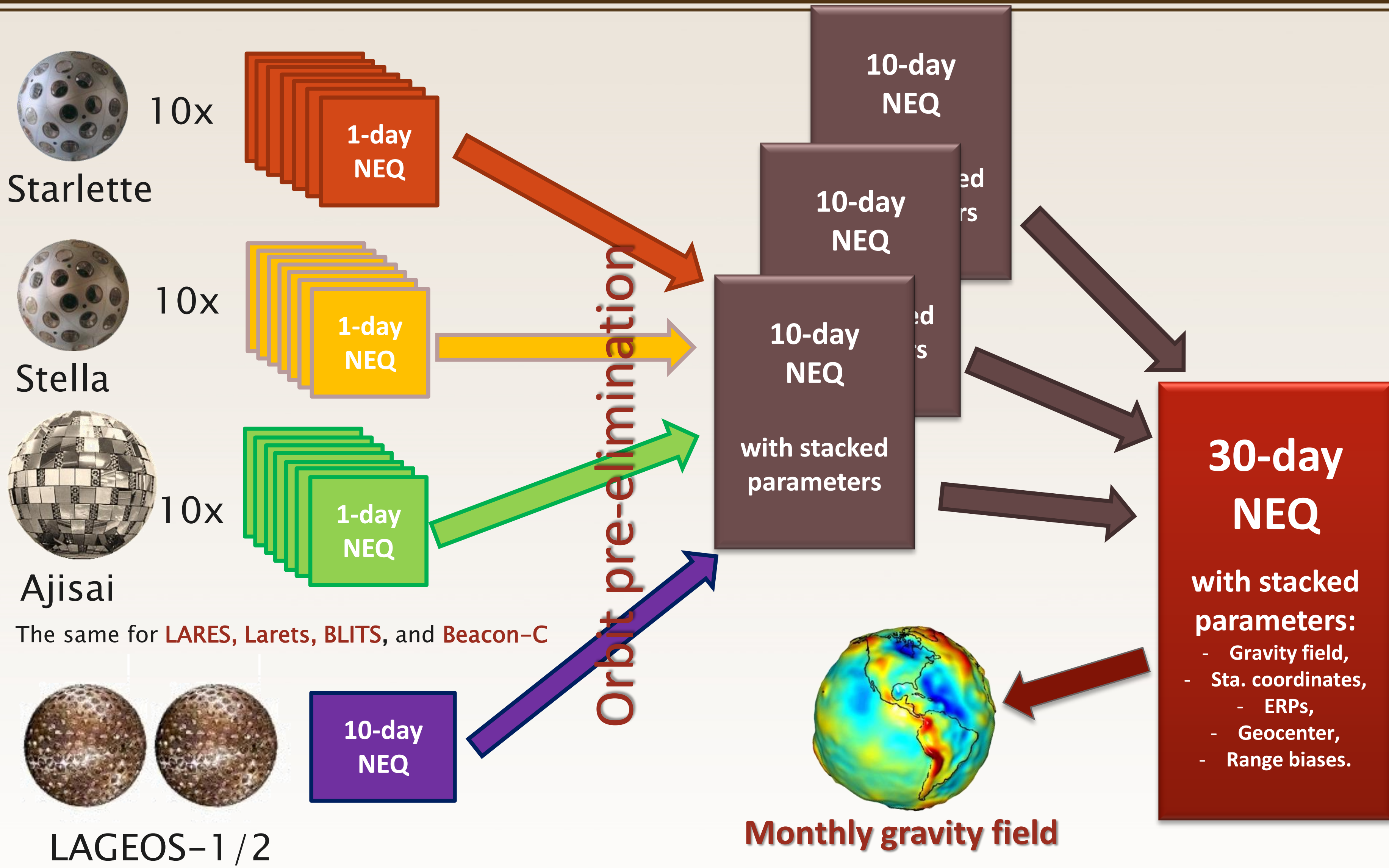
GRACE	SLR
Kinematic orbit solutions + K-band range and range rates	Dynamic approach
Microwave observations	Laser observations
Differential technique using (pseudo)ranges between satellites	Undifferentiated (direct) ranges between ground stations and satellites
~1M observations per month	~40k observations per month
High-rate observations	Normal points every 30 s (Starlette, Stella, AJISAI, LARES, Larets, BLITS) or every 120 s (LAGEOS)
Continuous observations	Noncontinuous observations limited by the station-satellite visibility
Homogeneous quality of observations	Quality of observations dependent on SLR stations (different frequencies and laser systems: 10Hz/kHz used)
Homogeneous distribution of observations	Most of tracking stations in the northern hemisphere
No weather dependency	Weather dependency on observations, + the Blue-Sky effect
Low and high-degree coefficients can be resolved	Typically only low-degree coefficients can be resolved
Reasonably small correlations between estimated parameters	Strong correlations between some harmonics resulting in the lumped coefficients
No direct link to reference frame	Directly connected to the terrestrial reference frame
Very low altitude of satellites ~380 km	Different altitudes, typically above 800 km
The same inclination for both GRACE satellites	Different inclinations
Strong S_2 aliasing with orbits	Strong S_2 aliasing only for some satellites (e.g., Stella, Larets, Blits)
Very sensitive to non-gravitational forces (atmospheric drag, albedo, solar radiation)	Sensitivity to non-gravitational forces substantially reduced
Sensitive to ionosphere activity	No ionosphere delay of the signal
Active satellites, expensive maintenance	Passive, low-cost satellites
Limited life-time	Unlimited life-time

SLR gravity field solutions in Bernese GNSS Software

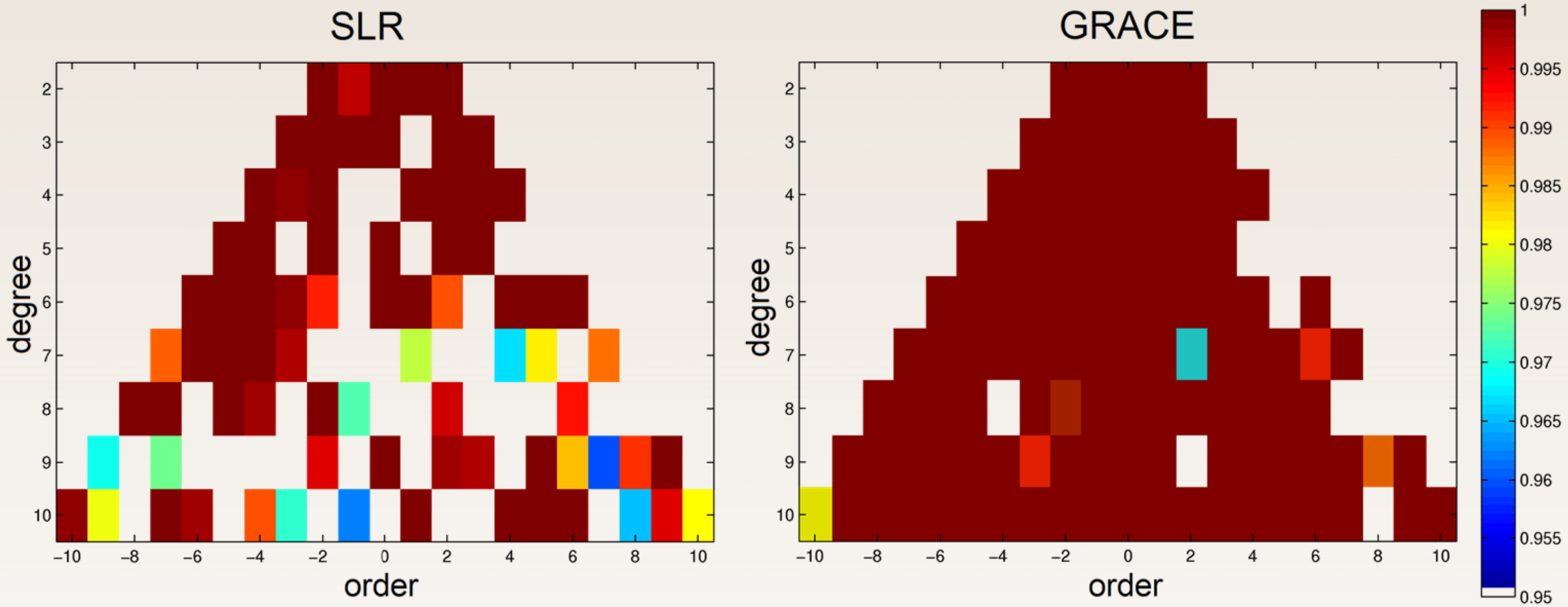
Estimated parameters		SLR solutions
		LAGEOS-1/2, Starlette, Stella, AJISAI, LARES, Blits, Larets, Beacon-C
Orbits	Osculating elements	a, e, i, Ω, ω, u_0 (LAGEOS: 1 set per 10 days, LEO: 1 set per 1 day)
Orbits	Dynamical parameters	LAGEOS-1/2 : S_0, S_S, S_C (1 set per 10 days) Sta/Ste/AJI : C_D, S_C, S_S, W_C, W_S (1 set per day)
Orbits	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 30 days
Earth gravity field		**Estimated up to d/o 10/10** (1 set per 30 days)
Station coordinates		1 set per 30 days
Other parameters		Range biases for all stations (LEO) and for selected stations (LAGEOS)

- Up to 9 SLR satellites with different altitudes and different inclinations are used.
- For LAGEOS-1/2: 10-day arcs are generated, for low orbiting satellites: 1-day arcs.
- Different weighting of observations is applied: from 8mm for LAGEOS-1/2 to 50mm for Beacon-C.
- Constraints introduced to regularize the normal equations (on GFC, pulses, EOPs).

SLR gravity field solutions in Bernese GNSS Software



SLR gravity field solutions



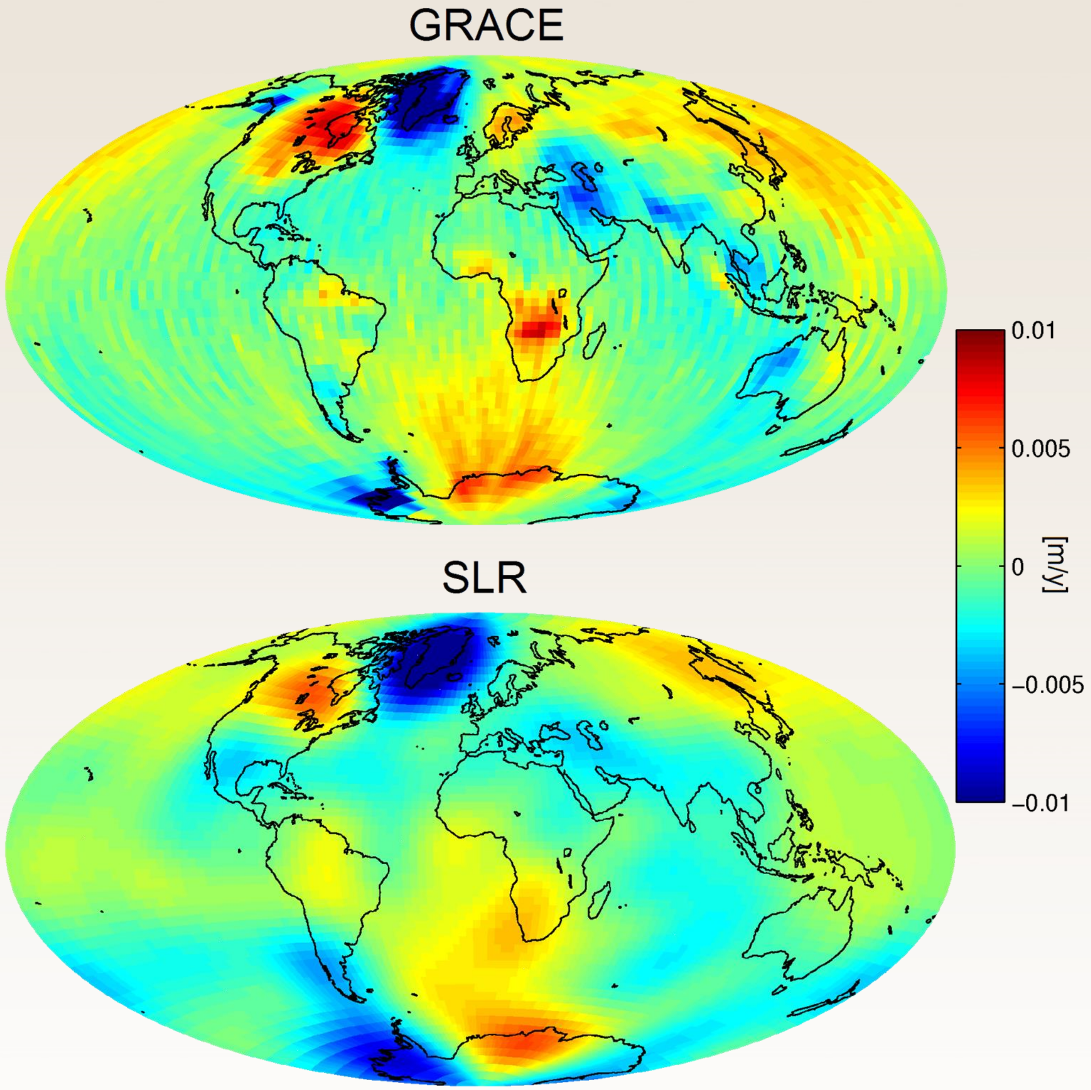
Associated cumulative distribution function showing the significance of the recovered annual signal for SLR solutions (left) and GRACE solutions (right).

=> SLR mostly sensitive to d/o 6/6

SLR gravity field solutions

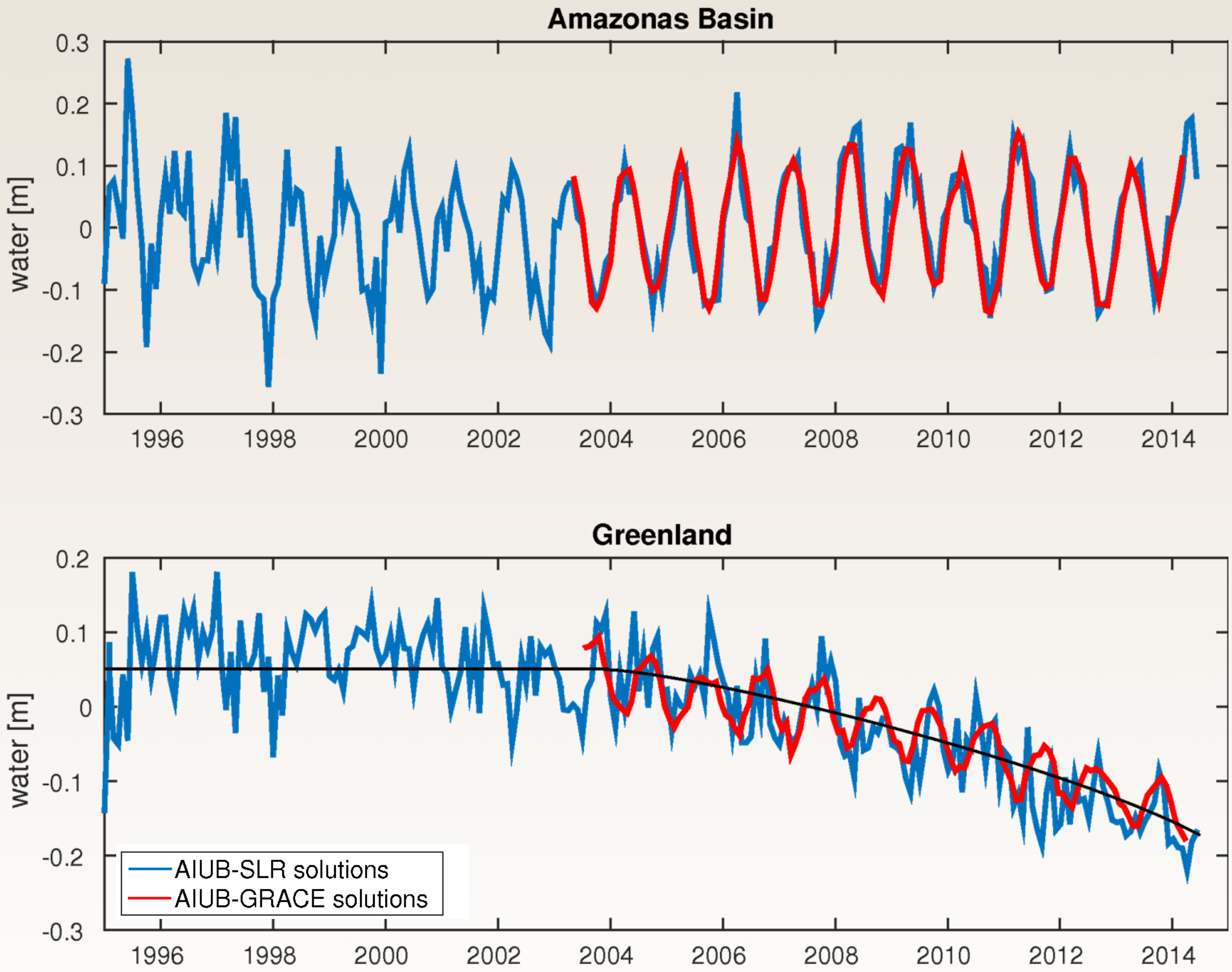
Secular changes of geoid deformations derived from SLR show a very high level of consistency with the GRACE-based results, however, with a lower spatial resolution.

The ice mass loss in Greenland, West Antarctica and Patagonia is well captured in the SLR solutions.



Reference: Sośnica, K., Jäggi, A., Meyer, U., Thaller, D., Beutler G., Arnold, D., Dach, R. (**2015**). *Time variable Earth's gravity field from SLR satellites*. **Journal of Geodesy,** on-line (http://link.springer.com/article/10.1007/s00190-015-0825-1)

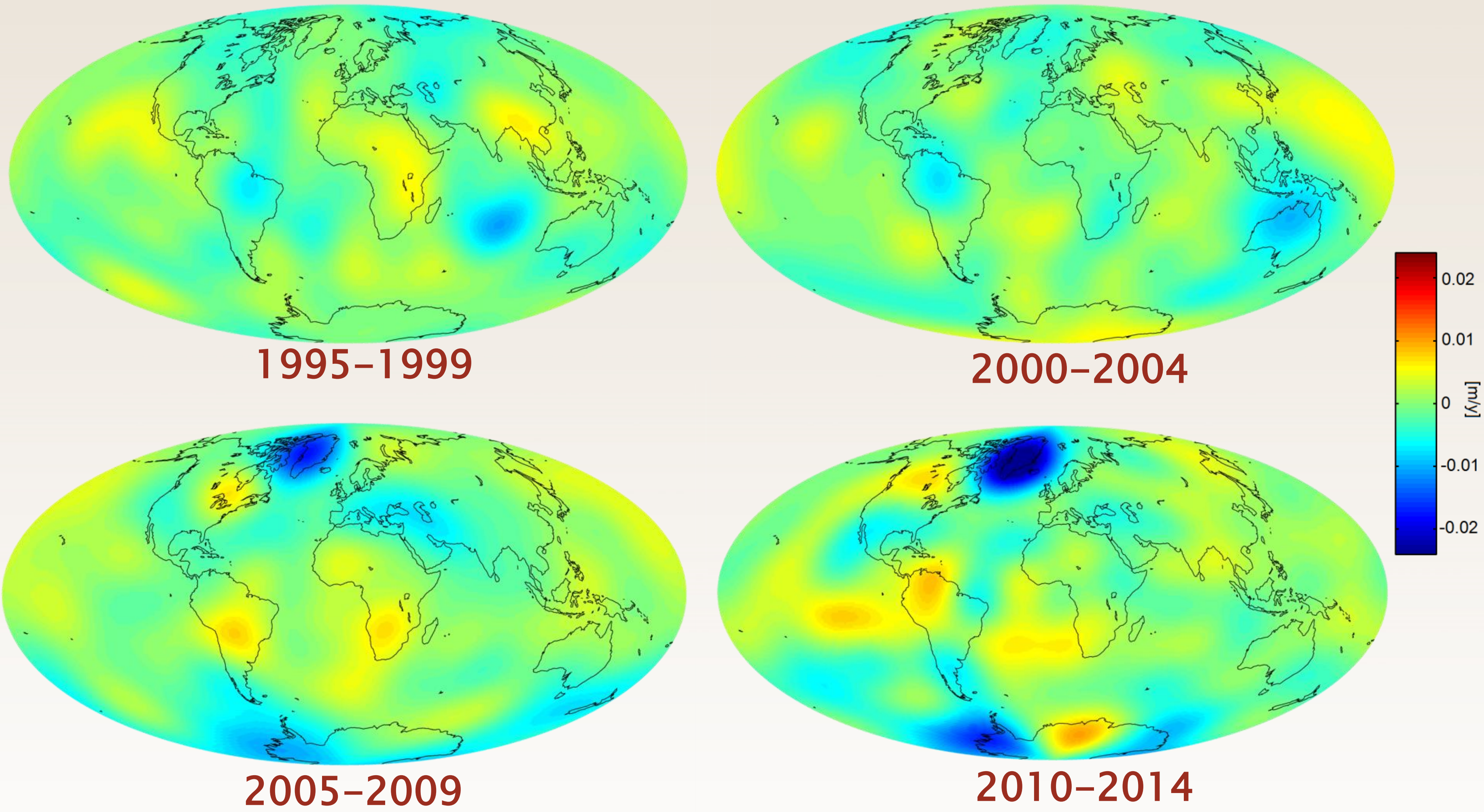
Comparison w.r.t. GRACE K-Band solutions



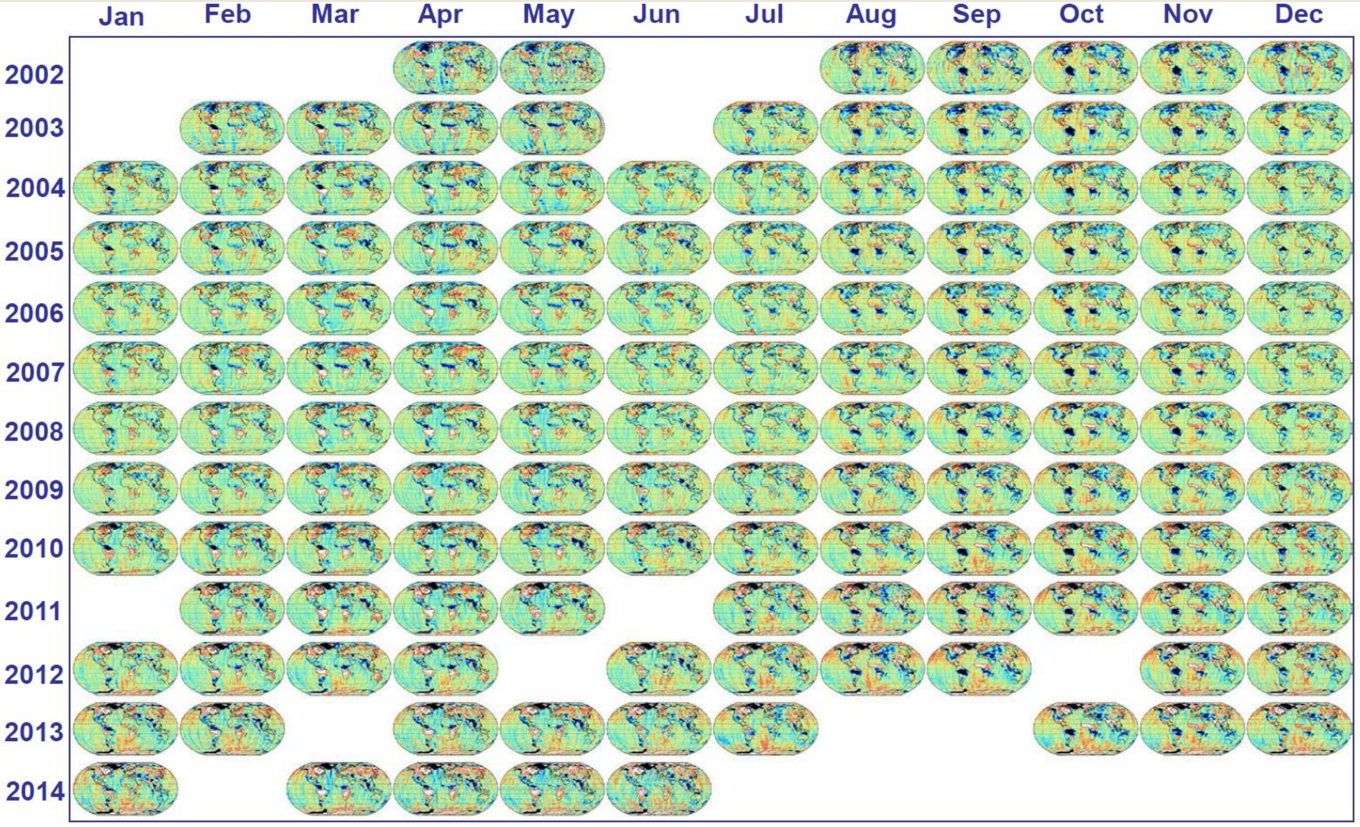
The SLR solutions can recover the largest seasonal and secular variations of the gravity field, which correspond to the large-scale mass transport in the system Earth, e.g., the accelerating ice mass depletion in Greenland.

The amplitudes in the SLR solutions up to d/o 10/10 are typically underestimated due to the limited sensitivity of SLR solutions to coefficients of degree 7-10.

Geoid height changes from SLR



GRACE monthly gravity field solutions



GRACE$_{K\text{-}Band}$ monthly gravity field solutions (CSR RL_05, status Oct 2014)

There are some gaps in the series of gravity field models due to K-Band outages, BUT the GPS receiver was active for most of the time.

=> Can the GRACE$_{GPS}$ + SLR combination replace GRACE$_{K\text{-}Band}$ solutions for the missing months?

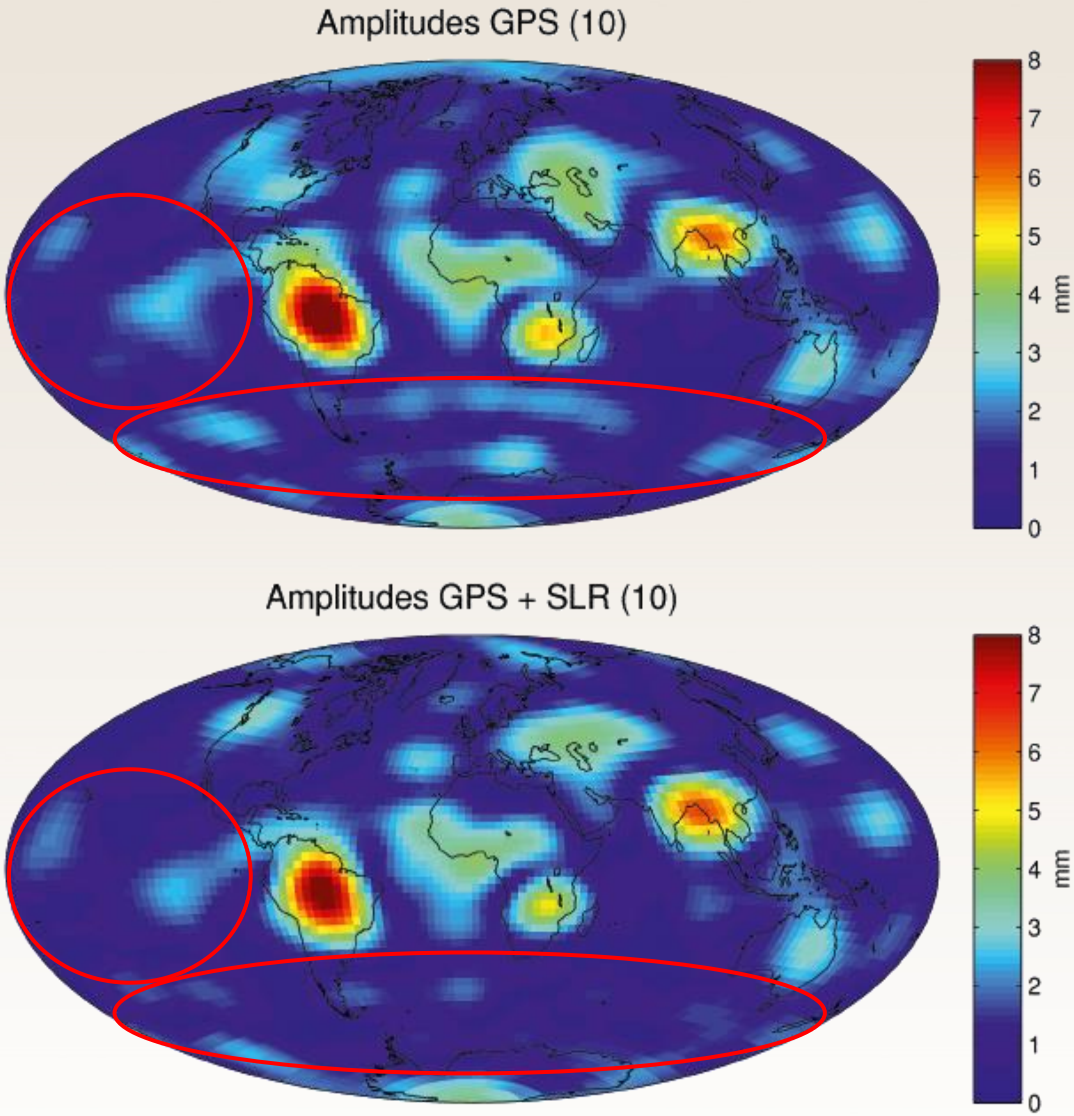
GRACE$_{GPS}$ + SLR combined solutions

SLR stabilizes the GRACE$_{GPS}$ solutions, in particular over the oceans.

The largest improvement is obtained for the southern hemisphere, despite barely few SLR stations in this region.

As a result the GRACE$_{GPS}$ +SLR solutions become more consistent with GRACE$_{K\text{-}Band}$ results.

=> GRACE$_{GPS}$ + SLR combination has a huge potential in filling the inner-GRACE gaps.



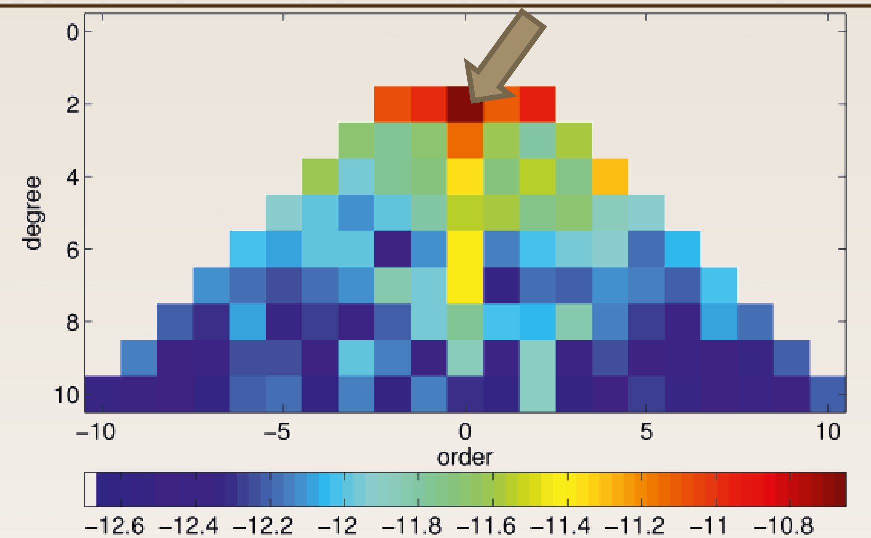
GRACE$_{K\text{-}Band}$ + GRACE$_{GPS}$ + SLR solutions

Can SLR contribute anything at all?

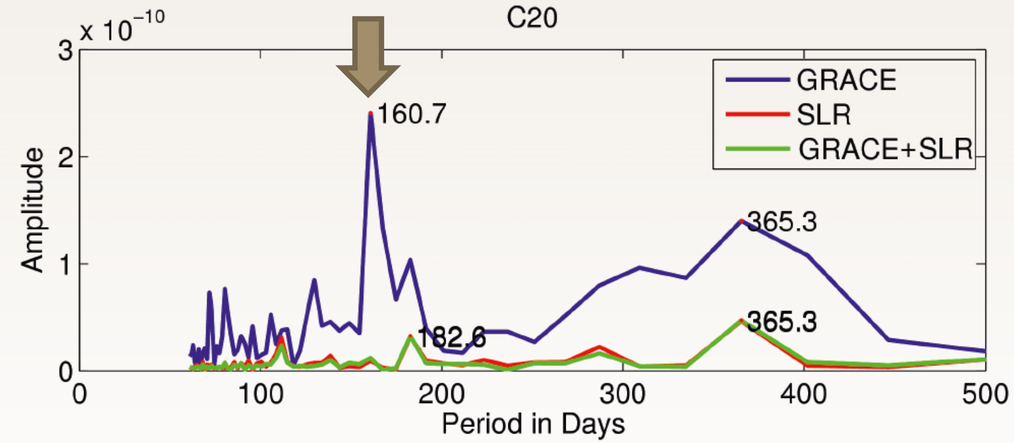
SLR contributes most to the zonal gravity field coefficients and the coefficients of degree-2.

C_{20} is degraded in the GRACE solutions due to long-period signals, because some signals in C_{20} have the same period as the S_2 and S_1 tidal aliases with GRACE orbits. This degradation is reflected in a large peak of 160 days in the C_{20} spectra.

Combination of GRACE with SLR solutions remarkably reduces the spurious 160-day peak in C_{20} series.



Impact of SLR on monthly GRACE$_{K\text{-}Band}$+ GRACE$_{GPS}$ solutions in terms of the RMS of the differences GRACE only – combined.



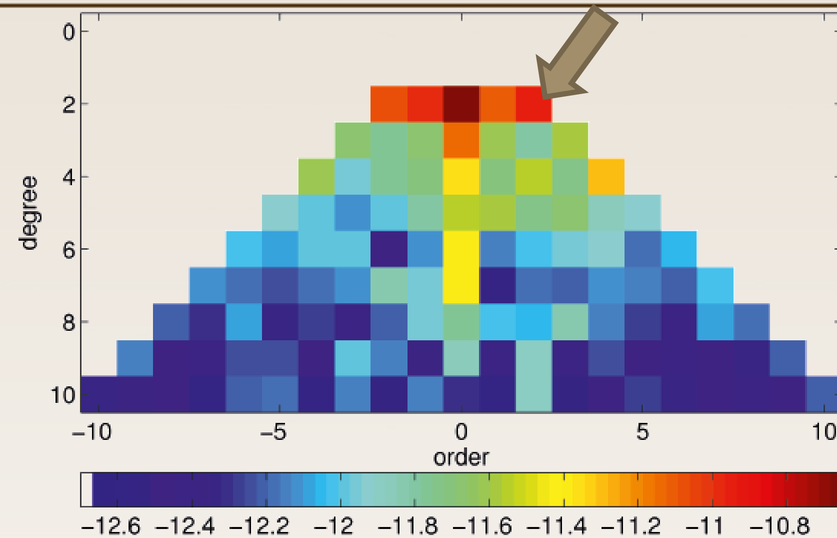
Spectra of monthly C20 -values from 2003-2013. GRACE solutions are affected by spurious signal at 160d-period that is cured by the combination with SLR.

GRACE$_{\text{K-Band}}$ + GRACE$_{\text{GPS}}$ + SLR solutions

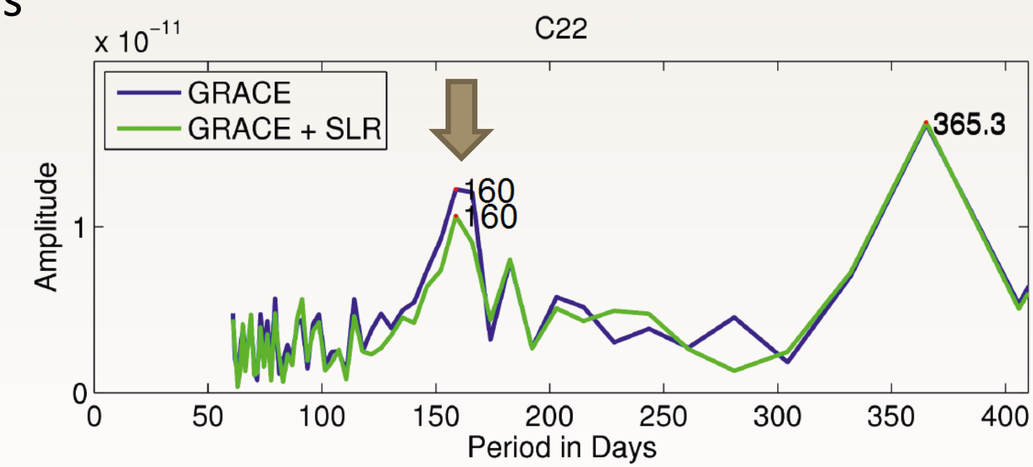
Can SLR contribute anything at all?

Not only C_{20} is improved by SLR, but also some other coefficients which are affected by the S_1/S_2 alias, e.g., C_{22}.

However, the impact of the S_1/S_2 alias is not fully removed.

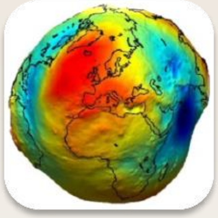


Impact of SLR on monthly GRACE$_{\text{K-Band}}$+ GRACE$_{\text{GPS}}$ solutions in terms of the RMS of the differences GRACE only – combined.

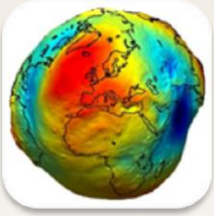


Summary

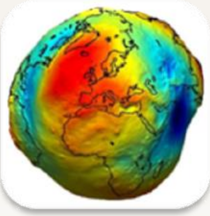
SLR or combined $GRACE_{GPS}$ + SLR solutions provide information about:



Gravity field variations prior to the launch of GRACE satellites,



Gravity field variations for the months with missing $GRACE_{K\text{-}Band}$ observations,



Gravity field variations between GRACE and GRACE-FO missions (in case of a GRACE failure).

The spurious peaks of 160 days due to S_1/S_2 aliasing are remarkably reduced for C_{20} and other coefficients when combining GRACE with SLR solutions.

Thank you
for your attention