SLR research activities and products @ DGFI-TUM

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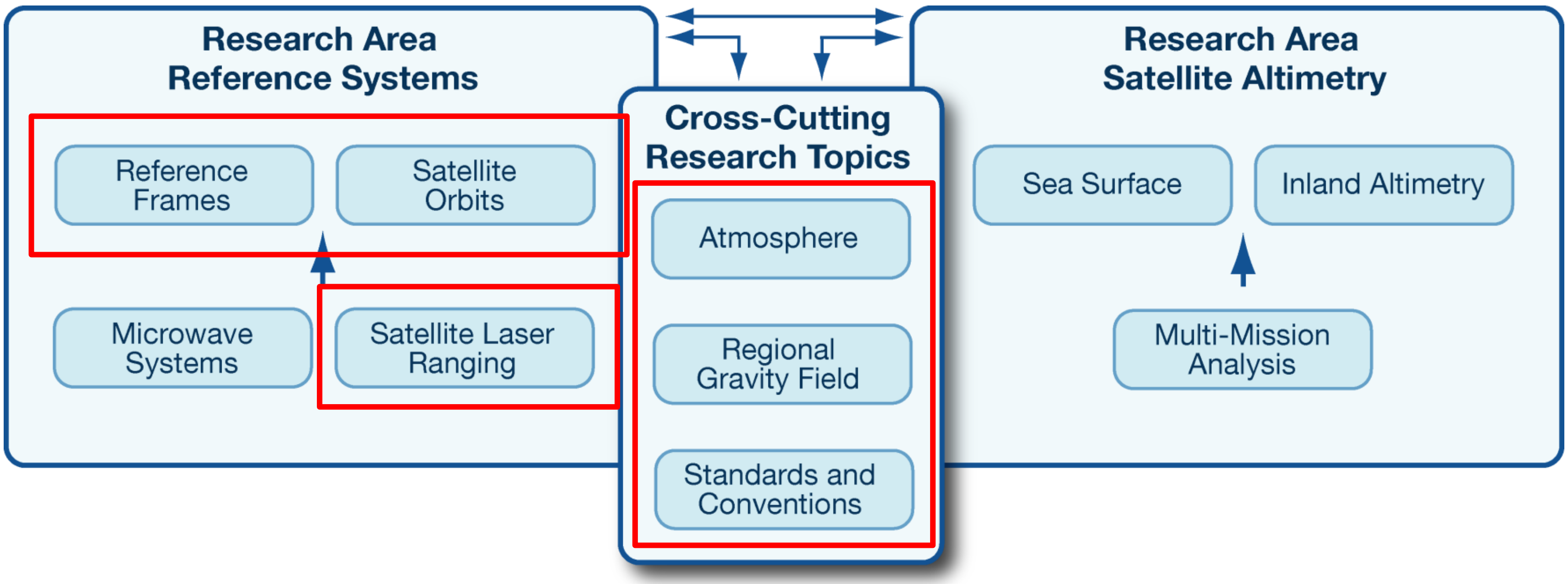
DGFI-TUM research program & scientific services

- SLR-related topics (red boxes) within the DGFI-TUM research program



- DGFI-TUM serves the **IAG-ILRS** as an **official analysis center** (AC) for many years
  - **ILRS Quality Control Center** (frequent bias estimation, SLRF station coordinate updates, performance feedback to SLR stations)
  - **ILRS Governing Board** member & **Data Center (DC) representative**
  - ILRS Data Formats and Procedures working group/several ILRS pilot projects
- **Eurolas Data Center (EDC)** and **ILRS Operation Center**

DGFI-TUM SLR software DOGS-OC/CS

- DGFI-TUM developed its own software to analyze SLR observations called DGFI Orbit and Geodetic parameter estimation Software (DOGS)
  - **DOGS-OC** (Orbit Computation): dynamic orbit integration, simulation of SLR observations/stations/satellites, POD
  - **DOGS-CS** (Combination and Solution): combination of satellite-/technique-specific NEQs, computation of minimum-/loose-constrained solutions (e.g., DTRF2008/DTRF2014)

- With DOGS-OC/CS, it is possible to compute SLR normal equations (NEQs) …

  … which comprise SLR observations to **numerous spherical** and **non-spherical satellites** (altitudes between 250 km and 20000 km)

  … which cover a time span from **1972 until 2016**

  … based on different arc lengths (**daily, weekly, 2-weekly, monthly**)

  … which include station coordinates, EOP, Stokes coefficients, etc.

  … which are based on various geophysical a priori models (ocean tides, ...)

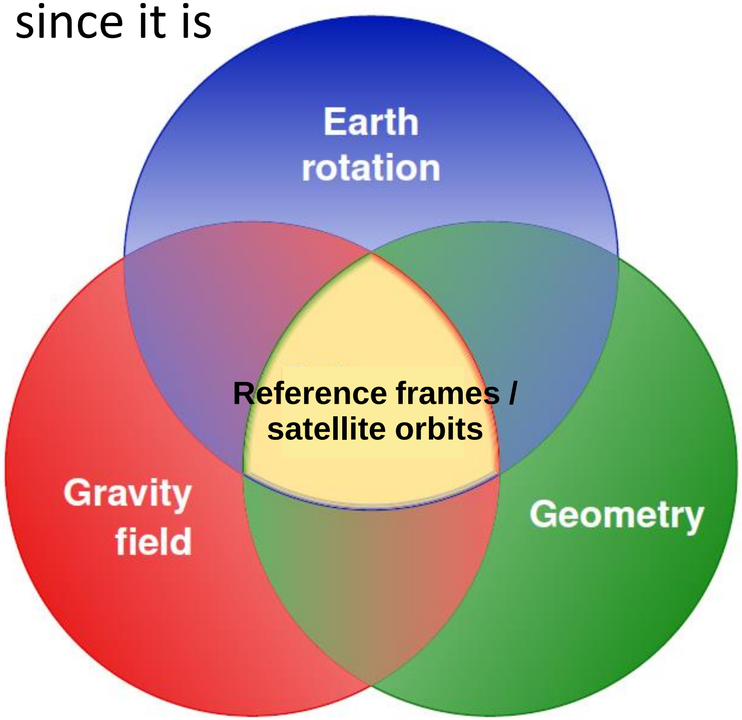
Bloßfeld M.: **The key role of Satellite Laser Ranging towards the integrated estimation of geometry, rotation and gravitational field of the Earth**. Dissertation, Technical University of Munich and Reihe C of the Deutsche Geodätische Kommission ISBN: 978-3-7696-5157-7, 2015

The key role of SLR for GGOS

- SLR is capable to determine the fundamental geodetic parameters of the Global Geodetic Observing System with high accuracy, since it is

  sensitive w.r.t. the reference frames (ITRF/satellite orbits) and EOP:
  measurement principle: 2-way light travel time measurements from crust-fixed stations to satellites in the inertial frame

  sensitive to the long wavelengths of the Earth's gravity field (Stokes coefficients):
  measured orbit disturbances of spherical satellites



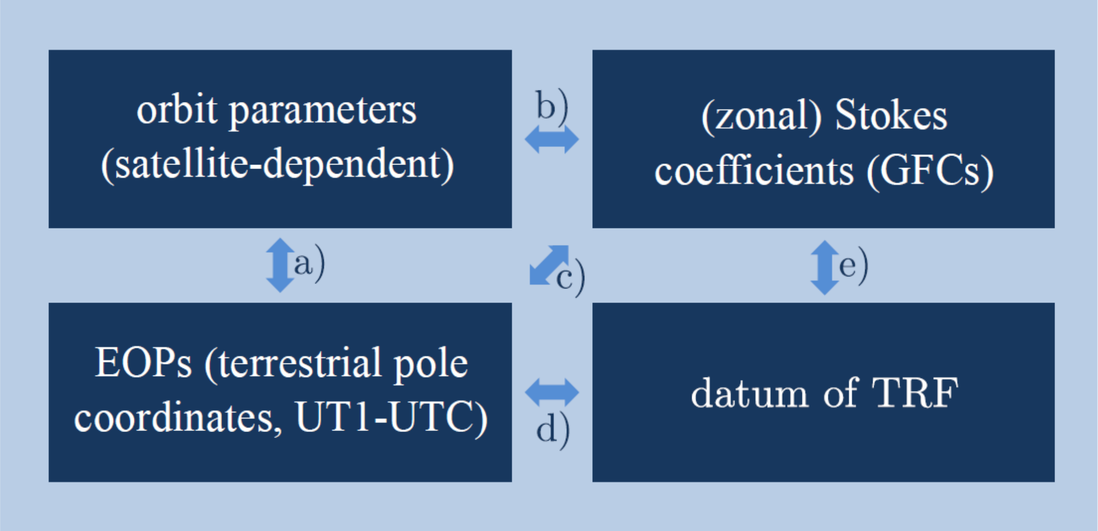
[acc. Rummel, 2000; Plag & Pearlman, 2009]

- **SLR is the unique measurement technique which allows an accurate and consistent estimation of TRF, EOP and Stokes coefficients**
- **BUT: if all parameters are estimated together, correlations might corrupt reliable estimates**

Bloßfeld M., Stefka V., Müller H., Gerstl M.: **Satellite laser ranging - a tool to realize GGOS?**. IAG Symposia 143, DOI: 10.1007/1345_2015_202, 2015

The key role of SLR for GGOS - correlations

- Parameter correlations related to Stokes coefficients



- b) correlations of orbit parameters and Stokes coefficients
- c) correlations of LOD and C_{l0}; x_p/y_p with C_{21}/S_{21}
- e) correlation of TRF scale with C_{00}; origin with $C_{10}/C_{11}/S_{11}$; orientation with $C_{21}/S_{21}/C_{22}/S_{22}$

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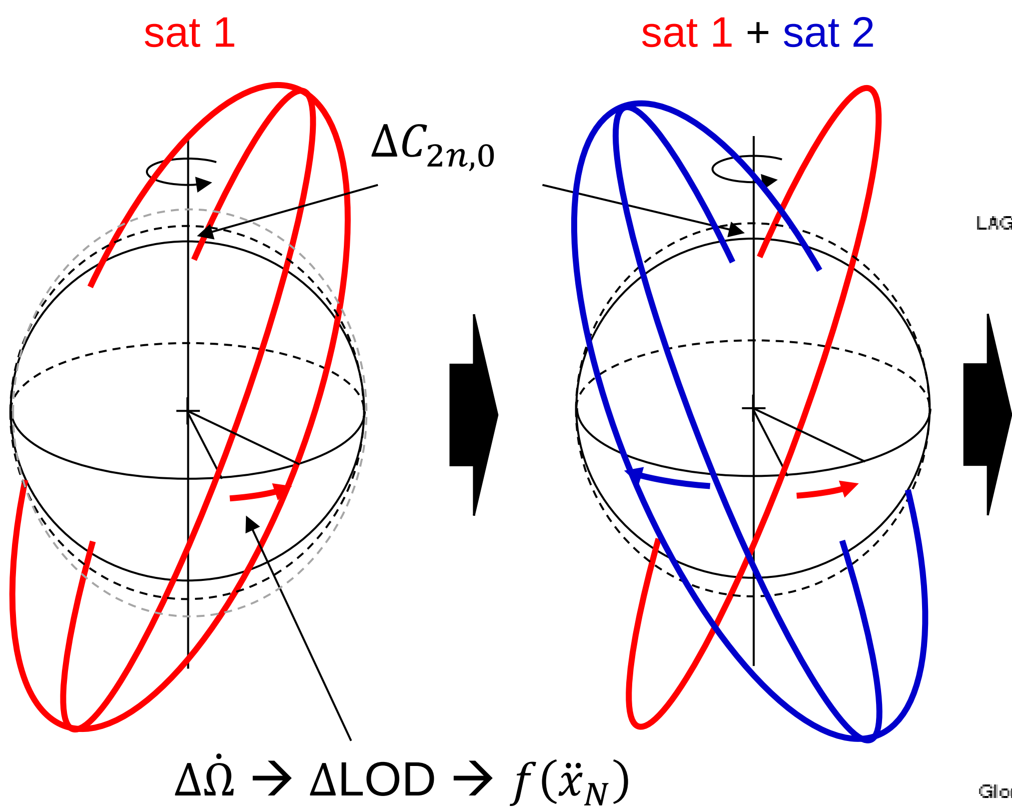
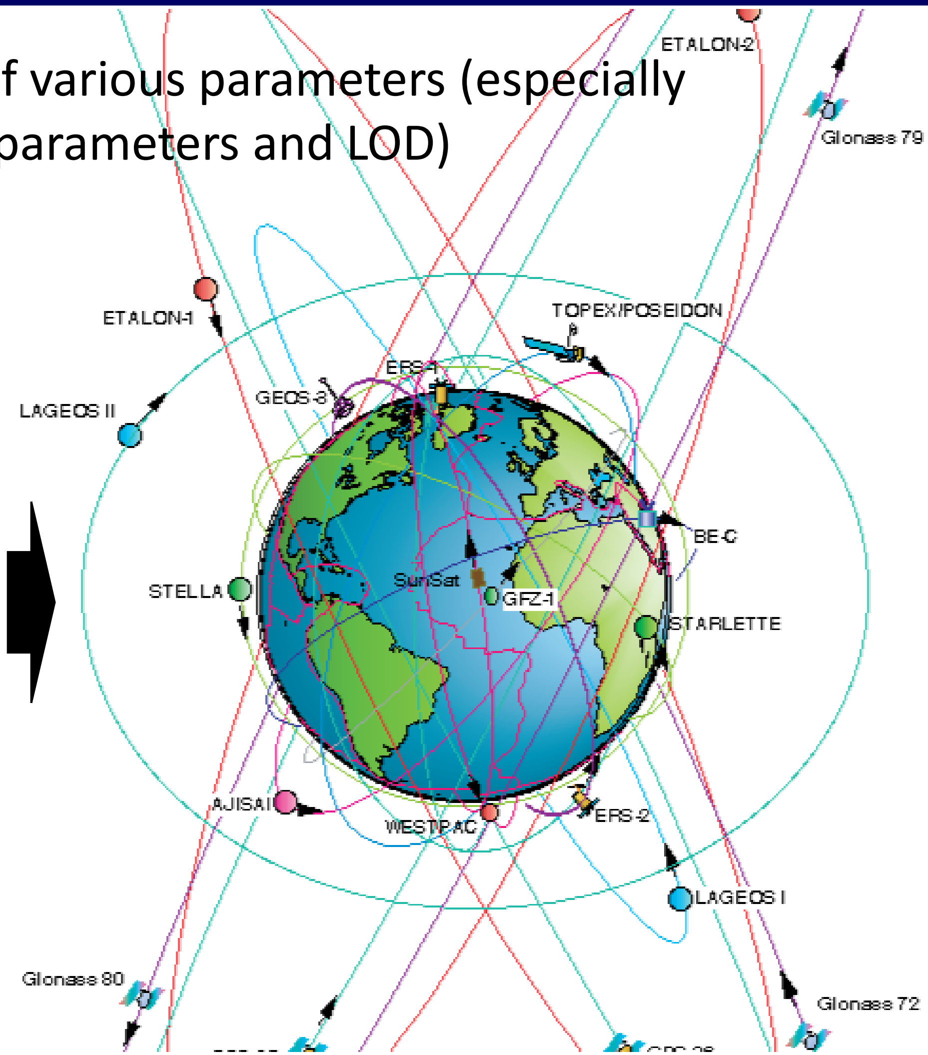
DGFI-TUM SLR multi-satellite solution

- Single-satellite solution: high correlation of various parameters (especially between zonal coefficients, satellite orbit parameters and LOD)



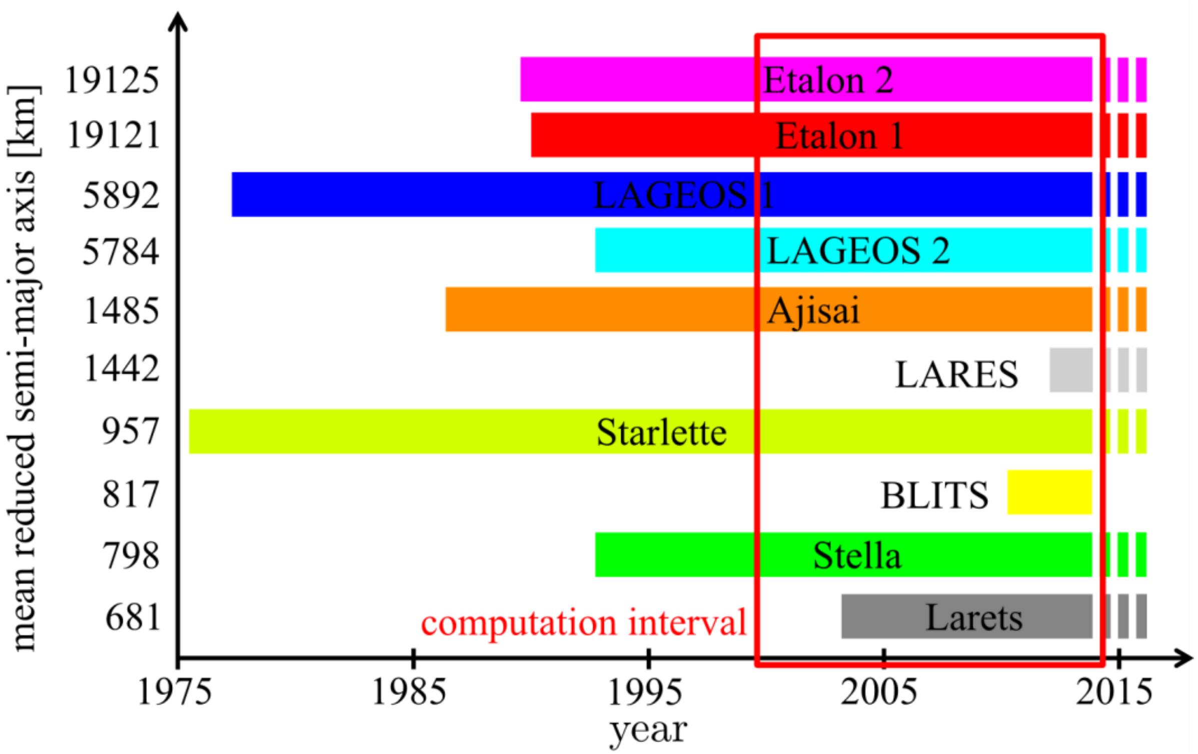


- Multi-satellite solution (MSS): de-correlation of parameters due to combination of inclinations (e.g. C_{l0} and Ω) → reliable estimates of zonal coefficients

Bloßfeld M., Gerstl M., Hugentobler U., Angermann D., Müller H.: **Systematic effects in LOD from SLR observations**. Advances in Space Research 54(6): 1049-1063, 10.1016/j.asr.2014.06.009, 2014

DGFI-TUM SLR MSS – de-correlation of C_{l0} and Ω

- DGFI-TUM SLR MSS comprises SLR observations to up to 10 spherical satellites
- relative weighting realized via Variance Component Estimation (VCE)
- Etalon1/2, BLITS and Larets do not help to significantly decrease $\rho(C_{20}, \Omega)$



solution	$\rho(C_{20}, \Omega)$
LA 1	1.00
LA 1/2	0.44
LA 1/2 + ET 1/2	0.44
4-sat. + BTS	0.43
4-sat. + LTS	0.41
4-sat. + STE	0.31
4-sat. + STA	0.28
4-sat. + AJI	0.24
4-sat. + LRS	0.24
10-sat.	0.08

Bloßfeld M., Müller H., Gerstl M., Stefka V., Bouman J., Göttl F., Horwath M.: **Second-degree Stokes coefficients from multi-satellite SLR**. Journal of Geodesy 89(9): 857-871, 10.1007/s00190-015-0819-z, 2015

DGFI-TUM SLR MSS – C_{2m} estimates

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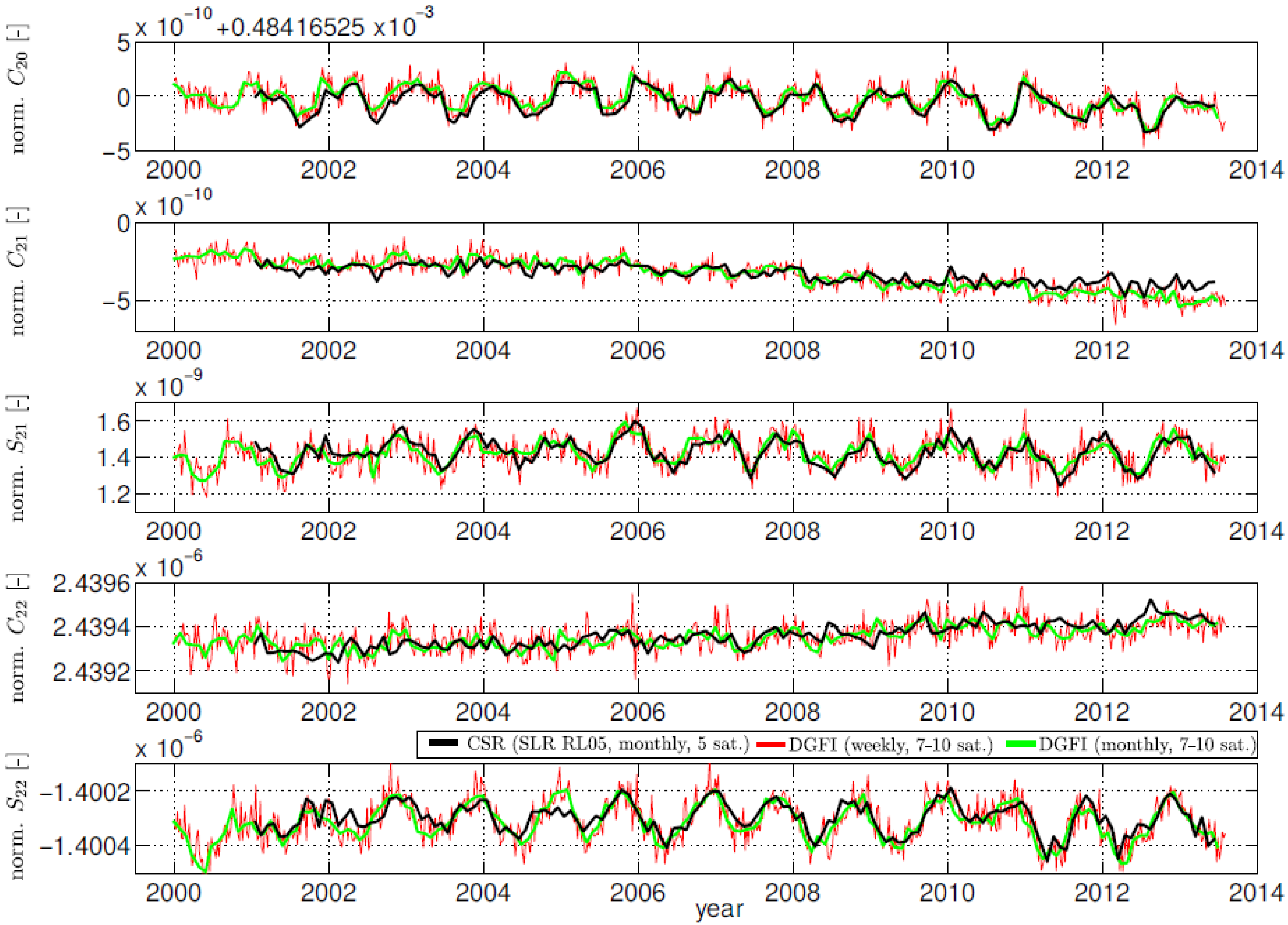

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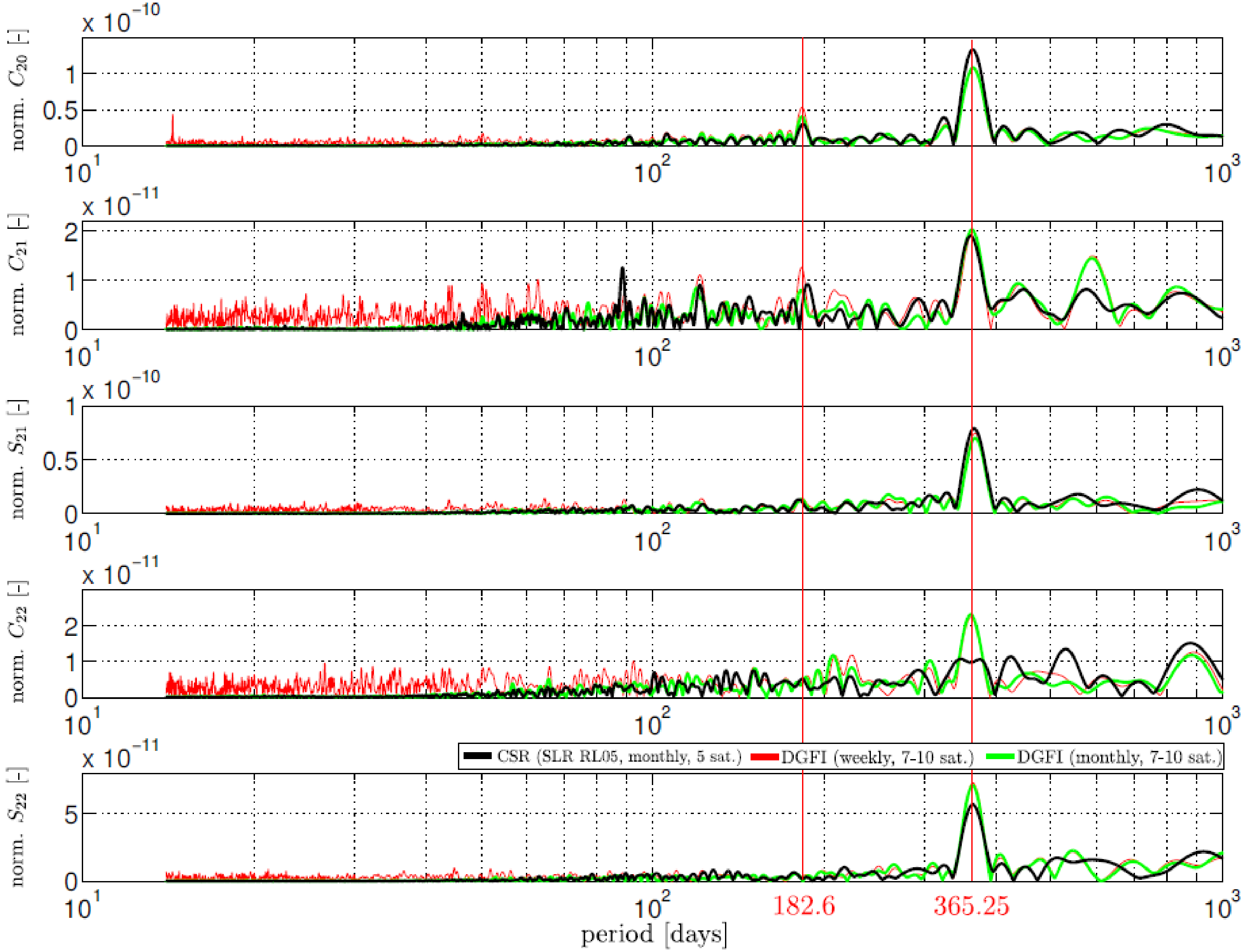
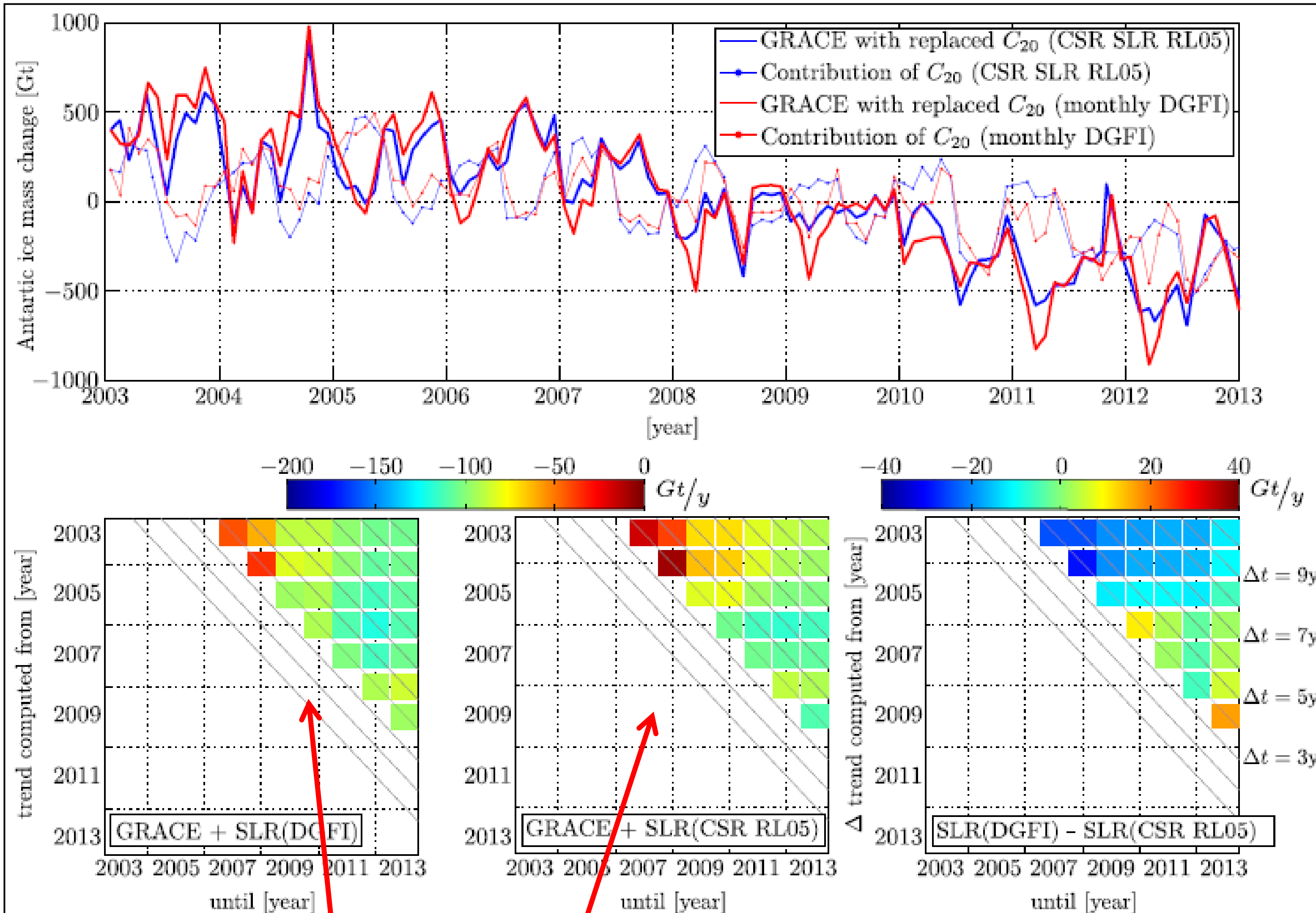


Bloßfeld M., Müller H., Gerstl M., Stefka V., Bouman J., Göttl F., Horwath M.: **Second-degree Stokes coefficients from multi-satellite SLR**. Journal of Geodesy 89(9): 857-871, 10.1007/s00190-015-0819-z, 2015

Different estimates of C_{20} – geophysical interpretation

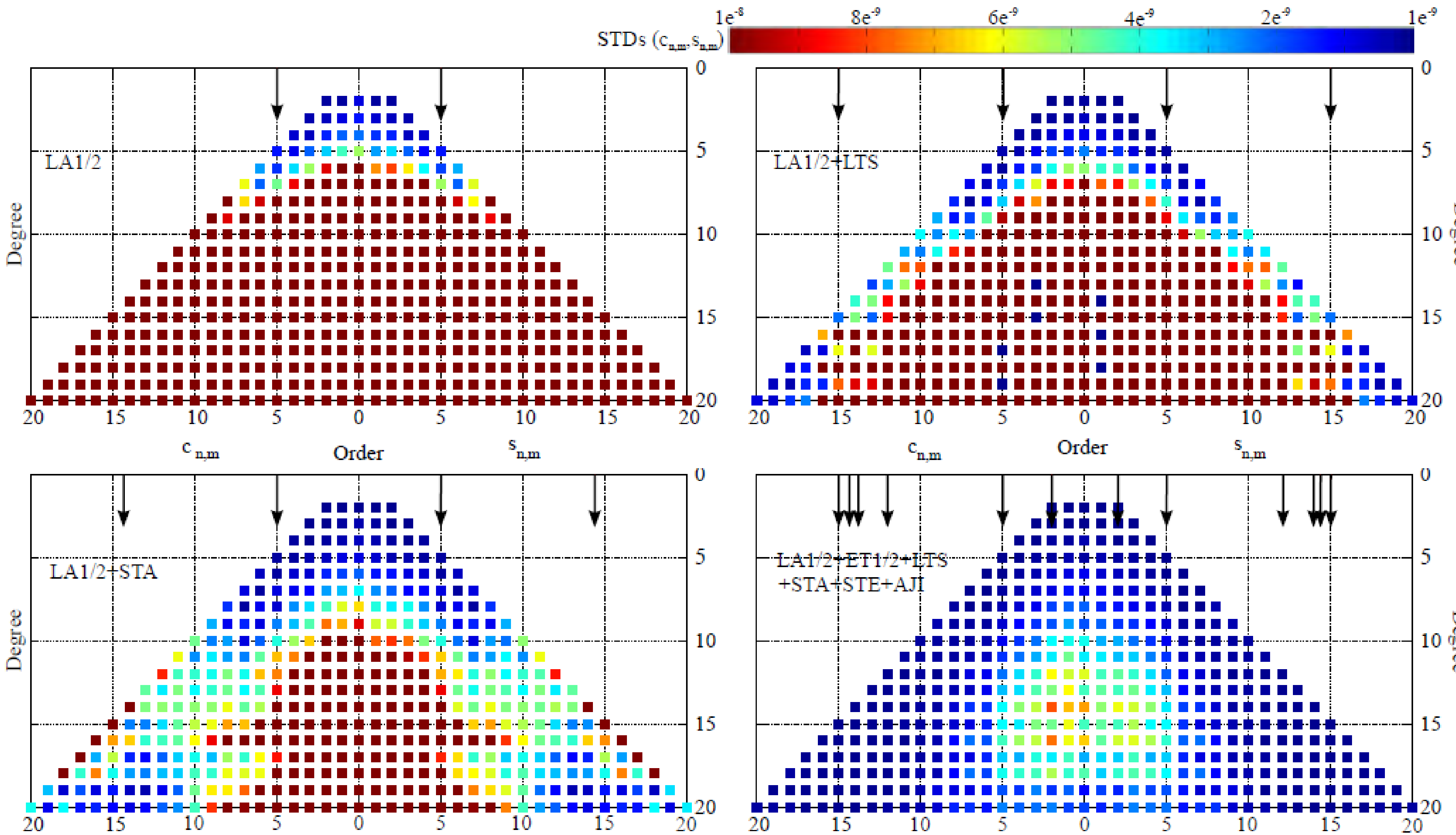


Larger acceleration of ice mass loss in CSR solution compared to DGFI solution

Bloßfeld M., Müller H., Gerstl M., Stefka V., Bouman J., Göttl F., Horwath M.: **Second-degree Stokes coefficients from multi-satellite SLR**. Journal of Geodesy 89(9): 857-871, 10.1007/s00190-015-0819-z, 2015

DGFI-TUM SLR MSS – Stokes coefficients

- Estimated STDs of Stokes coefficients (stabilized) up to d/o 20 for January 2007



Bloßfeld M., Müller H., Gerstl M., Stefka V., Bouman J., Göttl F., Horwath M.: **Second-degree Stokes coefficients from multi-satellite SLR**. Journal of Geodesy 89(9): 857-871, 10.1007/s00190-015-0819-z, 2015

Combination of SLR and GRACE @ DGFI-TUM

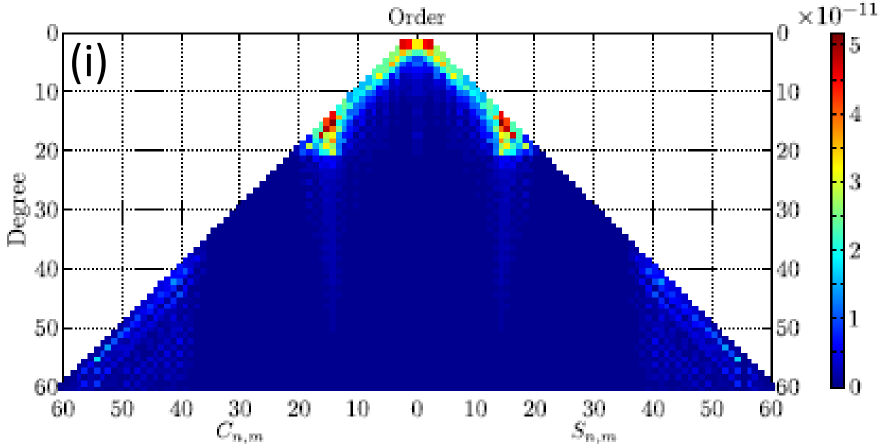


Fig. 4 STDs of the GRACE-only solution minus STDs of the combined solution. $\hat{\sigma}^2_{GRACE} = 8.8 \cdot 10^{-11}$ and $\hat{\sigma}^2_{SLR} = 7.9 \cdot 10^{-1}$.

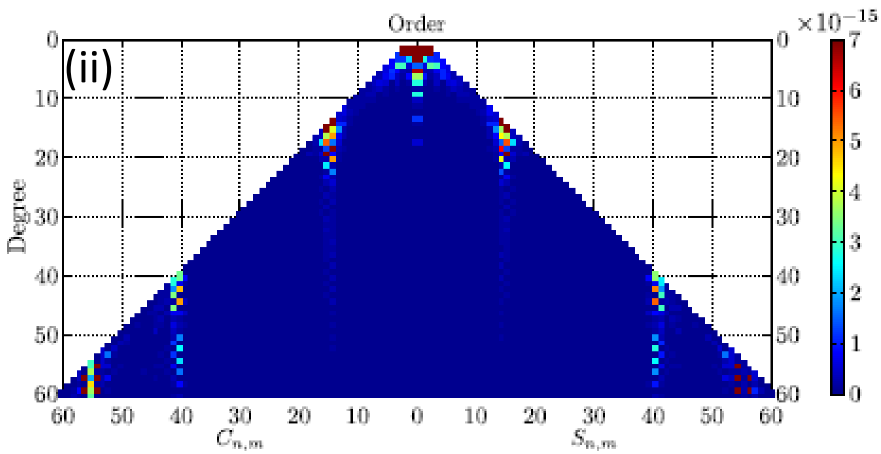


Fig. 5 STDs of the GRACE-only solution minus STDs of the combined solution. $\hat{\sigma}^2_{GRACE} = 1.6 \cdot 10^{-14}$ and $\hat{\sigma}^2_{SLR} = 7.9 \cdot 10^{-1}$.

- Combination of SLR and GRACE NEQs
- GRACE: monthly arc based on IEA approach (KBR-data only)
- 2 scenarios:
  - (i) **optimistic rel. weight** of GRACE NEQ:
    large improvements of STDs caused by SLR especially on degree 2 and tesseral coefficients
  - (ii) **realistic rel. weight** of GRACE NEQ:
    still improvements on degree 2 coefficients and satellite resonance frequencies are visible

Haberkorn C., Bloßfeld M., Bouman J., Fuchs M., Schmidt M.: **Towards a consistent estimation of the Earth`s gravity field by combining normal equation matrices from GRACE and SLR**. IAG Symposia 143, DOI: 10.1007/1345_2015_76, 2015

TUM

DGFI

Possible contributions to EGSIEM (e.g., validation) …

- DGFI-TUM can provide SLR NEQs with full variance/co-variance information in SINEX format …

  … which comprise SLR observations to **numerous spherical** and/or **non-spherical satellites** with altitudes between 250 km and 20000 km

  … which cover a time span from **1972 until 2016**

  … which are based on various arc lengths (**daily, weekly, 2-weekly, monthly**)

  … which include (station coordinates, EOP), **Stokes coefficients (up to d/o 60)**, etc…

  … which are based on **numerous different a priori models** (ocean tides, non-tidal loading effects, relativistic effects, …) → EGSIEM standards?

name	parai
orbital elements	initial set of osculatir
empirical accelerations	daily offsets at 0 h in ; sine-/cosine-term* in ;
solar radiation scaling coef.	weekly offset
atmospheric drag scaling coef. (for LEOs)	daily of
station coordinates (in SLRF2008)	weekly offsets
station coordinates (not in SLRF2008)	weekly offsets
station dependent range bias	weekly offsets
terrestrial pole coordinates	daily of
Length-Of-Day (LOD)	daily offs
Stokes coefficients with degree/order ≤ 6	weekly offsets
Stokes coefficients with degree/order > 6	weekly offsets

effect	model
station coordinates	updated SLRF2008
EOPs	IERS 08 C04
mean pole	(*Petit and Luzum*, 2010)
solid Earth tides (station)	IERS2003, anelastic
solid Earth tides (orbit)	IERS2003, anelastic
ocean tides (station)	FES2004 (*Lyard et al.*, 2006)
ocean tides (orbit)	FES2004 + BB2003 (*Biancale and Bode*, 2006) + 62 adm. waves (*Petit and Luzum*, 2010)
ocean pole tide (station)	*Desai* (2002)
ocean pole tide (orbit)	*Desai* (2002)
Earth's gravitational field	EIGEN-6s ($n, m \leq 120$)
atmospheric density model	JB2008 (*Bowman et al.*, 2008)
atmospheric tides (station)	*Ray and Ponte* (2003)

In the table, (E) means estimated, (L) means eliminated and (R) means reduced. * once-per-revolution

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