GFR processing standards at IfE

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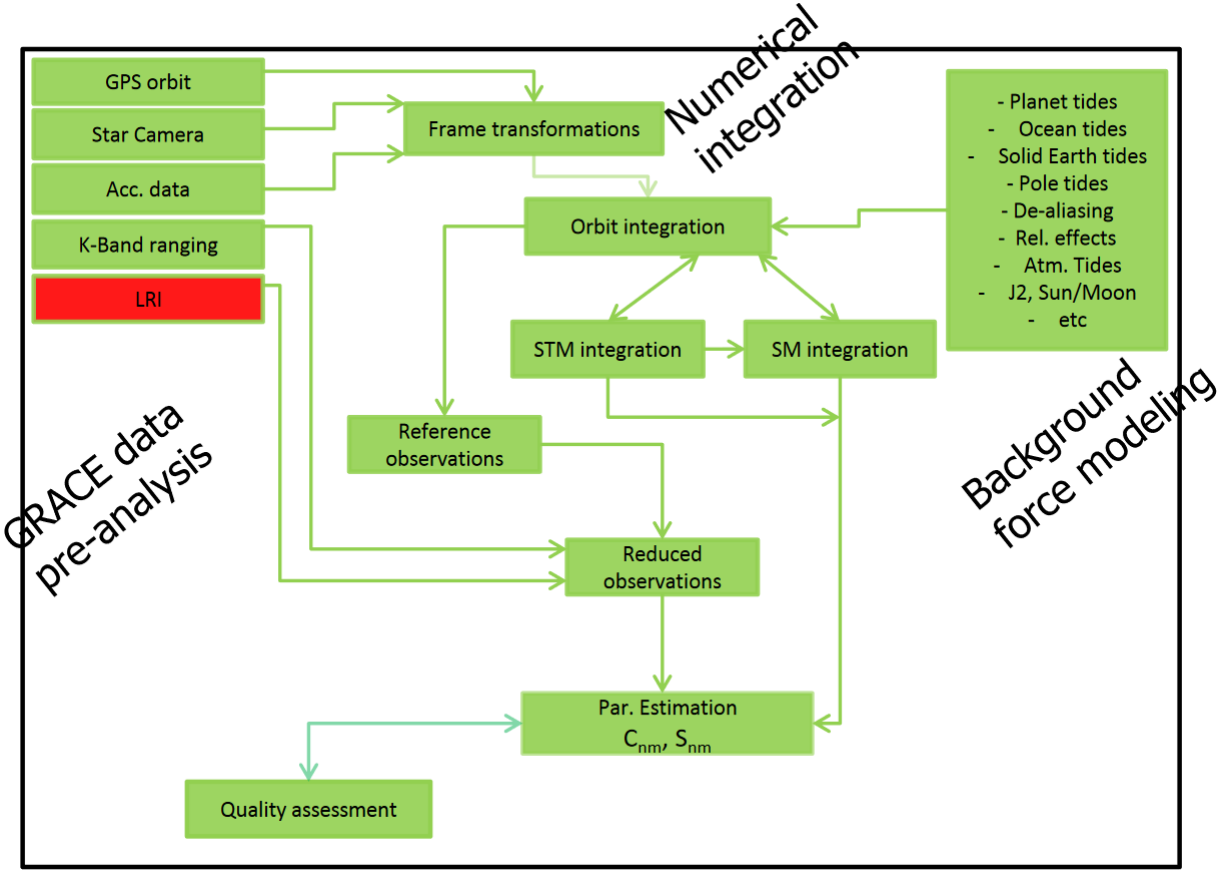
GRACE-SIGMA

- New compact software package for gravity field recovery from GRACE sensor data
- Implemented in MATLAB from scratch [M. Naeimi et al., 2018]
- Competitive run time
- Variational equations approach

GFR overview



[Naeimi et al., 2018]

Variational equations approach

$$\dot{\rho}_o = \dot{\rho}_{ref} + \frac{\partial \dot{\rho}_{ref}}{\partial u}\delta u$$

$$\dot{\rho}_o - \dot{\rho}_{ref} = \frac{\partial \dot{\rho}_{ref}}{\partial u}\delta u$$

$$\Delta\dot{\rho} = \mathbf{A}\delta u$$

Important aspects:

- Numerical integration
- Force modeling
- Adjustment strategy

Numerical integration

- Modified Gauss-Jackson integrator
- Without correction step (contribution to the position vector below 1E-12 m)
- Multistep integration method (→ RK4 for initialization)
- Vectorized computation of ephemerides, STM and SM

- More information:

M. Naeimi: A modified Gauss-Jackson method for the numerical integration of the variational equations, poster, EGU 2018, Vienna.

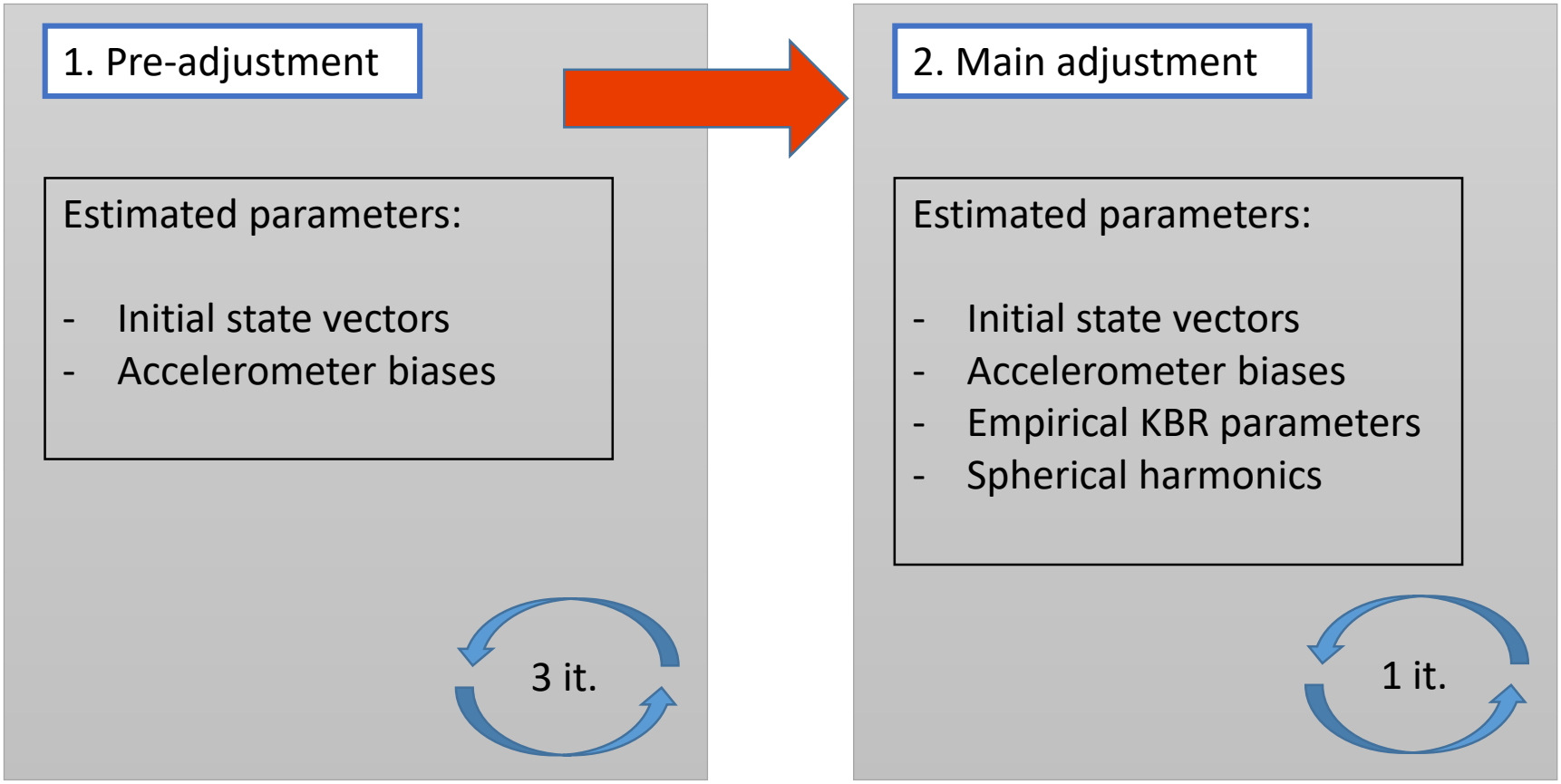
Force modeling

Effect	Model	Reference
Gravity field	GIF48 (d/o: 300)	Ries et al., 2011
Third bodies	Moon and Sun, Ephemerides: DE405	Standish, 1998
Solid Earth tides	IERS Conventions	Petit a. Luzum, 2010
Ocean tides	EOT11a including minor waves (d/o: 80)	Rieser et al., 2012
Solid Earth pole tides	IERS Conventions	Petit a. Luzum, 2010
Ocean pole tides	IERS Conventions (d/o: 60)	Petit a. Luzum, 2010
Relativistic	IERS Conventions	Petit a. Luzum, 2010
Non-tidal	AOD1B RL05 (d/o: 100)	Flechtner et al., 2015
Non-gravitational	Linear acceleration measurements	Case et al., 2010

Force modeling

- In order to decrease the computational time, the major part of the force effects is calculated once using the L1B reduced dynamic orbits
- During orbit improvement these effects are not re-computed
- Only accelerations due to the geopotential and non-gravitational accelerations are evaluated every iteration

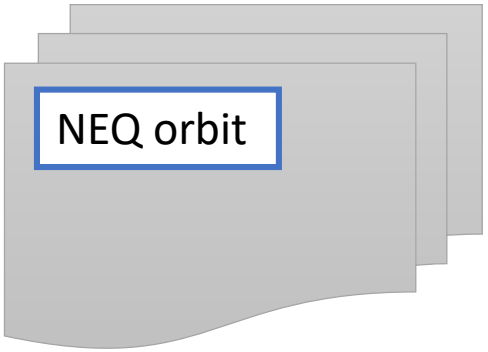
Adjustment strategy

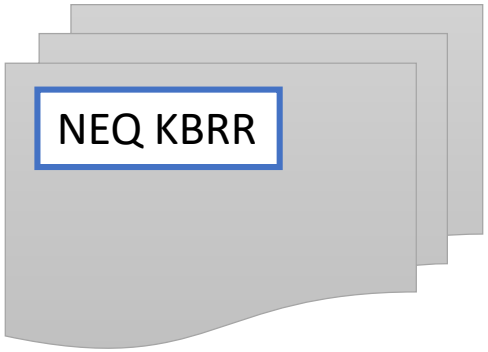


Stochastic modeling

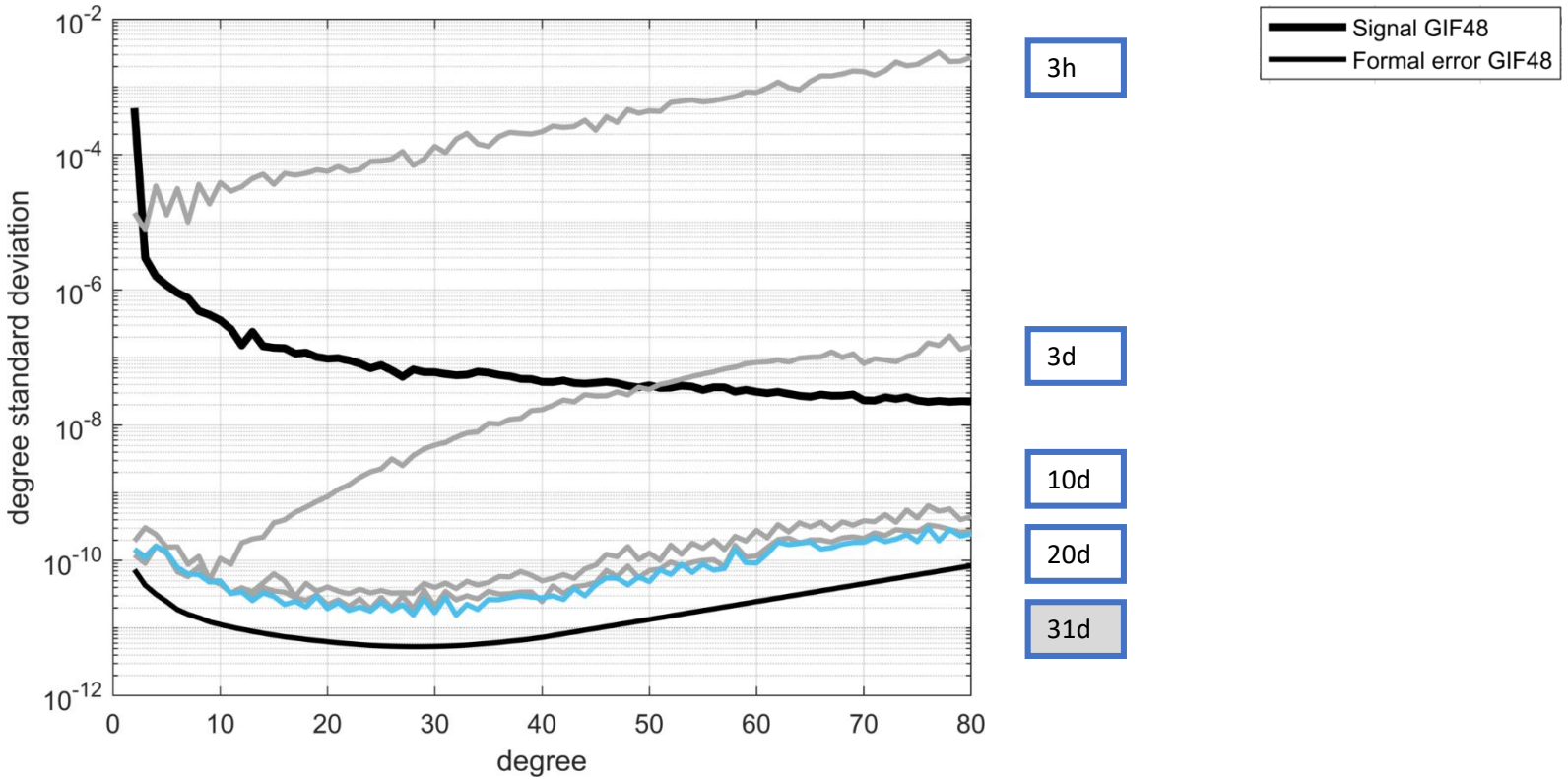
- Orbit (30 sec) + KBRR (5 sec)
- $\sigma_{\mathrm{Orbit}} = 1\mathrm{E}\text{-}02$ m $\quad \sigma_{\mathrm{KBRR}} = 1\mathrm{E}\text{-}07$ m/s

- → relative weighting of normal matrices

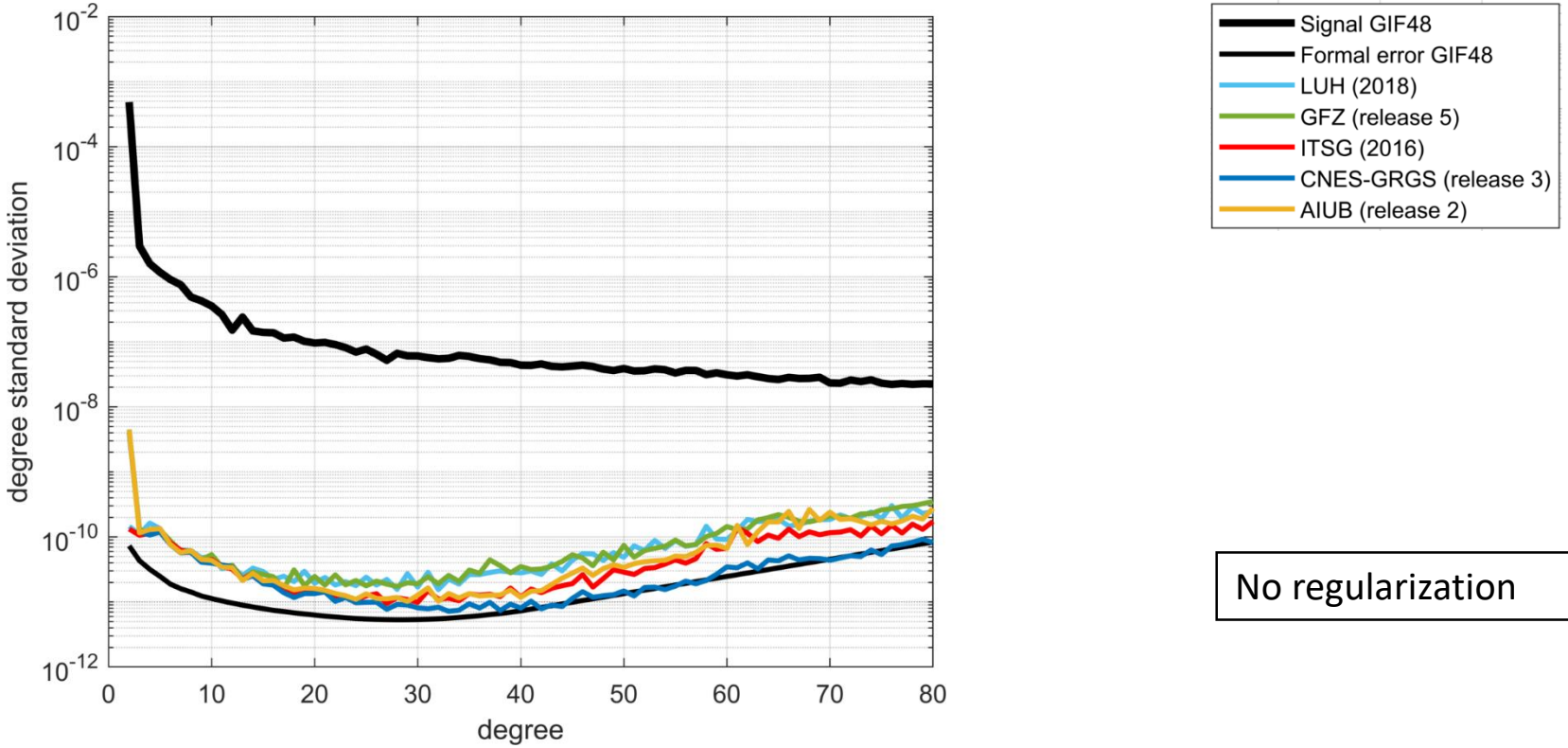
1 × 

1E10 × 

Arcwise NEQ stacking

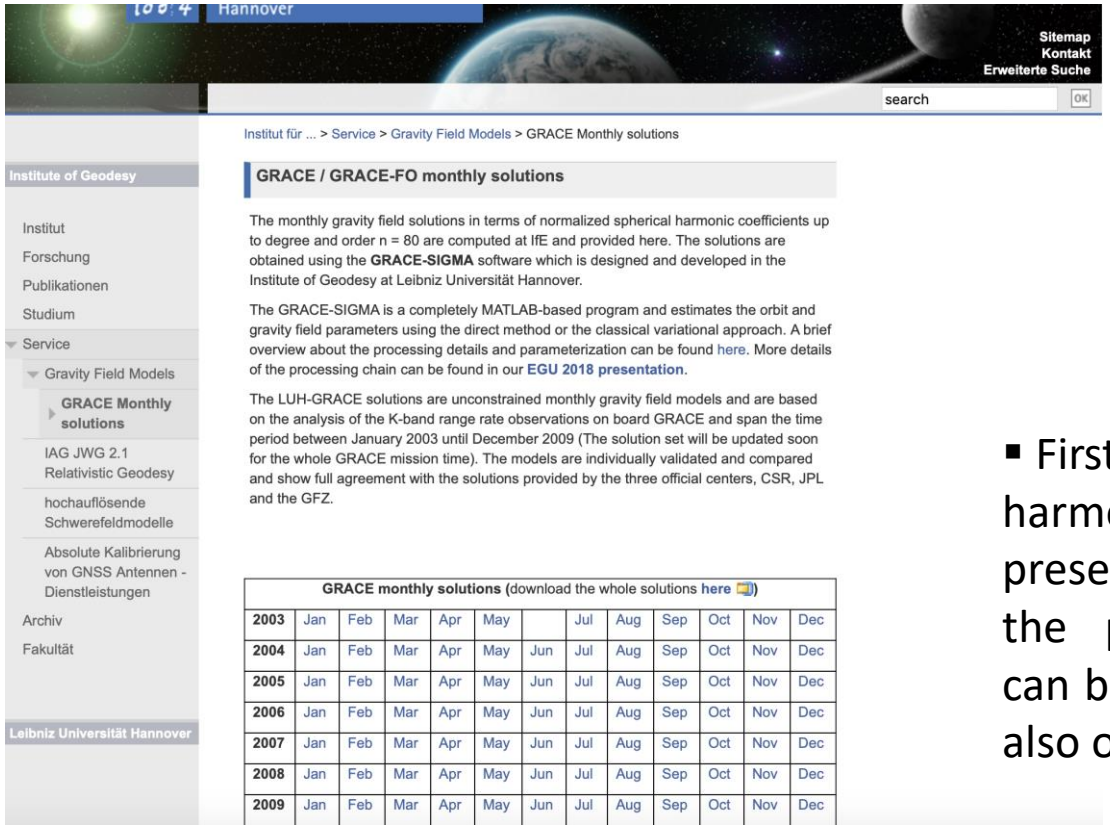


Arcwise NEQ stacking



No regularization

Published solutions



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GRACE / GRACE-FO monthly solutions

The monthly gravity field solutions in terms of normalized spherical harmonic coefficients up to degree and order n = 80 are computed at IfE and provided here. The solutions are obtained using the **GRACE-SIGMA** software which is designed and developed in the Institute of Geodesy at Leibniz Universität Hannover.

The GRACE-SIGMA is a completely MATLAB-based program and estimates the orbit and gravity field parameters using the direct method or the classical variational approach. A brief overview about the processing details and parameterization can be found here. More details of the processing chain can be found in our **EGU 2018 presentation**.

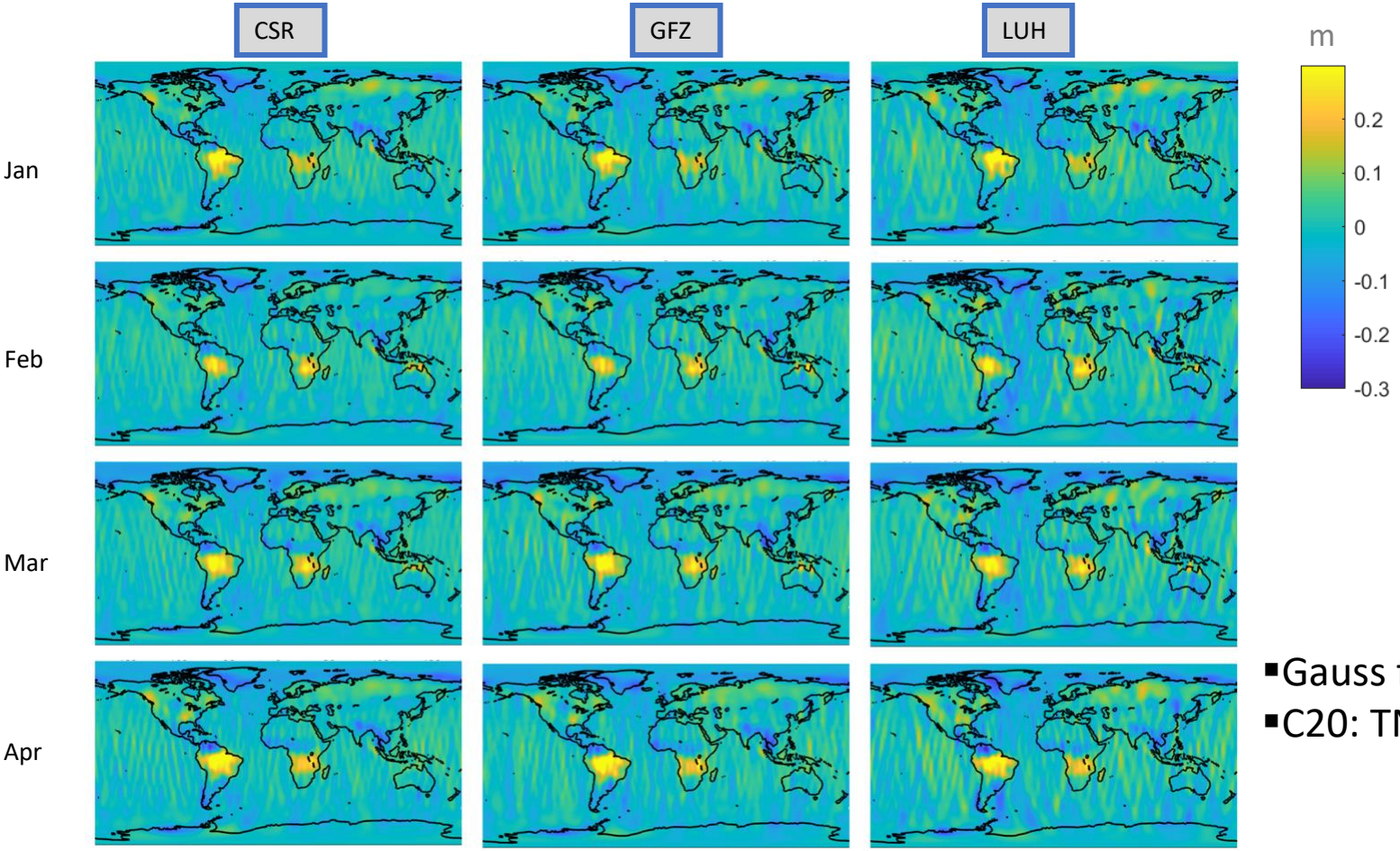
The LUH-GRACE solutions are unconstrained monthly gravity field models and are based on the analysis of the K-band range rate observations on board GRACE and span the time period between January 2003 until December 2009 (The solution set will be updated soon for the whole GRACE mission time). The models are individually validated and compared and show full agreement with the solutions provided by the three official centers, CSR, JPL and the GFZ.

GRACE monthly solutions (download the whole solutions here)

2003	Jan	Feb	Mar	Apr	May		Jul	Aug	Sep	Oct	Nov	Dec
2004	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2005	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2006	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2007	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2008	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2009	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec

- First batch of spherical harmonics using the presented strategy for the period 2003-2009 can be found on IfE and also on ICGEM website

Exemplary EWHs (2008)



- Gauss filter (350 km)
- C20: TN SLR values

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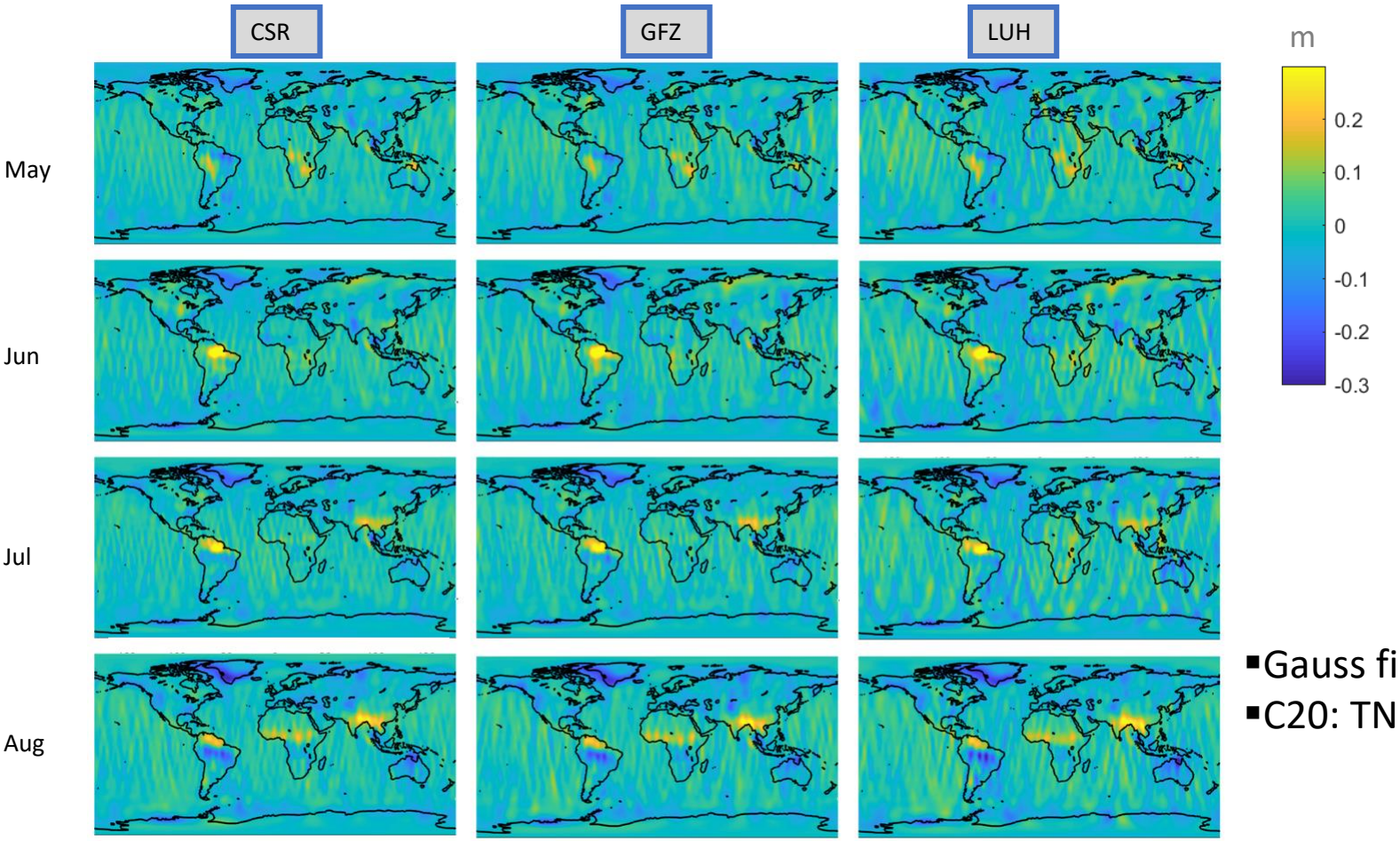

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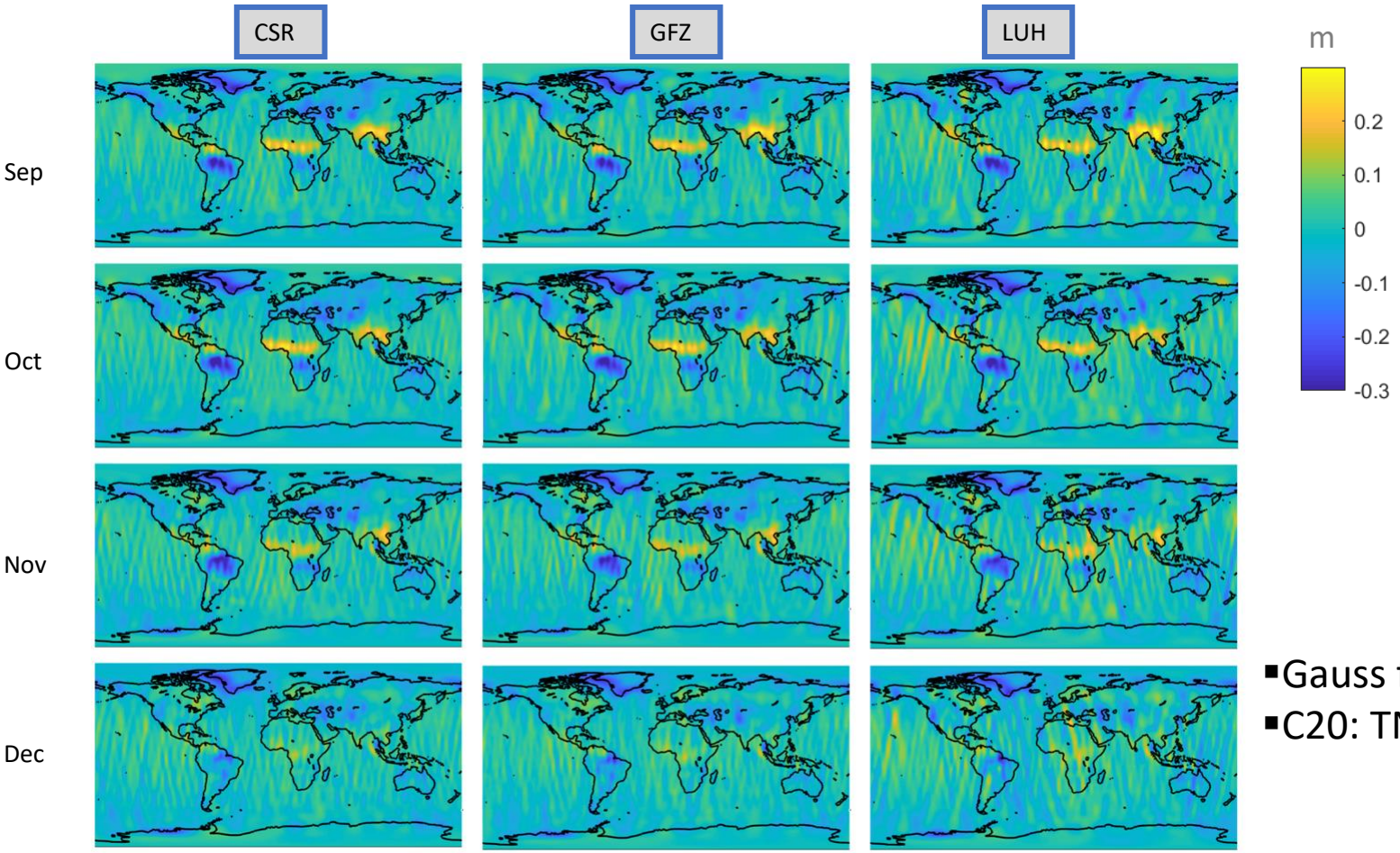

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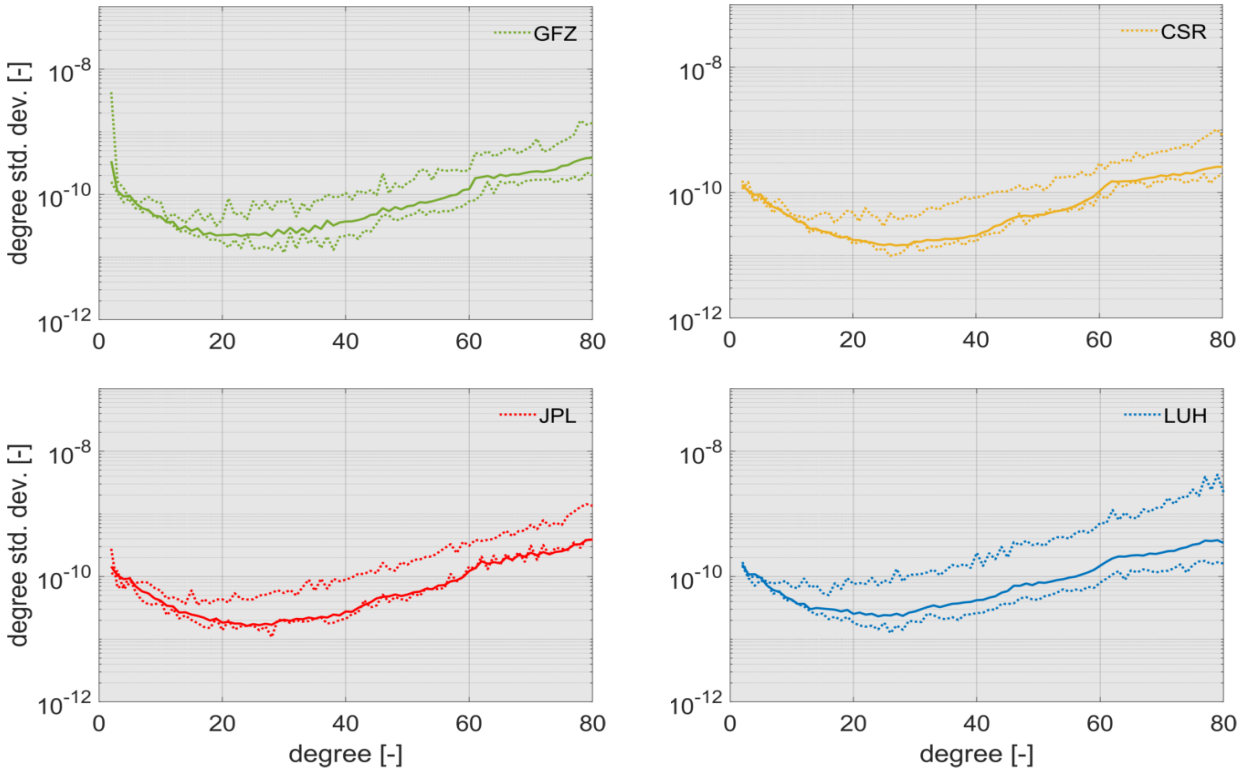
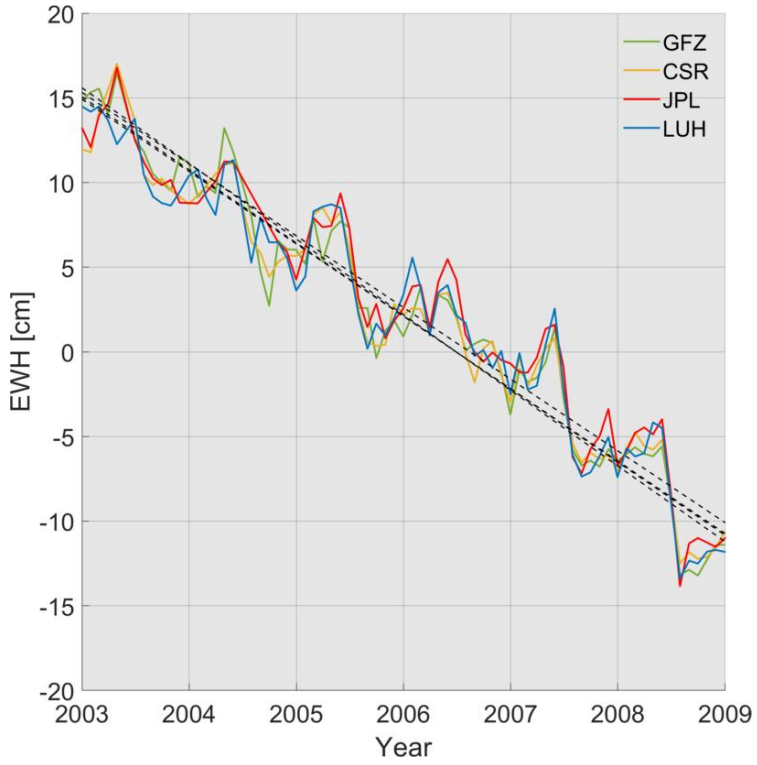
Comparison of degree standard deviations (2003-2009)

- Results are in a good agreement with GFZ, CSR and JPL solutions



EWH Greenland (2003-2009)



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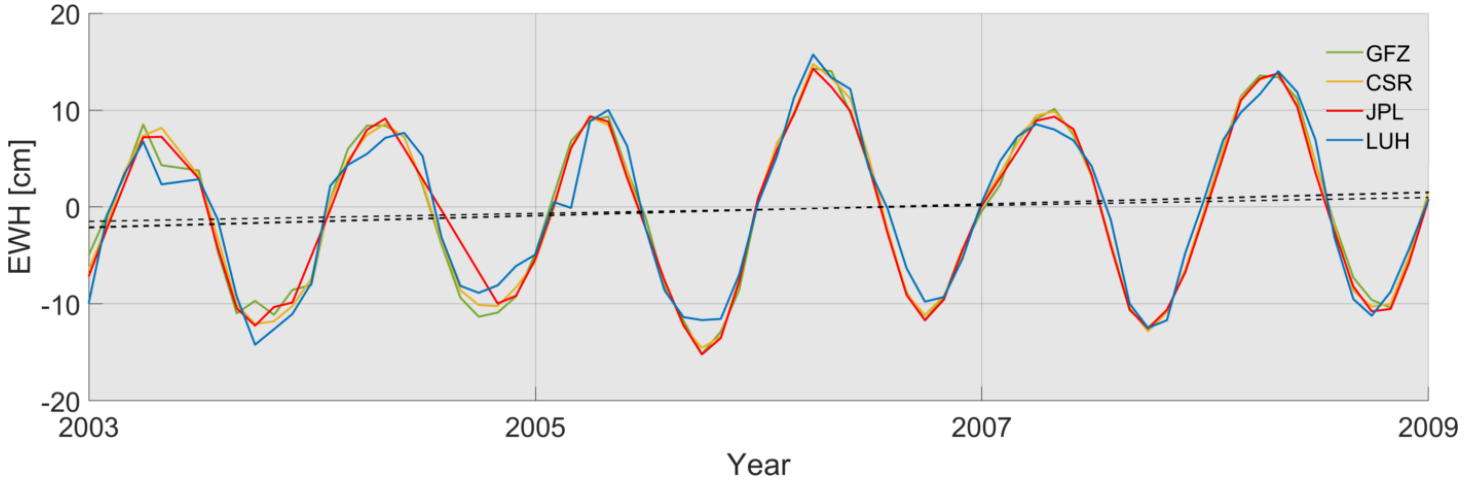
EWH Amazonas (2003-2009)



- Gauss filter (350 km)
- C20: TN SLR values

Future plans

- **Force models**: atmospheric tides, AOD1B RL06, FES2014, dynamic empiric parameters
- **Parametrization:** arc length, scale factors
- **Data**: L1B RL03
- Range rate residuals analysis
- Code extending for GRACE-FO

References

- ***Case et al.* (2010):** GRACE level 1B data product user handbook (JPL D-22027), Technical report.
- ***Naeimi et al. (2018)***: IfE monthly gravity field solutions using the variational equations, EGU 2018, Vienna.
- ***Naeimi (2018)***: A modified Gauss-Jackson method for the numerical integration of the variational equations, poster, EGU 2018, Vienna.
- ***Petit and Luzum* (2010):** IERS Conventions (2010), IERS technical note 36, Verlag des Bundesamts für Kartographie und Geodäsie, Frankfurt am Main.
- ***Ries et al.* (2011):** Mean background gravity fields for GRACE processing, GRACE Science Team Meeting Austin, TX, August 8-10.
- ***Rieser et al.* (2012):** The ocean tide model EOT11a in spherical harmonics representation, Technical report.
- ***Standish* (1998):** JPL planetary and lunar ephemerides, DE405/LE405, Jet Propulsion Laboratory Interoffice Memorandum IOM 312.F-98-048.