GRACE-FO MONTHLY SOLUTIONS USING THE GRACE-SIGMA SOFTWARE

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A – Abstract

In this contribution we present gravity field monthly solutions from GRACE Follow-On (GRACE-FO) Level-1B sensor data. The monthly solutions are computed with the GRACE-SIGMA software developed at the Institute of Geodesy, Leibniz University Hannover. The solutions are obtained using a two-step approach. In a first step, the orbits of the two satellites are pre-adjusted by estimating local arc parameters. In a second step, the monthly gravity field potential in terms of normalized spherical harmonic coefficients is recovered. Several parametrization scenarios are tested and the obtained solutions are compared with solutions of other processing centers. Furthermore, K-band range-rate (KBRR) post-fit residuals are analyzed in time, frequency and space domain and are compared to the typical post-fit residuals of the GRACE mission.

B – GRACE-SIGMA

The processing approach for the solutions is the method of dynamic orbit and gravity field determination based on the equations of motion, also often referred to as the variational equations (VE) approach [1]. The VE approach is implemented in a compact all-Matlab program named GRACE-SIGMA. A generalized overview over the gravity field recovery from GRACE and GRACE-FO Level-1B data products based on VE can be seen in Fig. 1.

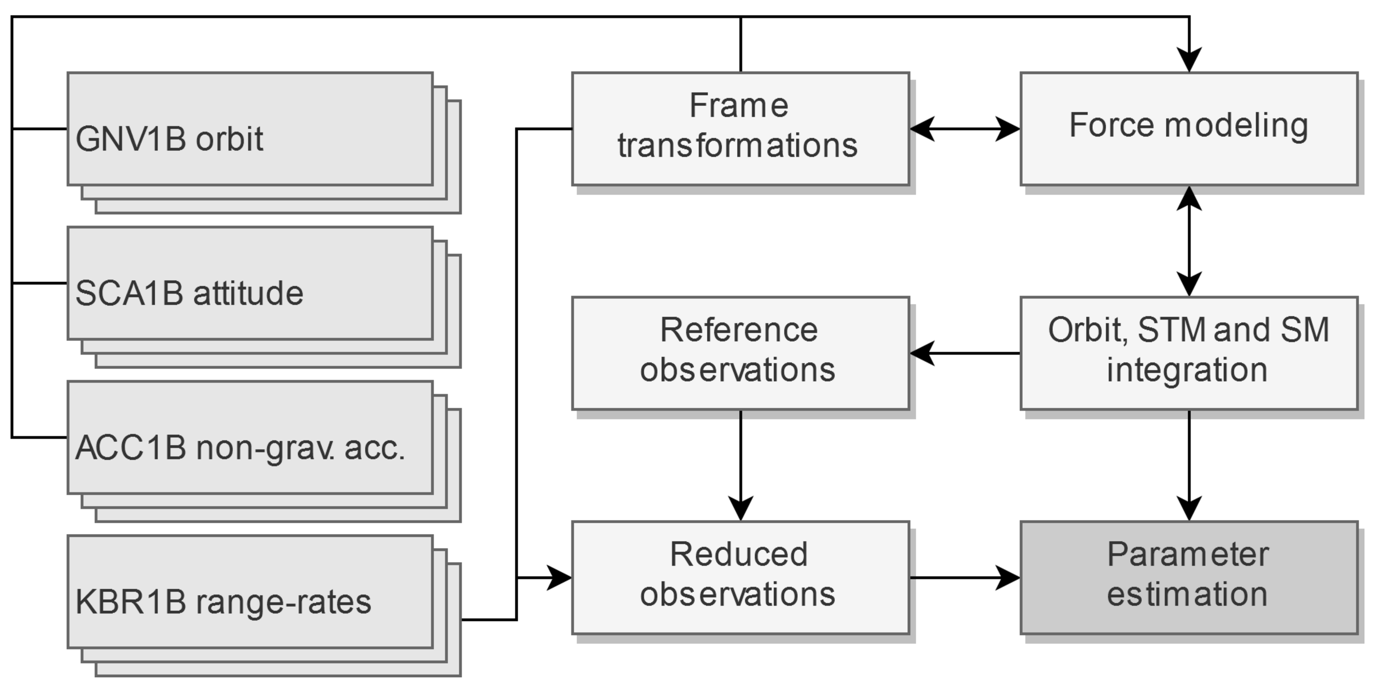

Fig. 1: Simplified gravity field recovery procedure.

C – Current G-FO standard processing

Tab. 1: Force models applied for orbit modeling.

force	model
gravity	mean background: GIF48 (d/o: 300) [2]
third bodies	Sun and Moon, ephemerides: DE405 [3]
solid Earth tide	Sun and Moon [3]
ocean tide	EOT11a (d/o: 80) [4]
relativistic effects	IERS Conventions 2010 [5]
solid Earth pole tide	IERS Conventions 2010 [5]
ocean pole tide	IERS Conventions 2010 (d/o: 30) [5]
atmospheric tide	Biancale and Bode [6]
non-tidal	AOD1B RL06 (d/o: 180) [7]
non-gravitational	Level-1B accelerometer measurements

- Arc-length: 3h
- Numerical integration: modified Gauss-Jackson
- Parameters: see Tab. 2 (scenario #0) + empirical kinematic KBRR parameters [8]
- Empirical parameters include a low-low bias + bias-rate (two sets per arc) and 4 low-low periodic bias + bias-rates (one set per arc)
- No consraint + regularization

D – Exemplary EWH time series

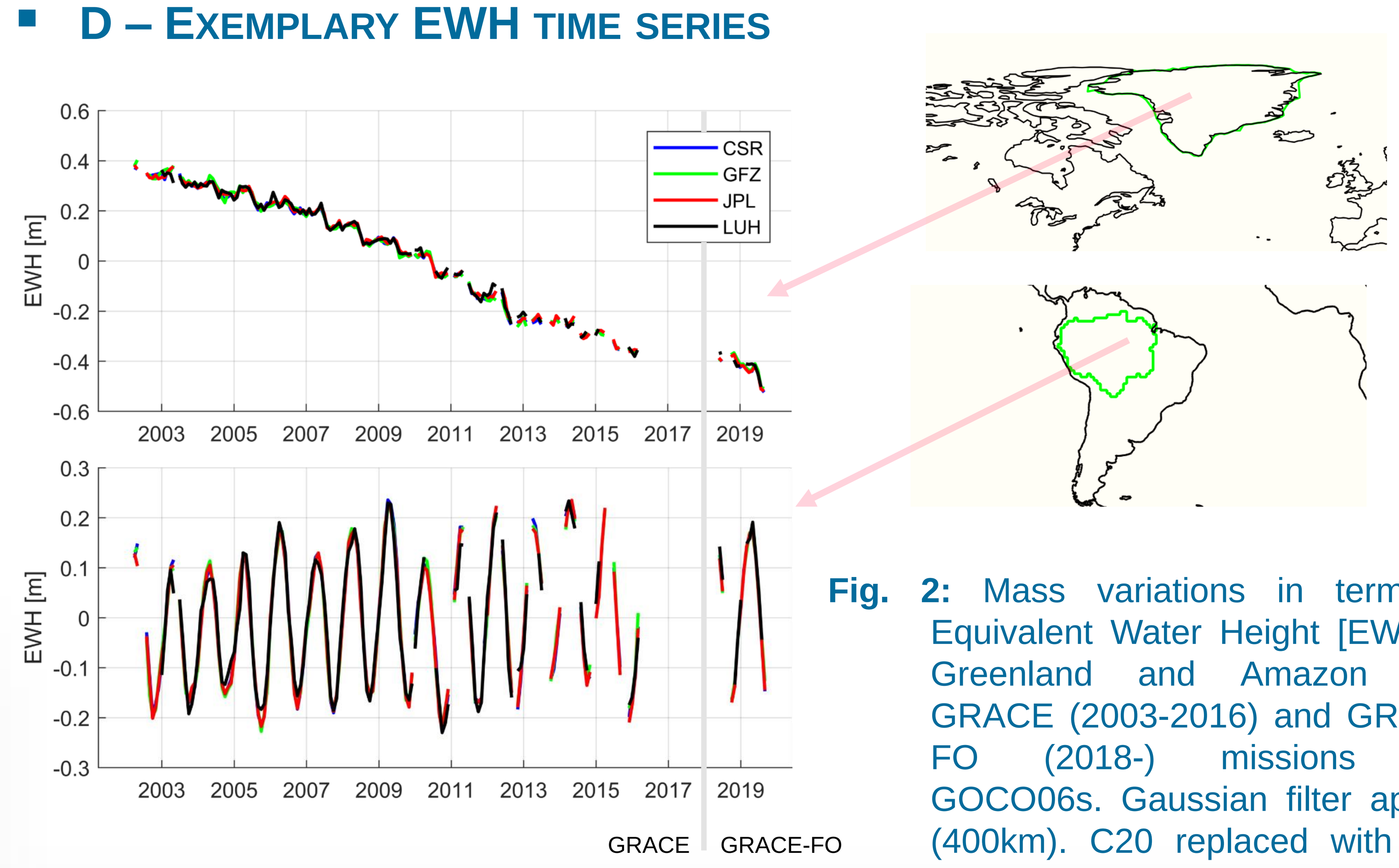

Fig. 2: Mass variations in terms of Equivalent Water Height [EWH] in Greenland and Amazon from GRACE (2003-2016) and GRACE-FO (2018-) missions w.r.t GOCO06s. Gaussian filter applied (400km). C20 replaced with SLR values.

E – Tested scenarios

Tab. 2: Tested scenarios. Abbreviations: acc.: accelerometer, TVG: time-variable gravity, d/o: degree/order. In addition empirical kinematic KBRR parameters are estimated (see section C). Testing different parametrization scenarios is an ongoing work and has to be performed systematically in future.

scenario	local dynamic	global	notes
#0	▪ state (3h) ▪ acc. bias (3h) ▪ acc. scale (3h)	▪ TVG d/o 96	
#1	▪ state (3h) ▪ acc. bias (3h) ▪ acc. scale (3h)	▪ TVG d/o 96	▪ integration: 5s→1s
#2	▪ state (1.5h) ▪ acc. bias (1.5h) ▪ acc. scale (1.5h)	▪ TVG d/o 96	▪ one revolution arc-length
#3	▪ state (3h) ▪ acc. bias (3h) ▪ acc. scale (3h)	▪ TVG d/o 96	▪ acc. bias+scale estimated only for satellite C ▪ then applied for both satellites
#4	▪ state (3h) ▪ acc. bias (3h)	▪ TVG d/o 96 ▪ acc. scale	

F – RMS of post-fit residuals and error degree standard deviations

scenario	RMS
#0	1.0307E-7 m/s
#1	1.0247E-7 m/s
#2	8.6324E-8 m/s
#3	1.8533E-7 m/s
#4	1.2356E-7 m/s

Tab. 3: KBRR post-fit residuals RMS of the tested scenarios.

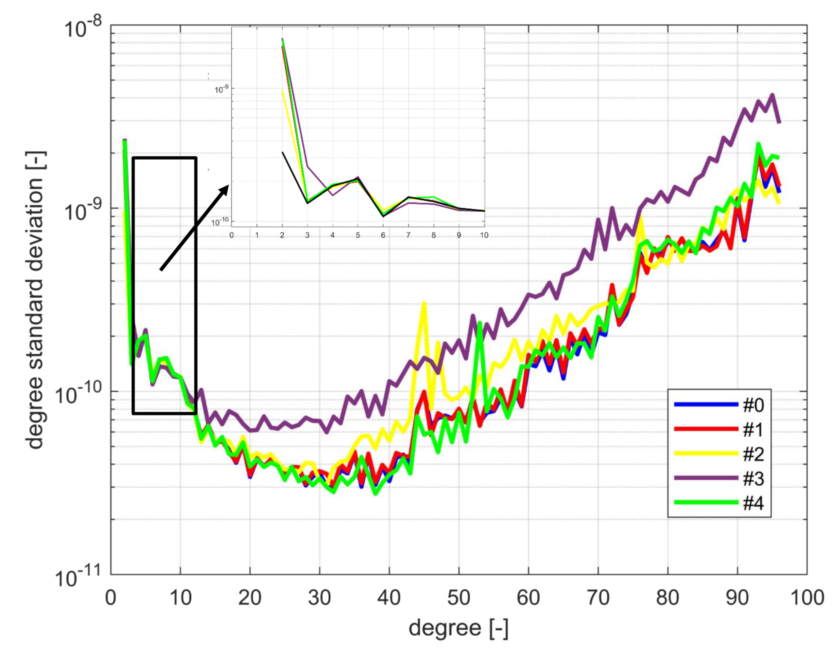

Fig. 3: Corresponding error degree standard deviations w.r.t. GOCO06s.

G – Post-fit residuals - PSD

We define KBRR post-fit residuals as follows:

$$\hat{\mathbf{v}} = \mathbf{A}_{\sim\mathrm{CD}}\,\hat{\mathbf{x}}_{\sim} + \mathbf{A}_{\oplus\mathrm{CD}}\,\hat{\mathbf{x}}_{\oplus} - \mathbf{l}_{\mathrm{CD}}$$

where $\hat{\mathbf{v}}$: estimated KBRR post-fit residuals, $\mathbf{A}_{\sim\mathrm{CD}}$: design matrix of arc-specific parameters, $\mathbf{A}_{\oplus\mathrm{CD}}$: design matrix of spherical harmonic coefficients, $\hat{\mathbf{x}}_{\sim}$: estimated arc-specific parameters, $\hat{\mathbf{x}}_{\oplus}$: estimated spherical harmonic coefficients, and $\mathbf{l}_{\mathrm{CD}}$: reduced KBRR observations.

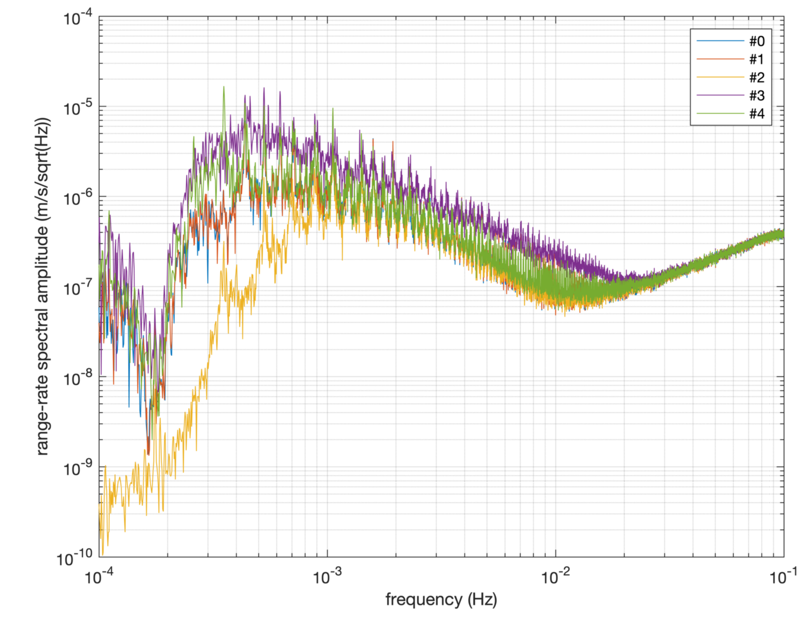

Fig. 4: Logarithmic Power Spectral Density [9] of the KBRR post-fit residuals. Different parametrizations are shown (see Tab. 2).

H – GRACE-FO and GRACE post-fit residuals

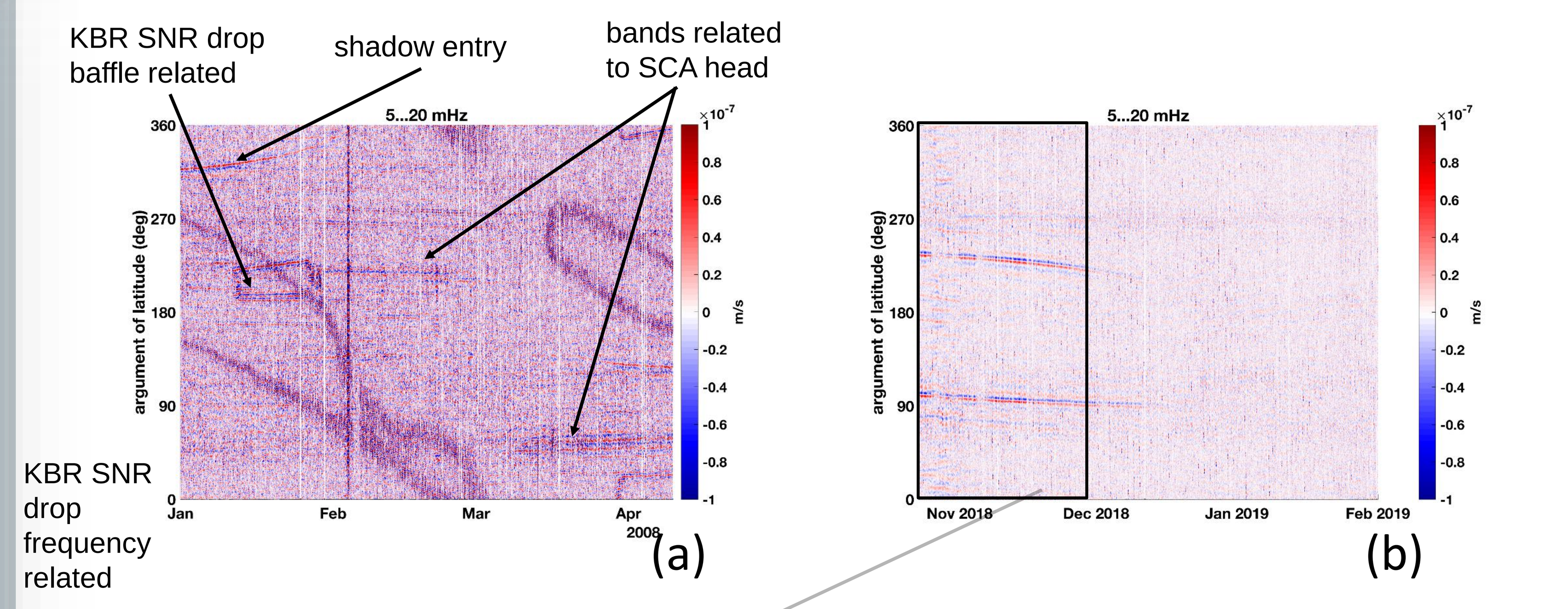

Fig. 5: Typical GRACE (a) and GRACE-FO (b) KBRR post-fit residuals. X-axis: time, Y-axis: argument of latitude. The major part of systematic features that were present in the GRACE residuals can not be seen in GRACE-FO residuals anymore.

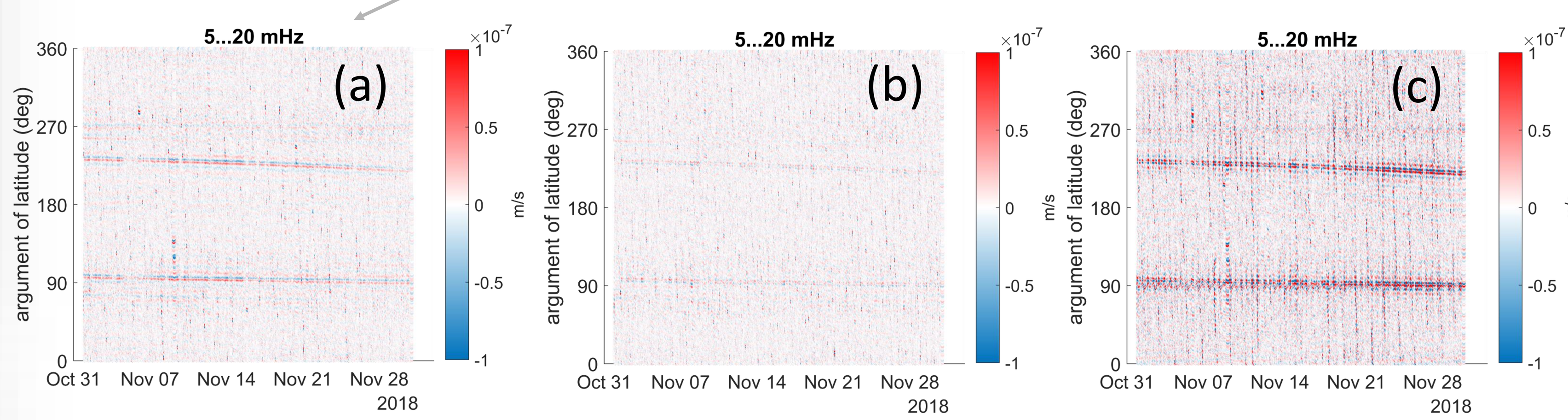

Fig. 6: Impact of selected parametrizations on the post-fit residuals. (a) scenario #0, (b) scenario #2, (c) scenario #3.

References

[1] ***Naeimi et al.* (2018):** IfE monthly gravity field solutions using the variational equations, EGU General Assembly 2018, Vienna, Austria. [2] ***Ries et al.* (2011):** Mean Background Gravity Fields for GRACE Processing, GRACE Science Team Meeting 2011, Austin, TX, USA. [3] ***Standish (1998):*** JPL Planetary and Lunar Ephemerides, DE405/LE405, JPL Interoffice Memorandum IOM 312.F-98-048. [4] ***Savchenko and Bosch (2012):*** EOT11a - Empirical Ocean Tide Model from Multi-Mission Satellite Altimetry. DGFI Report No. 89, Deutsches Geodätisches Forschungsinstitut (DGFI), München, Germany. [5] ***Petit and Luzum (2010):*** IERS Conventions (2010), IERS Technical Note No. 36. Verlag des Bundesamts für Kartographie, Frankfurt am Main, Germany. [6] ***Biancale and Bode (2006):*** Mean Annual and Seasonal Atmospheric Tide Models Based on 3-hourly and 6-hourly ECMWF Surface Pressure Data. Scientific Technical Report STR06/01, GeoForschungsZentrum Potsdam, Germany. [7] ***Dobslaw et al. (2017):*** A new high-resolution model of non-tidal atmosphere and ocean mass variability for de-aliasing of satellite gravity observations: AOD1B RL06, Geophysical Journal International 211(1). [8] ***Kim* (2000):** Simulation study of a low-low satellite-to-satellite tracking mission, PhD thesis, The University at Austin Texas. [9] ***Tröbs and Heinzel* (2006):** Improved spectrum estimation from digitized time serieson a logarithmic frequency axis. Measurements 39.

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