Influence of Accelerometer Parametrizations on GRACE Post-Fit Residuals

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A – Introduction

Abstract

Accelerometers onboard of satellites can be regarded as a key improvement in gravity field recovery. These instruments are located in the center of mass of the satellite and are precisely measuring non-gravitational forces acting on the satellite surfaces. Accelerometer measurements are distorted in their magnitude and amplitude, so an accelerometer calibration has to be carried out. Usually, in orbit determination and gravity field parameter estimation, a priori values are introduced and corresponding numeric corrections are estimated iteratively. Within the gravity field recovery community various accelerometer calibration parametrizations are applied. We have tested several parametrization scenarios within our in-house developed GRACE-SIGMA gravity field recovery software. In this contribution, we present the impact of these scenarios on post-fit KBRR residuals.

Motivation

The current release of monthly gravity field potential solutions with the name LUH-GRACE2018 computed at the Institute of Geodesy (IfE) / Leibniz University Hannover (LUH) introduces accelerometer biases as unknown parameters. During orbit and gravity field recovery bias parameters for every of the three GRACE science reference frame axes and 3-hour-arcs are estimated. During the gravity field recovery the three accelerometer scale factors are held fixed to a-priori values. In order to get a more realistic accelerometer parametrization and in addition to absorb force modeling inaccuracies we also introduce scale factors as unknowns to the estimation procedure.

B – LUH-GRACE2018 Estimation Procedure

step 1:

Orbit pre-adjustment

9 local parameters/arc

- initial state (6)
- accelerometer bias (3)

3 iterations

step 2:

Orbit adjustment and gravity field recovery

9 local parameters/arc

- initial state (6)
- accelerometer bias (3)

8 common parameters/arc

- empirical KBRR (8) [3]

6561 global parameters/month

- normalized spherical harmonic coefficients of the Earth's geopotential

1 iteration

GRACE-SIGMA software consists of two main processing steps. In a pre-adjustment L1B reduced-dynamic orbits are improved by estimating corrections to the initial satellite states and a-priori accelerometer biases. Pre-adjusted orbits are used as initial orbits in step 2. In this step, GRACE-SIGMA recovers the gravity field using batch least squares. Local parameters and common parameters are eliminated and the normal matrices containing spherical harmonic coefficients are stacked.

FORCE MODELS: cf. [1], [2]

NUMERICAL INTEGRATION: cf. [4]

OBSERVATIONS: In orbit pre-adjustment reduced-dynamic GNV1B positions are used as observations; in the final step, reduced-dynamic GNV1B positions, as well as KBRR measurements are used.

C – Two Calibration Parametrizations

Equation (1) shows the common accelerometer calibration equation that is usually applied in gravity field parameter estimation. This equation corrects the magnitude of the uncalibrated acceleration by the bias vector **b**; the amplitude is corrected by the scale matrix **S**.

$$\mathbf{a}_{\mathrm{CAL}} = \mathbf{S}\,\mathbf{a}_{\mathrm{OBS}} + \mathbf{b} \qquad (1)$$

Tab. 1: Tested scenarios.

Scenario		*Description*
1	(LUH-GRACE2018)	Bias: per arc (3h) Scale: fixed to a-priori values [5]
2		Bias: per arc (3h) Scale: diagonal elements per arc (3h)

D – Parametrization Influence on Step 1

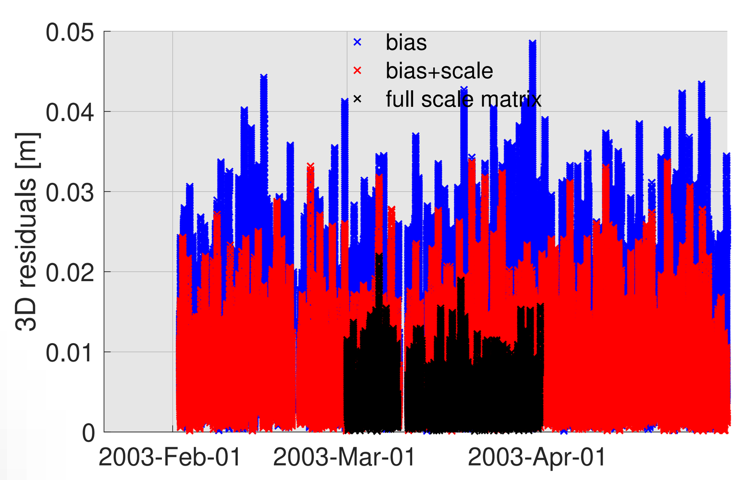

Fig. 1: 3D orbit fit error of the tested calibration scenarios w.r.t. GNV1B orbits for the three months 2003/02 – 2003/04.

In order to guarantee a correct implementation of the scale parameter sensitivity matrices, at first we test the influence of the two aforementioned scale matrix parametrizations on orbit pre-adjustment (see box B). Note that in step 1 a scale matrix with off-diagonal elements [6] was also tested (one month). This scenario is not mentioned in Tab. 1, since the influence of this parametrization on gravity field estimation has not been evaluated yet. While for the LUH-GRACE2018 parametrization usually only three iterations are needed, the introduction of the scale matrix components requires a higher amount of iterations for convergence.

E – Estimated Calibration Parameters

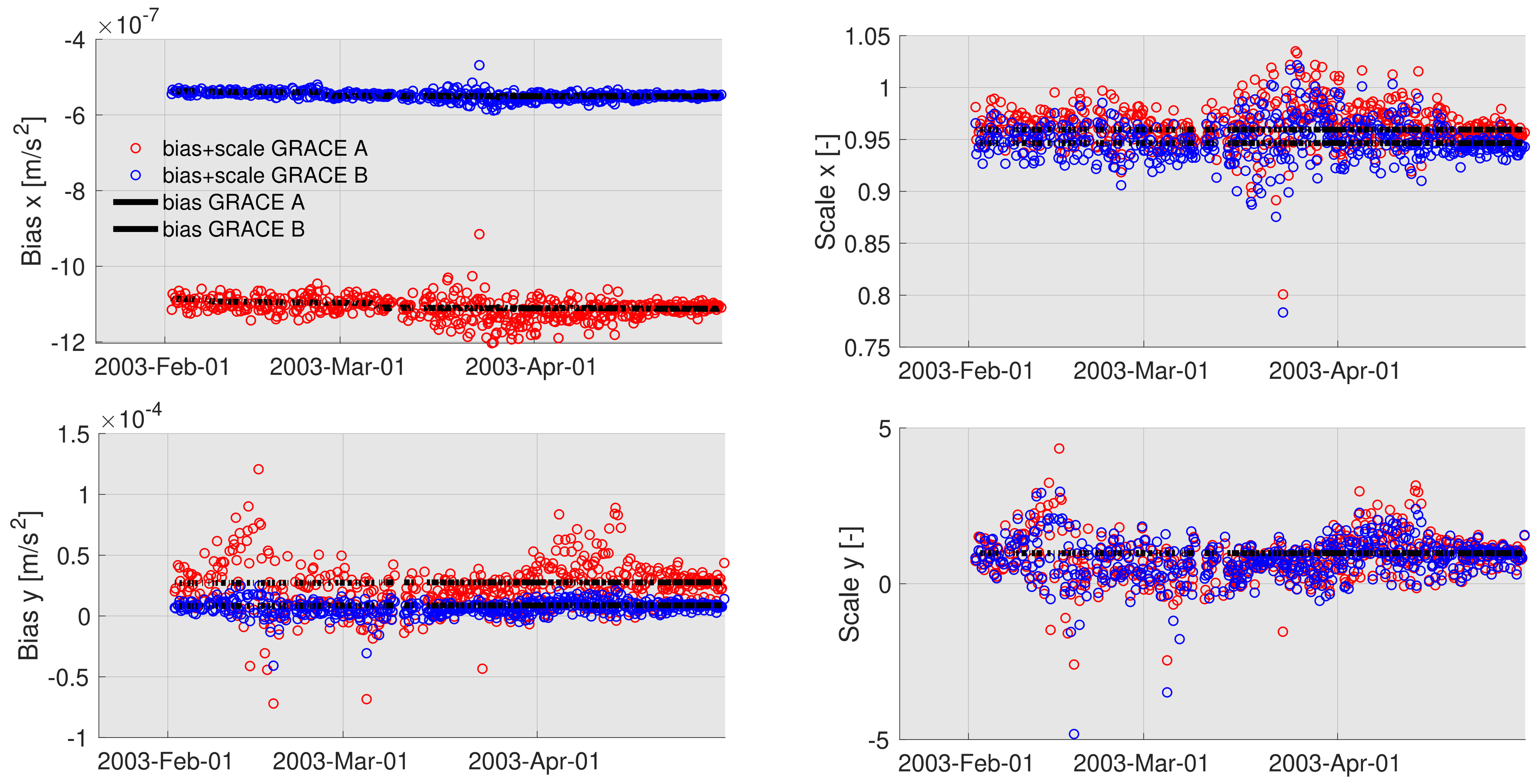

Fig. 2: (Estimated) accelerometer calibration parameters.

The panels of Fig. 2 show the estimated accelerometer calibration parameters using the two aforementioned parametrizations. On the left side you can see the biases; on the right side the scales. The upper panel refers to the x-axis (along-track) of the GRACE science reference frame (SRF); the bottom panel to the y-axis (cross-track). For reasons of space, z-axis (radial) parameters are not shown. Please note that the major part of the non-gravitational acceleration acts in x-axis direction. The small signal on y-axis makes it more difficult to obtain scale factors around 1.

F – Post-Fit Residuals and Degree Standard Deviations

We define GRACE K band post-fit range rate residuals as follows:

$$\hat{\mathbf{v}} = \mathbf{A}_{\sim\mathrm{AB}}\,\hat{\mathbf{x}}_{\sim} + \mathbf{A}_{\oplus\mathrm{AB}}\,\hat{\mathbf{x}}_{\oplus} - \mathbf{l}_{\mathrm{AB}} \qquad (2)$$

with $\hat{\mathbf{v}}$: estimated K band post fit range rate residuals, $\mathbf{A}_{\sim\mathrm{AB}}$: design matrix of arc specific parameters, $\mathbf{A}_{\oplus\mathrm{AB}}$: design matrix of spherical harmonic coefficients, $\hat{\mathbf{x}}_{\sim}$: estimated arc specific parameters, $\hat{\mathbf{x}}_{\oplus}$: estimated spherical harmonic coefficients, and $\mathbf{l}_{\mathrm{AB}}$: reduced K band range rate observations.

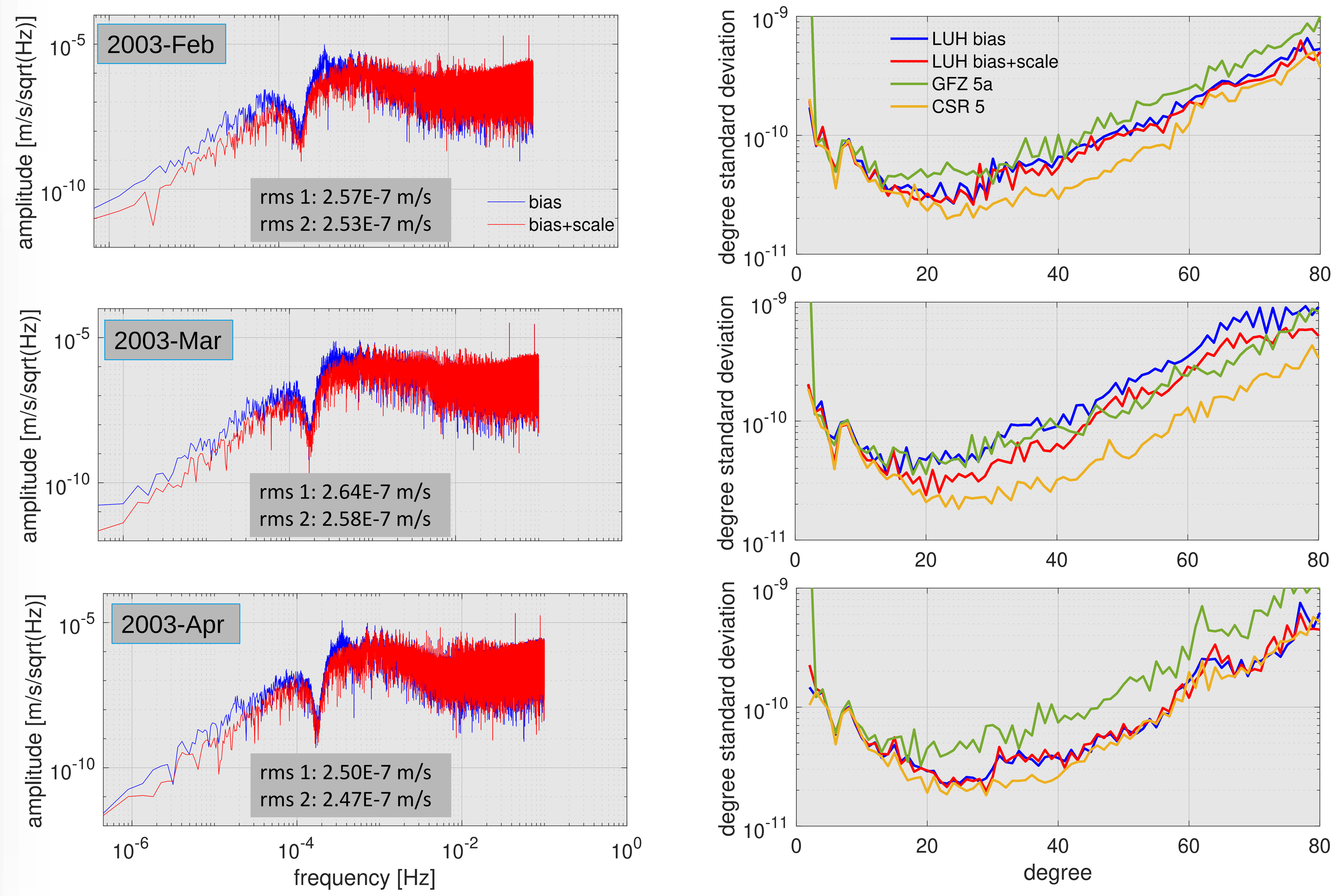

Fig. 3: Power spectrum densities of the post-fit residuals and degree standard deviations of the monthly solutions. GFZ release 5a and CSR release 5 solutions are shown as reference.

G – Discussion

For the test period of three month, the introduction of the diagonal elements of the accelerometer scale matrix could decrease the post-fit KBRR residuals in the 10^{-7}–10^{-3} Hertz bandwidth. In most cases, the diagonal scale matrix also slightly improved the quality of the monthly solutions in terms of degree standard deviations. When solving for the biases and scale factors every 3 hours, the estimated parameters show a large variance compared to the long term values. The variance can be decreased by constraining the calibration parameters or by treating the scale parameters not as local arc parameters, i.e. estimating scales for larger periods. Further studies on this topic are needed. The influence of a scale matrix with off-diagonal elements was tested on orbit pre-adjustment; the influence on gravity field recovery is pending.

References

[1] **Naeimi et al. (2018):** IfE monthly gravity field solutions using the variational equations, EGU General Assembly 2018, 8.-13. April 2018, Vienna, Austria. [2] **Koch et al. (2018):** LUH-GRACE2018: A new time series of monthly gravity field solutions from GRACE, GRACE/GRACE-FO Science Team Meeting 2018, 9.-11.10.2018, Potsdam, Germany. [3] **Kim (2000):** Simulation study of a low-low satellite-to-satellite tracking mission, PhD thesis, The University at Austin Texas. [4] **Naeimi (2018):** A modified Gauss-Jackson method for the numerical integration of the variational equations, EGU General Assembly 2018, 8.-13. April 2018, Vienna, Austria. [5] **Bettadpur (2009):** Recommendation for a-priori bias & scale parameters for Level-1B ACC data (version 2). Tech. note, Center for Space Research [6] **Klinger and Mayer-Gürr (2016):** The role of accelerometer data calibration within GRACE gravity field recovery: results from ITSG-Grace2016.

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