GNSS-based Calibration of GRACE Accelerometers

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Introduction

Accelerometer on-board GRACE measures the non-gravitational acceleration acting on the satellites. The measurements are distorted in their magnitude and amplitude, so instrumental biases and scale factors have to be introduced for each of the three axes to get values that do represent the true nature of the environmental forces. Because the calibration can not be done in 1g-environment, scale and bias are usually directly estimated in orbit determination or gravity field recovery procedures.

In this work, with particular focus on the influence of solar activity, two complementary approaches for the computation of reference acceleration, which can be used for calibration, are compared. Some similar studies concerning individual aspects that are presented, can for example be found in [1], [2] and [3]. In addition to the linear accelerometer measurements (ACC1B), several other official GRACE Level 1B products including the reduced-dynamic orbits (GNV1B), star camera (SCA1B), thrust (THR1B) and mass data (MAS1B) were utilized.

Two Approaches

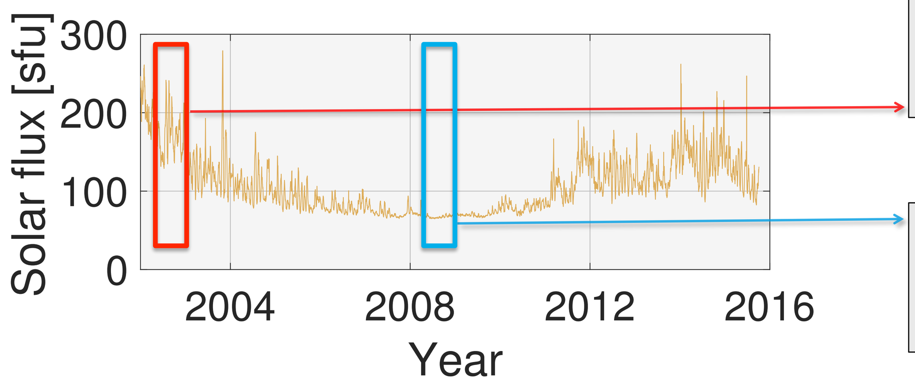
$$\mathbf{a}_{NG01} = \mathbf{a}_{non\text{-}gr} \qquad \mathbf{a}_{NG02} = \mathbf{a}_{tot} - \mathbf{a}_{gr}$$

Tab. 1: Standard models and data for determining the reference gravitational and non-gravitational acceleration (d/o: indicates the maximum degree/order of the spherical harmonic coefficients).

	Acceleration	Model	
$\mathbf{a}_{gr}$	Gravity	**EIGEN-6S4** (d/o: 180); tide-free; temporal variations	[4]
$\mathbf{a}_{gr}$	Third bodies	Sun, Moon, Venus and Jupiter; Ephemerides: **DE430**	[5]
$\mathbf{a}_{gr}$	Solid Earth tide	Sun, Moon, Venus and Jupiter (d/o: 2-4)	
$\mathbf{a}_{gr}$	Ocean tide	**EOT11a** (d/o: 120)	[6]
$\mathbf{a}_{gr}$	Relativistic effects	IERS Conventions 2010	[7]
$\mathbf{a}_{gr}$	Solid Earth pole tide	IERS Conventions 2010	
$\mathbf{a}_{gr}$	Ocean pole tide	IERS Conventions 2010	
$\mathbf{a}_{non\text{-}gr}$	Atmospheric drag	Density: **NRLMSISE-00**; Wind: co-rotation; $C_D = 2.3$	[8]
$\mathbf{a}_{non\text{-}gr}$	Solar radiation pres.	W = 1367 [W/m²]; Shadow: conical	

Two Periods

- The solar activity has a major influence on the density of air and consequently on the contribution of atmospheric drag. The difference in solar activity during the two periods leads to different magnitudes of the non-gravitational acceleration.



Date:	2002/11/01 –2003/01/31
Altitude:	486 [km]
Acc. magnitude:	10^{-7} [m/s²]

Date:	2008/06/01 – 2008/08/31
Altitude:	477 [km]
Acc. magnitude:	10^{-8} [m/s²]

Fig. 1: Solar activity during the period 2002–2016.

Calibration

$$\mathbf{a}_c = \mathbf{S}\,\mathbf{a}_o + \mathbf{b}$$

- The non-gravitational acceleration $\mathbf{a}_o$ measured by the accelerometers was calibrated using the two types of reference values ($\mathbf{a}_{NG01}$, $\mathbf{a}_{NG02}$). A scale matrix $\mathbf{S}$ and bias vector $\mathbf{b}$ were estimated on a daily basis by means of least squares adjustment. No constraints were applied and no a priori values introduced. Epochs that correspond to thruster events and some neighboring values were not considered in the calibration procedure.

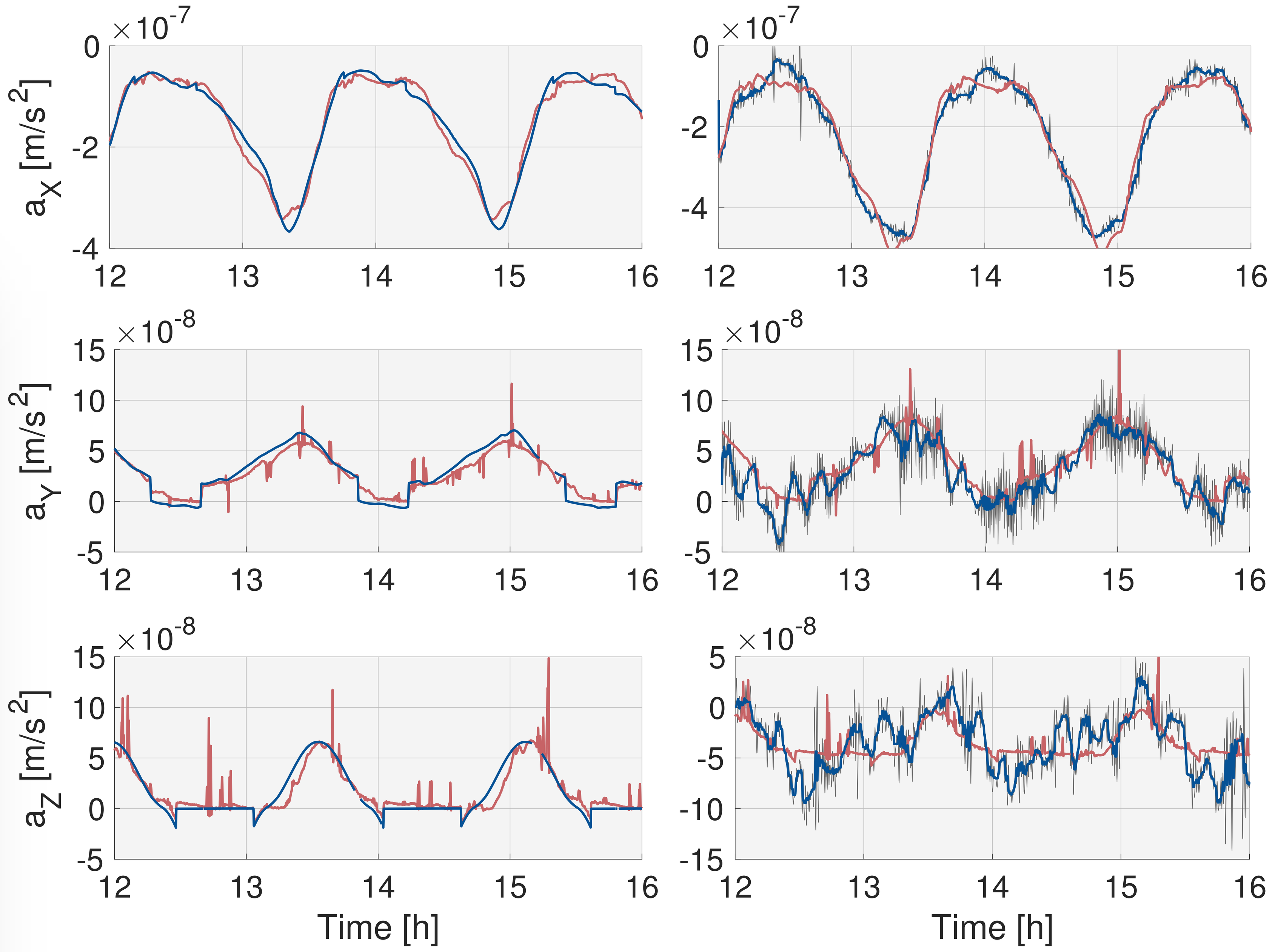


Fig. 2: Exemplary calibrated GRACE B accelerometer measurements (red) using approaches NG01 (left) and NG02 (right). The three panels correspond to random epochs from the period with strong solar activity (see Fig. 1). **Upper panel:** along-track (X), **middle panel:** cross-track (Y) and **bottom panel:** radial (Z). Reference acceleration is shown in blue. The NG02 accelerations were smoothed by a median filter and shown in grey.

- The differentiation in approach NG02 leads to an amplification of noise. Therefore the modeled non-gravitational accelleration should be smoothed before calibration. In this study, a median filter was applied. The cross-track and radial axes usually have a smaller magnitude compared to along-track. Consequently, it is more difficult to retrieve the real signal.

Total Acceleration

- A polynomial function of degree seven was used to approximate short orbit arcs of 100 seconds. Arc-specific polynomial coefficients were computed by means of least squares adjustment.
- To estimate the total acceleration acting on GRACE, consisting of a gravitational and non-gravitational contribution, second derivatives with respect to time were evaluated at the central points of each short arc.

Scale Time Series

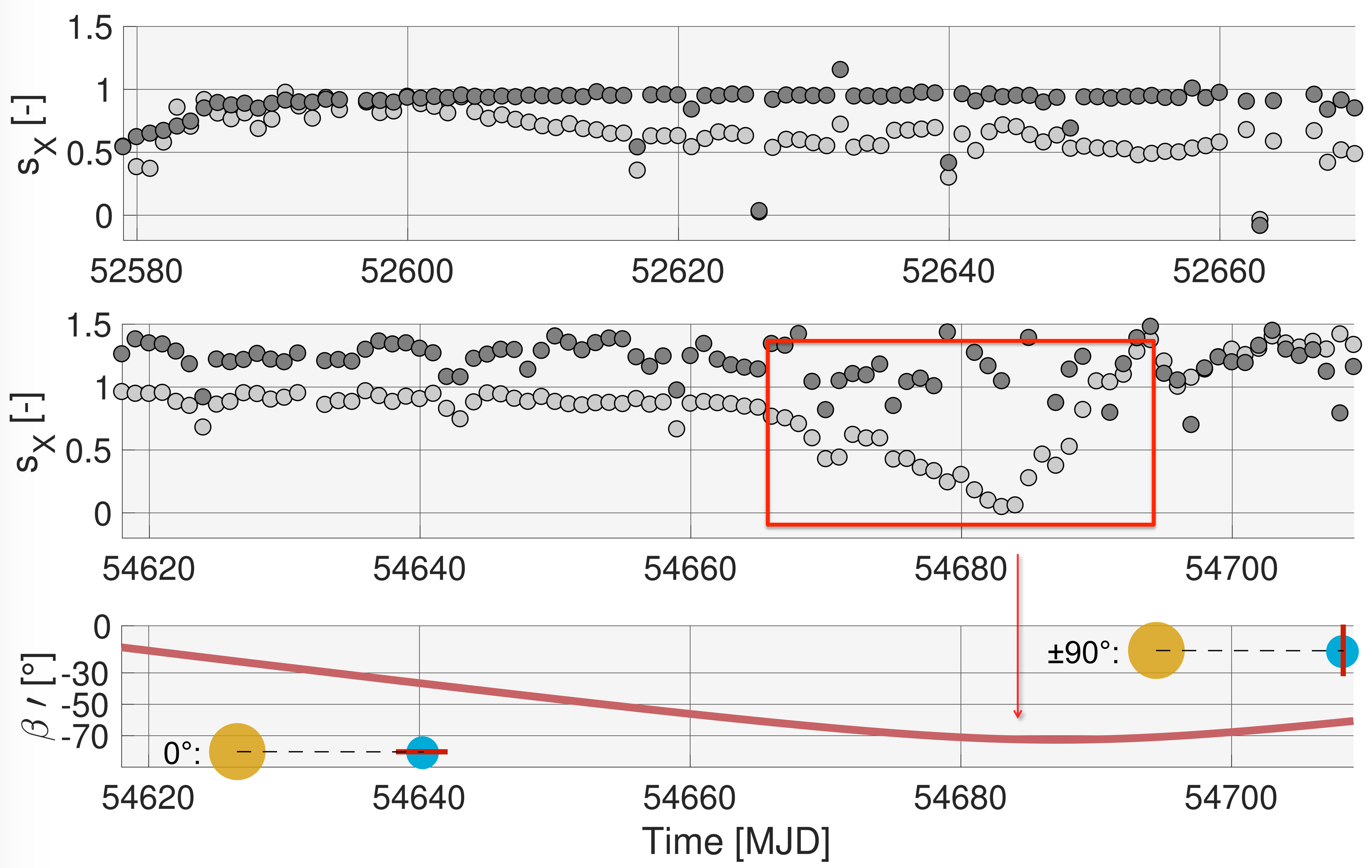


Fig. 2: **Upper and middle panels:** Estimated GRACE B along-track (X) scale factors for the periods with weak and strong solar activity. **Lower panel:** Orientation of GRACE B orbit w.r.t. the Sun for the period with weak solar activity (NG01 results are shown in light grey; NG02 in dark grey).

- When the satellite spends minimal time in the umbra region (beta prime angle closer to ±90°), a strong variation of the scale factors estimated with approach NG01 can be seen (see middle panel of Fig. 2).

Discussion

- Approach NG02 has advantage over approach NG01 in the time period of strong solar activity. For along-track, appropriate scale factors can be obtained without information on satellite geometry, orientation and surface materials. Approach NG02 may provide more realistic calibration parameters for periods with a specific orientation of the orbital plane w.r.t. the Sun.
- In the time period of weak solar activity, better results can be obtained with approach NG01. Moreover, for axes with a small contribution to the total non-gravitational acceleration, more precise calibration parameters can be estimated based on approach NG01.
- In the time series, several outliers e.g. due to bad quality of star camera data can be seen. Furthermore, biases and scale factors are highly correlated due to not applying constraints.

References

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