INSTITUTE OF THEORETICAL GEODESY AND SATELLITE GEODESY
GRAZ UNIVERSITY OF TECHNOLOGY

COMBINATION OF GRACE STAR CAMERA AND ANGULAR ACCELERATION DATA

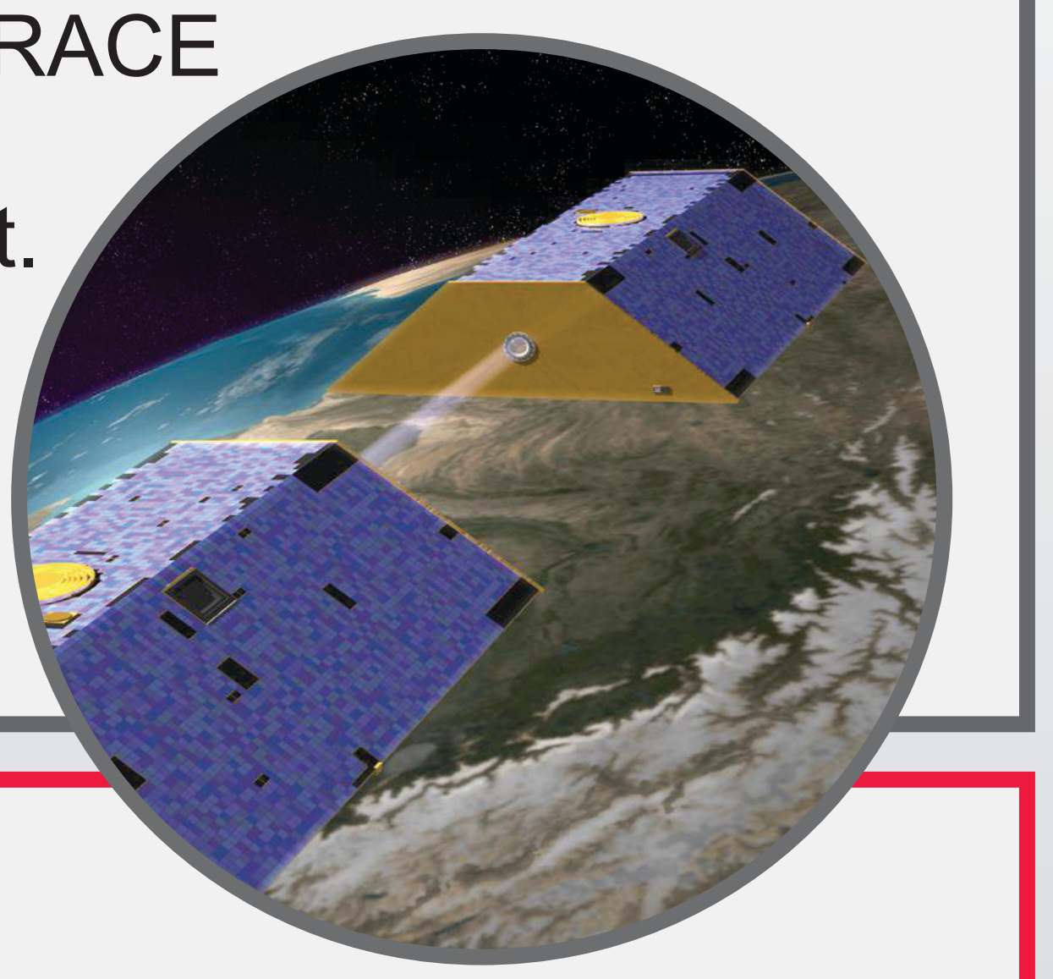
Beate Klinger and Torsten Mayer-Gürr

Institute of Theoretical Geodesy and Satellite Geodesy, Graz University of Technology

EGU General Assembly 2014, 27 April - 02 May, Vienna

INTRODUCTION

The GRACE (Gravity Recovery and Climate Experiment) satellite mission provides K-band ranging (KBR) measurements between the two twin satellites GRACE-A and GRACE-B for the purpose of gravity field recovery.
Although the accuracy of gravity field solutions has increased during the last years, there still remains an offset between the present error level of gravity field solutions and the GRACE baseline accuracy, i.e. the predicted accuracy from pre-launch simulations.
Pointing variations are one of the potential contributors to the error budget. Unmodeled errors in the Level-1B data products related to the alignment seem to have an influence on the recovered gravity field solutions. Furthermore, the improved understanding of the attitude data and/or possible error sources is essential for follow-on missions where higher accuracies should be achieved.



SENSOR FUSION

Up to now:

- attitude determination and alignment between the two satellites solely by the two star cameras on board each spacecraft

But:

- accelerometer provides additional attitude information in terms of angular accelerations

Therefore, *we combine both angular accelerometer and star camera data in a least squares adjustment* to improve the satellites' attitude estimation. The optimal combination of both data types is achieved by means of variance component estimation.

INPUT DATA

Star camera (SCA1B):

- quaternions: rotation from SRF to IRF

Accelerometer (ACC1B):

- angular accelerations in x/y/z-direction [rad/s²]

OUTPUT DATA

Star camera (sensor fusion):

- *estimated quaternions*: rotation from SRF to IRF
- *optional:* angular rates and accelerations

Antenna Offset Correction:

- range, range rate, range acceleration

METHODS: ANGULAR ACCELERATIONS

One of the main aspects of the sensor fusion is the relation between quaternions and angular accelerations. This relation can be established through the quaternion rate matrix W:

$$\blacktriangleright\ \dot{\omega} = 2W(\mathbf{q})\ddot{\mathbf{q}} = 2\begin{bmatrix} -q_1 & q_0 & q_3 & -q_2 \\ -q_2 & -q_3 & q_0 & q_1 \\ -q_3 & q_2 & -q_1 & q_0 \end{bmatrix}\begin{bmatrix} \ddot{q}_0 \\ \ddot{q}_1 \\ \ddot{q}_2 \\ \ddot{q}_3 \end{bmatrix}$$

Here, the second order derivatives of the quaternions can be approximated by a second order difference quotient:

$$\blacktriangleright\ i \geq 0: \quad \ddot{q}^i = \frac{q^{i+2} - 2q^{i+1} + q^i}{\Delta t^2}$$

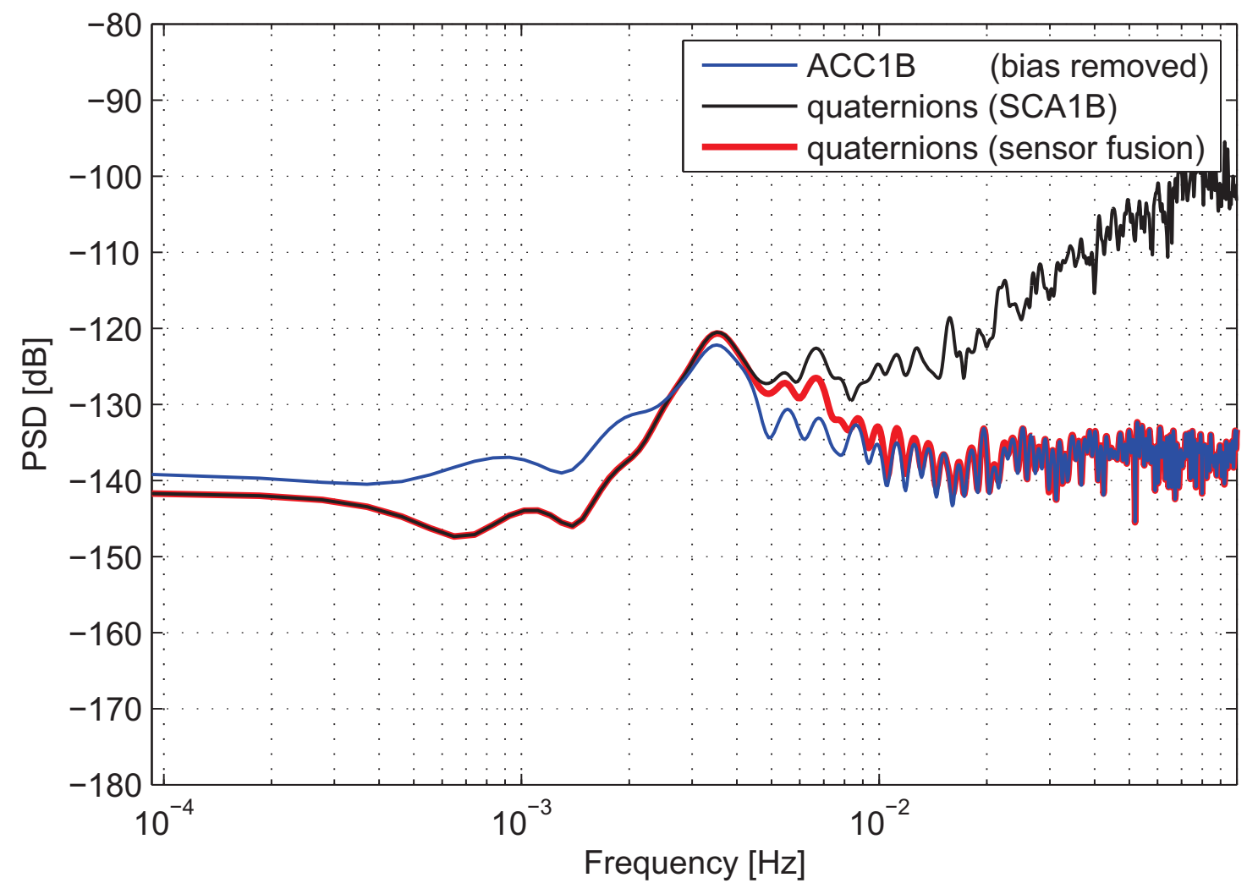


Fig. 1: Power spectral density of angular accelerations in y-direction. Blue graph: observations (ACC1B, bias removed); black graph: modeled from star camera data (SCA1B); red graph: modeled from combined quaternions (sensor fusion).

INTER-SATELLITE POINTING

The KBR system measures the range between the two satellites' KBR antenna phase centers (APC). To convert the original ranging observation to a distance between the two satellites' center of mass (CoM) a geometric correction has to be added. The antenna offset correction (AOC) depends on the inter-satellite alignment:

$$\blacktriangleright\ AOC_\rho = \mathbf{phC}\ \cos\varphi = \mathbf{e}_{AB}\cdot(\mathbf{R}^{\mathrm{IRF}}_{\mathrm{SRF,\,A}}\,\mathbf{phC}_{\mathrm{A}}) - \mathbf{e}_{AB}\cdot(\mathbf{R}^{\mathrm{IRF}}_{\mathrm{SRF,\,B}}\,\mathbf{phC}_{\mathrm{B}})$$

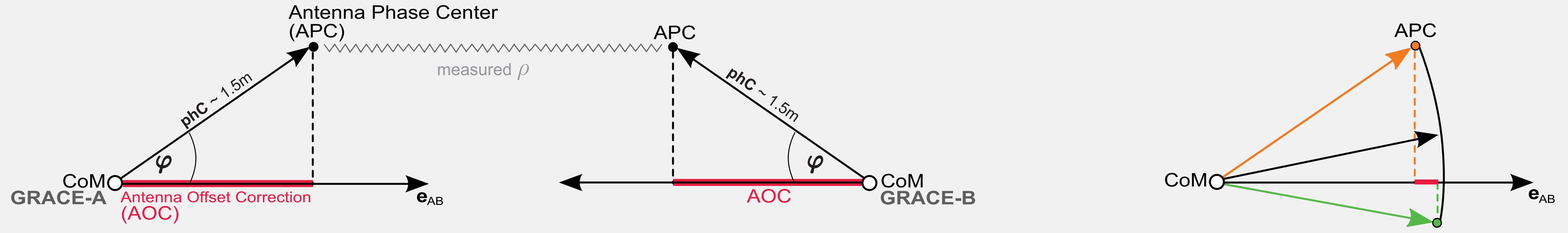


Fig. 2: Inter-satellite pointing: KBR antenna offset correction for ranges. Left panel: AOC for GRACE-A and GRACE-B; right panel: influence of the APC position.

ANTENNA OFFSET CORRECTIONS

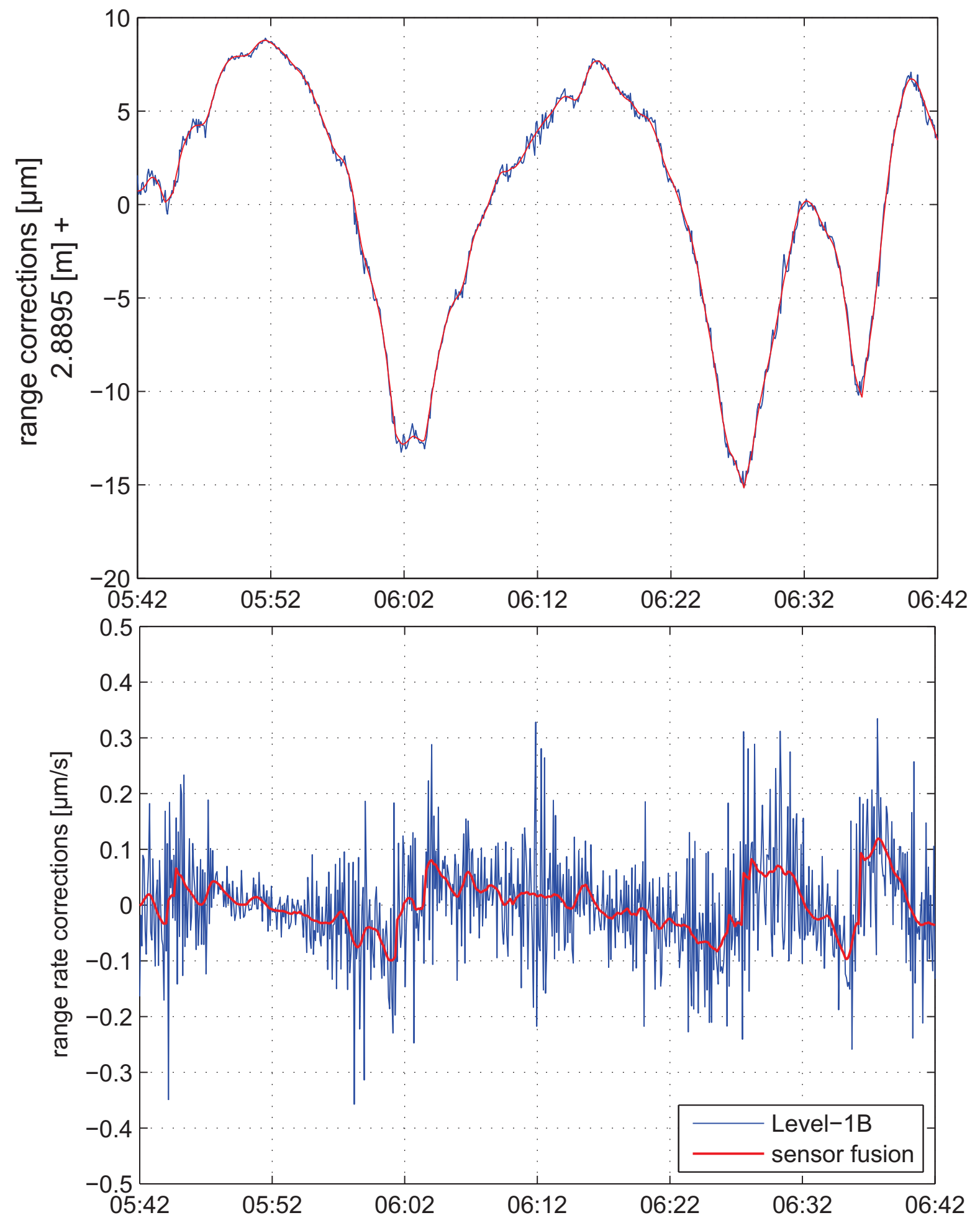


Fig. 3: KBR antenna offset corrections for ranges (upper panel) and range rates (lower panel) for 1 hour on August 15, 2008. Blue graph: Level1B data (KBR1B); red graph: AOCs derived from combined data (sensor fusion).

GRAVITY FIELD RECOVERY

First tests of the effect of the improved satellites' attitude on the gravity field solutions have been made. The combined star camera data (sensor fusion) and the re-calculated AOCs were used to compute monthly gravity field solutions. The following two scenarios were compared:

- **Scenario 1:** official Level-1B data
- **Scenario 2:** combined star camera data & derived AOCs

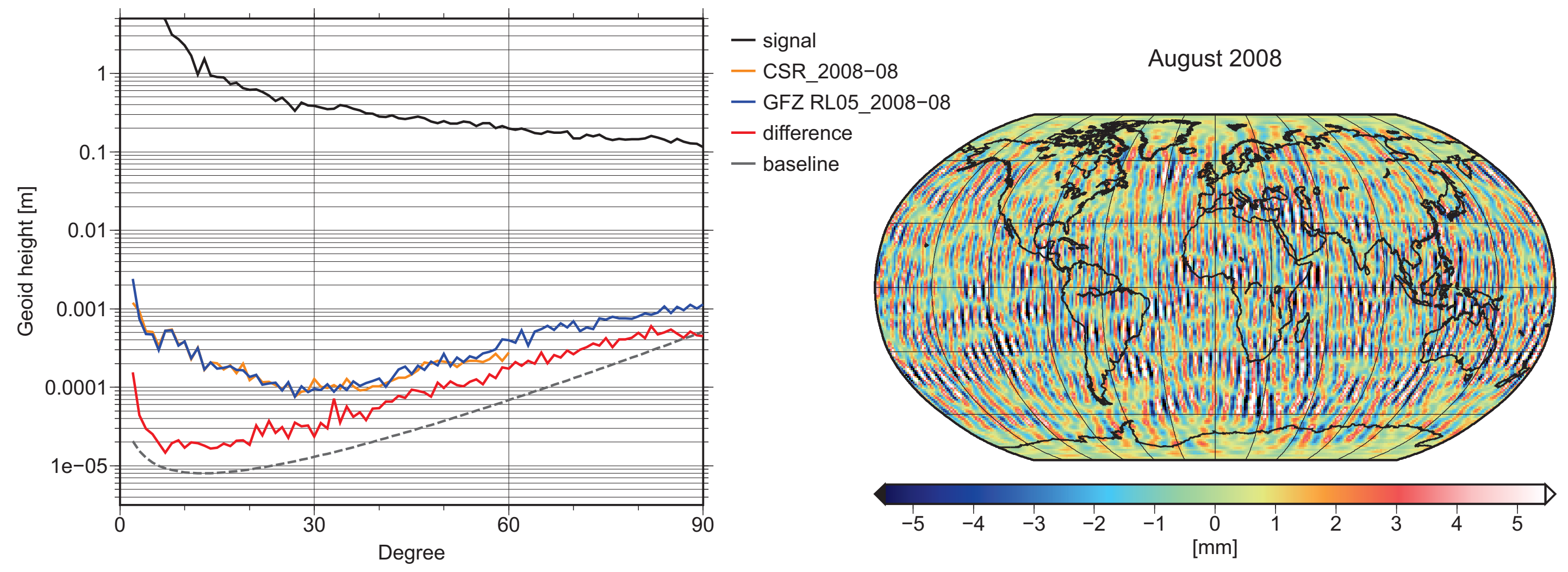


Fig. 4: Differences between the gravity field solutions for Scenario 1 and Scenario 2 in August 2008. Left panel: degree variances (red graph); right panel: Geoid heights.

CONCLUSIONS

The presented results are based on a sensor fusion approach, which combines star camera and angular acceleration data. As shown in Fig. 1, the angular accelerations contribute to the higher frequencies, whereas the star camera data mainly contributes to the long wavelength. Consequently, the noise within the AOCs can be reduced significantly (see Fig. 3); which in turn affects recovered gravity field solutions. The stripes in Fig. 4 could be due to the noise present in the official Level-1B attitude data.

REFERENCES

Bandikova T, et al. (2011): Characteristics and accuracies of the GRACE inter-satellite pointing. Advances in Space Research 50: 123-135.
Mayer-Gürr T (2006): Gravitationsfeldbestimmung aus der Analyse kurzer Bahnbögen am Beispiel der Satellitenmissionen CHAMP und GRACE. University of Bonn.

CONTACT

Beate Klinger
email: beate.klinger@tugraz.at
phone: +43 316 873 6344

Torsten Mayer-Gürr
email: mayer-guerr@tugraz.at
phone: +43 316 873 6359

www.itsg.tugraz.at