IMPROVED STAR CAMERA ATTITUDE DATA AND THEIR EFFECT ON THE GRAVITY FIELD

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1 – THE IMPROVED STAR CAMERA DATA

Recent analysis of the GRACE Level-1B star camera data (SCA1B RL02) revealed their systematically higher noise than expected (Bandikova&Flury, 2014). The reason is the incorrect implementation of algorithms for quaternion combination in the JPL processing routines. After correct implementation of the combination method, significant improvement of about a factor 3-4 over the whole spectrum was achieved, cf. Fig. 1 and 2. The combined solution, however, cannot be obtained when valid data from only one camera is available. The data availability for December 2008 is shown in Fig. 3.

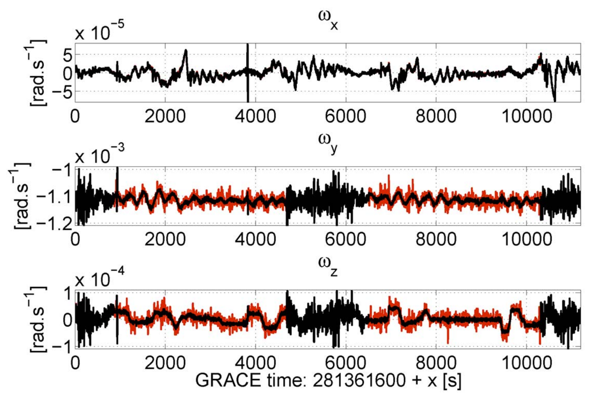


Fig. 1 - The angular rates about the science reference frame axes derived from the "SCA IfE" solution (black) and from the official "SCA1B RL02" generated by JPL (red). Shown for GRACE-A for 2 orbital periods on 2008-12-01

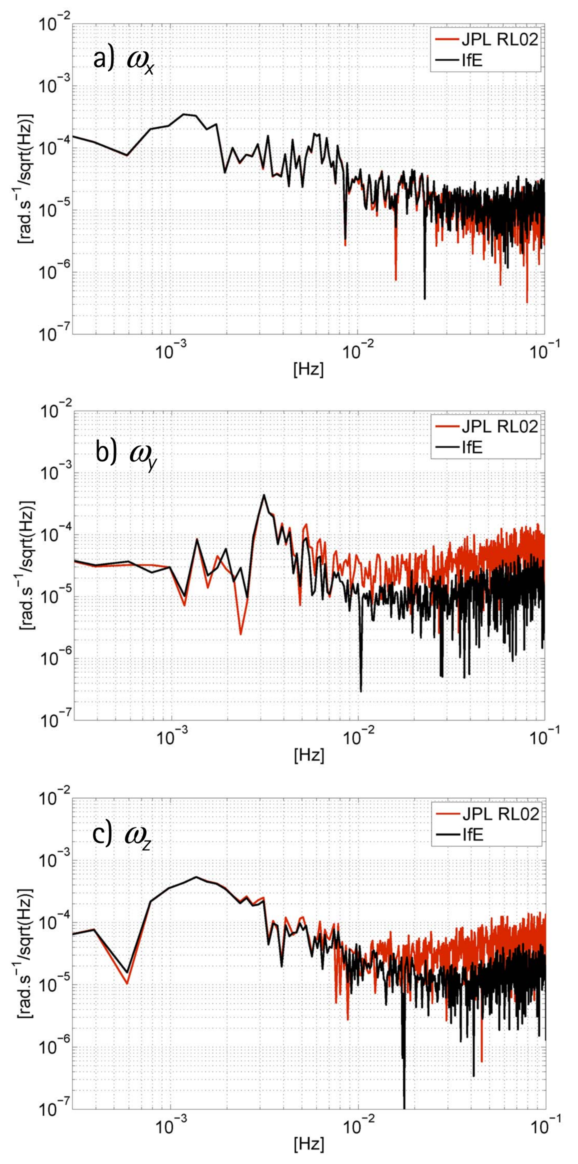


Fig. 2 – The same as Fig.1 in terms of square root power spectral density. The noise level of these two solutions differs for ω_y and ω_z about a factor 3-4

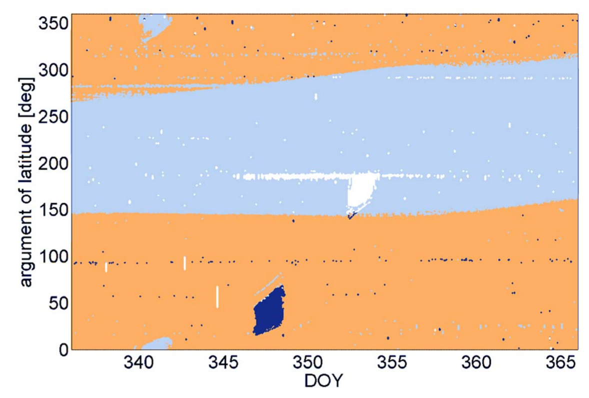


Fig. 3 – Availability of valid star camera data in Dec 2008 for GRACE A : orange – combined and improved attitude data, light&dark blue – single camera data, white – no data

As the SCA attitude data are essential for the processing of the K-band ranging data and the accelerometer data, which are fundamental for the gravity field recovery, the quantification of the effect of the improved star camera data on these observations and on the gravity field is needed and presented here.

2 – THE EFFECT ON THE OBSERVATIONS

A) The effect on the KBR observations

The inter-satellite K-band ranging (KBR) observations (range r, range-rate $\dot{r}$, range-acceleration $\ddot{r}$) are corrected for the imperfect inter-satellite pointing (Bandikova et al., 2012) by applying the KBR antenna offset correction (AOC).

The significant effect of the improved attitude data on the KBR antenna offset correction for range rate is demonstrated in Fig. 4. Additionally in Fig. 4b, the difference of these two solutions is compared to the KBR system error which is modeled as white noise of $1\,\mu m/\sqrt{Hz}$ at the range level (Gerlach et al., 2004). Clearly, at frequencies below $2 \cdot 10^{-2} Hz$ the differences are above the expected error level.

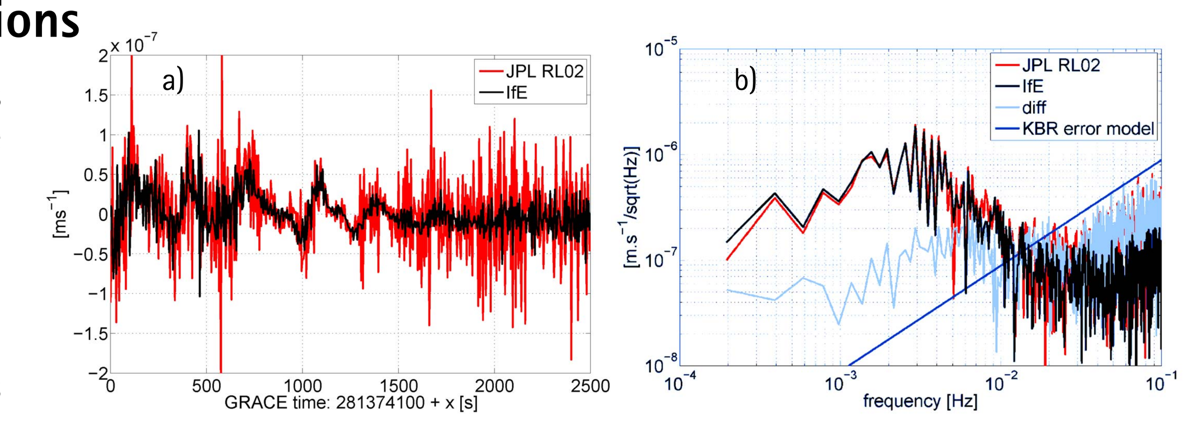


Fig. 4 - The KBR antenna offset correction for range rate derived from the "SCA L1B RL02" data (red) and from the "SCA IfE" data (black) in time domain (a) and in frequency domain (b). The differences of these two solutions (light blue) are compared to the KBR system error (blue)

B) The effect on the linear accelerations

The linear accelerations sensed by the accelerometer (ACC) represent the non-gravitational forces acting on the satellite. These accelerations are rotated from the science reference frame (SRF) into an orbit related frame, which in case of the Celestial mechanics approach is the so called true radial reference frame (TRRF).

$\vec{x}_{TRRF} = \vec{y} \times \vec{z}$ (along track)
$\vec{y}_{TRRF} = \frac{\vec{r} \times \vec{v}}{|\vec{r} \times \vec{v}|}$ (cross track)
$\vec{z}_{TRRF} = \frac{\vec{r}}{|\vec{r}|}$ (radial)

The differences of the rotated linear accelerations (using the "SCA1B Rl02" and "SCA IfE" data) reach up to to $1.5 \cdot 10^{-8}$ ms^{-2} (Fig. 5) which is up to two orders of magnitude above the expected error level (Fig. 6). The ACC error models (Stanton, 2000) are originally defined for the ACC sensor frame (identical to SRF). However, as the TRRF is along the orbit almost aligned with the SRF, the error model can be adopted and is considered as true in TRRF.

$$E_{radial,along-track}(f) = (1 + 0.005/f) \times 10^{-20} m^2 s^{-4}/Hz$$
$$E_{cross-track}(f) = (1 + 0.1/f) \times 10^{-18} m^2 s^{-4}/Hz$$

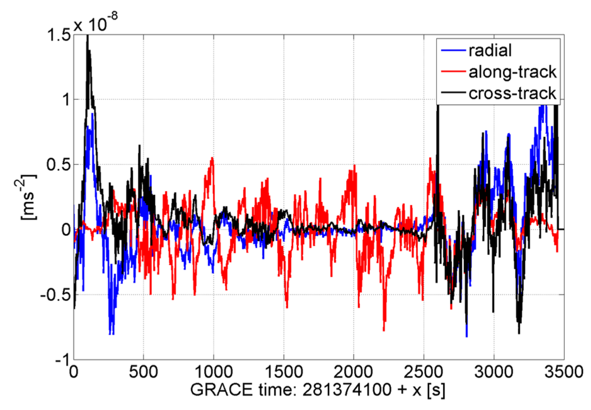


Fig. 5 - Differences of the linear accelerations rotated into TRRF using the "SCA1B RL02" data and the "SCA IfE" star camera data

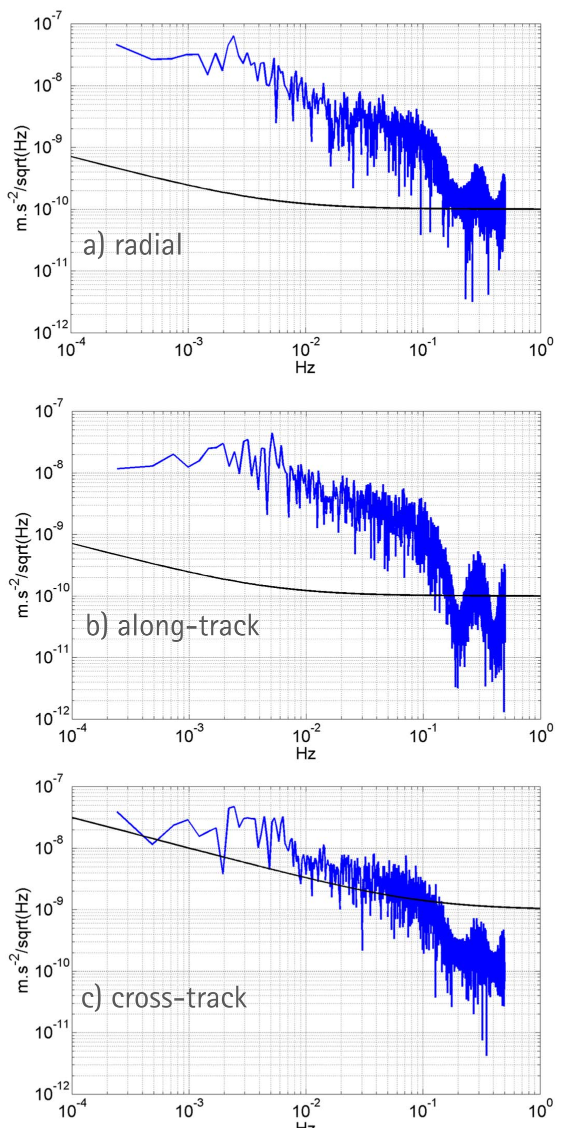


Fig. 6 - The same as Fig. 5 in terms of square root power spectral density, compared to the ACC error models (black curve)

3 – THE EFFECT ON THE GRAVITY FIELD

A) Simulation study

The expected effect of the improved attitude data on the satellite's orbits and inter-satellite range rates was estimated using the RSES GRACE simulator. Starting with an a priori position and velocity, using the standard background models and the SCA ("SCA1B RL02" and "SCA IfE") and ACC data, 12 hour orbits for both satellites were integrated.

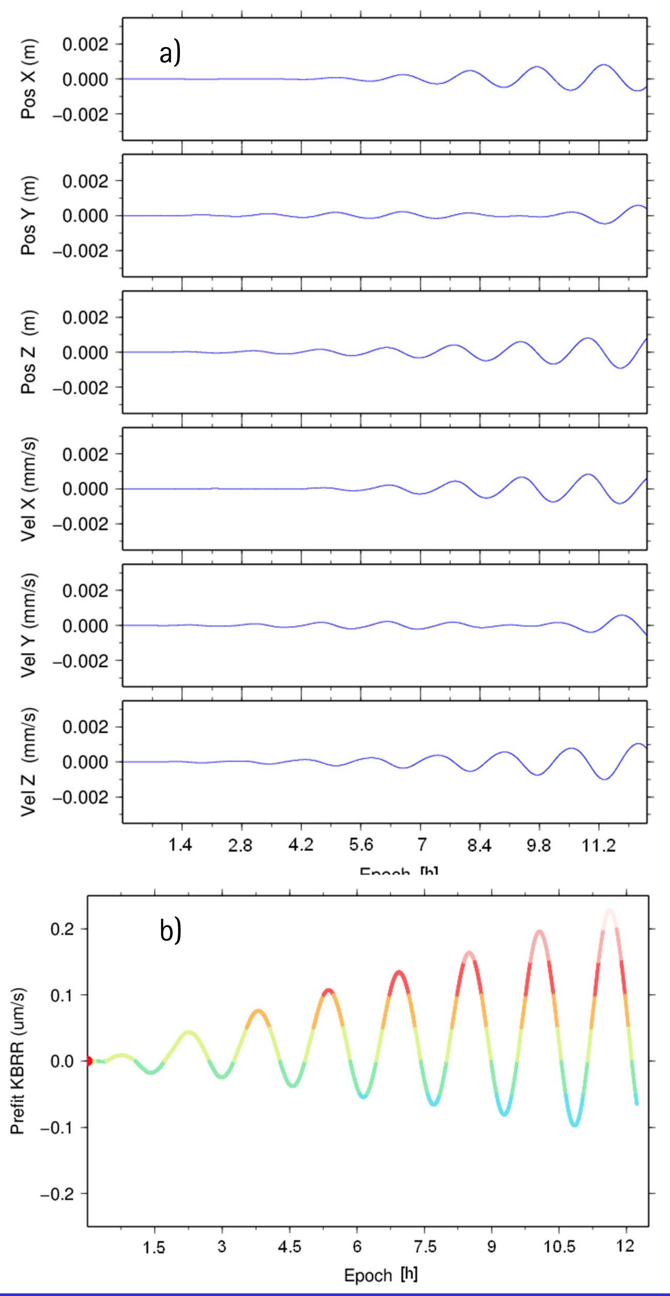


Fig. 7 shows the differences of these two data sets, which are solely caused by the differences in the star camera data. After 12 hours, the positions are altered by ~ 2 mm and the range rates up to ~ 0.2 μm/s with obvious 1/rev pattern (which corresponds well with the magnitude of the AOC differences presented in Fig. 4).

Considering the current accuracy of the GRACE orbits (2 cm for position and 20 μm/s for velocity) and of the inter-satellite ranging (0.19 μm/s), the simulated effect of the attitude errors is below or right at the current accuracy level. Because these impacts on the observables are small, the effect on the temporal gravity field estimates is likely to be small.

Fig. 7
Simulated satellite position and velocity (a) and inter-satellite range-rate (b) alterations caused entirely by the differences in the "SCA1B RL02" and "SCA IfE" data

Monthly gravity field model up to d/o 90 for Dec 2008 was generated based on the "SCA1B RL02" and "SCA IfE" data using two different mathematical approaches:

B) Celestial mechanics approach

Celestial mechanics approach
AIUB (Beutler et al., 2010)
Static field: AIUB-GRACE03s

The difference degree amplitudes relative to the static field are shown in Fig. 8. Tiny differences are obvious between degree 15 and degree 40. Above degree 30, the difference degree amplitudes are dominated by noise.

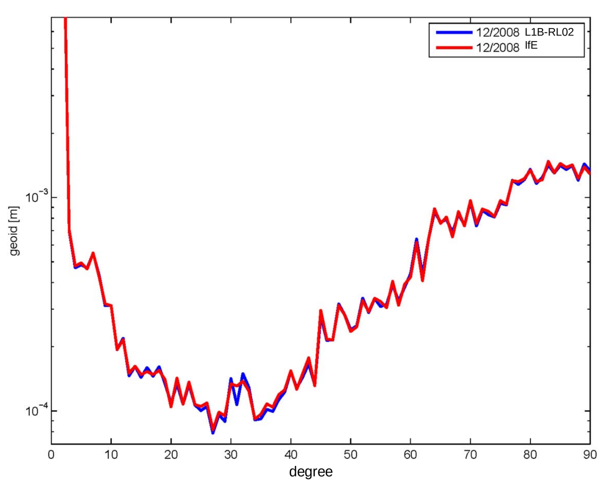
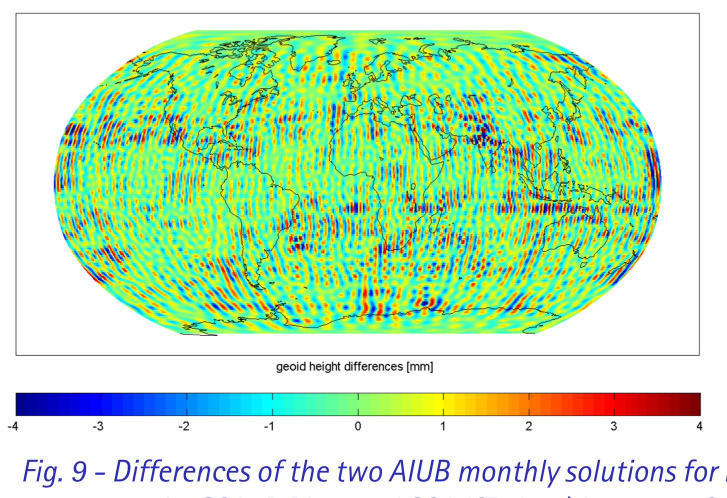


Fig. 8
difference degree amplitudes relative to the AIUB static field for the L1B and IfE solution



The differences between the two solutions are expressed in terms geoid heights (Fig. 9). The differences are at the mm-level. The global rms of these geiod height differences is 0.98 mm.

Fig. 9 - Differences of the two AIUB monthly solutions for Dec 2008 (based on the SCA1B RL02 and SCA IfE data) in terms of geoid heights

C) Variational equations approach

Variational equations approach
ITSG (Montenbruck & Gill, 2000)
Static field: GOCO03s

The difference degree amplitudes relative to the static field for the two monthly solutions are again almost identical (cf. Fig. 10). Tiny differences can be found between degrees 20-60.

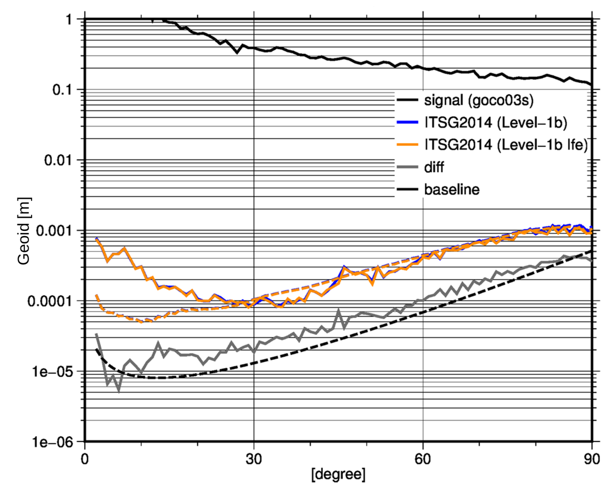


Fig. 10
difference degree amplitudes relative to the GOCO03s field for the L1B and IfE solution. The gray curve represents the difference of the L1B and IfE solution

In terms of geoid heights, the differences between these two solutions are at mm-level (Fig.11). The global rms of these differences is 1.4 mm.

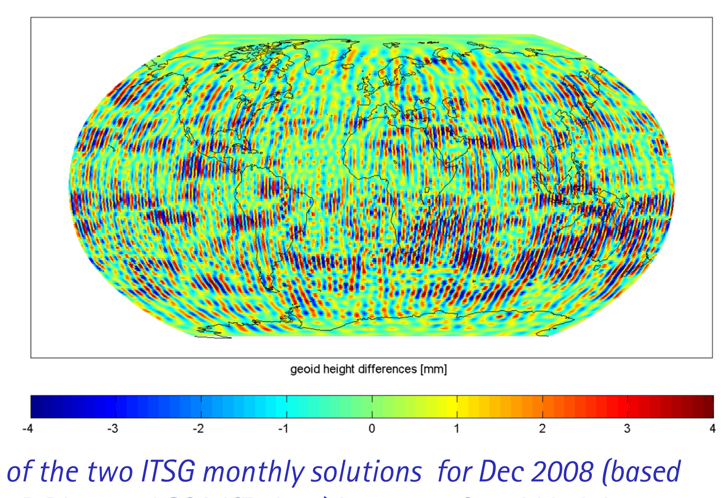


Fig. 11 - differences of the two ITSG monthly solutions for Dec 2008 (based on the SCA1B RL02 and SCA IfE data) in terms of geoid heights

The results of the AIUB and ITSG gravity field analysis match very well together. Both confirm that the effect of the improved star camera data on the monthly gravity field is at mm-level in terms of geoid heights. The AIUB and ITSG results confirm the predictions from the RSES simulation. The rather small effect might be also caused by the restricted availability of the improved star camera data (only when none of the two cameras is blinded by the Sun or the Moon).

4 – CONCLUSIONS

- The improved star camera data generated by IfE substantially improve the accuracy of the KBR ranging observations and linear accelerations as their noise is decreased by up to 2 orders of magnitude
- The effect on the gravity field is at mm-level in terms of geoid.
- The error budget of the current temporal gravity field releases is dominated by errors coming from sources other than from the imperfect quaternion combination in SCA1B RL02

5 – REFERENCES

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6 – ACKNOWLEDGEMENTS

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