MORE RESULTS ON HIGH-RESOLUTION ANALYSIS OF GRACE SENSOR DATA

Jakob Flury[1,2], Tamara Bandikova[1,2], Nadja Peterseim[1], Ung Dai Ko[3]
[1] Leibniz Universität Hannover, Germany, Institut für Erdmessung; flury@ife.uni-hannover.de
[2] Centre for Quantum Engineering and Space-Time Research, Hannover, Germany
[3] University of Texas at Austin, Center for Space Research

GRACE Science Team Meeting, Nov 5-6, 2009, Austin, TX

Attitude systematics and attitude errors

Precise knowledge of satellite attitude and precise pointing of the satellites is a central requirement for the overall GRACE performance and for gravity field determination. Analysis of postfit residuals together with attitude data indicates that attitude systematics and attitude errors have a substantial impact on gravity field results, possibly even more than aliasing effects due to rapid geophysical mass variations.

For both GRACE satellites, attitude angles vary w.r.t. the velocity vector (or w.r.t. the line of sight to the other satellite) typically within 4 mrad for pitch (Fig.1) and within 9 mrad for yaw (Fig.2) and roll. In science mode, pitch angles are controlled using magnetic torquer rods (MTQ) whereas yaw and roll is controlled by a combination of thrusters and MTQ torques. Attitude variations influence the K-band ranging (KBR) measurements in the order of tens of µm. To fully exploit the KBR accuracies, this effect has to be corrected. A geometric correction is provided in the KBR1B product. However, any error in this correction will directly impact the quality of KBR and gravity field results.

Pitch variations (Fig.1) are dominated by higher harmonics of the orbital period (Fig.3) which are apparently amplified at frequencies between 3 and 5 mHz (periods between 200 and 300 seconds). Along the ground track, a pattern of zonal bands is obtained. These systematics - which are very consistent in time - seem to be commanded by the autonomous attitude and orbit control system (AOCS) by way of periodic MTQ currents (Fig.4).

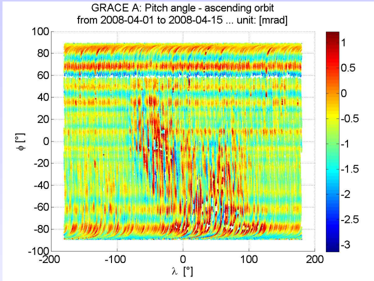

Fig. 1: Pitch angle of GRACE A w.r.t. the line of sight to GRACE B for 15 days, plotted along the ground track.

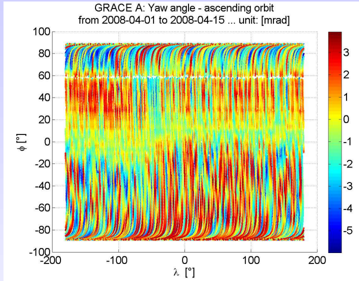

Fig. 2: Yaw angle of GRACE A w.r.t. the line of sight to GRACE B for 15 days, plotted along the ground track.

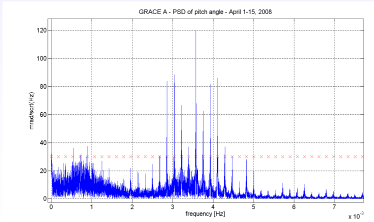

Fig. 3: Square root power spectral density of pitch as linear scale plot. Red crosses represent the multiples of orbital period.

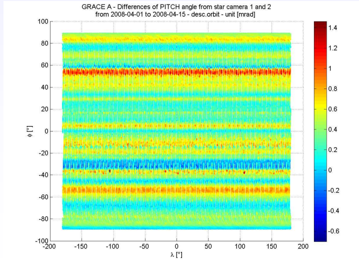

Fig. 5: Differences between pitch angles obtain from the two star camera heads plotted along the ground track; two weeks data.

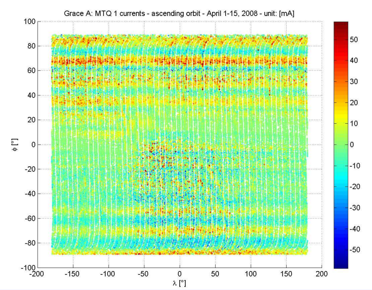

Fig. 4: Magnetic torquer electric currents applied to along track rod

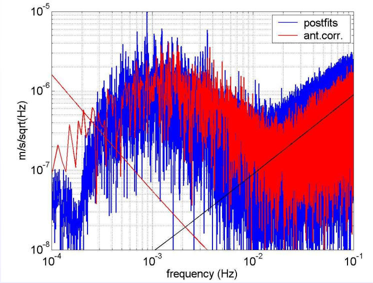

Fig. 6: Square root PSD of CSR RL04 postfit residuals and geometric antenna correction from KBR1B product. Straight lines show error models for KBR and accelerometer instruments.

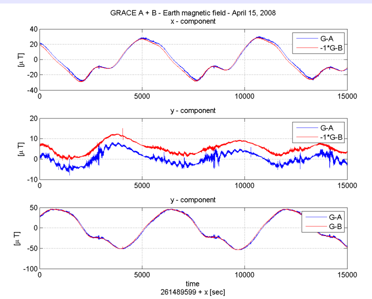

Fig. 8: Earth magnetic field vector B at satellite altitude observed by magnetometer on board GRACE A and GRACE B. Note the 300 s wiggle period.

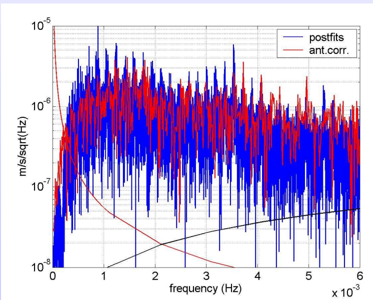

Fig. 7: Same as in Fig. 6, but with linear frequency axis. Peaks in both antenna correction and postfits occur at harmonics of the orbital frequency.

Inconsistencies between the two star camera heads on board of each of the satellites were used to derive estimates of attitude errors. Inconsistencies are in the order of 2mrad and show characteristics similar to the actual attitude angles (Fig.5). Also attitude errors seem to be dominated by harmonics of the orbital frequency between 3 and 5 mHz.

Harmonics of the orbital frequency also dominate the geometric correction and postfit residuals (Fig. 6, 7), and their power is clearly amplified at 3 to 5 mHz. This indicates that the geometric correction in the KBR1B product does not sufficiently remove effects due to satellite rotation.

Possibly, star camera errors are leading to a periodic oscillation mode in the AOCS. Star camera errors will also be propagated to the geometric correction and to the gravity field solutions. Harmonics of the orbital frequency may introduce errors and correlations in particular to zonal coefficients of the static and time variable gravity field.

To lower the level of postfit residuals and to improve gravity field results, a better understanding of attitude effects and processes introducing harmonics of the orbital frequency seems essential.

Periodicities in MTQ currents (Fig.4) have another side effect. Both satellites carry magnetometers on booms attached to the nadir side. They sense the natural magnetic field of the Earth, but also the field due to the variable MTQ dipoles. This leads to 300 second wiggles in the magnetometer observations (Fig.8). For the AOCS, the effect is taken into account by an onboard correction algorithm.

Conclusions

- The accuracy of current GRACE gravity field results seems to be limited by imperfect correction of satellite attitude effects, possibly related to star camera errors. These effects seem to exceed errors due to aliasing.
- The impact of attitude errors on other observations (e.g., accelerometer data) should be further studied.
- Better understanding of attitude effects may help to improve GRACE results, and to achieve better accuracy with follow-on missions. Precise pointing will be even more important for future laser interfermotric ranging between satellites.
- Improved understanding of accelerometer signal components can be obtained using empirical models for magnetic torquer spikes, twangs, and other satellite-induced effects.

Magnetic torquer acceleration spikes

Electric currents in the three MTQ rods are controlled using incremental current steps once per second. Simultaneously with the current steps, small acceleration spikes up to 20 nm/s² are observed by the GRACE accelerometers. This may be related to small deformations of the rather heavy (0.5 kg) ferromagnetic core of the MTQ rods due to the changing magnetization (Fig 9). The effect is not unexpected but has not been studied before.

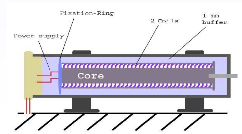

Fig. 9: Magnetic torquer rod (ZARM)

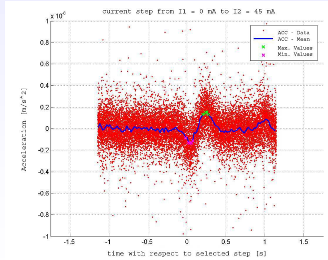

Fig. 10: Observed acceleration spike after 45mA current steps (GRACE A)

Acceleration spikes were extracted and empirically modeled based on 10 Hz ACC1A data and 1 Hz MAG1B data (Fig.10). Results show that spike amplitudes increase with the current step amplitude, and that the effect increases in a non-linear way for currents close to the saturation current of 120 mA (Fig.11).

Preliminary results indicate that an additional acceleration noise of slightly below 10^{-10} m/s²/sqrt(Hz) can be expected. No major impact on GRACE gravity field results is expected. For follow-on missions, this additional noise source should be avoided, possibly by modification of the MTQ design.

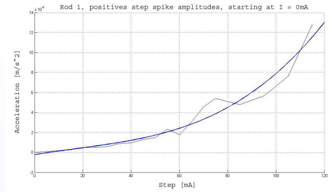

Fig. 11: Emperical regression between electric current step and acceleration spike amplitude (GRACE A)

Twangs

Some progress has been achieved to understand the strong damped oscillations ('twangs') in the GRACE accelerometer signal (Fig.12). Various twang categories were identified. Some categories occur when the nadir side of the satellite is hit by solar radiation (Fig.13). Other categories are found at distinct locations along the orbit with some correlation with the orientation of the orbital plane towards the sun (Fig.14).

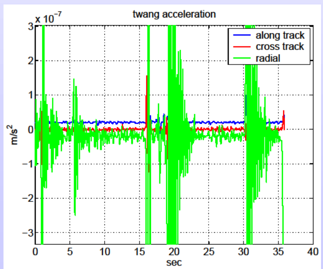

Fig. 12: Typical „twangs"

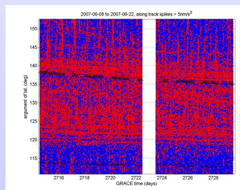

Fig.13: Strong „twang" activity between entry of the nadir into direct sunlight (black crosses) and entry of the satellite into Earth shadow (triangles)

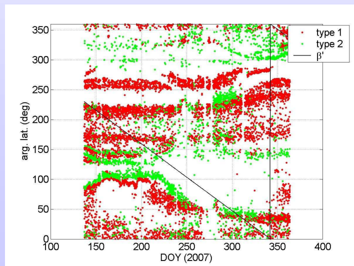

Fig. 14: Distribution of two „twang" sub-categories along the orbit. The black line indicates the angle of the orbital plane towards the sun