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GOCE Aerodynamic Torque Modeling

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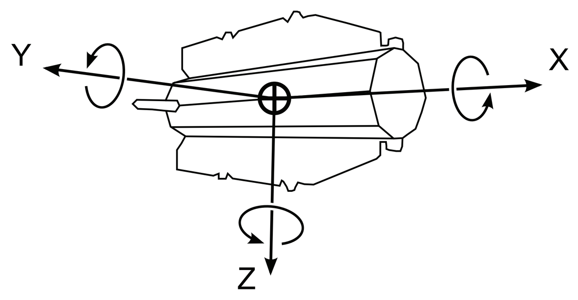
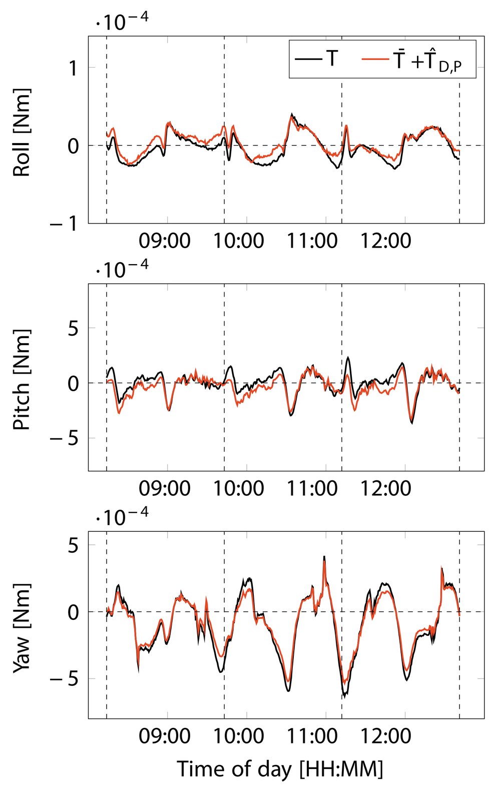


In recent studies thermospheric densities and cross-winds have been derived from linear acceleration measurements of the gradiometer on board the GOCE satellite. Our current work is aimed at analyzing also the **angular accelerations**, in order to improve the thermosphere density and wind data by allowing for the estimation of more unknown parameters. On this poster an overview is provided of the modeling efforts involved in **isolating the aerodynamic torque**. The intermediate result is a comparison of modeled and measured torques.
Each box contains a plot of the torque from a **specific source**, compared to the measured torque, on October 16th, 2013. A short description of the model for each torque is also provided.

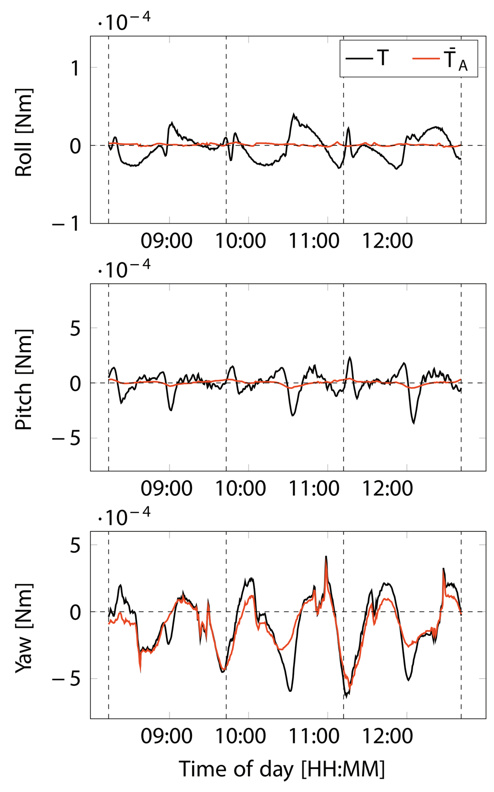
Total of modeled torques



All torques are calculated from a subset of the following data:
- Science orbit;
- Attitude quaternions;
- Angular accelerations;
- Angular rates;
- Solar activity indices;
- Geomagnetic indices;
- GOCE thermosphere data;
- Magnetometer readings;
- Magnetic torquer currents;
- Ion thruster magnet current;
- Ion thruster thrust;
- Interpolated inertia tensor.

The total of modeled and estimated torques closely resembles the measurements, with a relative root mean square error of 10% of the range in roll and pitch, and only 3% of the range in yaw.

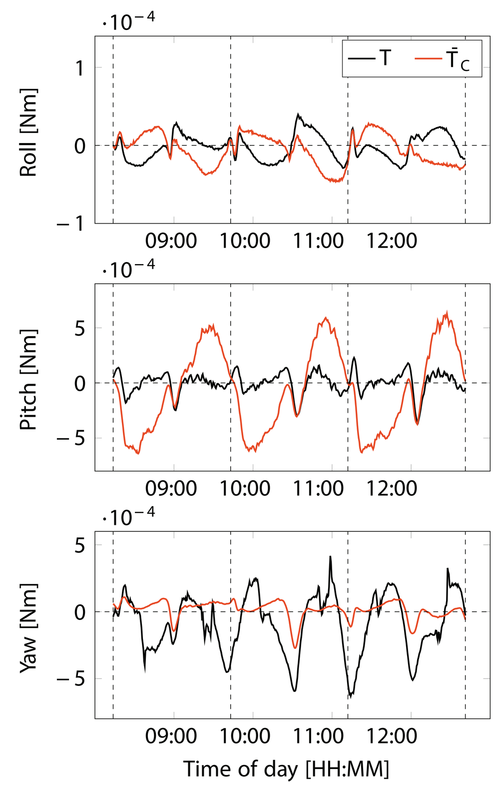
Aerodynamics



Improving the aerodynamic model is the main goal of this research, but for now a default model is used. The **force and moment coefficients** are obtained from a Monte-Carlo simulation in ANGARA*, as a function of aerodynamic angles and speed ratio. **Temperatures and particle densities** from NRLMSISE-00 are used to interpolate on these coefficients, while GOCE **density and cross-wind data** are used for the actual torque calculation.

Aerodynamics are the main cause of torque in the yaw direction. The effects of wind fluctuations at high latitudes are also clearly visible in this axis.

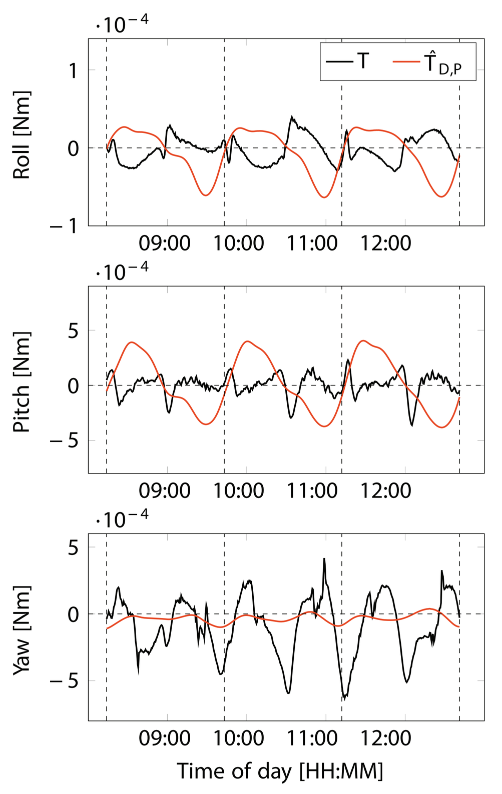
Magnetic torquers



Attitude control is realized by three magnetic torquers aligned with the three body axes of the satellite. The **current** through the torquers is available from the housekeeping data. These currents are converted to **dipoles** using an adaptive cubic polynomial model. Together with the calibrated **magnetometer field measurements** the control torque is obtained.

Whereas the control algorithm is actively correcting the pitch attitude, only minor corrections are made in the yaw axis. Here GOCE mostly relies on the weather vane principle to minimize drag.

Estimated payload dipole

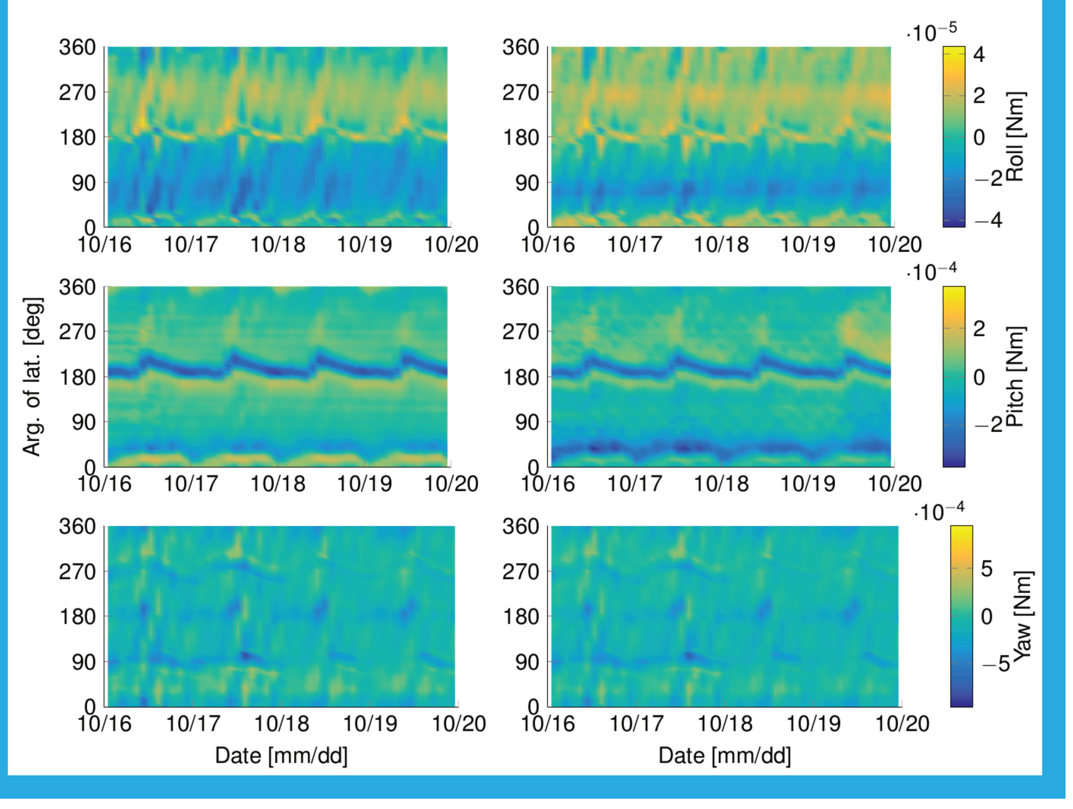


Dipole models are only available for the spacecraft bus, not for the payload and instruments. Therefore a **constant hard magnetic** and a **constant soft magnetic** dipole are fitted to the residual torque over four orbits on December 1st, 2009. On this day the solar activity was low, leading to a small aerodynamic contribution.

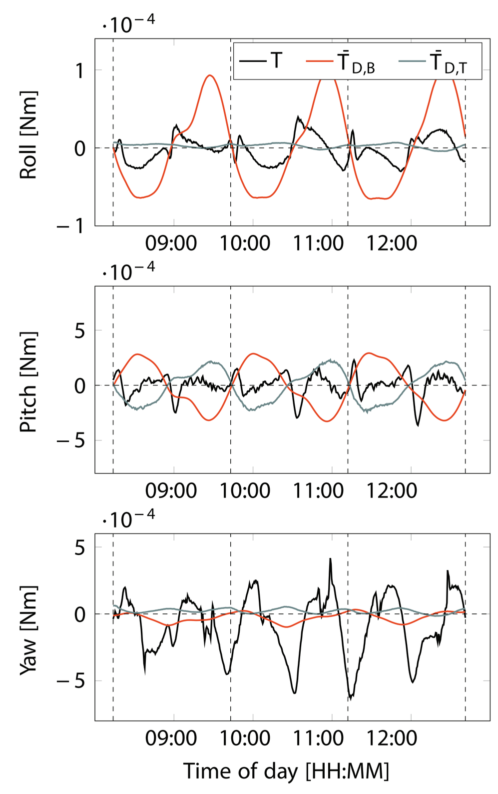
The estimated dipoles show a similar scale and direction as the dipole caused by the spacecraft bus. The same dipoles are used to find the payload induced magnetic torque on October 16th, 2013.

Comparison of measurements and models

Below the **measured (left)** and total **modeled (right)** torque are plotted as a function of time (in 2013) and argument of latitude. The magnetic **equator** and **poles** are clearly visible in pitch and yaw respectively.



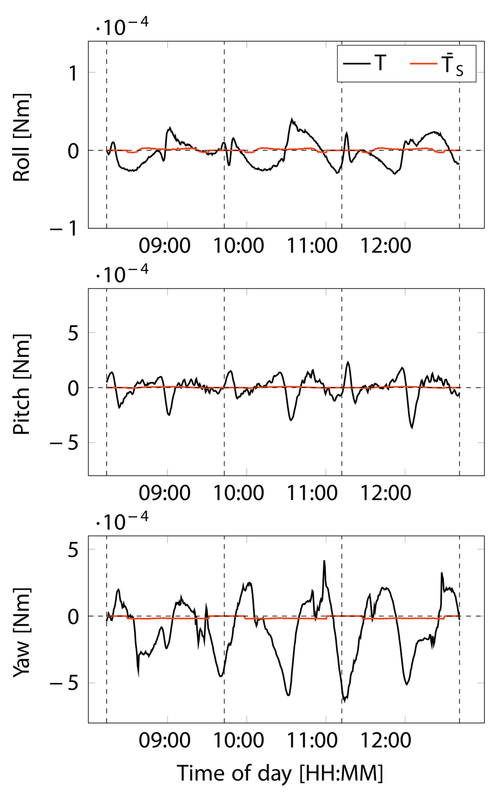
Spacecraft bus dipole



The spacecraft bus contains many elements apart from the torquers that generate a magnetic dipole. These dipoles again cause a magnetic torque depending on the **Earth magnetic field** direction.
Based on the results of a hook test performed on GOCE during development, a **hard magnetic dipole**, as well as several **soft-magnetic dipoles** are modeled. On top of that the magnet of the **ion thruster** causes a significant dipole (shown separately in the plot).

The mentioned dipoles are especially prominent in the roll and pitch axes.

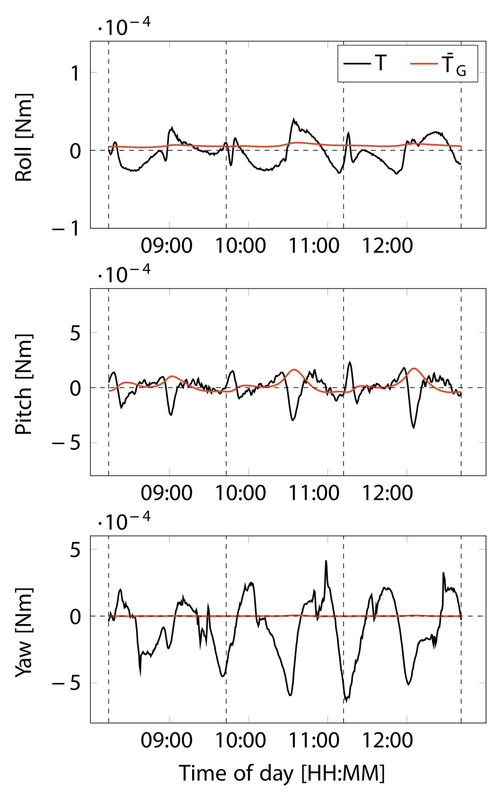
Solar radiation pressure



Solar radiation pressure causes the second to largest non-gravitational disturbance force in LEO, but the resulting torques are generally small. Due to the symmetric nature of GOCE, these effects are reduced even more. A similar model is used as for aerodynamic torques, with **force and moment coefficients** from a Monte-Carlo simulation in ANGARA* and the **sunlight vector** derived from the spacecraft attitude and the sun position from the Spice toolbox.

The contribution of solar radiation pressure to total torque is sufficiently small to justify ignoring albedo effects.

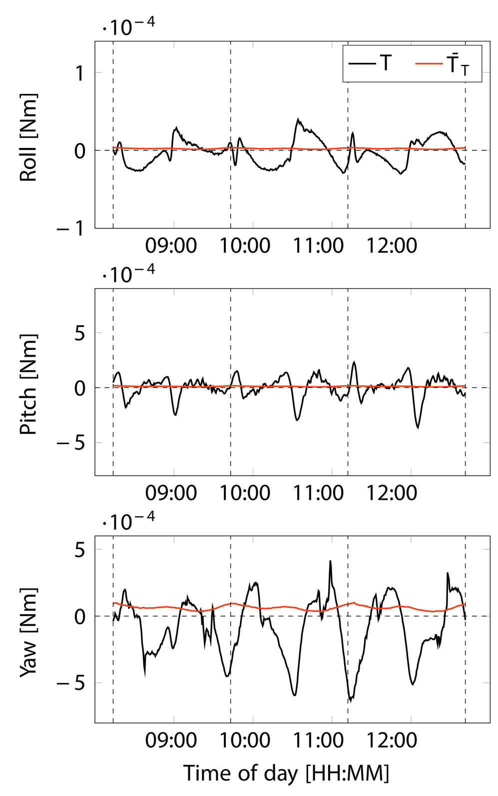
Gravity gradient



Gravity gradient torque is generally considered to be one of the major attitude disturbances to satellites in low orbits. Assuming a simple model, yet incorporating the **gravity vector** from EGM2008, this torque can be calculated. The **inertia tensor** is linearly interpolated between the beginning- and end-of-life values.

Indeed, gravity plays a significant role in the pitch torque, but in other directions the effects are limited.

Thruster misalignment



The ion thruster is aligned such that the thrust vector acts exactly between the beginning- and end-of-life centers of mass. This means that most of the time, the **thrust** will have a slight offset from the **center of mass**, causing a torque. As the center of mass only shifts slowly, the torque trend is equal to that of the thrust force.

The pointing error is largest in the body y-direction, causing a yaw torque. From a sensitivity analysis it was found that this torque is very sensitive to thruster pointing errors. It may be necessary in the future to estimate this pointing error as well.

* "Analysis of Non-Gravitational Accelerations due to Radiation and Aerodynamics", Hyperschall Technologie Göttingen GmbH

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