GOCE LOW ORBIT OPERATIONS: FROM 260 TO 230 KM ALTITUDE

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Keywords: *GOCE, LEO, Operations, drag-free*

ABSTRACT

The Gravity Field and Steady-State Ocean Circulation Explorer ESA mission GOCE has measured the Earth's gravity field and provided a model of the geoid with extremely high accuracy never achieved before. Launched on the 17th of March 2009 from the Plesetsk Cosmodrome on a Rockot launch vehicle, GOCE was injected on a near polar, dusk-dawn Sun synchronous orbit at an approximate mean altitude of 280 km. After a natural decay due to the atmospheric drag force, GOCE reached its final routine operational mean altitude of 260 km in September 2009. From that moment and until July 2012 GOCE was successfully operated at this mean altitude during its extended routine phase, owing the significant extension (GOCE mission was originally conceived to last 20 months) to the excellent scientific results, the good status of the satellite, and the large margin in the fuel budget for the ion propulsion system.
To maximize the scientific return of the mission prior to its end of life, in summer 2012 the GOCE Flight Operations Segment (FOS) started a campaign to gradually lower the orbit of GOCE even further, with the consequent improvement in the resolution of the gravity measurements. The orbit was lowered in several steps starting in August 2012, with the final altitude of 230 km reached at the end of May 2013.

This paper presents the results of the mission analysis studies performed by the GOCE Flight Dynamics team that led to select the final operational altitude of 230 km, as well as the preparatory work that was carried out by the GOCE Flight Dynamics Orbit Determination and Control team in order to support this last phase of low orbit operations, that were conducted from July 2012 until October 2013, when the depletion of the Xenon tank led to the final orbit decay and subsequent destructive re-entry on the 11th of November 2013.

In order to map the Earth's gravity field at a high accuracy and with a fine spatial resolution, GOCE had to orbit at the lowest possible altitude. At low altitudes the drag force and torques encountered by the spacecraft are significant. In order to cope with this regime, GOCE was

equipped with a new and sophisticated Drag Free Attitude and Orbit Control System (DFACS) that provided 3 axis stabilized attitude using magnetotorquers as actuators and an Ion Propulsion Assembly (IPA) that, working in close-loop with an electrostatic gravity gradiometer, continuously counteracted the atmospheric drag and kept the satellite flying undisturbed and drag-free along the flight direction.

The capability of GOCE to fly in the so-called Drag Free Mode (DFM) with the ion engine compensating the along-track drag force was the key aspect to conduct operations. The design of the low orbit operations scenario was essentially an evaluation of by how much the initial GOCE routine altitude (260 km) could be lowered while staying in a safe scenario from the drag levels point of view. The Flight Dynamics studies provided figures on the evolution of the altitude and the capability of ground to recover the mission in the event of an ion engine outage. The main parameters included in the study were:

- The duration of the ion engine outage.
- The solar activity assumed for the period of the GOCE low orbit operations (based on the Marshall Space Flight Centre predictions at different confidence bounds). The drag force encountered by the spacecraft depends on the atmospheric density which is determined to a large extent by the solar and geomagnetic activity.
- The behaviour of the spacecraft attitude, which affects the averaged spacecraft frontal area in the flight direction and therefore the drag force exerted on the spacecraft.
- The limitation on the maximum thrust provided by the ion engine, which depends on the power budget and is consequently dependant on the eclipse durations.

The main outcome of the analysis was the selection of an altitude of 240 km. A review of the analysis at a later point in time revealed that the solar and geomagnetic activity predictions used in the analysis were too conservative, allowing to target a final operational altitude of 230 km.

As additional preparatory activities for the orbit lowering, an analysis of the orbit predictions accuracy was carried out by the Flight Dynamics team, accounting for the expected errors in the prediction of the solar and geomagnetic activity, the air density model errors and the behaviour of the spacecraft attitude. The results of this analysis and the corresponding measures put in place to mitigate the risks of not acquiring the spacecraft signal when operating out of drag free mode are summarized in the paper.

The GOCE orbit lowering from 260 to 230 km was implemented in a progressive fashion in four steps:

- August 2012. From 260 to 251 km.
- November 2012. From 251 to 245 km.
- February 2013. From 245 to 240 km.
- May 2013. From 240 to 230 km.

The paper describes the operational experience gained by the GOCE Flight Dynamics team during these orbit lowering steps, which turned out to be an extremely valuable experience for the de-orbiting operations that were conducted in October-November 2013.