High-accuracy orbit determination for the GOCE re-entry phase

When the Xenon ion propulsion of ESA’s GOCE (Gravity field and steady-state Ocean Circulation Explorer) stopped operating after October 21, 2013, the satellite entered an uncontrolled, uncontrolled decay of orbital altitude (see Fig. 1). Despite the increasing air drag conditions, GOCE accelerometers and GPS receivers delivered high-quality data until November 8 and November 10, respectively, before GOCE finally disintegrated on November 11, around 0.16 UTC near the Falkland islands (see Fig. 2).

In the framework of the ESA study FREGO the data provided by GOCE during its re-entry phase shall be exploited to improve the capabilities on re-entry prediction. The study is conducted by Deimos Space, Made in Germany and the Astronomical Institute of the University of Bern (AIUB) as well as the Centre National d’Etudes Spatiales (CNES), Toulouse as subcontractors. The AIUB re-computes and provides the GPS-based precise GOCE orbits, which then serve as the reference truth for further re-entry analysis including Tracking and Imaging RADAR (TIRA) and Two-Line Elements (TLE) data.

Reproducing the GOCE HPF orbits

In the framework of the GOCE High-level Processing Facility (HPF) the AIUB was responsible for the generation of the official GOCE Precise Science Orbits (PSOs). Fig. 3 shows the workflow.

The PSOs were computed with a special version of the Bernese GNSS Software, which was frozen at the beginning of the GOCE activities. Non-gravitational accelerations were taken into account exclusively by estimating 6 minutes pseudo-stochastic piecewise-constant empirical accelerations. The orbits for this study are computed with the latest version of the Bernese GNSS Software. As a zero test, orbits have been computed with the new software and the old settings. They agree with the PSOs on a good level (see Fig. 4).

Air drag modeling

Air drag modeling has been implemented into the Bernese GNSS Software. GOCE is represented by a collection of flat plates, each characterized by area A and a vector c, contributing to the total drag and lift acceleration as follows:

\[ \mathbf{a}_{\text{drag}} = -\frac{\rho}{2} \cdot \mathbf{c} \cdot \mathbf{v}^2 \cdot \mathbf{c}, \quad \mathbf{a}_{\text{lift}} = -\frac{\rho}{2} \cdot \mathbf{c} \cdot \mathbf{v}^2 \cdot \mathbf{c} \cdot \mathbf{n} \]

(1)

where \( \rho \) is the atmospheric density, \( A \) the satellite mass, \( \mathbf{c} \) a reference area, \( n \) the magnitude of the velocity \( \mathbf{v} \). The atmospheres \( \mathbf{c} \) and \( \mathbf{c} \cdot \mathbf{v} \) are computed according to Sippel’s theory (Moe and Moe, 2005), which assumes that the atmospheric molecules are in a free molecular flow (for GOCE true only above \( \sim 150 \text{km} \)).

Cross-track and along-track orbit difference for the last three weeks (days 11/294-11/314).

In order to use accelerometer measurements for the derivation of atmospheric densities along the GOCE orbit, the kinematic orbit positions were computed with the Bernese GNSS Software. The orbit extrapolations were then performed using the software package GNIS of CNES. Figure 8 shows the impact of using different atmospheric models and orbit parametrizations.

Conclusions and outlook

The ESA study FREGO attempts to exploit the unique data set delivered by GOCE during its last days to improve re-entry prediction models. For this purpose high-precision GPS-based orbits are computed using the latest version of the Bernese GNSS Software.

- Air drag modeling has been implemented in the Bernese GNSS Software. This allows to substantially reduce the estimated empirical accelerations, to tighten the constraints of the piecewise-constant accelerations (reducing in orbits with more dynamical stiffness) and to reduce the error in the orbit extrapolation. Further improvements are expected once air drag scale factors are estimated.

- The on-board GPS receiver of GOCE produced a meter-accuracy navigation solution. While the last GPS phase measurement is at 17:15 UTC, the last position data set is at 22:46 UTC, and its appropriate inclusion can thus substantially improve the orbit extrapolation. Data problems (e.g., identical position at two or more different epochs) and the clarification of the related reference frame need to be addressed first.

References


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