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Precise orbit determination for the GOCE satellite using GPS

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Abstract

Apart from the gradiometer as the core instrument, the first ESA Earth Explorer Core Mission GOCE (Gravity field and steady-state Ocean Circulation Explorer) will carry a 12-channel GPS receiver dedicated for precise orbit determination (POD) of the satellite. The EGG-C (European GOCE Gravity-Consortium), led by the Technical University in Munich, is building the GOCE HPF (High-level Processing Facility) dedicated to the Level 1b to Level 2 data processing. One of the tasks of this facility is the computation of the Precise Science Orbit (PSO) for GOCE. The PSO includes a reduced-dynamic and a kinematic orbit solution.

The baseline for the PSO is a zero-difference procedure using GPS satellite orbits, clocks, and Earth Rotation Parameters (ERPs) from CODE (Center for Orbit Determination in Europe), one of the IGS (International GNSS Service) Analysis Centers. The scheme for reduced-dynamic and kinematic orbit determination is based on experiences gained from CHAMP and GRACE POD and is realized in one processing flow. Particular emphasis is put on maximum consistency in the analysis of day boundary overlapping orbital arcs, as well as on the higher data sampling rate with respect to CHAMP and GRACE and on differences originating from different GPS antenna configurations.

We focus on the description of the procedure used for the two different orbit determinations and on the validation of the procedure using real data from the two GRACE satellites as well as simulated GOCE data.

Keywords: GOCE; Precise orbit determination; Zero-difference; GPS; CHAMP; GRACE

1. Introduction

The GOCE (Gravity field and steady-state Ocean Circulation Explorer) satellite is the first ESA (European Space Agency) Earth Explorer Core Mission (Drinkwater et al., 2003) to be launched in December, 2007 from Plesetsk, Russia. The mission is dedicated to high-resolution gravity field extraction and carries, as the core instrument, a three-axis gradiometer. In addition, the measurements of the onboard GPS receiver allow for gravity field recovery of the low degree and order terms and for precise orbit determination (POD) of the satellite. The main focus of this paper is on the latter task.

ESA contracted the European GOCE Gravity-Consortium (EGG-C, see below) to implement the High-level Processing Facility (HPF) for the Level 1b to Level 2 data processing for the GOCE satellite and the computation of a highest quality static Earth gravity field and precise satellite orbits. DEOS (Department of Earth Observation and Space Systems, Delft University of Technology) and AIUB (Astronomical Institute of the University of Bern) together with IAPG (Institute of Astronomical and Physical Geodesy, Technical University of Munich) are – as part of EGG-C – responsible for the POD task, which is divided into the quicklook part (Rapid Science Orbit (RSO)) performed at DEOS and the Precise Science Orbit (PSO) (ESA, 2006) part performed at AIUB and IAPG.

The three groups have shown their capability to determine precise orbits of low Earth orbiting satellites equipped with GPS receivers like CHAMP (Reigber et al., 1998) or

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the two GRACE (Tapley and Reigber, 2001) satellites, e.g., Jäggi et al. (2006), Švehla et al. (2005), Van den IJssel and Visser (2003). The POD procedures for the GOCE satellite were developed when processing data gathered by these Low Earth Orbiters (LEOs). However, the procedures had to be revised and adapted for the new satellite mission. A detailed description of the procedure for the PSO is given in this paper.

A short description of the GOCE mission and the GOCE HPF is followed by a description of the POD procedures. The modifications for the 30-h processing and the impact of the special GOCE antenna characteristic are two issues, which are discussed in more detail.

2. The GOCE mission

The GOCE satellite will fly at the very low altitude of about 250 km in a sun-synchronous orbit with an inclination of 96.5° w.r.t. the Earth's equator. The payload of the spacecraft consists of the three-axis gradiometer, a 12-channel GPS receiver, and a Laser retro-reflector array, and star cameras and an ion propulsion assembly are part of the spacecraft system. The gradiometer and the GPS receiver are dedicated to gravity field recovery, where the GPS observations are mainly useful to recover the low degree and order terms of the geopotential. The star cameras are used for attitude control and the ion thruster, together with the accelerometers, for the realization of a drag-free flight of the satellite in along-track direction. The GPS receiver is connected to a helix antenna and provides dual-frequency GPS pseudorange and carrier phase measurements with a sampling rate of 1 Hz. The Laser retro-reflector array is used for SLR (Satellite Laser Ranging) measurements, which in this case serve mainly for an independent validation of the GPS POD.

3. The GOCE High-level Processing Facility

The GOCE High-level Processing Facility (HPF) is an ESA project performed by the EGG-C (European GOCE Gravity-Consortium). EGG-C is a group of the following ten European institutions (in alphabetical order of acronyms):

- Astronomical Institute of the University of Bern (AIUB), Switzerland.
- Centre d'Etudes Spatiales (CNES), Groupe de Recherche de Géodésie Spatiales (GRGS), Toulouse, France.
- Department of Earth Observation and Space Systems (DEOS), Delft University of Technology, The Netherlands.
- GeoForschungsZentrum (GFZ), Department 1 "Geodesy and Remote Sensing", Potsdam, Germany.
- Institute for Astronomical and Physical Geodesy (IAPG), Technical University of Munich, Germany, Principal Investigator of the project.
- Institute for Theoretical Geodesy (ITG), University of Bonn, Germany.
- Sezione Rilevamento, Politechnico di Milano (POLIMI), Italy.
- National Institute for Space Research (SRON), Utrecht, The Netherlands.
- Institute of Navigation and Satellite Geodesy, University of Technology (TUG), Graz, Austria.
- Department of Geophysics, University of Copenhagen (UCPH), Denmark.

It is the purpose of the GOCE HPF project to process the Level 1b data stemming from the GOCE satellite (gradiometer measurements, GPS data, and attitude data), and to produce the following Level 2 data:

- calibrated gravity field gradients,
- the Earth's static gravity field (accuracy: 1 mGal = 10^{-5} m/s^2 in terms of gravity anomalies, and 1–2 cm in terms of geoid heights with a resolution of 100 km), and
- precise orbits of the satellite (target accuracy: 1 cm, 1-dimensional).

Subsequently, we focus on the POD for the satellite, which is a central task of the HPF project. It consists of two parts, the Rapid Science Orbit (RSO) determination (Quicklook part) and a final analysis, the Precise Science Orbit (PSO) determination. DEOS is responsible for the generation of the RSO and AIUB for the generation of the PSO. The PSO itself is separated into two parts. Two kinds of orbit solutions are generated by AIUB, whereas the SLR-validation and the quality assessment are performed at IAPG.

4. Precise orbit determination procedures

4.1. Rapid Science Orbit

The RSO chain provides two types of orbits, one based on a reduced-dynamic (Bertiger et al., 1994) and the other on a kinematic orbit determination technique. The GPS ephemerides and clock parameters as well as the Earth Rotation Parameters (ERPs) are taken from quicklook ("rapid") solutions by the Center for Orbit Determination in Europe (CODE), one of the IGS (International GNSS service) (Dow et al., 2005) analysis centers, and kept fixed.

The reduced-dynamic orbit relies on triple differenced GPS dual-frequency carrier phase observations between GOCE, the GPS satellites and a nominal global network of 25 ground stations. By forming triple differences, one avoids to estimate clock parameters and carrier phase ambiguities. The methodology has been successfully applied for CHAMP POD (Van den IJssel and Visser, 2003). A large number of empirical accelerations is estimated by a Bayesian least-squares process. The nominal orbital arc length will be 30 h (each day) leading to 6-h overlaps between consecutive arcs. The center 24 h will be