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Impact of GPS antenna phase center variations on precise orbits of the GOCE satellite

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Abstract

The first European Space Agency Earth explorer core mission GOCE (Gravity field and steady-state Ocean Circulation Explorer) has been launched on March 17, 2009. The 12-channel dual-frequency Global Positioning System receiver delivers 1 Hz data and provides the basis for precise orbit determination (POD) on the few cm-level for such a very low orbiting satellite (254.9 km). As a member of the European GOCE Gravity Consortium, which is responsible for the GOCE High-level Processing Facility (HPF), the Astronomical Institute of the University of Bern (AIUB) provides the Precise Science Orbit (PSO) product for the GOCE satellite. The mission requirement for 1-dimensional POD accuracy is 2 cm. The use of in-flight determined antenna phase center variations (PCVs) is necessary to meet this requirement. The PCVs are determined from 154 days of data and the magnitude is up to 3-4 cm. The impact of the PCVs on the orbit determination is significant. The cross-track direction benefits most of the PCVs. The improvement is clearly seen in the orbit overlap analysis and in the validation with independent Satellite Laser Ranging (SLR) measurements. It is the first time that SLR could validate the cross-track component of a LEO orbit.

Keywords: GOCE; Phase center variations; GPS; Low earth orbiters; Precise orbit determination; SLR

1. Introduction

The Gravity field and steady-state Ocean Circulation Explorer (GOCE, Drinkwater et al., 2006) is the first satellite in the Earth explorer core mission program of the European Space Agency (ESA). It has been launched on March 17, 2009 from Plesetsk, Russia into a sun-synchronous dusk-dawn orbit with an inclination of 96.5°. Apart from the three-axis gradiometer as core sensor, the satellite is equipped with two dual-frequency, 12-channel Lagrange Global Positioning System (GPS) receivers. The two receivers are connected to independent helix antennas (Fig. 1) and deliver data at a sampling rate of 1 Hz. They are assigned as main and redundant receiver, which implies that they are nominally not running at the same time. The results presented in this article are all obtained from the main satellite-to-satellite tracking instrument (SSTI-A). The very low orbit of the satellite (254.9 km for the first measurement and operational phase) is maintained by an Ion Propulsion Assembly, which compensates for the non-gravitational forces (mainly atmospheric drag) acting on the satellite in flight direction resulting in a drag-free flight.

Precise orbit determination (POD) for the GOCE satellite is one task of the GOCE High-level Processing Facility (HPF, Koop et al., 2006). Both, Rapid Science Orbits (RSOs) with low latency and Precise Science Orbits (PSOs) are provided (Visser et al., 2009; Bock et al., submitted for publication). The RSO product is produced under the responsibility of the Department of Earth Observation and Space Systems (DEOS), Delft University of Technology, The Netherlands. The PSOs are processed at the Astronomical Institute of the University of Bern (AIUB), Switzerland.

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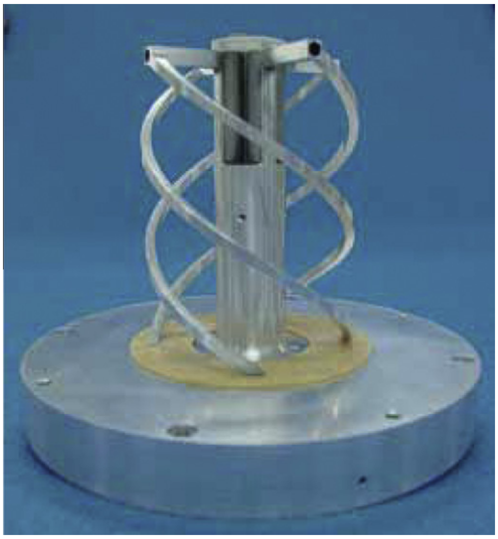

Fig. 1. Helix antenna; © ESA.

On 5 November 2006, the International GNSS Service (IGS, Dow et al., 2009) GNSS stands for Global Navigation Satellite System) started to provide their products with absolute calibrated ground station receiver and GPS transmitter antennas, (e.g., Schmid et al., 2005, 2007). The importance of establishing PCVs for LEO GPS antennas has already been recognized by, e.g., Luthcke et al. (2003) and Haines et al. (2004). First in-flight calibrations for spaceborne receiver antennas were generated for JASON-1, but they were not consistent with the absolute antenna models from the IGS. In the meantime, in-flight and/or ground calibrated phase center variations (PCVs) consistent with the absolute antenna models are made available and are applied for MetOp-A (Loiselet et al., 2000), TerraSAR-X (Buckreuss et al., 2003), and the two GRACE (Tapley et al., 2004) satellites by Montenbruck et al. (2008, 2009) and Jäggi et al. (2009).

The focus of this article is on the PCVs of the SSTI-A antenna. Ground calibrations for the GOCE SSTI helix antenna are available, but they were performed without or with only limited information related to the environment of the satellite (e.g., Dilßner et al., 2006). It is important, however, to take into account systematic effects (e.g., near-field multipath) encountered by the actual antenna environment (see e.g., Haines et al., 2004; Jäggi et al., 2009). The values for the helix antenna were not used for orbit determination as they do not improve the GOCE orbit results compared to results without correcting for PCVs.

Neglected or mismodeled antenna PCVs are one of the most important systematic error sources in LEO (Low Earth Orbiter) GPS data processing. The highest accuracy level for orbits may only be achieved when correcting for PCVs in LEO GPS data processing. Therefore, the decision was made to perform an in-flight determination of the PCVs from scratch following the so-called residual approach described by Jäggi et al. (2009). The main argument to use the residual approach rather than the direct approach is the resolution of the PCVs. The $1° \times 1°$ resolution, which is necessary due to the short scale structures, is not feasible with the direct approach due to the large computational burden.

The PSO generation procedure (Section 2) has been applied for the first time to real GOCE GPS data during the Commissioning Phase of the GOCE mission (March to September 2009). The in-flight GOCE SSTI-A antenna calibration has been accomplished (Section 3.1) during this time period. Additional studies (Section 3.2) were carried out to guarantee the quality and independency of the generated PCVs. Section 4 summarizes the results of the validation for orbits with and without corrected empirical PCVs. An internal (Section 4.1) as well as an external (Section 4.2) validation show significant improvements due to the correction of the empirical PCVs. Section 5 summarizes the key findings of the article.

2. PSO procedure

PSO determination results in two different orbit types, a kinematic (Švehla and Rothacher, 2005) and a reduced-dynamic (Jäggi et al., 2006) orbit. Both orbits are derived from one and the same procedure, using an automatic processing environment (Bernese Processing Engine (BPE)) in a tailored version of the Bernese GPS Software (Dach et al., 2007). Undifferenced dual-frequency GPS code and phase observations are used. First order ionospheric refraction effects in the observations are eliminated by forming the ionosphere-free linear combination from P1 and P2 and from L1 and L2, respectively. GPS orbits and Earth rotation parameters (ERPs) are introduced into the processing from the final product series of the Center for Orbit Determination in Europe (CODE) analysis center (Dach et al., 2009) of the IGS. CODE also provides a 5 s GPS clock product (Bock et al., 2009). These 5 s clock corrections, however, do not cover the timespan needed for the GOCE processing. Therefore, additional 5 s GPS clock corrections are generated at AIUB for usage within the HPF. In order to support the 1 s data from GOCE the 5 s GPS clock corrections are linearly interpolated. The connection to the terrestrial reference frame is given by fixed GPS orbits, clock corrections and ERPs. The main observables for orbit determination are carrier phase observations. The code observations are only used to derive an a priori orbit and to synchronize the receiver clock to GPS time.

The reduced-dynamic orbit is parametrized with six initial orbital elements, three constant accelerations in the radial, along-track and cross-track directions and (constrained) piecewise 6-min constant accelerations in these three directions. The EIGEN5S (Förste et al., 2008) gravity field model is used as a priori gravity field information up to degree and order 120. An elevation cut-off angle of 0° is applied. The reduced-dynamic orbits are based on observations sampled to 10 s. The kinematic orbits (spaced by 1 s)