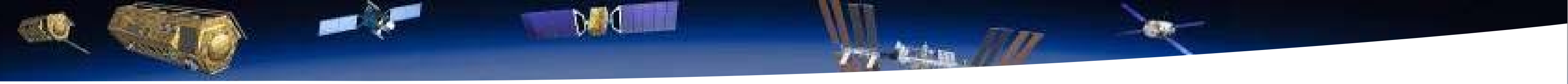

Accuracy Assessment of GOCE Orbit Solutions

P. Swatschina(1), O. Montenbruck(1), H. Bock(2), A. Jäggi(2)
(1)Deutsches Zentrum für Luft- und Raumfahrt (DLR), Germany
(2)Astronomical Institute, University of Bern (AIUB), Switzerland

Abstract

Reduced dynamic and kinematic orbit determination results for the GOCE mission obtained with the GPS High Precision Orbit Determination Tools (GHOST) are compared with the operational GOCE Precise Science Orbit (PSO) product. Systematic biases of about 3 cm in the antenna offset vector relative to the center-of-gravity (CoG) are identified from the analysis. A CoG mismatch is indicated by comparison with satellite laser ranging (SLR) measurements.

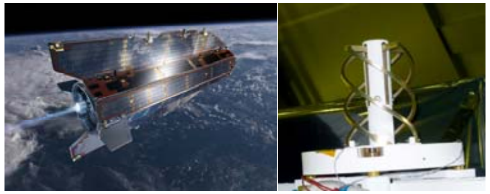

Fig. 1 GOCE satellite (*left*) and helix GPS antenna (*right*) (© ESA)

Data Sets

12 days of GPS data collected between 28 March and 8 April 2010 with both the main (front) and redundant (back) antenna (Fig. 1) were provided for the analysis. The original RINEX files were preprocessed to remove discontinuities at data dump boundaries and decimated to 10s intervals. GPS orbit and clock products at 30s intervals were provided by the Center for Orbit Determination in Europe (CODE).

Processing

The PSO is created at AIUB using the Bernese GPS Software [1]. A strongly reduced dynamic model is applied, in which a global set of unconstrained accelerations in radial (R), along-track (T) and cross-track (N) direction is adjusted along with constrained RTN accelerations at 6 min intervals.

The GHOST reduced dynamic orbit determination software [2] employs a priori models for non-gravitational forces (drag, radiation pressure) and adjusts piecewise constant RTN accelerations at 10 min intervals. Kinematic GHOST orbits are obtained by a precise point positioning technique and do not depend on orbit models.

Positions of the GPS antennas, laser retroreflector (LRR) and CoG and for the time of interest are based on established GOCE processing standards [3] and are summarized in Table 1.

For the GPS processing, L1 &L2 phase center offsets (PCOs) from the ground calibration [3] are employed along with empirical phase center variations (PCV) for the ionosphere-free L1/L2 combination from an in-flight calibration [4]. The PCVs have been derived by AIUB using a residuals stacking approach and are free of mean PCO shifts. PCV maps for both antennas are shown in Fig. 2.

Table 1 Center-of-gravity location and sensor coordinates

Item	X (forward) [m]	Y (right) [m]	Z (down) [m]
CoG (March/April 2010)	+2.5025	+0.0036	+0.0011
ARP GPS main	+3.1930	+0.0000	-1.0922
ARP GPS redundant	+1.3450	+0.0000	-1.0903
LRR ref. point	+4.9066	+0.0004	+0.5590

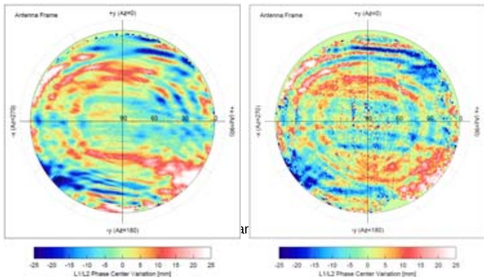

Fig. 2 L1/L2 phase center variations of the main (*left*) and redundant (*right*) GPS antenna of GOCE. The flight direction is chosen as azimuth origin.

Dynamic versus Kinematic Orbits

Dynamically constrained orbits reflect the motion of the CoG and are essentially independent of errors in the antenna offset vector. The altitude is determined by the orbital period and the modeled radial acceleration.

Kinematic orbit products reflect the motion of the GPS antenna phase center. The resulting CoG orbit depends on the adopted antenna offset vector.

Reduced dynamic (RD) orbits represent a compromise between both extremes. Due to the adjustment of free radial accelerations the height of the PSO closely matches the kinematic solution. GHOST reduced dynamic orbits are tuned to trust the model radial acceleration and may exhibit a height offset.

Differences between GHOST kinematic and reduced dynamic orbits can provide evidence of inconsistent CoG and antenna coordinates (Fig. 3). Alternatively, these differences may indicate an error in the modelled radial acceleration. As a rule of thumb, a supplementary radial acceleration of 50 nm/s² lowers the estimated orbit by 1 cm.

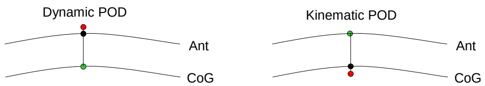

Fig. 3 Antenna offset errors in dynamic and kinematic orbit determination

Orbit Comparison

PSO products for the main antenna and GHOST reduced dynamic orbit solutions exhibit daily rms position differences with a median value of 4.0 cm. Median rms values for the radial, along-track, and cross-track direction amount to 3.0 cm, 2.1 cm, and 1.5 cm, respectively. The radial component is dominated by a mean offset that varies between 2 cm and 3 cm on the various days. The precise science orbits are systematically *lower* than the GHOST RD orbits (Fig. 4).

PSO type orbits derived from the redundant antenna exhibit an even higher radial offset and fall about 4 mm below the main antenna PSOs.

The kinematic GHOST orbits exhibit mean radial offsets of ±1 mm with respect to the respective PSO products but are likewise offset from the GHOST RD solutions by 2-4 cm (see Fig. 4).

The results demonstrate that the PSO orbit height is essentially unconstrained due to the free adjustment of a radial acceleration parameter in the Bernese S/W.

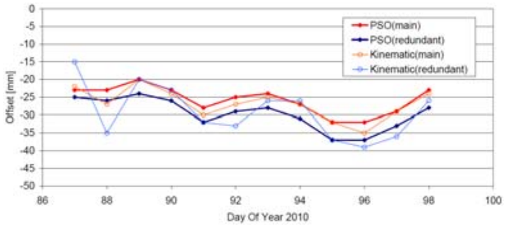

Fig. 4 Mean radial offsets of PSO (AIUB) and GHOST kinematic orbits for main and redundant antennas from GHOST reduced dynamic orbit determination solution (March/April 2010)

Satellite Laser Ranging Validation

Satellite laser ranging (SLR) measurements contributed by the ILRS have been used to independently validate the different types of reduced dynamic orbit products.

The results in Table 2 indicate an improved consistency of the modeled laser reflector trajectory for the PSO products as compared to the GHOST RD orbits. However, both solutions exhibit a mean offset at the 1-2 cm level.

Table 2 SLR residuals

	Range Residual	
Orbit	Mean±StdDev [mm]	RMS [mm]
PSO (main)	-12 ± 16	20
PSO (redundant)	-13 ± 19	23
GHOST RD (main)	-22 ± 23	32
GHOST RD (red)	-20 ± 22	29

Discussion

The differences of kinematic and reduced dynamic orbits can be attributed to erroneous assumptions on the GPS antenna offset from the CoG, which appears to be too large by 2-3 cm. At the same time, SLR residuals suggest that the adopted laser reflector offset is too short by a few cm. The comparison of orbits from the main and redundant GPS antenna, furthermore, indicate PCO uncertainties of at least ±2 mm in radial direction

A consistent leveling of reduced dynamic and kinematic orbits can be achieved by adopting a CoG offset of 2.7 cm in radial direction with respect to the published value. The associated improvement of carrier phase residuals and SLR residuals in the GHOST RD orbits is illustrated in Table 3.

Table 3 Goodness of fit of GPS carrier phase measurements and SLR measurements in GHOST reduced dynamic orbit determination with and without CoG correction

	GPS CP Residuals	SLR Residuals
Orbit	RMS [mm]	Mean±StdDev [mm]
GHOST RD (nom. CoG)	7.1	-22 ± 23
GHOST RD (CoG+2.7cm)	6.3	-6 ± 18

As an alternative to the CoG shift, an empirical acceleration in radial direction might be introduced to achieve a consistent modeling of all observations in the reduced dynamic orbit determination. However, the required value of 140 nm/s² is incompatible with the expected uncertainty of the employed dynamical model.

While systematic CoG offsets at the 1-3 cm level have earlier been identified in various other space missions, GOCE also shows suspicious day-to-day variations (Fig. 4) that deserve further investigation.

A comprehensive interagency comparison of GOCE precise orbit products based on different processing strategies is therefore encouraged along with a critical review of manufacturer supplied CoG and sensor coordinates.

References

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Contact

Paul Swatschina
DLR/GSOC, Münchnerstr. 20, 82234 Wessling, Germany
paul.swatschina@dlr.de