RAPID AND PRECISE ORBIT DETERMINATION FOR THE GOCE SATELLITE

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ABSTRACT

The European Space Agency (ESA) GOCE Core Explorer Mission will carry a 12-channel, dual-frequency GPS receiver for high-accuracy precise orbit determination. Precise GOCE orbit solutions will be used to accurately geolocate the observations taken by the primary science instrument, the gradiometer, that aims at collecting medium to short wavelength gravity information. In addition, the orbit solutions will provide complementary information for the long-wavelength gravity field part. Precise orbit determination is an integral part of the GOCE High-Level Processing Facility (HPF) that aims at producing the best gravity field model products possible. A rapid (RSO) and precise science orbit (PSO) determination chain will be implemented at respectively DEOS and AIUB with typical latencies of 1 day and 1 week. The RSO chain will support the operations of the GOCE satellite allowing quick checks of the scientific data streams and quick-look gravity field solutions. The PSO chain will provide the most accurate GOCE orbit solutions possible for use in the final gravity field determinations. This paper provides a brief overview of the HPF orbit determination architecture and products.

Key words: GOCE, High-level Processing Facility (HPF), Precise Orbit Determination (POD), Rapid Science Orbits (RSO), Precise Science Orbits (PSO).

1. INTRODUCTION

Precise orbit determination (POD) will play a crucial role in the future GOCE data reduction and forms an integral part of the HPF. Precise GOCE orbit solutions are first of all required to geolocate the observations from the gradiometer and second to support the long-wavelength part of the gravity field recovery.

The HPF POD infrastructure consists of five main modules (Figure 1): two modules for rapid reduced-dynamic and kinematic orbit determination, one module for the precise science orbit determinations, one module for computing high-rate solutions for the GPS clocks, and one module for a quality assessment of the several orbit solutions. These modules are briefly described in Section 3, after first specifying the POD products in Section 2.

2. PRODUCTS

Two POD chains have been defined: the Rapid Science Orbit (RSO) and the Precise Science Orbit (PSO) computations. The RSO chain will in particular support the GOCE operations and provide the means for a quick check of the GOCE GPS receiver performance. In addition, the production of quick-look gravity field solutions that are generated to check the gradiometer observations relies partly on the RSO products as well. The PSO products will be required and used as input products for the final gravity field recovery.

The RSO product will be provided to the HPF Central Processing Facility (CPF) at the Netherlands Institute for Space Research (SRON) in Utrecht with a latency of 1 day after availability of the Satellite-to-Satellite Tracking (SST) observations from the GOCE GPS receiver. Several input products are required, where all data are checked, formatted (if required) and passed through the CPF. These products include (but are not limited to):

From GOCE instruments

SST_RNX: SST observations (RINEX format);
STR_QUA: Star tracker data (quaternions);

External providers

AUX_IGS: GPS ephemeris/clocks, ground station data;
AUX_ITRF: ground station coordinates & eccentricities;
AUX_ILRS: Satellite Laser Ranging observations (for validation purposes);
AUX_ICGEM: a priori gravity field model;
AUX_TIDE: ocean tide model.

The RSO product consists of the following sub-products:

- reduced-dynamic orbit solution: time series of Earth-centered, Earth-fixed fixed (ECF) position and velocity coordinates (SP3 format);

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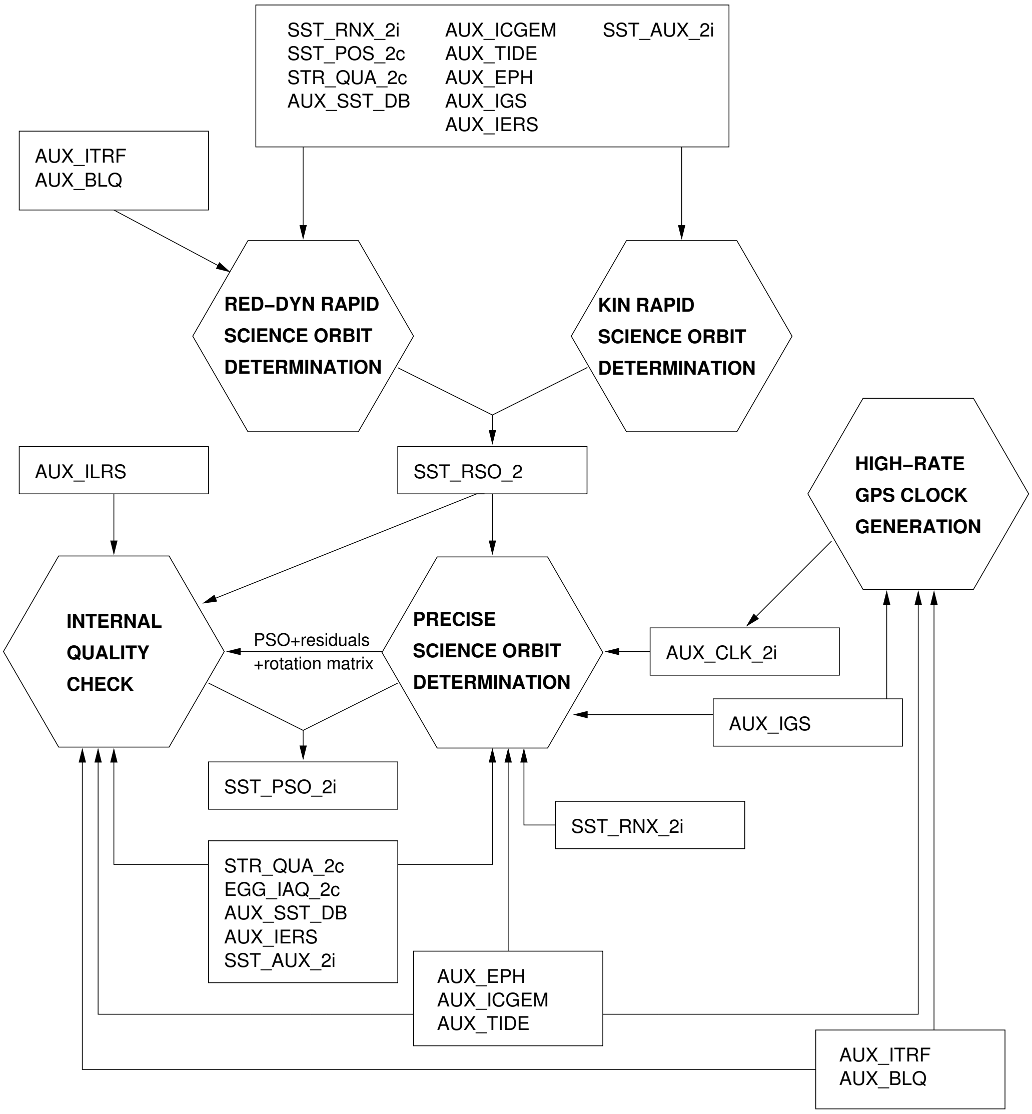

Figure 1. GOCE Precise Orbit Determination architecture (High-level Processing Facility): indicated are the five main modules and several input/output products and data streams.

- kinematic orbit solution: time series of ECF position coordinates (pseudo-SP3 format);
- time series of rotation matrices (J2000 ↔ ECF);
- observation residuals from reduced-dynamic POD;
- observation residuals from kinematic POD;
- quality report.

Since kinematic orbit solutions can be obtained only for epochs with GPS SST observations, data gaps might occur, which will result in missing epochs in the SP3 file. Nominally, SP3 files have a constant time step with no gaps. The HPF kinematic orbit solutions are given at the corrected GOCE GPS receiver times for only those epochs with a sufficient number of GPS satellites in view. The resulting orbit files are therefor referred to as pseudo-SP3. The 3-dimensional (3D) accuracy requirement for the RSO orbit solutions is 50 cm in terms of position, where the time step of consecutive position coordinates is 10 sec. The quality report contains information from the POD process, such as root-mean-square of fit of the observations, statistical information from comparison between the two orbit solutions, etc.

The PSO products contains predominantly the same type of sub-products as the RSO product:

- reduced-dynamic orbit solution: time series of Earth-centered, Earth-fixed fixed (ECF) position and velocity coordinates (SP3 format);
- kinematic orbit solution: time series of ECF position coordinates (pseudo-SP3 format);
- time series of rotation matrices (J2000 ↔ ECF);
- observation residuals from reduced-dynamic POD;
- observation residuals from kinematic POD;
- variance/covariance matrix (kinematic solution only);

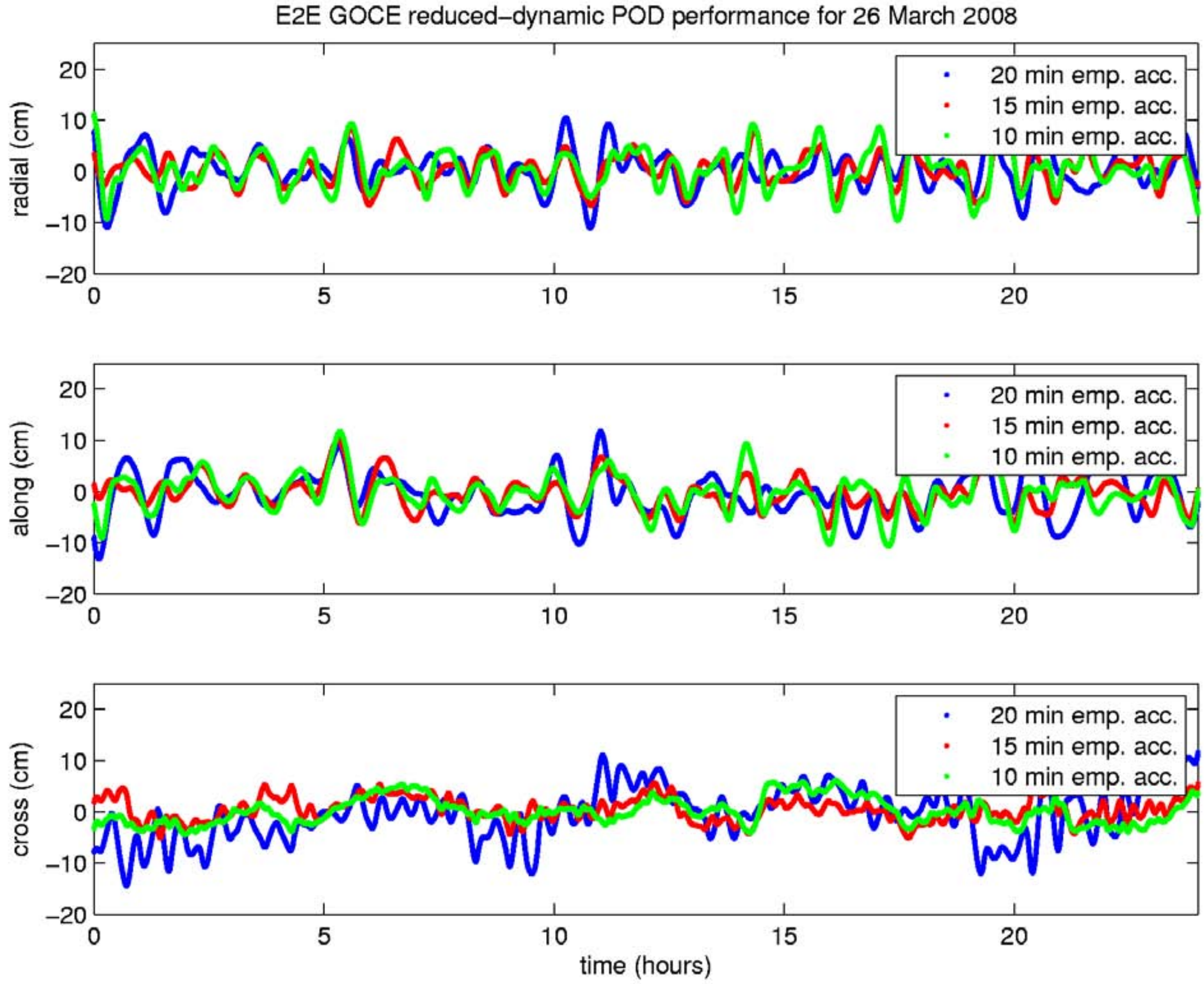

Figure 2. GOCE orbit errors for reduced-dynamic orbit computation with GEODYN using simulated E2E SSTI data for 3 different time intervals for the estimated empirical accelerations

- quality report.

It has to be noted that the PSO chain will result in so-called intermediate and final products, where the first includes all the above mentioned sub-products. The final product does not include the residual files. Moreover, the latency for the final product is about 4 weeks that allows to make use of accurate products from the International Earth Rotation Service (IERS). Therefore, the J2000 ↔ ECF rotation matrices will be recomputed and replaced. Finally, a more rigorous quality check will be conducted that will result in an updated quality report as well.

The PSO accuracy requirement is 2 cm for each direction (goal 1 cm) for the position coordinates. The time interval for the coordinates is either 10 sec (reduced-dynamic) or 1 sec (kinematic). The kinematic orbit solution comes together with a reduced variance/covariance matrix that represents the covariances between consecutive position estimates. These covariances are crucial for deriving the best possible GOCE velocities from the position time series. These velocities are required for gravity field recovery methods that are based on energy integral equations. The quality report will include results of comparisons between the RSO and PSO solutions.

The PSO chain is supported by a separate module that generates high-rate (5 Hz) solutions for the GPS clocks. Such high-rate clock solutions are crucial for the generating 1 Hz kinematic precise orbit solutions.

3. IMPLEMENTATION

The HPF POD infrastructure was built for a large part based on heritage from CHAMP (and in the mean time also GRACE) precise orbit computations in Delft, Bern and Munich [1, 2, 3, 4]. The RSO reduced-dynamic orbit module is based on triple differenced GPS observations using a network of 30 IGS ground stations, rapid products for the GPS ephemeris plus clocks, and the earth orientation parameters (EOPs) from the AIUB Center for Orbit Determination in Europe (CODE). Instead, the RSO kinematic orbit solution relies on undifferenced SST observations. Use is made of respectively the GEODYN and

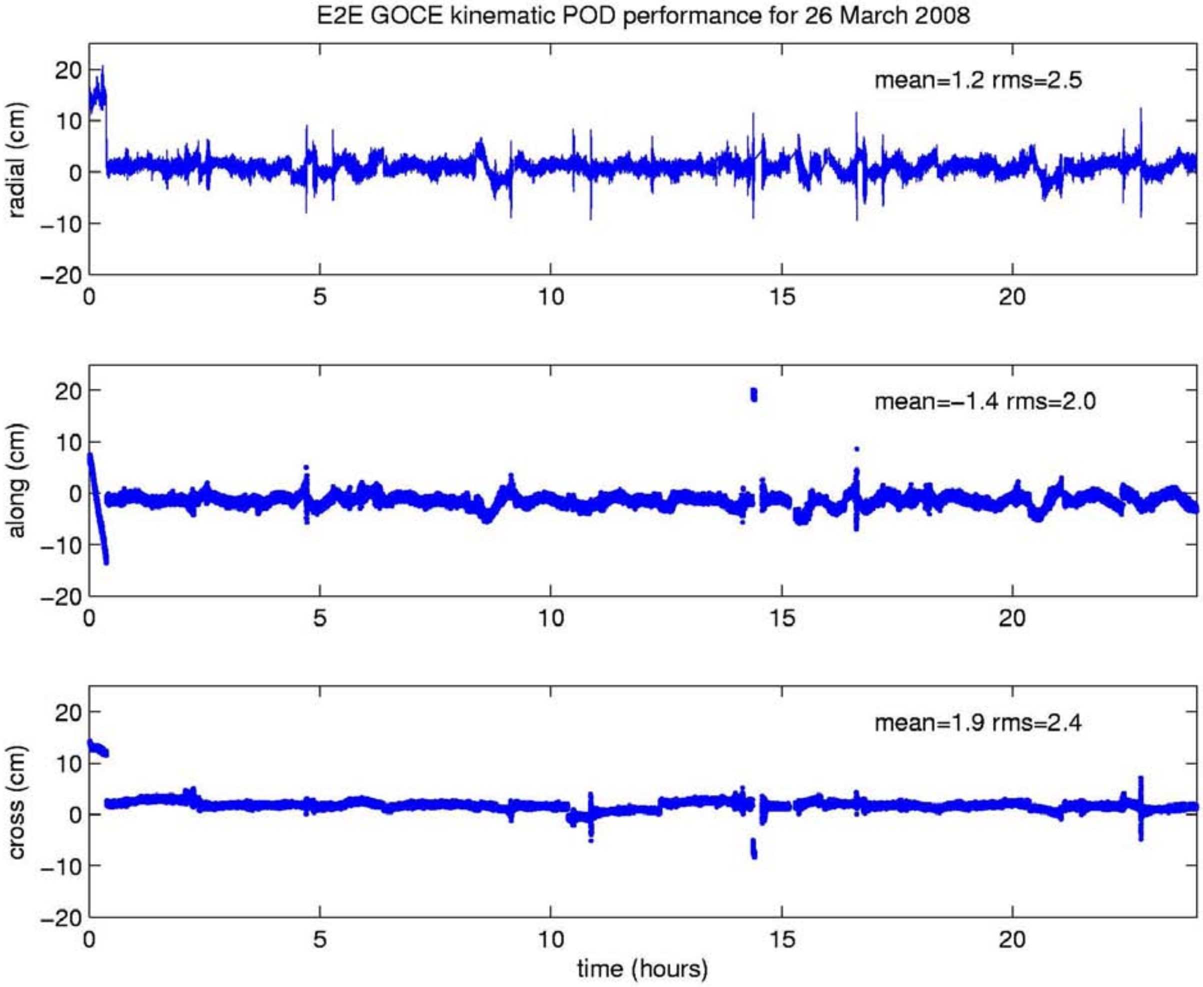

Figure 3. GOCE orbit errors for kinematic orbit computation with GHOST using simulated E2E SSTI data

GHOST software packages, which are kindly provided by the NASA Goddard Space Flight Center and the German Space Operations Centre (GSOC), where GHOST is partly co-developed by GSOC and DEOS.

Both the kinematic and reduced-dynamic PSO solutions are nominally based on undifferenced GPS observations, making use of the Bernese software which is being developed and maintained by AIUB with support from IAPG. An additional module, which forms part of the Bernese software suite, provides high-rate (5 Hz) GPS ephemeris and clock solutions, and also EOPs.

All the modules and POD strategies were tested first with real CHAMP data, kindly provided by the GeoForschungsZentrum (GFZ) in Potsdam, Germany. In order to make an ”honest” comparison, use was made of final IGS products for the GPS ephemeris and EOPs. The consistency between all RSO and PSO orbit solutions was found to be at a level of a few cm, within the requirements set for GOCE. In addition, tests were done with simulated GOCE End-to-End (E2E) data that were provided to the HPF by ESA. After applying some corrections, which are required because of for example differences between the real-world and E2E implementations of reference frames, all the implemented HPF POD strategies resulted in differences with respect to the (known) ”truth” orbit of around a few cm (see Figures 2 and 3).

It has to be noted that the RSO chain was also tested with CHAMP data with degraded - Rapid IGS - solutions for the GPS clocks and ephemeris, since in reality use will have to be made of such rapid (or even partly predicted) solutions. The resulting orbit differences with the precise orbit solutions was found to be at a level of 20 cm per coordinate axis (35 cm 3D), which is within the requirement.

4. SUMMARY AND OUTLOOK

The HPF GOCE POD processing chains have been successfully implemented and tested with both real data (CHAMP) and simulated data (E2E GOCE simulator). The consistency level between all orbit solutions is at the few cm level in case use is made of precise GPS clock and ephemeris solutions. Although the current implementations are in compliance with the HPF requirements, possibilities for improvement will be explored which might lead to enhanced implementations.

ACKNOWLEDGMENTS

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