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Precise science orbits for the Swarm satellite constellation

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Abstract

The European Space Agency (ESA) Swarm mission was launched on 22 November 2013 to study the dynamics of the Earth's magnetic field and its interaction with the Earth system. The mission consists of three identical satellites, flying in carefully selected near polar orbits. Two satellites fly almost side-by-side at an initial altitude of about 480 km, and will descend due to drag to around 300 km during the mission lifetime. The third satellite was placed in a higher orbit of about 530 km altitude, and therefore descends much more slowly. To geolocate the Swarm observations, each satellite is equipped with an 8-channel, dual-frequency GPS receiver for Precise Orbit Determination (POD). Onboard laser retroreflectors provide the opportunity to validate the orbits computed from the GPS observations using Satellite Laser Ranging (SLR) data. Precise Science Orbits (PSOs) for the Swarm satellites are computed by the Faculty of Aerospace Engineering at Delft University of Technology in the framework of the Swarm Satellite Constellation Application and Research Facility (SCARF). The PSO product consists of both a reduced-dynamic and a kinematic orbit solution. After a short description of the Swarm GPS data characteristics, the adopted POD strategy for both orbit types is explained and first PSO results from more than one year of Swarm GPS data are presented. Independent SLR validation shows that the reduced-dynamic Swarm PSOs have an accuracy of better than 2 cm, while the kinematic orbits have a slightly reduced accuracy of about 4–5 cm. Orbit comparisons indicate that the consistency between the reduced-dynamic and kinematic Swarm PSO for most parts of the Earth is at the 4–5 cm level. Close to the geomagnetic poles and along the geomagnetic equator, however, the kinematic orbits show larger errors, which are probably due to ionospheric scintillations that affect the Swarm GPS receivers over these areas.

Keywords: Swarm; GPS; Precise Orbit Determination; Ionospheric scintillation

1. Introduction

The European Space Agency (ESA) Earth Explorer Swarm mission was launched on 22 November 2013 to study the dynamics of the Earth's magnetic field and its interactions with the Earth system (Friis-Christensen et al., 2008). To fulfil its primary mission objective of providing the best ever survey of the geomagnetic field and its temporal evolution, the mission consists of a constellation of three identical satellites, which carry a number of advanced scientific instruments. To measure the strength and direction of the Earth's magnetic field, each satellite is equipped with a vector field magnetometer and absolute scalar magnetometer. Information about the Earth's electric field is delivered by an electrical field instrument, consisting of a thermal ion imager and a Langmuir probe. An onboard accelerometer measures the satellite's non-gravitational accelerations, which can be used to derive information about the thermosphere density and wind (Visser et al., 2013). A Global Positioning System (GPS) receiver is used for the Precise Orbit Determination (POD) of the satellite and a laser retroreflector provides the opportunity to validate the orbits computed from the GPS observations.

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In order to get an optimal sampling of the instrument measurements in space and time, the three Swarm satellites have been placed into carefully selected near polar orbits. An overview of the evolution of the daily minimum, maximum and mean orbit altitude of the three satellites since the beginning of the mission is given in the top panel of Fig. 1. This figure clearly shows the orbit manoeuvres that have been executed from January to April of 2014 to place the Swarm satellites in their selected orbit. Swarm-B was placed in a relatively high orbit with an average altitude of about 530 km, while the other two satellites were placed to fly almost side-by-side at a lower altitude of about 480 km. Although all three satellites experience drag, which results in a natural orbit decay, this effect will be significantly larger for the lower pair. It is expected that the lower pair will stay above 300 km at the end of the planned four year mission duration, even without the use of orbit raising manoeuvres that could be used to extend the mission in-orbit lifetime. Note that the altitudes listed above and shown in Fig. 1 are different than the height values specified in the ESA documentation. ESA uses heights that are computed from the orbit's semi-major axis minus the equatorial radius of the Earth, which results in values which are about 15 km lower than the averaged true altitude. Due to a small difference in inclination, as well as the altitude difference, the orbital planes of the lower pair and the higher satellite precess at different rates and will become close to perpendicular in the third year of operations. The bottom panel of Fig. 1 shows the local solar time coverage due to this precession. At the end of 2014, the difference in local time at the equator crossings between the high flying satellite and the lower pair has grown to about 76 min.

The computation of precise orbits for the Swarm satellites is part of the activities performed in the Swarm Satellite Constellation Application and Research Facility (SCARF) (Olsen et al., 2013). This consortium of research institutes is responsible for generating advanced so-called Swarm level 2 data products under contract with ESA. Within this consortium, the Faculty of Aerospace Engineering at Delft University of Technology is responsible for providing, amongst others, Swarm level 2 Precise Science Orbits (PSOs). The PSOs support the primary Swarm mission objective by providing the information for precise geolocation of magnetic and electric field observations. The PSOs are also used for the calibration and precise geolocation of the accelerometer observations. These accelerometer observations are used to derive information about the thermospheric density and winds, which is a secondary Swarm mission objective. Although gravity field determination is not part of the official Swarm mission objectives, it is expected that the Swarm GPS tracking data could also contribute to the continued monitoring of the Earth's time-variable gravity field, due to the good spatial

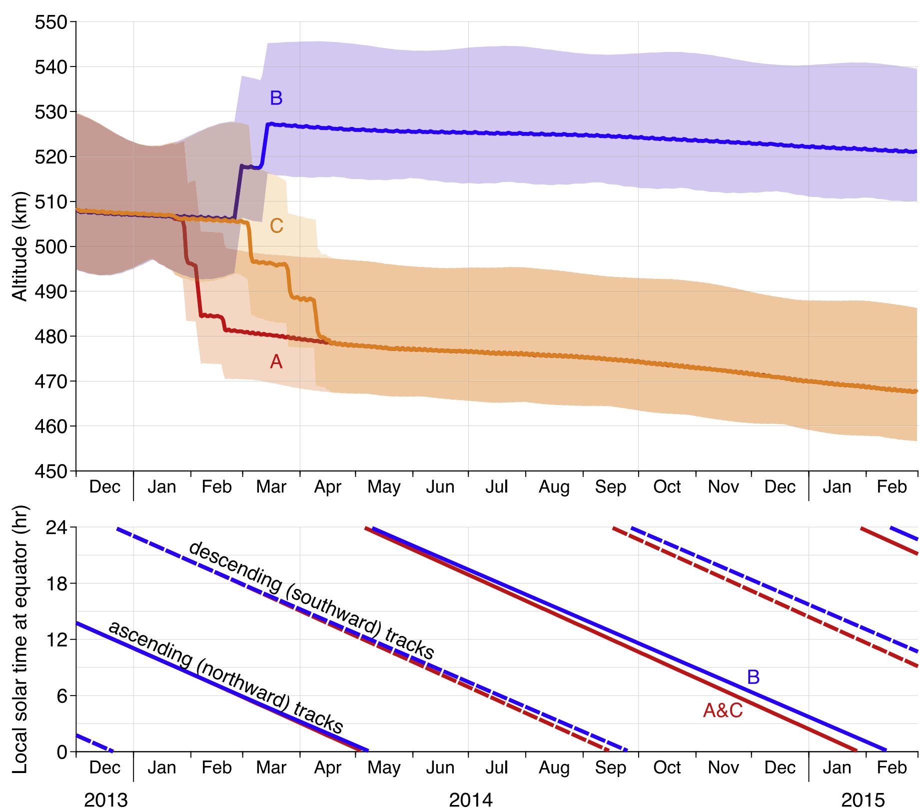

Fig. 1. Evolution of the Swarm-A, B and C satellite orbits. In the top panel, the solid line shows the daily average altitude above the GRS80 reference ellipsoid, while the shaded areas indicate the daily minimum and maximum altitude above the ellipsoid. The bottom panel shows the local time at equator crossings.