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Galileo Declassified: IOV Spacecraft Metadata and Its Impact on Precise Orbit Determination

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In December 2016, shortly after the declaration of Galileo Initial Services, the European GNSS Agency (GSA) disclosed Galileo spacecraft metadata relevant to precise orbit determination (POD), such as antenna phase center parameters, dimensions of the solar panels and the main body, specularity and reflectivity coefficients for the surface materials, yaw attitude steering law, and signal group delays. The metadata relates to the first four operational Galileo satellites, known as the In-Orbit Validation (IOV) satellites, and is publicly available through the European GNSS Service Center (GSC) web site. One of the dataset's major benefits is that it includes nearly all information about the satellites' surface properties needed to develop a physically meaningful analytical solar radiation pressure (SRP) macro model, or "box-wing" (BW) model. Such a BW model for the IOV spacecraft has now been generated for use in NAPEOS, the European Space Operation Centre's (ESOC's) main geodetic software package for POD. The model represents the satellite as a simple six-sided box with two attached panels, or "wings", and allows for the a priori computation of the direct and indirect (Earth albedo) SRP force. Further valuable parameters of the metadata set are the IOV navigation antenna (NAVANT) phase center offsets (PCOs) and variations (PCVs) inferred from pre-launch anechoic chamber measurements.

In this work, we report on the validation of the Galileo IOV metadata and its impact on POD, an activity ESOC has been deeply committed to since the launch of the first Galileo experimental satellite, GIOVE-A, in 2005. We first reanalyze the full history of Galileo tracking data the global International GNSS Service (IGS) network has collected since 2012. We generate orbit and clock solutions based on the widely used Empirical CODE Orbit Model (ECOM) with and without the IOV a priori BW model. For the satellite antennas, we apply the new as well as the standard IGS-recommended phase center corrections ("igs08.atx"). Results are evaluated according to several internal and external metrics, such as carrier phase residuals, satellite laser ranging (SLR) data, satellite clock residuals, day-to-day orbit overlap differences, and narrow-lane (NL) double differences as a measure of the quality of the unresolved phase ambiguity estimates. We demonstrate that the use of the new IOV BW and antenna models brings substantial improvements over the standard approach without the a priori model and with igs08.atx. Particularly striking here is the reduction of the SLR residual RMS by a factor of two to three as well as the five-to-ten-times-tighter distribution of the NL residuals – an important aspect for standard NL integer ambiguity resolution. During eclipse season, when the sun's elevation angle is small, the combination of the standard ECOM with the BW model even outperforms the enhanced ECOM ("ECOM2"). Moreover, we elaborate on the Galileo IOV yaw attitude scheme and evaluate noon- and midnight-turn maneuvers by way of reverse point positioning (RPP). The RPP technique takes advantage of the approximately 17 cm horizontal offset of the IOV NAVANT from the spacecraft's yaw axis to estimate the yaw angle. Finally, we estimate the NAVANT's PCO and PCV parameters by utilizing multiple years of IGS tracking data and compare them against the chamber calibration values.