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Satellite clock modeling for kinematic determination of GNSS orbits and satellite attitude

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The availability of high-precision GNSS orbits is an essential prerequisite for highly accurate positioning applications. The present orbit products of the IGS analysis centers are based on dynamic orbit models including a variety of perturbation forces. In contrast to the orbit determination strategy used by the IGS analysis centers, we perform a purely kinematic estimation of the satellite positions with zero-difference processing. The GNSS satellite positions are determined independently from epoch to epoch and are free of any assumptions on the dynamic orbit models. Due to the high correlation between the radial orbit component and the satellite clock correction, the radial orbit component is, however, very ill-determined.
The latest generation of GNSS satellites is equipped with advanced and extremely stable clocks (e.g., the Passive Hydrogen Masers (PHM) on Galileo and the Rubidium Atomic Frequency Standards (RAFS) on GPS Block IIF), which allows a modeling of the satellite clock behavior by using a low-degree polynomial and relative constraints between subsequent epochs to account for short-time variations. With this approach, the radial orbit component and the satellite clock corrections can be decorrelated, leading to substantial improvements in the radial component of the kinematic orbit determination.
The resulting kinematic orbits are then compared with precise orbits from ESOC and CODE-MGEX. The results presented here are based on GNSS data covering two 30-day periods and a network of 80 ground stations distributed around the world. The GNSS data sampling interval is 5 minutes. This analysis focuses on 13 Galileo satellites and the 12 Block IIF GPS satellites. The recently published attitude models for the Galileo satellites are applied.
By varying the relative constraints applied between epoch-wise clock estimates, a distinct behavior of the differences in the radial orbit component is observed. For the Galileo PHM and GPS Block IIF RAFS, radial orbit deviations between kinematic and dynamic orbits are decreasing with increasing constraints, showing the positive effect of the decorrelation mentioned above. With optimal constraining, the RMS of the orbit differences in the radial components are as low as 2 cm for some Galileo satellites and up to 8 cm for GPS satellites. Satellites with less stable clocks show a clear degradation of the orbit differences when relative clock constraining is increased.
The kinematic orbits can also be used to assess the deficiencies in the dynamic orbit models. On a long time scale, the radial orbit differences show clear variations at frequencies of once and twice per revolutions, when represented by the argument of latitude with respect to the Sun. This is in agreement with Satellite Laser Ranging (SLR) data obtained for Galileo satellites. The high sampling rate compared to SLR allows for the detailed analysis of short-term effects, specially orbit and attitude modeling at low β angles and during shadow periods.

Keywords: Kinematic orbit determination; GNSS clock modeling; Galileo; GPS