Accepted Manuscript

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PII: S0273-1177(17)30845-1
DOI: https://doi.org/10.1016/j.asr.2017.11.034
Reference: JASR 13523

To appear in: *Advances in Space Research*

Received Date: 12 September 2017
Revised Date: 14 November 2017
Accepted Date: 24 November 2017

Please cite this article as: Li, Q., Ma, G., Lu, W., Wan, Q., Fan, J., Wang, X., Li, J., Li, C., A Method of Estimating GPS instrumental Biases with a Convolution Algorithm, *Advances in Space Research* (2017), doi: https://doi.org/10.1016/j.asr.2017.11.034

A Method of Estimating GPS instrumental Biases with a Convolution Algorithm

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Abstract. This paper presents a method of deriving the instrumental differential code biases (DCBs) of GPS satellites and dual frequency receivers. Considering that the total electron content (TEC) varies smoothly over a small area, one ionospheric pierce point (IPP) and four more nearby IPPs were selected to build an equation with a convolution algorithm. In addition, unknown DCB parameters were arranged into a set of equations with GPS observations in a day unit by assuming that DCBs do not vary within a day. Then, the DCBs of satellites and receivers were determined by solving the equation set with the least-squares fitting technique. The performance of this method is examined by applying it to 361 days in 2014 using the observation data from 1,311 GPS Earth Observation Network (GEONET) receivers. The result was crosswise-compared with the DCB estimated by the mesh method and the IONEX products from the Center for Orbit Determination in Europe (CODE). The DCB values derived by this method agree with those of the mesh method and the CODE products, with biases of 0.091 ns and 0.321 ns, respectively. The convolution method's accuracy and stability were quite good and showed improvements over the mesh method.

Keywords. GPS; DCB; TEC; Ionospheric; Convolution; GEONET

1 Introduction

The total electron content (TEC) and instrumental differential code bias (DCB) are considered to be the two main causes of differences in Global Positioning System (GPS) dual-frequency observations. TEC is one of the most important parameters used in the study of ionospheric properties. Acting as a dispersive medium to the GPS satellite signals, the ionosphere causes a group delay and a phase advance to the radio waves propagating from a GPS satellite to a ground-based receiver, and the delayed value depends on the TEC in the wave path and differs according to the wave frequency (Appleton 1932). Thus, the TEC can be obtained from the differences in the delays of dual-frequency GPS observations. However, DCB exists in every satellite/receiver when transiting/receiving signals and a DCB's magnitude can be comparable to the ionospheric delay. Therefore, estimating and removing DCBs are crucial when deriving TEC from GPS observations.

The first systematic method of deriving DCBs from GPS observations was proposed by Lanyi and Roth (1988), who assumed that all the electrons in the ionosphere are concentrated within a thin shell at a fixed height above sea level. This thin shell model is still currently widely used because it is convenient and causes little loss of accuracy. In Lanyi and Roth's study, the observation data were acquired by the Jet Propulsion Laboratory's (JPL) receiver, and a third-order polynomial TEC model was used to calculate the TEC and DCB simultaneously. The results showed that DCBs are quite stable: their variation is less than 0.5 ns over 6 months. Then, also using the polynomial model, Coco et al. (1991) concluded that the L2–L1 DCBs of satellites varied less than 0.3 ns using five weeks of measurements collected by a receiver in Austin, Texas.

However, the polynomial TEC model loses accuracy when the sky coverage is large. To fit the ionospheric shell better, Wilson et al. (1995) developed a surface harmonic filling technique to calculate the TEC and DCB. The data used by Wilson were acquired from 30 globally distributed receivers. Wilson's study produced a global TEC map, and the root-mean-square (RMS) of the TEC fit residuals was less than 3 TECu (1 ns delay corresponds to 2.853 TECu, and 1 TECu=10^{16} electrons/m^2).

In 1994, another method based on the Kalman filtering technique was published (Sardon et al. 1994) in which Sardon et al. analyzed the GPS data collected at different places by the NASA Deep Space Network and found that the variation of satellite DCB was less than 1 ns during a 1-year period. Sardon and Zarraoa (1997) further analyzed 19 months of GPS data collected by 19 receivers, and found that day-to-day variation was always less than 0.5 ns for the satellites and 1 ns for the receivers.

Otsuka et al. (2002), and G. Ma and Maruyama (2003), proposed a mesh method to calculate the TEC and DCB using data collected by the 1,000+ receivers of the GEONET in Japan. In this mesh method, the ionospheric shell was divided in to small grids, and the TEC at any point within a given grid was assumed to be identical. In Otsuka's study, the grid size was set to 0.15° × 0.15° in latitude and longitude, GPS data on a geomagnetic storm day (September 25, 1998) were analyzed, and a sudden TEC enhancement was found during the geomagnetic storm. G. Ma and Maruyama (2003) estimated DCB by setting the grid size to 2°× 2°, and found that the standard deviation of satellite DCB is from 0.076 ns to 0.664 ns, varying with the satellites for 9 days over the six-month time span. Then, also using GEONET data, X. F. Ma et al. (2005) proposed a neural network method to estimate the differential biases of GPS receivers.

Over time, more researchers developed different methods based on different observation data: Hong et al.(2008) proposed an efficient method to estimate receiver's DCBs which is not depend on thin shell assumption, and applied the method to Ohio observation network during Apr-1st to 3rd 2004. Sarma et al. (2008) estimated the instrumental biases using India area observations. Jusoh et al. (2009) introduced a leveling technique to improve the accuracy of DCB derivation using Malaysia area observations. Choi et al. (2013) made a comparison of receiver DCB estimation methods between relative and single methods based on South Korean area observations. Zhang et al.(2014) analyzed BDS (BeiDou Navigation Satellite) system's DCBs with spherical harmonic function model and with 14 stations in the Eastern Hemisphere, showed that IGSO satellites DCB's stabilities are higher than MEO

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