Estimation and analysis of the short-term variations of multi-GNSS receiver differential code biases using global ionosphere maps

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Introduction

Care should be taken to minimize the adverse impact of Differential Code Biases (DCBs) when sensing the ionosphere using Global Navigation Satellite System (GNSS). For the sake of convenience, satellite and receiver DCBs in both the two published multi-GNSS DCB products, provided by German Aerospace Center (DLR) and Chinese Academy of Sciences (CAS) at the International GNSS Service (IGS) CDDIS repositories, are treated as constants over a period of 24h. However, if DCB estimates show remarkable intra-day variability, the DCBs estimated as constants over one day period will partially account for the ionospheric TEC modeling error, in this case DCBs will be required to be estimated over shorter time period (e.g. less than 1 hour). Therefore, it is important to gain insight into the intrinsic characteristics of receiver DCBs and further precisely determine receiver DCBs. In this presentation, the method to determine the receiver DCBs of legacy and modernized GNSS signals is introduced and variations within receiver DCBs over relatively short-term intervals (ranging from one day to an hour) are revealed.

Methods

The proposed algorithm, designed as IGG, for the estimation of receiver DCBs includes two steps: first, extract the ionospheric observables from geometry-free linear combinations of un-differenced GNSS measurements using the "pseudorange-leveled carrier-phase" technique; second, determine the receiver-specific DCBs by subtracting the slant TEC that is interpolated using the combined IGS-provided GIMs and DLR-provided satellite DCBs.

$$\begin{cases} B^k = (\tilde{P}^k_{i,4} - A \cdot STEC^k_i)/c - B_i \\ STEC = VTEC \cdot MF(z) \\ MF(z) = [1 - \sin^2 z \cdot R_E^2/(R_E + H_{ion})^2]^{-1/2} \\ p = 1/(1+\cos^2 E) \cdot \sigma_I^{-2} \end{cases}$$

To effectively make use of high-precision ionospheric estimates and to weaken the impact of low-precision ionospheric estimates, unlike the DLR-based method regards all a priori ionospheric TEC values that are interpolated from the GIMs to be equal-weighted, receiver DCB pseudo-observations in the porposed are weighted based on both the RMS values within the GIMs and the elevation angle of the satellite linked to the corresponding receiver.

Validation of the receiver DCB estimation algorithm

To valid the performance of the multi-GNSS receiver DCB estimation algorithm, we summarize the differences between daily receiver DCB estimates derived using IGG algorithm and those obtained from the DLR-based method at each MGEX station in January 2015. As shown in Table1, in addition to a mean offset of negative 0.25 ns, all of the estimated monthly receiver DCB estimates based on the IGG method, in comparison with the monthly DCB products of the DLR, exhibit a mean RMS of 0.24 ns for GPS, 0.28 ns for GLONASS, 0.28 ns for BDS, and 0.30 ns for Galileo.

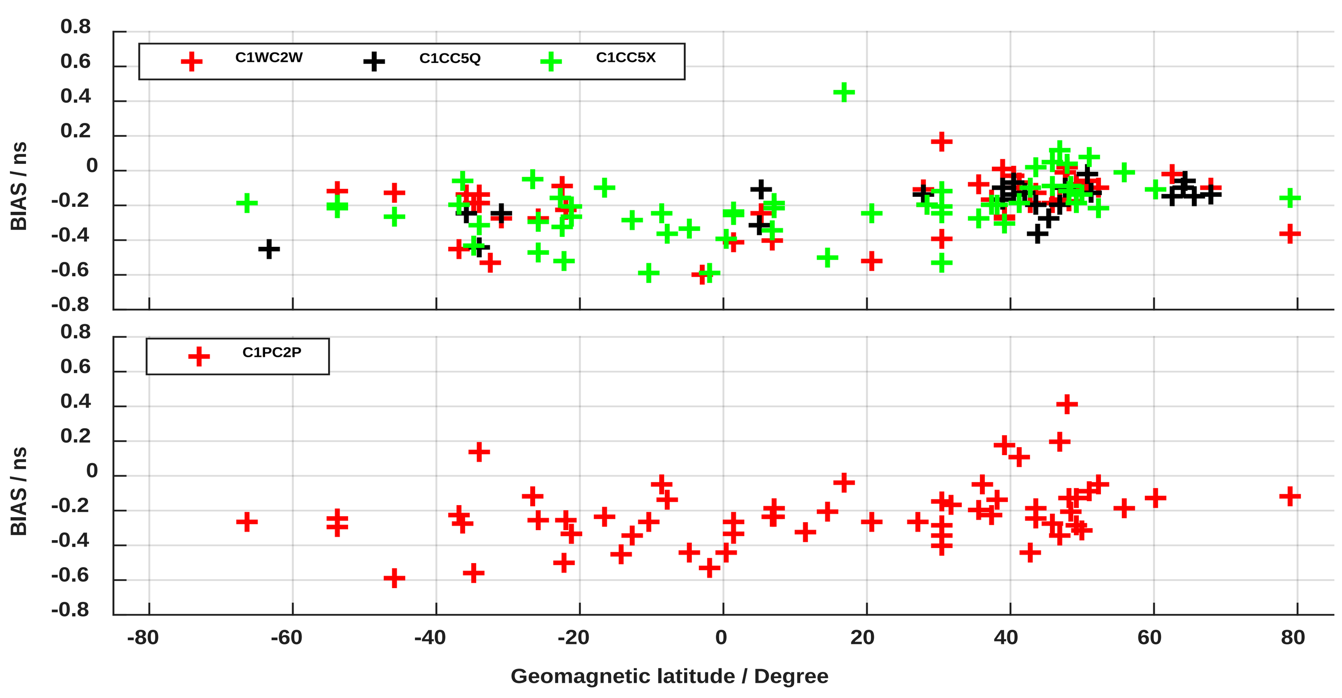

Fig 1. Bias between the IGG-based and DLR-based monthly GPS (upper) and GLONASS (bottom) receiver DCB estimates

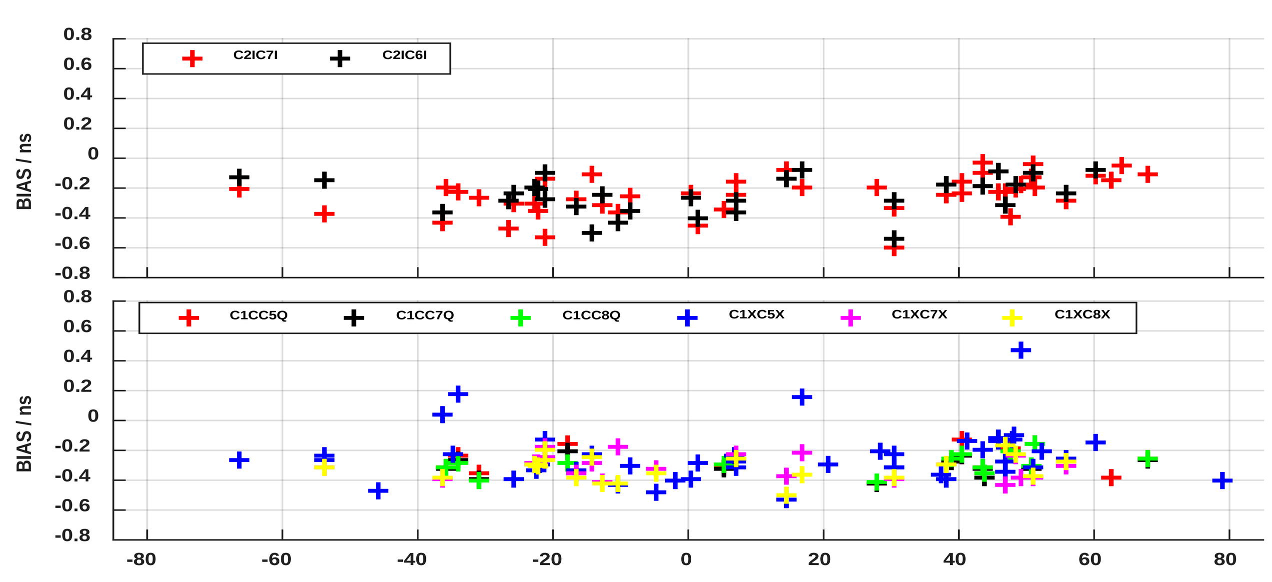

Fig 2. Bias between the IGG-based and DLR-based monthly BDS (upper) and Galileo (bottom) receiver DCB estimates

Table 1. Mean and RMS values of the differences between the monthly receiver DCB estimates based on the IGG algorithm and the monthly receiver DCB products from the DLR in January 2015 (unit: ns)

System	GPS	GPS	GPS	GLO	BDS	BDS
Bias type	C1WC2W	C1CC5Q	C1CC5X	C1PC2P	C2IC7I	C2IC6I
Bias	-0.19	-0.18	-0.21	-0.22	-0.25	-0.25
RMS	0.24	0.22	0.28	0.29	0.28	0.28
System	GAL	GAL	GAL	GAL	GAL	GAL
Bias type	C1CC5Q	C1CC7Q	C1CC8Q	C1XC5X	C1XC7X	C1XC8X
Bias	-0.28	-0.29	-0.29	-0.23	-0.31	-0.32
RMS	0.29	0.30	0.30	0.31	0.32	0.33

Intra-day stability of receiver DCBs on a single day

To gain a better understanding of the characteristics of the receiver DCB variations over short-term intervals (e.g., 1 hour in this study), the intra-day stability index of the hourly receiver DCB estimates for all of the stations and all of the four GNSS systems on January 1, 2015, including the average, minimum and maximum STD values, are presented in Table 2. Table 2 demonstrates that, although the average STDs of hourly receiver DCB estimates over a one day period for all of the four GNSS systems are less than 1.15 ns, the maximum STD for several receivers is capable of exceeding 3.38/1.69 ns for the GPS-C1WC2W/GLONASS-C1WC2W DCB estimates, respectively, at station AUT0. According to the statistics, station AUT0 also shows an abnormal intra-day variation of DCB estimates on DOY 003, 015 and 024 in 2015.

Table 2. Intra-day stability of the hourly receiver DCB estimates determined by the proposed IGG method on January 1, 2015 (unit: ns).

System	GPS	GPS	GPS	GLO	BDS	BDS
Bias type	C1WC2W	C1CC5Q	C1CC5X	C1PC2P	C2IC7I	C2IC6I
Min STD	0.12	0.35	0.26	0.24	0.23	0.22
Max STD	3.38	1.55	2.07	1.69	1.81	1.97
Mean STD	0.53	0.65	0.93	0.69	0.82	0.80
System	GAL	GAL	GAL	GAL	GAL	GAL
Bias type	C1CC5Q	C1CC7Q	C1CC8Q	C1XC5X	C1XC7X	C1XC8X
Min STD	0.15	0.25	0.27	0.16	0.23	0.21
Max STD	1.61	1.73	2.02	2.96	2.59	2.91
Mean STD	0.66	0.68	0.72	1.02	1.15	1.11

Abnormal intra-day variation of the hourly receiver DCB estimates

Using station AUT0, which presents an abnormal intra-day variation, as an example, we plot the time series of the GPS C1WC2W DCB estimates obtained using the IGG method for DOY 001-002 and 024-025 of 2015 in Fig 3. The averaged difference between the IGG-based DCB estimates and those of the DLR-based method is approximately negative 0.22 ns on DOY 002 and 025, 2015. This further shows an encouraging consistency between these two DCB estimation methods. It can be seen that although the DCB estimates obtained from both the IGG-based and DLR-based methods are found to have remarkable differences between two consecutive days (DOY 024-025 and DOY 001-002), however, there is a significant difference between the variation trends of these two DCB products.

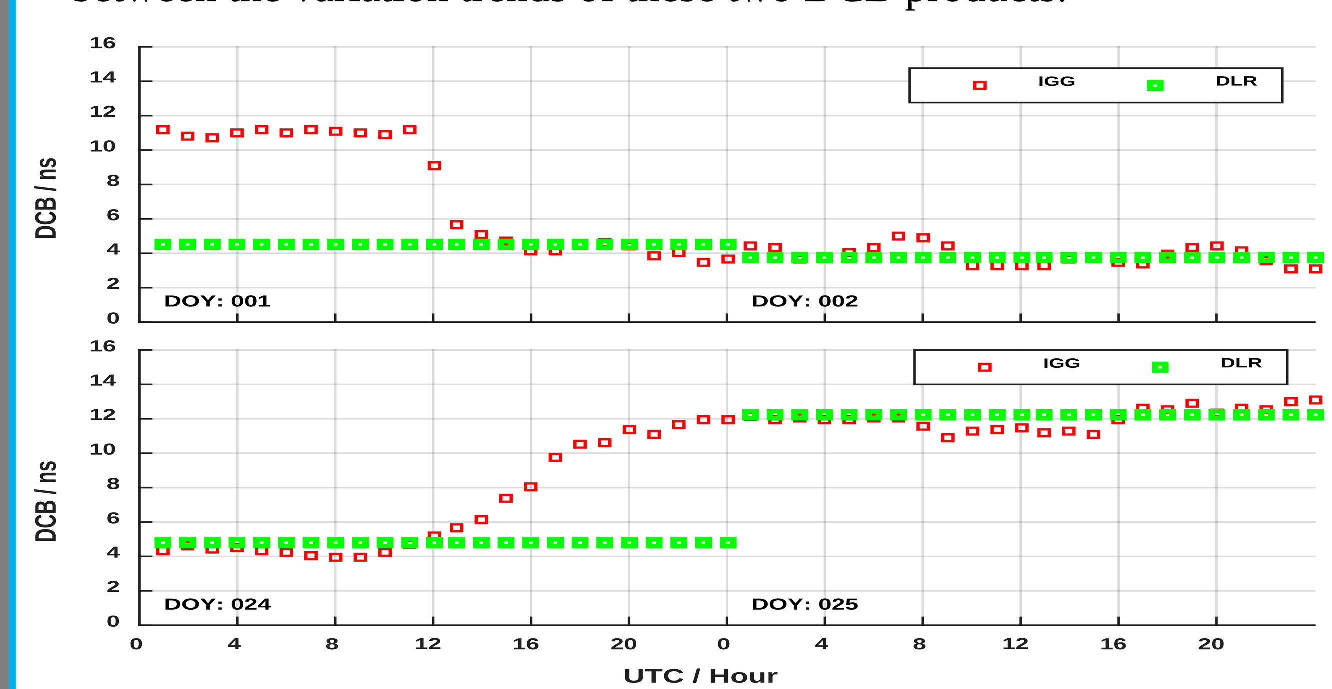

Fig 3. Time series of GPS C1WC2W DCB estimates at station AUT0 for DOY 001-002 and 024-025, 2015.

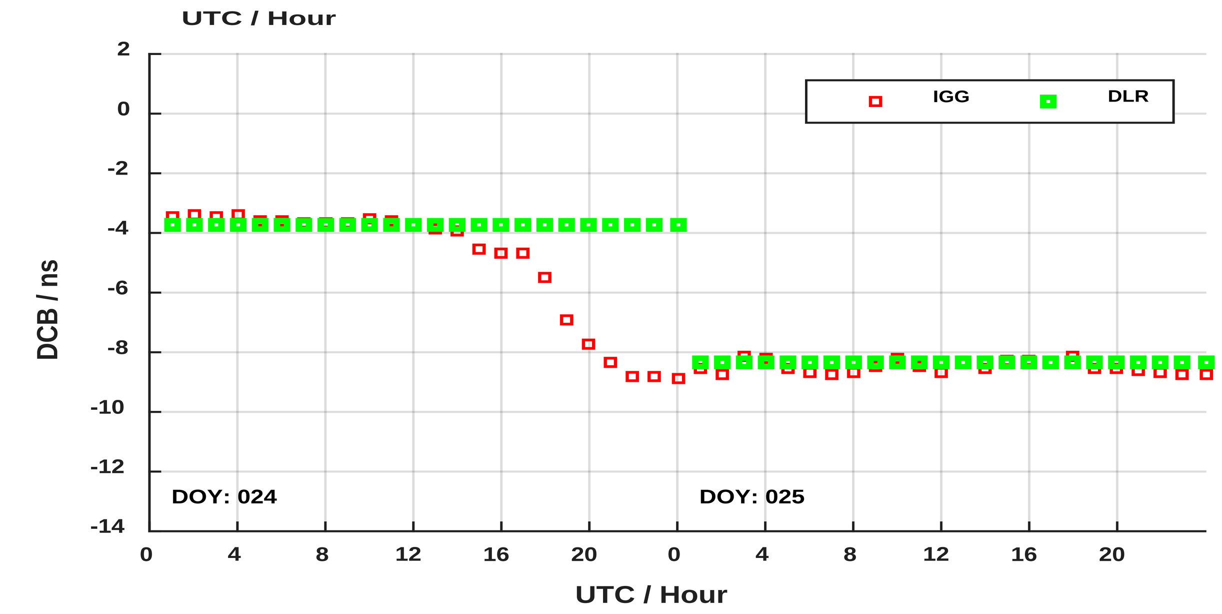

Fig 4. Time series of GLONASS C1CC2P DCB estimates at station AUT0 for DOY 024 and 025, 2015.

From Figs 3 and 4 , three conclusions can be drawn. First, the receiver DCBs did not change abruptly between the two consecutive days, and instead changed gradually at short-term intervals. Second, compared to DLR day-to-day DCB estimates, the hourly DCB estimates obtained from the IGG algorithm can reflect the short-term variations of DCBs more dedicatedly. Third, remarkable variations of receiver DCB estimates occurred concurrently for different systems.

Summary

a. A good agreement within the receiver DCBs is found between the resulting DCB estimates using the proposed method and multi-GNSS DCB products from DLR.
b. Compared to DLR-based DCB estimates on a daily basis, the hourly DCB estimates obtained from the IGG algorithm can reflect the short-term variations of DCB estimates more dedicatedly.
c. Large fluctuations (more than 9 ns) of receiver DCBs over a one day period are observed, it means that it may not be reasonable to treat all receiver DCB as constant over one day period.

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