Postprint: Analysis of Satellite DCB Characteristics Based on CAS and DLR Products

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Date: 2023-06-07T00:00:00+00:00

Abstract

Differential code bias (DCB) plays a critical role in the generation and transmission of GNSS spatiotemporal information, and characteristic analysis of DCB parameters is of great significance for promoting high-precision GNSS navigation, positioning, and timing applications. Based on DCB products released by the Chinese Academy of Sciences (CAS) and the German Aerospace Center (DLR), we analyzed the average monthly stability of GPS satellite intra-frequency bias, inter-frequency bias, and BDS satellite inter-frequency bias, and investigated the influence of different ionospheric processing strategies on the periodic characteristics of inter-frequency bias. The results show that the average monthly stability of GPS satellite intra-frequency bias provided by the two analysis centers is less than 0.07 ns, the average monthly stability of GPS satellite and BDS satellite inter-frequency bias is less than 0.08 ns and 1.12 ns, respectively, the stability of GPS satellite inter-frequency bias is superior to that of BDS satellites; some GPS satellites exhibit annual or semi-annual periodic variations in C1C-C2W inter-frequency bias, and the periodicity of the two DCB products shows no difference due to different solution methods.

Full Text

Characteristic Analysis of Satellite DCB Products Provided by CAS and DLR

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Abstract

Differential code bias (DCB) plays a key role in the generation and transmission of GNSS spatiotemporal information, and the characteristic analysis of DCB parameters is of great significance for promoting high-precision GNSS navigation, positioning, and timing applications. Based on DCB products provided by the Chinese Academy of Sciences (CAS) and the German Aerospace Center (DLR), this study analyzes the average monthly stability of GPS satellite intra-frequency bias, GPS satellite inter-frequency bias, and BDS satellite inter-frequency bias, and investigates the influence of different ionospheric processing strategies on the periodic characteristics of inter-frequency bias. The results show that the average monthly stability of GPS satellite intra-frequency bias products from both analysis centers is less than 0.07 ns, while the average monthly stability of GPS and BDS satellite inter-frequency bias products is less than 0.08 ns and 1.12 ns, respectively. The stability of GPS satellite inter-frequency bias is superior to that of BDS satellites. Some GPS satellites exhibit annual or semi-annual periodic variations in C1C-C2W inter-frequency bias, and the periodic characteristics of DCB products from CAS and DLR show no significant differences despite their different processing methods.

Keywords: GNSS; DCB; monthly stability; periodicity

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1 Introduction

In GNSS data processing, the generation and transmission of spatiotemporal information is achieved through code pseudorange and carrier phase combination observations. Precise clock products generated by different analysis centers using various data processing algorithms are referenced to specific combination observations and contain observable-specific biases (OSB) []. OSB can be divided into code OSB and phase OSB. Phase OSB is typically used in PPP-AR (precise point positioning ambiguity resolution), manifesting as wide-lane UPD (uncalibrated phase delay) and narrow-lane UPD [], while pseudorange OSB has a convertible relationship with differential code bias (DCB) and timing group delay (TGD) [], and affects UPD estimation []. Pseudorange OSB is usually solved by adding an ionosphere-free clock datum constraint based on DCB estimation [], making DCB crucial in GNSS spatiotemporal information generation and transmission. Consequently, characteristic analysis of DCB parameters is essential for advancing high-precision GNSS navigation, positioning, and timing applications.

DCB originates from time delays experienced by ranging code signals of different frequencies or types as they pass through different channels of satellites or receivers []. Based on the location of delay generation, DCB can be classified as satellite DCB or receiver DCB, and based on signal mechanism, it can be divided into intra-frequency bias and inter-frequency bias. Intra-frequency bias estimation methods can be categorized into three types: (1) simultaneous estimation with satellite clock offset; (2) differencing corresponding code observations, summing epoch-by-epoch, and then averaging to estimate satellite-plus-receiver (SPR) intra-frequency bias parameters; and (3) determination based on PPP technology. Inter-frequency bias estimation primarily employs two approaches: (1) simultaneous estimation with ionospheric modeling, and (2) obtaining SPR inter-frequency bias parameters after correcting ionospheric TEC (total electron content) using empirical values or ionospheric models. Since satellite and receiver inter-frequency bias parameters are linearly correlated, a reference datum must be introduced to separate satellite and receiver DCB parameters. Three types of reference datums are commonly used: (1) using a receiver with calibrated hardware delay as the reference datum, employed by the GPS ground control system; (2) constructing a "zero-mean" datum from all satellites, used by IGS and MGEX DCB products; and (3) constructing a "quasi-stable" datum using satellites with relatively stable DCB parameters [].

Both the Chinese Academy of Sciences (CAS) and the German Aerospace Center (DLR) submit DCB products to the IGS (International GNSS Service). CAS and DLR employ the same method for solving intra-frequency bias—selecting corresponding code observations for direct combination—while adopting different ionospheric TEC processing strategies for inter-frequency bias parameters: DLR uses global ionospheric maps (GIMs) data to remove ionospheric TEC effects [], whereas CAS employs the IGGDCB (Institute of Geodesy and Geophysics Differential Code Bias) method for ionospheric modeling and DCB estimation [], as shown in .

Research indicates that the asymmetry index of peak values in different longitude circles between the northern and southern hemispheres, calculated using GIMs data, exhibits annual and seasonal cycles []. GPS satellite DCB shows significant trend terms, with all satellites sharing the same variation trend, and the recent annual cycle variation of DCB correlates with the annual variation of ionospheric TEC []. The strong correlation between inter-frequency DCB and the ionosphere leads to DCB estimation accuracy being affected by ionospheric estimation errors, with the periodic characteristics of the ionosphere manifesting in DCB.

Stable satellite DCB can better serve clock offset solution [], high-precision GNSS TEC extraction [], and PPP []. Wang Ningbo compared the stability of inter-frequency bias products for GPS satellites C1W-C2W, C1C-C5X, and C1C-C7Q and BDS-2 satellites C2I-C7I from CAS and DLR for 2013–2014, finding that DLR's monthly stability was slightly better than CAS's, but without investigating GPS satellite intra-frequency bias stability []. Ren Xiaodong studied the monthly stability of GPS satellite C2W-C2S intra-frequency bias and C1W-C2W and C1C-C5Q inter-frequency bias products from CAS and DLR for 2015–2016. Due to the susceptibility of single-station ionospheric modeling to station location, CAS products generally showed poorer monthly stability, and BDS satellite stability was not investigated []. The studied product timeframes are relatively distant from the present, and changes in the space environment, equipment aging during operation, and replacement of different satellite types may have altered satellite DCB parameters. Additionally, there is the increase in BDS-3 satellites and DCB product types. Therefore, it is necessary to study more recent satellite DCB product stability.

Based on previous research, to analyze the impact of the two analysis centers' processing methods on DCB product periodic characteristics and investigate the stability of GPS and BDS satellite DCB products, this paper addresses the following issues: (1) investigating the stability of GPS satellite intra-frequency bias, GPS satellite inter-frequency bias, and BDS satellite inter-frequency bias products from CAS and DLR; (2) analyzing the periodic characteristics of GPS satellite inter-frequency bias products from CAS and DLR; and (3) comparing the periodic characteristics of GPS satellite intra-frequency bias and inter-frequency bias products between CAS and DLR.

2 DCB Product Stability Study

To investigate the stability of GPS and BDS satellite DCB products, we selected DCB products for GPS and BDS satellites released by CAS and DLR from January 1, 2021, to December 31, 2021, and calculated their monthly stability. Monthly stability reflects the variation of daily DCB means relative to monthly means, which can indicate the stability and reliability of DCB parameter estimation to some extent []. The calculation formula is as follows:

Sj;m = d=1(DCBd;j;m (cid:0) DCB Dm (cid:0) 1

where Sj;m is the DCB monthly stability of satellite j in month m, DCBd;j;m is the DCB daily estimate of satellite j on day d of month m, DCBj;m represents the monthly average of daily DCB estimates for satellite j in month m, and Dm denotes the number of days in month m.

To better reflect the monthly stability of DCB products and minimize errors caused by month selection, we averaged the monthly stability values of satellite DCB for the 12 months of 2021 to obtain the average monthly stability. The calculation formula is as follows:

Sj;m ; j is the average monthly stability of satellite j in 2021.

Additionally, since the number of satellite DCB parameters estimated daily by CAS and DLR differs, the datums applied when separating satellite and receiver DCB vary. Therefore, when comparing satellite DCB products between the two analysis centers, datum unification must first be performed []. This paper constructs a new satellite "zero datum" using satellites that are common to both analysis centers and relatively stable, then unifies the datum of DC products from different institutions on different days before conducting monthly stability studies and periodic analysis.

2.1 GPS Satellite Intra-Frequency Bias Stability Study Since neither CAS nor DLR DCB products provide BDS satellite intra-frequency bias, this section analyzes only four types of GPS satellite intra-frequency bias: C1C-C1W, C2W-C2L, C2W-C2S, and C2W-C2X. The average monthly stability for each satellite was obtained by summing and averaging its monthly stability values.

[Figure 1: see original paper] presents the calculated average monthly stability of GPS satellite intra-frequency bias from CAS and DLR for January 1, 2021, to December 31, 2021, with the horizontal axis showing the satellite space vehicle number (SVN) and the vertical axis showing the average monthly stability of satellite intra-frequency bias.

As shown in [Figure 1: see original paper], the average monthly stability of all four GPS satellite intra-frequency bias products provided by CAS and DLR is within 0.07 ns, with comparable stability. The C1C-C1W intra-frequency bias product demonstrates slightly better stability than the other three types.

2.2 GPS and BDS Satellite Inter-Frequency Bias Stability Analysis We investigated the stability of GPS satellite C1C-C2W and C1C-C5Q inter-frequency bias and BDS satellite C2I-C6I and C2I-C7I inter-frequency bias. [Figure 2: see original paper] shows the calculated average monthly stability of GPS satellite inter-frequency bias, while [Figure 3: see original paper] presents the results for BDS satellite inter-frequency bias.

[Figure 2: see original paper] indicates that the average monthly stability of GPS satellite C1C-C2W inter-frequency bias from both CAS and DLR is within 0.07 ns, while C1C-C5Q monthly stability is within 0.09 ns and 0.08 ns, respectively. The C1C-C2W inter-frequency bias demonstrates better stability than C1C-C5Q, and DLR GPS satellite inter-frequency bias stability is slightly superior to that of CAS.

From [Figure 3: see original paper], the average monthly stability of BDS satellite C2I-C6I inter-frequency bias from CAS and DLR is within 1.12 ns and 1.10 ns, respectively, while C2I-C7I monthly stability is within 0.13 ns and 0.17 ns. Compared with 2015–2016 results where C1C-C5Q monthly stability was within 0.21 ns and 0.14 ns, and C2I-C7I monthly stability was within 0.35 ns and 0.31 ns [], there is noticeable improvement. This enhancement is attributed to the increasing number of MGEX stations used in DCB estimation over the years, leading to improved monthly stability. Additionally, BDS-2 satellites C007, C008, C009, C010, C017, and C019 show poor monthly stability for C2I-C6I inter-frequency bias due to a ~10 ns jump occurring between day 29 and day 50 of 2021, which degraded the monthly stability for the corresponding months and affected the average monthly stability. The time series of this jump is shown in [Figure 4: see original paper].

Comparing [Figure 2: see original paper] and [Figure 3: see original paper] reveals that GPS satellite inter-frequency bias stability is superior to BDS satellite inter-frequency bias stability. This is because, on one hand, the number of stations tracking GPS signals exceeds those tracking BDS signals, and on the other hand, satellite and receiver inter-frequency biases are estimated simultaneously. The stability of GPS receiver DCB is better than that of BDS receiver DCB, resulting in correspondingly better stability of GPS satellite DCB.

summarizes the average monthly stability across all satellites for each DCB product type shown in [Figure 1: see original paper], [Figure 2: see original paper], and [Figure 3: see original paper]. The results indicate: (1) GPS satellite intra-frequency bias stability is superior to inter-frequency bias, with average monthly stability values of 0.03 ns and 0.08 ns, respectively, for 2021; (2) intra-frequency biases on GPS L1 and L2 frequencies show comparable stability; and (3) GPS satellite inter-frequency bias stability is superior to BDS satellite inter-frequency bias stability.

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3 DCB Product Periodic Characteristic Analysis

To verify whether different ionospheric processing strategies affect DCB products, we selected GPS satellite C1C-C2W inter-frequency bias products from CAS and DLR for 2016–2021 to analyze periodic variation characteristics. A total of 28 satellites were selected, with SVN numbers: G041, G043-G045, G047, G048, G050-G053, G055-G059, G061-G073.

[Figure 5: see original paper] presents the time series of GPS satellite C1C-C2W inter-frequency bias without datum unification, where the legend shows the satellite pseudo-random noise code (PRN) in parentheses, i.e., satellite SVN (PRN). The figure shows that most GPS satellite DCB exhibits clear and similar long-term trend variations, with simultaneous jumps in the same direction at identical time points, consistent with the findings of Zhong et al. []. These jumps result from applying a zero-mean condition to all satellite DCB during the separation of satellite and receiver DCB, as well as replacement of different GPS satellite types (GPS- , GPS- , GPS- A, GPS- R/ R-M, GPS- F, GPS- , etc., with the first three types having been fully retired []). For example, the jump on February 19, 2020, occurred because satellite G041(G14) was replaced by G077(G14), G034(G18) by G075(G18), and G060(G23) by G076(G23).

Therefore, continuously operating GPS satellites should be used as the reference datum in DCB analysis. We selected six satellites with long data spans and relatively stable characteristics as the reference datum, then performed daily datum unification for the satellite DCB products.

[Figure 6: see original paper] shows the time series of satellite C1C-C2W inter-frequency bias parameters after datum unification, revealing approximately 5 ns variations in GPS satellite DCB parameters from both CAS and DLR.

To further analyze the periodic characteristics of inter-frequency bias, we employed the fast Fourier transform (FFT) method to obtain amplitude at each frequency point. To ensure periodic reliability, we filtered the results, retaining only periods with time spans less than half of the total data time span. Using satellite G043(G13) C1C-C2W inter-frequency bias as an example, [Figure 7: see original paper] demonstrates the presence of semi-annual and annual terms in the DCB product.

Among the 28 analyzed satellites, nine exhibit semi-annual or annual periods in C1C-C2W inter-frequency bias, with spectra similar to satellite G043(G13). details the specific GPS satellites and their periodic terms, showing that satellites G043-G045, G055, G058, G061, G065, G066, and G72 have semi-annual or annual periods in their C1C-C2W inter-frequency bias products. Research indicates that TEC also exhibits semi-annual and annual cycles [], suggesting that incomplete removal of ionospheric effects during DCB calculation may cause these periodic characteristics in GPS satellite C1C-C2W inter-frequency bias products.

Furthermore, despite CAS and DLR employing different ionospheric processing strategies—station-by-station ionospheric TEC modeling versus GIMs-based ionospheric TEC removal—their products do not exhibit different long-term temporal variation characteristics.

4 Comparison of Periodic Characteristics Between Satellite Intra-Frequency and Inter-Frequency Bias

Different data analysis centers use different methods to calculate inter-frequency bias, and the same analysis center employs different processes for solving satellite intra-frequency and inter-frequency biases. In intra-frequency bias calculation, code observations share the same frequency, and theoretically, ionospheric effects have been removed. In contrast, inter-frequency bias requires ionospheric TEC modeling or GIMs-based ionospheric TEC removal, potentially leaving residual ionospheric effects. We extracted periodic characteristics from both GPS satellite intra-frequency and inter-frequency biases for comparison to determine whether they exhibit different periodic terms.

We analyzed the periodic characteristics of GPS satellite C1C-C1W intra-frequency bias and C1C-C2W inter-frequency bias from CAS and DLR products, with the comparison shown in [Figure 8: see original paper]. The displayed periods represent the two most significant periods (largest amplitude) extracted via FFT for each satellite's DCB, with the horizontal axis showing satellite SVN and the vertical axis showing period in cycles per year (cpy).

The results show that CAS GPS satellite DCB exhibits prominent periods greater than 1.75 cpy (shorter than 0.57 years) or less than 1.50 cpy (longer than 0.67 years). In DLR results, satellites G043, G045, G055, and G071 show prominent periods greater than 1.50 cpy in C1C-C2W inter-frequency bias, while other periods greater than 1.50 cpy belong to C1C-C1W intra-frequency bias.

In summary, GPS satellite C1C-C1W intra-frequency bias and C1C-C2W inter-frequency bias do not show distinct differences in periodic terms, and the reasons for periodicity in intra-frequency bias remain unclear.

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5 Results and Discussion

Based on DCB products from CAS and DLR for 2016–2021, this study investigated the stability of GPS and BDS satellite DCB products and analyzed the influence of different ionospheric processing strategies on the periodic characteristics of GPS satellite intra-frequency and inter-frequency biases. The conclusions are as follows:

(1) The satellite DCB product stability from both analysis centers in 2021 is comparable, with GPS satellite DCB product stability superior to that of BDS satellites.

(2) GPS satellite DCB exhibits significant linear trends, with all satellites changing simultaneously in the same direction, consistent with the findings of Zhong et al. []. This results from the zero-mean datum condition applied during satellite and receiver DCB separation and the replacement of participating satellite types.

(3) In DCB products from both CAS and DLR, some GPS satellites exhibit semi-annual or annual terms in C1C-C2W inter-frequency bias, likely due to residual ionospheric effects in the products. Despite differences in processing methods between the two analysis centers, the periodic terms in inter-frequency bias products are similar.

(4) For most CAS GPS satellites, prominent periods of intra-frequency and inter-frequency bias are shorter than 0.57 years or longer than 0.67 years. DLR shows more satellites with C1C-C1W intra-frequency bias having prominent periods shorter than 0.57 years. No clear distinction exists between the periodic terms of GPS satellite intra-frequency and inter-frequency biases.

These conclusions contribute to further research on DCB product patterns and improvements in clock offset solution, TEC extraction, and precise positioning accuracy. Future work will continue to investigate the causes of periodicity and develop correction methods.

References

[1] Banville S, Geng J, Loyer S, et al. Journal of Geodesy, 2020, 94(1): 10
[2] Li X, Han X, Li X, et al. GPS Solutions, 2021, 25(2): 66
[3] Guo F, Zhang X, Wang J. Journal of Geodesy, 2015, 89(5): 427
[4] Wang N, Yuan Y, Zhang B, et al. Acta Geodaetica et Cartographica Sinica,

2016, 45(8): 919
[5] Nie W. Ph.D. Thesis. Weihai: Shandong University (Weihai), 2019: 5
[6] Wang N. Ph.D. Thesis. Wuhan: Institute of Geodesy and Geophysics, Chinese Academy of Sciences, 2016: 5
[7] Montenbruck O, Hauschild A, Steigenberger P. Navigation, 2014, 61(3): 191
[8] Li Z, Yuan Y, Li H, et al. Journal of Geodesy, 2012, 86(11): 1059
[9] Wang N, Yuan Y, Li Z, et al. Journal of Geodesy, 2016, 90(3): 209
[10] Huang L, Chen J, Li C, et al. Science Technology and Engineering, 2018, 18(18): 212
[11] Yang H. Ph.D. Thesis. Xi'an: University of Chinese Academy of Sciences (National Time Service Center, Chinese Academy of Sciences), 2016: 104
[12] Montenbruck O, Hauschild A. ION GPS 2013, San Diego, 2013: 616
[13] Zhang B, Yuan Y, Ou J. Chinese Journal of Geophysics, 2016, 59(01): 101
[14] Gu S, Dang Y, Wang H, et al. Science of Surveying and Mapping, 2020, 45(10): 10
[15] Ren X. Ph.D. Thesis. Wuhan: Wuhan University, 2017: 8
[16] Wilson B D, Mannucci A J. ION GPS 1993, Salt Lake City, 1993: 1343
[17] Lu Y, Zhang G, Chen G, et al. Spacecraft Engineering, 2020, 29(04): 1
[18] Zhong J, Lei J, Dou X, et al. GPS Solutions, 2016, 20(3): 313
[19] Liu T, Zhang C, Yuan B, et al. Journal of Geodesy, 2019, 93(5): 765
[20] Wang B, Li S, Duan B, et al. Journal of Geodesy, 2020, 94(8): 74

Note: Figure translations are in progress. See original paper for figures.