Is the long-term variation of the estimated GPS differential code biases associated with ionospheric variability?

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Abstract

The Global Positioning System (GPS) differential code biases (DCB) provided by the International GNSS Service (IGS) show solar cycle-like variation during 2002-2013. This study is to examine whether this variation of the GPS DCBs is associated with ionospheric variability. The GPS observations from low earth orbit (LEO) satellites including CHAMP, GRACE and Jason-1 are used to address this issue. The GPS DCBs estimated from the LEO-based observations at different orbit altitudes show a similar tendency as the IGS DCBs. However, this solar cycle like dependency is eliminated when the DCBs of 13 continuously operating GPS satellites are constrained to zero-mean. Our results thus revealed that ionospheric variation is not responsible for the long-term variation of the GPS DCBs. Instead, it is attributed to the GPS satellite replacement with different satellite types and the zero-mean condition imposed on all satellites’ DCBs. The receiver DCB will suffer the opposite long-term variation of the GPS DCB. After the long-term variation caused by the GPS satellite replacement is removed, the CHAMP DCB is found to be strongly dependent on the receiver temperature. In addition, the assessment of vertical TEC mapping functions and an improved ZERO-TEC DCB method for space-based GNSS observations are presented.

Figure 1. Schematic of the (a) thin layer model and (b) F&K model.

Thin layer model:

\[ M(x) = \lim_{h \to 0} \frac{dM}{dh} = \frac{1}{\left(R_{\text{Earth}}/R_{\text{Sat}} \right)^2 \sin^2 \phi} \]

F\&K model [Foelsche and Kirchengast, 2002]:

\[ M(x) = \frac{dM}{dh} = \frac{1}{R_{\text{Sat}}} \left( \frac{1}{\cos \phi} \frac{R_{\text{Sat}}}{R_{\text{Earth}}} - \sin \phi \right) \]

Figure 2. Global averaged ionospheric effective heights (IEH) versus orbit altitude using Global Core Plasma Model (GCPM) [Gallagher et al., 2000].

Centroid method (the definition of the centroid): \( h_{\text{cm}} = \frac{\int N(x)h \, dh}{\int N(x) \, dh} \)

Integral median value method (one half of the total integral):

\[ \int N(x)h \, dh = \frac{1}{2} \int_{-\infty}^{\infty} N(x)h \, dh \]

Figure 3. Retrieved relative errors versus zenith angle at four different orbit altitudes based on the GCPM simulations that compare the vertical TEC converted by the mapping functions and the vertical TEC directly calculated by the model.

The results illustrate that the F&K geometric mapping function together with the IEH of the centroid method is more suitable for the LEO-based TEC conversion [Zhong et al., 2015a].

Figure 4. Variations of DCB1 and DCB2, representing the DCBs estimated from the daily minimum relative TEC and the lower quartile minimum relative TEC, respectively. The histogram bar of their difference is displayed at the corner. The vertical red line represents the Gaussian fitting center \( \mu \). The center of the Gaussian fitting \( \mu \) is used to correct the offset in the DCB0 (i.e., DCB = DCB1 + DCB2 + \mu) [Zhong et al., 2015c].

Long-term variation of GPS DCB

Figure 5. GPS DCB for PRN03 provided by the IGS and F107 from 2002 to 2013. The PRN03 DCB was monotonously descending from 2002 to 2009, while it increased from 2010 to 2013. Interestingly, the DCB shared a similar long-term trend with F107.

Data and Method

In order to minimize the effect of the ionospheric ionization, the GPS observations from CHAMP, GRACE and Jason-1 with average orbit altitudes of 400, 490 and 1,336 km, respectively, are utilized to estimate the GPS DCBs. The DCBs are estimated based on the regional spherical symmetry assumption of the ionosphere [Yue et al., 2011; Zhong et al., 2015b]. The combined satellite-receiver DCB (DCB, \( \Delta \) DCB) can be actually determined, but the satellite and receiver DCBs only can be obtained with respect to a particular reference value. The zero-mean condition is generally introduced to separate satellite and receiver DCBs as follows:

\[ \sum_{n=1}^{N} \Delta \text{DCB} = 0 \]

where \( n \) is the number of the observed GPS satellites. In addition, the DCBs for 13 continuously operating GPS satellites are assumed to satisfy the zero-mean condition. In this case, \( n \) is 13 in the equation.

Figure 6. IGS DCBs and LEO-based DCB estimated from LEO satellites for 13 continuously operating GPS satellites from 2002 to 2013. The long-term variations of GPS DCBs are consistent between the LEO-based and IGS results.

Figure 7. IGS DCBs and LEO-based DCBs estimated under the zero-mean condition imposed on the DCBs of 13 continuously operating satellites. The estimated LEO-based GPS DCBs do not present an obvious long-term variation as compared with the IGS DCBs.

Cause of the long-term variation of GPS DCB

Figure 8. IGS DCBs on December 31, 2013. The corresponding PRNs are shown at the bottom. DCB values for the same type of GPS satellites are similar. When a new satellite replaces an decommissioned one with different satellite type, the daily mean value of all satellite DCBs should change. However, under the zero-mean condition imposed on the DCBs for all satellites, the daily mean value is still set as zero. Though the replacement of one GPS satellite just causes slight variations on GPS DCBs, the accumulative changes over the years might be enough to cause long-term variation of GPS DCBs.

Dependence of DCB on receiver temperature

Figure 9. Variations of DCBs and receiver CPU temperature for CHAMP. The CHAMP DCB was reconstructed under the zero-mean condition imposed on the DCBs of 13 continuously operating GPS. For individual days, the mean value for the IGS DCBs of those 13 continuously operating satellites was calculated and then this offset was added to the original CHAMP DCB. The reconstructed DCB well matches with both the short-term and long-term variations of the receiver temperature [Zhong et al., 2015c]. (The CHAMP GPS receiver CPU temperature was kindly provided by Jens Wickert and Wolfgang Koehler from GFZ.)

Conclusions

1. The GPS DCBs estimated from three LEO satellites at different orbit altitudes showed similar long-term tendency with the IGS DCBs.
2. The long-term variations of the GPS DCBs and solar activity happened to share the similar trend, but they do not have a cause-effect relationship.
3. The long-term variation of the GPS DCB is not caused by the ionospheric variation. Instead, it is mainly associated with GPS satellite replacement.
4. The long-term variation of CHAMP DCB is generally associated with the GPS satellite replacement, while the periodic variation is mainly attributed to the variation of the CHAMP receiver temperature.

References


