Estimation of GPS/GLONASS Differential Code Biases and Their Long-time Variations

Yury V. Yasyukevich[1,2], **Anna A. Mylnikova**[1],
Vyacheslav E. Kunitsyn[1,3], **and Artem M. Padokhin**[1,3]

[1]Institute of Solar-Terrestrial Physics, Siberian Branch of Russian Academy of Sciences, Irkutsk, Russia
[2]Irkutsk State University, Irkutsk, Russia
[3]Lomonosov Moscow State University, Moscow, Russia

Abstract— While estimating ionospheric total electron content by using both pseudorange and phase GPS/GLONASS data, there occurs a significant systematic error caused by differential code biases (DCBs). In some cases, along with systematic DCB variations, there are seasonal variations most likely related to variations in the receiver environment (temperature, humidity). We have developed an algorithm to estimate DCBs from the data of a single GPS/GLONASS station. The results of the algorithm operation are compared with the CODE DCB data. The main differences were recorded for GLONASS data.

1. INTRODUCTION

Along with navigation and precise time applications, Global Navigation Satellite Systems (GNSS) are widely used nowadays to remotely sense the ionosphere in equatorial, mid-latitude, and arctic regions [1]. Ionospheric TEC can be estimated by using dual-frequency code and phase measurements of pseudo ranges between a satellite and a receiver [3]. While estimating absolute TEC via using the code and phase measurements simultaneously, a systematic error occurs. This error depends on both the satellite and the receiver, and the cause is because the processing times for L1 and L2 signals in radio frequency (RF) paths differ and depend on the signal frequency. Due to these differential code biases (known as DCBs), TEC, in some cases, can obtain even non-physical negative values. A 1-ns DCB leads to an ~ 2.9 TECU error (2.85 TECU for GPS and 2.92 TECU for GLONASS frequencies). Thus, one should take DCBs into account for precise absolute TEC estimations [4]. It is especially important when analyzing long period TEC datasets obtained not only from GPS/GLONASS data, but also from geostationary SBAS data [5]. Long period TEC datasets obtained from geostationary SBAS can have a DCB-related systematic variation. This systematic variation can be mistaken for ionospheric TEC variation. We also note the complexity of estimating DCB for geostationary SBAS data, because the elevation angle of geostationary satellites varies slightly, and it is very difficult to distinguish between DCBs and real TEC variations.

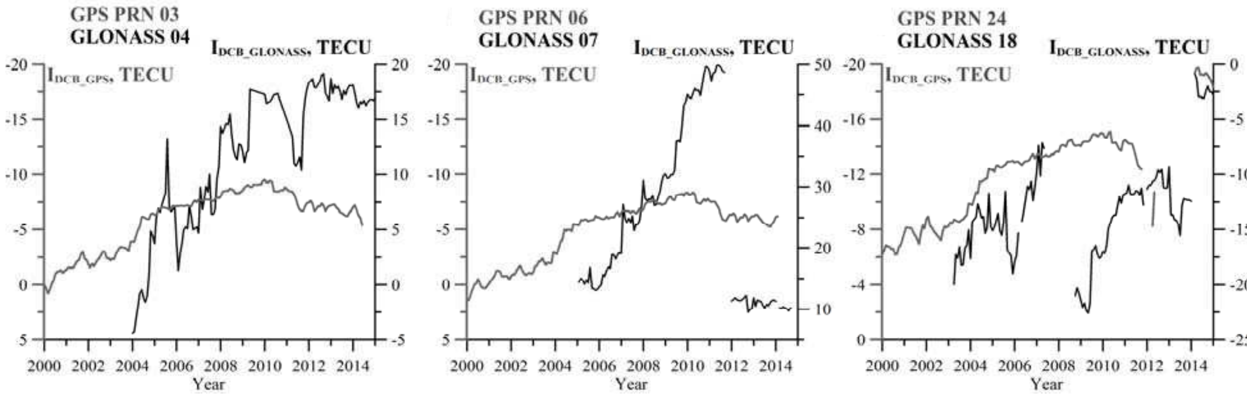
2. ESTIMATING DCB DYNAMICS

In this study, we analyze DCB dynamics and TEC estimation errors associated with satellites and receiver DCBs for 2000–2014 [6]. For such estimates, we used the CODE laboratory data (ftp://ftp.unibe.ch/aiub/CODE/) based on the measurements at the worldwide IGS network (International GNSS Service) (http://igscb.jpl.nasa.gov/) of GPS/GLONASS receiving stations. All the results of DCB estimations shown below are presented in TEC units (1 TECU $= 10^{16}$ electrons/m^2).

Figure 1 shows an example for the dynamics (variability) of DCB-related errors in TEC estimations for several GLONASS and GPS satellites. The GPS scale was inverted to compare the systematic variability. This TEC estimation error variability for the GPS satellites (~ 1 TECU/year) is three times less than that for the GLONASS satellites (~ 3 TECU/year). There are also significant variations in TEC errors for GLONASS satellites with amplitude up to ~ 5 TECU compared to quite small variations for GPS. Such significant differences between the GLONASS and GPS systems also occur for other satellites.

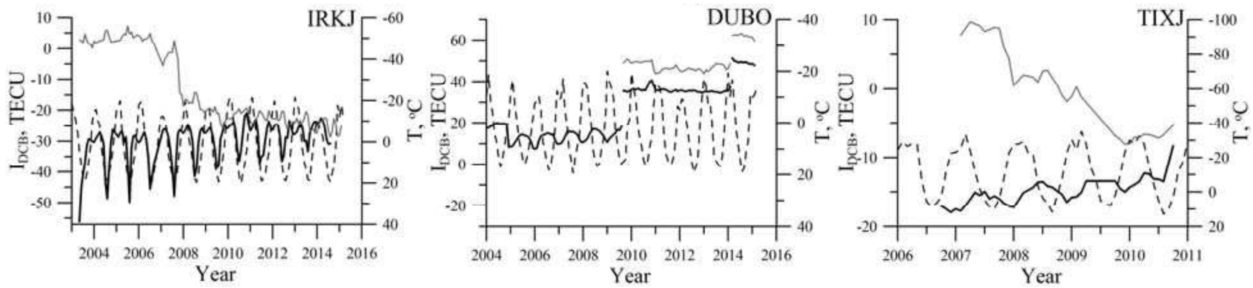
We also analyzed the DCB variability in the receiver frequency channels for several stations of the IGS network. Fig. 2 presents the DCB variability for mid-latitude and arctic stations. Summarizing, the receiver DCBs for the GLONASS frequency range can reach up to ~ 17.5 ns, leading to TEC errors up to ~ 50 TECU. For the GPS frequency range, these value reach ~ 21 ns and ~ 60 TECU, respectively. These results agree with [7] who showed that DCBs may reach 20-ns for receiver RF paths and 10 ns for satellites RF paths.

Systematic DCB variation, both for GLONASS and GPS frequency channels, is observed to significantly change depending on station. For the GLONASS and GPS frequency channels, seasonal



(a) (b) (c)

Figure 1: Dynamics of the DCB-related TEC estimation error for GLONASS (black line, right scale) and for GPS (gray line, left scale) satellites. (a) GPS PRN 03, GLONASS 04, (b) GPS PRN 06, GLONASS 07, (c) GPS PRN 24, GLONASS 18.



(a) (b) (c)

Figure 2: Dynamics of the DCB-related TEC estimation error for GLONASS (gray line) and GPS (black line) receiver frequency channels: (a) IRKJ station (mid-latitude); (b) DUBO (mid-latitude); (c) TIXJ (Arctic region). Dashed line marks temperature (°C).

variations in estimated DCB-related TEC errors up to ~ 20 TECU (~ 7 nc) for mid-latitude station IRKJ (see Fig. 2(a)), ~ 10 TECU (~ 3 nc) for mid-latitude station DUBO (see Fig. 2(b)) and ~ 5 TECU (~ 2 nc) for arctic station TIXJ (see Fig. 2(b)) are observed (see Fig. 2(a)). Such strong variations may be associated with variations in the receiver environment, especially meteoparameters, such as temperature and humidity. It is not just the type of receiver hardware problems, because such variations are observed for the other receivers of the different type. Fig. 2 shows temperature from the meteorological stations closed to chosen receivers (http://www.ncdc.noaa.gov/cdo-web/). The temperature seasonal variation maximum corresponds to the DCB seasonal variation minimum for IRKJ station. On the contrary, the temperature seasonal variation minimum corresponds to the DCB seasonal variation maximum for DUBO and TIXJ stations. This proves our hypothesis.

3. ALGORITHM FOR ESTIMATING DCBS

To determine the absolute TEC accounting for DCBs from the data of a single GPS/GLONASS station, we have developed the following algorithm [12]:

1. Calculate the TEC from code I_p and phase I_φ measurements.
2. Separate data sequences into continuous-time intervals.
3. Detect and eliminate the impact of outliers and signal tracking losses in the TEC data [Blewitt, 1990].
4. Remove the ambiguity of phase measurements: const $= \frac{1}{N}\sum_{i=1}^{N}(I_p - I_\varphi)_i$; where N is the number of measurements at a continuous interval.
5. Estimate DCBs by using a simple model for measurements. The model parameters are determined based on the minimization of the standard deviation between the experimental and

model data (see below).

6. Correct TEC sequences obtained in item 4 by the DCB value.

We use the following model for TEC measurements:

$$I_M = S_j^i\Big[I_V(\phi_0, l_0, t_0) + G_\phi \Delta\phi_j^i + G_{q\_\phi}\left(\Delta\phi_j^i\right)^2 + G_l \Delta l_j^i + G_{q\_l}\left(\Delta l_j^i\right)^2 + G_t \Delta t_j^i + G_{q\_t}\left(\Delta t_j^i\right)^2\Big] + I_{DCB,j},$$

where I_V is the absolute vertical TEC value; $\Delta\phi$ is the latitude difference between the ionospheric point coordinate ϕ and that of the ϕ_0 station; Δl is the longitude difference between the ionospheric point coordinate l and that of the l_0 station; Δt is the difference between the measurement time t and the time t_0, for which the calculation is performed; $G_\phi = \partial I_V/\partial\phi$, $G_l = \partial I_V/\partial l$, $G_{q\_\phi} = \partial^2 I_V/\partial\phi^2$, $G_{q\_l} = \partial^2 I_V/\partial l^2$ are linear and quadratic spatial TEC gradients; $G_t = \partial I_V/\partial t$ and $G_{q\_t} = \partial^2 I_V/\partial t^2$ are the first and second time derivatives, respectively. Here, we neglect the mixed spatial and time derivatives. This assumes that TEC changes more slowly in space during the time interval for which the calculation is performed, than the vertical TEC value at the same time does.

$$S_i^j = \left[\cos\left\{\arcsin\left(\frac{R_E}{R_E + h_{\max}}\sin[\alpha\cdot(90 - \theta_i^j)]\right)\right\}\right]^{-1}$$

is the oblique factor [9], R_E is the Earth radius, $h_{\max}$ is the height of the thin spherical layer (450 km), and a is a coefficient which depends on geographic latitude of station, for mid-latitudes $a = 0.97$, for high latitudes $a = 0.94$, θ_i^j is satellite elevation angle. We note that there are other algorithms and models to determine DCBs, for example [9–11].

Figure 3 presents the comparison between the DCB results (a), (d) obtained by the above algorithm and by the CODE data for all the satellites. The 2012 April 11 data is for the IRKJ mid-latitude station ($\phi = 52.2°$N, $l = 104.3°$E). Also, we present the results of correcting the initial oblique TEC for all the satellites accounting for DCBs obtained by the above algorithm (b), (e), and by the CODE data (c), (f). The thick grey line shows the absolute vertical TEC data obtained

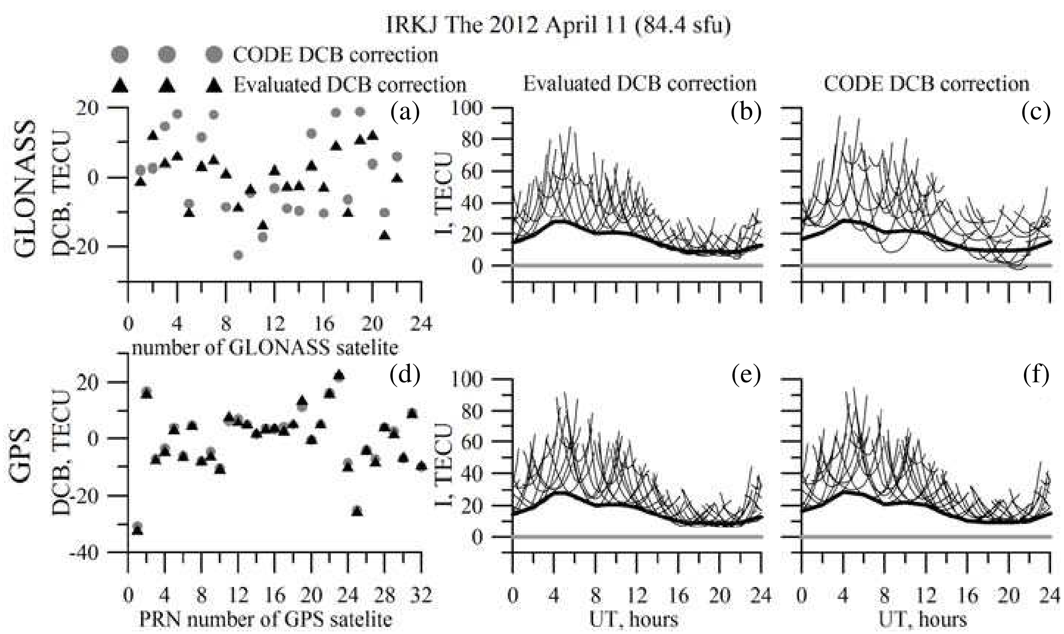


Figure 3: (a), (d) DCB results (left column) obtained by the above algorithm and by the CODE data for all (a) GLONASS and (d) GPS satellites observed at the IRKJ mid-latitude station. (b), (c), (e), (f) Variations in TEC from all the satellites using the correction based on the described algorithm (middle column) and on the CODE data (right column). The thick line is the absolute vertical TEC data obtained by the above algorithm (middle column) and by the CODE data (right column).

by the above algorithm (middle column) and by the CODE data (right column). These results were obtained with GPS and GLONASS measurements from the IRKJ station (within the International GNSS Service). After the CODE DCB correction, there appear unphysical negative TEC values in the GLONASS data. This indicates the revaluation of the DCB values. The TEC values obtained by the described above algorithm are more physically plausible.

Figure 4 presents the same data as those in Fig. 3, but for the THU2 arctic station data ($\phi = 76.5°\text{N}$, $l = -70°\text{W}$). The initial uncorrected TEC may possess very high and unphysical values, untypical of high latitudes. It is due to high DCB value. Unphysical small TEC values appear in the GLONASS data after the CODE DCB correction. This also indicates the CODE re-estimation of the DCB values.

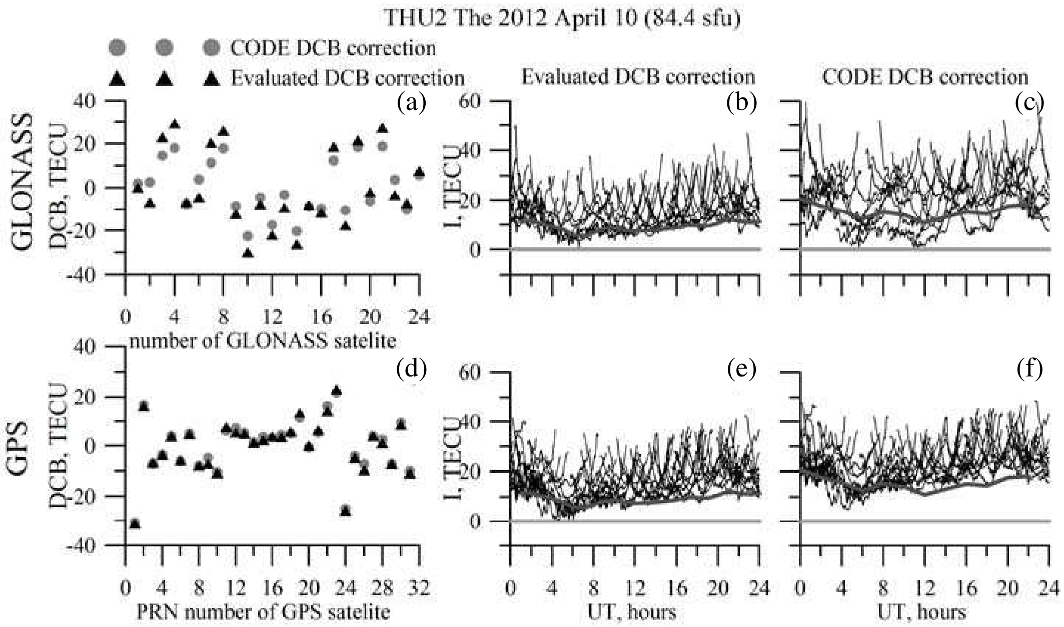


Figure 4: The same as in Fig. 3, but for the THU2 arctic station.

4. CONCLUSION

The obtained data indicate a need to calibrate GLONASS and GPS receivers and satellites while on-stream. The estimation algorithm is one of many problems. In some cases, one can see that using the CODE data to correct TEC measurements leads to obtaining TEC erroneous values.

ACKNOWLEDGMENT

The study was supported by the Grant from the Russian Science Foundation (Project No. 14-37-00027).

We are grateful to CODE and IGS [2] laboratory staff for providing DCB and GPS/GLONASS data.

REFERENCES

1. Afraimovich, E. L., E. I. Astafyeva, V. V. Demyanov, I. K. Edemskiy, N. S. Gavrilyuk, A. B. Ishin, E. A. Kosogorov, L. A. Leonovich, O. S. Lesyuta, K. S. Palamartchouk, N. P. Perevalova, A. S. Polyakova, G. Y. Smolkov, S. V. Voeykov, Yu. V. Yasyukevich, and I. V. Zhivetiev, "A review of GPS/GLONASS studies of the ionospheric response to natural and anthropogenic processes and phenomena," *J. Space Weather Space Clim.*, Vol. 3, A27, 2013.
2. Dow, J. M., R. E. Neilan, and C. Rizos, "The international GNSS service in a changing landscape of global navigation satellite systems," *Journal of Geodesy*, Vol. 83, No. 3–4, 191–198, 2009, DOI: 10.1007.
3. Hofmann-Wellenhof, B., H. Lichtenegger, and J. Collins, *GPS: Theory and Practice*, 389, Springer-Verlag Wien, New York, 1998.

4. Li, Z., Y. Yuan, H. Li, J. Ou, and X. Hou, "Two-step method for the determination of the differential code biases of COMPASS satellites," *Journal of Geodesy*, Vol. 86, No. 11, 1059–1076, 2012.
5. Kunitsyn, V., G. Kurbatov, Yu. Yasyukevich, and A. Padokhin, "Investigation of SBAS L1/L5 signals and their application to the ionospheric TEC studies," *Geoscience and Remote Sensing Letters*, 2014, doi: 10.1109/LGRS.2014.2350037.
6. Mylnikova, A. A., Yu. V. Yasyukevich, V. E. Kunitsyn, and A. M. Padokhin, "Variability of GPS/GLONASS differential code biases," *Results in Physics*, Vol. 5, 9–10, 2015.
7. Schaer, S., "Overview of GNSS biases," International GNSS Service, Workshop on GNSS Biases, 2012, http://www.biasws2012.unibe.ch/pdf/bws12_1.3.1.pdf.
8. Blewitt, G., "An automatic editing algorithm for GPS data," *Geophysical Research Letters*, Vol. 17, 483–492, 1990.
9. Schaer, S., "Mapping and predicting the Earth's ionosphere using the global positioning system," Dissertation, Astronomical Institute, University of Berne, Berne, Switzerland, Mar. 25, 1999.
10. Jin, R., S. Jin, and G. Feng, "M_DCB: Matlab code for estimating GNSS satellite and receiver differential code biases," *GPS Solutions*, Vol. 16, No. 4, 541–548, 2012.
11. Mannucci, A. J., B. D. Wilson, D. N. Yuan, C. H. Ho, U. J. Lindqwister, and T. F. Runge, "A global mapping technique for GPS-derived ionospheric TEC measurements," *Radio Sci.*, Vol. 33, No. 3, 565–582, 1998.
12. Yasyukevich, Yu. V., A. A. Mylnikova, and A. S. Polyakova, "Estimating the total electron content absolute value from the GPS/GLONASS data," *Results in Physics*, Vol. 5, 32–33, 2015.