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ORIGINAL ARTICLE

Temporal and spatial variation of differential code biases: A case study of regional network in Egypt

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Abstract Measurements of Global Positioning Satellite System receivers are affected by systematic offsets related to group and phase delays of the signal generation and processing chain. One of the important factors affecting the ionosphere Total Electron Content estimation accuracy is the hardware differential code biases inherited in both Global Positioning System satellites and receivers. The resulting code and phase biases depend on the transmission frequency and the employed signal modulation. An efficient algorithm using the geometry conditions between satellite and tracking receivers is proposed to determine the receiver differential code biases using Egyptian permanent reference stations. This method does not require a traditional single-layer ionosphere model and can be used for estimating differential code biases of receivers in a regional network.

This paper estimates receiver differential code biases for nine receivers located within Egyptian network. The results showed that the estimated mean value of the receiver differential code biases varied from −28 ns (nanosecond) to 39 ns. It is clear from the results that differential code biases values for Egyptian sites do not vary much with latitude and longitude, except at Aswan and Abu Simpel. Differential code biases values increase gradually with increasing height.

1. Introduction

Today Global Positioning System (GPS) is widely used for navigation and positioning in either static or kinematic mode in a number of applications. Ionospheric influence can reduce the accuracy of positioning by tens of meters. The ionospheric influence might reach more than a hundred meters during a violent ionospheric storm. This ionospheric effect has apparently become the largest error source in GNSS navigation and positioning after Selective Availability (SA) is turned-off for single-frequency users [2]. Therefore, the ionospheric effects must be considered for high accuracy positioning.

The Total Electron Content (TEC) in the ionosphere can be easily estimated from the combination of the Global Positioning System (GPS) data. The derived TEC data by GPS measurements have an uncertainty because each GPS satellite transmitter and receiver hardware have associated biases that seriously affect the accuracy of the ionospheric TEC estimates [1,6].

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In general, GPS TEC is calculated with the so-called geometry-free linear combination of two frequencies (L1–L2). Hardware biases usually remain in the ionosphere TEC after subtracting measurements at different frequencies. These differences in the hardware biases of GPS code measurements are called differential code biases (DCBs) [8,9]. In other words, the differential code bias (DCB) is the differential hardware (e.g., the satellite or receiver) delay that occurs between two different observations obtained at the same or two different frequencies. The characteristics of the hardware delay are mainly related to the performances of corresponding instruments, and their values are different for each observation and each frequency. The DCB is actually treated in a relative sense, where the hardware delay of a given observation is used as the standard. DCB can be classified into two categories: the inter-frequency bias, which is the bias between observations at two different frequencies; and the intra-frequency bias, which is the bias between two observations at the same frequency [7].

The magnitude of the combined satellite and receiver DCBs can reach up to several nanoseconds (ns), one ns corresponds to approximately 30 cm in range units. To improve the accuracy of TEC estimates, it is necessary to precisely estimate GPS satellite and receiver DCBs. Usually, DCBs are estimated together with the ionosphere model; thus, there exists a high correlation between the estimated DCBs and the selected ionosphere model. According to Wilson and Mannucci [13], the TEC, when estimated from GPS measurements, may result in errors from ±3 ns to ±10 ns. One approach for receiver DCB estimation is suggested by determination of the receiver DCBs using a regional GPS network. However, one of the receiver DCBs needs to be set to an arbitrary reference value in order to avoid singularities in the parameter estimation process. Another approach is to estimate DCB for a single receiver at the zero difference level.

In this study, receiver DCB of an Egyptian Permanent GNSS Network (EPGN) is estimated using the single receiver approach. Data of about 36 days spanning a year are used. The variation of DCB with site and time is estimated to check the temporal and spatial DCB variation. The results indicate that DCB changes with time and site. The range of change is about −11 to −22 ns in the south part of Egypt, while in the north DCB values are about −9 to −16 ns.

2. Data

The used data were collected from a chosen part of EPGN. This part of EPGN is composed of nine dual frequency GPS receivers. The locations of these receivers are shown in Fig. 1. Table 1 shows the Cartesian coordinates of the nine stations. The network covers an area of about 947 km by 484 km in latitude and longitude approximately. Data are collected using two different Trimble model receivers, namely Trimble 5700 and Trimble NETR5. Both receivers provide non-correlated C1 and P2 observation data types. The data used were collected over a whole year, where every month was represented by three days. This makes thirty-six (36) days of data for the whole year. The original data were in Receiver Independent Exchange format (RINEX) format with one second sampling rate. These data were decimated to 30 s sampling rate before processing to reduce the number of equations. The elevation cut-off angle of 10° was used for the collected data. The precise ephemeris (SP3) and ionospheric models are taken from IGS.

3. Data analysis

The DCB of a GPS receiver varies depending on the properties of the receiver and the observation type. Thus, for precise applications in geodesy and surveying, distinct DCBs for the various C1/P2 receivers should be derived from actual observations. As it is shown in Fig. 1, the data from the local nine GPS reference stations of EPGN were used for the calculation and analysis of the DCB over Egypt.

DCB is generally estimated once a day because space weather can affect DCB results and the daily variation of the receiver DCB is relatively stable. In this study, the receiver DCB values are estimated using the weighted Least Square Adjustment (LSA) and determined as daily value. The daily averages are obtained by taking the overall mean of the daily receiver DCBs over one day. The processing main steps are summarized as a block diagram in Fig 2. Starting with the Rinex files, the algorithm calculates the L4 and P4 linear combination. Also, receiver position is calculated. The P4 is then smoothed before LSA. Sp3 ephemeris is used to estimate the satellite positions. Receiver and satellite positions are then used to calculate the ionosphere pierce point (IPP). IPP and smoothed P4 are used in the LSA to estimate the DCBs.

3.1. DCB algorithm description

The software was developed in MATLAB by Jin et al. [3] and revised and updated by Sedeek et al. [11]. GPS RINEX observation files and precise ephemeris are the input data. Rinex files used here have C1 and P2 data. The outputs are the DCB estimates of the satellites and receivers. The revised software package can estimate the DCB for a single station or for multiple stations. For a single station, usually not all the GPS satellites are available in one GPS receiver view. It is not convenient to use the constraint condition for such a case. IONEX files are used to confirm our estimate using the same constraint conditions. The DCBs of satellites without observations are set as known parameters.

3.2. GNSS observations and pre-processing

GNSS observations include carrier phase and pseudorange observations stored in RINEX format. The GPS observation equations for pseudorange and carrier phase observables can be stated as follows (e.g. [4]):

$$P^i_{k,j} = \rho^i_j + d^i_{ion,k,j} + d^i_{trop,j} + c(\tau^i - \tau_j) + d^i_k + d_{k,j} + \varepsilon^i_{p,k,j} \tag{1}$$

$$L^i_{k,j} = \rho^i_j - d^i_{ion,k,j} + d^i_{trop,j} + c(\tau^i - \tau_j) - \lambda(b^i_{k,j} + N^i_{k,j}) + \varepsilon^i_{L,k,j} \tag{2}$$

where P is the GPS pseudorange measurement, L is the GPS carrier phase measurement, ρ is true distance between the GPS receiver (j) and satellite (i), d_{ion} is ionosphere delay, d_{trop} is troposphere delay, c is speed of light in a vacuum, τ^i is the satellite clock error, τ_j is the receiver clock error, the remaining d are the code delays for the satellite and receiver instrument biases, b is the phase advance of the satellite and receiver instrument biases, N is the ambiguity of the carrier phase, and ε are the residuals in the GPS measurements. Here, the subscript k ($=1, 2$) stands for the frequency, the superscript