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Ionospheric Mapping in Indian Region and Differential Code Bias Estimation from NaVIC Observations

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Abstract

IGS (International GNSS Services) provides the Differential Code Bias (DCB) of different navigation system like GPS, GLONASS and other. Currently the knowledge of NaVIC DCB is not available due to the limited number of Reference station. During the initial phase of NaVIC a method was explored where the DCB of NaVIC satellites was computed using Global Ionosphere Map (GIM). In this paper we have presented a method to model the Vertical total Electron Content (VTEC) in Indian region along with the DCB of NaVIC satellites and Ground receiver. We have processed the data of six reference station, distributed in Indian region, and computed the VTEC and DCBs using Spherical Harmonic Function.

1 Introduction

NaVIC (Navigation with Indian Constellation) is an independent satellite based regional navigation system, developed by India, with an aim to provide accurate positioning and timing service to users in India as well as 1500 km away from its boundary. NaVIC is a constellation of seven satellites which includes 3 GSO (Geosynchronous orbit) and 4 IGSO (Inclined Geosynchronous orbit) satellites [3].

NaVIC provides navigation services in L5 (1176.45 MHz) and S band (2492.028 MHz). The measurements at these frequencies are affected by systematic bias, due to signal processing unit at satellite and receiver end. Bias in code and carrier measurements depend on the carrier frequency and signal modulation and bias between two codes at same or different frequency is known Differential Code Bias [6].

There are Ionospheric Associated Analysis centers (IAAC), started by International GNSS services (IGS) with the aim of providing DCB of GNSS satellites along with the Ionospheric Map in a same format called IONospheric Map Exchange (IONEX) [4]. Currently centers like Center for orbit Determination in Europe (CODE), Jet Propulsion Laboratory (JPL), European Space Agency (ESA), Technical university of Catalonia (UPC) and Chinese Academy of Science (CAS), are involved in estimating DCB of GNSS satellites along with Global Ionospheric Map (GIM). They take the observations of more than 200 reference stations, and processes together for DCB estimation. These analysis centers are using different approaches for generating GIM.

The DCB of any constellation can be either estimated along with Ionospheric modeling or estimated by supplying precise Ionospheric delay in the line of sight of receiver and satellite [1,2]. During the earlier phase of NaVIC constellation a method was purposed where the DCB of NaVIC constellation was estimated using Precise Ionospheric corrections supplied by Global Ionospheric Map of IGS [1].

In this paper we have estimated the DCB of NaVIC satellite along with Local Ionospheric mapping in Indian region. The approach used for estimation is spherical harmonic function. The observations of six NaVIC reference receivers were taken for five days and Ionospheric VTEC in Indian region is modeled by Spherical Harmonic function of order and degree of four.

In order to assess the quality of estimated DCBs, it is compared with the DCBs, estimated using GIM based method, and DCB of receivers is compared with the absolute Group delay of the receiver. Estimated VTEC at different Ionospheric Pierce Point (IPP) is compared with VTEC obtained from IGS, and found the close agreement among them.

2 Estimation Theory

NaVIC receiver provides the code and carrier phase measurements in L5 and S Band. The pseudoranges and carrier phase observations may be written as follows:

$$P_{L5} = P_o + \frac{I}{f_{L5}^2} + T + c(\partial t_r - \partial t^s) + D_{L5}^r + D_{L5}^s + \varepsilon_p^{L5} \quad (1)$$

$$P_S = P_o + \frac{I}{f_S^2} + T + c(\partial t_r - \partial t^s) + D_S^r + D_S^s + \varepsilon_p^S \quad (2)$$

$$L_{L5} = P_o - \frac{I}{f_{L5}^2} + T + c(\partial t_r - \partial t^s) + \lambda_{L5}(N_{L5} + \alpha_{L5}^r + \alpha_{L5}^s) + \varepsilon_{\emptyset}^{L5} \quad (3)$$

$$L_S = P_o - \frac{I}{f_S^2} + T + c(\partial t_r - \partial t^s) + \lambda_S(N_S + \alpha_S^r + \alpha_S^s) + \varepsilon_{\emptyset}^{S} \quad (4)$$

Here L5 and S is NaVIC frequency band. P is NaVIC pseudorange measurement, L is NaVIC carrier phase measurements, Po is a geometric range between receiver and satellite, and 'I' stands for Ionospheric delay. T is tropospheric delay, ∂t_r is receiver clock bias, ∂t^s is satellite clock bias, D^r is code delay in receiver, D^s is code delay in satellite, N is the ambiguity of carrier phase, α^r and α^s are phase delay because of satellite and receiver hardware, ε stands for receiver and multipath noise. 'f' represents the carrier phase frequency. The Geometry free combination of pseudorange measurement may be computed as follows,

$$P_4 = P_{L5} - P_S = I\left({}^{1}/_{f_{L5}^2} - {}^{1}/_{f_S^2}\right) + DCBSat + DCBRx \quad (5)$$

$$L_4 = L_{L5} - L_S = -I\left({}^{1}/_{f_{L5}^2} - {}^{1}/_{f_S^2}\right) + (\lambda_{L5}N_{L5} - \lambda_S N_S) + (\lambda_{L5}\alpha_{L5}^r - \lambda_S\alpha_S^r) + (\lambda_{L5}\alpha_{L5}^s - \lambda_S\alpha_S^s) \quad (6)$$

Where DCBSat $= D_{L5}^s - D_S^s$ and DCBRx $= D_{L5}^r - D_S^r$ are the differential code biases of satellite and receiver. 'I' Ionospheric Delay can be represented by using the first order of Ionospheric term as follows:

$$I = \frac{40.3}{f^2} STEC \quad (7)$$

As the difference of pseudorange is noisier than difference of carrier phase measurement, so carrier measurement is used to smooth the code phase measurement using Hatch filter [1,2], but before that the cycle slip in the measurements were detected using Melbourne-Wubeena combination [7]. So after cycle slip detection and smoothening the geometry free equation (5) can be written as follows:

$$P_{4sm} = 40.3\left({}^{1}/_{f_{L5}^2} - {}^{1}/_{f_S^2}\right) STEC + DCBSat + DCBRx \quad (8)$$

STEC can be translated into VTEC using a Mapping function (MF) designed using Modified Single Layer Model (MSLM). VTEC is represented using a Spherical Harmonic Function described as follows:

$$VTEC = \sum_{n=0}^{N}\sum_{m=0}^{n} P_{nm}(\sin(\beta))(\alpha_{nm}\cos ms + b_{nm}\sin ms) \quad (9)$$

$$\text{and } MF = \cos\left(\sin^{-1}\left(\frac{R}{R+H}\sin(\alpha z)\right)\right) \quad (10)$$

Here β and s are the latitude and longitude of IPPs in solar geomagnetic reference frame P_{nm} is normalized Legendre polynomial function with the degree n and order m. N represents the order of SH function, chosen 4 for the current processing. α_{nm} and $b_{nm}$are the coefficient of SH function, R is radius of earth, H is height of Ionospheric layer (=450km) and z is zenith angle. Now combining equation (8), (9), and (10) a normal equation may be written as:

$$\sum_{n=0}^{N}\sum_{m=0}^{n} P_{nm}(\sin(\beta))(\alpha_{nm}\cos ms + b_{nm}\sin ms) = \cos\left(\sin^{-1}\left(\frac{R}{R+H}\sin(z)\right)\right)\left[-\frac{f_{L5}^2 f_S^2}{40.3(f_{L5}^2 - f_S^2)}(P_{4sm} - DCBSat - DCBRx)\right] \quad (11)$$

Here α_{nm} and b_{nm} and DCBSat and DCBRx are unknown parameters. Number of Coefficient α_{nm} and b_{nm} depends on the order of SH function. Satellites and receiver DCB is assumed constant over a day and coefficients are computed for every two hours. Equation (11) is processed using Least Square Estimation Technique. For the order of 4, 300 coefficients representing VTEC for a day along with DCB of 7 satellites and six receivers were estimated.

3 Step of Processing

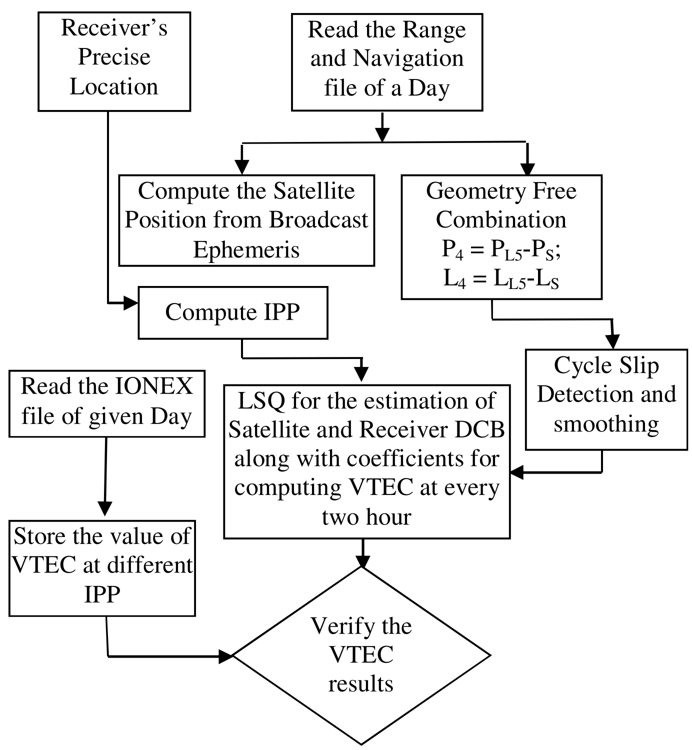


Figure 1. Steps of Processing

Range and navigation data was extracted from the receiver of reference station located at Bangalore, Port Blair, Shillong, Lucknow, Bhopal, and Jodhpur, and processed together for five days. Estimated VTEC at different IPP was compared with IGS published GIM **(ftp://cddis.gsfc.nasa.gov/gnss/products/ionex/)**.

4 Results and Discussion

The observation from all reference station were processed together to estimate DCB and VTEC in Indian region. Due to limited number of satellites and small variation in the IPP over a day (especially for GSO satellite at 5 Deg inclination), single station observations does not provides stable results while estimating the DCB and VTEC using SH function [1], so multiple station observation were taken for processing. Processing was implemented in MATLAB using the observations of Reference station located at Bangalore, Port Blair, Shillong, Lucknow, Bhopal, and Jodhpur for DOY 03 to 07 of year 2020. In order to separate the DCB of receiver and satellite, it is assumed that the sum of DCB of satellites in constellation is equal to zero. Figure 2 and 3 shows the DCB of NaVIC satellites and receiver separated by imposing the zero mean condition.

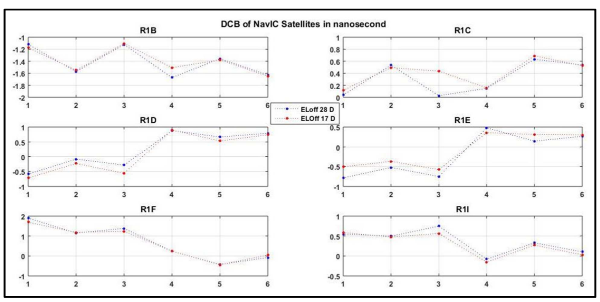


Figure 2. DCB of NaVIC satellites

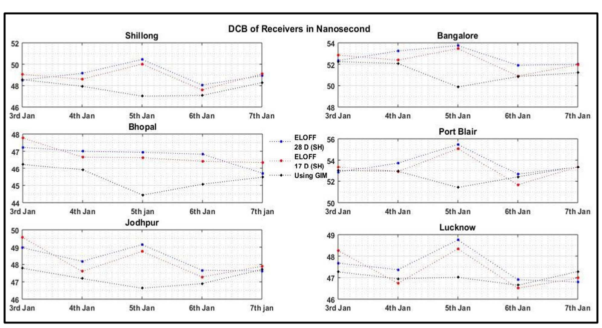


Figure 3. DCB of NaVIC Reference Receivers

Estimation was done for two different elevation cutoffs. Higher elevation cutoff is recommended to avoid the multipath and terrestrial noise. However higher elevation cutoff reduces the number of measurements and affects the estimation accuracy. We have processed the observation with elevation cutoff of 28 degree and 17 degree and results are shown in figures. In figure 3, the receiver DCB is compared with the DCB computed using GIM based method (where precise Ionospheric corrections were supplied using GIM products). GIM results show better stability to SH based estimates. Here DCB is computed for 6 satellites only, as one of satellite '1G' is in 'Alert' Mode. Figure 4 shows 'Satellite+Receiver' bias of NaVIC constellation for Jodhpur Station.

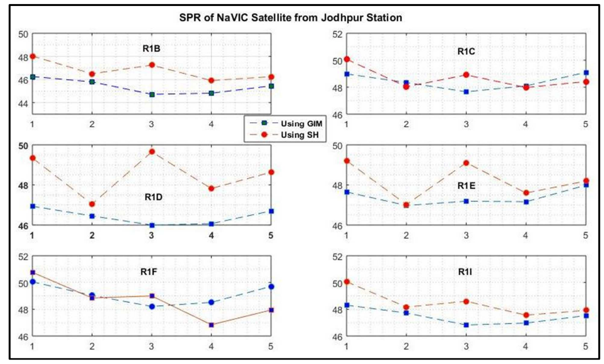


Figure 4. Comparison of Satellite plus Receiver Bias using GIM and SH function Method

The Standard deviation (SD) of 'Satellite plus Receiver' (SPR) Bias using GIM based method and with Spherical harmonic function for five days is as follows.

Table 1. Comparison of GIM and SH method

Satellite ID	SD of SPR using GIM based Method	SD of SPR using SH function
R1B	0.6505	0.8518
R1C	0.6060	0.8617
R1D	0.4025	1.0774
R1E	0.4136	0.9466
R1F	0.7765	1.4471
R1G	-	-
R1I	0.6002	0.9688

DCB, estimated using GIM based method are more stable than using Spherical harmonics and the probable reason of that is, as the data during the peak hour is avoided for the estimation of DCB. The stability and accuracy of the DCB, using spherical harmonic function based method can be improved with adding more reference station.

DCB is computed in relative sense as 'zero mean condition' is used on satellites DCB to separate the bias of satellites and receiver [1,2]. As estimation is done using the observations of all six station, so constant difference is expected between estimated DCB and absolute DCB. The computed DCB for each receiver for five days was compared with the absolute bias (between two codes) and the constant difference was observed for all stations (within ±1ns). Figure 5 shows the difference between absolute and estimated differential code bias.

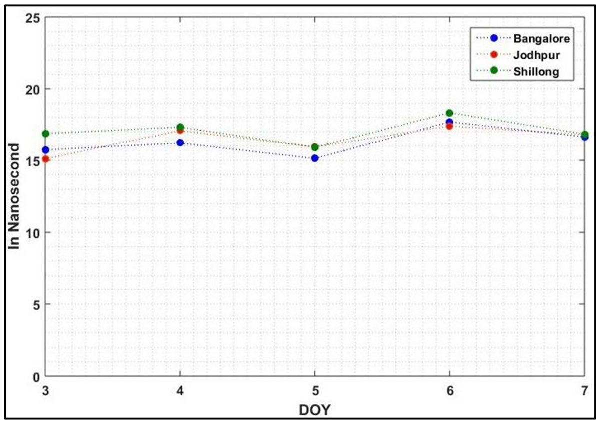
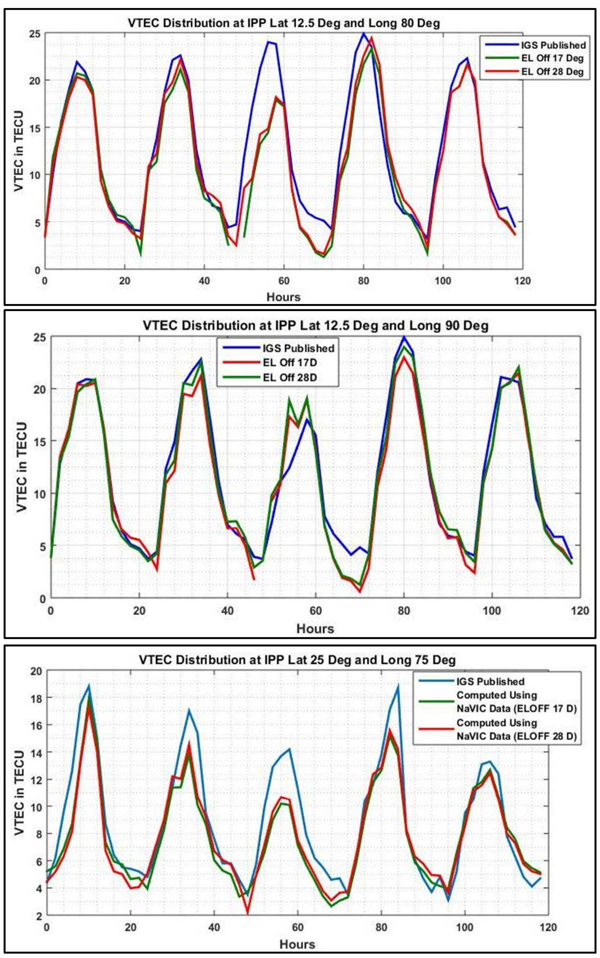


Figure 5. Difference of Absolute and Estimated DCB

We have estimated the coefficients of Spherical harmonic function, representing the Ionospheric distribution in Indian region, for two hour of interval. Computed VTEC at different Ionospheric Pierce Point (IPP) at the height of 450 km is compared with the VTEC published by IGS at same location and found the close agreement. Figure 6 shows the VTEC Distribution at different IPP estimated for five days from DOY 3-7.



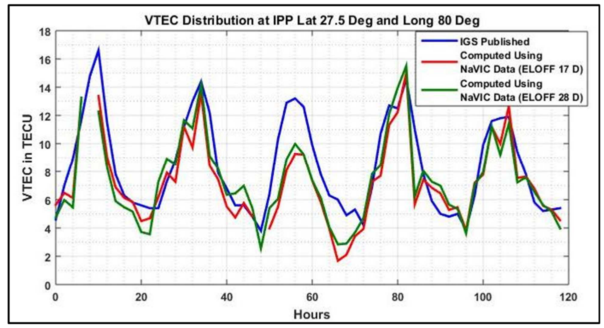


Figure 6. Estimated VTEC Distribution at Different IPP

VTEC estimated using SH method is closely matching with VTEC published by IGS. However estimation accuracy depends upon the availability of Data and further the number of satellite in constellation and order of SH function.

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6 References

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