Monitoring the Ionospheric Vertical Total Electron Content Variations over the Low Latitude Region using GPS

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Abstract

In Modern radio systems such as global positioning system (GPS), in which accuracy is based on Time of Arrival (TOA) of the signal, the propagation of the signal through atmospheric layers causes a delay in the arrival of the signal at the receiver. In order to access the accuracy of the system, it is required to estimate the delay of the signal in predominant atmospheric layers i.e. ionosphere and troposphere. As the delay of the signal in troposphere is independent of frequency, it is required to compute the delay of the signal in ionosphere which is frequency dependent and is function of in total electron content (TEC) in the ionosphere. The aim of this paper is to compute TEC in the line of sight of the satellite and the receiver and to estimate the vertical TEC, which is useful to image the ionosphere over low latitude region like India. The data provided by Scripps Orbit Permanent Array Center (SOPAC) for an IGS station NGRI, Hyderabad located in India at Lat/Long: 17°24'39"N/78°33'4"E for 11th September 2014 is collected and processed by using Convert software tool . In this paper, VTEC is computed using different mapping functions to investigate the suitable mapping function over the low latitude regions.

Keywords: Ionosphere**,** Total Electron Content, mapping function.

1. Introduction

As Global Positioning System is based on TOA, ionosphere is a greatest source of error in precise time transfer of the signal at the receiver. Ionosphere is predominant region of the terrestrial atmosphere, in which plasma is created due to photo-ionization which significantly influences the dynamics of the region. The study of ionosphere is vital as the temporal (with time of the day, seasons, solar cycle etc.) and spatial (with the latitude and longitude on the earth) variations of ionosphere have significant effect on radio waves propagating through it.

GPS signal experiences group delay and phase advance as it interacts with free electrons along its transmission path. The number of free electrons in a rectangular solid with a one square meter cross section extending from the receiver to the satellite is

expressed as TEC and is given by

$$TEC = \int_{path} Ne(s)ds \quad \ldots\ldots\ldots \tag{1}$$

Where, N_e (s) is the electron content per unit volume and path is the propagation path between the GPS satellite and the GPS receiver.

The factors that affect the TEC are local time, geomagnetic and geographic coordinates and solar cycle. Knowledge of elevation and azimuth of the satellite, station position sunspot activity are required to determine TEC.

TEC is classified as slant TEC (TECs) and vertical TEC (TECv). Slant TEC is a measure of the total electron content of the ionosphere along the ray path from the receiver to satellite, which is a function of elevation angle of the satellite. Vertical TEC (TECv) enables total electron content to be mapped across the surface of the earth and is dependent on mapping function.

2. Mapping function

The mapping function (MF) is the ratio of the electrical path length (i.e. line of sight path length) through the atmosphere at a geometric elevation, *e*, to the electrical path length in the zenith direction. It could be expressed as 1/sin*(e)* for a planar atmosphere. The atmosphere appears more planar, if the ratio of the thickness of atmosphere to the radius of earth decreases.

In order to image the ionosphere, it is required to convert the TEC in the direction of ray path (TECs) into vertical total electron content (TECv) with an assumption that electrons concentrate in a layer in ionosphere and the height of this layer is called shell height or effective ionospheric height.

The TECs in the line of sight of satellite and the receiver can be converted to an equivalent vertical TEC (TECv) using the mapping function MF, which, is given as:

$$TEC_v = TEC_S / MF \quad \ldots\ldots\ldots \tag{2}$$

Based on the pseudo range measurements on both frequencies, f1 = 1575.42 MHz and f2 = 1227.60 MHz, TECs can be computed using

$$TEC = \frac{1}{40.3}\left[\frac{1}{f_1^{\,2}} - \frac{1}{f_2^{\,2}}\right]^{-1} \left|(pr_1 - pr_2)\right| \quad \ldots\ldots \tag{3}$$

pr1 and pr2 are pseudo range measurements on L1 and L2 frequencies.

In this paper, single layer model (SLM) mapping function and modified single layer model (MSLM) mapping function for GPS observations are investigated and are compared with IRI-2012 model, which is a web based empirical model.

2.1 Single-Layer Model SLM (thin) Mapping Function

The single-layer model (SLM) is the most commonly used thin ionospheric mapping function, which is elevation angle-dependent. The precision of this mapping function is critical with an elevation cut-off of 20^o. The global effective ionosphere height is 450 km, but variations can be stated, predominantly in the North-South direction.

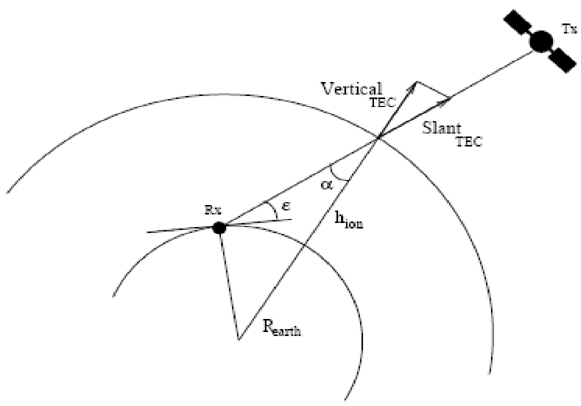

Fig. 1. Geometry of Single layer model (SLM) with (Rx) receiver and (Tx) transmitter.

The SLM mapping function F_{SLM} can be defined as:

$$F_{SLM} = \frac{1}{(1 - ((R\cos(E)/(R+h))^2)^{1/2}} \tag{4}$$

Where E is the elevation angle which can be calculated from a known satellite position and approximate coordinates of the receiver location, h is the height corresponding to the maximum electron density in ionosphere and its altitude is about 350 to 500 km for low latitudes and R the mean Earth radius (6371km). Typical value of h is set to 350Km.

2.2 Modified SLM (MSLM) Mapping function

The mapping function used in IGS Global TEC maps is modified SLM (MSLM), which is a more precise mapping function. The modified single layer model (MSLM) mapping function is defined as;

$$F_{MSLM} = \frac{1}{(1 - ((R\cos(\alpha E)/(R+h))^2)^{1/2}} \quad (5)$$

It is very clear that the difference between SLM and MSLM is only 'α', which is a heuristic factor. With MSLM, best results can be is achieved with $\alpha = 0.9782$ and $R = 6371$ km .

2.3 IRI-2012-Model

The IRI (International Reference Ionosphere) is an empirical model of the ionosphere developed by the COSPAR (Committee on Space Research) and the URSI (International Union of Radio Science). The model gives spatial and temporal information of ionospheric parameters such as TEC, electron content etc. While computing the TEC values, the IRI model provides users to select from the three available topside options which are Ne-Quick, the IRI01-cor, and the IRI2001

3. Results and Discussions

The dual frequency receiver data is taken from one of the IGS station ie. for NGRI, Hyderabad from SOPAC for 11th September 2014 . The results are obtained from the collected data.

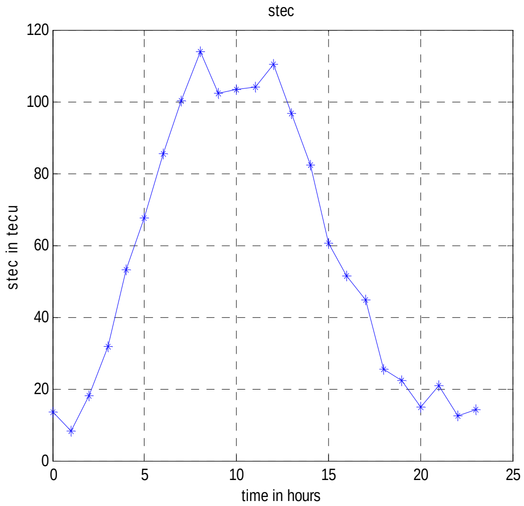

Fig 2: STEC versus time plot

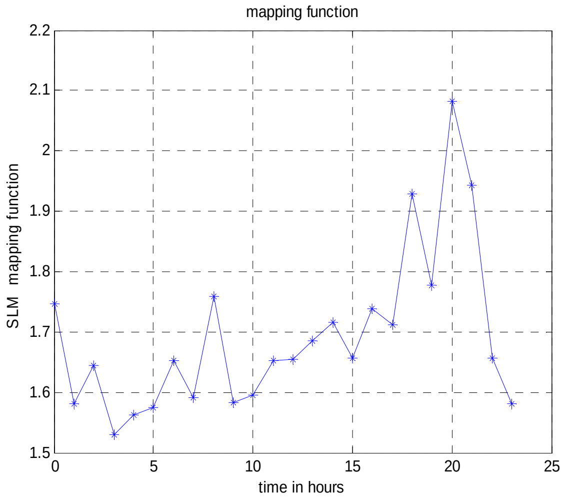

Fig 3: Mapping function versus time in hours plot using SLM Mapping Function

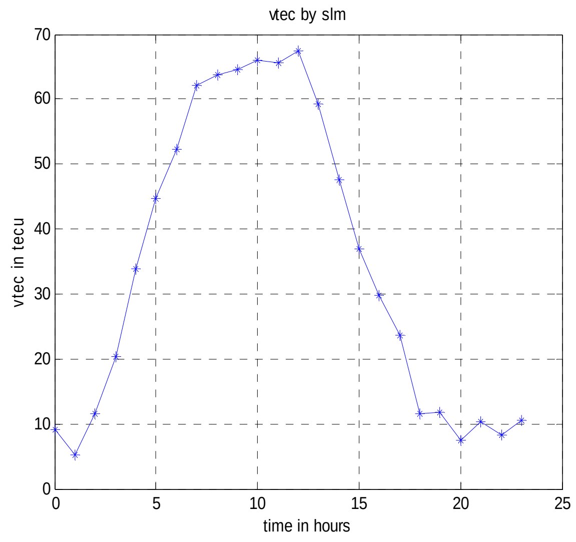

Fig 4: VTEC plot by SLM Mapping function

Fig 2 shows variation of STEC as function of time in hour's computed using pseudo range values showing the highest STEC of 113.8306 TECU.

Fig 3 shows mapping function versus time in hours plot using SLM mapping Function The highest mapping function value is 2.0817 is obtained at 350km.

Fig 4 shows VTEC versus time in hours plot using SLM mapping Function the highest VTEC value is 67.3593 TECU.

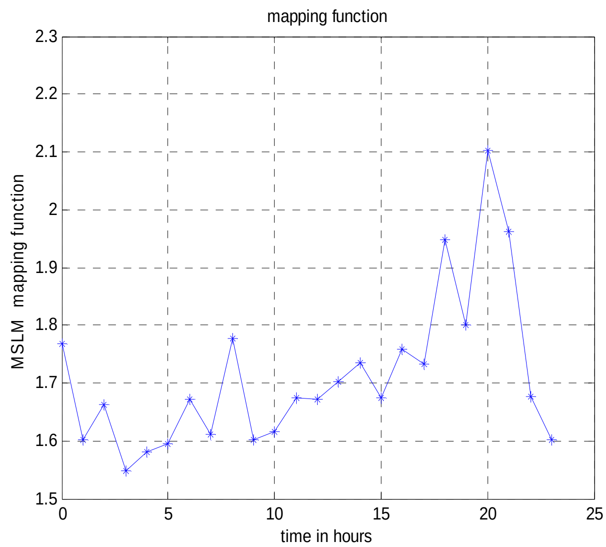

Fig 5: Mapping function versus time in hours plot using MSLM Mapping Function

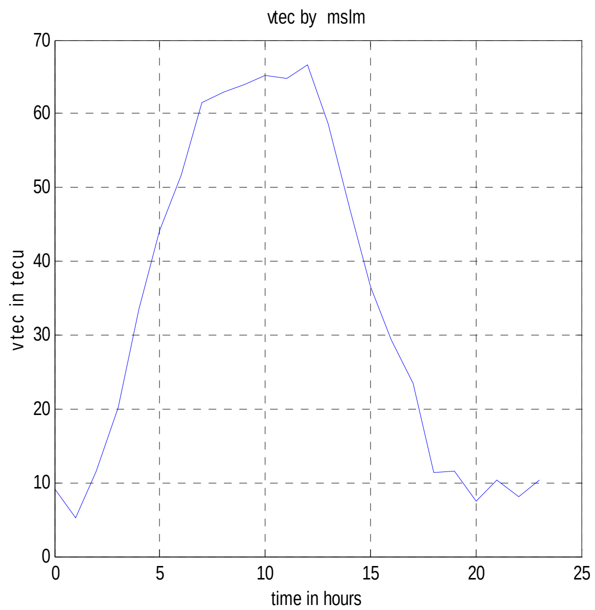

Fig 6: VTEC plot by MSLM Mapping function

Fig 5 shows mapping function versus time in hours plot using MSLM mapping Function The highest mapping function value is 2.1017 is obtained at 350km.

Fig 6 shows VTEC versus time in hours plot using MSLM mapping the highest VTEC value is 66.6065 TECU.

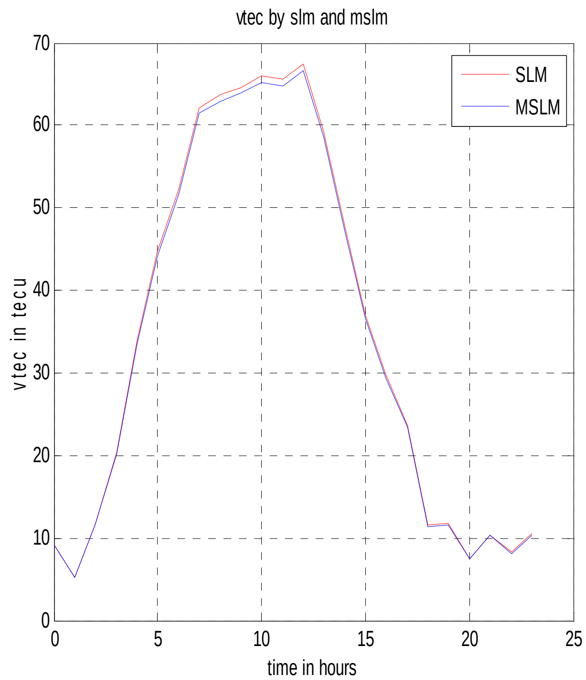

Fig. 7 Comparison of VTEC as function of time in hours using SLM and MSLM mapping function

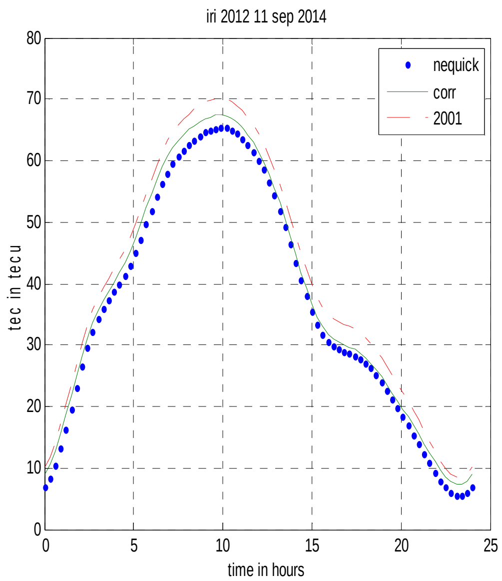

Fig 8: VTEC plot using IRI -2012 by using NeQuick , IRI-2001 and IRI-CORR Model at 350 km

Fig. 7 compares VTEC values using SLM and MSLM which shows VTEC of SLM is more than MSLM.

Fig 8 shows VTEC plot using IRI -2012 by NeQuick Model, IRI-01 corr Model and IRI-2001 at 350 km. Showing highest VTEC of 65.40 TECU by NeQuick Model , 67.40 TECU by IRI-01 corr Model and 71.1 TECU by IRI-2001 Model.

Table 1: Maximum mapping function values and VTEC values of SLM and MSLM

Altitude (km)	SLM		MSLM	
	Max. mapping value	VTEC IN TECU	Max. mapping value	VTEC IN TECU
350	2.0817	67.3593	2.1017	66.6065

Table 2: Comparison of maximum VTEC for SLM & MSLM mapping function values with IRI-2012 at 350 km .

Altitude (km)	SLM	MSLM	IRI 2012 (VTEC IN TECU)		
	(VTEC IN TECU)	(VTEC IN TECU)	NeQuick	IRI01-corr	IRI-2001
350	67.3593	66.6065	65.40	67.40	71.1

4. Conclusion

This paper describes about SLM and MSLM mapping function to calculate the total electron content of the ionosphere from GPS measurements. The suitable mapping function is used to get a good vertical TEC estimation. The parameter that most influences the mapping function is height over the Earth's surface.

The simple mapping function for the ground based TEC conversion is a single layer model (SLM). Based on the SLM, a modified single-layer model mapping function by the JPL extended slab model mapping function is applied in the CODE Global TEC map.

The VTEC computation is done using SLM and MSLM mapping functions and the results are validated using IRI -2012 for 11 September 2014.

From this it is concluded that mapping function value of MSLM is more than SLM and therefore VTEC of SLM is more than MSLM.

References

[1] Latitudinal characteristics of GPS derived ionospheric TEC: A comparative study with IRI 2012 model Monti Chakraborty1, Sanjay Kumar2, Barin Kumar De1, Anirban Guha1, ANNALS OF GEOPHYSICS, 57, 5, 2014, A0539; doi:10.4401/ag-6438.

[2] Wyllie, S. J., Zhang, K. F., and Talbot, N. C.(July 2003). A Comparison of Ionospheric Models for Precise Positioning in Victoria.

[3] The Scripps Orbit and Permanent Array Center.http://sopac.ucsd.edu/dataArchive.

[4] Kaplan, E. D., ed., 'Understanding GPS Principles and Applications', 1996

[5] Spilker JJ, Parkinson BW 'Global positioning system: theory and applications', vol 1. AIAA, pages 485–515.

[6] G.S.Rao, 'Global Navigation Satellite Systems', Tata McGraw Hill publications, 2010.

[7] D. Bilitza (ed.), "International Reference Ionosphere 1990", NSSDC 90-22, Greenbelt, Maryland, 1990.

[8] K. Durga Rao, Dr. V B S Srilatha Indira Dutt Estimation of ionospheric delay for single and dual frequency GPS receivers: A comparision , International journal of system and technologies ISSN 0974-2107 Vol 6, Issue 1, 2013, pp 30-37

[9] Mannucci, A., Wilson, B. D., Yuan, D. N., Ho (1998). A global mapping technique for GPS-derived ionospheric total electron content measurements. Radio Science.

[10] D. Bilitza, K. Rawer, and S. Pallaschke [1988], "Study Of Ionospheric Models For Satellite Orbit Determination," Radio Science

[11] V B S Srilatha Indira Dutt and Prof. G Sasibhushana Rao"Imaging of Ionospheric Electron Density Profile using Modified Spherical Harmonic Analysis", International Journal of Advanced Engineering Sciences and Technologies, ISSN-2230-7818,Vol.7,Issue.2,pp 319-322.

[12] V B S Srilatha Indira Dutt "Ionospheric Delay estimation Using Klobuchar Algorithm for single frequency GPS recivers‟, International Journal of Advanced Research in Electronics and Communications Engineering,, ISSN-2278-909X,Vol.2,Issue.2,pp 202-207.