Validation of TEC Derived from CRABEX Receiver with GPS Data at a Low Latitude Station

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ABSTRACT

Ionospheric Tomography is an established technique for imaging of the electron density over a particular geographical region of interest. In this technique, data from a network of stations can be used to study the equatorial anomaly, equatorial electrojet, equatorial bubbles and Traveling Ionospheric Disturbance (TID) effects. CRABEX receiver measures the differential Doppler phase and amplitudes of 150 and 400 MHz signals from Navy Navigational Satellite Systems (NNSS) satellites and is also known as Naval Ionospheric Measuring System (NIMS). For typical days vertical TEC due to NNSS and GPS satellite signals are calculated at the IPPs. It is observed that both TEC measurements are agreeing well with each other. The results are found to be useful for validating the ionospheric tomography techniques.

INTRODUCTION

The total electron content (TEC) is one of the most important parameters used in the investigation of the ionospheric effects on Communication, Navigation, and Surveillance systems. It is defined as the total number of electrons in a column with a cross sectional area of $1m^2$ along the ray path. Space Physics Laboratory (SPL) of Vikram Sarabhai Space Centre (VSSC), Trivandrum has identified a network of 12 stations to carryout ionospheric tomography studies. As a part of this, a Coherent Radio Beacon experiment (CRABEX) receiver is located at Research and Training Unit for Navigational Electronics (NERTU), Hyderabad (78.5^0 E, 17.4^0 N). These experimental studies will help in understanding the temporal and spatial evolution of equatorial and low-latitude ionospheric phenomena, Equatorial Ionization Anomaly (EIA) and Equatorial Spread F (ESF)[1]. Noting that TEC estimation depends on the measured phase difference and initial phase offset of two coherent signals, differential Doppler measurements of signals form NNSS satellites can be used to estimate the TEC of the ionosphere. The phase offset can be evaluated by either single or two-station procedure. The general criteria of these procedures are reported by Lietinger et.al [2]. For the polar orbiting satellites, receiving stations located in low to mid latitudes the geographic longitude of ionospheric points remains nearly constant and the corresponding differential Doppler measurements can be considered to reveal the latitude dependence of ionospheric electron content [3]. The procedure for comparing TEC due to NNSS and GPS satellites is described by Ciraolo, et, al [4]. In this procedure, the TEC value at particular latitude of GPS station was interpolated from the latitudinal curve obtained from NNSS data. This NNSS TEC value was compared with TEC value, which is obtained from GPS data at the epoch of the closest approach instead of with the actual time of crossing the parallel of the GPS station. However, in this paper a different validation procedure is described. TEC measurements due to NNSS are compared to the nearest IPP of GPS satellite with in the spacing of 0.25^0.

NNSS TEC ESTIMATION

NNSS transmit phase-locked radio carrier waves at 150 and 400 MHz. The CRABEX receiver tracks these signals. The measured differential phase (d) is related to the Slant TEC (STEC) along any ray as [3],

$$d = k * STEC + \beta \qquad (1)$$

Where, $k=1.6132x10^{-15}m^2$

β =Phase offset in radians

STEC measurements (Oscar 31) acquired simultaneously from three stations namely Hyderabad , Banglore and Trivandrum on 10th March 2004 at 14.30 are presented in Fig.1. For all these stations, the minimum STEC observed around 14.34 Hrs. STEC is converted to vertical TEC by multiplying with mapping function at the Ionospheric Pierce Points (IPP). The

intersection of line of sight from receiver to satellite and the shell defined at a designated height of 350 km is known as an IPP.

$$VTEC = STEC \cos\chi \tag{2}$$

where χ is the angle between the ray path and the vertical at the IPP,

$$\chi = \arcsin\left(\frac{R_E \cos(el)}{R_E + h}\right) \tag{3}$$

Where, R_E = Radius of the Earth in Kms
el= Elevation angle of the NNSS satellite in degrees
h = Ionospheric mean height in Kms

The evaluation of the phase offset (β) is the crucial in the estimation of TEC. In this paper single station method is used for determining the phase offset. Single station procedure is based on the assumption of nearly linear dependence of VTEC with respect to time. The single station solution method sometimes results in ill-conditioned solutions. The two-station procedure provides reliable phase offset estimation by comparing vertical TEC from the same satellite in the overlapping arcs of two stations. However, in the present analysis, the single station method was used due to non availability of two stations data.

Using Eqs(1) and (2), VTEC with respect to time can be expressed as[4],

$$VTEC(\phi, t) = (d - \beta)\cos\chi \tag{4}$$

Where ϕ is the IPP latitude. For NNSS, ϕ is assumed to be varying linearly with time.

By taking the first difference of VTEC, we obtain

$$\Delta VTEC = \Delta(d\cos\chi) - \beta\Delta\cos\chi \tag{5}$$

β can be estimated by using the linear regression method from all possible $\Delta(d\cos\chi)$ and $\Delta\cos\chi$ values[4]. Once the offset is obtained, the VTEC can be evaluated by using Eq (4). Fig.2 shows the slant TEC estimated before and after removal of phase offset for Oscar31 satellite pass on 22nd December 2004 at 21.23 Hrs. From the figure it can be seen that the phase offset is 3 TECU.

GPS TEC ESTIMATION

Global Positioning System (GPS) is a satellite based navigation system developed by Department of Defence (DoD), USA and gives three dimensional user position, time and velocity at any time. The satellite constellation comprises 24 satellites, such that at least four satellites are visible anywhere on the Earth at any time. The orbits are essentially circular, at an altitude of about 20,200 km, with orbital inclinations of 55^0 and with 12 h (sidereal time) duration [5]. The positional accuracy is limited by several errors due to ionosphere, troposphere, multipath in the receive antenna environment, satellite transmit biases and receiver biases. Out of all these, ionospheric error is the most predominant one. It can be eliminated by dual frequency GPS receiver, which is a very powerful tool to estimate TEC using two coherent frequencies L1 (1575 MHz) and L2 (1227 MHz). A Dual frequency GPS receiver (Model No: AOA ICS 4000Z) also known as Ionospheric calibration system is located at NERTU. TEC can be estimated from GPS carrier phase and pseudo range measurements. However, in the present work, TEC results due to pseudo range measurements are considered. The data in Turbo Binary format is converted into CONAN ASCII format by Nconvert software. The data is sampled at an effective sampling rate of 60 seconds. From this sample data, required parameters such as GPS week, GPS sec, PRN number, elevation angle, azimuth angle and TEC are considered for the required analysis.

VALIDATION PROCEDURE

Data from GPS satellites is continuously available where as data due to NNSS satellites is limited to about 8 to 15 minutes for each satellite pass. The propagation path length of NNSS and GPS satellites are about 1100 Kms and 21,150 Kms respectively at zenith. For typical days, vertical TEC due to NNSS and GPS satellite signals are calculated at the IPPs. From these data, IPPs that fall within 0.25^0 of latitude simultaneously are identified. In this way, pairs of IPPs, one corresponding to CRABEX and the other corresponding to GPS are identified. The differences between the TEC measurements at these IPPs and their mean and standard deviation for each pass are estimated.

The data from Oscar32 and GPS SV No: 9 satellites, acquired on 20th January 2005 at 14.14 Hrs is used for the analysis. By using the validation procedure 139 pairs of TEC values at various IPPs are identified for comparison. Fig.3(a) shows the TEC measurements at the selected IPPs from both satellites. The maximum difference in TEC measurements is approximately 11 TECU. The mean and standard deviation of vertical TEC difference between these satellites are 7.67 and 2.59 TECU respectively. Fig.3 (b) also shows comparison of TEC measurements made by Oscar32 and GPS SV 5 satellites on 29th January 2005 at 13.30 Hrs. 609 pairs of TEC measurements at IPPs are identified from Oscar 32 and GPS SV 5. The maximum difference is 14 TECU and their mean and standard deviation are 4.67 and 3.17 TECU respectively. These results indicate that both TEC measurements are reasonably agreeing well with each other. The small deviation can be attributed due to difference in altitude of the satellites and the mapping function used in the conversion from slant to vertical TEC.

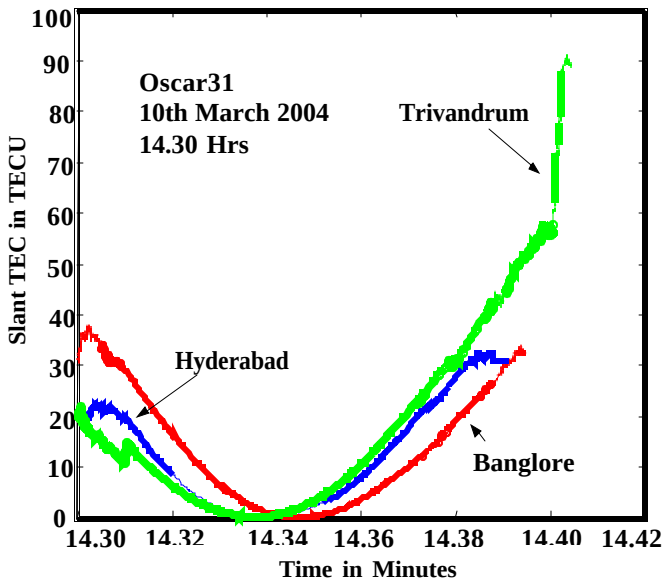


Fig.1 Simultaneous TEC observations from three different stations

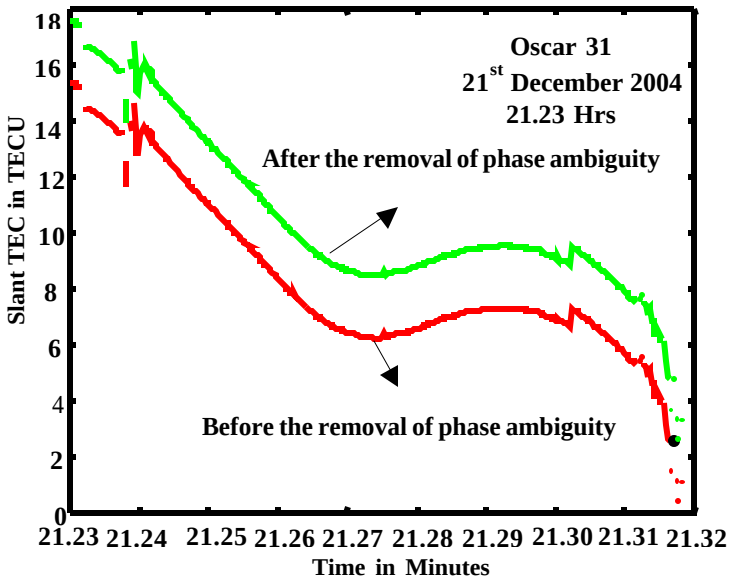
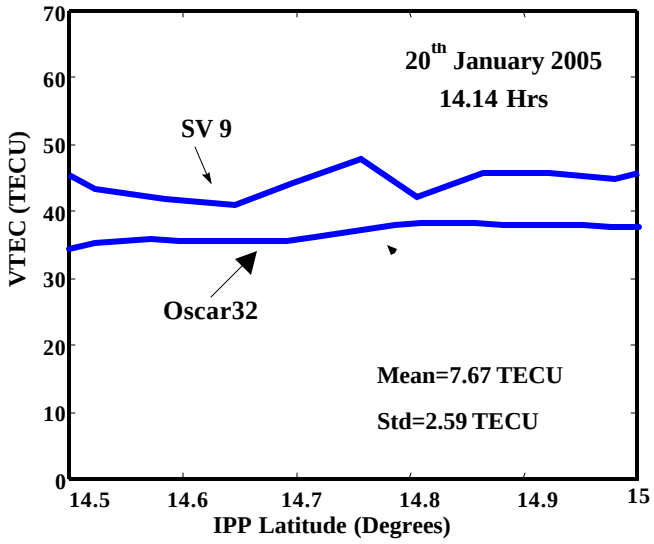
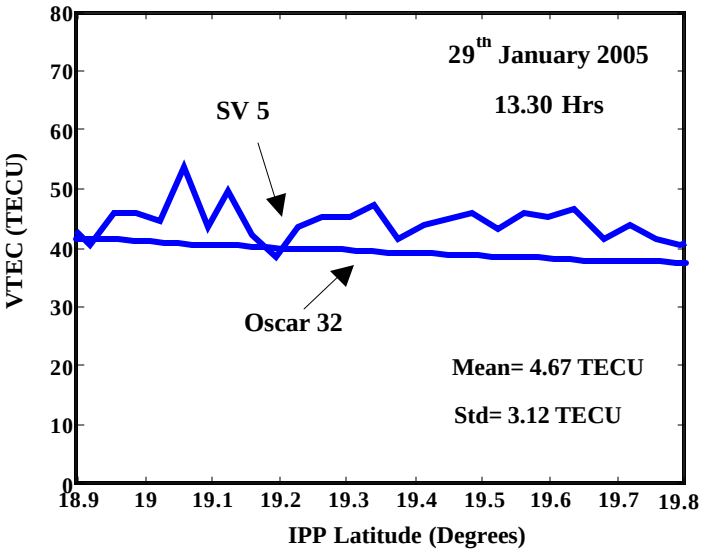


Fig2. Phase offset determination using single station method



(a)



(b)

Fig.3. Comparison TEC estimation due to NNSS and GPS signals

CONCLUSIONS

The results indicate that the TEC measurements due to NNSS satellites are closely following the GPS measurements. It is also evident from the results that the GPS TEC values are higher than CRABEX TEC values in the order of few TECUs, which could be due to longer propagation path of GPS signals in the ionosphere. The comparison of TEC estimation from the GPS and NNSS will be useful to solve the initial phase ambiguity problem of the CRABEX receiver and also to further validate the tomography technique. Analysis presented in this paper can be extended to other stations, for several seasons, which would be useful in improving the quality of Ionospheric tomograms over low latitude region such as India.

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