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Ionospheric Total Electron Content Estimation Using IRNSS L5 and S-Band Observations

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Abstract:

The Indian Regional Navigation Satellite System (IRNSS), now known as NavIC, is India's independent regional satellite navigation system designed to provide accurate positioning, navigation, and timing services over India and the surrounding region. The system operates at two frequencies, namely the L5 band (1176.45 MHz) and the S-band (2492.08 MHz). The present study introduces the basic features of the IRNSS system and presents the estimation of ionospheric Total Electron Content (TEC) using IRNSS observations. TEC is an important ionospheric parameter that affects the propagation of satellite navigation signals and plays a significant role in understanding ionospheric variability and its impact on navigation system performance. The estimation of TEC using dual-frequency IRNSS observations can therefore provide valuable information on ionospheric conditions and the influence of space-weather-induced disturbances on satellite navigation signals. The analysis is carried out using observations obtained from a low-latitude station located at Sangli (16°52′ N, 74°34′ E), India. The IRNSS-UR software is used for receiving and extracting the observational data. MATLAB-based programs have been developed for estimating TEC using data recorded in the RINEX 3 format. The results demonstrate the capability of IRNSS L5 and S-band observations for estimating ionospheric TEC and monitoring its temporal variations over the Indian low-latitude region.

Keywords: IRNSS system; TEC estimation, Estimation of Group delay and Phase Delay for IRNSS.

Introduction:

Indian Regional Navigational Satellite System (IRNSS) is India’s independent navigational system. Term Global Navigation Satellite System (GNSS) consists group of number of navigation systems innovated by various countries (Gattupalli et al., 2015). Different GNSS System operates on different frequency. Global Navigation System (GPS) is one of well-known navigation system which developed by United States Department of Defense. GPS comprises 32 MEOs and works with two frequencies L1 (1575.42 MHz) and L2 (1227 MHz). Global Navigation Satellite System (GLONASS) is a navigation system introduced by Russia which has 24 satellites. GLONASS operates on 1.602 GHz (SP) and 1.246 GHz (SP) Frequency. Europe has developed navigation system named as Galileo which has 30 MEO satellites and operates on 1.164–1.215 GHz (E5a and E5b). GPS, GLONASS and Galileo are fully operational navigation system.

Along with these navigation systems, there are some more systems which are in development state. Such GNSS systems are BeiDou by China with 30 MEOs and 5 GSOs operating on 1.561098 GHz (B1), 1.589742 GHz (B1-2), 1.20714 GHz (B2) and 1.26852 GHz (B3) frequency is in development state and that will be regional as well as global navigation system. Also, QZSS system which is regional navigation system is under development state by Japan. So, this is a present scenario all over world regarding with the GNSS system

IRNSS consist 7 satellites out of which 3 are GEO (Geostationary Earth Orbit) and 4 are GSO (Geosynchronous Earth Orbit) (e.g. Sharma et al., 2019). The 3 GEOs are located at 32.5^{o}E, 83^{o}E and 131.5^{o}E and 4 GSOs have their longitude crossings 55^{o} E and 111.75^{o} E. IRNSS uses two frequency bands namely L5(1176.45 MHz) and S (2492.028 MHz) band. IRNSS provides two services:

1. Standard Positioning Services (SPS):

2. Restricted Services (RS):

The bandwidth of SPS-L5 is 24 MHz (1164.45-1188.45 MHZ) and SPS-S is 16.5 (2483.50-2500.00MHz) (Gattupalli et al., 2015). A receiver which is one of IRNSS network is installed in Kasturbai Walchand College, Sangli Station by ISRO which is named as ACCORD (IRNSS/GPS/SBAS). All signals are received and logged by this receiver.

For every Navigation Satellite system, it is mandatory that the received signals transmitted from satellite have to get received properly. But in practical situation the signals which are transmitted from satellite has to go through the no. of layers present over the Earth. Each of layers has its own characteristics and specific height and hence, has different impact on satellite signal. Troposphere, Stratosphere, Mesosphere etc. are the various layers out of which Ionosphere significantly influences the satellite navigational signal. Ionosphere extends from 70 – 1000 km in altitude. It is partially ionized by radiations from sun and these ions disturb the navigation signal. These signals also have a great impact of solar activities, cycles and various gasses illumined by it. Plasma sphere is the layer which also affects the signals to greater extent (Rama Rao et al. 2006). Equatorial magnetic effect of Earth leads to high variation in electrons in equatorial region. Variation occurs in electron density with the day time. Electron density is observed to be highest in noon time and low in the midnight (Vijeshree et al. 2016).

The analysis of TEC have been studied by various researchers in the past (e.g. Nade et al., 2015, Buhari et al., 2017, Ghodpage et al., 2018, Shetti et al., 2019). The present paper has major concern with estimation of Total Electron Content (TEC). TEC depend on various factors such as latitude, longitude, local time season, geomagnetic activities and viewing direction. The measurement of electron density between two points in one meter square cross section column is TEC. Dual frequency system offers so many benefits in terms of accuracy and estimating parameters. Dual frequency system gives provision to analyze effect of ionosphere on the satellite signal. Also, relative phase difference can be calculated by doing operation at both frequencies simultaneously which will ultimately lead to estimate precise slant TEC (Rama Rao et al. 2006). Its detail analysis and respective parameter estimation will be carried out further in this paper.

Description of The Research:

Paper presents the first results for estimation of Total Electron Contents for IRNSS. Codes are developed for the relative code and phase TEC that can be used for the comparative study of IRNSS with other GNSS system. Continuous data of IRNSS is collected and processed to get TEC Values. As per the results it can be said that TEC follows the similar trends as per estimated for other GNSS systems. Estimation process comprises calculations of some theoretical formula and constants for IRNSS.

Earth has different atmospheric layers. A layer called Ionosphere gets formed with Thermosphere and part of Mesosphere and Exosphere which comprise free electrons and have major effect on wave propagation. This layer is approximately lies from 60 km to 1000 km above the Earth surface. This layer has a dispersive nature, which means its seeming effect on wave propagation is dependent on frequency of signal. Ionospheric delay is a function of TEC.

Methodology:

Estimation of the Total Electron Content for the IRNSS System is carried out using a RINEX 3.03 data format. Codes are developed using MATLAB programming tool. The estimated parameters can be listed in detail as below:

1. **TEC from Group Delay**
2. **TEC from Phase Delay**
3. **Slant and Vertical TEC**

Further, paper comprises detailed explanation of each mentioned parameter and procedure followed for respective estimation.

TEC from Group Delay:

Ionosphere time delay is one of largest source of error. The ionosphere is *dispersive,* which means that the apparent time delay contributed by the ionosphere depends on the frequency of the signal. This nature affects the signal. As a result, the codes, navigation message etc. appears to be delayed or slowed affected by what is known as known a Group Delay.

Estimation of Multiplication constant for IRNSS system to estimate TEC:

Ionospheric signal delay $= \frac{40.3}{(f^2)} TEC$ (1)

For S band frequencies:

Delay $= \left(\frac{40.3}{(2492.08*10^6)^2}\right) * 10^{16}$ (2)

$= 0.06489049492$ m

For L5 band frequencies:

Delay $= \left(\frac{40.3}{(1176.45*10^6)^2}\right) * 10^{16}$ (3)

$= 0.2911776911$ m

Multiplication Constant= $\frac{1}{0.2911776911-0.06489049492}$

= **4.419 m** (4)

Hence, the procedure followed for the estimation of Multiplication Constant is derived from Eq. (1) to Eq. (4).

Where, Eq. (1) gives the basic formula to estimate the ionospheric signal delay. Eq. (2) and Eq. (3) are proceeded to estimate delay for the IRNSS frequencies. Hence, finally Eq. (4) evaluates the multiplication constant for the IRNSS system.

Following is the expression to estimate group TEC,

TECgroup = (P1-P2)* 4.4191 m (5)

Where f1 & f2 are L5 and S carrier frequencies andP1 & P2 are pseudo-range observables.

TEC from Phase Advance:

The space conditions mainly Ionosphere also make phase of signal to get vary, it is advanced with respect to its phase in absence of ionosphere. Eq.5 gives the formula used for estimating the phase delay. C1 and C2 are the received carrier phase measurements.

TECphase = (C1 - C2) * 4.4191 m (6)

Where, C1 & C2 are carrier phase measurements in meters. Both the readings for Group and Phase TEC will be in meter.

Slant and Vertical TEC:

"The total number of electrons in a column of cross-sectional area of one-square meter along the signal path between the satellite and the receiver is termed as TEC." [8]It is often referred in multiples of so called TEC unit (TECU=10^{16} el/m^2). Ionospheric TEC is often characterized by observing carrier phase delays of received radio signal transmitted from satellites located above ionosphere, often using GPS satellite. TEC is strongly affected by solar activity.

$VTEC = [STEC – (b_R + b_S)]/ S (E)$ (7)

Here

VTEC = vertical TEC

STEC = slant TEC

S (E) is the projection angle given below:

$$S(E) = \frac{1}{\cos(Z)} = \left\{1 - \left(\frac{R_E \times \cos(E)}{R_E + h_s}\right)^2\right\}^{-0.5} \quad (8)$$

R_E = radius of earth (6371 km)

h_s = Height of Ionosphere (350 km)

E = elevation angle

Analysis and Results:

All the received data logged by Accord Receiver can be monitored in IRNSS-UR software. This software also provides the provision of data extraction in which RAW Data received by Accord Receiver can be extracted in two types of data formats, one is '.csv' data format and other is RINEX data format. Accord receiver receives L1 (GPS), L5 & S (IRNSS) frequency data.

RINEX 3.03 data format records four parameter of each frequency. They are:

a) Pseudo range b) Carrier Phase c) Doppler d) Signal Strength.

Data analysis is carried out by using RINEX 3.03 data format for the period of 24 Hrs, from 10 AM to 10 AM. Further, paper presents the discussion and results achieved by data processing.

1. Cycle Slip Detection:

In GNSS receiver carrier phase measurement can be used to improve the receiver position accuracy. In order to maintain the accuracy cycle slip must be detected and corrected instantaneously and accurately (Kersley et al., 2004). Cycle slip may cause by due to obstruction to satellite signal due to trees, buildings etc. or low signal to noise ration due to bad Ionospheric conditions.

2. Cycle Slip Correction:

Receiver consist phase tracking loop which suffers temporary loss of lock when cycle slip occurs as shown in Fig.1. The algorithm is designed to repair a cycle slip in which difference of two consecutive points is estimated and leveling of same is done, when estimated difference crosses predefined threshold value. The process of detection of a cycle slip and correcting it both will get achieved by designed algorithm. Fig. 2 is a graph results after post-processing for cycle slip correction.

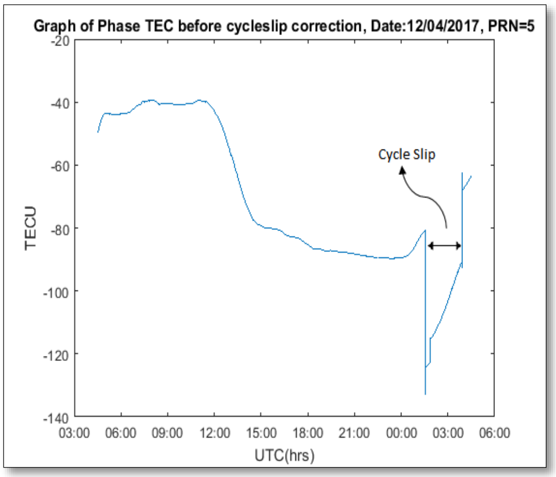

Figure 1: Graph of Phase TEC beforeCorrecting Cycle Slip

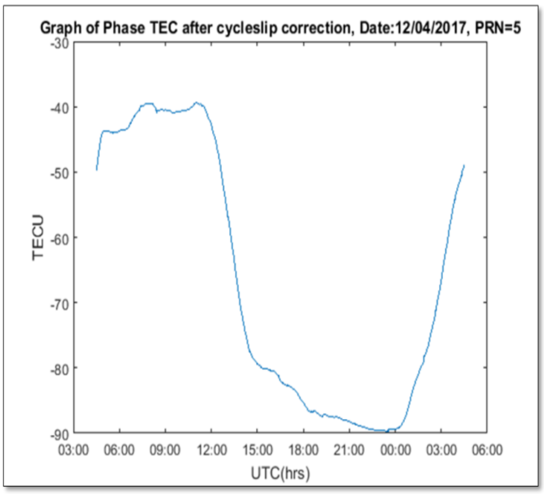

Figure 2: Graph of phase TEC after Correcting Cycle Slip

3. Group and Phase TEC:

Figure 3 shows resultant graph of group TEC for each PRN of IRNSS. Graph is plotted Time vs. TECU. It can be seen that maximum value of the Group TEC shown is approximately 91 TECU by IRNSS-1B. TEC values are ranged maximum approximately between 40 and 70 at noon time whereas dropped to 10 TECU at midnight. These are unbiased TEC values. Figure 4 shows graph of phase TEC which is plotted time vs. TECU for each PRN of

IRNSS. It shows the representation of phase TEC for data of 24 hrs. While travelling through ionosphere the values of phase TEC gets affected keeping its shape unaffected whereas values of Group TEC remain undisturbed while shape gets affected. Dedicated period/day is chosen to represent the estimated TEC values as TEC values raise high during the month of April.

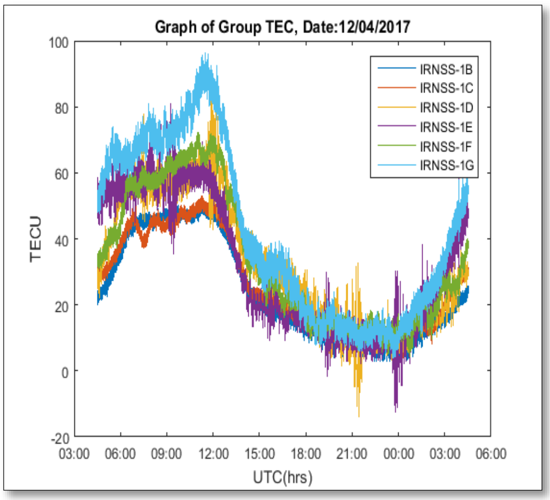

Figure 3: Graph of Group TEC for 24 Hrs. data of 12/4/2017

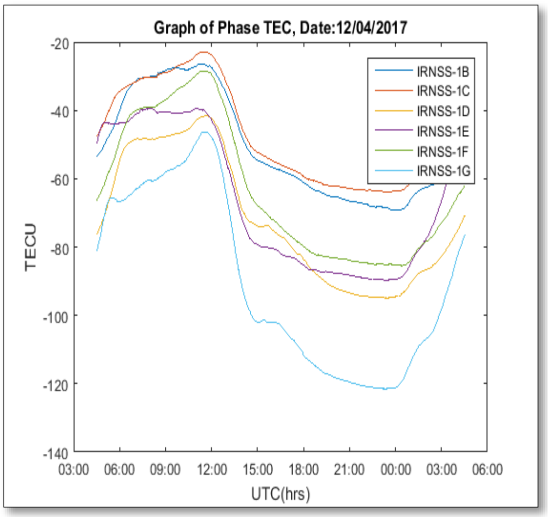

Figure 4: Graph of Phase TEC for 24 Hrs. data of 12/4/2017

4. Calibrated Relative Slant TEC:

Fig. 5 and Fig. 6 show plots of calibrated Slant and Vertical TEC respectively for each PRN of IRNSS system. The calibrated slant TEC is estimated by plotting Group and Phase TEC on same plane and approximating values of group according with shape of phase and then converted to vertical TEC as shown in Fig.6.

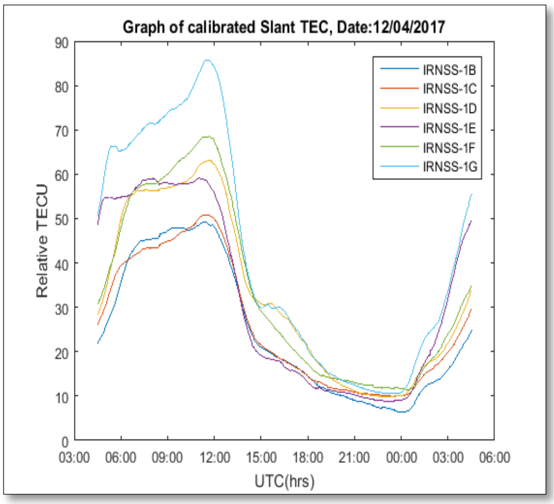

Figure 5: Graph of Calibrated Slant TEC for 24 Hrs. data of 12/4/2017

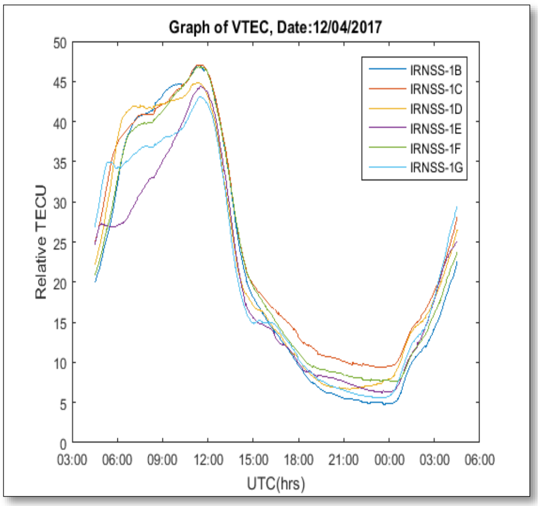

Figure 6: Graph of Vertical TEC for24 Hrs. data of 12/4/2017 for IRNSS system

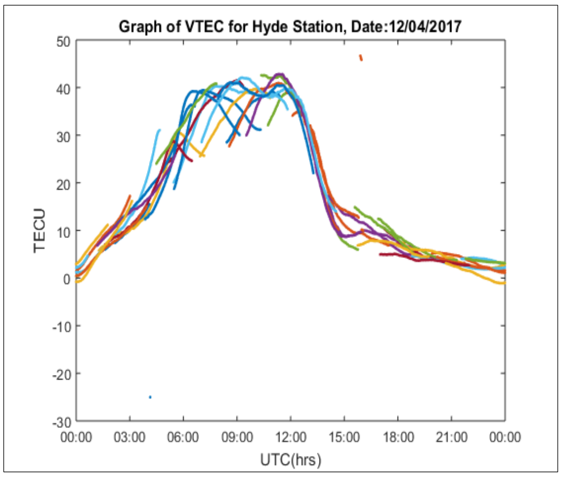

Figure 7: Graph of Vertical TEC for24 Hrs. data of 12/4/2017 for GPS system

Fig 6 and fig 7 gives the comparative results of vertical TEC for low latitude Sangli (16° 52' 0" North, 74° 34' 0" East) and Hydrabad (17.3850° N, 78.4867° E) station. Sangli station is showing results for IRNSS whereas Hydrabad station is showing results for GPS. Both the results are estimated for the date 12 April 2017. Both these stations lie on approximately same latitude. Both the TEC values reach to its maximum value at noon time. As the sun radiations and temperature will be higher at the noon time, the process of ionization gets increased which results in maximum value of TEC. Whereas due to lesser/absence of sun radiation and lesser temperature the recombination rate gets increased which results in lesser TEC.

Summary:

By observing behavioral pattern of both Group and Phase Total Electron Content (TEC), it can be conclude that TEC value is high in noon time approximately for the time duration of 12 PM to 3 PM. In contrast, TEC decreases significantly at midnight. Due to various obstructions and low SNR values, carrier phase suffers from cycle slip. Figure 1 gives a graph for PRN 5 which consists a cycle slip. Fine algorithm is designed for detection and correction of such occurrences of cycle slips in carrier phase and resultant graph is shown in figure 2 which properly deals with it and removes cycle slip. Hence, paper presents first results of Relative Total Electron Contents along with detection and correction of cycle slip for India's own Navigational Satellite System IRNSS. Process of estimation comprises of properly logging of data and to analyze it for calculating the respective multiplication constants.

Future Direction:

Current paper presents results of relative TEC for IRNSS which is Biased TEC. Our work is going on for estimation of unbiased TEC using Least Square Method and this work will further extend to determine ionospheric plasma bubbles, space weather and storm effect on IRNSS signals.

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