A Comparative Analysis of Ionospheric Effects on Indian Regional Navigation Satellite System (IRNSS) Signals at Low Latitude Region, Surat, India Using GDF and Nakagami-m Distribution

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Abstract. Indian regional navigation satellite system (IRNSS) is our own navigation system designed to provide various navigational and timing services in Indian region. The present paper discusses ionospheric scintillation effects on IRNSS signals in Surat, (21.16°N, 72.68°E; Geomagnetic 12.90°N, 147.35°E) India, a low latitude station. Ionospheric scintillations are one of the major sources of errors in satellite communication which may results in loss of lock of with particular satellite causing discontinuity of satellite services. Ionospheric Scintillation is experienced by satellite signals when propagating through various layers of atmosphere in terms of random fluctuations in amplitude and phase of signals, and also causes ionospheric delay. The present analysis is done on 3rd October 2015 data for calculation of Ionospheric scintillation measuring parameters like total electron content (TEC) and Vertical TEC using IRNSS data. During this time only four satellites were launched from PRN 1 to 4 by Indian space research organization (ISRO). The comparative behavioral analysis of TEC variation is done using Gaussian distribution function (GDF) and Nakagami m (NGK) model distribution. The carrier to noise (C/N) ratio and elevation angle variations for satellite PRN numbers from 1 through 4 is also carried out. It is seen from comparative analysis that total electron content variations in this geographical location are more following the Nakagami distribution as compared with GDF. The results can be utilized further for developing model for analyzing variations in TEC in this region.

Keywords: Errors in satellite communication · GDF · GNSS Ionospheric scintillation · Ionospheric scintillation parameters · IRNSS signals Nakagami distribution · Satellite navigation

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1 Introduction

The Indian Regional Navigation Satellite System (IRNSS) is an independent navigation system which is developed by Indian Space Research Organization (ISRO), India. This navigation system is going to provide many applications related to navigational (standard positioning service and restricted service) and timing services in India as well as fifteen hundred kilometers around the Indian region. It is comprising of three segments like Space segment, ground segment and User segment. The space segment is comprising of seven satellites starting from IRNSS 1A to 1F, out of which three satellites are launched in geostationary earth orbit (GEO) at 32.5°, 83° and 131.5° East and four in Geosynchronous orbit (GSO) at inclination of 29° with longitude crossing at 55° and 111.75° East. The ground segment consists of various master and controlling earth stations keeping track of various orbital parameters of satellite location in orbit. User segment is comprising of IRNSS receiver which will be able to receive satellite signals decode them and able to provide useful navigational and timing information to user.

One of the IRNSS receiver granted by ISRO, Ahmedabad, is located at SVNIT, Surat which is situated at low latitude and equatorial anomaly region of India is as shown in Fig. 1. Hence it is more interesting to investigate the effects caused on IRNSS signals when it is propagating through various layers of atmosphere in this region. Figure 2 is illustrating sky plot of seven satellites starting from Pseudo Random number (PRN) 1 through 7 over the SVNIT region.

Satellite signals when propagating through various layers of atmosphere experience various sources of errors. Ionospheric scintillation is one of the major source of error for satellite signals. It is phenomena in which there can be sudden fluctuation in the satellite signals, there can be phase variations and amplitude scintillations. This can lead to loss of lock and cycle slip with respective satellite because of degradation in carrier to noise (C/N) ratio of the signals and hence can disrupt all services offered by the satellite during that period. This has led to scintillation studies in which various

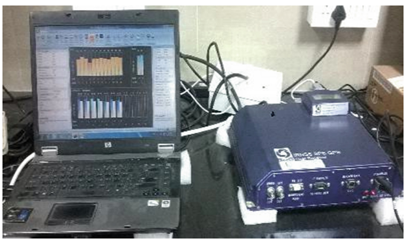

Fig. 1. Set up of IRNSS receiver at SVNIT, Surat.

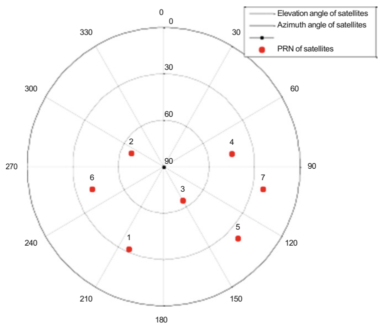

Fig. 2. Sky plot of IRNSS Constellation over SVNIT, Surat

researchers are analyzing the ionospheric scintillation effects on satellite signals and how it can be minimized.

This paper also discusses ionospheric scintillation effects on IRNSS signals. Ionospheric scintillation effects are very fast and random fluctuations of satellite signals in terms of variations in amplitude and phase caused by small scale irregularities present in the Ionosphere. This effects varies form geographical location, local time, season, solar radiations and magnetic activity as mentioned by Kintner et al. [1].

Paper is organized as follows. Section 2 is reviewing related work with IRNSS & Ionospheric Scintillation. Data and its analysis is presented in Sect. 3. Results are presented in Sect. 4. Finally discussions are concluded in Sect. 5.

2 Related Work

IRNSS receiver can be single frequency or dual frequency receivers operating in two frequencies namely L5 (1176.45 MHz) and/or S (2492.028 MHz) band. Modulation schemes used for signals are Binary phase shift keying (BPSK-1) and Binary offset carrier (BOC 5, 2) as mentioned by Saini and Gupta [2]. IRNSS receiver designed by ISRO is also capable of receiving Global Positioning System (GPS) signals. The advantages of our Indian navigational satellite programs developed by India like Geo augmentation system (GAGAN), IRNSS and INSAT-MSS system for the civilian use in Srilanka region is also discussed by Senanayake [3].

The IRNSS service is also beneficial to Australian continent as mentioned by Zaminpardaz et al. [4]. This paper provides insights about stand-alone positioning services over Australia. The SPS signals Pseudo random codes (PRN) are accomplished by Yashaswini [5]. It also highlights use of PRN gold codes by using Matlab, Xilinx, ISE simulator and Sparton FPGA environments. The Geometric dilusion of Precision (GDop) is very important parameter for identifying satellite geometry and finding range error in meters as described by Sekhar et al. [6].

A software designed receiver FGI-GSRx was developed by Thombre et al. for tracking IRNSS signals in northern Europe as mentioned in [7]. The receiver was able to carrier to noise power ratio for three IRNSS and GPS satellites. It has been shown by Majithiya et al. that IRNSS signal has group delay differential correction parameter to correct for L5 and S band as presented in [8]. Kalman filter based approach can be used to track the loop of Phase locked loop and provide better performance of receiver under ionospheric scintillation effects as discussed by Manjula et al. [9]. The analysis of position accuracies provided by various navigation system like GPS, IRNSS and hybrid are done by Manjunatha and Kiran [10]. Kumar et al. [11] has discussed the estimation of satellite geometry of IRNSS in terms of absolute, relative velocity, psuedorange and carrier phase.

Ionospheric scintillation effects on satellite or GPS signals results into Signal refraction and Signal diffraction [12]. Ionospheric scintillation measuring parameters are Amplitude scintillation index known as S4, Phase scintillation index $\sigma\phi$, Percentage of Scintillation occurrence (PSO), Total electron content (TEC) or Slant TEC, Vertical TEC (VTEC), Rate of Change of TEC (ROT), Satellite Elevation angle, Lock time, as mentioned by various researchers in [13–15]. Ionospheric scintillation studies for GPS signals for a particular day for diurnal study is done by Parmar et al. [16]. Ionospheric scintillation effects on IRNSS signals using GDF and Nakagami distribution is also investigated by Parmar et al. [17]. Thus in this section related work done by various researchers in area of IRNSS and Ionospheric scintillation effects on GPS and satellite signals are discussed.

3 Data and Analysis of Work

The data and work done here is collected and received by IRNSS UR receiver which is installed at SVNIT, Surat. The receiver is capable of tracking all PRN satellites at L5 and S band. Measurement and calculation of different ionospheric scintillation parameters is done in MATLAB using the 3 Oct 2015 data and by using mathematical formulation as presented by Tanna et al. for the same region in [14]. There are various ionospheric scintillation parameters but out of them total electron content is considered here for analysis purpose. Earlier studies have been done for GPS signals.

3.1 Calculation of Total Electron Content (TEC) or Slant TEC (STEC)

The speed of propagation of satellite signals depends upon number of free electrons in its path, known as total electron content (Slant TEC), the number of free electrons in a tube of 1 m^2 cross section extending from the receiver to the satellite as mentioned by Misra and Enge [12]. One TECU is 10^{16} electrons per m^2.

$$TEC = \int_S^R n_e\ (l)dl \tag{1}$$

Where n_e (l) is the variable electron density along the signal path, and the integration is along the signal path from the satellite to the receiver. TEC varies typically between 1 and 150 TECU. TEC is calculated here using the Eq. (2), where for IRNSS receiver, **f1 = (L5 band frequency = 2492.028 MHz) and f2 = (S1 band frequency = 1176.45 MHz)**, P1 and P2 are Pseudo ranges of each frequencies f1 and f2 respectively.

$$TEC = \left[\frac{f_1^2 * f_2^2}{f_2^2 - f_1^2}\right]\frac{(P_1 - P_2)}{40.3} \tag{2}$$

3.2 Calculation of Vertical Total Electron Content (VTEC)

The STEC depends upon the signal path geometry when it is propagating through various layers of ionosphere it is important to calculate VTEC which is not depending to upon the elevation of signal path. TEC variations forms the electron irregular patches in the ionosphere. And when the satellite signal propagates through these patches;

Ionospheric scintillation results. The VTEC is calculated using the Eq. (3) as mentioned by Klobuchar [18]. In Eq. (3), Re is the radius of the earth (6378 km), hmax is height (350 km), and θ is the elevation angle of satellite in radians.

$$VTEC = STEC * \cos\left\{\arcsin\left[\frac{R_e \cos\theta}{R_e + h_{\max}}\right]\right\} \tag{3}$$

3.3 Nakagami-m Distribution

Nakagami distributions are mostly used in electronics communication for modelling scattered radio frequency signals which arrive at the receiver through various paths. Due to this signal will have different fading characteristics. Rayleigh and Nakagami distributions are used to model dense scatters, and the Rician distributions are used to model fading with a stronger line of sight. If x has a Nakagami distribution with parameters μ and ω, then x^2 has a gamma distribution with shape parameter μ and scale parameter ω/μ (μ > ½ and ω > 0). Its probability density function (pdf) is given as

$$\mathrm{F}(x; \mu, \omega) = 2\left\{\frac{\mu}{\omega}\right\}^{\mu}\frac{x^{(2\mu-1)}e^{\frac{-\mu x^2}{\omega}}}{\Gamma(\mu)} \tag{4}$$

3.4 Gaussian Distribution Function (GDF)

GDF or normal distribution is a very commonly used probability distribution function in statistics analysis approach for representing real valued random variables whose distributions are unknown. It is also known as bell curve because of the shape of the distribution curve. Here GDF is utilized to determine variations in the TEC and analyzing it. The normal distribution is given by Eq. (5).

$$y = f(x \mid \mu, \sigma) = \frac{e^{\frac{-(x-\mu)^2}{2\sigma^2}}}{\sigma\sqrt{2\pi}} \tag{5}$$

In Eq. (5), μ is the mean, σ is the standard deviation. The standard normal distribution is written as [ϕ(x)] sets μ to zero and σ to 1.

4 Results

The data received by IRNSS receiver on 3rd October 2015 is used as sample data for analysis. Calculation of parameters like TEC and VTEC is done using Eqs. (2) and (3). GDF and Nakagami distribution function of TEC data is also calculated. Figures 3, 4, 5, 6 and 7 is representing the GDF of TEC on Y axis and TEC in TEC units (TECU) on x axis for all PRN, and PRN 1 to PRN 4 respectively. It can be observed that TEC is varying from 5 TECU to 80 TECU. It can be seen that TEC is following GDF and the

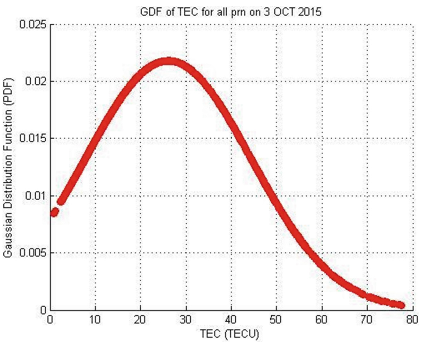

Fig. 3. GDF of TEC for all PRN from 1–4 on 3 Oct 2015.

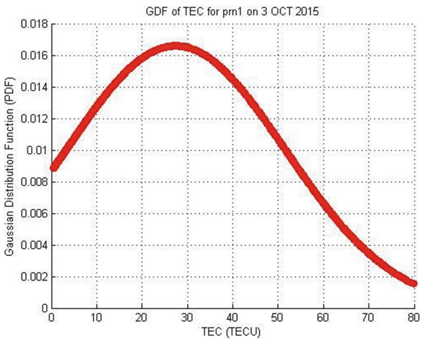

Fig. 4. GDF of TEC for PRN 1 on Oct 2015.

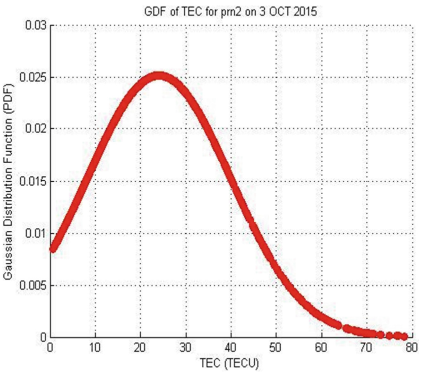

Fig. 5. GDF of TEC for PRN 2 on 3 Oct 2015.

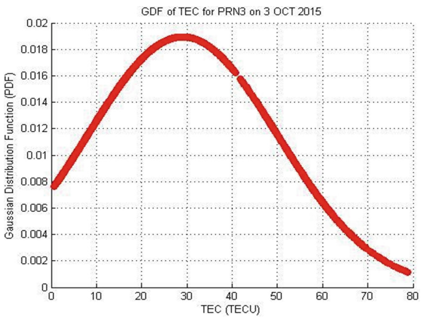

Fig. 6. GDF of TEC for PRN 3 on 3 Oct 2015.

shape of curve is bell shaped. The GDF values are varying from 0.008 to 0.025 for different values of TEC. Figures 8, 9, 10, 11 and 12 are representing comparison of GDF and Nakagami distribution function of TEC for all PRN and PRN 1–4 separately. TEC data are plotted using light blue colour bars as background of plot and GDF is indicated in red colour curve and Nakagami distribution function is indicated in blue colour on Y axis simultaneously for comparison purpose. From blue colour curve it is predicted that TEC variations are more following Nakagami distributions as compared to GDF.

Figures 13, 14, 15 and 16 are highlighting variations of Carrier to noise ratio (C/N) in decibel-Hertz and elevation angle in degrees for each PRN from PRN1 to PRN 4 for L5 and S band respectively. From Fig. 13 it seen that the C/N ratio is about 48 to 55 dB-Hz for L5 band and 43 to 47 dB-Hz for S band of PRN 1. And elevation angle

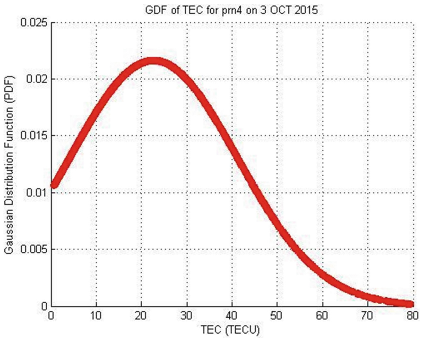

Fig. 7. GDF of TEC for PRN 4 on 3 Oct 2015.

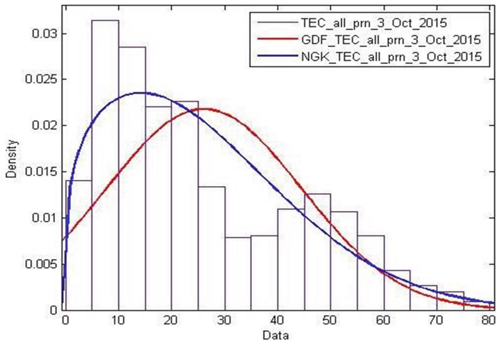

Fig. 8. Comparison of GDF and NGK of TEC for all PRN (1–4) on 3 Oct 2015. (Color figure online)

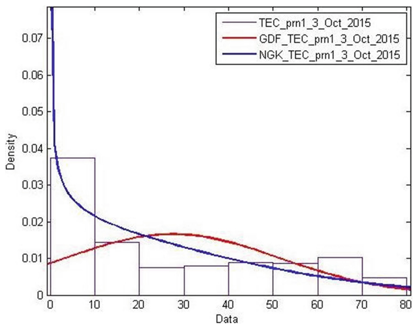

Fig. 9. Comparison of GDF and NGK of TEC for PRN 1 on 3 Oct 2015. (Color figure online)

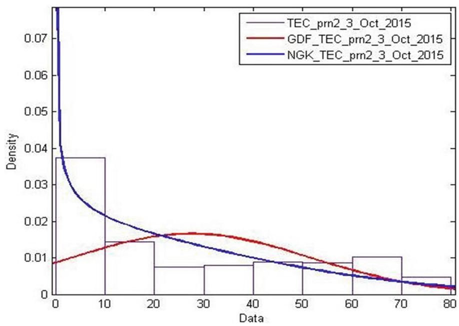

Fig. 10. Comparison of GDF and NGK of TEC for PRN 2 on 3 Oct 2015. (Color figure online)

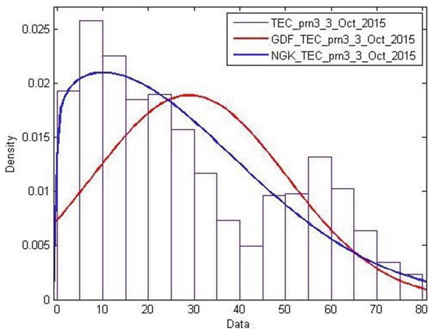

Fig. 11. Comparison of GDF and NGK of TEC for PRN 3 on 3 Oct 2015. (Color figure online)

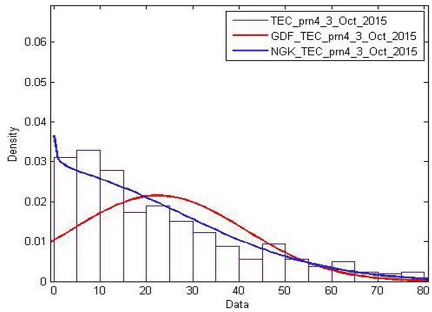

Fig. 12. Comparison of GDF and NGK of TEC for PRN 4 on 3 Oct 2015. (Color figure online)

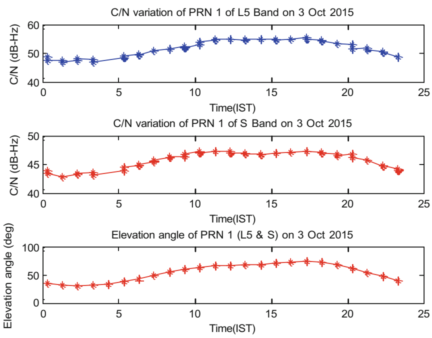

Fig. 13. Variation of C/N ratio and Elevation angle (L5 and S band) for PRN 1 on 3 Oct 2015

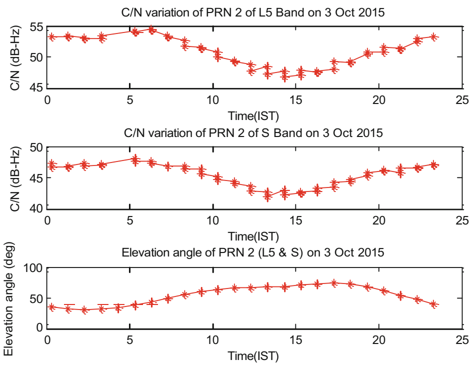

Fig. 14. Variation of C/N ratio and Elevation angle (L5 and S band) for PRN 2 on 3 Oct 2015

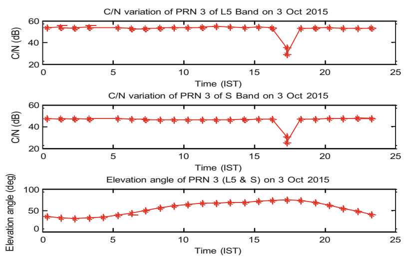

Fig. 15. Variation of C/N ratio and Elevation angle (L5 and S band) for PRN 3 on 3 Oct 2015

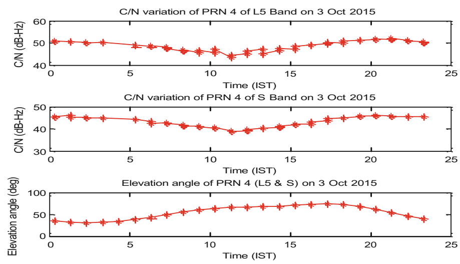

Fig. 16. Variation of C/N ratio and Elevation angle (L5 and S band) for PRN 4 on 3 Oct 2015

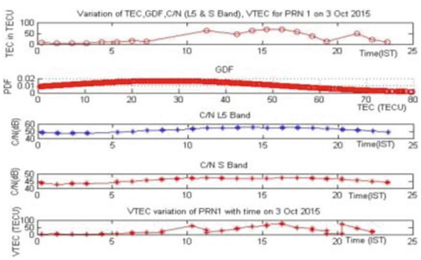

Fig. 17. Variation of TEC, GDF, C/N (L5 Band & S Band) for PRN 1 on 3 Oct 2015

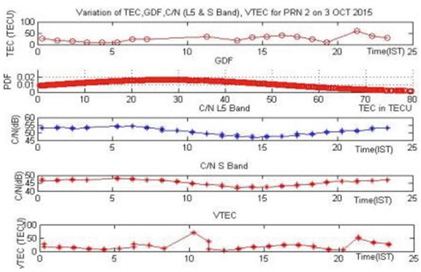

Fig. 18. Variation of TEC, GDF, C/N (L5 Band & S Band) for PRN 2 on 3 Oct 2015

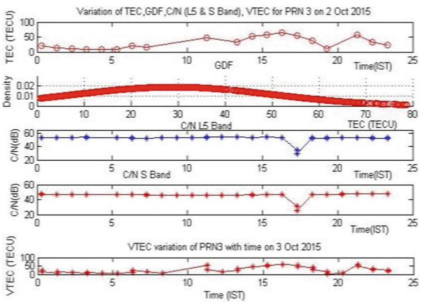

Fig. 19. Variation of TEC, GDF, C/N (L5 Band & S Band) for PRN 3 on 3 Oct 2015.

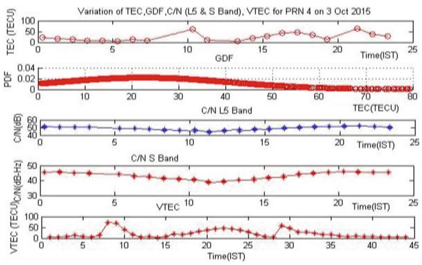

Fig. 20. Variation of TEC, GDF, C/N ratio (L5 Band & S Band) for PRN 4 on 3 Oct 2015.

of PRN1 is varying from 30° to 74°. From Fig. 14 it is seen that the C/N ratio is from 46 to 53 dB-Hz for L5 band and 41 to 48 dB-Hz for S band of PRN 2. And elevation angle of PRN 2 is varying from 30° to 74°. Figure 15 is indicating that C/N ratio for L5 band of PRN 3 from 29 to 54 dB-Hz and 25 to 47 dB-Hz for S band of PRN 3. Thus it is observed that for both L5 and S band the C/N ratio for PRN 3 is dropping around 25 to 30 dB-Hz around 17:30 IST. This can result in loss of lock of receiver with PRN 3 during this period. And elevation angle of PRN 3 is varying from 30° to 74°. Figure 16 is showing that C/N ratio for L5 band of PRN 4 is varying from 44 to 51 dB-Hz and 38 to 46 dB-Hz for S band of PRN 4. And elevation angle is varying from 30° to 74°. Figures 17, 18, 19 and 20 is showing variations in TEC in TECU on (Y-axis) versus IST local time (x-axis), GDF (Y-axis) of TEC data (x-axis), C/N ratio (Y-axis) in dB-Hz for L5 and S band with IST local time and VTEC in TECU versus IST local time for all PRN and PRN 1 to 4 respectively.

Thus the variations of various parameters like TEC, C/N ratio, Elevation angle and VTEC is carried out here for IRNSS signals captured on 3 Oct 2015.

5 Conclusions

Thus in this paper the variations of various parameters like carrier to noise power (C/N) ratio in dB-Hz, Elevation angle in degrees, Total Electron content (TEC) in TEC units (TECU) and Vertical TEC are studied for four satellites having PRN numbers from IRNSS 1A – IRNSS 1D (PRN 1–4). The Gaussian distribution function and Nakagami-m model distribution functions are also utilized for understanding behavioral pattern of TEC variations in this low latitude station and it is seen from the results that the TEC variations are more following the Nakagami distributions as compared to Gaussian distribution functions. The results can be further utilized for modelling ionospheric scintillation parameters in this region.

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