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Equatorial Plasma Bubbles Characteristics Studies using IRNSS Data around Bangalore

Journal of Electrical Systems

Abstract: - TEC analysis stands as a cornerstone in navigation, enabling the examination of sudden shifts in Total Electron Content (TEC). Equatorial Plasma Bubbles (EPBs) are discerned through TEC analysis, which proves superior to alternative approaches. This method furnishes insights into EPB occurrences, offering valuable data on their daily and seasonal fluctuations within the ionosphere. Analysis of TEC data from January 2015 to 2022, derived from IRNSS observations in Bangalore, reveals patterns in EPB occurrence correlated with the sunspot cycle and solar flux variations. This alignment, observed during a phase of low solar activity, underscores the reliability of TEC analysis in capturing ionospheric dynamics.

Keywords: Equatorial plasma bubbles, IRNSS, Total electron content

I. INTRODUCTION

Irregularities within the ionosphere denote areas where electron density deviates from the surrounding background levels, showcasing both positive and negative variations. Equatorial Plasma Bubbles (EPBs) manifest as large-scale depletions within the ionosphere, exhibiting internal structures spanning from mere centimeters to several kilometers. These formations possess the capability to disrupt telecommunication signals traversing the ionosphere. Monitoring and analysis of plasma bubbles are conducted extensively through optical methods, satellite observations, rocket soundings, and digisondes. The genesis and behavior of EPBs have been subjects of numerous theoretical and numerical investigations [1].

Radio communication serves as a means to confirm the presence of ionized layers within the atmospheric region. Discrepancies observed in radio communication are linked to irregularities in electron concentration within the ionosphere, with ionosondes serving as vital tools for such detection. These irregularities give rise to frequency spreading, particularly pronounced in the F-region near the equator, termed Equatorial Spread F (ESF), which intensifies during nocturnal hours, adversely affecting navigation, communication, and geodesic systems. The term "equatorial bubble" is coined to describe these irregularities within the F-region [2].

In the ionospheric E-region, the vertical E×B drift exhibits an upward trajectory at dawn and descends at dusk, reversing around sunset. Prior to this reversal, there's irregular augmentation in the upward drift, known as Pre-Reversal Enhancement (PRE), potentially originating from the F-region dynamo. The Equatorial Electrojet (EEJ) denotes an eastward ionospheric current during the day, flowing along the equatorial dip. The occurrence of the Counter Electrojet (CEJ), where the electric field shifts westward just before sunset, is also noted. Analysis of magnetic field data reveals significant deviations in both EEJ and CEJ concerning the horizontal component. This complex interplay significantly influences the growth rate of plasma bubbles, further illustrating the intricate dynamics within the ionosphere [3].

1.1 IRNSS

The Indian Regional Navigation Satellite System (IRNSS) consists of a constellation comprising three spacecraft in Geostationary Orbit (GEO) and four spacecraft in Geosynchronous Orbit (GSO). Operating under the name Navigation with Indian Constellation (NAVIC), IRNSS comprises seven satellites offering two types of services: the Standard Positioning System (SPS), accessible to all users, and the Restricted Services (RS), available to authorized clients, including the military. IRNSS finds applications in terrestrial, aerial, and marine navigation, disaster management, vehicle tracking and fleet management, coordination with mobile phones, terrestrial navigation assistance for hikers and commuters, and providing visual and auditory navigation cues for motorists.

For Total Electron Content (TEC) calculations using IRNSS data, carrier phase delays of signals received from IRNSS spacecraft are processed. These satellites transmit electromagnetic waves on both L5 band (1164-1215 MHz)

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and S band (2483.5-2500 MHz). Receivers are equipped for dual-frequency operation to process these signals, allowing for TEC estimatio[4].n along the line of sight from the spacecraft to the receiver. The standard position and limited services of IRNSS are communicated via the L5 and S bands, as depicted in Figure 1 illustrating the user receivers.

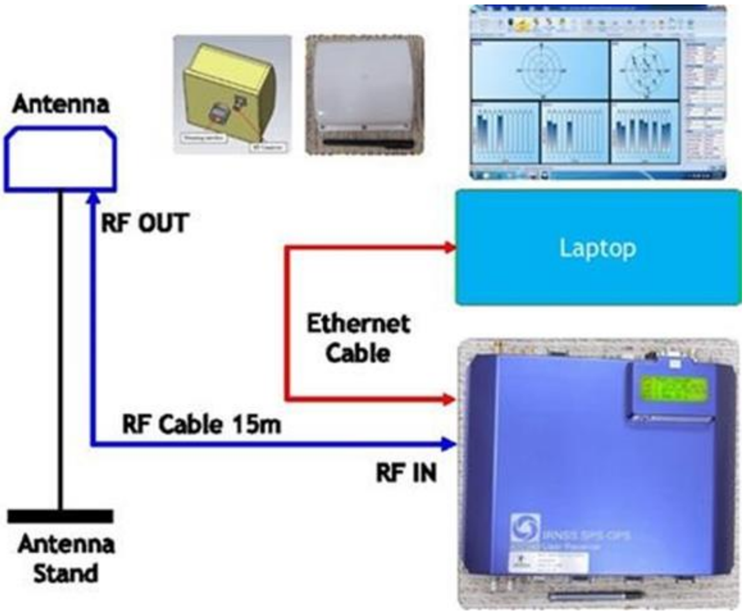


Figure 1. IRNSS user Receiver set up (Courtesy: isro.gov.in)

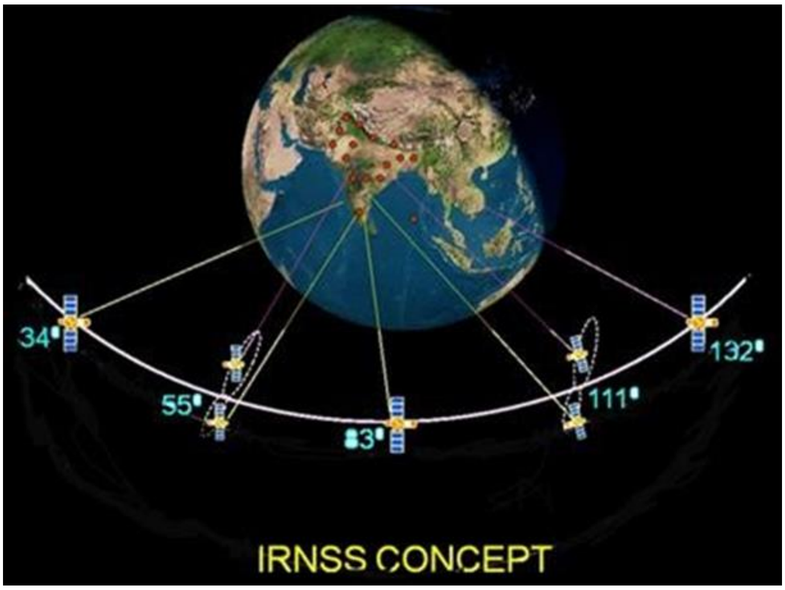


Figure 2. IRNSS Configuration (Courtesy: isro.gov.in)

II. METHODOLOGY

The TEC measurements are performed using the pseudo ranges of dual frequency signals from L5 and S bands. The data received from receiver is processed to estimate the delay experienced by the radio signals. The delay estimation calculation is shown in equation 1 [5].

$$PR_{ionofree} = \frac{(PR_S - \gamma PR_{L5})}{1-\gamma} \quad (1)$$

$$\gamma = \left(\frac{f_{L5}}{f_S}\right)^2 \quad (2)$$

Equation (2) represents the ionosphere delay at L5 and S bands in terms of pseudo ranges. In the equations PR_S is pseudo-range at S band frequency; PR_{L5} is the pseudo-range at L5 frequency; f_{L5}= 1176.45 MHz and f_S= 2492.028 MHz For obtaining delay (in meters) at L5 and S bands, theexpressions are given in Equation 3 and Equation 4

$$\text{For L5 band TEC} = (\text{Delay at L5})*(f_{L5})^2 / 40.3) \quad (3)$$

$$\text{For S band TEC} = (\text{Delay at S}) * (f_S)^2 / 40.3) \quad (4)$$

$PR_{ionofree}$ is the measured delay differential (related to mean group) of frequencies PR_{L5} and PR_S.The scaling factor in equation is 1 / 1 - γ. $PR_{ionofree}$ is a correction term generated by IRNSS control station. It benefits users who use single frequency (PR_{L5} or PR_S).

III. 3. RESULT ANALYSIS

In the region of equatorial ionization, during the hours after sunset, the chance of occurrence of plasma irregularities exists. The irregularities in ionosphere occur in the form of EPBs (equatorial plasma bubbles). EPBs are plasma depletions which are aligned towards magnetic field. EPBs affect radio communication signals adversely. Hence there is a need for in-depth understanding and characterization of the behavior of ionosphere. TEC analysis is used for studies related to space plasma. It is a useful tool for investigation related to the behavior of ionosphere which impacts navigation systems. TEC analysis is performed by generating TEC maps using IRNSS satellite data for a particular geographical region [6].

This helps in various types of ionospheric analysis, like plasma bubble detection. This in turn provides insight on macroscopic behavior of ionosphere. We have used total electron content associated with low latitude Bangalore stations for construction of maps.

Continuous data supplied by IRNSS provides excellent scope to study EPBs characteristics after statistical analysis. Depletions in TEC were observed in the range 5–20 TECU over Bangalore region. This confirmed the presence of plasma bubbles [7]. The TEC maps in our work are related to distribution of electron content with reference to local time and are shown below as graphical plots, as shown in figures 3 to 17

EPBS in March equinox 2015

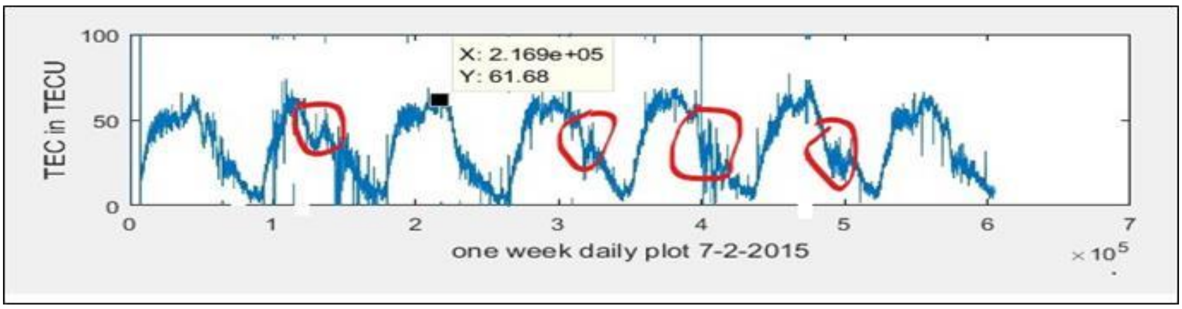


Figure 3. EPBs observed starting from 7-2-2015

EPBS in March equinox 2016

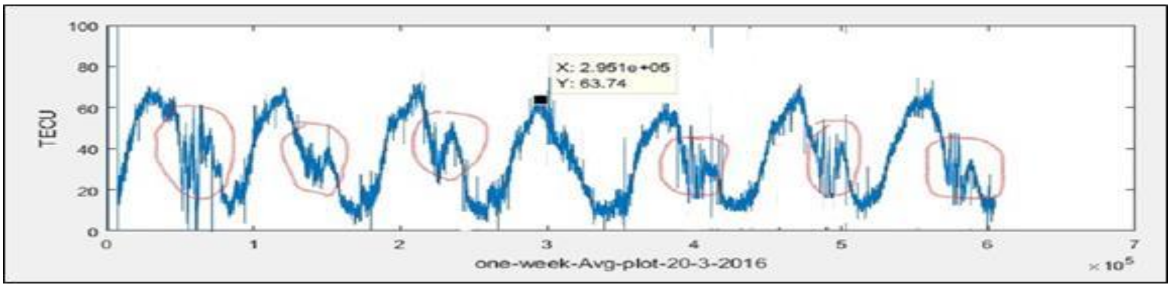


Figure 4. EPBs observed starting from 20-3-2016

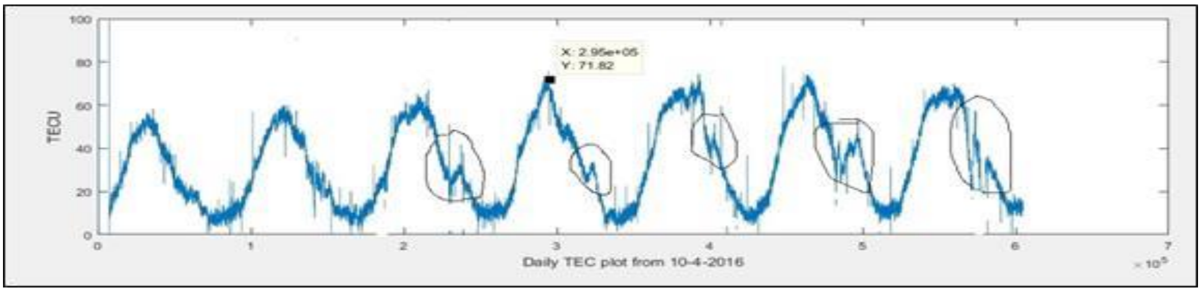


Figure 5 EPBs observed starting from 10-4-2016

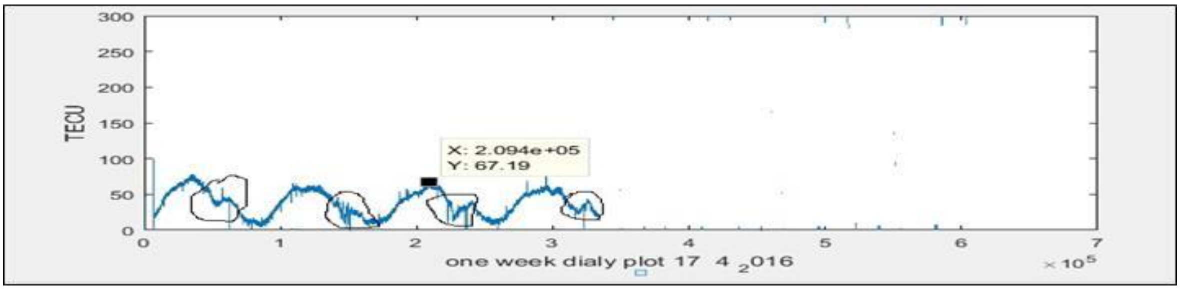


Figure 6 EPBs observed starting from 17-4-2016

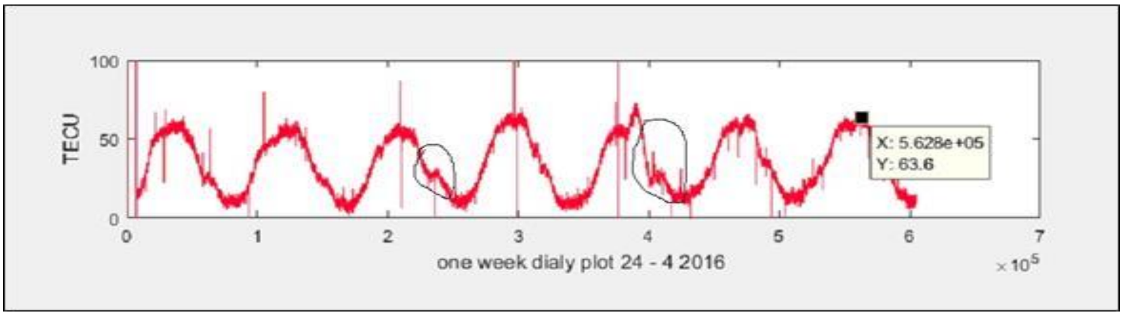


Figure 7. EPBs observed starting from 24-4-2016

EPBS in September equinox 2016

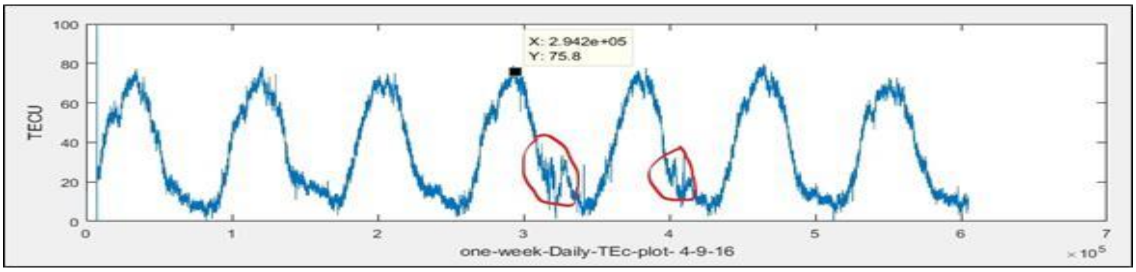


Figure 8. EPBs observed starting from 4-9-2016

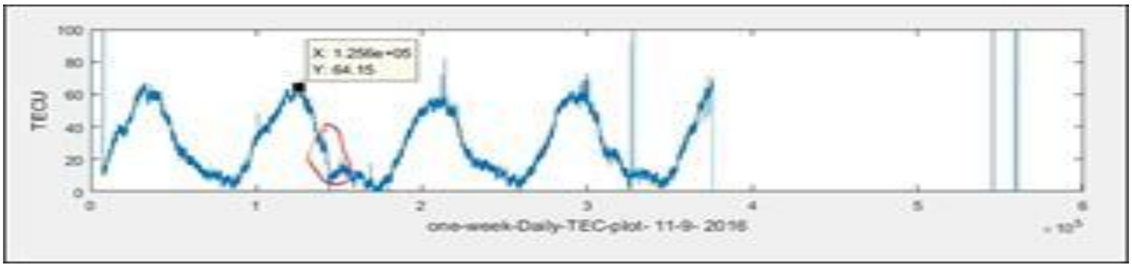


Figure 9. EPBs observed starting from 11-9-2016

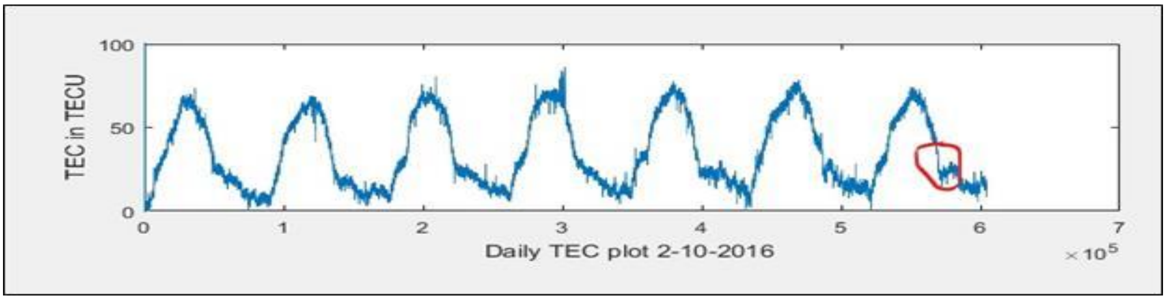


Figure 10. EPBs observed starting from 2-10-2016

EPBS in March equinox 2017

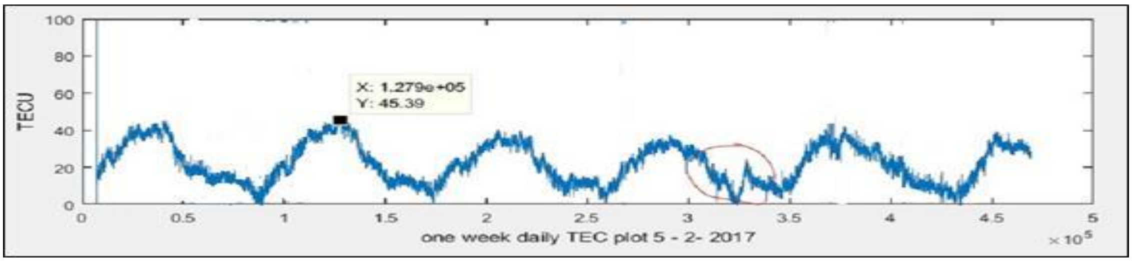


Figure 11 EPBs observed starting from 5-2-2017

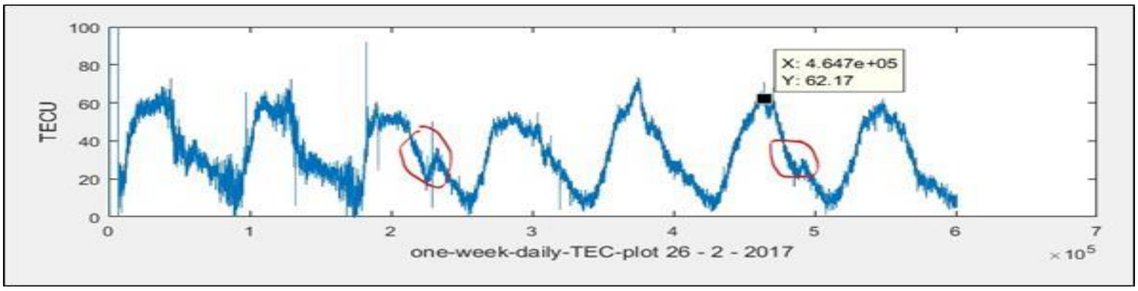


Figure 12. EPBs observed starting from 26-2-2017

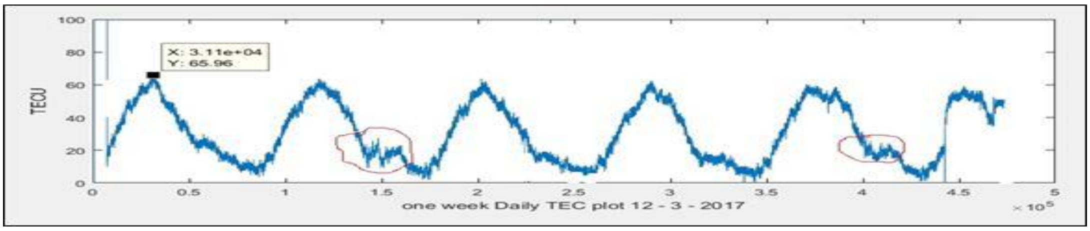


Figure 13. EPBs observed starting from12-3-2017

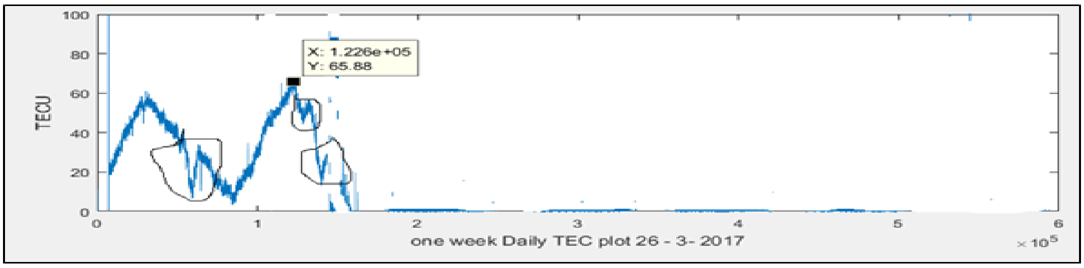


Figure 14. EPBs observed from 26-3-2017

EPBS in September equinox 2017

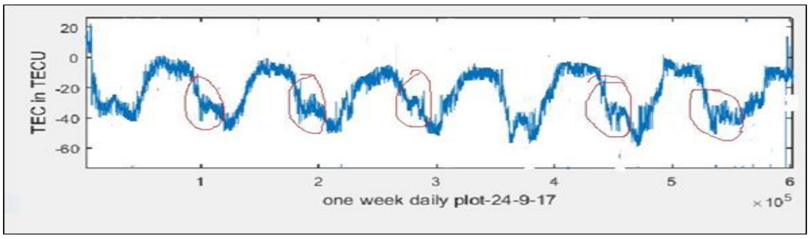


Figure 15. EPBs observed from 24-9-2017

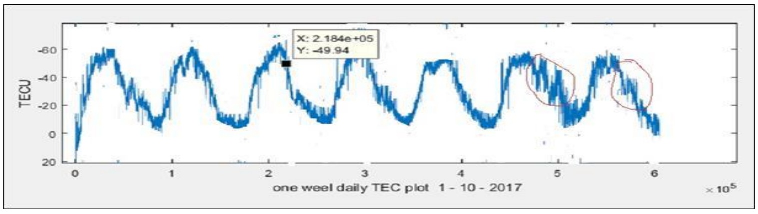
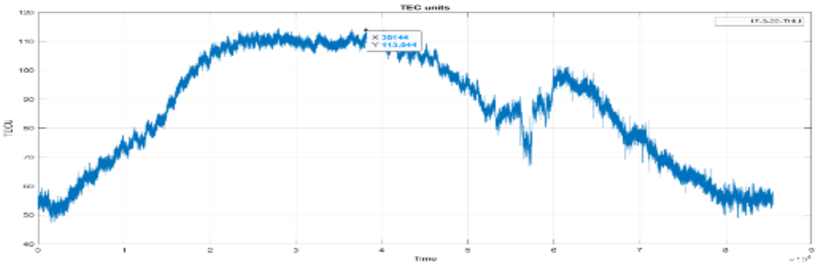
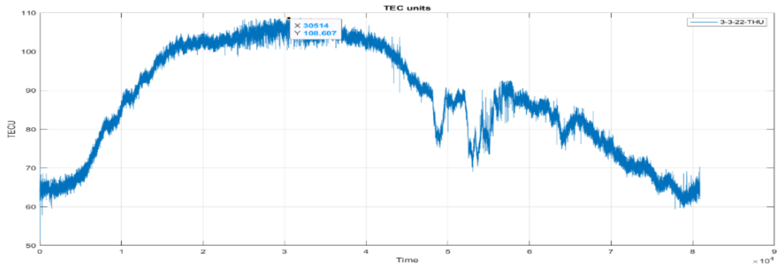


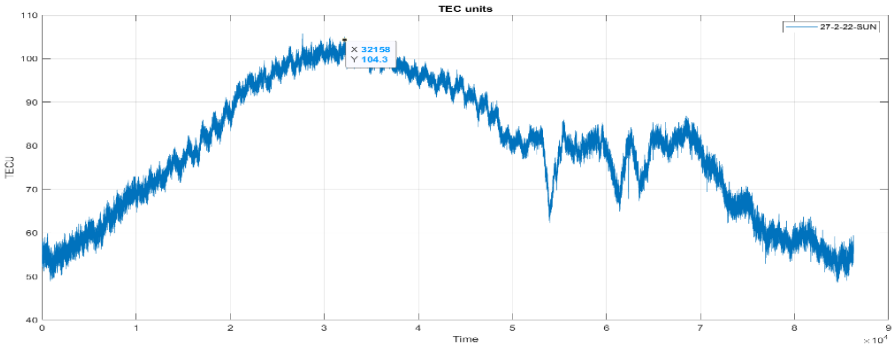
Figure 16. EPBs observed from1-10-2017



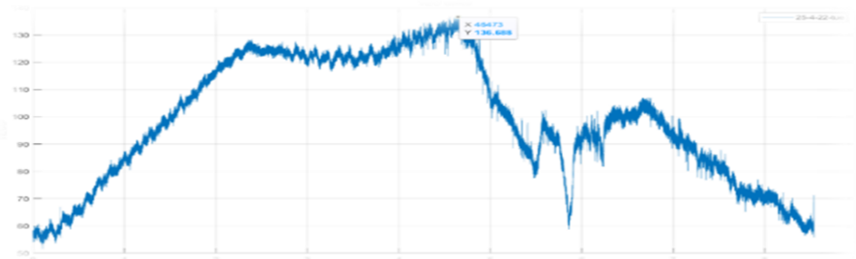
(a)



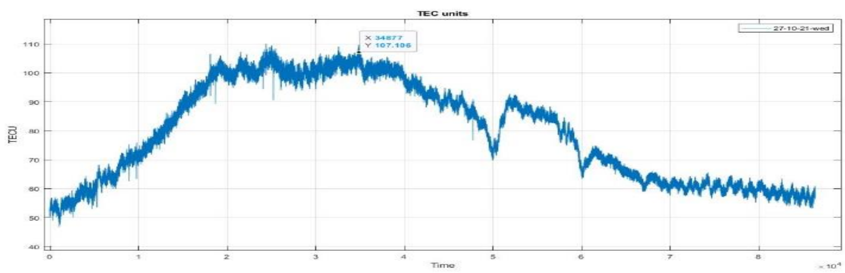
(b)



(c)



(d)



(e)

Figure 17. EPBs observed in March equinox and September equinox the year 2022

IV. OBSERVATIONS FROM RESULT ANALYSIS

From Figures 3- 7, it is observed that TEC depletions are more during the above period since it isMarch equinox month. In 2016 September equinox, number of TEC depletions are less compared to March Equinox of 2016. This is applicable to Figures 8 – 10. In 2017 March equinox, sunspot cycle is decreasing hence there are less number of TEC depletions as comparedto 2016 March equinox. This is applicable to Figures 11 – 14. From Figures 15-16 it is observed that in 2017 September equinox, more number of TEC depletions are observed as compared to March equinox 2017.

From the plots shown in figures 3 to 17.it is observed that there are more TEC depletions in equinox months during evening and night times. These days are magnetically quite days. The significant numbers of TEC depletions are found to occur during the post sunset hours.

SUNSPOT dependence: Strong correlation between annual EPBs (scintillations) and sunspot number. Strong relation between the magnitude of the EPBs (scintillation) and the every month sunspot number.

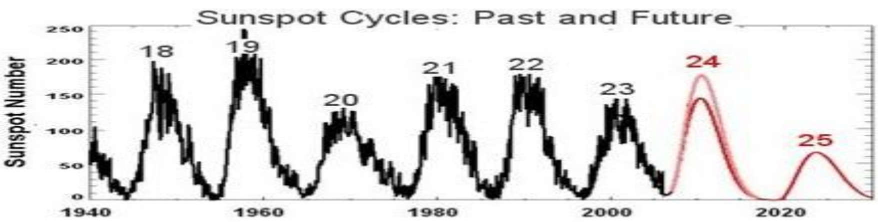


Figure 17. sunspot cycle

Source: http://science.nasa.gov/headlines/y2006/images/longrange/predictions3_strip.jpg

TEMPORAL dependence: Annual crest EPBs (scintillation) activities arise at or just follow the equinox periods. Peak daily EPBs (scintillation) activity occurs around 1 hour after the sunset at the ionosphere altitude.

GEOGRAPHIC reliance: The largest effects of EPBs (scintillation) are therefore seen at latitudes of around 15 degree and North and 15 degree south of the geomagnetic equator,where the combination of TEC and the path length tend to maximize. When the earth's magnetic field are parallel to the propagation path through the ionosphere, then increased ionosphere EPBs (scintillation) activity will result[8].

V. CONCLUSION

As the solar cycle enters its declining phase, the occurrence of plasma bubbles decreases accordingly, demonstrating a correlation between EPBs, the solar cycle, and F10.7 flux. Typically, a greater number of EPBs are observed during equinox months[7]. This study focuses on analyzing TEC data related to Bangalore, with previous research indicating that EPB occurrence is influenced by magnetic activity[7]. Magnetic activity, in turn, correlates with changes in the strength of the electric field near the equator, which governs vertical motion in the F-layer. This suggests that magnetic activity may suppress EPB occurrences.

Solar activity also impacts plasma bubble occurrences, with observations showing a higher frequency during quiet periods compared to disturbed ones, warranting further investigation. Our study delves into TEC variation analysis, considering factors such as season, day, magnetic activity, and solar activity. Conducted using IRNSS data, the study spans selected months from February 2015 to April 2022 over Bangalore. The overarching conclusion drawn from our analysis is that plasma bubble occurrence is intricately linked to solar activities, with a higher frequency observed during quiet periods compared to disturbed ones.

ACKNOWLEDGEMENT

This work was possible by the use of IRNSS Receiver provided by ISRO (Indian space research organisation) SAC, Ahmedabad.

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