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Ionospheric gradients in S-band navigation signals are estimated and analysed for the NAVIC system

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ABSTRACT

The most important aspect is ionospheric gradients, which can reduce users of the global navigation satellite system's positional accuracy, especially in low-latitude areas. This paper's primary goal is to estimate the fluctuations in the ionospheric gradient measured by the NAVIC receiver near Guntur, India (16.23 N, 80.44 E). Total electron content (TEC) measurements of S-band (2492.028 MHz) transmissions are used to calculate ionospheric time delays and carrier phase. This study is the first to examine ionospheric gradients over a low-latitude region using NAVIC's S-band signals. The RLS algorithm, short for recursive least squares, is implemented as a single frequency ionospheric model for determining the absolute TEC and the ionospheric gradients along the longitudinal (E-W) and latitudinal (N-S) axes.Also addressed is the annual statistical analysis of the periodic nature of the spatial ionospheric gradients observed in NAVIC S-band signals from June 2016 to May 2017. The RLS model clearly has the ability to predict ionospheric gradients for a single NAVIC station.The results of this effort will help us understand the climatology of ionospheric abnormalities across low-latitude regions.

Gradients, the ionosphere, NAVIC, recursive least squares (RLS), and TEC are index terms.

INTRODUCTION

NAVIC is an independent regional navigation system comprising seven satellites: three in Geo-Stationary Orbit (GEO) and four in Geo-Synchronous Transfer Orbit (GSO). This system is designed to provide position, velocity, navigation, and timing information for various applications. The primary goal of NAVIC is to achieve the required accuracy and integrity parameters of the Standard Positioning Service (SPS) and Restricted Service (RS) for civilian and authorized users, respectively [1]. In the user segment, a NAVIC receiver receives dual-frequency signals, namely L5 at 1176.45 MHz and S-band at 2492.028 MHz, which can be utilized in either SPS or RS modes. Additionally, the receiver can also receive signals from the

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GPS system, specifically the single-frequency L1 signal at 1575.42 MHz, as well as signals from the Satellite-Based Augmentation System (SBAS). The system aims to offer reliable and precise navigation services, catering to the needs of civilian and authorized users in the designated regional area.India being in a low-latitude region experiences significant ionospheric variations that are highly variable in nature [2 - 4]. These variations can lead to challenges in transmitting ionospheric differential corrections to Satellite-Based Augmentation System (SBAS) users via GEO satellites. The reason is that substantial ionospheric gradients between the ground station and the aircraft can cause drifting, which in turn poses a threat to the integrity of the system and can result in significant positioning errors. To address these issues, several researchers have focused on modeling ionospheric delay by estimating ionospheric gradients [5]. These efforts are aimed at understanding and characterizing the ionospheric behavior to improve the accuracy and reliability of navigation systems in the region. Investigations have been carried out to study sudden changes in Total Electron Content (TEC) with latitudinal gradients at the crest zone of the Equatorial Ionization Anomaly (EIA) for the Indian low-latitude region [6 - 8]. Additionally, studies have been conducted to analyze local-scale ionospheric spatial gradients in the Japan region during equinox and solstice periods. Monitoring these local measures of ionospheric gradients with seasonal changes is essential to gain insights into the morphological characteristics of the ionosphere in these regions. Overall, understanding the behavior of the ionosphere and modeling ionospheric gradients is crucial for improving the performance and reliability of navigation systems like NAVIC in low-latitude regions like India. It helps in mitigating the effects of ionospheric variability and ensuring accurate positioning and navigation for users [9].

Airborne GNSS (Global Navigation Satellite System) receivers commonly use single-frequency GNSS measurements to fulfill the navigation requirements for both Ground-Based Augmentation System (GBAS) and Space-Based Augmentation System (SBAS) applications. These receivers typically operate using GPS L1 frequency signals [10]. The code and carrier pseudo-range measurements obtained from GPS L1 signals can be utilized to derive the Total Electron Content (TEC) of the ionosphere. TEC represents the total number of electrons present along the path between the GNSS satellite and the receiver. By analyzing the TEC values derived from these measurements, it is possible to calculate the associated ionospheric gradients in latitude and longitude [11]. Deriving the ionospheric TEC and gradients is

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Research paper UGC CARE Listed (Group -I) Journal Volume 10, Iss 3, 2021

important for understanding the behavior of the ionosphere and its impact on GNSS signals. These measurements aid in the estimation and compensation of ionospheric delays, which can significantly improve the accuracy and reliability of airborne navigation systems using GNSS technology, especially in regions with variable ionospheric conditions like low-latitude areas. Moreover, the derived TEC and gradients also contribute to the overall performance of Ground-Based Augmentation Systems (GBAS) and Space-Based Augmentation Systems (SBAS) by providing valuable information for ionospheric corrections [12-14]. The first section presents the mathematical formulation of the weighted and recursive least squares technique. This technique is likely used for estimating ionospheric Total Electron Content (TEC) and associated ionospheric gradients.The second section provides the TEC data results for different seasonal conditions, such as Equinox and Solstice, as well as during geomagnetic disturbed days. The variations in East-West (E-W) and North-South (N-S) ionospheric gradients are analyzed and presented in this section. The third section involves the validation of the proposed algorithm [15]. To validate the technique, a Chi-square test is likely conducted, and the correlation between the modeled TEC values obtained from the algorithm and the actual measured TEC values is analyzed and reported.In the fourth section, the paper presents statistics related to the annual East-West (E-W) and North-South (N-S) spatial ionospheric gradients. These statistics likely illustrate the variations and characteristics of ionospheric gradients over a yearly timescale.The overall structure of the paper appears to focus on presenting the mathematical methodology, analyzing TEC data under different conditions, validating the proposed algorithm, and providing statistical insights into the spatial ionospheric gradients. This organization allows readers to understand the approach, its accuracy, and the behavior of the ionosphere in different scenarios.

I. CLOSE-UP OF THE LOCAL IONOSPHERE

TEC (Total Electron Content) is a measure of the total number of free electrons encountered by radio waves as they travel through the ionosphere from a GNSS satellite to the user's receiver. The TEC value depends on various factors and can be affected by geographic and geomagnetic effects [14]. It plays a crucial role in ionospheric delay, which is the additional time it takes for GNSS signals to propagate through the ionosphere. The ionospheric delay, denoted as I (in meters), at a specific frequency f (in Hertz), can be approximated using Equation (1): I=40.3f2×TECI=f240.3×TEC where TEC is the Total Electron Content in

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electron per square meter (el/m²). The equation shows that ionospheric delay is inversely proportional to the square of the frequency, and it is directly proportional to the TEC value. As TEC increases, the ionospheric delay also increases, causing a time delay in GNSS signals received by the user's receiver. Equation (1) provides a good first-order approximation for estimating the ionospheric delay based on the TEC value at a specific frequency. This relationship is essential for understanding and compensating for ionospheric delays in GNSS applications, as it directly affects the accuracy and reliability of navigation systems operating through the ionosphere.

CONCLUSIONS AND RESULTS

The NAVIC receiver, made by Accord Systems Inc., was used to collect the processed data at K L University in Guntur, India, which is located at coordinates 16.23 N and 80.44 E. The local ionospheric gradient analysis is performed utilising ground-based TEC data at a transition zone of the northern equatorial anomaly region (Geographic coordinates: 16.23 N Latitude, 80.44 E Longitude; in Geomagnetic coordinates at 7.65 N Latitude, 154.16 E Longitude). The receiver can pick up SBAS signals as well as triple frequency transmissions (GPS-L1, IRNSS L5, and S).

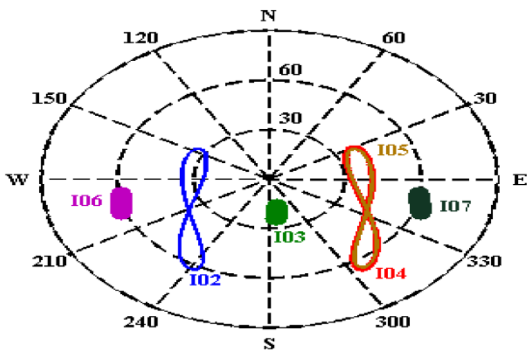

Figure 1 shows the sky-view of NAVIC S-band satellites as they were observed on one full day on December 20, 2016, using data from an Accord Systems NAVIC receiver in Guntur, India.

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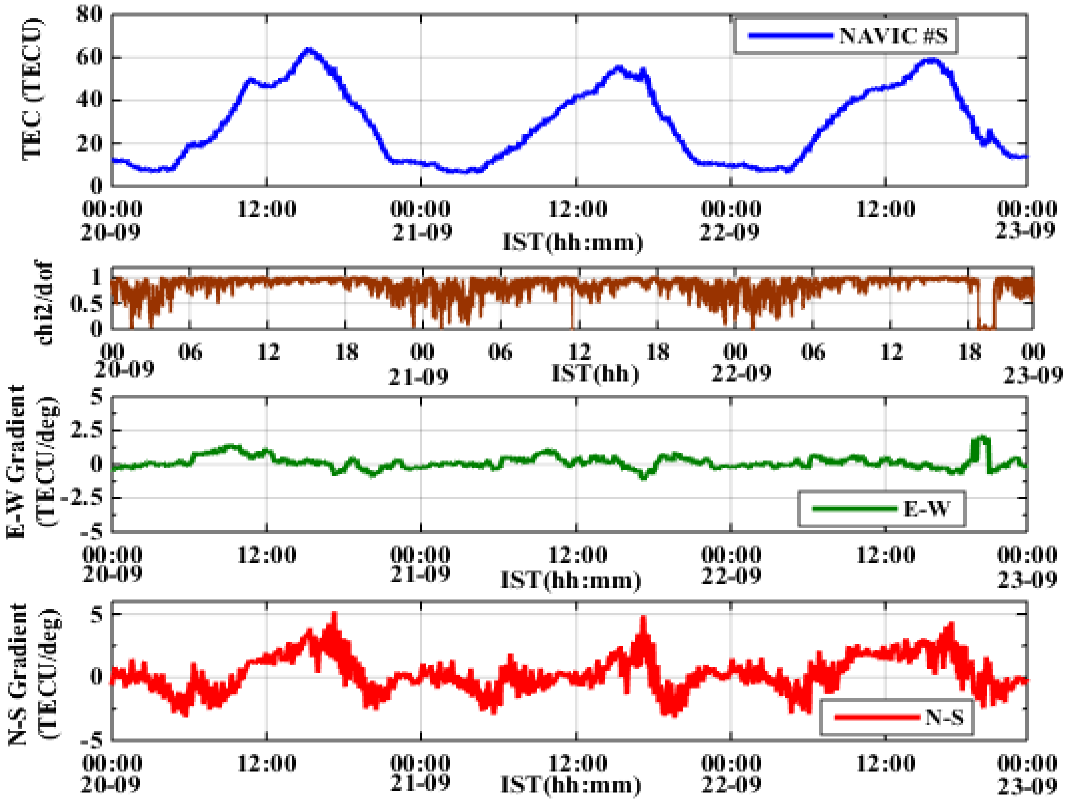

FIGURE 2: Information on the NAVIC S-band from the RLS algorithm for the three days leading up to the September equinox (20–22 September 2016 IST). (Top: Absolute TEC; Bottom:(E-W (green) and N-S (red) gradients, IST=UTC+5.30 hours; Second: Chi-square test scores.)

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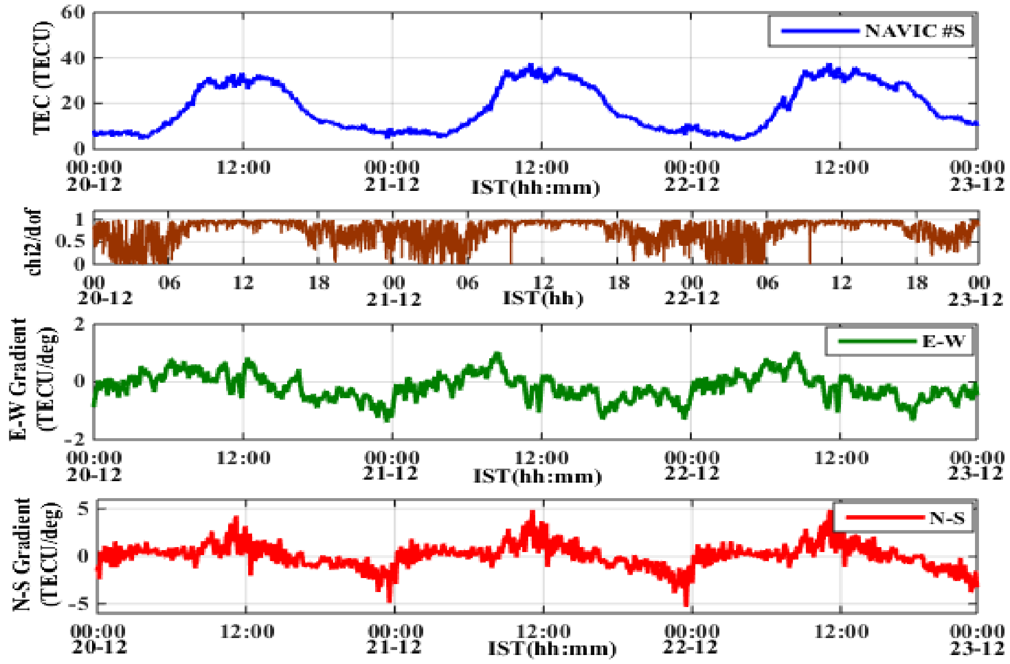

Figure 4 shows the absolute TEC fluctuations for the NAVIC S-band for the three days of the December solstice (20th to 22nd IST) that followed.

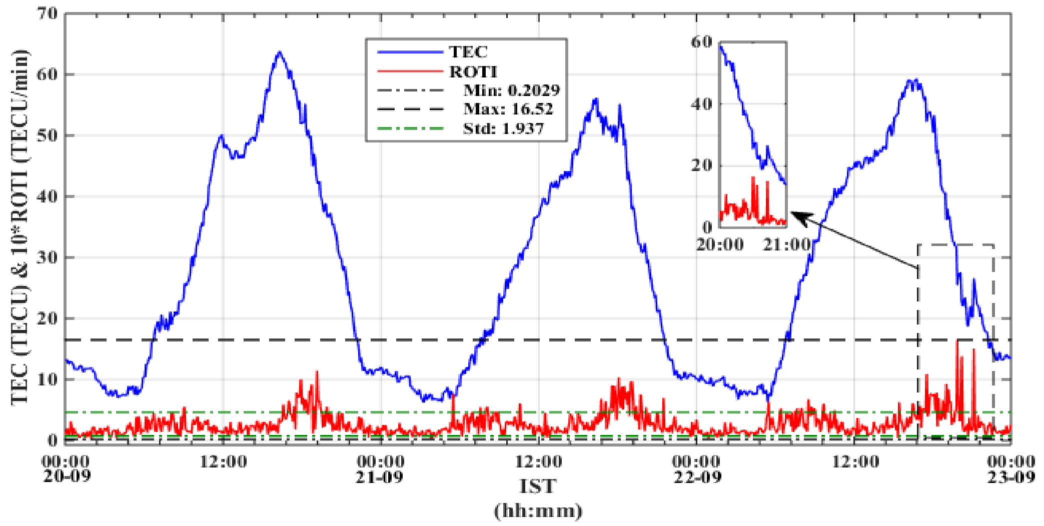

FIGURE 3. Data for the September Equinox using the TEC and Rate of TEC Index (ROTI).In the legend, the ROTI mean, maximum, and standard deviations are displayed.The insight box illustrates the significant changes in TEC and ROTI caused by plasma bubble structures.

C. TEC DATA WITH GEOMAGNETIC DISTURBANCES

The disturbed day is determined from a collection of peaceful days using a real-time Dst index given by the WDC for Geomagnetism, Kyoto (Fig. 5, Top panel). The Dst values decreased

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dramatically in the final week of May 2017, with a minimum of 125 nT at 13:30 IST on May 28, 2017. So, the four days between May 26 and May 29 are used for the ionospheric gradient analysis.

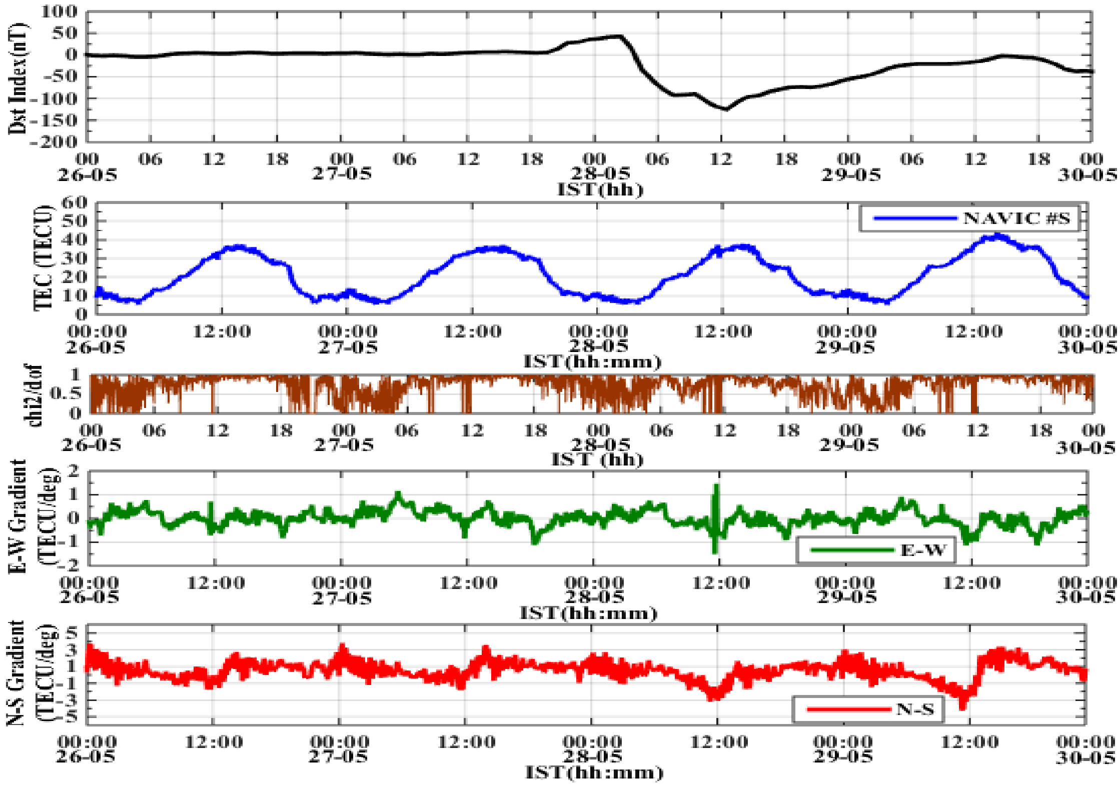
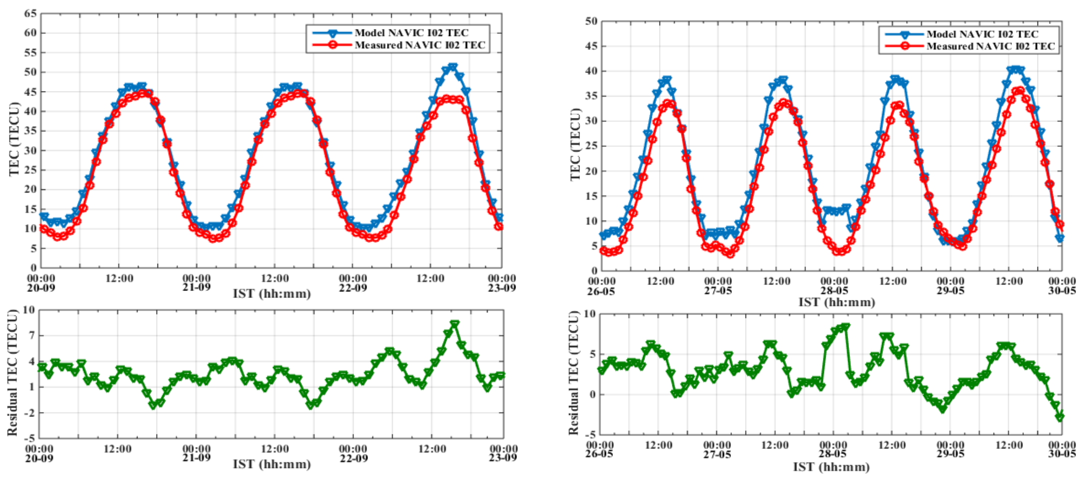


FIGURE 5. Dst Index values recorded during geomagnetic disturbed activity (26 May to 29 May IST) explaining the geomagnetic changes in (nT) values as well as Absolute TEC and ionospheric gradient variations for NAVIC S-band produced by RLS algorithm.



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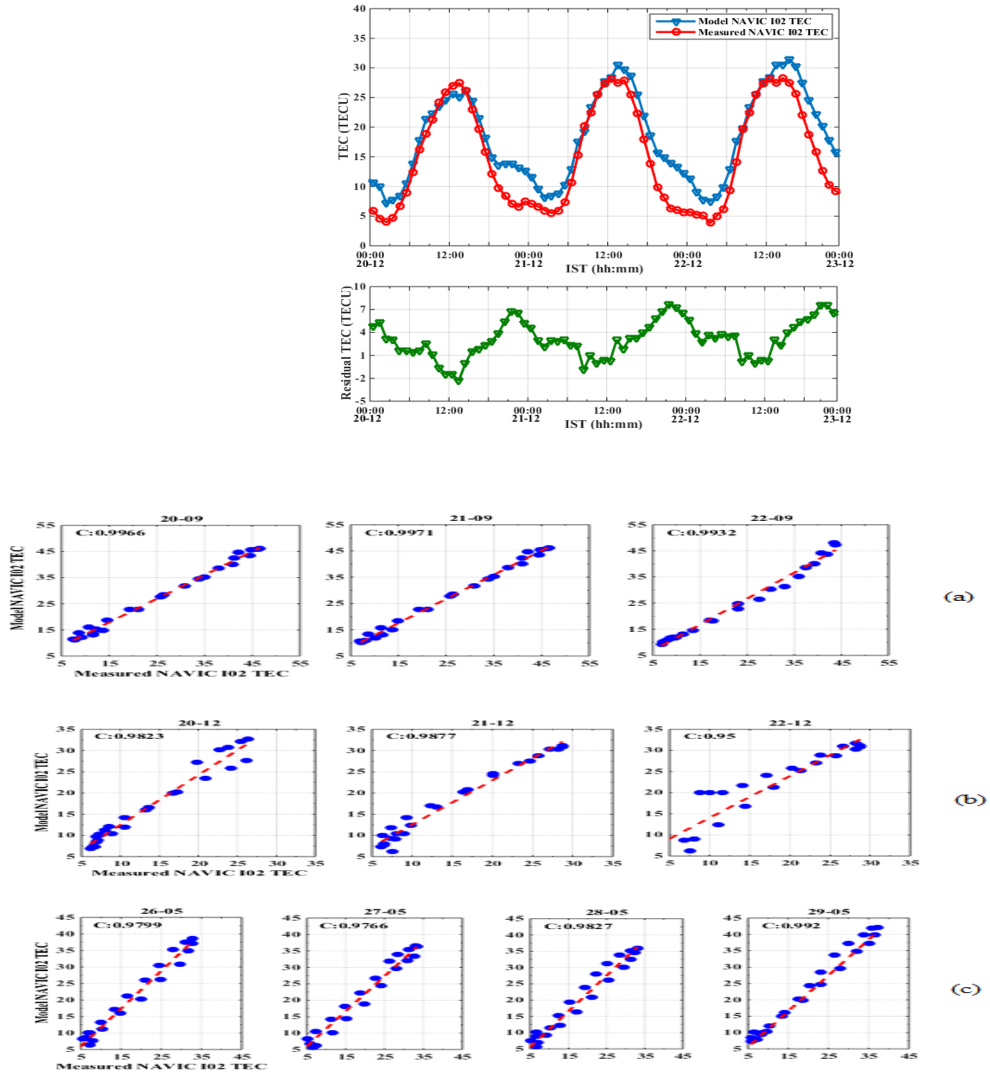

FIGURE 9. Measured and model NAVIC I02 TEC measurements were taken during the September equinox (20 September 2016 to 22 September 2016 IST), December solstice (20 December 2016 to 22 December 2016 IST), and geomagnetic disturbed activity (26 May 2017 to 29 May 2017 IST).

CONCLUSION

According to the results of the current investigation, S band signals are a strong candidate for single frequency ionospheric corrections in NAVIC receivers. The RLS algorithm did a good job of both recognising plasma bubbles and the EIA. The initial findings and analysis are valuable for examining the effects of S-band transmissions on accurate ionospheric gradient measurement.The findings show that TEC spatial ionospheric gradients are greater during

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times of the Autumn equinox than they are during times of the December solstice.To improve positional accuracy, it would be beneficial to study the effects of S-band signals on accurate ionospheric gradient estimation using the preliminary data and analysis.

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