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For Single Frequency GNSS User Applications, a New Ionospheric Model Using the Klobuchar Model Driven by Auto Regressive Moving Average (SAKARMA) Method Over the Indian Region

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ABSTRACT

To forecast and improve the accuracy of ionospheric delay estimations for GNSS users, a new model called Single Frequency GNSS User Applications utilising Klobuchar model driven by Auto Regressive Moving Average Method (SAKARMA) is presented. The Assimilated Indian Regional Vertical Total Electron Content (AIRAVAT), which is only for the Indian region (longitude: 65°E to 100°E; latitude: 36°E), is used to produce the hourly VTEC maps.During the period from 2nd to 12th September 2017, a dual-frequency Navigation with Indian Constellation (NavIC) receiver was deployed at the KL Education Foundation in Guntur, India. The geographic coordinates of the receiver were 16.37°N latitude and 80.37°E longitude, while the geomagnetic coordinates were 7.44°N latitude and 153.75°E longitude.The receiver was used to collect observations during this time frame, specifically focusing on ionospheric delays. To validate the accuracy of the ionospheric model, the SAKARMA model was employed. This model was compared against other established models, including the Klobuchar model, which uses Klobuchar-style coefficients provided by the Center for Orbit Determination in Europe (CODE) under the CODKlob model. Additionally, the BeiDou System (BDS2) model and the NeQuick 2 model were also used for comparison.The purpose of this validation was to assess the effectiveness of the SAKARMA model in forecasting ionospheric delays at a low-latitude NavIC station. By comparing the results obtained from the SAKARMA model against the other established models, the study aimed to determine the model's accuracy and its ability to provide reliable ionospheric corrections for dual-frequency NavIC receivers operating in the Indian region.

KEYWORDS: Klobuchar model, auto regressive moving average (ARMA) model, SAKARMA model, GNSS, NavIC, ionospheric delay.

INTRODUCTION

The accuracy and reliability of Global Navigation Satellite System (GNSS) positioning and navigation applications can be adversely affected by ionospheric effects. Among these effects, ionospheric time delay is a significant source of error in satellite-based radio navigation systems [1]. This time delay is primarily caused by the presence of charged particles in the ionosphere, and it leads to errors in GNSS measurements. The magnitude of positioning errors due to ionospheric delay depends on the "Total Electron Content" (TEC) in the region of interest, considering the local time and geographic location of the receiver, as well as the radio frequency of the GNSS signal [2]. The relationship is represented by the equation I = 40.3/cf2 * TEC, where I is the ionospheric delay and cf is the frequency of the GNSS signal. One way to correct for ionospheric delay in GNSS measurements is by utilizing dual-frequency observations, taking advantage of the dispersive nature of the ionosphere [3-5]. However, in real-time applications, ionospheric errors still pose a threat to the accuracy of positioning and navigation, particularly for single-frequency GNSS receiver users. These errors can be substantial, ranging up to 100 meters, which significantly impacts the reliability of location-based services provided by the GNSS system [6]. The Indian Space Research Organisation (ISRO) has successfully developed India's own GPS system called the Indian Regional Navigation Satellite System (IRNSS), also known as Navigation with Indian Constellation (NavIC). NavIC provides users with three-dimensional positioning, space, and time information over and around a 1500 km area of the Indian region [7]. It offers greater positioning accuracy compared to other Global Navigation Satellite Systems (GNSS) in this region. [8] have proposed a methodology for correcting Klobuchar coefficients specifically tailored for NavIC single-frequency users [9]. These coefficients are crucial for mitigating ionospheric delays and improving the accuracy of GNSS positioning. In a study conducted [10], they evaluated the Klobuchar model's performance and found that the differences between the Klobuchar model and the measured dual-frequency ionospheric delays varied with solar activity and latitudes [11-13]. This highlights the importance of considering different environmental conditions when using ionospheric models for GNSS applications. Introduced a Sophisticated Klobuchar Model (SKM) based on the Holt-Winters exponential smoothing

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model, which was applied over the China region. The SKM was tested using six days of training data sets and aimed to fill missing data for dual-frequency receivers and forecast ionospheric delays [14]. Observed a degradation in the ionospheric correction rates of Beidou/GPS system models during a geomagnetic storm condition with high solar activity in 2015 [15]. Such findings underscore the significance of studying and accounting for space weather phenomena when developing and using GNSS models to ensure reliable performance during challenging conditions.Overall, these studies demonstrate the ongoing efforts to improve GNSS positioning accuracy and address ionospheric effects to enhance the performance and reliability of navigation systems like NavIC in specific regions.

PROPOSED IONOSPHERIC SAKARMA MODEL AND DATA

The Assimilated Indian Regional Vertical TEC (AIRAVAT) system generates VTEC (Vertical Total Electron Content) maps covering the geographic latitudes ranging from 5° to 40° and longitudes from 65° to 100°. These maps are represented on a spatial grid of 2.5° latitude by 5° longitude, resulting in 120 grid points. The temporal resolution of these maps is one hour (1 h). These VTEC maps provide valuable ionospheric information over the Indian region.For the validation of the SAKARMA model, VTEC data from the AIRAVAT maps during the period from 1st to 30th September 2016 was used.In addition to the AIRAVAT data, ionospheric delays estimated using measurements from the Navigation with Indian Constellation (NavIC) system were also considered. NavIC is a satellite navigation system developed by the Indian Space Research Organisation (ISRO), consisting of 7 satellites in its constellation, including 3 in Geo-Stationary Orbit (GEO) and 4 in Geo Synchronous Transfer Orbit (GSO). The NavIC system provides positioning, navigation, and timing services and also has capabilities for monitoring ionospheric space weather. The GEO satellites in the NavIC constellation are particularly valuable for ionospheric research, especially in the near-equatorial region, due to their stable position in the Ionospheric Pierce Point (IPP). This stability allows for better monitoring of dynamic changes in the low-latitude ionosphere, which is significant for regions like India that are susceptible to Equatorial Ionization Anomaly (EIA) effects on satellite communication and navigation links. Overall, the combination of VTEC data from AIRAVAT and ionospheric measurements from NavIC provides valuable information for validating and improving the SAKARMA model and enhances our understanding of the ionosphere's behavior over the Indian region.

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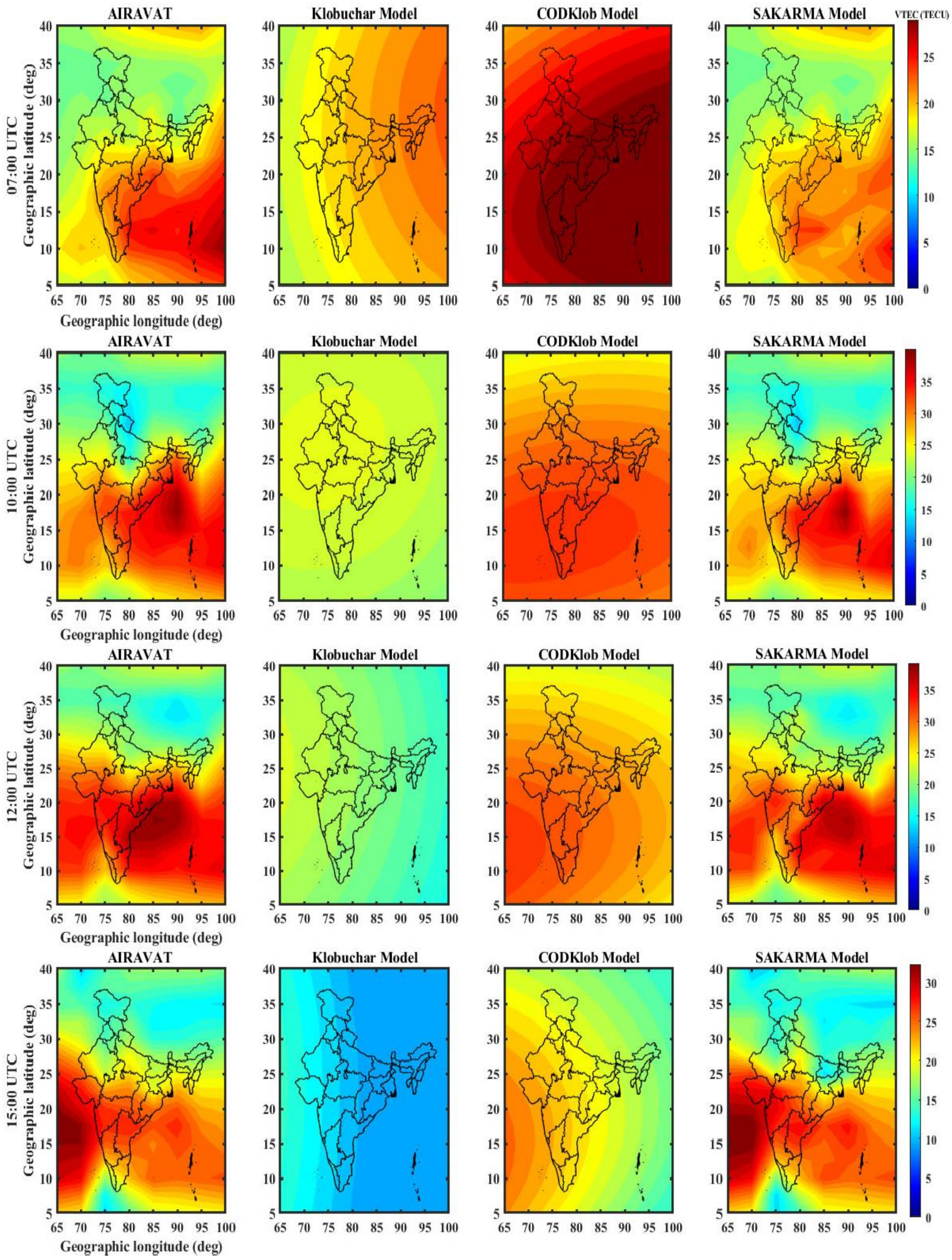

FIGURE 1 shows the performance validation of the SAKARMA Model in calculating ionospheric delays (colour bars indicate VTEC values in TECU).

During the International Geomagnetic Quiet Day on September 16, 2016, over the Indian region, FIGURE 1 shows the performance validation of the SAKARMA Model in calculating ionospheric delays (colour bars indicate VTEC values in TECU).

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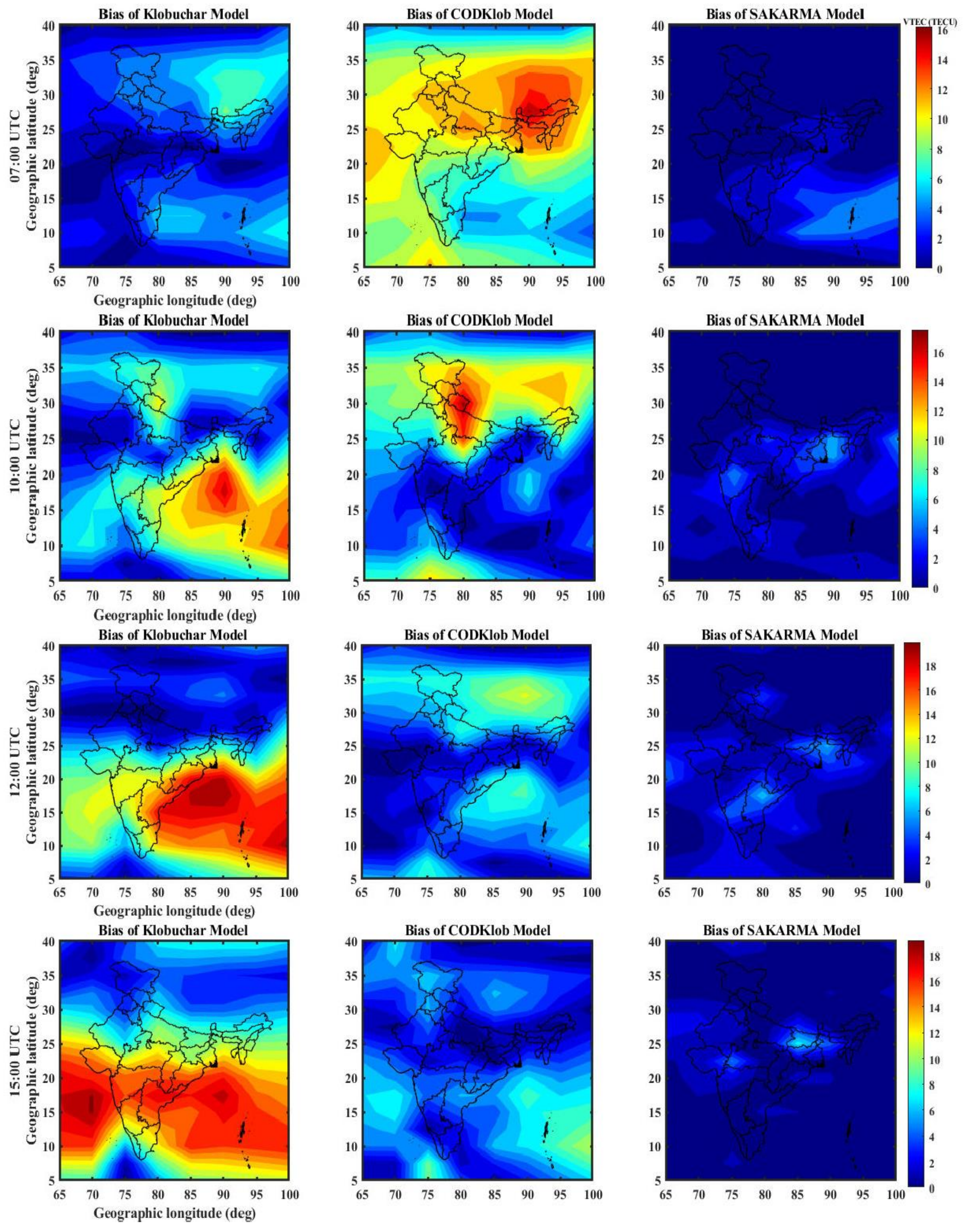

FIGURE 2. The actual absolute discrepancies of the Klobuchar, CODKlob, and SAKARMA models with respect to AIRAVAT VTEC data in calculating the ionospheric delays on September 16, 2016, the International Geomagnetic Quiet Day, across the Indian subcontinent.

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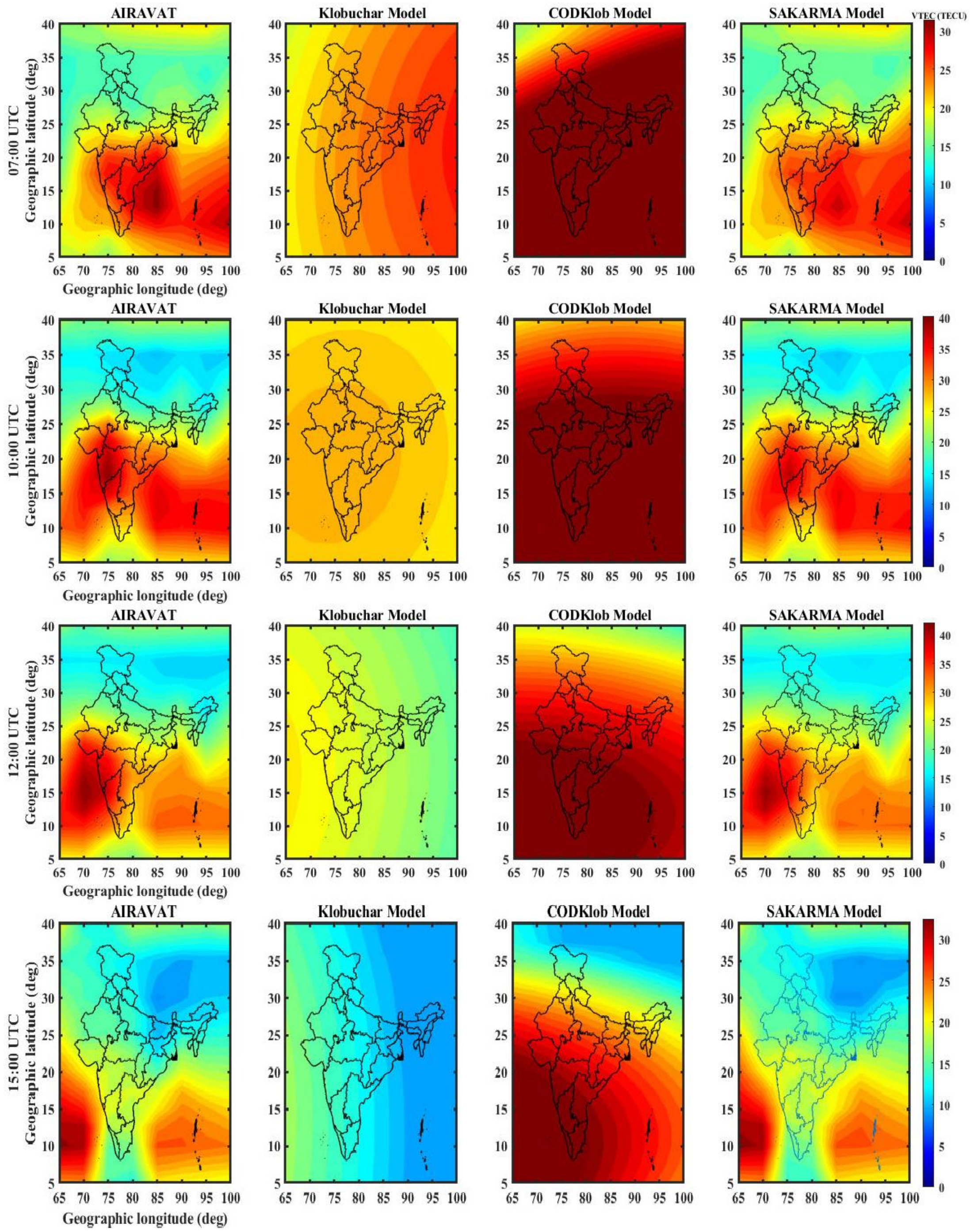

FIGURE 3 shows how well the SAKARMA Model performed in calculating ionospheric delays on September 29, 2016, the International Geomagnetic Disturbance Day, over the Indian subcontinent.

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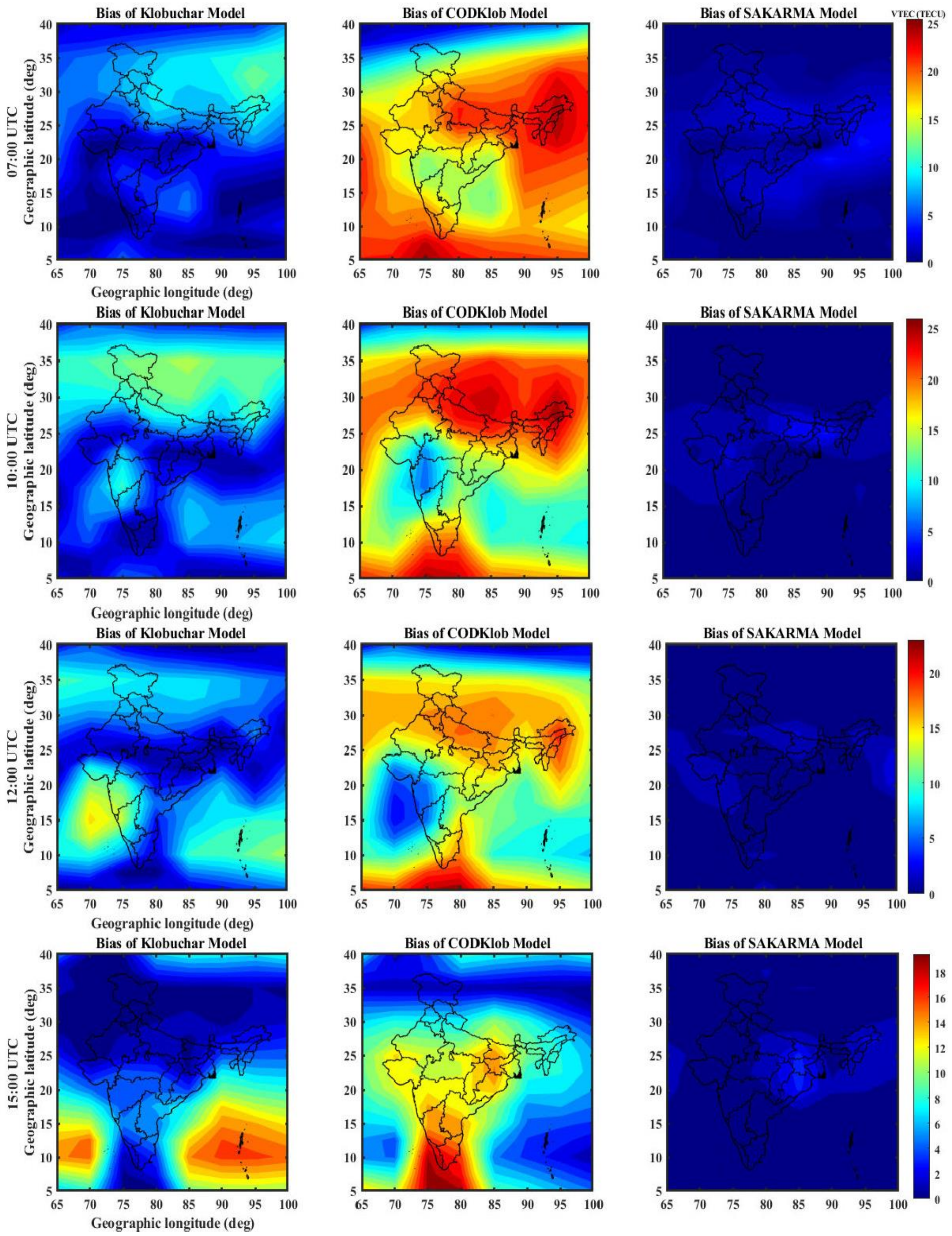

Figure 4 shows the actual absolute disparities between the Klobuchar, CODKlob, and SAKARMA models and the AIRAVAT VTEC data in calculating the ionospheric delays on

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September 29, 2016, the International Geomagnetic Disturbance Day, across the Indian region (colour bars represent VTEC values in TECU).

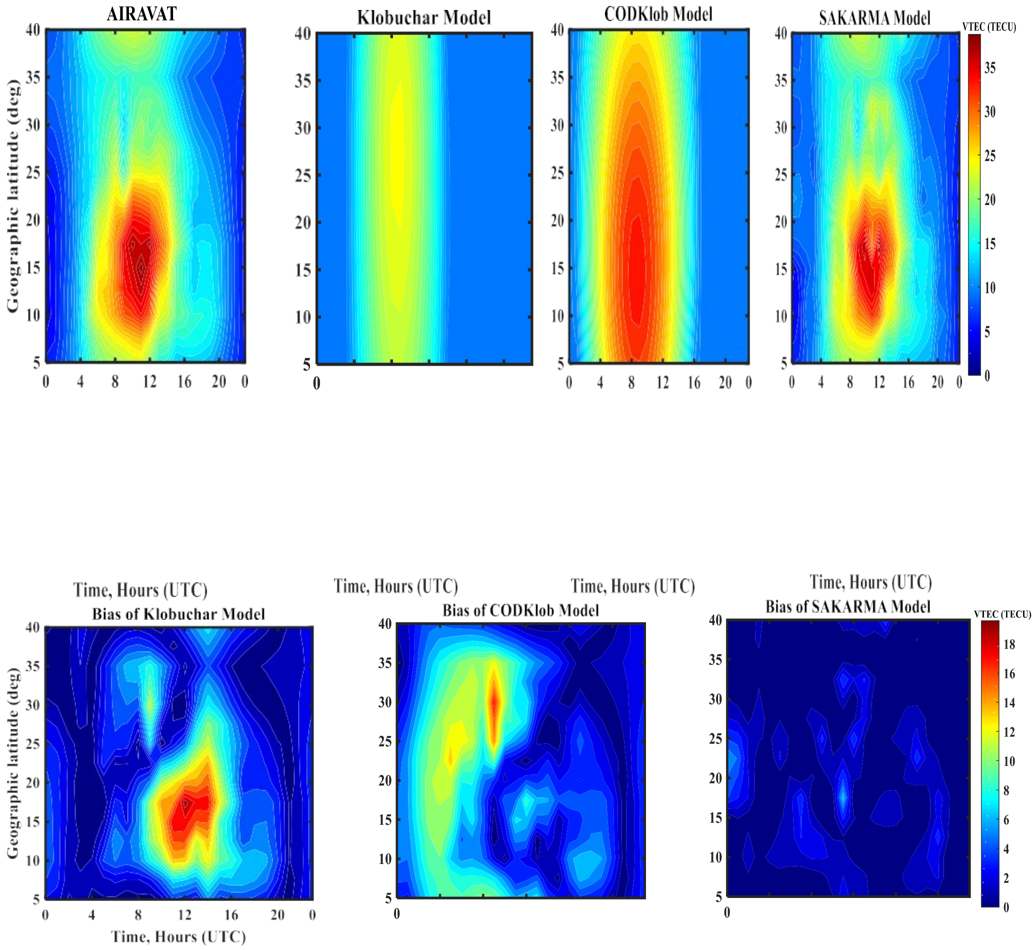

FIGURE 5. On September 16, 2016, a geomagnetic quiet day, the latitudinal EIA features predicted by the SAKARMA model.

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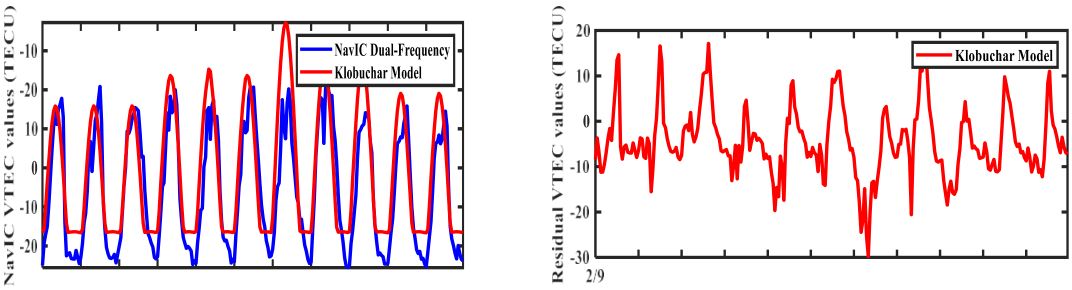
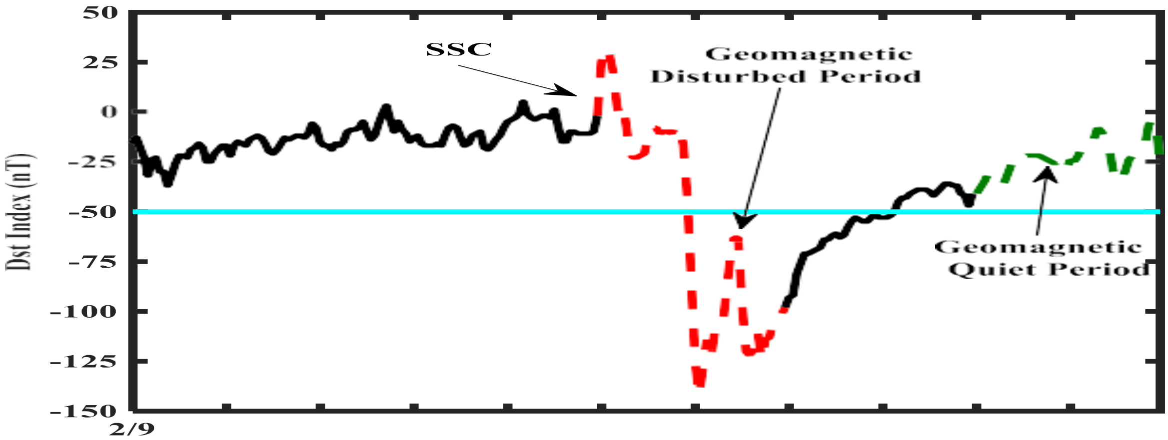
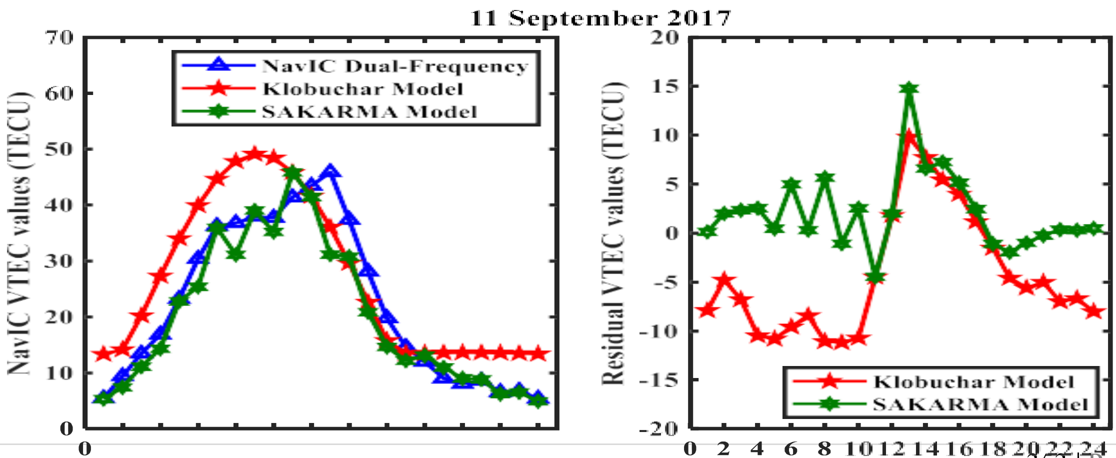


Figure 9 shows the estimated VTEC values from NavIC receiver data, the estimated VTEC values from the Klobuchar model, and the estimated residuals from the Klobuchar model.





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RESULTS AND DISCUSSION

The evaluation aims to determine the model's effectiveness in providing accurate ionospheric corrections for both the assimilated VTEC data and the real-time measurements from the NAVIC system.Additionally, the SAKARMA model is validated separately for two distinct periods: 1st to 30th September 2016 and 2nd to 12th September 2017. During these periods, the model's performance is tested using the AIRAVAT VTEC maps and the NAVIC observations, respectively. This validation allows for an assessment of the model's consistency and reliability over different years.The AIRAVAT VTEC maps are chosen for their data assimilation technique, which relies on the Kalman filter and incorporates regional ionospheric space weather data from both space and ground-based satellite observations over India [18]. This approach enhances the accuracy and completeness of the VTEC data used in the evaluation and validation of the SAKARMA model.By conducting these comprehensive evaluations and validations, researchers aim to determine the robustness and applicability of the SAKARMA model for different datasets and varying ionospheric conditions, ultimately improving the ionospheric corrections for GNSS applications in the Indian region.

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