Investigation on the effect of the solar/geomagnetic storm on NavIC ionosphere data

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Abstract

Ionosphere contributes the highest error for single frequency receivers. Solar storm is one of the major phenomenons which significantly impact the Earth's ionosphere and thus affect the position estimation of single frequency user receivers.
In this paper, a detailed study on the impact of recent solar and geomagnetic storms on the ionosphere delay over Equatorial Ionosphere Anomaly region is presented. The study aims to investigate the latitudinal and longitudinal variation of ionosphere delay during solar/geomagnetic storms in the year 2024 over the Indian region.
Our analysis focuses on the characterizing the temporal and spatial variations in the ionosphere delay derived by utilizing the reference receivers' data of Navigation with Indian Constellation (NavIC). The effect of the storm on the NavIC broadcast ionosphere models is also presented.
The results indicate that solar storm can cause rapid disturbances and fluctuations in the ionosphere delay. It has been observed that storm affects the ionosphere differently at different latitudes. However, there are no significant changes observed at different longitudes within Indian land mass. Additionally, the investigation highlights that the disturbances do not affect the accuracy of grid based NavIC ionosphere model.

Keywords: NavIC, Ionosphere, solar and geomagnetic storm

1. Introduction

The ionosphere plays a vital role in radio wave propagation and satellite communication. It is characterized by a high concentration of free electrons and ions, which are primarily generated through the ionization of neutral atoms and molecules by solar radiation [1]. Ionosphere delay directly impacts the accuracy and reliability of positioning, navigation, and timing (PNT) services. Variations in ionosphere delay are primarily due to fluctuations in the total electron content (TEC) along the line of sight between satellite and receiver pair.
During solar or geomagnetic storm events, the increased influx of solar radiation and energetic particles can lead to rapid enhancements or depletions in TEC, causing significant changes in the ionosphere delay [1-3]. These variations can introduce errors in the GNSS-based systems, affecting a wide range of navigation related applications [3]. NavIC service area covers the Equatorial Ionosphere Anomaly (EIA) region which gets highly impacted during these storms [3-5]. Therefore, understanding and modeling the effects of solar storms on ionosphere delay over Indian region is therefore, critical for improving the accuracy of NavIC ionosphere corrections, developing robust mitigation strategies, and enhancing space weather forecasting capabilities.
In this paper a detailed study on the impact of solar/geomagnetic storms on ionosphere delay is presented. Our analysis focuses on the characterizing the temporal and spatial variations in the ionosphere delay derived using Indian Regional Navigation Satellilte System (IRNSS) data.
The paper is structured as follows: Section 2 describes the data sources and methodologies used in this study. Section 3 presents the results of our analysis, highlighting the observed changes in ionosphere delay during solar/geomagnetic storms. Finally, section 4 summarizes our conclusions and outlines the potential directions for future research.

2. NavIC Ionosphere Measurements and Data used

NavIC comprises 15 reference receiver stations over Indian land mass which provide range measurements at L5 and S frequencies [6]. The L5 and S frequencies' data is used to estimate ionosphere delay by using the geometry free combination. The estimated delay is further processed to get true ionosphere delay by removing differential hardware biases [7-8]. The processed ionosphere measurements are used to generate broadcast ionosphere parameters for NavIC [6]. Currently, NavIC is broadcasting grid based and coefficient based ionosphere messages for the users [9-11]. It is advised to use the grid based ionosphere parameter to achieve the best accuracy among all the ionosphere models [4][9]. Therefore, in this paper, the accuracy of grid based ionosphere parameters during storm is studied.

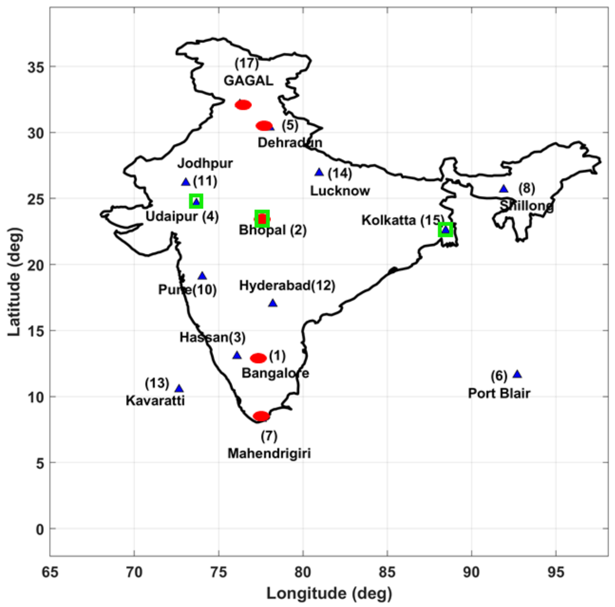

Figure 1: Location map of the NavIC reference receivers. The red circle and green rectangle indicate the receivers used for study.

In Fig. 1, red circle are the locations of the receivers which are used to analyses the effect of storm on the ionosphere delay varies latitudinal way. The longitudinal variation in all these stations are less than 1°. Similarly, green color rectangle represents the stations used to study longitudinal variations in ionosphere due to storms. The latitudinal variations of these locations are within 1°-2°. Two different sets of dates are selected based on the data availability as well as the solar and geomagnetic indices. First set of dates are 10-14 May 2024 (date set 1) and the other set of the dates are 28-30 June 2024 (date set 2). To avoid the elevation angle dependency, the Slant ionosphere Delay (SD) is converted to Vertical Delay (VD) for the analysis.

3. Results and discussion

The variations of solar and geomagnetic activities are presented through Solar radio Flux (SF) or F10.7, Dst, Kp and Ap indices for the month of May and June 2024 in Fig. 2. The green color vertical lines represent the dates which are chosen for study. As shown in the figure, the SF increases from May 1 and reaches to its peak on 10^{th} May. Afterwards, the kp and Ap indices increases and reached to the maximum on 11^{th} May. The Dst index also crosses -100 nT on 11^{th} May.

As shown in the figure, the SF is the highest on 10 May, however, the geomagnetic indices shows its impact on the next day on 11^{th} May. Similar observations are there for date set 2 also.

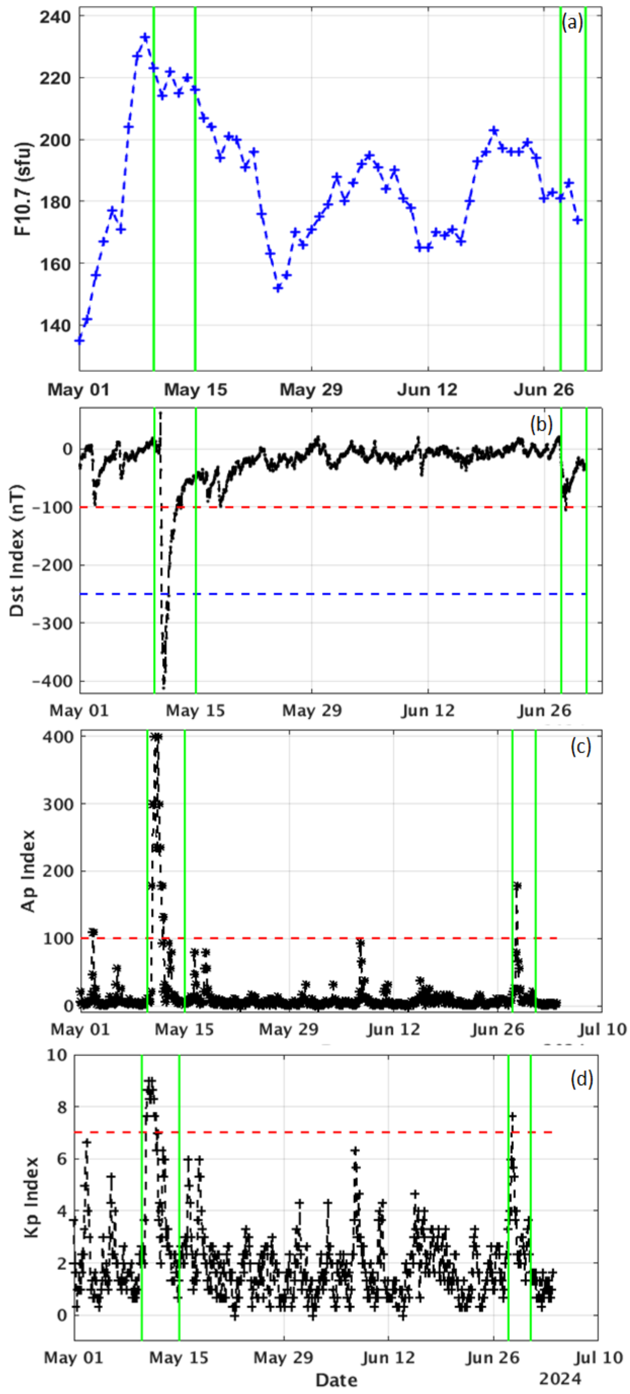

Figure 2: Variation of solar and geomagnetic indices for the months May and June 2024. Green color vertical lines covers the dates used in the analysis. Red color line indicates the threshold for intense storm.

The study is divided into three parts. The first and second parts access the latitudinal and longitudinal wise effect of the storms on the NavIC Ionosphere Measurements (IM). The third part is the assessment of the storm on grid based NavIC ionosphere model.

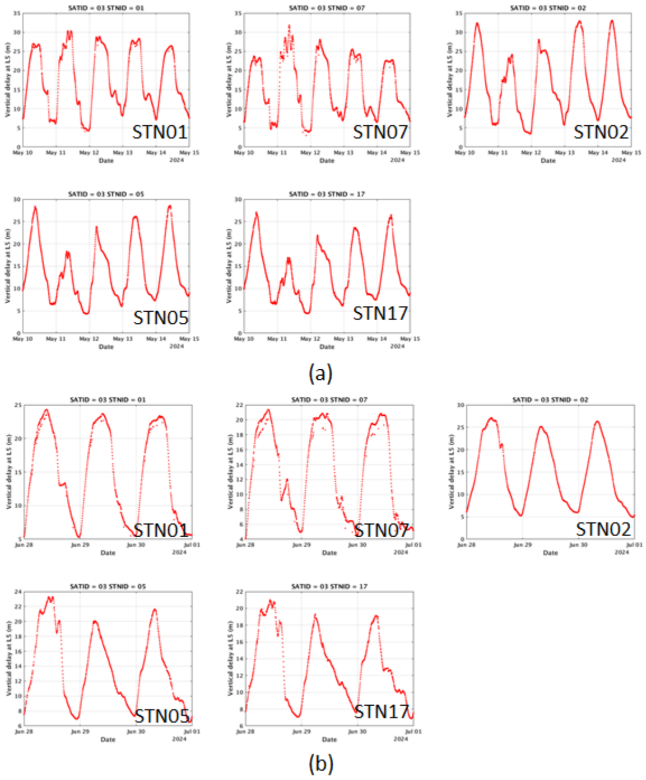

Figure 3: Latitude wise variations of the ionosphere delay measurements at different stations for (a) date set 1 and (b) date set 2.

To study the impact of storm on Indian latitudes, NavIC reference receiver stations with station id 01, 02, 05, 07 and 17 are chosen. The locations of these stations are shown in Fig. 2 with red color circles. Fig. 3 (a) and (b) are the variations of IM over time for both the date sets for latitude wise study.

Fig. 3 shows that the effect of storm on the IM is visible on 11th May not on the 10th May. As shown in the figure, for date set 1, stn 02, 05 and 17 only shows the strong Post Storm Depression (PSD) in the IM but other stations do not shows the similar variations. Since the storm for date set 2 is not as higher as for date set 2, the magnitude of PSD for date set 2 is not as high as it is with date set 1. The stations below 20° N does not show any PSD, however, the fluctuations of the peak time VD is observed due to storm.

Fig. 4 (a) and (b) represents the variations of the IM at different longitudes for (a) date set 1 and (b) date set 2. For this purpose, the reference receiver stations with id 02, 04 and 15 is chosen. The locations of these stations are shown in Fig. 2 by green color rectangles.

As observed in the Fig. 4 (a), the PSD is slightly different on 11-12 May among all dates of set 1. However, the impact of storm on date set 2 for all stations remain same. Time series variations show that longitudinally, the storm impacts the ionosphere in same way to all the receivers.

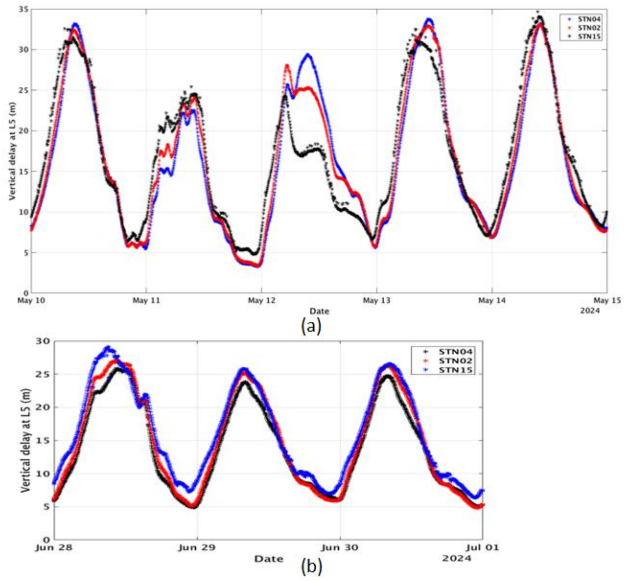

Figure 4: Variations of the ionosphere delay measurements at different longitudes for (a) date set 1 and (b) date set 2.

Fig. 5 represents the percentage of error correction in NavIC grid ionosphere data for (a) date set 1 and (b) date set 2. It has been observed that the performance of grid based ionosphere model remain consistent throughout the storm in both date set 1 and 2. Since it uses near real time data, the grid based model is able to capture the ionosphere fluctuations during storm and does not get significantly affected by it.

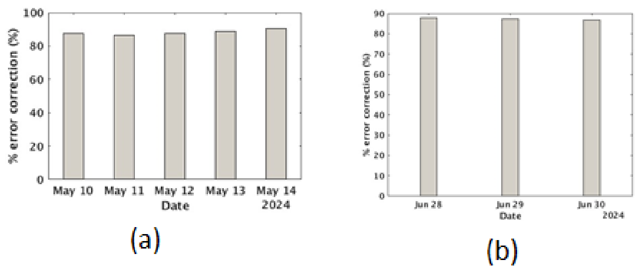

Figure 5: Percentage of error correction in NavIC grid based ionosphere delay model with respect to NavIC ionosphere measurements of all receivers for (a) date set 1 and (b) date set 2.

4. Conclusion

In this paper, the investigation is carried out on the effect of solar and geomagnetic storms on the NavIC ionosphere delay. It has been observed that the effect of solar and geomagnetic storms varies and affect differently on the receivers located at different latitudes but have similar longitude. However, the receivers located at different longitudes but at similar latitudes show similar characteristics during storm. The post storm depression is also observed on the receivers located at latitude above 20°N from the equator.

The analysis also found that the NavIC single frequency grid based ionosphere delay broadcast parameter does get affected by the storms significantly. In future we are intended to extend the analysis for the longer period of time.

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