*URSI GASS 2020, Rome, Italy, 29 August - 5 September 2020*

# Study of thunderstorm induced ionospheric irregularity and plasma bubbles using NavIC data

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## Abstract

Severe thunderstorm which behave as an electric generator sometimes introduce an electric current up to few kiloampere to the global electric circuit due to cloud-to-cloud and cloud-to-ground lightning [1]. The navigation satellite signal in L band, which is basically used for positioning application, provides a good opportunity for monitoring of Ionosphere from signal propagation delay affected by the medium. An effort on monitoring the lightning influenced irregularities over the ionosphere has been made in this article. Ionosphere contained total electron content (TEC) variation has been computed from newly launched Indian Regional Navigation Satellite System NavIC. The availability of S band in NavIC provides an extra opportunity to study the nature of atmospheric variables in a different frequency band. Both L and S band studies of TEC variation during lightning event are incorporated and compared with its consecutive non-lightning days in this article.

## 1 Introduction

The variation of ionospheric plasma is strongly correlated with the solar radiation and geomagnetic activity. However, some other reports have pointed out that the extreme tropospheric events such as thunderstorms, heavy lightning can also change the ionospheric total electron content distribution [2]. Lightning which is the discharge between separated positively charged ice particles and negatively charged small other particles generates a huge energy and couples through quasi electrostatic and electromagnetic pulsed field. This generated energy then reaches to lower ionosphere and produces reionization by heating up this medium. It is shown that atmospheric gravity wave generated by strong lightning event may also perturb lower ionosphere and heating the D layer redistribute the TEC in this layer [3].

Based on these reports we have carried some studies of ionospheric observation by a static NavIC GNSS receiver at Kolkata during lightning days.

## 2 Methodology

### 2.1. Experimental Description

The Indian Regional Navigation Satellite System, with operational name NavIC, is a regional navigation system over India subcontinent with seven satellites constellation (four are geosynchronous and three are geostationary) operated at two widely separated frequency bands, L5(1176.45 MHz) and S1(2492.028 MHz).

Data for this study has been collected from a dual frequency IRNSS/GPS/SBAS standard positioning service (SPS) user receiver installed on the rooftop of Indian Statistical Institute Kolkata. It is capable of tracking NavIC (dual frequency L5 and S1), GPS (L1) and SBAS signals and logged data with 1Hz resolution.

Lightning data has been observed from world-wide lightning network (WWLN) which provides lightning energy in Joules, latitude, longitude, date and time of strikes, maximum number of strikes observed by most number of stations operating over world-wide.

### 2.2. Data Pre-processing

doppler frequency shift are basic GNSS observables commonly used for navigation application and atmospheric studies. However, only carrier phase delay and the pseudorange, which are basically used for range determination between satellite and user, are considered for this study. Both of these two ranges which are expressed by Eq. 1 and 2 are erroneous by many error sources such as unintentional satellite clock and orbital errors, deterministic ionospheric error, tropospheric error, random multipath error and thermal noises. Among these error sources ionosphere has the most dominating contribution and can be estimated by standard two frequency measurements. Pseudorange is contaminated by random errors which are up to few meters level and for carrier phase it is up to centimeter level. The iono delay has been calculated by method provided by Braasch 1994 [4]. ROTI has been measured by the method provided by Kumar et al. [5].

## 4 Results and Discussion

### 4.1 VTEC Variation

The variation of 1min average VTEC during lightning day (May 13, 2018) has been shown in Fig. 1 and compared with non-lightning days (May 26 and 27, 2018). A sudden increase of VTEC has been clearly observed from UTC 8hr to 13hr during the lightning day compared to non-lightning days. Dst index of the chosen days show (>–25) indicating there was no geomagnetic disturbance during the selected days.

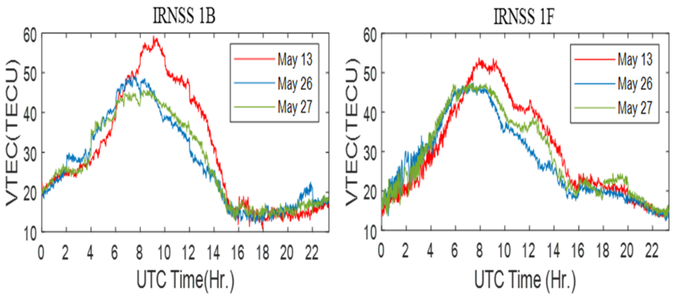


**Figure 1.** VTEC variation of lightning and nonlightning days.

We also have taken five geomagnetic calm days before and five days after the lightning event. For these days there is no lightning event happened. The time series of mean and the standard deviation of these selected days along with the variation of VTEC of lightning days is shown in Fig.2. The deviation of lightning day VTEC variation clearly correlates with the Fig.1

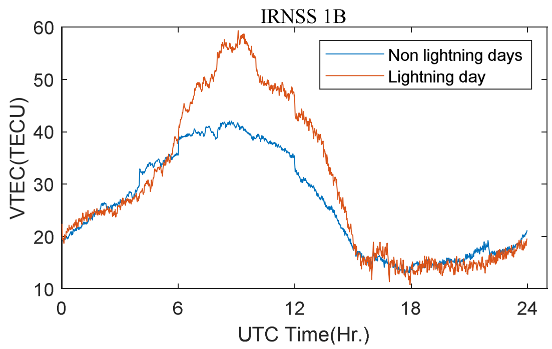


**Figure 2.** VTEC variation of lightning over average of nonlightning days.

WWLN data shows[Fig. 3] that there is plenty number of lightning events which are detected by number of stations around the study location. It clearly proves that this increase of TEC is influenced by the lightning events as the thunderstorm generated electric field and gravity wave may travel up to ionosphere and causes redistribution of ionization which in turn causes the enhancement of TEC

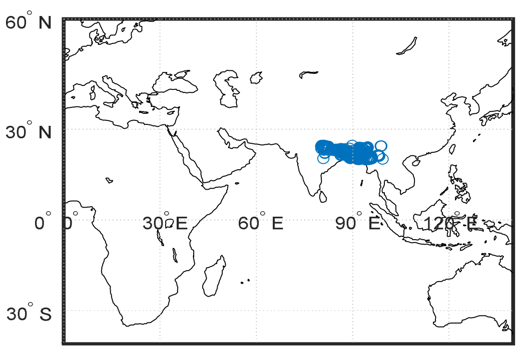


**Figure 3.** Lightning strike around kolkata.

by causing the plasma drift or heating up the medium and causing ionization [5].

## 4.2 Plasma bubble observation

Plasma bubble is an irregular and unstable plasma density region formed at equatorial ionosphere region due to the Rayleigh-Taylor (RT) instability process during the post sunset period [6]. The presence of plasma bubble over the earth atmosphere detected by GPS network was shown by Norsuzila et al by depletion of TEC during solar flare [7]. Fejer and Scherliess et al has reported that the occurrence of plasma bubble is mainly due to the geomagnetic disturbance [8]. Nishioka et al has shown a statistical report of spatial and temporal variation of plasma bubble occurrence over various continents by ground-based GPS observations [9]. They reported that the occurrence of plasma bubbles in Asian continent is maximum at just after the sunset during the magnetic equinox which is during end of March and end of September and the occurrence is more during the March than the September. Kumar et al. () showed the possibility of lightning induced plasma bubble development near ionospheric F region of strike location. They reported that the perturbation of lightning to the ionosphere by modifying electric field may causes E×B drift and Perkins instability and Rayleigh-Taylor instability which causes charge accumulation on both side of thunderstorm and lifting of low density plasma to upward direction which in turn causes the bubbles by high density plasmas.

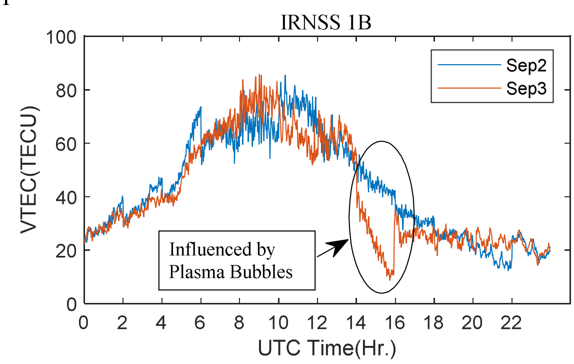


**Figure 4.** VTEC variation in presence of plasma bubbles.

We also found some irregular nature of VTEC variation during the early September 2018 by our ground based NavIC receiver observation. A sudden depletion of VTEC level from the measurement of IRNSS1E has been observed [Fig. 4] on September 3, 2018 from 12 UTC to 13:30 UTC. As the Dst index of the said day >-3 and the occurrence of depletion starts from almost 2hr after the sunset the possibility of geomagnetic influenced perturbation can be neglected. We have compared the VTEC variation by its consecutive day which is also a geomagnetic quiet day (Dst>-10) and no such irregularity has been observed for remaining time between these two days. This enhance the possibility of development of plasma bubbles influenced by the lightning events. To measure the small scale variation the standard deviation of ROTI has been also calculated for the lightning days and compared with non-lightning days as several articles suggested observation of ROTI as a proof of development of plasma bubble over the observation point.

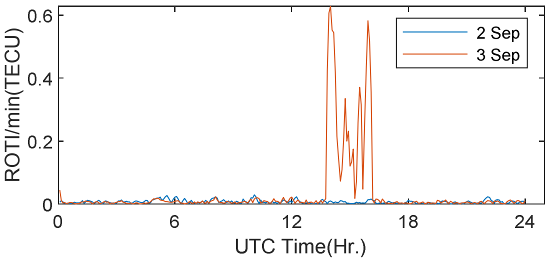


**Figure 4.** ROTI variation due to plasma bubbles.

We have calculated the ROTI with 5min window which is shown in Fig.5. The peaks over the variation of ROTI clearly emphasize our assumption of possibility of development of plasma bubbles.

## 5 Conclusions

The paper present observational evidence of lightning induced irregulates in the ionosphere using measurements from a NavIC receiver at Kolkata. The preliminary results indicate that plasma bubble can form long after sunset hours due to severe thunderstorms. The results indicate need for more such observation for better understanding of the coupling of lower atmosphere and ionosphere.

## 6 Acknowledgements

Authors thankfully acknowledge Space Applications Center, ISRO for providing the NavIC Receiver and financial support.

## 7 References

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