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Secondary Gravity Wave Observed over Eastern India and Bangladesh Region on April 1, 2018 by NavIC/GAGAN/GPS Network

Soumen Datta* (1), and Saurabh Das(1)
(1) Indian Institute of Technology Indore, Indore, India
Soumendatta88@gmail.com

Abstract

A study on travelling ionospheric disturbance (TID) has been done based on total electron content (TEC) measurement by using a set of NavIC/GAGAN/GPS receivers over eastern part of India and Bangladesh after severe lightning strikes. A very low frequency (~1.6mHz) signature in detected TID indicates the possible presence of gravity wave at ionospheric altitude. A very high horizontal phase speed ($C_H > 300$m/s) of detected TIDs indicates that possibly it was originated at thermospheric height. A detail investigation on various properties of gravity waves has been done based on the detected TIDs over the selected low latitude region.

1. Introduction

The consequences of severe lightning events on the upper atmosphere and further the concept of global electric circuit was revealed by Wilson [1]. The investigation on propagation of thunderstorm driven electromagnetic pulse to the upper atmosphere have been started from a long back. The recent interest has focused on the detection of atmospheric gravity wave with period longer than 5min at various layers of ionosphere. This atmospheric gravity waves assumed to be originated by overshooting of severe mesoscale system and propagates by various atmospheric filtering process such as photoionization, chemical loss, wind flow etc. and couple with the lower ionosphere as evidenced by wave nature detected in local electron density.

Most of these gravity waves are with large amplitudes but small phase speeds. It in turn causes dissipation at mesospheric height. A small amount of wave which reaches to thermospheric height have very high phase velocity and small amplitude [3]. The deep convection system, which induces a local body force, can accelerate the neutral wind along the direction of primary gravity wave propagation. This in turn crates momentum deposition at thermospheric height and generates secondary gravity wave. These gravity wave, which propapgates at thermosphere, can induce travelling ionospheric disturbances by neutral-ion collision.

Here we present a study on the signature of lightning induced gravity wave propagation over eastern region of India. A remarkable progress has been achieved in tropospheric as well as the ionospheric study with the worldwide establishment of GNSS network and the increasing number of ground-based receivers by providing the facility of continuous monitoring in all-weather condition. Some additional ray paths have been achieved after the recently launched Indian navigational satellite system (IRNSS) comes into operation which provides another unique opportunity of 24hr. monitoring with its all satellites by its geo constellation. Hence a great platform has been achieved for the study on the spatial as well as the temporal coverage of the ionospheric waves above the thunderstorm area by using our India's indigenous navigation system for the first time and validate it with other GNSS ground measurement.

2. Data and Methodology

The IRNSS data has been collected by a dual frequency IRNSS/GPS/SBAS ACCORD made receiver which is installed on the roof top of Indian Statistical Institute Kolkata. The receiver acquires data from dual frequency IRNSS (L5: 1176.45MHz and S1: 2492.028MHz), single frequency GPS (L1) and SBAS signal. Data extraction can be done in 1sec, 5Sec and 30Sec interval. For This study IRNSS data of 30Sec interval has been collected. The GAGAN data has been collected from Kolkata Airport GAGAN receiver. GAGAN is GPS Aided Geo Augmented Navigation system containing Space Based Augmentation System (SBAS). This system mainly contains a set of receivers and satellites which provide GPS signal corrections. The GNSS data has been collected from UNAVCO GNSS network. For this study GNSS data has been collected from UNAVCO network over Bangladesh. The lightning information data has been collected from WWLLN network.

The total electron content (TEC) from navigation signal has been collected in two different ways. Vertical total electron content (VTEC) from each individual GPS satellite from different receivers of has been estimated by using Gopi Seemala Software. Another approach of local ionospheric measurement has been done by using IRNSS signal. This has been done based on a adaptive Kalman

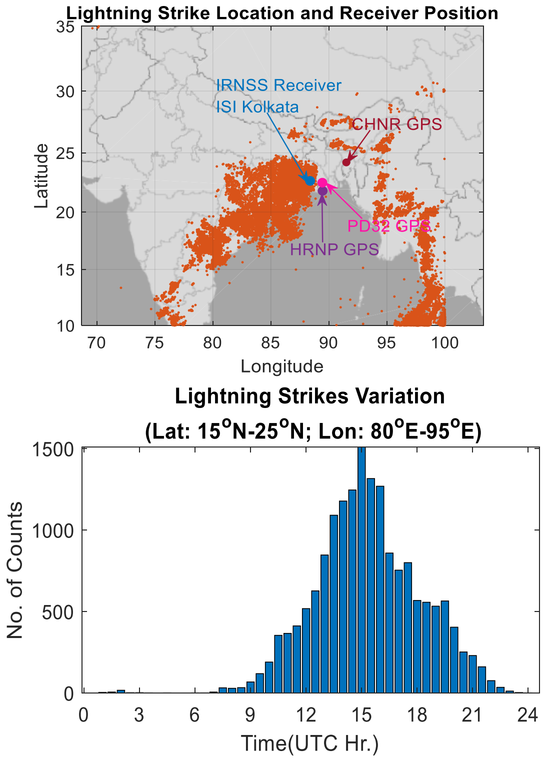

Figure1. Lightning strike location and histogram of lightning strike variation for each hour.

filtering approach which has been described by Mitch [2]. The parameters including the ambiguity factor of each individual satellite and the first and second order

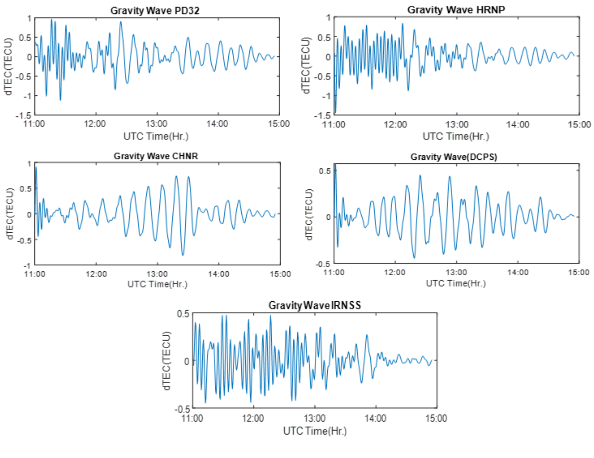

Figure 2. Signature of TIDs obtained from a single GPS and IRNSS satellite.

incremental components of VTEC measurement with respective to latitude and longitude difference between the IPP position of satellites and the receiver has been computed using the dual frequency signals from six IRNSS satellites. The VTEC true measurement has been taken from the worldwide VTEC data as given by NOAA.

3. Results and Discussion

3.1 Lightning Statistics

Severe lightning strikes occured on April 1, 2018, over the wide area of the eastern part of India and along the northern coastline of Bay of Bengal. This region has a tropical wet and dry climate and suffers by frequent weather extrimity. Nor'westers is one such extreme weathe event which occurs during the month of March to May over this region accompanied by strong squalls, severe lightning, and sometimes by hail, causing considerable damages to life and property. Figure 1 shows the lightning strike location on April 1 which indicate the severity of this extreme events. The WWLLN lightning strike information reavels that almost 8000 strikes above 1KJ intensity occured on that day. The severity brings our interest to study ionospheric perturbation caused by lightning strikes.

3.2 Signature of Ionospheric Perturbation

The TID signature has been investigated based on the differential TEC measurement as described above. Here the TID signature has been tested based on the TEC measurements both from GPS and IRNSS satellite signal. A 0.4 TECU to 0.8 TECU amplitude variation in most of the TIDs has been observed based on the IPP position of the satellite. Figure 2 shows the TID signature from a single GPS and NavIC satellite measurement by different receivers.

3.3 Properties of Gravity Wave

It is expected that gravity wave period (τ_r) depends linearly and the horizontal wavelength (λ_H) changes quadratically with the range from the source if the gravity waves are originated by a point source [3, 4]. Ignoring Coriolis frequency these relations can be expressed as:

$$\tau_r = \frac{2\pi}{N_B}\left(\frac{\mathcal{R}^2}{\Delta Z^2}+1\right)^{\frac{1}{2}} \qquad (1)$$

$$\lambda_H \simeq \frac{2\pi}{N_B} C_{gz}\left(\frac{\mathcal{R}^2}{\Delta Z^2}+1\right) \qquad (2)$$

N_B is the buoyancy frequency at IPP altitude; $\mathcal{R}$ is the radial distance of observation from the source; ΔZ is the vertical height of observation from source; C_{gz} is the vertical group velocity of gravity wave. The relation has been validated based on two different satellite TID measurements of two different directions. It is clearly observed from Figure 3 that both τ_r and λ_H are increasing significantly with increasing distance from lightning strike zone and the rate of change of λ_H is comparatively more than τ_r. Hence it is evident that the detected TIDs are consequence of interaction between ionospheric layers and gravity wave which is concentric.

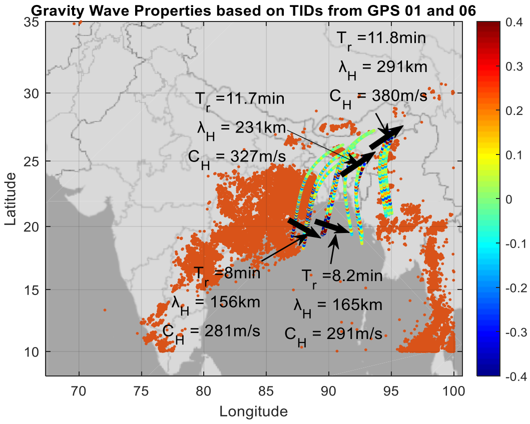

Figure3: Properties of Gravity wave opted from two different GPS satellite TID measurements of different group of receivers.

The horizontal phase velocities are also very significant. In middle and upper atmosphere horizontal wind velocity is a key tuning factor for gravity wave phase velocity. The intrinsic horizontal phase velocity and its range can be expressed as [3]:

$$C_H = \frac{\omega_{Ir}}{K_H} \qquad (3)$$

$$\omega_{Ir} = \omega_r - (K_1 U + K_2 V) \qquad (4)$$

$$\max(C_H) \simeq \frac{2\sqrt{\gamma - 1}}{\gamma} C_s \qquad (5)$$

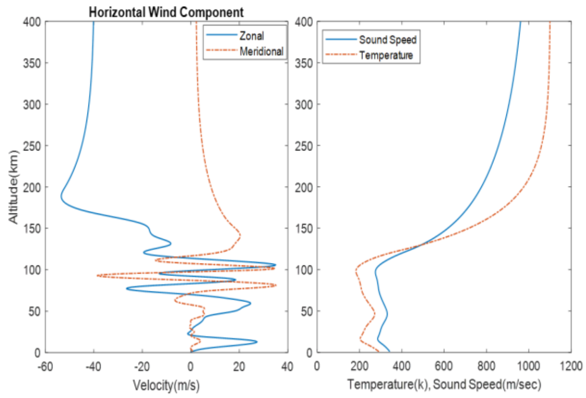

Figure4: Horizontal wind and sound speed variation with altitude during UTC 10:00hr. at 22ºN and 85ºE.

ω_{Ir} is the intrinsic frequency, ω_r is the observation frequency, K_H is the horizontal wave number, γ is ratio of specific heat of air, C_s is the sound speed. Two horizontal wind component (meridional and zonal) and sound speed at Lat: 22ºN and 85ºE during UTC 10hr is shown in Figure4. It is clearly observed that above the 200km altitude the wind is towards the west and northwest direction. Hence the westward propagating waves will dissipate more as compared to eastward waves because of low vertical wavelength and intrinsic horizontal phase velocity in west direction [5]. Moreover, it is reported that no gravity with horizontal phase velocity greater than 200m/s can propagate below 100km altitude. Hence it is evident from the observation results that possible altitude of gravity wave source is above 100km altitude.

4. Conclusion

The present study clearly shows the impact of lightning induced electromagnetic energy on the ionosphere using NavIC and GPS measurements of TEC. This study finds a detail wave propagation dynamic at mesosphere and thermosphere at lower latitude region. It finds how the various atmospheric condition plays role on gravity wave propagation at higher altitude. The TID measurement from GPS signal are compatible with the obtained result from NavIC signal.

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