Exploring Middle Atmosphere (D – Region) by Very Low Frequency (VLF) Waves

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***Abstract* - Naturally occurring radio signals from terrestrial lightning discharges produce weeks that can be potentially used in the diagnostic of middle atmosphere specially D-region because of its ability to propagate into the region. In the present study we have observed tweeks throughout in the month of July, 2012and have used as a tool in the estimation of medium parameters such electron density and ionospheric reflection height. D-region electron density estimated from cut-off frequencies of different modes ranged from 22.51 – 132.46 cm^{-3}. The ionospheric reflection height varied from 80 – 94.4 km. The existing time of tweeks was found to be in the range of 10 – 55 milliseconds. We have also tried to interpret the relation between cut-off frequency and relative amplitude of tweeks.**

***Keywords:* Radio wave propagation, lightning, tweeks, electron density and reflection height.**

I. INTRODUCTION

Very low frequency whistler waves have widely being used in exploration of upper atmosphere especially the magnetosphere [1] - [4]. In fact major portion of electromagnetic energy at very low frequencies radiated by the return strokes of lightning discharges propagates at approximately the speed of light in the Earth-Ionosphere Waveguide (EIWG) to large distances by the process of multiple reflections. The D – region of ionosphere (middle atmosphere) extended from 60 – 90 km at the low latitudes depending upon the solar zenith angle, solar flux, season and latitude wherein collisions between charged particles and neutrals dominate. In recent past, ground based whistler study has provided a potential tool in remote sensing of lower ionosphere (D-region) because of their access to the region. In fact, the altitude of the D-region ionosphere is too low for satellite measurements of electron density and too high for balloon measurements. Even ground-based active experiments using ionosondes and incoherent scatter radars in the high and very high frequency (HF-VHF) range can be conducted at any time, but these methods cannot receive ionospheric echoes due to the low electron densities ($< 10^3$ el./cm^3) especially in the nighttime[5]. MF radar has been utilized [6] at some locations, but this method is hindered by the high costs of their operations for active radio. Thus the D-region remains the least explored region of ionosphere. VLF transmitters have also been adopted to study the morphological features of the D-region [7] – [9]. But the disadvantage with VLF transmitter technique is its limited spatial coverage along the propagation path due to fixed number of VLF transmitters. In that case VLF waves are useful scientifically because they largely reflect from the D-region of the Earth's ionosphere and are efficiently guided to the Earth's ionosphere waveguide to global distances [10].

In the present study tweeks observation have play a role of potential tool. Tweeks are basically sferics subjected to dispersive distortion by sub-ionosphere propagation and have sharp falling tones with duration of 25 to 150 ms [10]. These tweeks originate from lightning discharges during thunderstorms and propagated in the EIWG mode over long distances. The main focus of tweeks observations has been to investigate the D-region ionospheric parameters like electron density at tweek reflection heights and propagation distance etc.[10] – [11].The reflection of higher harmonics of tweeks from higher D – region is also estimated and it suggests that the EIWG deviates from perfect conductor conditions even at the VLF frequencies. Earth's magnetic field makes ionosphere as an anisotropic medium.

II. EXPERIMENTAL DATA AND ANALYSIS

The broadband VLF data were recorded by the Automatic Whistler Detector (AWD) system installed at Physics Department, University of Lucknow, Lucknow (Geom. lat. 17.6^{0}N; Geom. long. 154.5^{0}E), India. The AWD instrument automatically detects and collects tweeks and whistlers data for the investigation of ionosphere and magnetosphere [12]. AWD system can record both broadband and narrowband data. Broadband data was recorded in the synoptic mode with 1 min at every 15 min interval. Narrowband data recording made in continuous mode gives the amplitude and phase of VLF transmitter signals which is not a part of present work. Large numbers of tweeks have been recorded at Lucknow during the continuous observations. We have analyzed broadband data using a MATLAB code which produces dynamic spectrograms of selected duration (usually 1 sec) showing atmospherics tweeks. The first-order cut-off mode frequency f_c of tweeks in spectrograms was measured and used to calculate the ionospheric reflection height h and the D – region electron density n_e at the reflection height. For present study, we have selected nighttime (18:00 - 6:00 LT) tweeks recorded in the month of July, 2012. Dynamic spectrogram of some of tweeks recorded at Lucknow is shown in Figure 1. The vertical lines on the spectrograms are called atmospherics (without hook shape). The vertical lines with hook shape at a particular frequency are called tweeks. During the observations, tweeks were observed up to 6th harmonic. Mode numbers of tweeks are labeled on the respective spectrograms. The horizontal line on the spectrogram near 18.2 kHz is the signal from VTX transmitter operated by India at Katabomman (latitude 8.47^{0}N, longitude 77.40^{0}E).

We have adopted electron gyro frequency f_H = 1.1±0.2 MHz according to the International Geomagnetic Reference Field (IGRF) model. The electron density n_e at reflection height h is estimated using the expression obtained by Shvets and Hayakawa [13] given as:

$$n_e = 1.39 \times 10^{-2} f_{cn} \text{ cm}^{-3} \quad (1)$$

where f_{cn} is the cut-off frequency of n^{th} mode. The electromagnetic fields in the waveguide with perfectly conducting walls may be considered to be composed of a sequence of independent field structures (modes) that propagate with different group velocities [14]. Each mode is defined by its cut-off frequency, which for the nth mode is given by

$$f_{cn} = \frac{nc}{2h} \quad (2)$$

where, c is the velocity of light in the free space, h is the tweek reflection height and n is the mode number.

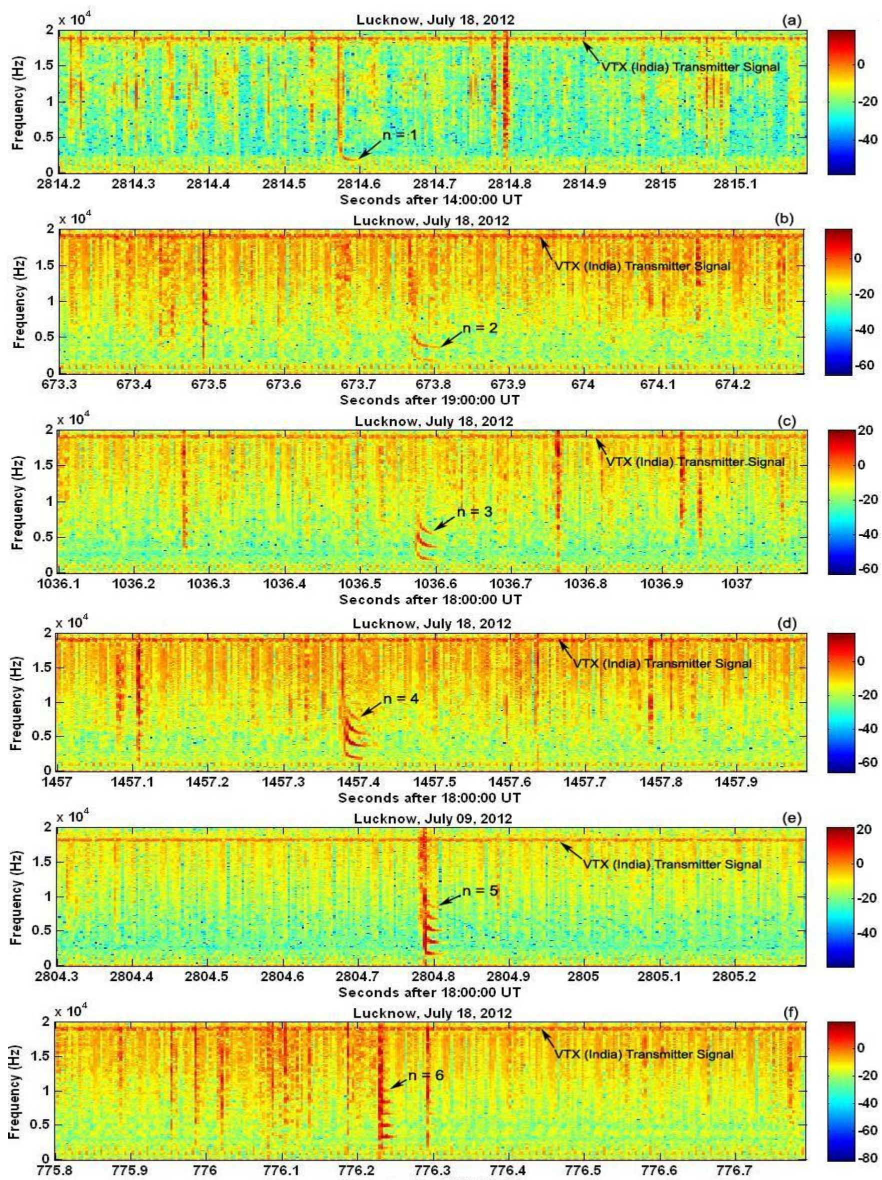


Fig.1 Dynamic spectrograms of some tweeks recorded during the observed period. The color scale shows the intensity of recorded signal.

III. RESULTS AND DISCUSSION

A total of 555 high quality tweeks with intensity levels ≥ 60 dB were observed in the nighttime during the month of July, 2012. There were no tweeks observed in the daytime recording may be due to the strong attenuation offered by daytime EIWG. The duration of tweeks section (dispersed portion) is found to be in the range 10 – 55 ms. Reference [15] found tweek duration in the range of 40–50 ms, which may reach up to 100 ms. The larger duration of dispersed section of tweeks shows the higher distance traveled by tweeks upon reaching the receiving station which depends on conditions along the propagation path and strength of sferics generated by lightning.

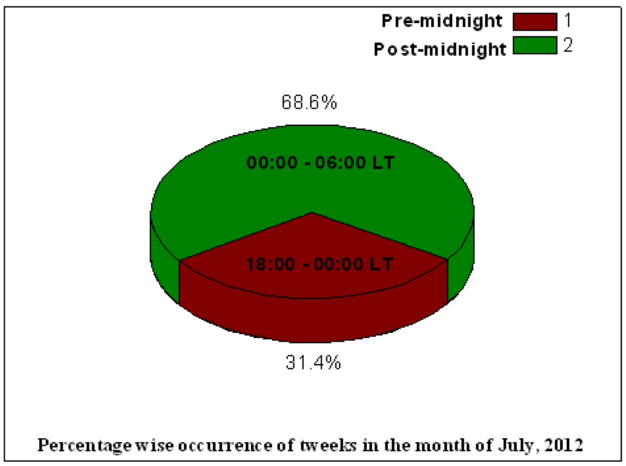


Fig.2 Pie-chart of percent wise occurrence of tweeks during pre- and post-midnight time sector

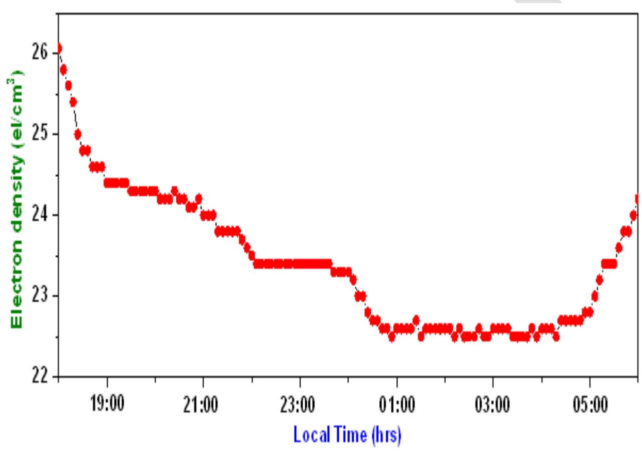


Fig.3 Temporal variation in the nighttime electron density estimated from first mode cut-off frequency of tweeks recorded at Lucknow in month of July, 2012

To study the variation in the occurrence pattern of tweeks, local nighttime is divided into two periods: pre – midnight (18:00 – 00:00 LT) and post – midnight (00:00 – 6:00 LT). The overall occurrence of tweeks at Lucknow increases as the night advances with the maximum occurrence in the post – midnight period. Though it is the lightning activity which determines the occurrence pattern of tweeks at any observation site but conditions at lower ionospheric height during different seasons may also have some contribution toward the occurrence of tweeks and their higher modes. The occurrence of tweeks between considered time sectors in July, 2012 is shown in Figure 2. From figure we can see that tweeks occurrence is maximum in post – midnight. This is because the attenuation in post – midnight is less as compared to pre – midnight. The chemistry, ionization and recombination cycle of the D – region are complicated. However, the gradual increase in the reflection height with the nighttime can be attributed to the decrease in electron density at reflection heights mainly due to electron loss processes over the nighttime ionization. Scattered Lyman α is an important source of nighttime D – region ionization at low latitudes and mid-latitudes[16].

The detailed analysis of recorded tweeks reveal that the D – region electron density estimated from cut-off frequencies of first - order mode ranged from 22.5 – 26.06 cm^{-3} over the ionospheric reflection height of 80 – 92.5 km. The electron density estimated from cut-off frequency of first six modes of tweeks shown in Figure 1(f) varies from 22.51 – 132.46 cm^{-3} over the ionospheric reflection height of 92.5 – 94.4 km in the altitude range of 1.9 km. Figure 3 shows the variation in the nighttime electron density estimated from first mode cut-off frequency of tweeks recorded at Lucknow. The electron density starts decreasing in pre – midnight during evening hours with sun set. It almost stabilizes in post midnight and again starts increasing during morning hours with the Sun rise. The obtained features are in consistent with the variation of ionosphere during quiet geomagnetic conditions.

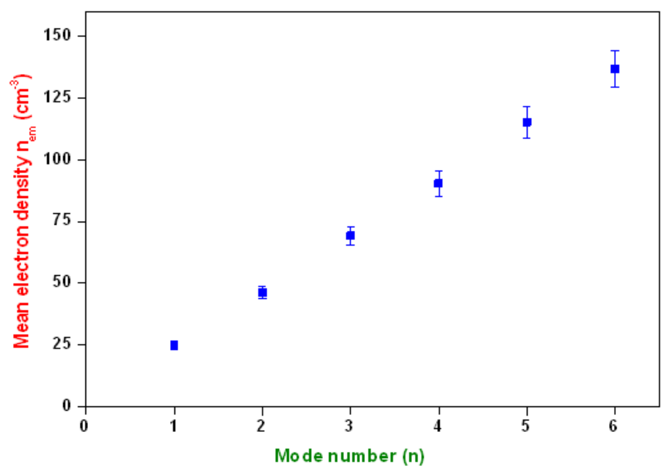


Fig.4 Variation of mean electron density (blue squares with error bar) with mode number of observed tweeks

Figure 4 shows the variation of mean electron density with mode number. The mean electron densities (n_{em}) in the present study vary from 24.82 – 136.82 cm^{-3}. The frequency components from the spectrograms are measured with an accuracy of ± 26 Hz. The mean electron densities have been computed with accuracy of ± 1.76 cm^{-3} and for various harmonics. The mean reflection height increases with mode number showing that higher mode of same tweek penetrate deeper into the D – region ionosphere. So, the mean electron density also increases with mode number. Higher order harmonics have higher electron density which is reflected from higher altitude. Figure 5 shows the variation of electron density with reflection height. It reveals that the electron density increases rapidly as we go at higher height (higher mode of tweek) into the atmosphere.

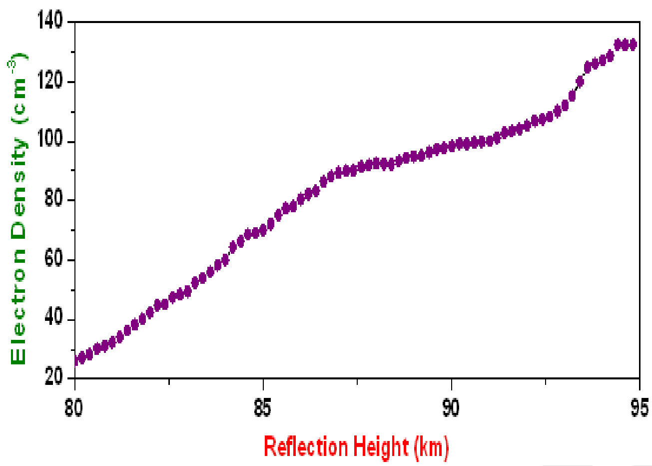
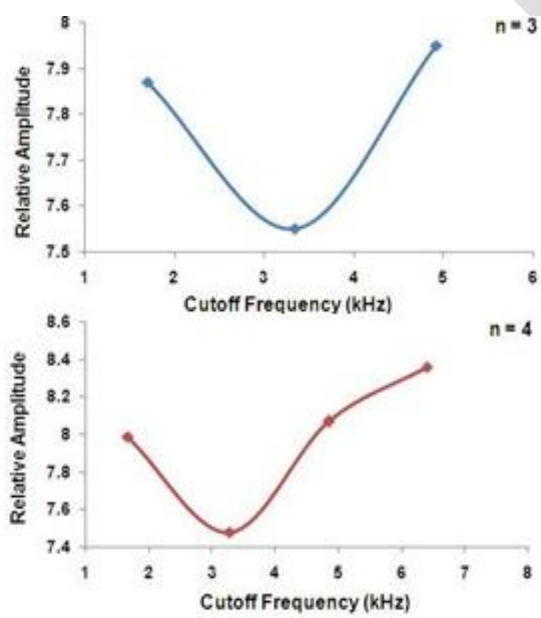


Fig.5 Variation of electron density with ionospheric reflection height in July, 2012 at Lucknow, India



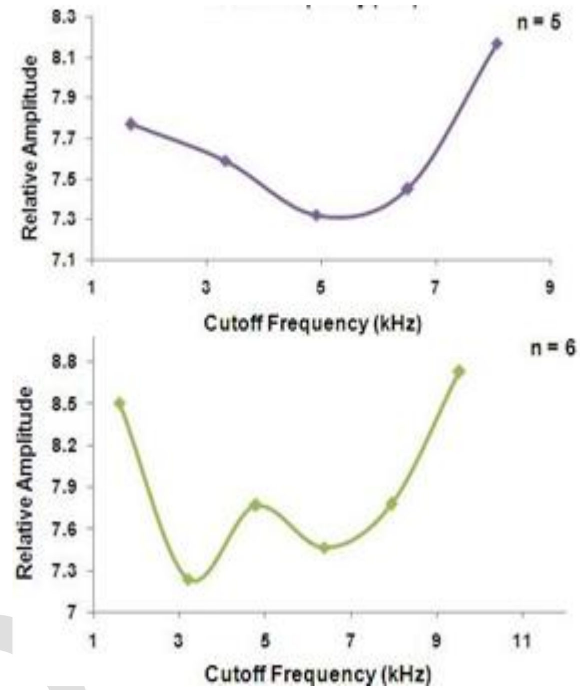


Fig.6 Variation of relative amplitude with cut-off frequency of tweeks of different modes (3 – 6 modes) as shown in figure 1(c) to 1(f)

The relative amplitude of tweeks of different modes (for n = 3 to n = 6) shown in Figure 1(c) – 1(f) also have been calculated. The energy spectrum of a radio atmospheric at the receiving end depends on (i) the energy spectrum of the radio atmospheric at the source, which is determined by the energy excited in the different frequency channels by a particular lightning discharge and (ii) the characteristics of the propagation path (over land, buildings, rivers, sea) between the receiver and the lightning discharge. Figure 6 shows the variation of relative amplitude with the cut-off frequency of tweeks of different modes. The spectral analysis of the tweeks showed that the amplitude was found to build up with the arrival of the atmospheric pulse, and when the pulse was over, the amplitude was found to decrease. The regular and continuous amplitude variations in the Figure 5, showed return stroke pulses with successive reflections from the ionosphere. But we have found no regular patterns of relative amplitude with cut-off frequency (increasing or decreasing pattern) of tweeks.

IV. CONCLUSIONS

In this paper, we have used tweeks as diagnostic tool to explore the middle atmosphere and ultimately to estimate nighttime electron density at reflection heights from the cut-off frequency of different harmonics of tweeks at our low latitude station Lucknow, India. The critical analysis of recorded tweeks infer that the D – region electron density estimated from cut-off frequencies of first – order mode ranged from 22.5 – 26.06 cm^{-3} over the ionospheric reflection height of 80 – 92.5 km. Temporal variation in nighttime electron density is also shown. The variation of relative amplitude of tweeks with cut-off frequency of different modes does not show any particular trend. This study may be very useful in the electron density profiling of lower ionosphere.

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