Propagational Features of Magnetospheric VLF Emmissions Observed at Lucknow, India

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Abstract - **Very low frequency (VLF) emissions are naturally occurring phenomena found in the frequency range 500 Hz to 5 kHz. These emissions include hiss, chorus, discrete, triggered emissions, oscillating tone and riser, periodic and quasi-periodic, etc. At our low latitude Indian station Lucknow (Geomagnetic Latitude 17.6^{0}N; Geomagnetic Longitude154.5^{0}E; L = 1.10), we have observed some interesting VLF signatures in the form of discrete emissions (risers) and triggered emissions recorded by the automatic whistler detector (AWD) setup. The present paper deals the generation and propagational features of these magnetospheric emissions propogated along different L-values.**

Keywords – Wave propagation; VLF emissions; Magnetosphere; Wave-particle interaction, L-value.

I. INTRODUCTION

The role of waves in the exchange of energy between different regions of geospace is very important. The gyroresonance interaction between whistler-mode waves and energetic electrons is the reason behind the linear wave amplification and generation of VLF emissions [1]. The popularity of magnetospheric VLF whistler mode waves as a subject of investigation in geospace research stems largely from the fact that they can propagate along the geomagnetic field aligned ducts, penetrate the ionosphere and can be received by the simple audio frequency receiver on the ground in conjugate hemisphere [2] - [5].The wave and wave-particle interactions occurring in the magnetosphere generate wide variety of emissions in the VLF range. These emissions have become a very important diagnostic tool for probing the upper atmosphere (Singh et al., 2005).

VLF emissions although less understood than whistlers, are believed to have their origin in the ionosphere-magnetosphere coupled system and this is because of plasma instabilities. The VLF emissions are characterized by their triggering source. The emissions are observed to be triggered from the lightning whistlers and wave-particle interactions in the magnetosphere. Systematic classifications of VLF emissions according to their frequency-time spectra have been given by [7]. Reference [8] has classified these emissions into hiss, chorus, hook, periodic, quasi-periodic and triggered emissions. The group of VLF emissions is further divided into two sub-groups: (a) continuous emissions in both time and frequency which tend to maintain a steady state such as hiss, resonance bands and noise band near the ion-cyclotron frequency, and (b) discrete emissions often with periodic and quasi-periodic nature.

Though the VLF emissions are basically high and middle latitude phenomena but there are ample evidences of their occurrence in low-latitude ground stations also. Japanese workers [9] – [11] have reported the observations of hiss-type emissions in their low latitude ground stations, whereas Indian workers [12] – [13] have reported the observations of discrete-type emissions at low latitude ground station, Varanasi (L= 1.07). The existence of intense zones of ELF/VLF emissions in the low-latitude ionosphere has been confirmed by satellite observations also [14].

In this paper, we have reported some unusual events of riser and discrete emissions, which are recorded at the low latitude ground station Lucknow. An attempt has been made to discuss briefly the generation and propagation mechanism of these emissions.

II. EXPERIMENTAL SETUP AND OBSERVATIONS

The VLF data is continuously being recorded using Automatic Whistler Detector (AWD) setup installed at Department of Physics, University of Lucknow, Lucknow (Geomag. Lat. 17.6^{0}N; Geomag. Long. 154.5^{0}E; L = 1.10), India. During the routine observations and analysis of whistlers and tweeks, various types of VLF emissions are also observed. The operation of automatic whistler detection system has been previously described by [15]. The details of the system description and algorithm development can be found from [16] – [17]. A brief description of the AWD system is presented here for the simplicity to readers. The AWD system consists of the following parts: (i) antenna (ii) preamplifier; and (iii) AWD software running on a personal computer with a Linux Kernel. Antenna is crossed magnetic loop antennae oriented geomagnetic north-south and east-west so that the receiver picks up magnetic fields parallel to ground from any direction. Impedance matched pre-amplifier is placed at the bottom of the antenna for maximum power transfer as well as signal amplification. The VLF data stream is sampled at a rate of 44.1 kHz using a 16-bit soundcard in a standard personal computer. The personal computer time is synchronized with the pulse per second (PPS) signal of a global positioning system (GPS) receiver. The PPS timing accuracy is better than 1 µs, which is smaller than the data sampling period (~ 22 µs) [16]. The data stream is taken from the magnetic North-South loop antenna situated at Lucknow. While the operational system can independently sample from the data streams provided from both the NS and EW loops, there were high man-made noise levels in the EW loop observations, and thus we only trigger of the NS loop. Normally, such waves are not transmitted to the ground due to heavy absorption in the lower ionosphere and large wave normal angles associated with them. We have checked various possibilities for the occurrence of recorded emissions which include (a) that they are caused by instrument; (b) they are caused by HF heating of the lower ionosphere. However, these possibilities are ruled out because such emissions were also recorded at some lower latitude stations like Varanasi and Allahabad. The HF heating peaks at frequency near 2 kHz which are not observable on the ground if the receiver is away from the source. Thus, the only possibility left is that these emissions are generated at different locations in the magnetosphere.

III. GENERATION MECHANISM AND OCCURRENCE

In order to understand the generation mechanism of VLF emissions, it is essential to know the mode of propagation from the source region to the observation point, the source of energy and the mechanism which converts part of energy into VLF emissions. The source of the wave energy is the distribution function of energetic electrons in the magnetosphere. The energy transfer mechanism could be classified as either incoherent or coherent. Several theories have been proposed from time to time to explain the origin of these emissions. They differ significantly and can be classified into the following categories: Cerenkov radiation, traveling wave tube mechanism, backward wave oscillator (BWO), cyclotron radiation and transverse resonance instability [18] – [21].

Earlier studies have shown that incoherent mechanisms, such as cyclotron, synchrotron and Cerenkov radiation, could not explain the observed amplitude of the waves [22] – [23]. Reference [23] has suggested that the waves generated by an incoherent mechanism could be amplified during propagation through the process of wave-particle interaction and hence the observed wave amplitude could be explained. In the coherent mechanism, the cyclotron resonance instability is the widely accepted process for the generation of VLF emissions [24] – [26]. In this process, a whistler mode wave resonantly interacts with the counter streaming energetic electrons at or near the equatorial planes and is amplified at the expense of particle energy. The amplification factor or the growth rate depends upon the energy spectrum and pitch angle distribution of the energetic electrons participating in the interaction process.

Detailed analysis of the VLF emissions observed at low latitude ground station Lucknow was made to find out the possibility of their occurrence. The possibility that the occurrence of these emissions was just a coincidence does not seem to be likely because we have observed many events which occurred one after the other during the same day of observation. In present study the L-value of the source in magnetosphere is determined using upper boundary frequency of discrete emissions [27]:

$$L = (440/f_{UB})^{1/3}$$

where f_{UB} is the upper boundary frequency of emissions in kHz.

A. Event of March 07, 2014

Upper panel of Figure 1 shows the spectrogram of VLF emission (rising tone) recorded by AWD system on March 07, 2014 at 06:11:01.47 UT. The frequency range of the rising emission is 2.3-5.3 kHz, and its time of observance is 0.14s. Frequency sweeping rate (df/dt) for this event comes out to be 21.42 kHz/sec. The computed L-value comes out to be 4.3. Thus the reported emission may have been generated in the outer radiation belt (L > 3). Lower panel of the figure shows the geomagnetic conditions during the event. At the time of riser occurrence the Dst index was reported -4 nT while the three hourly K_P index was 0, that indicated about the absence of geomagnetic activity and lower degree of geomagnetic disturbance.

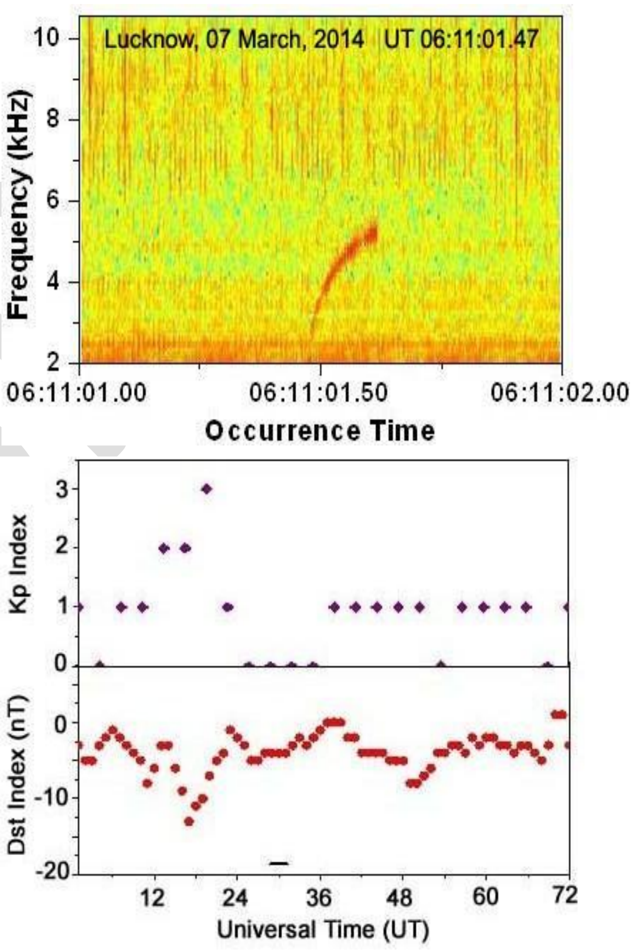

Fig. 1 Upper panel showed the typical example of frequency-time spectrogram of VLF emission (rising tone) observed at Lucknow on 07 March, 2014 while lower panel of the figure has indicated about the variations in Dst index and K_P index during March 6-8, 2014

B. Events of October 30, 2014

Figure 2 show discrete emissions (riser) which were recorded on October 30, 2014 at 07:50:52.38 and 08:14:38.15 UT respectively lasted for 0.18 and 0.66 sec respectively. The riser frequency varied between 2.2-5.1 kHz and 2.8 – 6.1 kHz respectively. The frequency sweeping rate for first event recorded on October 30 was found to be 16.11 kHz/sec while for the other case it was

5.00 kHz/sec. The L values for these emissions were computed to be 4.4 and 4.1 respectively. This revealed that the riser observed at Lucknow might have been generated in the equatorial region of the geomagnetic field at L = 4.4. and 4.1. Lower panel of Figure 2 showed the geomagnetic activity and disturbance condition recorded during the events. At the time of occurrence of the events K_P was 1 and Dst was recorded about -5 nT. This again reveled about lower level of geomagnetic activity and disturbances.

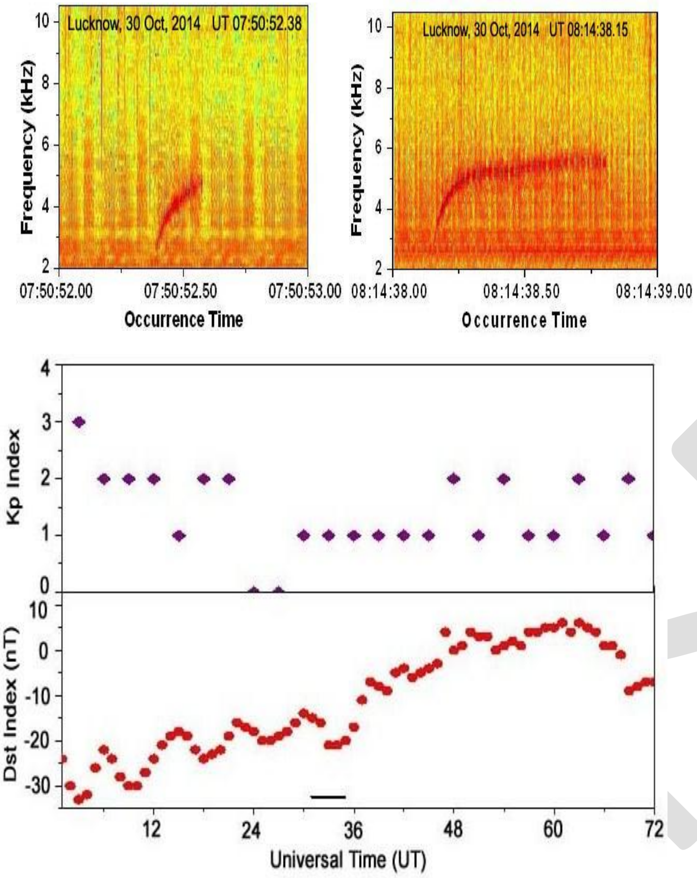

Fig.2 Occurrence time of emissions (rising tone) observed at Lucknow on 30 October, 2014 are shown in the upper panel of the figure while the lower panel showed the Dst and Kp index variations observed during October 29-31, 2014

C. Events of 22 December 2014:

Other events of VLF emissions observed at Lucknow are shown in Figure 3. Upper panel show the frequency – time spectrogram of discrete triggered emissions recorded on 22 December 2014 at 06:15:04.21 and 07:51:17.20 UT respectively. Frequencies of observed emissions varied from 2.8-5.5 kHz and 2.8-5.1 kHz respectively. Lower panel of Figure 3 has indicated about variation in K_P index and Dst index that only revealed that during the occurrence of emission there were moderate geomagnetic conditions (Dst < -50nT; K_P ~ 5). The calculated L values for these events were 4.2 and 2.9 respectively. The higher L-values of the source compared to that of Lucknow (L = 1.10) shows that the wave may have propagated towards significantly lower latitudes. The whistler mode wave propagating through the magnetosphere may shift towards lower L-shells [28].

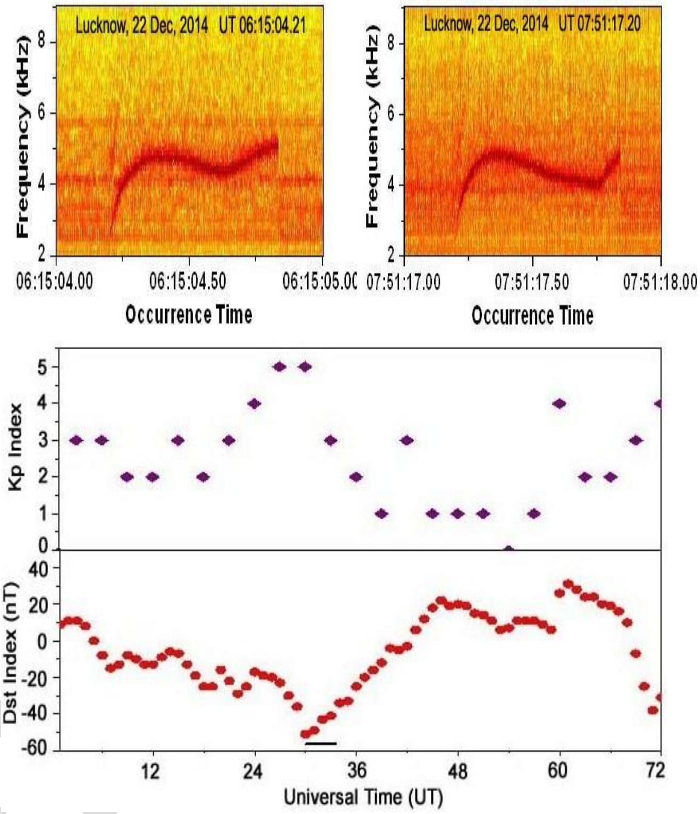

Fig.3 Upper panel showed the triggered emissions observed in two frequency ranges at Lucknow on December 22, 2014 while lower panel showed the Dst and Kp index variations observed during the moderate storm during December 21-23, 2014

IV. RESULTS AND DISCUSSION

The VLF emissions have been widely used for investigating the magnetospheric processes of wave generation and propagation, wave-particle interactions, wave-induced particle precipitation and for probing of magnetospheric plasma structures and motions. All these phenomena are generally considered to result from non-linear electron-cyclotron resonance or phase trapping in the equatorial region. This occurs in or near the equatorial plane for two reasons. Firstly, the cyclotron resonance velocity increases as one moves away from the equator and thus number of resonance particles decreases. Secondly, the ambient field gradient increases away from the equator and eventually suppresses on linear trapping. Emissions recorded at Lucknow are generated in the magnetosphere at higher L values (L>3) and probably in the outer radiation belt and have propagated towards lower latitude

V. CONCLUSIONS

The spectral analysis of different types of VLF emissions recorded at low latitude (L = 1.10) ground station Lucknow has been carried out and generation and propagation mechanism for these emissions was discussed. We have found that the reported emissions are generated in magnetosphere at L-values greater than that of our observation site. In such case, the propagation path might have two parts, propagation via the ducted whistler mode through the magnetosphere and via the Earth-ionosphere waveguide mode in the ionosphere. Triggered emissions are generated due to the phase bunching of electrons participating in the nonlinear interaction with whistler mode waves.

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