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Observation of very low frequency emissions at Indian Antarctic station, Maitri

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Abstract. Recently, we have succeeded in recording VLF emissions at the Indian Antarctic station, Maitri (geom. lat. 62°S, geom. long. 57.23°E, $L = 4.5$) using a T-type antenna, pre/main amplifiers and digital audio tape recorder. VLF hiss in the frequency ranges 11–13 kHz and 13–14.5 kHz and some riser-type emissions in the frequency range 3–5 kHz and magnetospheric lines at about 6.2, 8.0 and 9.2 kHz are reported for the first time. The generation and propagation mechanism of these emissions are discussed briefly.

Keywords. Very low frequency emissions; magnetospheric lines; whistler mode propagation; wave particle interaction.

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1. Introduction

VLF emissions are audio frequency electromagnetic signals propagating in whistler mode and readily detectable at ground station. They are important because of their probing potentiality of ambient medium and depending upon their spectral shapes, they are broadly divided into hiss, discrete, periodic, quasi-periodic and triggered emissions [1]. The required information to discuss the generation mechanism of these emissions are (a) mode of propagation from source to the observation point, (b) existence of the source of energy, and (c) coupling mechanism which can convert a fraction of source energy to the electromagnetic energy in the form of VLF emissions. Observation of these emissions at ground station indicates that the waves, after generation, may have propagated in the ducted whistler mode or pro-longitudinal mode because VLF wave propagating in any other mode may not reach the Earth's surface. Various mechanisms proposed from time to time to explain the origin of these emissions can be classified into four main categories: Cerenkov radiation, longitudinal instability or a mechanism analogous to travelling wave tube mechanism, cyclotron radiation and transverse resonance instability [2–7]. The feature common to most of these theories is the assumption that the energy of emissions is derived from the kinetic energy of electrons populating the magnetosphere or the ionosphere, either in trapped mode or in the precipitating mode.

Amongst different kinds of emissions, hiss emissions are well-known forms of electromagnetic emissions that arise in the magnetosphere and have constant spectral density in the limited frequency band. Chorus emissions are discrete in nature and may have rising/falling/hook type of dynamic spectra. Sometimes, complex combination of these emissions are also reported. These emissions are generated either during lightning discharges or during wave–particle interactions in the ionosphere and the magnetosphere. Triggered emissions are separate class of emissions accompanied with the triggering source, which could be either a whistler wave or hiss emissions. Accordingly they are termed as whistler-triggered or hiss-triggered emissions [8].

In this paper we have reported VLF hiss, hiss triggered chorus emission and magnetospheric lines recorded at the Indian Antarctic station, Maitri during February–March 2001. Generation and propagation mechanisms are also briefly discussed.

2. Experimental observations

VLF wave recording set-up consisting of T-type (vertical) antenna of 10 m height and 40 m horizontal length supported by two poles, transistorized amplifier and digital audio tape recorder is used to record VLF data at the Indian Antarctic station, Maitri. The location of the hut containing the recording set-up is geom. lat. $= 62°$S, long. $= 57.2°$E; the observation was carried out by the Physics Department, Banaras Hindu University, Varanasi during 10 January to 10 March 2001. The data are stored on digital audio tapes. Tapes are replayed and some of the events are analysed. During the analysis, it was found that the noise in some cases was very high. The data with low noise level were selected for further analysis. Figure 1 shows VLF hiss at relatively higher frequencies (11 kHz $< f <$ 13 kHz) observed on 17 February 2001 at 11.30:35 h GMT. From the figure it is noted that the noise level is very low. In addition to VLF hiss, three horizontal lines at 6.2, 8.0 and 9.2 kHz are seen which were present throughout the recording period for 2 h and decrease in intensity with the increase in frequency is observed. That is, the intensity of 6.2 kHz line is greater than the other two lines. These lines are quite parallel showing fairly constant frequency on the spectrogram. Similar lines on the dynamic spectra in the frequency range 2.0–5.0 kHz were reported from the ground-based stations Siple (Antarctica) and Roberval (Quebec) [9]. These lines were termed as magnetospheric lines. Park and Helliwell [10] reported magnetospheric lines in the frequency range 1.5–8.5 kHz with a strong peak at 2.5–3.5 kHz. Recently, Rodger *et al* [11] analysing ISIS-2 satellite data have reported magnetospheric lines in the frequency range 1.8–2.3 kHz.

The hiss events presented in figure 1 continued for 2 h (11–13 h GMT) having almost the same intensity as inferred from the colour of the spectrogram. Figure 2 shows risers in the frequency range 3–5 kHz and hiss in the frequency band 13–14.3 kHz recorded on 3 February 2001 at 12.46:50 h GMT. The possibility that these emissions were caused by the instrument has been ruled out. The hiss emission continued for more than 1 h and risers in sufficient numbers were observed for about 1 h. As frequency increases, df/dt increases. It is noted that the risers originated from a narrow hiss band (3.5 kHz $< f <$ 3.75 kHz). From the spectrograph we also note that there is strong noise at lower frequencies ($f <$ 2.2 kHz).

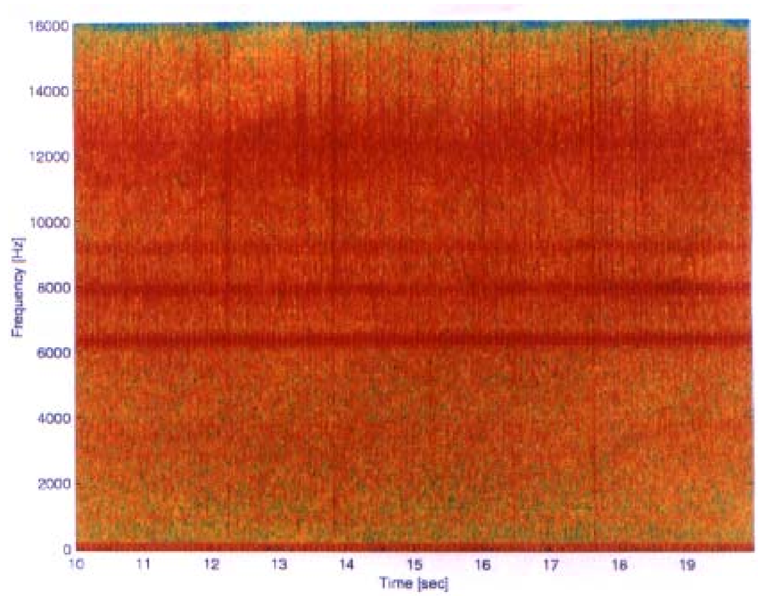

Figure 1. VLF hiss recorded at Indian Antarctic station, Maitri on 17 February 2001 at 11.30:35 h GMT.

3. Generation and propagation mechanisms

The observed VLF spectra depend on the genereration and propagation mechanisms between the source and observation point. Attempts were made to explain the amplitude and frequency spectrum of VLF emissions in terms of incoherent Cerenkov radiation from different models of the magnetosphere, the ionosphere and precipitating electron beams [3–7]. The computed amplitude fell smaller than the measured one and collective phenomena such as coherent radiation mechanism or instability mechanism was proposed [2,4,12]. Solomon *et al* [13] suggested that the amplification of the background noise could explain the measured intensity spectrum. Analysing the measured and simulated data, Savchenko and Vaisman [14] suggested that VLF hiss bursts observed on the ground can also be formed by refraction and scattering of VLF waves in the ionosphere on irregularities generated during the precipitation of energetic electrons induced by whistlers. The peak in the electron distribution function around 1 keV with respect to $v_{||}$ suggests that incoherently radiated waves can be further amplified due to Cerenkov instability [6,15], when the wave phase velocity corresponds to the region where $\partial F_0/\partial v_{||} > 0$ for electrons with energy close to 1 keV. An alternate source of VLF hiss could be lightning itself. Parrot [16] has shown that the regions of high thunderstorm activity is correlated with maximum intensity of VLF hiss, which may indicate the embryonic effect of lightning in generating VLF hiss [17,18].

The magnetospheric lines observed at the Indian Antarctic station, Maitri appear to be the same phenomena as the semi-coherent emissions (power line harmonic radiation described by other workers [10,11,19]). Analysing ISIS-2 satellite data, Rodger *et al* [11]

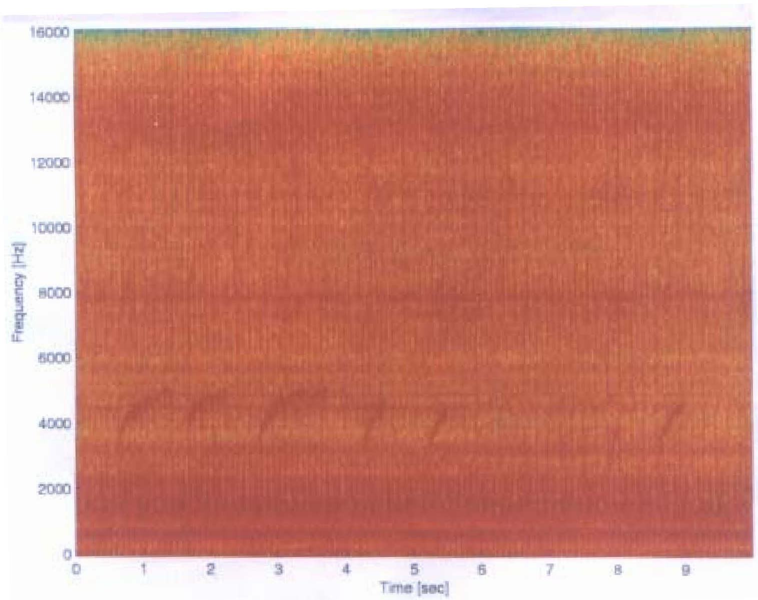

Figure 2. Example of VLF risers (3 kHz $< f <$ 5 kHz) and VLF hiss (11 kHz $< f <$ 14.3 kHz) recorded at Indian Antarctic station, Maitri on 3 February 2001 at 12.46:50 h GMT.

have shown that the observed magnetospheric lines do not support generation by power line harmonics. They did not find any evidence of harmonics of 50 or 60 Hz power lines in the observed magnetospheric lines. Even in the frequency spacing of these events harmonics of 50 or 60 Hz could not be ascertained. Thus, the generation mechanism of magnetospheric lines is not understood and it needs further investigation.

A prominent feature of natural hiss is its tendency to trigger chorus emissions from the upper edge of its band. Similar observations have been reported from many ground stations [20,21]. These emissions are generated by cyclotron resonance mechanism in the equatorial region for $L = 4.5$ (corresponding to Maitri station). The resonant energies for the chorus emissions are calculated using the formulation of Molvig *et al* [22], which comes out between 1 keV and 100 keV for the frequencies between 1 kHz and 10 kHz. The computed values are in good agreement with those reported by Molvig *et al* [22] and Lalmani *et al* [23]. Trakhtengerts *et al* [24] have discussed that during the development of cyclotron instability, a singularity in the form of the step on the distribution function of energetic electrons is formed, which serves as a boundary in velocity space between resonant and non-resonant electrons. When the non-resonant region is small (which is valid in a sufficiently dense cold plasma), this singularity can be neglected and one deals with hiss generation. In the opposite case the steeping of a step leads to a major change of the cyclotron instability (phase effects become very important) and a new, so-called backward wave oscillator generation regime is realized leading to the generation of discrete emission [25]. However, in this mechanism the appearance of a succession of discrete elements remains unresolved.

The observation of VLF emissions at the ground station suggests that these waves could have propagated along the geomagnetic field lines either in ducted or non-ducted mode. Based on VLF wave measurements onboard rockets and satellites, Mosier and Gurnett [26] have reported the Poynting vector of VLF hiss to be directed continuously towards the Earth, implying that hiss emissions propagate towards the Earth without necessarily following the magnetic field lines. The wave propagating along field line tends to be reflected back from a level where its frequency matches with the lower hybrid resonance frequency (f_{LH}). Hence, we would not be able to receive auroral hiss on the Earth's surface at frequencies above the maximum f_{LH} in the ionosphere. However, waves trapped in ducts formed by electron density irregularities along magnetic field in the magnetosphere are not reflected at $f = f_{\mathrm{LH}}$, and such waves can be received on the Earth's surface. This shows that the observed waves on the Earth's surface with $f > f_{\mathrm{LH}}$ may have propagated in ducted mode. The waves propagating in pro-longitudinal mode can also be received on the Earth's surface provided wave-normal angle is less than 4° [27].

4. Conclusion

VLF hiss, magnetospheric lines and riser-type emissions are reported for the first time from the Indian Antarctic station, Maitri. The basic physical processes leading to the generation of these emissions have been discussed briefly. The waves from the source region may have propagated in ducted mode or pro-longitudinal mode along the field line.

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