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Very Low Frequency Wave Observation at Maitri During the Summer Period of 20th Indian Antarctic Expedition

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Abstract

Ground based observation of very low frequency (VLF) signals were carried out at Indian Antarctic Station Maitri (S Lat. 70° 46' E Long. 11° 44'). The extremely **low** frequency and very low frequency ELF/VLF recording system was successfully installed during the 20Ih Indian Scientific Expedition and data were collected from January 12, 2001 to February 24, 2001. VLF emissions including hiss and rising type of discrete events have been observed. Whistlers could not be detected in the partly analyzed data, although a large number of atmospherics have been observed. To explain the VLF emissions, we have considered Cerenkov radiation as the generation mechanism.

Keywords: VLF Hiss emission, riser emission, generation mechanism of VLF Hiss, Cerenkov radiation.

Introduction

The study of wave phenomena during quiet and disturbed periods of solar activity serves as useful diagnostic tool for detailed probing of microstructures and microphysical processes taking place in the Earth's ionosphere and magnetosphere. The frequency spectrum from natural sources covers a wide variety of electromagnetic phenomena such as micropulsations, gyromagnetic resonances, solar whistlers, different types of VLF emissions, terrestrial whistlers and sferics. A general survey of the whistler research published so far indicates that the whistler observations at low latitudes are very meager in comparison with middle and high latitudes. This is due to the extremely low occurrence rate of whistlers at low latitudes. Whistlers in large number observed during periods of high geomagnetic activity. The main contributions to the ground observations of whistlers at low latitudes have been made by Japanese and Indian Scientists. The whistler research in India was initiated by Prof. Tantry at Banaras Hindu University, Varanasi when Somayajulu et al. (1965) reported for the first time whistlers recorded at Gulmarg, J & K State, India (N lat. 24° 10). Since then whistler observations have been extended to still lower latitudes such as Nainital, Agra, Bhopal and Varanasi. The return strokes of lightning discharges radiate copious amount of energy spread over wide band of electromagnetic spectrum (10^2 Hz < f < 10^7 Hz). The radiated spectrum intensity peaks at some frequency in the very low frequency (VLF) range and decrease either side as $f^{''n}$, where n >1, and varies with frequency ranges. Kawasaki et al. (1987) have obtained the Fourier spectra of positive lightning fields during winter thunderstorms, which show an f^1 dependence from 100 kHz to 400 kHz, and f^2 dependence between 400 kHz and 2 MHz.

Whistler wave is an audio frequency electromagnetic signal, which when heard aurally resembles a gliding tone usually descending in frequency (ascending tones are also observed sometimes) and lasting for about a second. These are right hand polarized electromagnetic waves. The natural whistlers find their origin in lightning discharges. The dispersion in the signal is produced during propagation of the wave from source to the observation point. The fact that the return stroke of the lightning flash from which the whistler originates usually lasts for $10''^{14}$ second only, shows that pulse radiated by the return stroke has to traverse very long distances through a dispersive medium in order to transform itself in to a dispersed wave form. Short whistler propagates through the magnetosphere only once, which is also called as one-hope whistler. The long whistler may traverse the magnetosphere two times or more. If it travels two times then it is called as two-hope whistler. A whistler is called an n-hope if it traverses the magnetosphere n times.

VLF emissions are also important because of their dynamic spectrum and sensitiveness toward the magneto-plasma present in the ionosphere and magnetosphere. These are a class of naturally occurring audio-frequency, electromagnetic back-ground radiations which propagate in the whistler mode and are readily detectable at middle and high latitudes by means of equipments which are almost similar to those used in whistler observations. VLF emissions can be broadly divided in to six characteristic types (i) Hiss (ii) discrete emissions (iii) periodic emissions (iv) chorus emissions (v) quasi-periodic emissions and (vi) triggered emissions. In order to understand the mechanism by which the natural VLF emissions are generated, several types of information are necessary. First, the mode of propagation of emission from the source to the observation point should be specified. Secondly a source of energy must exit and thirdly a coupling mechanism should exist which can transform a fraction of energy from the source to the electromagnetic energy of VLF emissions.

The electromagnetic signals generated during lightning flashes are guided along the Earth's magnetic field lines and are received at the conjugate points. During propagation along the field line **the** monochromatic wave packet gets dispersed and whistler wave form is produced. Whistlers are the radio signals in the audio-frequency range. The path of whistlers reach heights of many thousand kilometers above the Earth surface (~ 6 Re or more). Various types of whistlers such as short, multi-flash, multi-path, sharp, diffuse, riser, twin, low dispersion, high dispersion, banded, hook etc have been observed at low latitude stations (Singh, 1993). These signals contain information about the plasma medium through which they are propagating. The frequency verses time measurement of the whistlers yields information about electron density, total electron content in a flux tube (Brice, 1965; Park and Carpenter, 1970; Singh et al., 1998). Apart from determination of electron density in the equatorial magnetosphere, low latitude whistlers have also been used to determine large scale electric field in the magnetosphere (Khosa et al., 1982; Mishra et al, 1980; Singh, 1995; Narayan, 1998; Singh et al., 1998). The radial electric field in the plasmasphere/magnetosphere produces E x B drift of flux tubes. The flux-tube interchange gives rise to enhancements and depression in the electron plasma density. Since the nose frequency is related to the equatorial electron gyrofrequency, it is argued that the change in nose frequency amounts to change in whistler path in the equatorial plane which is supposed to be caused by the electric drift of magnetic Field line (drift velocity = E_w x B_{eq} / B_{eq}^2 = d/dt (ReL). Where E_w is westward component of the magnetospheric electric fields. The magnitude of this electric field in the equatorial region then is given by

$$E = 2.07 \times 10^{-2} \, d/dt \, (f_n^{2/3}) \;\; V/m$$

where f_n nose frequency measured in Hz. If f_n increases with time, then electric field is directed from east to west and in the reverse case it is directed from west to east. Analyzing whistlers recorded at Varanasi, Nainital and Gulmarg. The electric field has been estimated which is 0.3-0.7 mV/m during pre-midnight sector in the eastward direction and 0.1-0.7 mV/m in the post-midnight sector in westward direction (Khosa et al, 1982; Singh et **al, 1998).**

Objective

To understand the generation and propagation mechanism of VLF waves at high latitudes, we record VLF waves at the Indian Antarctic

Station Maitri (geogr. lat. 70° 46 S; geogr. long. 11° 44' E). Continuous observation of very low frequency, whistlers and related phenomenon with the help of digital audio tape recorder was carried out during the 20th expedition. The data will also be used to study the coupling of ionosphere and magnetosphere. Medium parameters can also be estimated and hence the waves can be used as the diagnostic tool of the medium.

Experimental Setup

The experiment for recording very low frequency (VLF) waves can be setup at any place where noise level is very low. At the Indian Station Maitri the setup consists of T-type antenna made of copper wire, pre-amplifier, main amplifier, magnetic tape (Digital audio tape) recorder and digital cassettes. The block diagram of experimental setup is shown in Figure 1. The T-type antenna installed during XVII expedition was damaged and the same was repaired and reinstalled. The ELF/VLF signal received by T-type antenna is vertical component of wave electric field which is amplified by pre-amplifier kept near the recording system. The signal is amplified by the main-amplifier before being recorded by the digital audio tape recorder and sound could be listened by the head phone. The recorded data are analyzed with the help of VLF analysis system

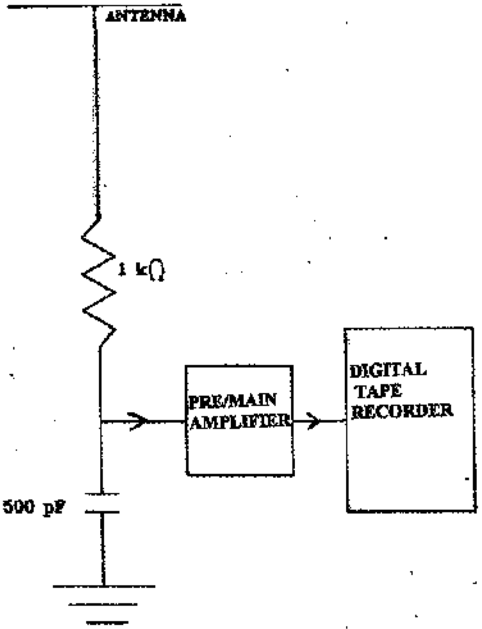

Fig. 1: Block diagram of whistler/VLF emissions recording system.

called Advance VLF data analysis system (AVDAS) at the Physics Department, Banaras Hindu University, Varanasi.

Data and method of analysis

After repairing all the equipments installed during the XVII and XVIII expedition, data were recorded from January 13, 2001 to January 16, 2001. The new T-type antenna was installed on 16 January 2001 and recording was carried out using new antenna set up from January 17, 2001. The continuous recording was carried out from January 17, 2001 to, February 24, 2001. From the detailed analysis of the recorded data, it is found that the most popular part of the very low frequency emissions "VLF hiss" is recorded. Earlier hiss was supposed to be high latitude phenomena, but recent observations show that there are three principal zones of intense hiss activity: the first zone is located near invariant latitude of 70°, the second zone is near 50° invariant latitude and the third zone lies below ± 30°. Hiss events occurring in the third zone are also called as low latitude or equatorial hiss and they are less intense than the mid/high latitude hiss. Hiss events observed in the first zone is also called as auroral hiss (4 kHz $< f <$ 30 kHz). The recorded data during the XXth Indian Antarctic Scientific Expedition at Maitri, Antarctica was digitized and analyzed. During the analysis it was found that the noise was very high in some of the data. Spherics was observed but we could not find whistlers in these data sets. The data with low noise level were selected for further analysis. Figure 2 shows VLF hiss at relatively higher frequencies (11kHz $< f <$ 13

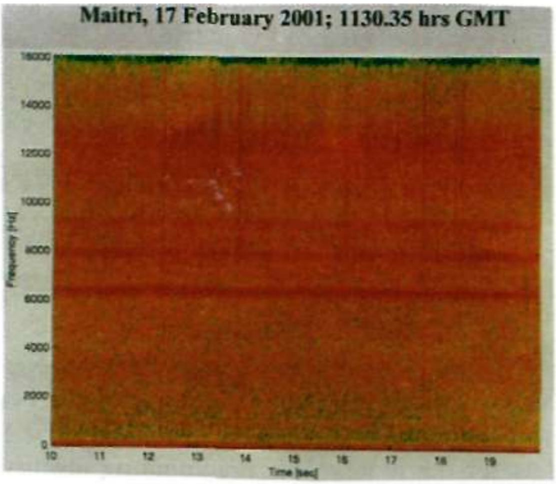

Fig. 2: VLF hiss recorded at Indian Antarctic Station, Maitri on February 17, 2001 at 11.30:35 hrs GMT.

kHz) observed on February 17, 2001 at 11.30:35 hrs GMT. From the figure 2, it is noted that the noise level is very low. Three horizontal lines at 6.2, 8.0 and 9.2 kHz seems to be the transmitter signals. The hiss events presented in figure 2 continued for two hours (11-13 hrs GMT) having almost the same intensity as inferred from the colour of the spectrogram. Figure 3 shows risers in the frequency range 3 kHz-5 kHz and hiss in the frequency band 13 kHz-14.3 kHz recorded on February 3, 2001 at 12.46:50 hrs GMT. The hiss emission continued for more than one hour and risers in sufficient numbers were observed for about one hour, df/dt increases as frequency 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).

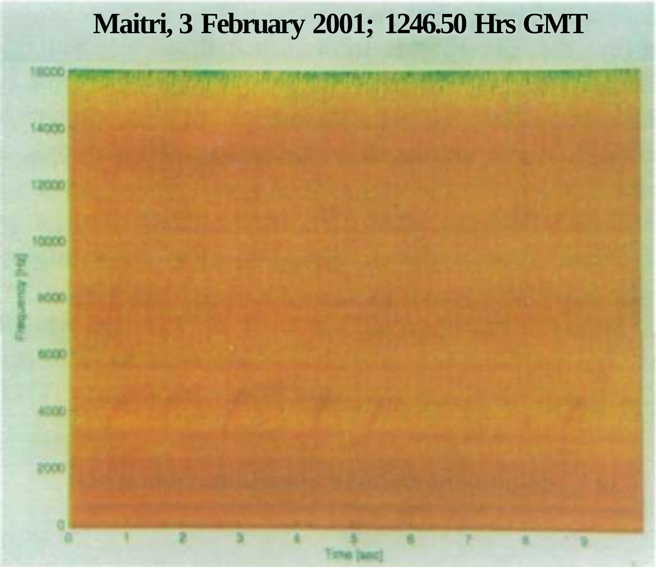
Maitri, 3 February 2001; 1246.50 Hrs GMT

Fig. 3: Example ofVLF risers (3kHz<f<5 kHz) and VLF hiss (13 kHz <f, 14.3 kHz) recorded at Indian Antarctic Station, Maitri on February 3, 2001 at 12.46:50 hrs GMT.

Generation mechanism of VLF Hiss

Early observations were explained in terms of incoherent Crenkov radiation mechanism following observed close correlation between auroral hiss events and precipitating electrons at energies below 1 KeV. Using different models for the ionosphere, precipitating electron beams and magnetospheric parameters, this mechanism has been studied in detail (Ellis, 1957; Jorgensen, 1968; Singh and Singh, 1969; Lim and Laaspere, 1972; James, 1973; Taylor and Shawhan, 1974; Maeda, 1975; De and Bandyopadhyay, 1985; Singh et al., 1999; 2001). In the present computation, we have considered Mansfield (1964) formulation which is based on the Fourier transform method originally developed by Sitenko and Kolomenskii (1956). Assuming medium to be cold, collisionless, dispersive and anisotropic in nature, the radiated power from a charged particle moving along the geomagnetic lines of force having small pitch angle ($V_\perp \approx 0$) is given by (Mansfield, 1964)

$$dP/df = (e^2 \beta_{\|} \omega / 2 \varepsilon_0 c) T_{33} \times \{1/(B_n^2 - 4 c_n \varepsilon_1)^{1/2}\} \text{ W/Hz} \qquad (1)$$

where $T_{33} = \varepsilon_1^2 - \varepsilon_2^2 - \varepsilon_1 n^2 + (n^4 - \varepsilon_1 n^2) \text{Cos}^2\theta$

$B_n = n^2 \text{Cos}^2\theta (\varepsilon_3 - \varepsilon_1) + \varepsilon_2^2 - \varepsilon_1^2 - \varepsilon_1 \varepsilon_3$

$C_n = n^2 \text{Cos}^2\theta (\varepsilon_1^2 - \varepsilon_2^2 - \varepsilon_1 \varepsilon_3) + \varepsilon_3 (\varepsilon_1^2 - \varepsilon_2^2)$

and $\beta_{\|} = V_{\|} /c$

The total power from the incoherent Cerenkov radiation is computed by the expression

$$P_{Total} = P_e \times N_e \times V \qquad (2)$$

where P_e = average power emitted per electron, N_e = number density of energetic electrons and V = volume of the region where VLF waves are generated.

Discussion

VLF hiss and riser type emissions are reported for the first time from the Indian Antarctic Station, Maitri. The location of the hut containing the recording setup (geogr. lat. 70° $46^{;}$ S, geogr. long. 11° 44^{7} E and geomag. lat. 62.4° S, geomag. long. 52° E) is shown in Figure 4. A large

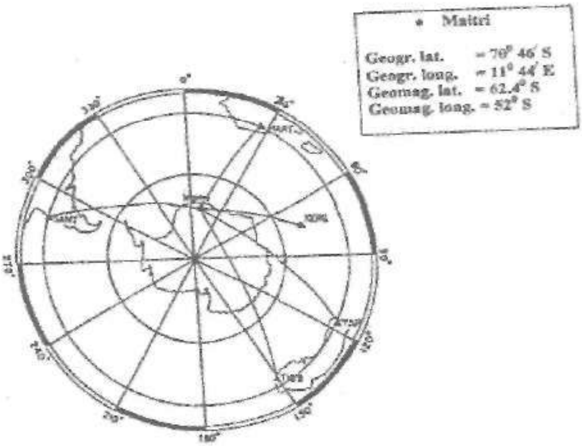

Fig. 4: The location of the hut containing the recording system.

amount of data are still to be analyzed. To explain the observed VLF hiss, we have evaluated power radiated by single electrons in different frequency ranges. The computation is repeated for different energy of radiating electrons. To compute the total power radiated per unit volume per unit frequency, the actual distribution of electron energy spectrum has been used (Evans, 1966; Frank and Ackerson, 1971). For ready reference, the same is presented in Figure 5. The energetic electron flux suddenly decreases as is seen from the figure (E > 10 keV). Detailed analysis shows that the Cerenkov radiated power comes from the electrons having energy less than 500 eV. Thus, in the energy range of our interest the electron flux slowly decreases as energy increases, which means that the number of participating electrons decreases with the increase in their energy. As the electrons move along the geomagnetic field line, the gyrofrequency and plasma frequency increases, which increases the radiation bandwidth. To evaluate the total power, we computed the radiated power at $\phi = 0°, 30°, 45°, 55°$ for $L = 4.5$ and $L = 5.0$. If we assume that all the electrons radiate in phase and there is no loss of power during the propagation from the source to the receiving point, then we may add up

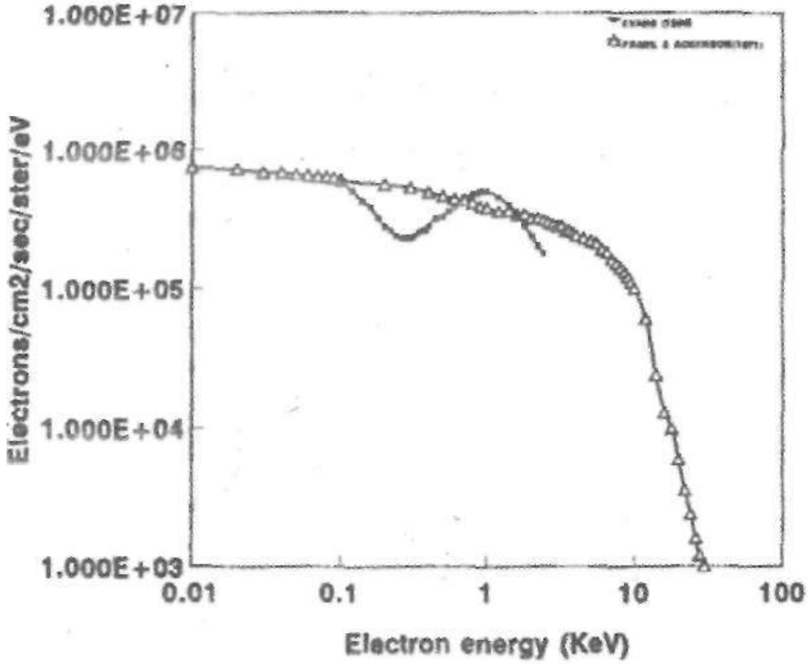

Fig. 5: The distribution of electron energy spectrum used in the computation of total radiated power in the Cerenkov mode (After Evans, 1966 and Frank and Ackerson, 1971).

the power radiated from individual electrons distributed in energy spectrum and distributed in space along the field lines. The radiated power to be received on the Earth surface as a function of frequency is shown in Figure (6). The estimated power ~ $10^{-16} - 10^{-15}$ $Wm^{-2}Hz^{-1}$.

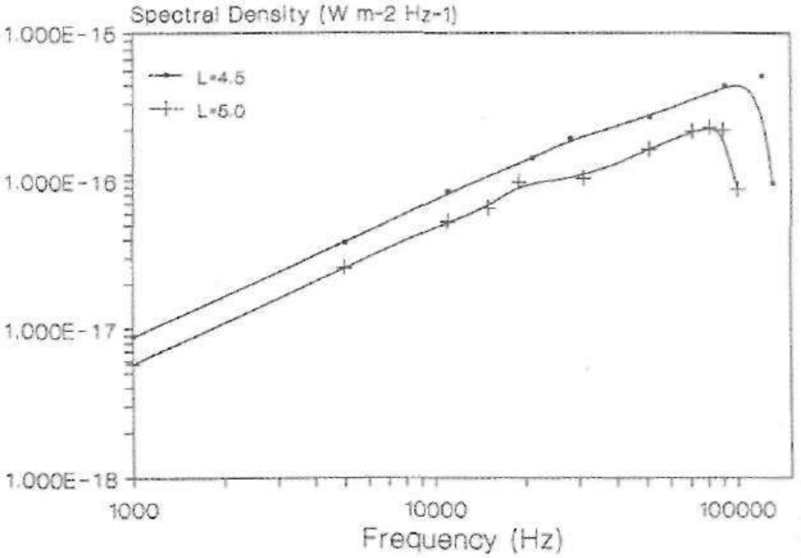

Fig. 6: The radiated power to be received on the Earth surface as a function of frequency.

It may be noted that the radiated power is much smaller than that reported by other workers (Church and Thorne, 1983; Cornilleau et al., 1985; Bering et al., 1987; Singh et al., 1999). If we take the effect of attenuation and consider that all the electrons may not radiate in phase, then the estimated power will be quite small and we must reach some other mechanism of generation to explain the measured power. Under such circumstances we consider that the generation mechanism of VLF hiss consists of two steps. In the first step waves of small amplitude are generated by Cerenkov process from the electrons having energy less than 1 keV. These waves interact with electrons having energy in the range of 100 eV and 1 keV. The energy spectrum reported by Frank and Ackerson (1971) (as shown in Fig. 5) is suitable for amplification of waves. The VLF waves during its propagation back and forth along the geomagnetic field lines may get amplified to the level of received intensity. These amplified waves may penetrate the ionosphere and be received on the earth surface.

Conclusion

We have reported the VLF hiss and VLF risers recorded at the Indian Antarctic Station Maitri. These are the first reported VLF observations. Tentatively we have worked out the generation mechanism of VLF hiss. We have shown that the generation mechanism consists of two steps. In the first step, small amplitude VLF hiss are generated by the electrons through the process of Cerenkov mechanism. In the second step these small amplitude waves could be amplified to the observed level. The waves propagate in whistler mode along the geomagnetic field lines.

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