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Study of Very Low Frequency (VLF) Phenomena at Maitri, Antarctica

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Abstract

Ground based observations of Very Low Frequency (VLF) electromagnetic signals at the Indian station Maitri (70°46 'S, 11°44'E) in Antarctica have been described in detailed. The ELF and VLF recording experiment was successfully installed during the 19^{th} expedition and observations were carried out during Jan-March, 2000 using a T-type antenna and loop type antenna in E-W and N-S directions.

Objectives

1. The continuous recording of whistlers at Antarctic with the help of digital systems interfaced with computer during summer and winter months.
2. Real time analysis of whistlers with the help of data acquisition and analysis system.
3. To study the statistical properties to whistlers under quiet and magnetic storm conditions. (in collaboration with EG, Bombay.)
4. Multi-station recording of whistlers (Bhopal, Agra, Varanasi and Jammu)

Introduction

The electromagnetic waves generated by a lightning stroke (or spherical) over a wide frequency range under the suitable conditions penetrate ionosphere and propagate along geomagnetic field lines to opposite hemisphere where they can be recorded by receiving system. The waves propagating through plasma medium are dispersed, low frequencies preceding high frequencies, and entire signals are called whistlers. These signals contain the information on the structure of magnetosphere. The frequency versus time measurements of the whistlers yields the information on the medium parameters such as electron density, total electron content of a flux tube (Park *et al,* 1978, Sazhin *et al,* 1992, Singh *et al,* 1998), magnetic field and small and large-scale electric fields (Block and

Carpenter, 1974). ELF/VLF wave phenomena have been observed and studied for decades, and have been widely used for investigating the magnetospheric processes of wave generation and propagation, wave-particle interactions and wave-induced particle precipitation and for probing of magnetospheric plasma structures and motions (Carpenter, (1978). A systematic survey at few globally distributed sites was initiated by Stanford University in 1985 (Smith *et al,* 1988). In 1992, a well-calibrated long term ELF/VLF monitoring experiment called VELOX (Smith, 1995) was set at Haley, and few of the results from there are reported by Smith and Jenkins (1988).

Whistler studies have been mainly carried out at low and mid latitudes. Helliwell (1965) carried out a latitudinal survey of whistlers by the US research ship and observed whistlers at geomagnetic latitudes above 15°S. Hayakawa and Ohtsu (1973) could not observe any whistler at Kagoshivna (Geomag. Lat. 20.7°N), and they have concluded that field-aligned whistler ducts can exits only at geomag. Lat. 21 °N in quiet periods. The whistlers have been observed in India at Gulmarg, Jammu, Varanasi, Agra and Bhopal. Further an extensive survey of whistler and VLF phenomena was carried immediately following the International Geophysical Year (IGY) 1957-58 with some more than 50 monitoring stations extending from equator to poles. It soon became clear that Antarctica is an ideal place for VLF research. Further favourable factors in Antarctica include low levels of both man made and natural electromagnetic noise such as spherics, low inospheric absorption during long winter nights and exceptionally high whistler rates. Recently, Singh *et al.* (1998) in a review have reported the plasma parameters derived from the exploitation of whistler spectra recorded at low mid and high latitude ground whistlers. The parameters derived are electron density, total electron content of flux tube, electric field, duct properties etc. we present here the detailed reported of the very low frequency (VLF) signal observations at Indian Antarctic station, Maitri (70°46'S, 11°44'E) during January-February 2000.

Technical Details

As per our work plan, we have finished two Phases during 17th and 18th expeditions by sending Analog and Digital Systems for recording of whistlers and VLF related phenomena on routine basis. Third Phase includes routine recording of whistler using standard techniques of digital system at Antarctica. For real-time analysis, we would send digital system interfaced with Computer having Data Acquisition and Analysis Systems. Since lot of data should be expected during summer and winter months, therefore, this system would give real-time analysis as and when required. Antenna system, installed at Maitri may also be replaced by the triangular antenna system with modified pre and main amplifier using adequate filters. Circuit has already been designed and tested. For routine measurement of the phenomena, Logistic will be only to install antenna triangular system at Antarctic.

Methodology

Usual T-type of antenna, pre-amplifier, main amplifier, digital audio-recorded assembly is sufficient to record whistler on magnetic tape in digital from. This assembly already exists. For future work a modified triangular loop antenna would be installed at Maitri. OP _AMP based pre-and main-amplifier with filter circuit may be used for better recording of the VLF phenomena. With the help of Computer based system for data acquisition and analysis, we may be able to do real time ELF Spectrum analysis. This would facilitate an accurate and quick interpretation of data taken throughout the summer and winter months.

Experimental Setup

A simplified block diagram of VLF is shown in Fig. 1. It consists of T-type Anetenna. This T-type antenna was installed during 17th expedition. Preamplifier kept at the bottom of pole at which T-type antenna is installed amplifies the ELF/VLF signals received by T-type antenna. These signals receive loop antennae are first filtered by VLF filter and then amplified by pre-amplifiers. The output of pre-amplifiers was further amplified by main amplifier and recorded by Digital Audio Tape Recorder (PCM). The data recorded on magnetic tapes were analyzed using Advanced Very Low

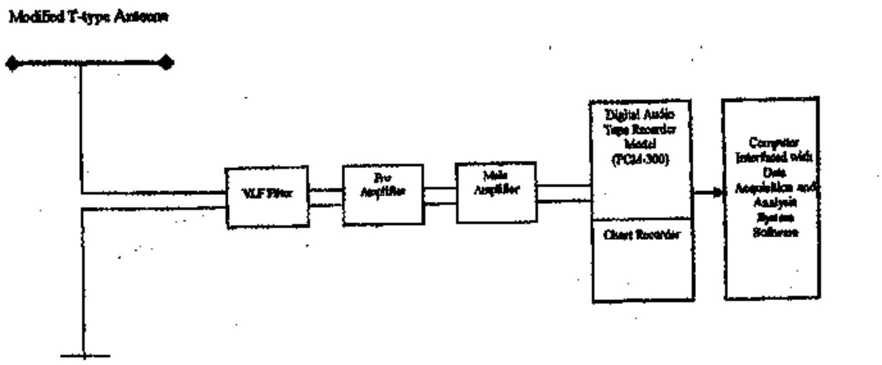

Fig. 1: Block diagram of ELF-VLF recording system during XIX IAE at Maitri, Antarctica

Frequency Data Analyzer System (ADVAS), Sonogram and Speech Station 2 Software at Banaras Hindu University, Varanasi and Central Electronics Engineering Research Institute (CEERI), New Delhi. The VLF data were analyzed in frequency range 1-8 kHz out of which 1-4 kHz is the frequency range in which spheric noise is depressed by attenuation in the Earth-ionosphere wave guide, is dominated by magnetospheric emissions.

Results & Discussion

The experiment was set up on 5th January 2000. It was tested and initially recording was stalled with the antenna system installed during the 17th expedition. The New T-type antenna was installed on 10th of January and the recording started on 15th January. A continuous recording was carried out from morning 0800 hrs to evening 1700 hrs and mid-night 2300 hrs to morning 0400 hrs at regular intervals up to 15th February. From the detailed analysis of the ELF/VLF data it is found that the whistlers and VLF emissions at a number of occasions could be recorded at the Indian Antarctic station. The whistler waves recorded on ground, at high latitudes like Antarctica propagate in ducted mode or prologitudinal mode along the geomagnetic field lines. The waves propagating in a non-ducted mode cannot reach the Earth's surface due to reflection at the lower hybrid resonance frequency (Kimura, 1985). For field-aligned propagation of whistler waves, the wavelength at any given wave frequency increases with decreasing altitude. Due to divergent nature of the geomagnetic field, the duct width decreases with the decreasing altitude. The wave leaks out from the duct wherever the wavelength becomes of the same order as the duct width. As a result of the combined effect of the wavelength and the duct with variations, there is a leakage of down going ducted waves. After emerging from the duct the waves may either propagate to the receiving site in a non-conducted mode or penetrate the ionosphere and reach the observation site propagating in the Earth-ionosphere wave-guide. This mechanism also explains the observed high dispersion of some whistlers recorded at low latitude ground stations in India.

The shape of whistler dynamic spectra is determined by the group delay time of whistler wave at various frequencies from source to receiver. Different magnetospheric parameters from whistlers spectrum are derived by determining the nose frequency f_n (frequency of minimum time travel), corresponding arrival time t_n and inverting integral (Singh *et al,* 1993). Further, we need to adopt reasonable field lime distribution model of electron gyrofrequency (f_H). From time to time various models have been proposed such as diffusive equilibrium model ($f_n = 0.37 f_H$), collision less model ($f_n = 0.41 f_H$). A measurement of t_n for a given path provides a scale factor for the assumed field line model of the distribution of plasma frequency (f_p). Once the plasma frequency is proportional to $n^{1/2}$, where n is the electron density, an estimate of electron density distribution along the path can thus be made.

Some good results observed during the 17th and 18th expeditions are mentioned in Fig. 2 to Fig. 5. The ELF/VLF emissions for decades, and have been widely used for investigating the magnetospheric processes of wave generation and propagation, wave-particle interactions, were-induced particle precipitation and for probing of magnetospheric plasma structures and motions (Carpenter, 1988). The phenomena are generally considered to result from nonlinear electron cyclotron resonance or phase trapping in the equatorial region. This occurs predominately in or near the equatorial plane for two reasons. First, the cyclotron resonance velocity increases as one moves away from equator and thus number of resonance particles decreases quickly. Second, the ambient field gradient increases away from the equator and eventually suppresses non-linear trapping. From the detailed analysis of the data collected during the expedition, it is reported here that ELF/VLF emissions of different types such as discrete chorus emissions, periodic and quasi-periodic emissions, rising and falling emissions of hook type, rising emissions, hiss etc. frequently occur at Maitri, with a maximum occurrence of chorus type emissions: In Fig. 2, we show the frequency-

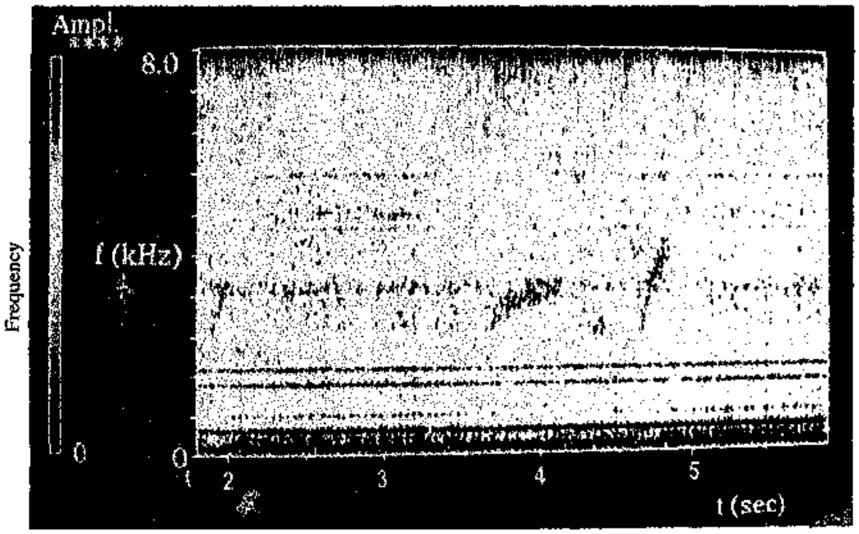

Fig. 2: Spectrogram of chorus riser emission observed at Maitri, Antarctica on 22 January 1998

time spectrogram of chorus riser emission observed on 22nd January 1998 at 1045 UT. The mean upper boundary frequency for this riser is *5.5 K*Hz.

The event in Fig. 2 corresponds to a moderate day, with a daily sum of Kp and Ap indices of 17+ and 6 respectively. Several workers on ground have investigated morphological features of discrete chorus emissions throughout the magnetosphere and satellite based observations (Nurin 1979; Nunn and Sazhin, 1991 ; Hayakawa 1975 ; Sazhin and Hayakawa, 1992). The studies have revealed the chorus emissions are observed mainly at L-values between plasma pause and magnetopause at all local times. The Indian Antarctic Station, Maitri provides a good situation for the observation of chorus emissions. Fig.3 shows discrete rising emissions on 22nd Jan 1998 at 10:50 UT, near a constant frequency of about 2.4 kHz, and have different cut-off frequencies. The rate of rise in frequency (df/dt) is also different for these emissions. In this case df/dt is maximum for first event and minimum for second case can be easily judged from this figure.

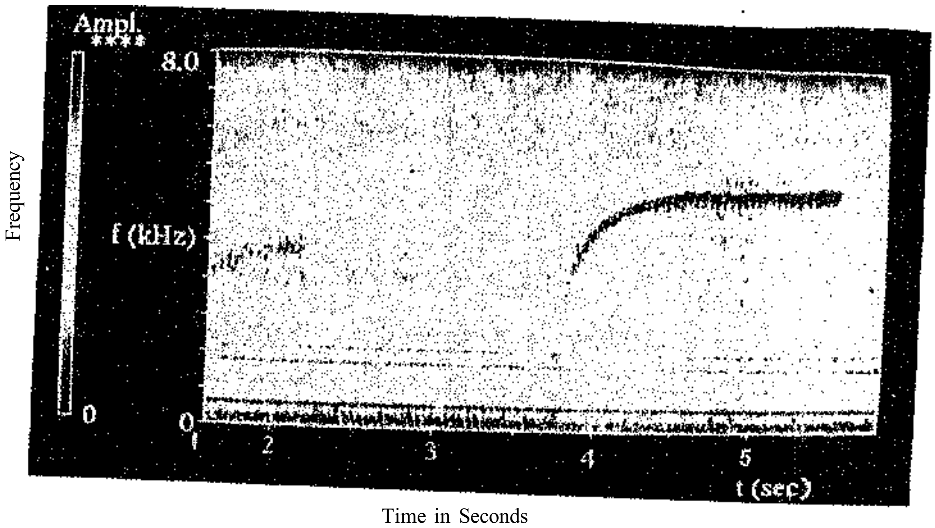

Fig. 3: Spectrogram of discrete rising emissions observed at Maitri, Antarctica on 22 January 1998

The spectra in Fig. 4 shows unusual rising emission recorded on 20th January 1999 in the frequency range 2.5-4.2 kHz. It was a moderate day with three hourly Kp value reaching maximum 3_0 at sixth three hourly averages, and the sum of Kp and Ap were 13+ and 8 respectively. The noise below 1.7 kHz is due to instrument, which has been found to occur, in our all records. A careful look at spectrogram reveals at the rate of rise in frequency is very high to about 20 kHz/ sec. (i.e. is df/dt « 20 kHz/sec). As it rises in frequency the amplitude starts increasing from 2.7 kHz until

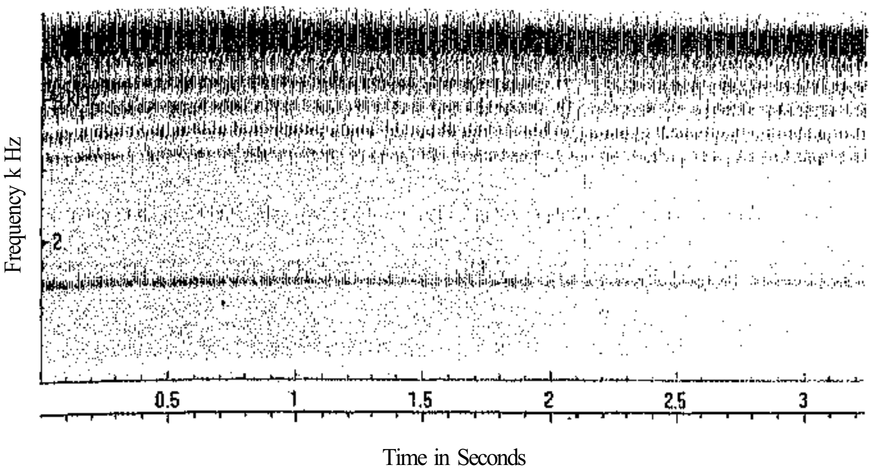

Fig. 4: Spectrogram of rising emissions observed at Maitri, Antarctica on 20 January 1999

this riser is cut-off at frequency 4.2 kHz. For some other similar events, not shown here, the starting and cut-off frequency and rate of risers of frequency is found to vary from event to event. In Fig. 5 we present an example of discrete emissions between frequency range of 4.2-5.5 kHz observed on 20th January 1999 at 1420 UT. An interesting feature of these emissions is that they show hooks near their upper and lower cut-off frequencies. The hook emissions are known to be caused by wave particle interactions between up-and down-going energetic electrons and whistler mode wave along the field lines near the magnetic equator at higher L shells (L > 2) hence are generally observed at high latitudes. The detailed

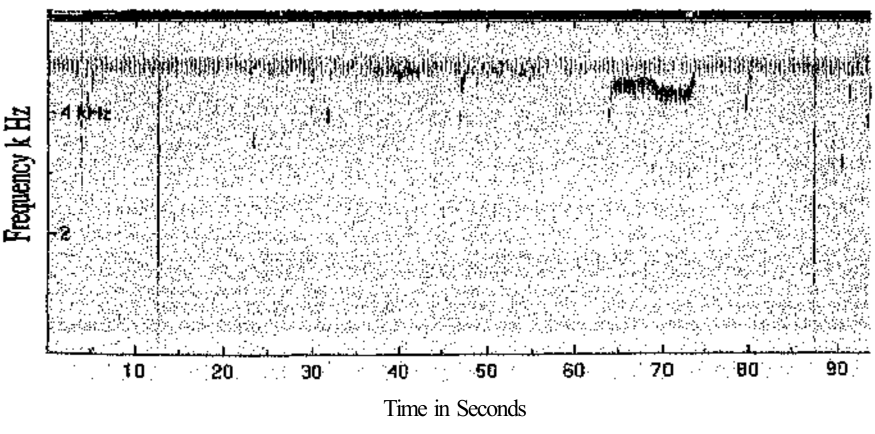

Fig. 5: Spectrogram of typical hook emissions observed at Maitri, Antarctica on 20 January 1999

study of the ELF/VLF emissions observed during these expeditions, their associations with storms and sub-storms, geomagnetic pulsations, and their interactions is in progress, which may explain many questions on the nature of these emissions and their relationships to sub-storms and magnetic pulsations.

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