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RESEARCH ARTICLE

MAGNETOSPHERIC DISCRETE VLF RISING-TONE CHORUS EMISSIONS OBSERVED AT INDIAN ANTARCTIC STATION MAITRI (L = 4.5), ANTARCTICA

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ABSTRACT

The magnetospheric discrete VLF chorus emissions observed at Indian Antarctic Station Maitri, Antarctica (geomag. lat. = 70^0 $46^/$ S, geomag. log. = 11^0 $50^/$ E, L = 4.5) has been analyzed during quite period on 5th February 2001 are presented. The detailed spectral analysis of recorded discrete VLF chorus emissions, we found that intensity seems to decrease with increase in frequency and also it varies from event to event and each chorus emissions originates from upper edge of narrow hiss band and chorus events are hiss-triggered. They are generated in the magnetosphere near the geomagnetic equator by trapping of the energetic electrons. To explain the observed dynamic spectra of these events, a possible generation mechanism is presented based on the Helliwell's theory. To understand the generation mechanism of discrete VLF chorus emissions, using Helliwell's (1967) theory and previous presented satellite VLF data, some plasmaspheric parameters such as phase velocity, group velocity, parallel and perpendicular velocity of interacting electrons, source length, source location, wave magnetic field, power density, transverse current etc. are computed. Our results are good agreement to other workers.

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INTRODUCTION

Magnetospheric discrete rising tone chorus emissions are the most common form of very low frequency (VLF) emissions in the Earth's magnetosphere and other planetary magnetospheres. These are usually consists of a succession of discrete elements with rising frequency having repetition period of ~ 0.1 – 1 s and typical duration of chorus emissions being 0.5 – 1 h (Helliwell, 1965). Very low frequency waves are defined and categorized depending upon the dynamic spectrum of shapes. They are generally classified into two different types namely unstructured hiss and structured or discrete chorus (Helliwell, 1965; Sazhin and Hayakawa, 1992; Hattori and Hayakawa, 1994). Magnetospheric chorus waves have been observed and presented (Helliwell, 1965; Tsurutani and Smith, 1974; Burtis and Helliwell, 1976; Anderson and Kurth, 1989; Sazhin and Hayakawa, 1992; Lauben *et al*., 1998; Meredith *et al*., 2001, Santolik *et al*., 2003; Singh and Patel, 2004; Chum *et al*., 2007 and references therein). Gyroresonant interactions of electrons with chorus play an important role in the physics of the Earth's radiation belts. Gyroresonant pitch-angle scattering of electrons by chorus waves can lead to significant precipitation into the atmosphere and net loss of energetic electrons from the outer radiation belt (Lorentzen *et al*., 2001; O'Brien *et al*., 2004; Summers *et al*., 2005; Thorne *et al*., 2005). The generation mechanism of chorus emissions have been studies (Nunn, 1974; Omura and Matsumoto, 1982; Trakhtengerts, 1995, 1999; Nunn *et al*., 1997; Katoh and Omura, 2007; Chum *et al*., 2007). It is generally accepted that chorus waves can be excited by cyclotron resonance with anisotropic 10–100 keV electrons. Simulation the generation process of chorus emissions by a Vlasov-hybrid simulation method using a coherent wave as a seed of a chorus emissions (Nunn, 1974; Nunn *et al*., 1997). Trakhtengerts (1995; 1999) suggested a generation mechanism of chorus emissions based on the backward wave oscillator regime of a magnetospheric cyclotron maser. Theory and simulation of the generation of whistler-mode chorus waves has explained (Omura *et al*., 2008). The generation mechanism of spontaneous chorus emissions has been studied by several workers (Burton and Holtzer, 1974; Nunn, 1974; Bespalov and Trakhtengerts, 1974; Curtis, 1978; Goldstein and Tsurutani, 1984; Hayakawa *et al*., 1984; Hattori and Hayakawa, 1994). Hiss-triggered chorus emissions observed at high latitude has reported by (Patel, 2015; 2016).

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Koons (1981) has presented hiss-triggering chorus emissions observed by the SCATHA satellite and suggested that the structures or large-amplitude spectral components existing in the hiss band are able to phase-bunch electrons, which excite the chorus emissions. In this paper, we present magnetospheric discrete VLF rising tone emissions recorded at high-latitude Indian Antarctic Station Maitri Antarctica (geomag. lat. = 70^0 $46^/$ S, geomag. log. = 11^0 $50^/$ E, L = 4.5) during a quiet period on 5th February 2001. From the analysis, it is observed that each chorus events starts from the hiss band and hence it is suggested that the hiss has important role for the generation of discrete chorus emissions in the outer magnetosphere. Further, the generation mechanism of discrete emissions proposed theory (Helliwell, 1967) based on experimental results and various parameters connected with these events such as phase velocity, group velocity, parallel and perpendicular velocity of interacting electrons, source length, source location, wave magnetic field, power density, transverse current etc. are computed.

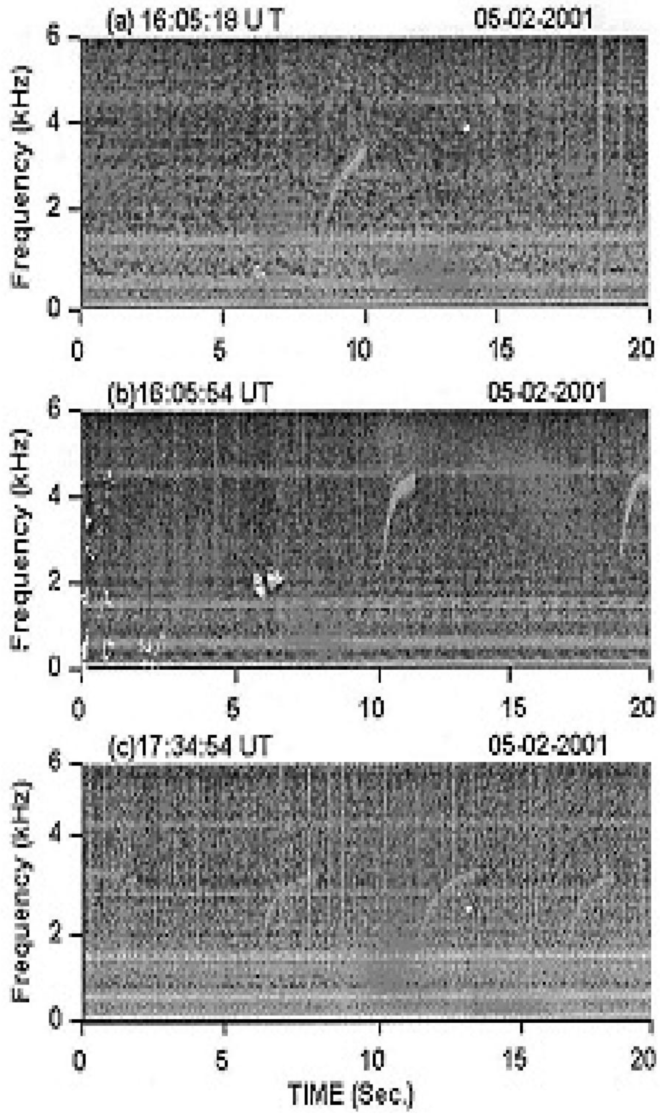

Figure 1. Example of discrete VLF rising tone chorus emissions recorded on 5 February 2001 during 16:05 UT to 17:40 UT at the Indian Antarctic Station, Maitri, Antarctica

EXPERIMENTAL DATA AND ANALYSIS

The VLF wave recording setup consists of T-type vertical antenna of 10 meter height and 40 meter length supported by two poles, transistorized amplifier and a digital tape recorder. Observations were carried out by the Dr. R. P. Patel, Department of Physics, Banaras Hindu University, Varanasi during the summer part of the XXth Indian Antarctic Expedition from 10 January to 10 March 2001. Pre-amplifier is kept at the bottom of the pole at which an antenna is to install to amplify by main-amplifier. The data are stored in digital audio tapes. The recorded data were analyzed and choose the low noise level VLF waves (Patel, 2002; Patel *et al*, 2003; Singh and Patel, 2004).

The dynamic spectrum of discrete VLF rising tone emissions are shown in figure 1a,b,c. Chorus emissions originate from a narrow hiss band. The whole observation period of discrete chorus events continued for about 1h 35 min. From figure 1(a), the upper cutoff frequency of 3.4 kHz and a frequency sweep rate df/dt of 1.6 kHz/s. In figure 1 (b) shows two chorus emissions with a repetition period of 6s and an upper cutoff frequency of 4.3 kHz. The frequency sweep rates of chorus events are 2.7 and 3.1 kHz/s respectively. For the next 1 h the upper cutoff frequency remains the same and then decrease to reach 3.2 kHz as shown figure 1 (c), which contains three discrete chorus events. The repetition period of about 4.2 s and the frequency sweep rate decreases to a value of 1.1 kHz/s. The observed mean chorus element parameters are as follows: $f_{min.}$ = 1.8 kHz, f_{UB} = 4.3 kHz, frequency sweep rate df/dt = 2.1 kHz/s and repetition period T = 4.2 s. These discrete rising tone emissions were recorded during a geomagnetic quiet day on 5 February 2001 with $\sum K_P = 5_+$, a maximum AE index of 123nT and D_{st} – index of 14nT (Singh *et al.*, 2010).

GENERATION MECHANISM OF CHORUS EMISSIONS

The analysis of discrete VLF rising tone chorus emissions observed at high latitude Indian Antarctic Station Maitri, Antarctica, which is generated due to wave-particle interaction in the magnetosphere.

Using the upper boundary frequency (UBF) method developed by Smirnova (1984) to find out the location of source for the discrete chorus emissions. The upper boundary frequency of the ground based observation of VLF chorus events is determined on the assumption of dipolar geomagnetic field configuration, by the half equatorial electron gyro-frequency in the generation region, irrespective of the latitude of the observation station. According to Smirnova (1984) method, the L-value of the chorus emissions source is written as

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

where f_{UB} is upper boundary frequency of the observed emissions in kHz. Using the observed parameter f_{UB} = 4.3 kHz in equation (1) the source location of discrete VLF emissions is found to be L_{Source} = 4.6. Let us consider that S be the source length near the equatorial plane, wave moving south to north and electron moving north to south direction. Then the wave frequency is well known relation Helliwell (1967)

$$f = f_{HO} \frac{V_P}{V_P + V_\parallel} \qquad (2)$$

and frequency variation by

$$\mathrm{df} = f\left(\frac{df_{HO}}{f_{HO}} + \frac{dV_P}{V_P}\right) - \frac{f^2}{f_{HO}V_P}\left(dV_P + dV_{\|}\right) \qquad (3)$$

where f_{HO} is the electron gyrofrequency, V_P is the phase velocity of the wave in negative direction, $V_{\|}$ is the parallel component of electron velocity in positive direction. The path of propagation aligned with Earth's magnetic field and refractive index is assumed much larger than unity, then the phase and group velocity is given as Helliwell (1963)

$$V_P = \frac{cf^{1/2}\,(f_{HO} - f)^{1/2}}{f_N} \qquad (4)$$

$$V_g = \frac{2cf^{1/2}\,(f_{HO} - f)^{3/2}}{f_N f_{HO}} \qquad (5)$$

where c is the velocity of light, f_N is the plasma frequency. Using equation (2) and (4), the parallel velocity of resonantly interacting electron is written as

$$V_{\|} = \frac{c\,(f_{HO} - f)^{3/2}}{f_N\, f^{1/2}} \qquad (6)$$

The corresponding characteristic value of the perpendicular velocity is given as Helliwell (1967)

$$V_{\perp} = 0.577\, V_{\|} \qquad (7)$$

According to Helliwell (1967) theory, the expression for the source length S along the dipolar geomagnetic field line is given by

$$S = 5.85 \times 10^5\, \frac{(1-\lambda)^{1/2}}{f_N^{1/3}\, f_{HO}^{2/9}\, \lambda^{1/6}}\, km \qquad (8)$$

where frequencies are expressed in Hz, $\boldsymbol{\lambda} = f/f_{HO}$, f is the wave frequency, f_{HO} is electron gyrofrequency at the top of the path and f_N is electron plasma frequency. The limiting value of the wave magnetic field (B_ω) has proposed by Helliwell (1967)

$$B_\omega = 5.8 \times 10^{-13}\, \frac{f_{HO}^{13/9}\,(1-\lambda)}{f_P^{4/3}\, \lambda^{2/3}}\, cot\alpha \ \text{weber/m}^2 \qquad (9)$$

$$J_{\perp\max} = \frac{15\pi\, B_\omega}{16\, \mu_0\, S}\, amps/m^2 \text{where } \mu = \mu_0 = 4\,\pi \times 10^{-7} \text{ H/m.} \qquad (10)$$

We have computed magnetospheric parameters, at the L-value of the source region is $L_{Source} = 4.6$ and the equatorial electron gyrofrequency is $f_{HO} = 9.99$ kHz for the discrete VLF rising tone chorus emissions. For the computation of above value we have taken electron density is ~ 65 electrons cm^{-3}. The corresponding plasma frequency is $f_N = 72.56$ kHz, electron gyrofrequency $f_{HO} = 9.99$ kHz. At the wave frequency of 1.8 kHz, velocity of light $c = 3 \times 10^8$ meter/second then the source length comes out to be about 2184 km. The corresponding parallel velocity of electron $V_{\|} = 0.72 \times 10^5$ km/sec, the corresponding characteristic value of the perpendicular velocity $V_{\perp} = 0.42 \times 10^5$ km/sec and wave magnetic field $B_\omega = 0.15 \times 10^{-13}$ weber/m^2, which is good agreement with the result reported by (Helliwell 1967; Smirnova, 1984; Singh *et al.*, 2000). The corresponding concentration of electrons in the transverse current is computed by $J_{\perp\max} = NqV_{\perp}$ and comes to be about 0.07 m^{-3}.

Conclusion

In this paper, we have presented some good patches of discrete VLF rising tone emissions observed at high latitude Indian Antarctic Station, Maitri, Antarctica. All chorus emission of df/dt increases with increasing frequency and chorus originate from the narrow hiss band and hence it is suggested that the hiss has important role for the generation of discrete VLF rising tone chorus emissions in the outer magnetosphere. Further, for the generation mechanism of discrete emissions proposed theory (Helliwell, 1967; Smirnova, 1984) has been used. Possible magnetospheric parameters are computed with the help of Helliwell theory. Our estimated parameters lie within the range of observations and are in good agreement with the results reported by Helliwell (1967) and Smirnova (1984).

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