

WHISTLER-TRIGGERED VLF EMISSIONS RECORDED AT JAMMU DURING DAY TIME

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Abstract: Whistler-triggered VLF emissions recorded at low latitude station Jammu (Geomagnetic latitude = $22^{\circ} 26' N$; $L = 1.17$) during day time period on 19th February 1999 at 14:35 hrs. IST. The recorded data have been analyzed. Based on whistler-triggered VLF emissions spectrum, the VLF waves propagate along the path with L – values lying between $L = 4.4$ and 4.38 . During the observation period, magnetic activity was very high. Mostly these types of emissions recorded at mid latitudes. These whistler-triggered emission waves propagate along the geomagnetic field lines either in a ducted mode or in a pro-longitudinal mode. Relative amplitude of whistlers waves is almost equal to relative amplitude of triggered emissions. The proposed generation mechanism explains through the dynamic spectra of the whistler-triggered emissions.

Key words: Whistlers, Triggered Emissions, Wave-Particle Interaction, Resonance Conditions.

Introduction

Whistlers are electromagnetic waves whose energy originates from natural lightning discharges and propagate through the magnetosphere, whereas VLF emissions are electromagnetic waves generated by (a) particle interactions occurring in the Earth's magnetosphere (Helliwell, 1965). The wave particle interactions occurring in the magnetosphere generates a variety of emissions in VLF range. These emissions, both continuous or unstructured and discrete or structured in natural are very fascinating, challenging and interesting natural phenomena. These emissions are classified into hiss, discrete chorus, hook and inverted hook, periodic and quasi-periodic and triggered emissions (Helliwell, 1965, Nunn and Smith, 1996). Some signal receives from VLF transmitters (Helliwell, 1965; Bell et al., 1982) and some types of chorus emissions arise from the upper frequency of hiss (Helliwell, 1969, Reeve and Rycroft, 1971, Koons, 1981 Hattori et al., 1989, Singh et al., 2000a). Many observations support the idea that strong VLF emissions may be triggered even by very weak signals. The second order cyclotron resonance along an inhomogeneous dipolar magnetic field was discussed by (Helliwell, 1967, Nunn, 1974, Karpman et al., 1974) and has become very useful in theories of triggered emissions. In this paper, we present a details analysis of whistler-triggered emissions observed at a low latitude Indian station Jammu during day time. These events propagate along the higher L-values lying between 1.9 and 4.4 as compared to be observation station Jammu ($L = 1.17$). Thus, the waves are a part of mid latitude whistlers that may have propagated through the Earth ionosphere wave guide towards the equator. The proposed generation mechanism is a nonlinear cyclotron interaction between whistler triggered emissions and counter streaming energetic electrons. Some parameters have been calculated numerically such as parallel resonance energy, trapping time, Bunching time, oscillation period for the trapped electrons.

Experimental observations and Data Analysis

At low latitude ground station Jammu, the wideband VLF signals are recorded by T-type antenna, suitably amplified by pre and main amplifiers and recorded using a tape recorder. The recorded waves were analyzed by Advance VLF Data Analysis System (AVDAS) and sonograms. Some dynamic spectra of whistler triggered emissions are presented. In Figure 1c shows that two events of whistler triggered emissions recorded on February 19, 1999 at 14:35 hrs. (IST) in which discrete chorus risers are triggered from bottom side of the whistler spectrums. During the observation period K_p – index was 6. to 3. and D_{st} index is -106, which is shown in figure 1a,b. The first observed whistler wave frequency varies between 5.3 kHz to 8.4 kHz and second event is 4.3 kHz to 8.5 kHz whereas the frequency of triggered chorus emission varies between 5.1 kHz and 7.9 kHz in the first event and 4.5 kHz and 7.1 kHz in the second event. The relative intensity of whistler wave and triggered chorus emissions are given in triggered emission is almost same. The df/dt value of triggered emission is 1.38 kHz/sec and 1.41 kHz/sec for first and second event respectively. The dispersion of whistler is $88.9 S^{1/2}$ and $88.6 s^{1/2}$, corresponding path of propagation is $L = 4.4$ and 4.38 for the first and second waves respectively.

Table 01: Relative intensity of whistler and Triggered emission of figure 01c.

Whistler wave		Triggered emissions	
Frequency (kHz)	Relative intensity (dB)	Frequency (kHz)	Relative intensity (dB)
8.4	58	7.9	58
7.6	59	7.6	59
6.8	60	6.8	60
6.1	61	6.1	61
5.3	61	5.1	61

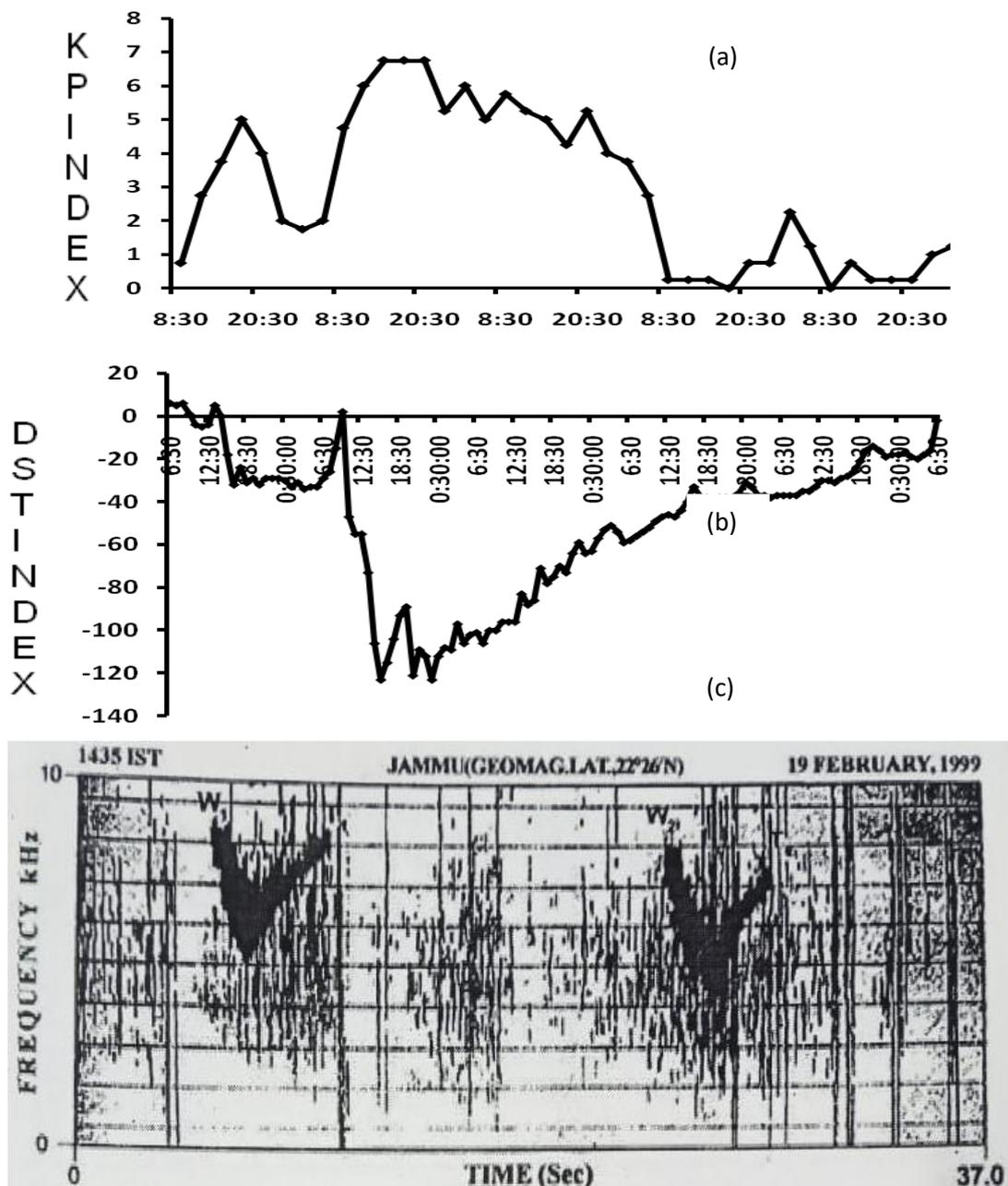


Figure 01: (a) Variation of K_p - index. (b) Variation of D_{st} - index. (c) Dynamic spectrum of the whistler-triggered emissions recorded at Jammu on 19th February 1999 at 14:35 hrs. (IST)

Generation Mechanism

The non-linear self-consistent resonant interaction of energetic electrons with narrow band VLF waves in the Earth's magnetosphere has been used to explain many of the qualitative physical features underlying triggered emissions (Helliwell, 1967; Karpman et al., 1974; Yoshida et al., 1983; Molvig et al., 1988; Omura et al., 1991; Nunn et al., 1997; Trakhtengerts and Rycroft, 2000). A large number of workers have been made to solve the problem using different numerical model such as sheet current model (Helliwell and Inan, 1982; Carlson et al., 1990), non-linear resonant current model (Nunn, 1984), electromagnetic full particle model (Cuperman and Lyons, 1974; Omura and Matsumoto, 1987), fluid-particle (hybrid) model (Vomvoridis and Denavit, 1980; Vomvoridis et al., 1982) and Vlasov hybrid model (Nunn, 1990; Nunn and Smith, 1996). On the basis of non-linear cyclotron resonant interaction between whistler mode waves and counter streaming energetic electrons, the cyclotron resonance condition is written as

$$\omega - \omega_H / \gamma = k v_{||} \quad (1)$$

Where ω and k are the wave frequency and wave vector of the whistler waves, $k = |k|$, ω_H is the electron gyro-frequency, $v_{||}$ is the field aligned component of the electron velocity, $\gamma = (1 - v^2/c^2)^{-1/2}$ is the relativistic factor, v and c is the interacting particle velocity and light velocity in free space. For ducted whistler propagation $K||B_0$, B_0 being the vector geomagnetic field. In an inhomogeneous magnetic field, ω_H , $v_{||}$ and k are functions of the coordinate z along the magnetic field B_0 . The electrons with different $v_{||}$ interact with the same wave (ω , k) at different points along the geomagnetic field lines.

According to non-linear theory, the field equation for slowly varying in magnetic field can be written as (Omura et al., 1991; Trakhtengerts and Rycroft, 2000)

$$(\partial/\partial t + v_g \partial/\partial z) B\omega = (\mu_0/2) v_g J_R \quad (2)$$

where $B\omega$ is the complex amplitude of the magnetic wave field, v_g is the group velocity and J_R is the current due to the resonant electrons. The dispersion relation for the whistler mode waves propagating along the geomagnetic field line is given as

$$k = [(\omega_P \omega^{1/2}/c)(\omega_H - \omega)^{1/2}] \quad (3)$$

where ω_P is the electron plasma frequency. Combining equation (1) and (3), the resonant electron energy is written as

$$E_R = mV_R^2/2 \quad (4)$$

where m is the mass of electron. The resonance velocity $V_R = V_{||}$ written as

$$V_R = [c \cos\alpha (\omega_H - \omega)^{1/2} \{(\omega_H + \omega)(\omega_H - \omega)^2 + \omega_P^2 \omega \cos^2\alpha\}^{1/2} - \omega_P \omega^{3/2} \cos\alpha] / [\omega_H^2 (\omega_H - \omega) + \omega_P^2 \omega \cos^2\alpha] \quad (5)$$

Where α is the pitch angle of the electron. In our numerical computation for relativistic parallel resonance energy, we have used normalized electron density verses distance along the field line from the equator according to the collision-less model. We have taken equatorial electron density 550 and 65 electrons cm^{-3} for two path of propagation $L=3$ and 4.5 respectively and the corresponding plasma frequency is $\sim 211, 72$ kHz and electron gyro-frequency is ~ 32 and 9 kHz. Calculate the value of parallel velocity is $V_{||} \sim 2.48 \times 10^8$ m/s and perpendicular velocity is $V_{\perp} \sim 0.64 \times 10^8$ m/s, which is parallel velocity is greater than the perpendicular velocity of resonant electron. Using equation (4), we calculate the value of relativistic parallel resonance energy for $L=3$ and 4.5 for pitch angle ($\alpha = 30^\circ$) and different wave frequency of electrons. We found that the $E_R \sim 6.61 \times 10^3$ keV to 0.003 keV For $L=3$, wave frequency varies between 0.1 to 30 kHz, and for $L=4.5$, frequency varies between 0.1 to 8 kHz, E_R decreases from 764 keV to 0.028 keV. The resonant energy decreases with increasing wave frequency. Thus, it is clearly seen that in the inner magnetosphere high energy particles are actually participating in the triggering process. As pitch angle (α) increases, resonant electron energy increases but the overall pitch angle dependence is non-linear. For low latitude ground station Varanasi, the interaction region corresponding to inner magnetosphere for $L=2, 3$ and 4, E_R varies between MeV to keV have presented by (Patel, 2002; Singh et al., 2003).

If the rates of change of electron gyrofrequency and of the wave frequency balance each other, then the electron will remain in resonance for a longer duration and the phase angle remains constant. This means that the full derivative of equation (1) along the particle path is zero, which is the idea of second order resonance, first formulated by (Helliwell, 1967). This was suggested to be the necessary condition for the most effective wave-particle interaction in the inhomogeneous magnetic field. The resonant electrons are then phase bunched by the $(eV_{\perp} \times B\omega)$ force acting along the field line. Solving equation of motion of an electron traveling in an inhomogeneous medium, in the presence of a whistler wave, it can be shown that the wave trapped electrons oscillate with a period (Dysthe, 1971; Inan et al., 1978; Yoshida et al., 1983)

$$T_r = \{(2\pi m V_P)/(eV_{\perp} f B\omega)\}^{1/2} \quad (6)$$

where m is the mass of electron, e is the charge of electron, f is the wave frequency, $B\omega$ is the wave magnetic field, $V_p = \omega/k$ is the phase velocity, V_{\perp} is the velocity of the electron perpendicular to the field. The trapped electron oscillates with a frequency $\Omega_{tr} = (keV_{\perp} B\omega/m)^{1/2}$. Yoshida et al. (1983) have concluded that electrons whose absolute initial phase (ϕ) is less than 90° , will be bunched at $\phi = 0^\circ$ after a period of $T_r/4$ is called as bunching time (T_B). We have used some parameters for computing bunching time, wave frequency $f = 1$ kHz, $\phi = 0^\circ$, $B\omega = 1m\gamma$, $\alpha = 15^\circ$, bunching time $T_B \sim 17$ ms for $L = 2$. The same for $L = 4.5$ is 54 ms. The initial geomagnetic latitude increases with decreasing bunching time. Also wave magnetic field increases, bunching time is decreases. As wave frequency increases as in the presence of dense plasma, bunching time decreases.

Conclusions

In this paper, we present detailed spectral analysis of whistler triggered emissions observed at the low latitude ground Jammu during daytime period. Based on observations and computations reported following some point emerge.

1. Whistler-triggered emission waves are recorded at low latitude ground station Jammu for the first time during daytime period.
2. The K_p – index and D_{st} – index was very high during the observation period.
3. These events may actually be mid-latitude emissions, because our analysis of whistler waves propagated along geomagnetic field line is higher L-values lying between 4.4 and 4.38.
4. They are propagated along the geomagnetic field lines ($4.38 \leq L \leq 4.4$) and after exiting from the ionosphere and excite the Earth-ionosphere wave guide and propagate towards the equator along with whistlers.
5. The relative amplitude of whistlers and triggered emissions are almost same.
6. The relativistic parallel resonance energy of electrons decreases with increasing frequency but energy increases with decreasing L-value. The reported resonance electron energy lies in the keV range.
7. Bunching time decreases with increasing of both geomagnetic latitude and wave magnetic field. Wave frequency increases as in the presence of dense plasma, bunching time decreases.

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