Research Article

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Study of Quasi-Pulsing VLF/ELF Hiss Emissions at a Low Latitude Indian Ground Station

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ABSTRACT

This paper report an unexpected simultaneous observation of band-limited quasi-periodic pulsing ELF/VLF hiss emissions. The data shown in this paper indicate that there is a strong possibility that lightning is an important source of different types of VLF/ELF emissions, at least in the embryonic sense, recorded at Jammu. The present observation is, in fact, the first simultaneous occurrence of VLF/ELF hiss emissions.

Keywords: ELF/VLF emissions; Magnetosphere; Pulsing hiss.

1. INTRODUCTION

Whistler mode waves and their interactions with energetic particles have been a subject of interest since the discovery of radiation belts. The wave-particle interactions occurring in the magnetosphere generate a variety of emissions in the ELF/VLF range. ELF/VLF emissions from the Earth's magnetosphere in the range of few hertz to 30 kHz, both continuous or unstructured and discrete or structured in nature, are fascinating, challenging, and interesting natural phenomena Helliwell (1965). Although the ELF/VLF emissions of different types are often observed at different times at low latitude ground stations in Japan and India (Hayakawa et al. 1975; Khosa *et al.* 1981; Singh *et al.* 1999), almost there is no evidence of their simultaneous occurrence during daytime.

We here report the first simultaneous observation of ELF/VLF waves during daytime at a low latitude Indian ground station Jammu, band-limited quasi-periodic pulsing ELF/VLF hiss emissions,

2. EXPERIMENTAL RESULTS

We have conducted an initial observation of whistlers and VLF/ELF emissions at our ground-based station Jammu and obtained a unique and very interesting result of the simultaneous occurrence of whistlers and different types of VLF/ELF emissions during daytime. Such type of daytime observations has never been reported from any of the low latitude ground stations so far and is the first result to be reported here. A preliminary description of whistlers and different types of VLF/ELF emissions recorded simultaneously during daytime at Jammu in the magnetically disturbed periods on 06 January 1999, along with their possible interpretations, are given. It is very interesting to examine the simultaneous occurrence of whistlers and different types of ELF/VLF emissions at a low latitude ground station in view of the origin of these reported emissions. Some typical and interesting examples of these simultaneously recorded ELF/VLF data at Jammu are shown in Figures 2- 7. The date and time of the observation of each whistler and VLF/ELF emissions are mentioned on the top of each figure. These were observed simultaneously only on a single day in winter local day times on 06 January 1999 during the magnetically disturbed period with the sum of K_p indices as 18 ($\sum K_p = 18+$). This activity started around 1400 hrs IST (Indian Standard Time) and continued for about two hours.

Fig. 1 illustrates the temporal variation of geomagnetic activity during this event; 3-hour K_p indices are used. The times of having observed whistlers and VLF/ELF emissions simultaneously are indicated in the upper panel by rectangles just above the abscissa of the panel. It seems that the occurrence of these whistlers and VLF/ELF emissions appears to be well correlated with geomagnetic substorms designated by a peak in the K_p index at ~ 8h UT on 06 January 1999. Taking into account the relationship of local time IST = U.T. + 5.5h, every whistler and emissions described below have taken place in the local afternoon hours.

Fig. 2 illustrates typical examples of frequency spectra of quasi-periodic pulsing hiss emissions recorded simultaneously at 1510 hrs IST. This figure contains pulsing hiss in both frequency range of VLF and ELF starting from ~ 300 Hz upto ~ 8 kHz frequencies. It is very interesting to see that the noise band structure is not at all visible and disappeared in this figure at the time of occurrence of these VLF/ELF hiss emissions. From the figure, it is noted that the frequency spectrum of pulses is irregular in structure and intensity. The upper cut-off frequency varies from pulse to pulse. The time period is difficult to determine, although, during 2 seconds, we have about 14 pulses of hiss emissions in the frequency range 50 Hz – 8 kHz. Before and after the pulsing hiss event, a large number of sferics were seen with almost no noise at low frequencies. Pulsing hiss emissions during the entire period has approximately the same frequency range and periodicity. However, the intensity of the emissions near the end of the event decreases with time. The VLF activity at low latitudes is more prevalent during magnetically disturbed periods, as it is clearly evident from the simultaneous observations of different types of VLF/ELF emissions reported in this paper. The bandwidth of the pulsing hiss also decreases with an increase in frequency. The entire dynamic spectrum has an irregular structure and varied from pulse to pulse.

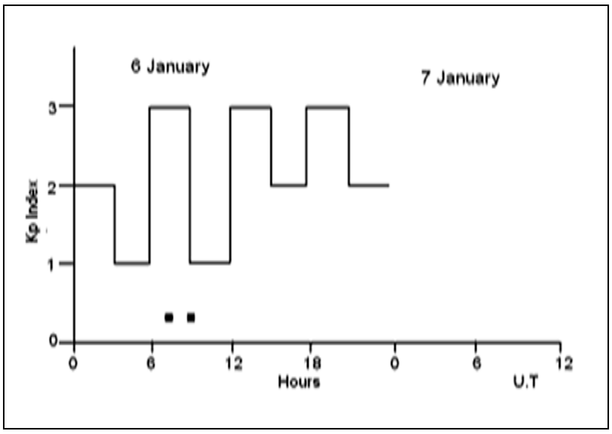

Fig. 1: Temporal evolution of the geomagnetic activity K_p index for the event 06 January 1999. The times when whistlers and ELF/VLF emissions observed are indicated by rectangles just above the abscissa of the panel.

Careful spectrum analysis shows that bands of noise like structure appear almost from the very beginning of the start of the observation and persisted almost throughout the observation on 06 January 1999, but it disappeared in between, especially at the time of occurrence of the hiss and quasi-periodic hiss emissions as shown in Fig. 2. We could not find any possibility of its being an artifact. Hence, we strongly feel that it could be most probably due to some local noise.

3. GENERATION MECHANISM

The most important event recorded simultaneously on 06 January 1999 at Jammu is QP pulsing hiss. In order to interpret the dynamic spectrum of pulsing hiss recorded simultaneously

Whistler mode waves propagating along geomagnetic field lines and interacting with counter streaming energetic electrons would scatter electrons into the loss cone. This may drive highly localized field-aligned currents leading to the generation of Alfven waves that may set up ULF waves along the field lines. Thus, the equilibrium conditions break down when considering such fast variations, and interaction between the waves and the electrons becomes the function of time. However, the condition of resonance interaction remains the same, and only the involved physical parameters become the function of time.

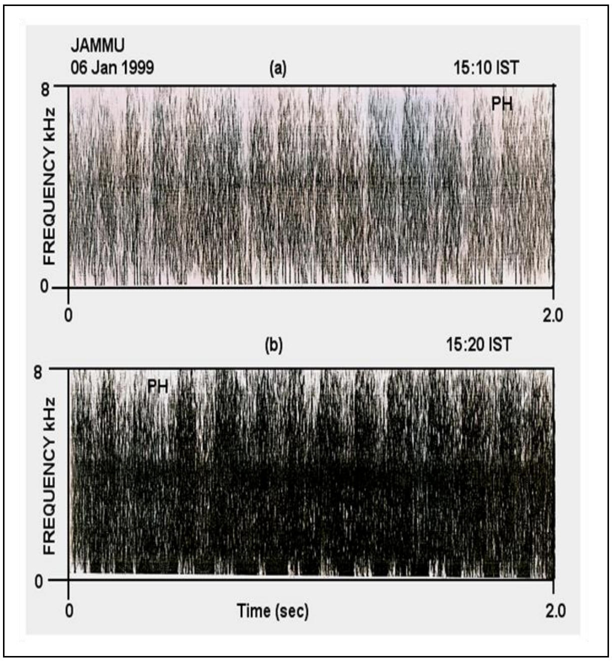

Fig. 2: Typical Examples of Frequency Spectra of Quasiperiodic Pulsing Hiss Emissions Recorded Simultaneously at 1510 hrs IST.

Considering the parameters appearing in the wave growth as time-dependent functions, separating the variables and differentiating the basic equation for the wave growth coefficient γ can be written as (Coronoti and Kennel, 1970).

$$d \ln \gamma / dt = d \ln \omega_H / dt + d \ln \eta / dt + d \ln A / dt \qquad (1)$$

Where ω_H is the local electron gyrofrequency, η is a fraction of electrons near resonance, $A = (T_\perp - T_\parallel)/T_\parallel$ is an anisotropy factor. $T_\perp$ and $T_\parallel$ are the characteristic temperatures of the electron's motion perpendicular and parallel to the local geomagnetic field, respectively. In the presence of micropulsation of frequency ω_o, the local magnetic field is modified and can be expressed as

$$B = B_o(1 + b \cos\omega_o t);\ \ b << 1 \qquad (2)$$

Where B_o is the background magnetic field having dipolar variation, b is the normalized amplitude of propagating micropulsation / ULF wave. The perturbation of the local magnetic field affects all the three terms on the right side of eq (1) because a change in B implies a change in ω_H, which governs the proposed mechanism of hiss generation through the Doppler-shifted cyclotron resonance condition $\omega - kv = \omega_H$. Thus, a change in ω_H is directly linked with a change in γ.

For a Maxwellian distribution in $T_{\parallel}$ and first adiabatic invariant $T_{\perp} \propto B$, eq(1) can be written as (see for detail Ward et al., 1982).

$$d \ln \gamma/dt = \left\{-b\omega_o \left[\left\{\frac{1+2A}{A}\right\} - \frac{m\Omega_0^2}{KT \quad K_\omega^2}\right] \sin\omega_0 t\, 1 + b \cos \omega_0 t\right\} - \left[\frac{m\Omega_0^2 b^2 \omega_0}{KT \quad K_\omega^2}\right] sin^2\, \omega_0 t\, 1 + b \cos \omega_0 t \quad (3)$$

Where m is the mass of the electron, K is the Boltzmann constant, K_ω is the wave vector of the interacting wave. The above equation reveals that pulsations in hiss could have two components of frequency ω_o and $2\omega_o$, the former being due to the modification of $T_{\perp}$ by a changing magnetic field, whereas the latter is due to the independence of $T_{\parallel}$ to such changes.

Integrating eq (3), the growth rate is written as

$$\gamma = \left(\left(\frac{\omega_0 t\, 1 + b \cos \omega_0 t}{1} + b\right)\right)^{\left(1+2\frac{A}{A}\right)-\left(\frac{3m\Omega_0^2}{KT \quad K_\omega^2}\right)} \text{X}$$

$$exp\left[\left\{\frac{2m\Omega_0^2 b}{KT \quad K_\omega^2}\right\}(\cos \omega_0 t - 1)\right] \quad (4)$$

This shows that hiss amplitude has a fundamental frequency component of micropulsations. The second harmonics do not appear. We have evaluated Equation (4) for the parameters relevant to L = 1.17, 3, and 4.0, which is shown in fig. 3. In the computation b = 0.05, $\omega = 2\pi f_o$, f_o =1.9987 Hz, A = 1.5, $T_{\parallel} = 4.6615 \times 10^7$ ^oK has been used, ω_H and ω_P are chosen corresponding to the equatorial value for L = 1.17, 3.0, and 4.0and wave frequency is taken as 8 kHz. The growth rate in oscillating and amplitude of oscillation decreases as L-value increases for L = 4.0. The oscillation lies between 0.78 and 1.26.

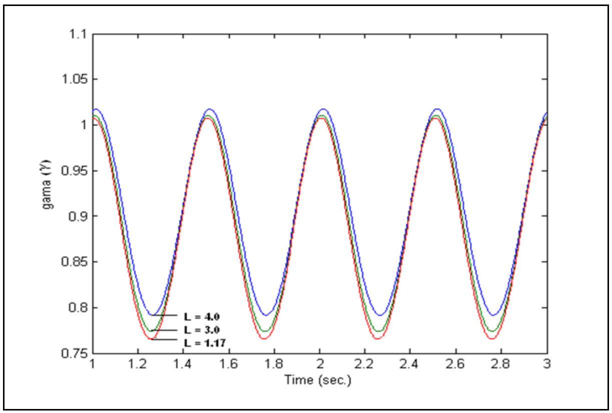

Fig. 3: Variation of growth rate with time for different L-values (L = 1.17, 3.0, and 4.0).

4. RESULTS & DISCUSSION

According to the simplified model given by Singh *et al.* (2003), oscillating tones are triggered when the interaction region oscillates near the equatorial zone along the field line. In the present case of quasi-periodic pulsing hiss observed simultaneously at Jammu during the daytime on 06 January 1999, the pulsing hiss time period is about 0.5 sec which corresponds to continuous pulsation PC 1. PC 1 forms a standing wave pattern along the geomagnetic field line and thus produces oscillation in the trapped electrons bouncing back and forth along the field lines. Thus the wave-particle interaction is also modified. Considering hiss emission intensity to be the result of amplification of waves, we except the corresponding pulsation in the hiss-emission intensity.

An alternate source of VLF/ELF hiss (Fig.3) could be lightning discharge. Parrot (1990) has shown that the regions of high thunderstorm activity are correlated with the maximum intensity of hiss, which is indicative of the embryonic effect of lightning in generating hiss (Sonwalkar and Inan, 1989; Draganov *et al.* 1992). VLF hiss generating by the embryonic process could also be modulated through wave-particle interaction in the presence of micropulsations. Ward *et al.* (1982) and Ward (1984), based on a comparative study of pulsing hiss and pulsating aurora, showed that hiss pulses and auroral pulses have similar periods, whereas the micropulsations had periods that were considerably longer for the cases analyzed. These discussions show that while working out the generation mechanism of pulsing hiss, one should take into account the generation mechanism of pulsing aurora and micropulsation, which find their origin in the ionosphere. Davidson and Chiu (1991) have discussed a non-linear mechanism for auroral pulsation, which may provide some indication of the possible origin of pulsing hiss.

5. CONCLUSION

The present experimental study is the first simultaneous observation of whistlers and different types of ELF/VLF emissions during daytime at low latitudes. The most important simultaneous observations are pulsing hiss, and its generation mechanism is reported for the first time during the daytime. Dynamic spectra of pulsing hiss contain irregular structures. The intensity and frequency distribution vary from one pulse to the other pulse. Pulsing hiss emissions are supposed to be generated during Doppler-shifted cyclotron resonance interaction. ULF waves propagating along the geomagnetic field lines may have modulated the intensity of the emission resulting in the pulsing hiss. Nonetheless, the idea has the potential to be a 'circuit breaker' in our understanding of the generation mechanism of the VLF/ELF emissions observed at low latitudes. However, the further detailed mechanism (or process) of the data presented here is a challenging problem, and this task will be left for further investigations.

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CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest.

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