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A study of some unusual discrete VLF hiss-triggered chorus emissions observed at a low latitude ground station at Jammu

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Abstract . A detailed analysis of the VLF emissions obtained during continuous whistler recordings at the low latitude ground station Jammu (geomagnetic latitude, 22°26'N) has yielded some unusual discrete VLF emissions of the rising type and hiss-triggered chorus emissions These include (i) emissions occurring simultaneously in different frequency ranges, (ii) hiss-triggered discrete chorus emissions of the rising type. In the present study, the observed characteristics of these emissions are described and interpreted It is shown that unusual occurrence of the discrete chorus emission in two different frequency ranges at the same time may possibly be linked with their generation at two different locations From the analysis of the hiss-triggered chorus emissions observed at Jammu, it is found that a chorus element is likely to have originated from the hiss band Then their generation and propagation in the inner plasmasphere have been discussed, and future problems are suggested

Keywords : Whistler, VLF hiss-triggered chorus emission, low latitude ground station.

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Very low frequency (VLF) emissions like whistlers, is a class of natural radio phenomenon [1]. The wave-particle interactions occurring in the ionosphere/magnetosphere generate variety of emissions in the extremely low frequency (ELF)/very low frequency (VLF) range. Helliwell [1] has classified these emissions into hiss, discrete, periodic, chorus, and triggered emissions. Rycroft [2] and Sazhin and Hayakawa [3] have presented excellent reviews on magnetospheric chorus emissions observed in the ground stations, rockets, and satellites. Recently, Nunn and Sazhin [4] and Trakhtengertz *et al* [5] have presented chorus models.

Until a few years ago, VLF emissions have been a subject of middle and high latitudes only. Though, the VLF emissions are basically a middle (geomag. lat. 30°–50°) and high latitude (geomag. lat. > 50°) phenomena, there are ample evidences of their occurrence in low latitude ground station also. Japanese workers [6] have reported the observation of hiss-type emissions in their low latitude ground stations, where as Indian workers [7–9] have reported the observations of discrete-hiss-type emissions in their ground stations. The existence of intense zone of VLF emissions in the low latitude ionosphere has also been confirmed by satellite observation [10].

Very low frequency chorus and hiss are well known forms of electromagnetic emissions which arise in the ionosphere/magnetosphere. However, their origins are poorly understood. Chorus and hiss signals are believed to play an important role in the precipitation of the electrons from the radiation belts [11] A prominent feature of natural hiss is its tendency of trigger chorus emissions at the upper edge of its band [1]. Similar phenomena have also been observed at our low latitude ground station Jammu along with discrete chorus emissions. The generation mechanism of spontaneous

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chorus emissions has been studied experimentally by Burton and Holzer [12], Goldstein and Tsurutani [13], Hayakawa *et al* [14] and Hattori and Hayakawa [15] and theoretically by Nunn [16], Bespalov and Trakhtengertz [17] and Curtis [18]. The ground and satellite VLF/ELF measurements have indicated that chorus hiss is frequently accompanied by a background of hiss [19]. These experimental results suggest that hiss has an important role in the generation of chorus in the outer magnetosphere. However, at low latitudes, this phenomena has not attracted the attention of many workers in this field because of scarce ground-based observational results. An understanding of the generation mechanism of some unusual discrete VLF and hiss-triggered chorus emissions observed at our low latitude ground station Jammu (latitude 22°26'N, longitude 147°10'E), could be most useful for inferring the properties of the high energy trapped electrons.

In the present paper, we pick up some interesting cases of unusual discrete VLF emissions and hiss-triggered discrete VLF emissions observed at our low-latitude ground station Jammu during a period of about three years and interpret their morphological characteristics.

The VLF emissions are observed with the same set of equipments as that required for the observations of whistlers. Using standard whistler observation equipments consisting of a T-type antenna, 25 m high, suitably amplified by a transistorised pre- and main amplifiers having band pass of 500 to 1500 Hz, and a magnetic tape recorder, we conducted routine observations of whistlers at our low-latitude ground station Jammu University Campus, Canal Road, Jammu, between January, 1997 to June, 1999. This station is a noise free area. The observations were taken continuously during night hours. The accumulated data on magnetic tapes were analysed on a digital sonograph.

The results of the detailed spectrum analysis showed a number of discrete VLF emissions and hiss-triggered discrete VLF emissions recorded at our station over a span of three years. A typical spectrum of a discrete type VLF emissions out of a large number of data recorded on 6 January, 1999 during nightime between 0100 hrs IST to 0300 hrs IST (Indian Standard Time) at Jammu is shown in Figure 1.

Figure 1(a) contains only one riser in the frequency range of 3.6 to 6 kHz. Figure 1(b) shows two riser events The first riser emission lies in the frequency range of 2.8 to 5.5 kHz whereas second riser emission lies in the frequency range of 2.8 to 5.6 kHz. Figure 1(c) contains two groups of riser emissions each group consisting of two riser events. The first riser emission of the first group lies in the frequency range of 3.4 to 5.9 kHz whereas the second riser of this group lies in the frequency range of 5.2 to 8 kHz. The other two riser emissions of the second group are in the frequency range of 3.8 to 5.4 kHz and 5.9 to 7 8 kHz respectively. Figure 1(d) shows three groups of discrete chorus riser emissions, each group consisting of two riser events. The two riser emissions of the first group are in the frequency range of 3.1 to 4 4 kHz and 4.9 to 6.4 kHz respectively. The first riser emissions of the second group is found in the frequency range of 3 1 to 4.4 kHz whereas the second riser emission is found in the frequency range of 4 7 to 6.5 kHz. The two riser emissions of the third group are found in the frequency range of 3 5 to 4.6 kHz and 5.2 to 7.1 kHz. The events in Figure 1 correspond to a magnetically disturbed day.

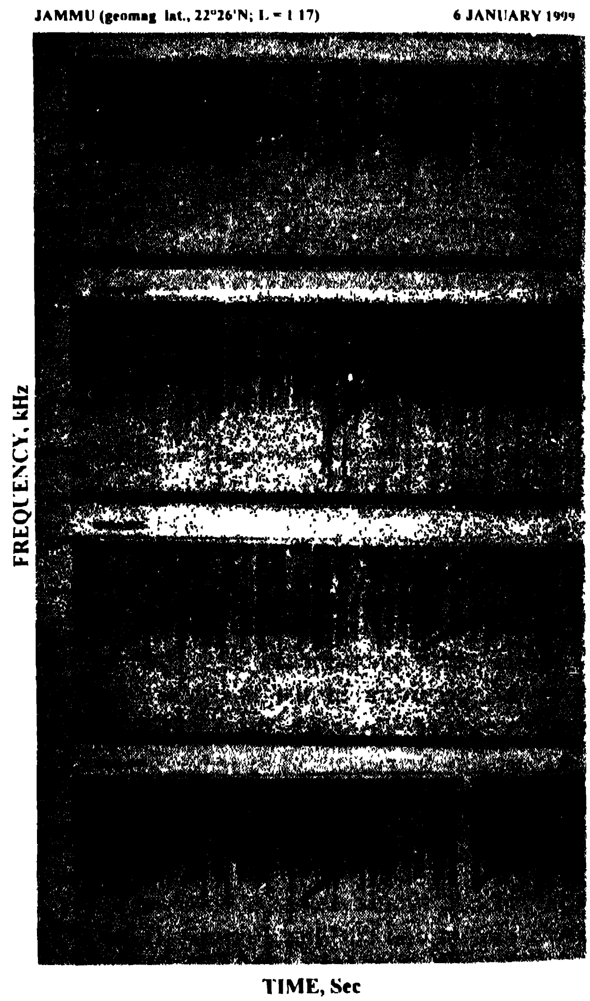

Figure 1. Sonograms of discrete type of chorus emissions recorded on 6 January, 1999 during night time at Jammu.

The spectrograms of some unusual type of discrete VLF emissions triggered by VLF hiss band are shown in Figure 2. These events were recorded on different days during night hours. The spectrum shown in Figure 2(a) contains inverted hook emissions which are triggered by lower and upper hiss band 2.2 to 3.9 kHz. Figure 2(b) shows discrete chorus emissions, combinations of rising and falling tones. This event is triggered by the upper band of VLF hiss observed in the frequency range of 2.2 to 3.9 kHz. The events shown in Figures 2(a) and (b) were recorded on January 5, 1999, which corresponds to a magnetically disturbed day with the sum of the 'Planetary 3-hour magnetic index' K_p as 15 ($\Sigma K_p = 15$). The spectrum shown in Figure 2(c) contains two discrete chorus events. The first event is a riser and second event is a falling tone which are seen to be triggered by lower boundary of a VLF band in the frequency range of 2.7 to 4.2 kHz. The events shown in Figure 2(c) were recorded on 23 January, 1999 and correspond to a magnetically disturbed day with the sum of K_p as 27 ($\Sigma K_p = 27$). Figure 2(d) shows two long risers having upper boundary frequencies of 5 kHz and 8 kHz respectively which are triggered by the upper boundaries of a hiss-band in the frequency range of 1 to 2.5 kHz. This event was recorded on February 17, 1999 [(Figure 2(d))] which corresponds to a magnetically disturbed day with sum of K_p indices as 22 ($\Sigma K_p = 22$).

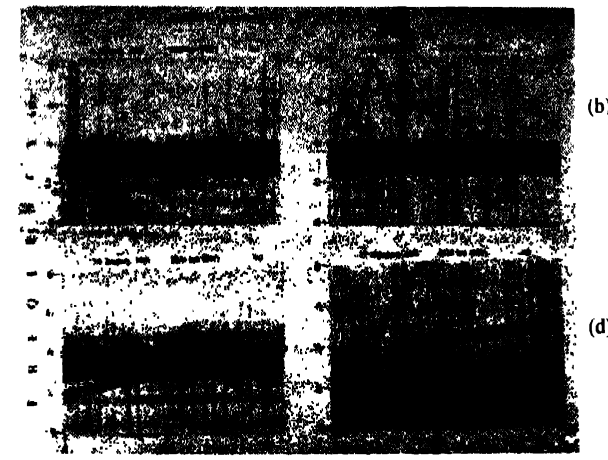

Figure 2. (a, b) Sonograms of some unusual type of discrete VLF emissions triggered by VLF hiss-band recorded on 5 January, 1999 at 2025 IST and 2035 IST respectively, at Jammu, (c) Sonograms of some unusual type of discrete VLF emissions triggered by VLF hiss-band recorded on 23 January, 1999 during night time at Jammu and (d) Sonograms of some unusual type of discrete VLF emissions triggered by VLF hiss-band recorded on 17 February, 1999 during night time at Jammu

The discrete type of chorus emissions shown in Figure 1 differ markedly in frequency and the rate of change of frequency with the time from those of the riser whistlers observed earlier at low-latitude ground station Gulmarg (geomag. 24°10'N) [6]; hence, the possibility that these emissions are also riser whistlers, is ruled out. Further, the possibility that these emissions was just a coincidence, does not seem to be likely because Khosa *et al* [7] have reported other cases also in which more than two emissions occurred one after the other during the same night of observation.

We have examined various possibilities for occurrence of these emissions shown in Figure 1 which include (1) that they were caused by instrument, (2) they were generated due to second order cyclotron resonances, (3) they were caused by HF heating of the lower inosphere. However, these possibilities are ruled out because such emissions were also recorded at Varanasi [7,8], the socond order cyclotron resonance requires energetic electrons of ~50 MeV which are not available at $L = 1.2$ [20], and radiations from HF heating peaks at frequency near 2 kHz which are not observable on the ground if the receiver is away from the source [8]. Thus, the only possibility left is that these emissions are generated at slightly different locations in the magnetosphere. Further, the possibility that these emission are high-latitude discrete chorus emissions which have propagated to our low-latitude ground station Jammu in the Earth-Ionosphere waveguide mode of propagation, is also ruled out because there is a strong absorption band in the frequency range around 2 kHz. The possibility that these emissions are generated at high and less L-values in the vicinity of the plasmapause and propagated to our ground station after successive magnetospheric reflections in a manner similar to those of the ELF hiss observed by satellites in the inner zone [21] does not seem to be tenable. This is because, at the frequency of these emissions, the attenuation losses during various magnetospheric reflections could be high and thus waves could not be detected on the ground [11]. Thus, we believe that these emissions are generated in the equatorial region at $L = 1.2$ (Inner Zone radiation belt) under cyclotron resonance mechanism and propagated to our ground station in nonducted mode of propagation. In order to test cyclotron resonance as the possible generation mechanism for these emissions, we calculated the resonant energy of the involved electrons and growth rates at $L = 1.2$ in the equatorial plane. The resonant energies for various frequencies of the emissions were calculated from the expression given by Tsurutani *et al* [21]. The resonant energies for various frequencies for the emissions were found to be in the range 3–5 MeV in good agreement with the results reported by other workers [7,9]. Using the expression (2.20) of Kennel and Petschek [11], we calculated the growth rates for various frequencies of the emissions at $L = 1.2$ and found to be ~3 rad. sec^{-1} indicating a significant wave amplification. These waves, thus generated at $L = 1.2$, were propagated to the ground station of Jammu in nonducted mode of propagation.

From the analysis of the hiss-triggered chorus events observed at Jammu shown in Figure 2, it is found that a chorus element is likely to have originated from the hiss-band and is asymptotic in the hiss-band. It is evident from Figure 2 that chorus events with different slopes (*df/dt*) and with varying intensities are observed. The sharpness/diffuseness varied from event to event. The duration of most of the chorus events is about 0.3 s and average *df/dt* is about 0.2 kHz s^{-1}. The similar events of hiss-triggered chorus emissions recorded at Gulmarg, have recently been reported by Singh *et al* [22].

Based on experimental results of hiss-triggered chorus emissions observed onboard satellite GEOS-1, recently Hattori and Hayakawa [15] have shown that the azimuthal angle values for both hiss and chorus emissions are the same and have suggested that both phenomenon come from the same source region. Further, they have shown that chorus is triggered from some island structures or wavelet existing at the upper edge of the hiss-band through a coherent wave-particle interaction in the case of an active VLF injection experiment.

Although at present, we do not have a universally accepted general theory of hiss-triggered chorus emissions at low latitudes, we believe that the Hattori and Hayakawa's theory [15] based simply on gyroresonance interaction between energetic streaming electrons and whistler-mode waves travelling in the opposite direction is able to explain most of the features of these emissions observed at our ground station Jammu. This mechanism based on Helliwell's theory [23] has also been adopted recently by Singh *et al* [22] to explain the features of the hiss-triggered chorus emissions observed at Gulmarg. Hattori and Hayakawa [15] have verified the proposed mechanism computationally to explain the hiss-triggered chorus emissions observed onboard satellites GEOS-1 on July 21, 1997 This mechanisms has two steps : at first, the energetic resonant electrons, with a wavelet which has enough intensity and duration located at the upper edge of the pre-existing hiss-band, are phase-bunched at the magnetic equator in the outer magnetosphere. Thus, these phase-bunched electrons move away from the equator along the earth's magnetic field line, radiating a coherent wave which satisfies the cyclotron resonance condition and the dispersion condition at any latitude; this causes a temporal change of frequency. The radiated wave propagates towards the equator and then to the ground to be received at the observing station.

In order to come to a firm conclusion on the generation mechanism of the hiss-triggered chorus emissions observed at low latitude ground station, a larger data is required. It would be much more helpful to have direction finding of VLF data containing simultaneous hiss and chorus, and the fine structure analysis at Jammu to check the source region of both hiss and chorus, but these measurements at Jammu are not available. Not withstanding these limitations the present exercise of studying the generation mechanism of hiss-triggered chorus emissions observed at our low latitude ground station Jammu is still worthwhile Hence further research is required to explain the micro-process of hiss-triggered chorus emissions observed at low latitudes.

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