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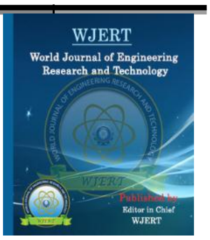

DIURNAL AND SEASONAL VARIATION OF WHISTLERS AT LOW LATITUDE GROUND STATION JAMMU AND RECORDING OF VLF HISS EMISSIONS

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ABSTRACT

This paper presents interesting observations based on the long term Data of whistlers and VLF hiss emission at a low latitude ground station Jammu (Geomagn. lat. 22°16′ N, $L = 1.17$). The simultaneous observations presented in this paper are unique and are reported for the first time from low latitude ground station Jammu. The present observation of VLF emissions and whistlers along with ESD whistlers at Jammu clearly suggest that these VLF emissions are generated in the magnetosphere due to whistler mode wave-interaction with particles. This experimental study is unlikely to be the final word on the origin of these events and further experimental confirmation will, of course, be required at low latitudes. From the dispersion analysis of the day time whistlers recorded at Jammu, it is found that all the Whistlers have extremely small dispersion (ESD) in the range of **5-10 $s^{1/2}$,** which clearly supports non-ducted propagation. With the advent of the satellites, VLF receivers were placed on rockets and satellites. These receivers detected whistlers whose paths deviated from Earth's magnetic field lines. Such whistlers are called **unducted or non-ducted whistlers**, completely in contrast with the earlier findings of ducted propagation of day-time whistlers. VLF emissions are known to originate within the ionosphere/magnetosphere but no satisfactory theory of their origin has yet been put forward. These are generally originated in the ionosphere/magnetosphere by two mechanisms, viz incoherent Cerenkov radiation mechanism and electron cyclotron resonance instability mechanism. The generation mechanism of whistler-mode VLF hiss remain controversial inspite of extensive amount of experimental and theoretical work. A number of mechanisms have been suggested for the generation of VLF hiss from time to time. Sazhin et al.,(1993) have reviewed the generation mechanism of the VLF hiss and have projected out that the most likely energy source of VLF hiss lie in the electrons at energies below 100 electron volts precipitating to the auroral ionosphere. They have shown that initially the waves are generated due to incoherent Cerenkov radiation and they are then amplified due to beam plasma instabilities in the Cerenkov resonance.

KEYWORDS: VLF Emissions, Whistlers, Low latitude ground station, ELF Emissions, Dispersion, diurnal and seasonal.

1. INTRODUCTION

Whistlers and emissions in very low frequency (VLF) ranges are considered to be invaluable tools in probing the plasma of ionosphere and magnetosphere. In particular whistler mode waves (VLF waves) and their interactions with energetic particles has 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 extremely low frequency (ELF) and very low frequency (VLF) ranges. 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 very fascinating, challenging and interesting natural phenomena. Helliwell (1965) has classified these emissions into hiss, discrete, periodic and quasi- periodic, chorus, hook and inverted hook, and triggered emissions. Of particular interest among these are the steady, incoherent hiss emissions that were identified as a dominant contributor to the loss of radiation belt particles (Kennel and Petschek, 1966; Lyons et al., 1972). On the other hand triggered emissions exhibit a bewildering variety of dynamical spectral forms and follow their apparent source. Even some types of chorus are known to arise from the upper boundary of the hiss (Hattori and Hayakawa, 1994; Singh et al., 2000). Many observations support the idea that strong VLF emissions may be triggered even by very weak signals. In extreme cases the triggered source may be invisible. The dynamic spectra of these triggered emissions are complex. The observed facts that (a) triggered emissions are non-stationary transient phenomena, (b) rate of variation of frequency differs from one event to another, and (c) the frequency of these emissions bears no relation to that of triggering signal, testify to this signal. All these type of emissions are frequently observed at high and mid latitudes (Helliwell, 1965; Parrot, 1990). Although the ELF/VLF emissions of different types are often observed at different times at low latitude ground stations in Japan and India, but there is no evidence of the simultaneous occurrence of unusual whistler doublet and triplet, and VLF hiss emission at low latitudes during night hours. Whistler studies in India, which have been in progress since 1963, have made significant contribution to the propagation of low latitude whistlers and VLF/ELF emissions, structure and dynamics of the low latitude plasmasphere (Somayajulu et al., 1972; Hayakawa and Tanaka, 1978; Singh, 1993). Under All India Coordinated Program of Ionosphere Thermosphere Studies (AICPITS) we have conducted initial observations of whistlers and VLF/ELF emissions at our Indian ground-based station Jammu and obtained unique and very interesting result of some unusual simultaneous occurrence of whistler doublets and triplets, and hiss emission in the early morning local time sector during magnetically highly disturbed periods. These observations at Jammu indicate that lightning generated whistlers may be an important embryonic source for magnetospheric hiss. In all the measurements known to the authors, there is no report of simultaneous occurrence of VLF hiss along with whistler doublets and triplets at low latitudes.

In the present paper, we provide a preliminary description and analysis of these whistlers and VLF hiss emissions observed at Jammu.

2. DATA SELECTION AND ANALYSIS

Using standard whistler recording equipment consisting of a T-type antenna, transistorised pre - and main amplifiers, and a magnetic tape recorder we conducted routine observations of whistlers and VLF emissions at our ground station Jammu during a span of three years. The observations were taken at night continuously. The accumulated data on magnetic tapes were analysed at Physics Department of Banaras Hindu University Varanasi. The results of the analysis showed a large number of VLF hiss recorded at Jammu. The frequency-time spectrograms of these VLF hiss out of large number of events are shown in **Fig.1.** The date and time of the observation of VLF hiss are mentioned at the top of the figures. About 60 events of nighttime VLF hiss are chosen for the present analysis. The sample records of nighttime VLF hiss are shown in **Fig.1** which were recorded on 3,4,5,6 January, 1999 respectively. The nighttime VLF hiss activity at Jammu was observed during quiet and disturbed days. The total Kp index corresponding to January 3, 1999 is 8 (Σk_P=8), which is magnetically a quietest day. The total Kp index corresponding to January 4 is 14 ((Σk_P =14), which is magnetically a disturbed day. The total Kp index corresponding to January 5 is 15 ((Σk_P =15), which is magnetically a disturbed day. The measured hiss band lies in the frequency range of 3.4-5.2 kHz, which is in the almost same frequency range as observed earlier at other low latitude ground stations (Khosa et al.,1981). From the detailed analysis it is found that VLF hiss at Jammu is observed both during quiet and disturbed days and are mostly recorded in the night hours. The studies demonstrated that VLF hiss emissions occur at all magnetic local time intervals but activity is maximum around mid-night as is evident from **Fig.1**. The VLF hiss emissions at Jammu appear most frequently during winter season and prominent in the month of March. The result is consistent with the earlier results reported by other workers at low latitude (Lalmani et al., 1970; Hayakawa,1991; Hayakawa,1993).The spectral densities computed from the theory of incoherent Cerenkov radiation in the local ionosphere are too inadequate to explain the VLF hiss recorded at Jammu especially due to the fact that VLF hiss generated in the local ionosphere should be trapped in wave guide mode propagation to reach the ground stations. Therefore, the possibility that VLF hiss observed at our low latitude ground station Jammu is a consequence of waveguide mode propagation of energy from sources as suggested by Ondoh and Isozaki (1965) and Lalmani et al.(1972). Under All India Coordinated Program of Ionosphere Thermosphere Studies (AICPITS) we have conducted initial observations of whistlers and VLF/ELF emissions at our Indian ground-based station Jammu and obtained unique and very interesting result of the some unusual simultaneous occurrence of whistler VLF emissions and hiss emission in the early morning local time sector during magnetically highly disturbed periods. These observations at Jammu indicate that lightning generated whistlers may be an important embryonic source for magnetospheric hiss. In all the measurements known to the authors, there is no report of simultaneous occurrence of VLF hiss along with whistler at low latitudes. In the present paper, we provide a preliminary description and analysis of these whistlers **(Fig.2) and VLF hiss emissions (Fig.1).** Possible interpretations are given. The dispersion analysis of the whistler recorded simultaneously with the hiss emission shows that they have propagated along higher propagation path with L-values lying between L=4.01 and L = 4.39. Thus, these reported events could be a part of mid/high latitude phenomena and after exiting from the duct they may have propagated through the Earth–ionosphere waveguide towards the equator to be observed at Jammu. Unusual whistlers have been recorded at almost all the whistler stations in India. Recently, Lalmani et al.(1999), have reported the observation of extremely small dispersion at low latitude ground station Jammu. A spectrogram of **ESD** whistlers is shown in **Fig.2**. Such extremely small dispersion **(ESD)** whistler events have not been previously reported. Most of the VLF emissions are rising tones, inverted hooks (riser followed by falling tone) and hiss. The measured dispersion values of all the recorded whistlers are found to be extremely small lying in the range of **5-10 $s^{1/2}$.**

The main problem in explaining the VLF hiss observed at low latitude ground stations is that the VLF hiss generated in the local ionosphere is weak in intensity and can seldom be observed at ground stations due to unfavourable propagation conditions of VLF waves at low latitudes. However, many workers have observed VLF hiss at low latitude ground stations and an explanation has been offered to explain VLF hiss at low latitude ground stations (Ondoh and Isozaki, 1965; Lalmani et al., 1970, 1972; Prakash et al., 1979). Jorgensen (1966) has summarized the ground observations of VLF hiss from 13 stations in both the hemispheres ranging in magnetic latitudes from 34° to 89° and has shown that the maximum spectral densities in the frequency range 4-9 kHz vary from 10^{-19} to 10^{-14} watts m^{-2} $Hz^{-'}$. He concluded that hiss comes down through the ionosphere over the auroral zone and then propagated through the Earth- ionosphere waveguide to lower latitudes. Similarly, Ondoh and Isozaki (1965) have suggested that their simultaneous hiss observations at Moshiri (geomag.lat., 34° N) and Hiraiso (geomag.lato, 22.2° N) are consistent with the attenuation rates of the dominant mode in the Earth- ionosphere wave guide. Similar suggestions have also been made earlier by Dowden (1961) and Ellis (1961). Evidently, it was desirable to see whether ground based hiss observations at a number of stations covering a reasonably wide range of latitudes could be satisfactorily accounted for by the mode propagation This possibility has been explored in detail by Lalmani et al.,(1972), where they have calculated the locus of point sources which could yield the observed power ratios for any given pair of stations. Their results indicated that point sources located suitably in the magnetic latitude range 60°-70° would account for the observations. Further, they have shown that the dominant mode attenuation factors can reasonably explain the observed power decrease with latitude only if one considers a source extended all along the auroral zone.

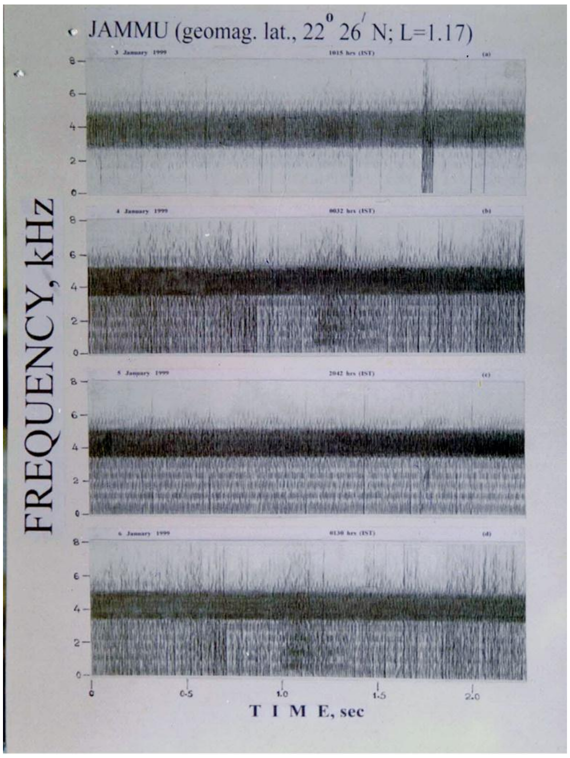

Fig. 1

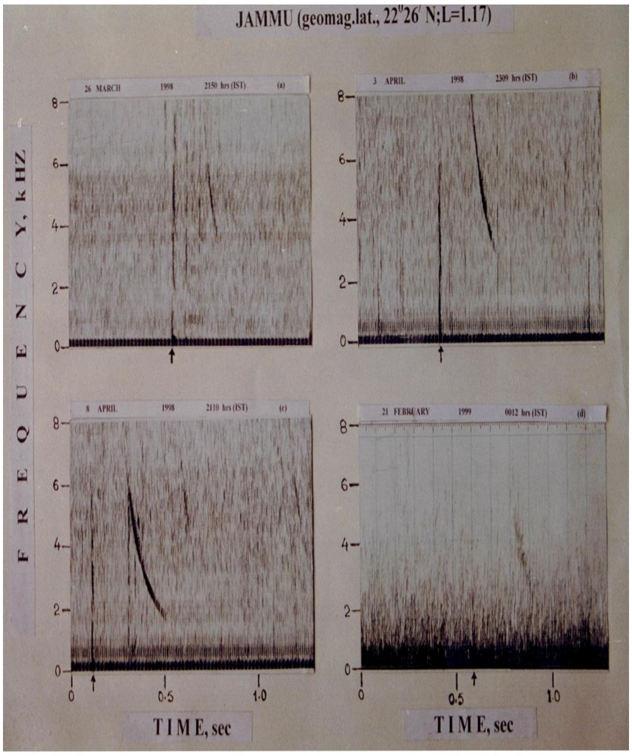

Fig. 2

Fig. 1: Spectrograms of simultaneously observed hiss emission.

Fig. 2: Frequency – Time spectrograms of whistlers recorded at Jammu.

3. Unusual whistlers and VLF emissions observed

Under All India Coordinated Program of Ionosphere Thermosphere Studies (AICPITS) we have conducted initial observations of whistlers and VLF/ELF emissions at our Indian ground-based station Jammu and obtained unique and very interesting result of some unusual simultaneous occurrence of whistler VLF emissions and hiss emission in the early morning local time sector during magnetically highly disturbed periods. These observations at Jammu indicate that lightning generated whistlers may be an important embryonic source for magnetospheric hiss. In all the measurements known to the authors, there is no report of simultaneous occurrence of VLF hiss along with whistler at low latitudes. In the present paper, we provide a preliminary description and analysis of these whistlers and VLF hiss emissions **(Fig.2).** Possible interpretations are given. The dispersion analysis of the whistler recorded simultaneously with the hiss emission shows that they have propagated along higher propagation path with L-values lying between L=4.01 and L = 4.39. Thus, these reported events could be a part of mid/high latitude phenomena and after exiting from the duct they may have propagated through the Earth–ionosphere waveguide towards the equator to be observed at Jammu. Unusual whistlers have been recorded at almost all the whistler stations in India. Recently, Lalmani et al.(1999), have reported the observation of extremely small dispersion at low latitude ground station Jammu. A spectrogram of ESD whistlers is shown in **Fig.**2. Such extremely small dispersion (ESD) whistler events have not been previously reported. Most of the VLF emissions are rising tones, inverted hooks (riser followed by falling tone) and hiss. The measured dispersion values of all the recorded whistlers are found to be extremely small lying in the range of 5-10 $s^{1/2.}$

4. Diurnal and seasonal variation of whistlers.

The diurnal and seasonal variation of the occurrence of nighttime whistlers observed at Jammu is shown in **Fig.3. and Fig.4.** At low latitude ground stations, the whistlers are frequently observed during night time, the rate being higher during midnight and early morning hours. During a single night the rate of occurrence of whistlers commonly varies in an irregular and arbitrary fashion. However, when the daily rates are averaged over a long period (i.e. a month or a year), a fairly consistent pattern of the diurnal variation emerges as show in **Fig 3**. Marked seasonal variation in whistler occurrence is seen at most stations. As the station covered by us is at low latitude and as only short whistlers are recorded, the whistler sources should correspond to opposite hemispheres. Thus, we should expect maximum occurrence in the winter months. That it is really so, is evident from **Fig 4**. Thus, the diurnal and seasonal variation of whistlers observed at Jammu, shown in **Fig 3 and Fig 4**, show that night time whistlers are observed frequently in early morning hours during winter season in the month of March and April. Our results are consistent with the previous work reported at low latitudes (Nainital, Gulmarg, Japan).

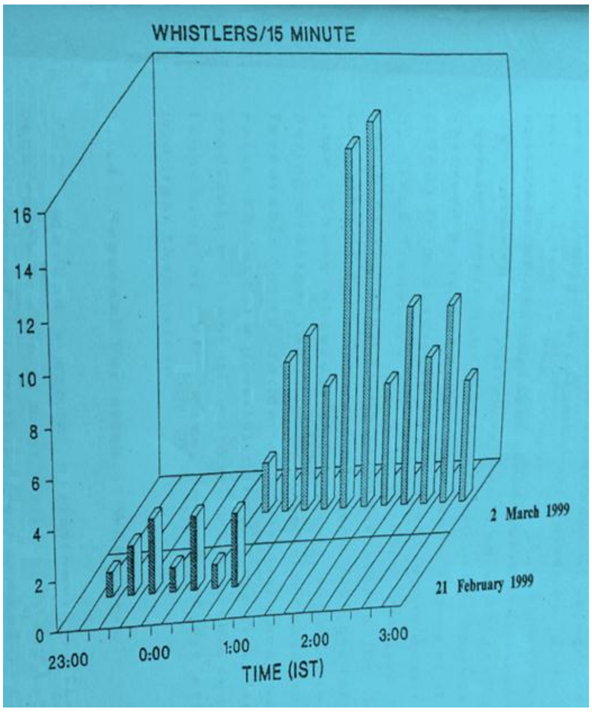

Fig 3

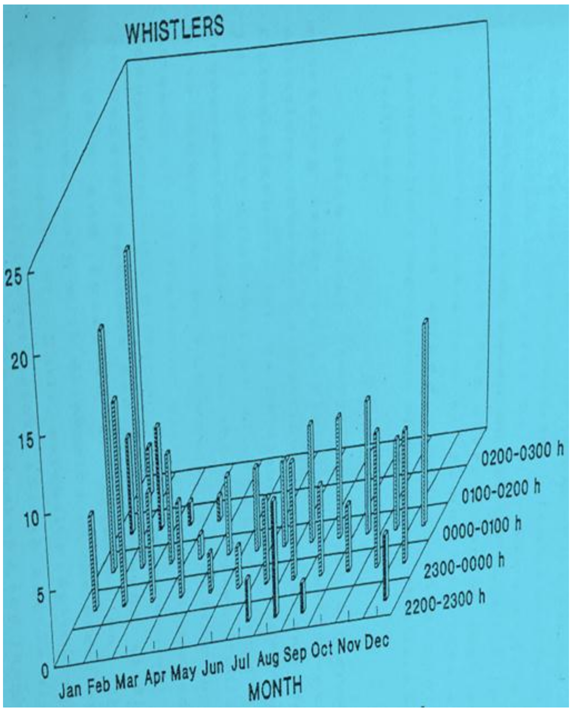

Fig 4

Fig 3: Diurnal variation of whistlers recorded at Jammu.

Fig 4: Seasonal variation of whistlers recorded at Jammu.

5. RESULTS AND DISCUSSIONS

The main problem in explaining the VLF hiss observed at low latitude ground stations is that the VLF hiss generated in the local ionosphere is weak in intensity and can seldom be observed at ground station due to un favourable propagation conditions of VLF waves at low latitudes. However, many workers have observed VLF hiss at low latitude ground stations and an explanation has to be offered to explain VLF hiss observed at low latitude ground stations. The problem of generation mechanism of the low-latitude VLF emissions has not been convincingly resolved as yet, though a few workers (Bullough et al.,1974; Kaiser,1972; Ondoh et al.,1972; Khosa et al.,1981) have suggested Cerenkov radiation from low energy electrons as a possible source of these emissions. Jorgensen (1966) has summarised the ground observations of VLF hiss from 13 stations in both the hemisphere ranging in the magnetic latitude from 24° to 89° and has shown that the maximum spectral densities in the frequency range 4-9 kHz vary from 10^{-19} to 10^{-14}W rn^{-2} Hz^{-1}. He concluded that hiss comes down through the ionosphere over the auroral zone and then propagated through the Earth - Ionosphere wave guide to lower latitudes. Similarly, Ondoh and Isozaki (1965) have suggested that their simultaneous hiss observations at Moshiri (geomag.lat., 34° N) and Haraiso (geomag.lat., 26.2°N) are consistent with the attenuation rates of the dominant mode in the Earth-Ionosphere waveguide. This have also been suggested earlier by Dowden and Ellis (1961). Lalmani et al.(1970) have carried out the detailed intensity calculations for the low latitude VLF hiss in a realistic ionosphere model by considering incoherent Cerenkov radiation as a possible source of these emissions. The calculated intensities in case of 100 eV-1 k eV electrons, were found to be inconsistent with the observed intensities of 10^{-19} - 10^{--18} $_{\mathrm{Wm}}{}^{-2}$ Hz^{-1} on the ground. On the basis of this result, they concluded that the spectral densities of the order of 10^{-15} Wm^{-2} Hz^{-1} computed from the theory of incoherent Cerenkov radiation by low energy electrons (100 eV - 1 keV) in the local ionosphere were too inadequate to explain the VLF hiss observed at low latitude ground stations. In order to explain low latitude VLF hiss observations, Lalmani et al.(1972), from the analysis of multistations ground observations of VLF hiss have shown that VLF hiss observed at low latitudes is a consequence of waveguide mode propagation of energy from sources located in auroral zone. Further they have also shown that the accepted values of dominant mode in the terrestrial waveguide can explain the observed hiss spectral densities at low latitudes only if we assume the presence of an extended source along the auroral zone.

This paper deals with the observations of VLF hiss recorded during nighttime at our low latitude ground station Jammu (geomag.lat.,22° 26' N; geomag.long., 147°10' E; L = 1.17). The characteristic signature of the VLF hiss observed at Jammu is broad band hiss in the range of 3-5 kHz exhibiting amplitude 'strips' on a conventional sonogram. An attempt has been made to examine critically the occurrence of VLF hiss at our low latitude ground station Jammu. The power emitted by incoherent Cerenkov radiation process at L = 1.17 corresponding to the field line of Jammu for electrons of 100 eV energy has been computed and is then compared with the observations at low latitudes. It is found that the calculated total power is 3 orders of magnitude less than the observed values of the power flux recorded by satellites and is inconsistent with the observed power at low latitude ground stations. Finally, results and discussions are presented where it is shown that the VLF hiss observed at our low latitude ground station Jammu are generated at middle latitudes by Cerenkov radiation process near plasma pause and reach at our low latitude ground station Jammu as a consequence of Earth-Ionosphere waveguide mode of propagation.

6. OBSERVATIONS

From the detailed study of whistlers and VLF emissions observed at low latitude ground station Jammu we conclude as:

1. The Whistlers and VLF emissions occur in the narrow frequency band cantered around **5 kHz.**

2. The Whistlers and VLF emissions at Jammu occur most frequently around mid-night hours during winter season and prominent in the month of March/April.

3. The Whistlers and VLF hiss emissions observed at our low latitude ground station Jammu are generated at middle latitudes by Cerenkov radiation process near plasma pause and reach at our ground station as a consequence of Earth-ionosphere waveguide mode of propagation.

7. CONCLUSION

This paper presents interesting observations based on the long term data of **Whistlers and VLF** hiss emission at a low latitude ground station Jammu showing that they are not limited to mid and high latitudes. These are observed during strong magnetic storm periods in post-midnight sector. The simultaneous observations presented in this paper are unique and is reported for the first time during geomagnetic storm period from low latitudes. The present observation of **VLF emissions and whistlers** along with **ESD** whistlers at Jammu clearly suggest that these **VLF** emissions are generated in the magnetosphere due to whistler mode wave interaction with particles. Much detailed experimental and modelling study remains to be done in this area, but our results naturally account for the essential features of whistler and VLF hiss emission simultaneously observed during storm periods. This experimental study is unlikely to be the final word on the origin of these events and further experimental confirmation will, of course, be required at low latitudes. Nonetheless, the observation has the potential to be a ‘circuit breaker’ in our understanding of the generation mechanism of these events observed at low latitudes. However, 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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