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Whistler and VLF Research at our Ground Station Jammu (L=1.17) India

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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) 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 modeling 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. 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 of day-time whistlers at low latitudes, completely in contrast with the earlier findings of ducted propagation of day-time whistlers in the presence of equatorial anomaly.***

Keywords: VLF Emissions, Whistlers, Low latitude ground station, ELF Emissions, Dispersion

1. Introduction

The first unambiguous report of whistlers was made by Barkhausen during world war 1 when it was common practice to eavesdrop on enemy telephone conversations at the front. Barkhausen carried out the systematic studies of whistlers and suggested that whistlers originated in lightening discharges and that their long descending tone was the result of propagation within a dispersive medium.(Barkhausen 1919,1930). However, magnetoionic theory was not known at that time.So quantitative explanation was not possible. Eckersley(1931) developed the wave propagation theory in a magnetoactive plasma like the ionosphere and magnetosphere which could lead to the whistler dispersion law in the low frequency limit. However, the observed dispersion required a puzzle. Eckersley and his colleagues also carried out a VLF / ELF emissions (chorus, hiss, etc). At the time of Eckersley's work, Burton and Boardman investigated whistlers and VLF emissions that were picked up by submarine cables. They carried the detailed studies of whistlers spectrograms, which probably showed different kinds of whistlers (including nose whistlers ,whistler- triggered emissions, etc.).A long period of inactivity followed in whistler research until pioneering work by Storey in 1953.During the last four decades,whistler research has progressed; it is impossible to cite here the individual contributions that have been made.

Following very interesting and useful studies at middle and high latitudes[1], whistler studies at low latitudes in India were started in the year 1963 at Banaras Hindu University, Varanasi by a research group led by late Prof B A P Tantry under a PL-480 research grant received from the USA. The observations were first started at High Altitude Research Observatory, Gulmarg (geomagn. lat. 24°10′N, long. 147°24′E). Encouraged by the results obtained at this station, these observations were extended to stations with lower latitudes like Nanital (geomagn. lat. 19°1′N, long. 150° 9′E) and Varanasi (geomagn. lat. 16°30′N, long. 144°E). Very useful and interesting whistlers were recorded at Gulmarg and Nanital ground stations which included short whistlers, multiflash whistlers, multipath whistlers, diffuse whistlers, riser whistlers, twin whistlers, and low dispersion whistlers. A detailed account of whistlers recorded at Gulmarg and Nanital ground stations has been given by Somayajulu[2] and Somayajulu*et al.*[3]

The frequency- time spectrograms of some of the unusual whistlers have been interpreted by ray tracing computations in a model magnetosphere[4-6]. Some of the important results obtained from the study of low latitude whistlers, included (1) the geomagnetic latitude dependence of whistlers in which couplings between ordinary and extra-ordinary waves in the lower ionosphere were suggested[7], (2) enhancement of whistler activity with magnetic activity[8], and (3) the improbability of ducting at low latitude, as it required large (~ 400 %) enhancement of ionisation along the field lines[9].

Later, whistler studies were extended to some more stations namely Agra[10] (geomagn. lat. 17°12′ N, L = 1.1), Jammu[11] (geomagn. lat. 22°16′ N, L = 1.17), and Bhopal[12] (geomagn. lat. 13° 47′ N, L = 1.06). The studies were made individually as well as in a network of All-India Coordinated Programme onIonosphere-Thermosphere Studies (AICPITS) conducted by the Department of Science & Technology (DST), New Delhi during 1989-1993. Singh *et al.*[10], reported the observation of large number of whistlers at Agra station which included some middle and high latitude whistlers also. An example of a whistler and VLF emission recorded at Jammu station during early days in the year 1997-1998 is presented in **Fig. 1(a,b).**

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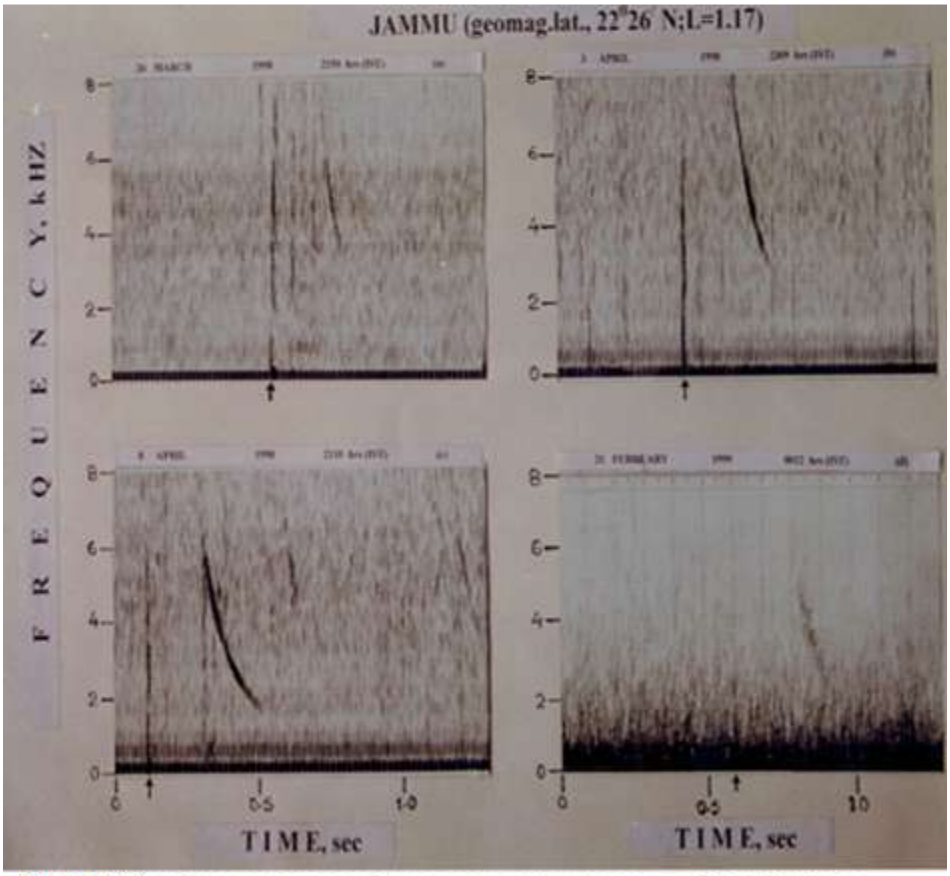

Figure 1(a) Frequency-time spectrograms of whistlers recorded at jammu

Figure 1(a)

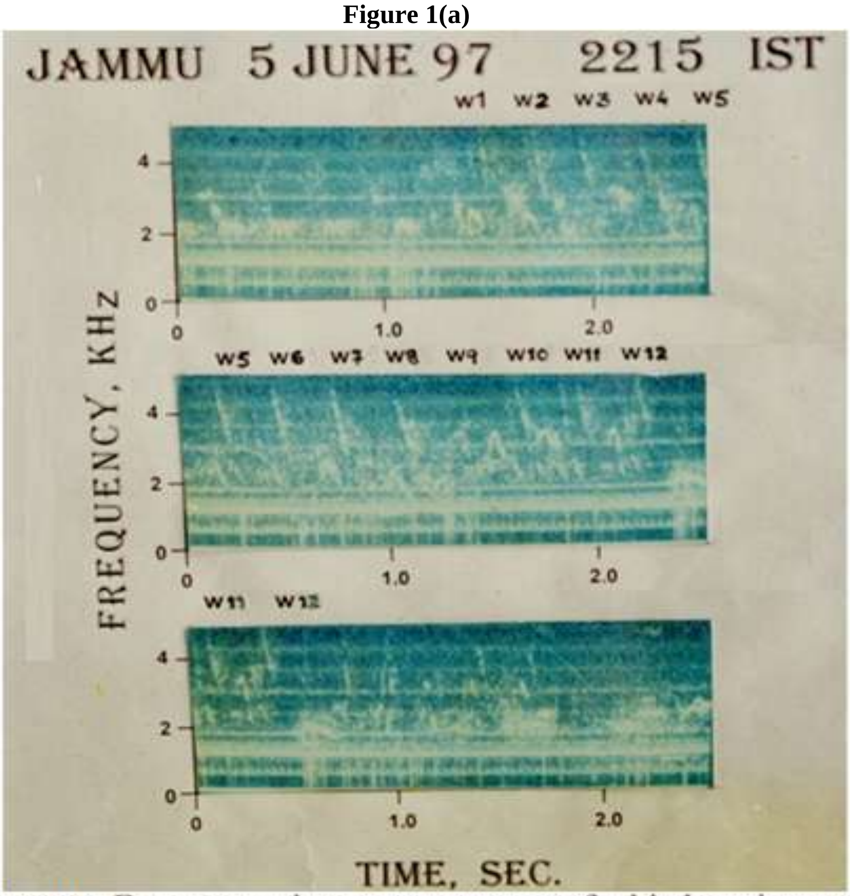

Figure 1(b) Frequency-time spectrograms of whistler-triggered periodic VLF emmisions recorded at jammu

Analyzing whistler data at Gulmarg, Nainital and Varanasi, Khosa*et al.*[13], showed eastward electric field (E ~ 0.3-0.7 mV/m) in pre-midnight sector and westward field (E ~ 0.1-0.7 mV/m) in post-midnight sector. Singh[14] has reviewed most of the early work done in Indian low latitude stations. He has also explained a method of calculating electron density distribution from whistler data.

In this paper, we, present work done in the field of whistlers, VLF emissions, and related phenomena at our low latitude ground stations Jammu.

2. Whistler Recoding Technique

Whistlers have been recorded in India with almost a similar analog technique at all the stations consisting of a T-type antenna, an amplifier and tape recorder[10-12]. The recorded data on tape were analysed initially on a sonograph machine available at Central Electronics Engineering Research Institute (CEERI), NPL Campus, New Delhi and later on a digital signal processor available in the Physics Department, Banaras Hindu University, Varanasi. However, this recording technique has undergone gradual modification from time to time. For example, Singh *et al.*[15]have used loop antennas in place of vertical T-type antenna to avoid the background noises and interferences from local sources. They reported enhanced whistler recording with the new set up, which included some unusual whistlers also. The direction finding analysis of some unusual whistlers and VLF emissions using crossed loop antenna method was also carried out[16-17].The setup employs a crossed loop antenna, amplifiers, low-pass filter, a sound card, and PC with a software specially designed for recording and analysis of VLF data. This new set-up makes the recording and analysis simpler in comparison to traditional whistler recorder in terms of time consumption, man power requirement, and cost involved in recording and analysis.

3. Morphologcial features of Whistler Occurrence

The occurrence of whistlers in Indian low latitude ground stations is normally low. The whistlers occur mostly during nighttime and their activities at thethree stations, Gulmarg, Nainital and Agra, peak in the month of March[3,18]. Recently, Singh *et al.*[19] havestudied the morphological features of whistler activity in Varanasi ground station. From a statistical analysis of the data for a period of 10 years between January, 1990 and December, 1999, they found maximum occurrence of whistlers in the months of January-March. The seasonal variation shows largest occurrence in winter followed by those in equinoxes and summer seasons, respectively. They have also studied the dependence of whistler activity on magnetic activity. The results show that whistler activity increases monotonically with magnetic activity.

4. 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 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 and VLF hiss triggered emissions**(Fig.3)**. 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.*[11] have reported the observation of extremely small dispersion at low latitude ground station Jammu. A spectrogram of ESDwhistlers 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 $s^{1/2}$.

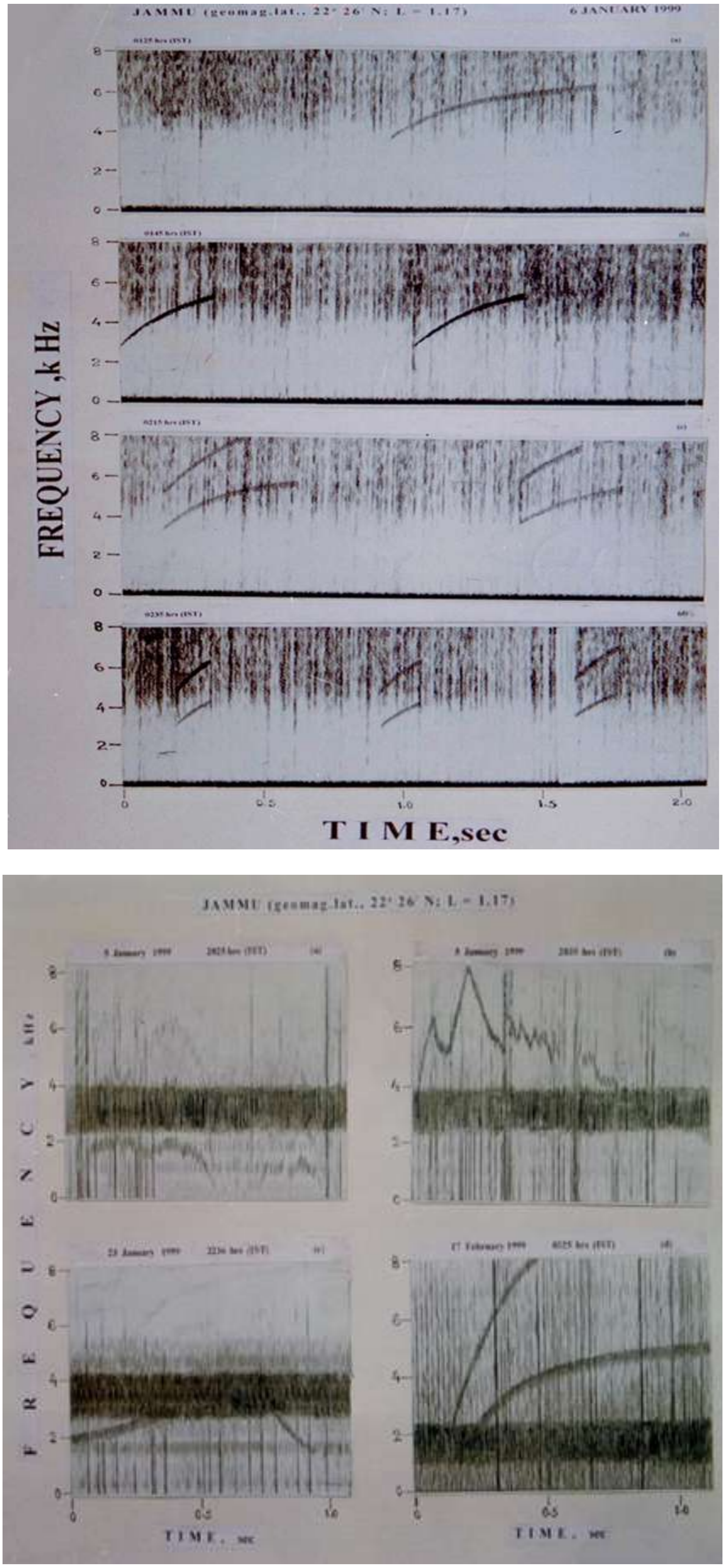

Figure 3: Frequency- time spectrograms of hiss-triggered VLF emissions recorded at Jammu

5. Some Special Techniques for Whistler Analysis

5.1 Matched filtering applied to low latitude whistlers

Matched filtering technique was developed to increase the accuracy in analysis and speed of data processing[20-22] for middle and high latitude whistlers. The technique employs dispersive digital filters, whose frequency-time response is matched to the frequency-time response of the signal to be analysed. Due to high resolution in frequency and time domain, many fine structure components with amplitude differencing in frequency and time are seen in dynamic spectra. The fine structures are individually analysed to determine accurately the L-value of propagation, and equatorial electron density, etc. Singh *et al.*[23] have applied this technique to short whistlers recorded at Jammu during magnetically quiet periods. They have shown that the short whistlers received at Jammu were the ones that propagated along higher L-shell ($L>$ 3.5). In some cases there is no correspondence in their dispersion and derived L-values, which shows the complexity of the propagation mechanism. Three new VLF stations are planned to be established by Indian Institute of Geomagnetism, Mumbai[24].

5.2 Automation of whistlers

The spectrograms of whistlers provide information about frequency and corresponding times of propagation. The f-t values so derived are used to calculate a quantity known as dispersion using the relation $D=t\ f^{1/2}$. However this is long and cumbersome process,because using f-t values one has to plot a graph between $f^{1/2}$ and t, then from the inverse of the slope D is calculated. In order to ease this problem, Sing B and his group at Agra Station have designed a software by which we can determine from the sonograms itself the dispersion and arriving latitude of whistlers. The main task while designing the software is to automate some physics based formulae involved in the calculations.

6. Propagation Mechanism of Whistlers

While middle and high latitude whistlers have been exploited fully for determining the structure and dynamics of the middle and high latitude ionosphere and magnetosphere, the low latitude whistlers have not been used fully to explore the low latitude ionosphere. The main reason for this is that the propagation path of low latitude whistlers can not be determined from frequency-time spectrograms of whistlers, because the nose frequencies of the low latitude whistlers are higher than 100 kHz, well above the pass band of the receiver and the frequency range of the sonogram. Unlike those of middle and high latitude whistlers, the propagation mechanism of low latitude whistlers has been a subject of controversy over the years. Singh and Hayakawa[18] have discussed the relative merits of ducted and non-ducted propagation and suggested that nighttime whistlers are propagated in the pro-longitudinal (PL) mode of propagation. The PL-mode was discovered by Scarabucci[25] and examined in the case of low latitude whistlers by Singh[26]. The PL-mode is defined as a mode of propagation, in which the wave-normal angle ψalong the entire ray path is always less than a characteristic wave-normal angle ψ_0, for which the component of the refractive index vector along the magnetic field line is minimum.i.e. $\delta/\delta\psi(\ \mu cos\psi) = 0$

Fig. 4 shows a set of PL-mode ray paths along different low latitude field line which have been calculated in a model magnetosphere above 300kmaltitude with different initial wave normalangles(Δ).The ray path corresponding to 25^0 field line is of special significance as it is mostly aligned with the field line similar to ducted propagation. The non-zero values of wave normal angles are due to horizontal gradients in the ionization in the low latitude ionosphere. The occurrence characteristics of whistlers during day time whistlers involve large dispersion. It has been suggested[27] that day time whistlers are propagated in equatorial anomaly in two modes: (1) PL-mode and (ii) whispering gallery mode,which also yield time delays comparable to ducted propagation. Now,there is almost a concensus on the above propagation mechanism for low latitude whistlers.

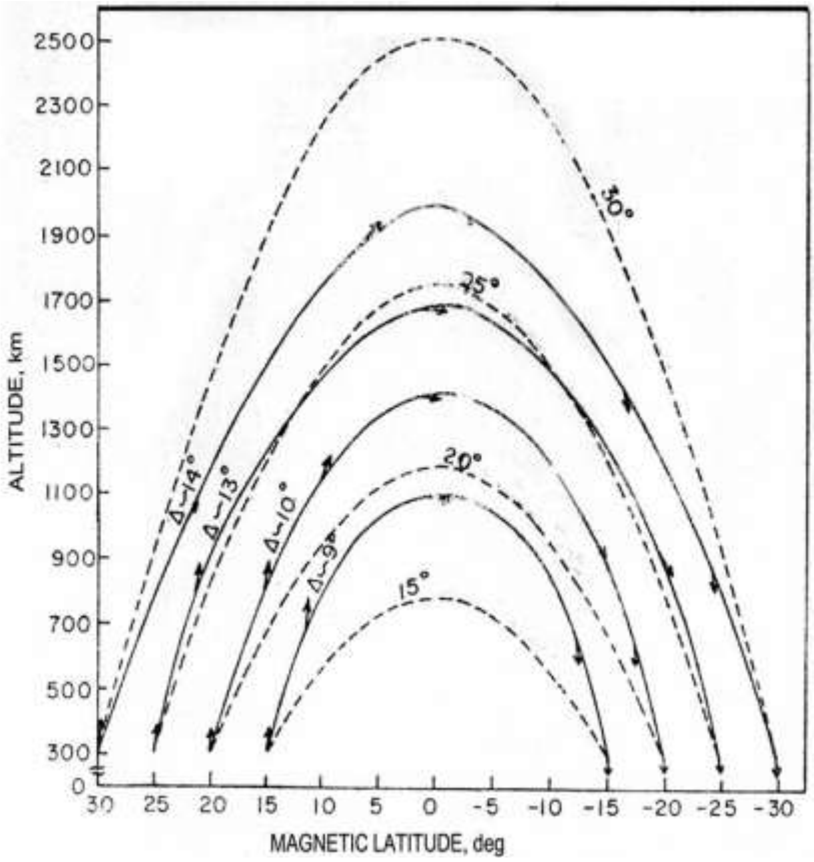

Figure 4: Ray path of PL-mode whistlers computed from 300 km altitude in a diffusive model. Dotted lines show the dipole field lines. Arrows along the path indicate the wave normal directions

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 whislers 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 modeling 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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