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OVER-VIEW OF WHISTLER AND VLF ACTIVITY IN JAMMU AND KASHMIR

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ABSTRACT

In this paper, an up to date review of VLF emissions and whistler research in Jammu and Kashmir has been presented. Some new results of existence of Whistlers and VLF emissions, periodic emissions, hiss type of emissions and chorus emissions at our low latitude ground station, Jammu have been presented. Using an improved system, a unique type of Whistlers in addition to usual type of VLF emissions have been recorded for the first time at our ground station, Jammu from the year 1997-2001 during day and night time. From the dispersion analysis of the 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, magneto ionic theory was not known at that time. So, quantitative explanation was not possible. Eckersley (1931) developed the wave propagation theory in a magneto active plasma like the ionosphere and magnetosphere which could lead to the whistler dispersion law in the low frequency 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 whistler 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 five 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 Somayajalu V V[2] and Somayajulu V V, Rao M & Tantaray B A P.[3]

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 on Ionosphere-Thermosphere Studies (AICPITS) conducted by the Department of Science & Technology (DST), New Delhi during 1989-1993. Singh H, Prakash R and Singh B.[10] reported the observation of large number of whistlers at Agra station which included some middle and high latitude whistlers also. Some examples of a whistlers and VLF emission recorded at Jammu station during early days in the year 1997-2001 are presented in **Fig. 1(a,b).**

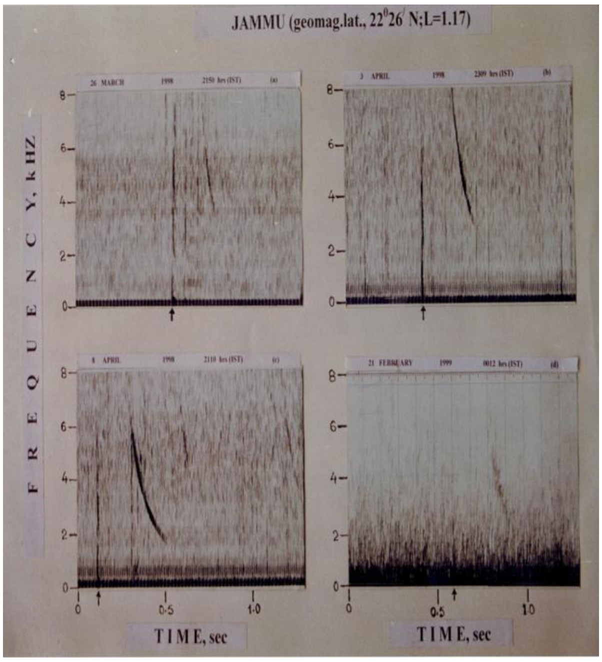

Fig. 1(a): Frequency-Time Spectrograms of Whistlers recoded at Jammu.

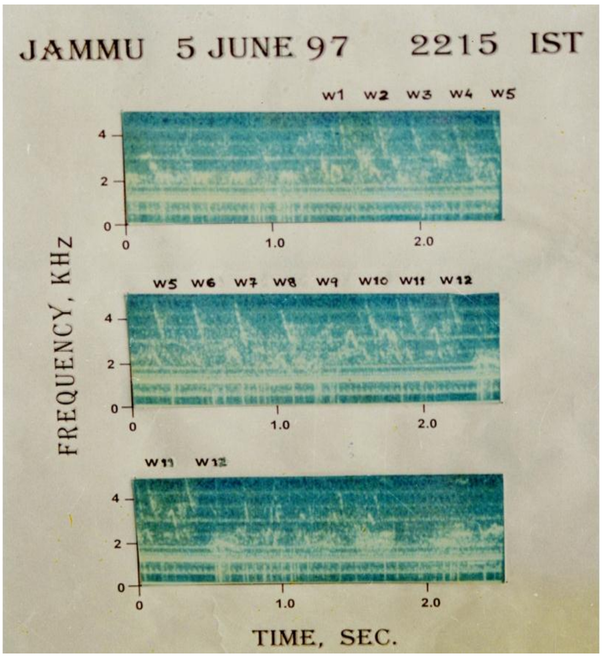

Fig. 1(b): Frequency-Time Spectrograms of Whistler-triggered periodic VLF emissions recorded at Jammu.

Analyzing whistler data at Gulmarg, Nainital and Varanasi, Khosa P N, Ahmed M M & Lalmani.[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 R P.[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 low latitude ground stations Jammu ((geomagn. lat. 22°16′ N, L = 1.17)).

2. Whistler Recording 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 B, Singh R & Singh R.[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 activity 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] This new set up 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. Unusual whistlers and VLF Emissions

The occurrence of whistlers in Indian low latitude ground stations is normally low. The whistlers occur mostly during nighttime and their activities at the three stations, Gulmarg, Nainital, Agra and Jammu, peak in the month of March.[3,18] Recently, Singh S, Patel R P, Singh K K, Singh A K & Singh R P.[19] and Lalmani, Kumar R, Singh R& Singh B.[11] have studied 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.

Unusual whistlers have been recorded at almost all the whistler stations in India. Recently, lalmani, Kumar R, Singh R & Singh B.[11,12] 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 $s^{1/2}$.

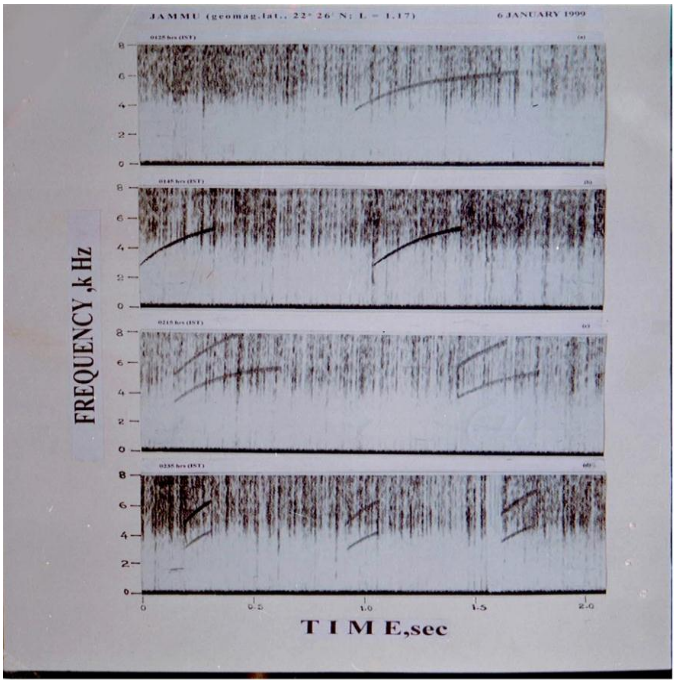

Fig. 2: A Spectrogram of ESD whistler.

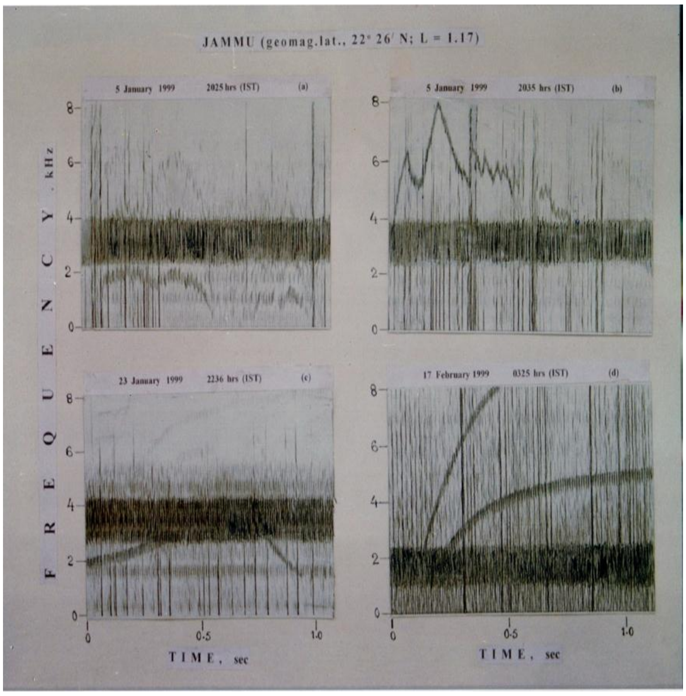

Fig. 3: Spectrograms showing hiss-triggered emissions.

Singh R, Singh A K & Singh R P.[21] have reported synchronized whistlers recorded at Varanasi, which they interpreted by arguing that one component of the synchronized whistler is generated from the lightning discharge, whereas the other one is generated during interaction of whistler waves with precipitating electrons in the southern hemisphere and both the components travel along the same filed line to the opposite hemisphere.

In addition to whistlers, several ELF/VLF emissions have been recorded in the low latitude ground stations. **Hiss-triggered VLF emissions** were observed for the first time in Jammu station,[11] with the same experimental set up as used for the recording of whistlers. The spectrograms showing hiss-triggered -VLF emissions are shown in **Fig.3**. Discrete chorus emissions were observed for the first time in Agra,[22] station, with the same experimental setup as used for recording of whistlers. The data also included a set of rising emissions with time interval in geometrical progression.[22,23] It was shown that increasing time delay between different components of the emissions matched closely with the propagation time of different hops of the whistlers of dispersion 19 $s^{1/2}$. Jain and Singh[24] have interpreted the observations of ELF emissions in Intercosmos-5 satellite at low ionospheric height of about 400 km. Prakash R, Singh D P & Singh B.[25] and Singh K, Singh A K and Singh R P.[26] have interpreted the generation of low latitude hiss type emissions in terms of incoherent Cerenkov process. Extensive theoretical research works on the generation and propagation mechanism of low latitude ELF/VLF emissions and their intensity verification from satellite data have also been carried out by Prakash R and Singh R P[27] and Prakash R, Gupta D D, Singh A P, Singh R P, Singh D P& Awashti R C.[28,29]

Hiss-triggered chorus emissions were recorded at Gulmarg station and their generation mechanism and source locations were examined.[30] Singh K K, Singh R P, Singh R& Shyampathi.[31] reported the observations of Hisslers, which are quasi-periodic VLF noise forms observed at low latitude ground station Jammu. Recently Singh A K and Singh R P.[32] have reported different type of VLF emissions recorded at Varanasi, Jammu and Gulmarg stations and carried out the spectral analysis of these emissions. They have proposed a generation mechanism of these emissions on the basis of background wave oscillations region of the magnetospheric cyclotron maser. Generation and propagation mechanism of VLF emissions have also been discussed by other workers. 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 $\mathbf{D=t\ f^{1/2}}$.

However this is long and cumbersome process, because using **f-t** values one has to plot a graph between $\mathbf{f^{1/2}}$ and **t**, then from the inverse of the slope, D is calculated. In order to ease this problem, Singh 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.

4. RESULTS AND DISCUSSION

The measured dispersion values of all the recorded whistlers on February 14, 1998 during daytime are found to be extremely small lying in the range of **5– 10** $s^{1/2}$. The observation of such daytime **ESD** whistlers provide an indirect and strong evidence in support of non-ducted propagation of daytime whistlers at low latitudes. The daytime ESD whistlers recorded at Jammu are found to obey the Eckersley law (dispersion being constant with frequency), thereby indicating that the whistlers had a quasi-longitudinal whistler mode of propagation with a right handed circular polarisation. The normal dispersion values of whistlers observed at Jammu should be about **22** $\mathbf{s^{1/2}}$ based on the minimum critical frequency of the F2-layer and the electron number density at the equatorial height of the geomagnetic line of force corresponding to Jammu, and from the regression line given by Hayakawa and Tanaka (1978),[33] and also based on the Allcock's formula.[34] The observation of such **ESD** whistlers provides us an indirect and strong evidence in support of non-ducted propagation of daytime whistlers at low latitudes. **Table I** shows the details of **ESD** whistlers recorded during daytime on February 14, 1998 at Jammu.

Table I: Details of Extremely Small Dispersion Daytime Whistlers Observed At Low Latitude Ground Station Jammu (L = 1.17) On February 14, 1998.

Time	Dispersion	Lower cut off	Upper cut off
1240	10	4.42	6.42
1300	10.3}multiflash	3.92	5.42
	10 }whistlers	3.21	5.35
1350	5	3.86	5.14

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.

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.

The **periodic VLF emissions** observed at Jammu on June 5, 1997, differ markedly in frequency and rate of change of frequency with time (df/dt) from those of periodic emissions observed at mid and high latitudes. The possibility that these emissions are high latitude periodic VLF emissions which have propagated to our low latitude ground station Jammu in the Earth-ionosphere waveguide of propagation is ruled out because the time period of the observed periodic VLF emissions at Jammu is very small of the order of o.2 s. This gives an evidence of low latitude origin of the periodic emissions observed at Jammu only. Further, the possibility that these emissions are generated at high L-values in the vicinity of the plasma pause and propagated to our ground station after successive magneto-spheric reflections in a manner similar to those of extremely low frequency (ELF) hiss observed by satellites in the inner zone does not seem to be tenable (Muzzio and Angerami, 1972; Tsurutani et al., 1975).[35,36] This is because, at the frequency of these emissions, the attenuation losses during various magnetospheric reflections would be high and waves could not be detected on the ground. Although the exact losses have not been calculated, a rough estimate can be made from the work of Kimura (1966).[37] He has shown from ray tracing computations in a model ionosphere that amount of attenuation suffered by the waves of frequency 1 kHz from 300 km at 30° N reaching L= 3 after 12 successive reflections is about 6 dB.

The measured period of nondispersive periodic emissions triggered by whistlers recorded at Jammu is found to lie in the range of **0.21-0.26 s** and this clearly shows that these are generated at only low latitude. The very small value of time period of the observed periodic emissions provides us an important information about the path latitude of whistler-triggered periodic emissions without the use of a direction finding. Since the measured dispersion of the whistlers - triggered periodic emissions are very small of the order of 12 $s^{1/2}$, it may be inferred that multi-flash one-hop whistlers shown in **Fig.4** are low latitude whistlers. Using the empirical relation between the dispersion of whistlers (D) and their path latitude propagation given by Allcock (1960) as D = 2.2 (Ø-12), the path latitude of whistler-triggered periodic emissions are found to be~18°. The estimated value of generation of whistler-triggered periodic emissions observed at Jammu is apparently around L =1.1. This L-value are known to fall in the region of inner radiation belt (L = 1.2). It is very acceptable to presume that the associated periodic VLF emission has nearly the same wave normal angle as the causative whistler because both are considered to propagate along the same field line (Hayakawa, 1991).[38] At the first glance, the whistler recorded at Jammu appear to be first, third, fifth etc., hops of multipath whistlers generated from the successive strokes of a lightning discharge. However, the measured dispersions of these whistlers remains constant and hence this possibility is ruled out.

From detailed spectrum analysis of the whistler-triggered periodic emission observed at Jammu, it is found that the time intervals between the consecutive periodic emissions are almost same with the time delays between any of the two successive hops of multi-flash whistlers. The interesting point in **Fig.4** is that the time period between any of the periodic VLF emissions and one-hop whistler traces is almost half of the time delay of one-hop whistler of dispersion ~12 $sec^{1/2}$ as shown in **Table 1**. We interpret this unusual relationship between the time intervals of these periodic VLF emissions and one-hop whistlers as follows: We assume that the consecutive periodic VLF emissions of these events were generated as a result of interactions between the trapped energetic particles and the various hops of multi-flash whistlers near the equatorial region under cyclotron resonance mechanism and propagated to our field station in non-ducted mode of whistler propagation. Under this assumption, we measure the time intervals between the consecutive periodic emissions at the frequency of 3 kHz and then match them with delays at 3 kHz between various hops of whistlers. We find that the observed time intervals of periodic emissions match closely with those of different hops of observed whistler dispersion of ~**12 $sec^{1/2}$** and the time period between any of the two successive periodic emissions and one-hop whistlers of the event are almost half of the time delay of a one-hop whistler of dispersions ~12 $sec^{1/2}$ within about 12% of the measurement error. This shows that time taken by both of the one-hop whistler and periodic VLF emissions is same to reach our receiving ground Jammu from the equatorial region. The detailed results are presented in the **Table 2.**

Table 2: A comparison of time period between different periodic VLF Emissions and time delays between different multiflash whistlers of dispersion~ 12 $s^{1/2}$. Periodic.

Periodic Emissions	Whistlers				
Traces	Time Period	One-hop	Time Delay at 3kHz Hz kHz Hz dDDD DDDDDDd DDDelay Dddelay	Time period Between Periodic Emissions	
	(At 3 kHz)	Traces		And one hop Whistlers (At 3 kHz).	
1- 2	0.23 s	1-2	0.22 s	1 - 1	0.12 s.
2- 3	0.23 s	2-3	0.22 s	2- 2	0.11 s.
3- 4	0.26 s	3-4	0.25 s	3- 3	0.12 s
4- 5	0.24 s	4-5	0.23 s	4- 4	0.11 s.
5- 6	0.26 s	5-6	0.25 s	5- 5	0.12 s.
6- 7	0.26 s	6-7	0.25 s	6- 6	0.12 s.
7- 8	0.26 s	7-8	0.26 s	7- 7	0.13 s.
8- 9	0.26 s	8-9	0.25 s	8- 8	0.12 s.
9 -10	0.24 s	9-10	0.23 s	9- 9	0.11 s.
10-11	024 s	10-11	0.23 s	10-10	0.11 s.
11-12	0.26 s	11-12	0.23 s	11- 11	0.11 s.

Our results summarised in **Table 2** clearly depict that the periodic VLF emissions observed at Jammu on June 5, 1997 shown in **Fig.4** are generated near the equatorial region at **L~1.2** as a result of interaction between trapped energetic particles and one-hop whistlers under cyclotron resonance mechanism and propagated to our ground station Jammu in non-ducted mode of whistler propagation. This provides a possible explanation of the chorus and the generation mechanism of the observed periodic VLF emissions and whistler-triggered periodic VLF emissions at Jammu.

The sample records of nighttime **VLF hiss** are shown in **Fig.5** 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 (ΣkP=8), which is magnetically a quietest day. The total Kp index corresponding to January 4 is 14 ((ΣkP =14), which is magnetically a disturbed day. The total Kp index corresponding to January 5 is 15 ((ΣkP =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).[39] 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.5**. 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).[40,38] 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).[41] and Lalmani et al. (1972).[42] 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 magneto-spheric hiss. In all the measurements known to the authors, there is no report of record Of Simultaneous occurrence of VLF hiss along with whistler at low latitudes. 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.

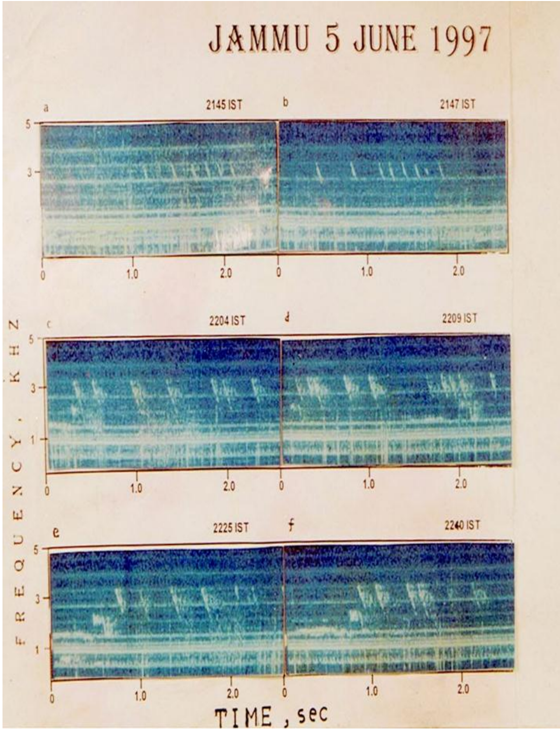

Fig. 4: Frequency-Time spectrograms of periodic VLF Emissions.

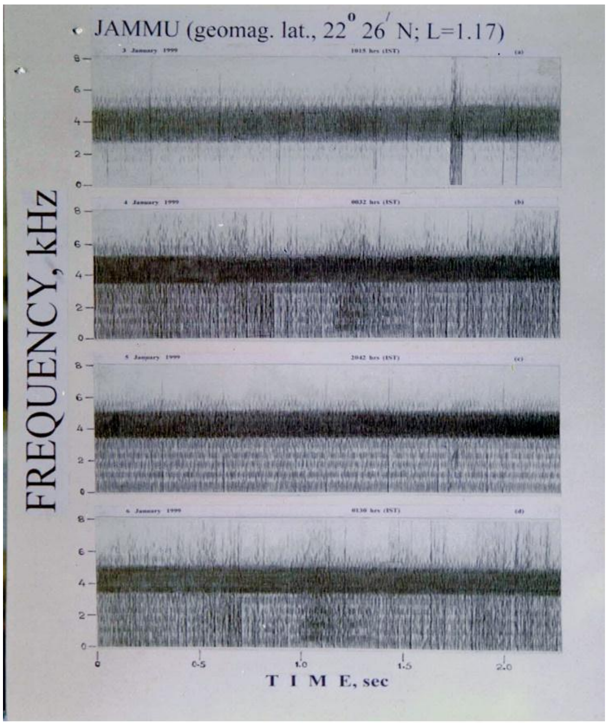

Fig. 5: Frequency-Time spectrograms of VLF Hiss.

5. CONCLUSIONS

Some new results of existence of Whistlers and VLF emissions, periodic emissions, hiss type of emissions and chorus emissions at our low latitude ground station, Jammu have been presented. Using an improved system, a unique type of Whistlers in addition to usual type of VLF emissions have been recorded for the first time at our ground station, Jammu from the year 1997-2001 during day and night time. From the dispersion analysis of the 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.

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REFERENCES

1. Helliwell R A, *Whistlers and related phenomena* (Stanford University Press, Stanford, USA), 1965.
2. Somayajulu V V, *Studies on low latitudes whistlers*, Ph. D dissereation, Banaras Hindu University, Varanasi, India, 1968.
3. Somayajulu V V, Rao M & Tantary B A P, Whistlers at low latitude, *Indian J Radio Space Phys*, 1972; 1: 102.
4. Singh B, Mishra S N & Tantary B A P, Ground riser whistlers at low latitudes, *Indian J Radio Space Phys*, 1972; 1: 188.
5. Singh B & Tantary B A P, Unusual multiflash whistlers at low latitude, *Indian J Radio Space Phys*, 1972; 1: 277.
6. Singh B, Mishra S N & Tantary B A P, Low dispersion whistlers observed simultaneously at low latitude stations, *J Geomagn Geoelectr (Japan)*, 1972; 24: 277.
7. Rao M, Lalmani, Somayajulu V V & Tantary B A P, Dependence of whistler activity on geomagnetic latitude, *Indian J Radio Space Phys*, 1972; 1: 192.
8. Somayajulu V V & Tantary B A P, Effect of magnetic storms on duct formation for whistler propagation, *J Geomagn Geoelectr (Japan)*, 1968; 20: 1.
9. Singh B & Tantary B A P, On ducting of whistlers at low latitudes, *Ann Geophys (France)*, 1973; 29: 5631.

10. Singh H, Prakash R & Singh B, A study of whistlers observed at Agra, *Indian J Radio Space Phys*, 1980; 9: 130.
11. Lalmani, Kumar R, Singh R & Singh B, Characteristics of the observed low latitude very low frequency emission periods and whistler-mode group delay at Jammu, *Indian J Radio Space Phys*, 2001; 30: 214.
12. Singh B Forty years of whistler Research in India, Indian journal of Radio and Space Physics, 2007; 36: 466-473.
13. Khosa P N, Ahmed M M & Lalmani, Whistler observation of magnetospheric electric fields in the nightside plasmasphere at low-latitude, *Moon Planet (Netherlands)*, 1982; 27: 453.
14. Singh R P, Whistler studies at low latitude: A review, *Indian J Radio Space Phys*, 1993; 22: 139.
15. Singh B, Singh R & Singh R, Initial results of whistler observations at Agra using modified experimental set up, *Indian J Radio Space Phys*, 1997; 26: 218.
16. Singh B, Singh R & Singh R, Transmission characteristics of some unusual whistlers and VLF emissions as determine from their polarization measurements at Agra, *J Atmos Elect (Japan)*, 1998; 18: 11.
17. Singh V, Kumar M & Singh B, A new whistler recorder and analyzer developed at Agra, *Indian J Radio Space Phys*, 2005; 34: 349.
18. Singh B & Hayakawa M, Propagation modes of low and very low latitudes whistlers, *J Atmos Solar-Terr Phys (Netherlands)*, 2001; 63: 1133.
19. Singh S, Patel R P, Singh K K, Singh A K & Singh R P, Role of geomagnetic disturbance on whistler occurrence at a low latitude station, *Planet Space Sci (GB)*, DOI 10. 1016/JPSS, 2007; 02.001.
20. Singh B, Singh R & Singh R, Whistler triplets, bands, and fine structures observed in low latitude ground station, *Geophys Res Lett (USA)*, 1997; 24: 2507.
21. Singh R, Singh A K & Singh R P, Synchronized whistlers recorded at Varanasi, *Pramana (India)*, 2003; 60: 1273.
22. Singh B, Prakash R & Singh H, Discrete chorus emissions observed at a low latitude station, *Nature (UK)*, 1991; 290: 37.
23. Singh B, Some unusual discrete VLF emissions observed at a low latitude ground station at Agra, *Ann Geophys (France)*, 1997; 15: 1005.
24. Jain VK & Singh B, ELF emissions at low ionospheric height in the inner radiation belt, *Indian J Radio Space Phys*, 1988; 17: 124.

25. Prakash R, Singh D P & Singh B, Incoherent Cerenkov process as a source of low-latitude VLF emissions, *Planet Space Sci (GB)*, 1979; 27: 1959.
26. Singh K, Singh A K & Singh R P, Propagation characteristics and generation mechanism of ELF/VLF hiss observed at low latitude ground station (*L* = 1.17), *Earth Moon & Planet (Netherlands)*, DOI 10.1007/s 11038-006-9070-1.
27. Prakash R & Singh R P, Generation mechanism of ELF hiss emissions in the detached plasma regions of magnetosphere, *Indian J Radio Space Phys*, 1994; 23.
28. Prakash R, Gupta D D & Singh A P, A Theoretical explanation of intensity of low latitude ELF emissions and identification of their generation mechanism, *Indian J Radio Space Phys*, 2005; 34: 91.
29. Prakash R,Singh R P ,Awashti R C and Singh D.P,a theoretical verification of intensity of plasmspheric ELF hissemissions:theory versus GEOS-1 observations, Ann, Geophys (France), 1997; 15: 597.
30. Singh R, Patel R P, Singh R P & Lalmani, An experimental study of hiss-triggered corous emissions at low latitude, *Earth Planet Space (Japan)*, 2000; 52: 37.
31. Singh K K, Singh R, Singh R P & Shyampathi, Hisslers: Quasi-periodic VLF noise forms observed at low latitude ground station Jammu (*L* = 1.17), *Geophys Res Lett (USA)*, 31 L19802 DOI: 10.1029/2004 GL020468, 2004.
32. Singh A K & Singh R P, Observation of discrete VLF emissions at low latitude and their generation mechanism, *Earth Planet Space (Japan)*, 2004; 56: 1067.
33. Hayakawa, M., Tanaka, Y. On the propagation of low latitude whistlers. Rev. Geophys. Space Phys, 1978; 16: 111–125.
34. Allcock, G. McK., ‘IGY Whistler Results’, Paper Presented at the 13th General Assembly URSI-London, 1960.
35. Muzzio J. L. R and and Angerami J. J, J. Geophys. Res., 1972; 77: 1157.
36. Tsuratani, B.T., Smith E.J., and Throne R.M., J.Geophys. Res., 1975; 80: 600-607.
37. Kimura, I., Effect of ions on whistler-mode ray tracing. Radio Sci., 1966; 269: 42.
38. Hayakawa,M. ,J.Geomag.,Geoelec., 1991; 43: 267276.
39. Khosa,P. N. ,Lalmani, Kausaria R.R., Ahmed, M.M.,Ind.J .Radio Phys.10,209210.
40. Lalmani, Somayajulu, V .V. and Tantry, BAP, Ind. J. Pure and Appl. Physics, 8,564568,1970
41. Ondoh, T. and Isizaki, S., Rept. onos.Space, 1965.
42. Lalmani, Somayajulu, V .V. and Tantry, BAP, J.Geomag. Geoelect, 1972; 24: 261-265.