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DUCT LIFETIMES AT MID LATITUDES

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Abstract

The power spectrum analysis of the occurrence rate of whistlers observed at Varanasi (geom. lat. 14°55′ N) shows periodicity of the order 70–80 min which has been interpreted as the lifetimes of the ducts trapping and guiding the whistlers. This is also corroborated by the dispersion analysis of the recorded whistlers. The observations clearly favour the existence of large numbers of ducts simultaneously. The analysis shows that these whistlers had propagated in the magnetosphere along higher L-values ($L = 2.1 - 2.7$).

Keywords: whistler, dispersion, duct, lifetime.

1. Introduction

It is generally believed that the ground-based whistlers at low as well as at high latitudes have been trapped in field-aligned ducts present throughout the magnetosphere [1–3]. Direct and indirect evidences for the presence of ducts have been accumulated from ground-based measurements [4], in situ observations on board OGO3 [5], ISIS [6] and on a rocket [7]. SMITH and ANGERAMI [8] analysed frequency spectra of whistlers recorded on board OGO-III, identified different ducts and measured their size and spacing. PARK [9] while studying interchange of ionization between the ionosphere and inner plasmasphere, identified the individual ducts.

At all low latitude Indian Stations (Varanasi, Agra, Nainital and Gulmarg), consistently increased whistler activity almost simultaneously with increase in K_p index has been observed. The enhancement in whistler activity is assigned to the formation of additional ducts during magnetic storm periods. The electron density in the F2 region and in the exospheric region enhances during magnetic storm periods and produces additional ducts in which whistlers are trapped and propagated to the conjugate hemisphere. SOMAYAJULU et al. [10] and SINGH et al. [11] using whistlers recorded at Gulmarg, discussed with evidence the formation of additional ducts during magnetic storm period. SOMAYAJULU et al. [10] showed that while for a duct to form might require 30 min or even less time, but to grow to its full size might take 3 h. The estimated duct lifetime ranges from a few hours to a few days. Considering the ducted propagation of whistlers, OKUZAWA et al. [12] suggested that a kind of periodicity in the whistler occurrence rate should appear depending upon the periodicity in the cyclic formation and decay of whistler ducts. The main purpose of this paper is to examine the suggestions of OKUZAWA et al. [12] and apply it to the whistler data to estimate the duct lifetime.

Here it is assumed that few ducts are present in the ambient medium whose growth/decay are cyclic in nature and the observed whistlers have propagated through one of these ducts. The presence/absence of periodicity in the occurrence rate can be detected by the standard technique of power spectrum analysis [13]. The evaluated period gives the lifetime of whistler ducts. The whistler data recorded at ground station Varanasi are analysed and lifetimes of whistler ducts are evaluated which are found to be in close agreement with those reported by other workers for low latitude stations.

2. Data Analysis

The good quality whistlers recorded at Varanasi on 8th March, 1991 were selected for analysis. Sample records of a few whistlers are shown in *Fig. 1.* The observation period ranged from 0030 to 0240 hrs IST. These whistlers were analysed and nose frequency for each whistler was determined [14]. The nose frequency is used to determine the path of propagation of whistlers. It is found that the propagation path varies form $L = 2.1$ to $L = 2.7$. Thus, the variation in path $L = 0.6$. Noting that the L-value of Varanasi is 1.07, it is found that the whistlers received at Varanasi had propagated along higher L-values in the magnetosphere. Such whistlers can only be received at lower latitude ground stations, if after exiting from the ionosphere, they follow the Earth ionosphere waveguide and propagate towards equator. Similar propagation mechanism was discussed by SINGH et al. [15].

The occurrence rate of whistlers is shown in *Fig. 2.* In this figure, the points indicate number of whistlers observed over 5 min. intervals. The occurrence rate of whistlers at any ground station would depend upon the occurrence rate of input signal (lightning discharge), the availability of suitable number of ducts and favourable conditions for the ionospheric transmission of the signal. While deriving information about the ducts, we assume that the input signal is of constant density during the observation period. Further, it is also supposed that the ionospheric transmission condition remains favourable during the said period. The information about the duct lifetime is derived from the power spectrum analysis of the occurrence rate. Treating occurrence rate as time varying function $f(t)$, autocorrelation of the function is determined which is shown in *Fig. 3.* The power spectrum densities in arbitrary units are shown in *Fig. 4.* It is clear that the power spectra show peaks at certain selected frequencies separated by slightly varying intervals. The time interval corresponding to the frequency separation between peaks lies in the range of 70–80 min. This result shows that a physical process with a periodicity of about 70 min. is present in the whistler occurrence rate recorded at Varanasi.

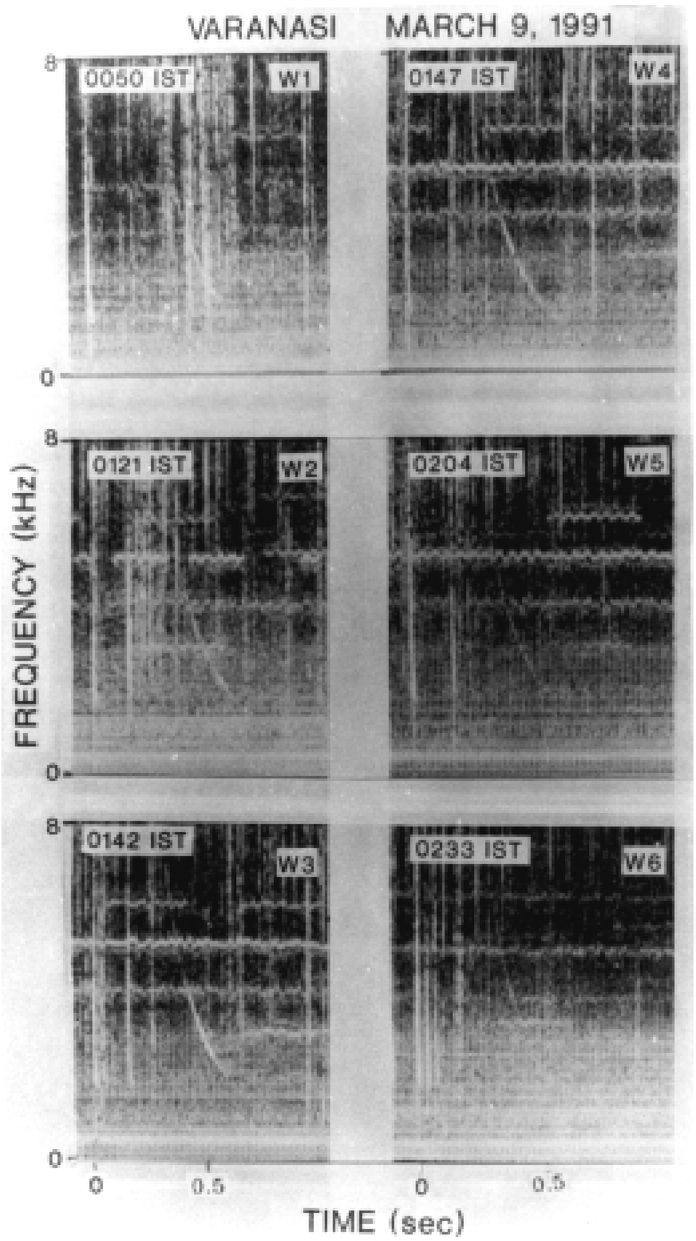

Fig. 1. Examples of whistlers observed at Varanasi on 8/9th March 1991

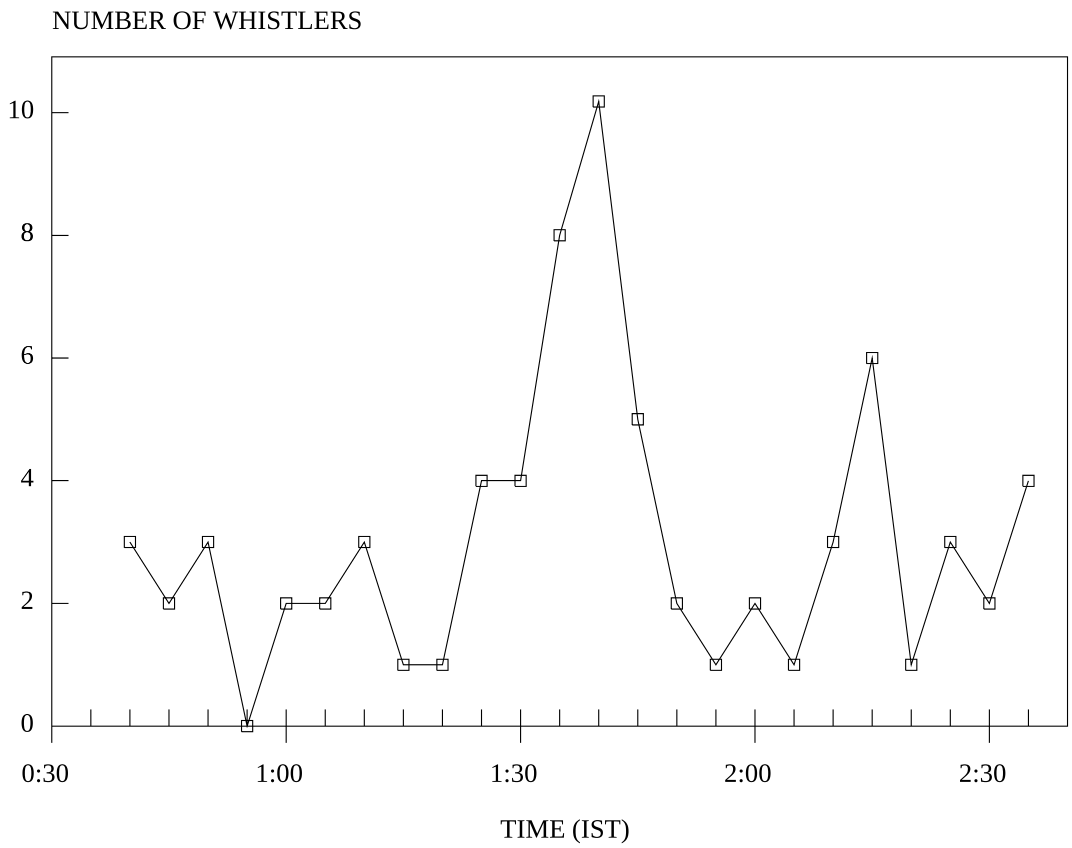

Fig. 2. Variation of whistler occurrence rate. The ordinate indicates number of whistlers recorded over 5-min. intervals

Apart from power spectral analysis, we have also determined dispersion of whistlers recorded on March 8, 1991. We have selected three cases with dispersions 28, 29 and 31 $sec^{1/2}$. *Fig. 5* shows the duration for which whistlers with a particular dispersion could be observed. For example, whistler with a dispersion of the 31 $sec^{1/2}$ could be observed only between 0044 IST and 0234 IST whereas whistlers with a dispersion of 29 $sec^{1/2}$ could be recorded only between 0100 hrs IST and 0210 hrs IST. The data presented in *Fig. 5* allow us to make the following qualitative statement: whistlers with a particular dispersion are observed during certain periods only. If we assume that the existence of 'discrete' dispersion implies the presence of different ducts, we might say that different ducts in fact have existed during the period of interest. It must be noted that the grouping of whistlers by dispersion in *Fig. 5* is not accurate. In spite of the inherent error in grouping, the qualitative statement that whistlers with a given dispersion are observed only during a specific period of time, is reasonably valid. Having grouped the whistlers by dispersion, we show in *Fig. 6*, how the occurrence rate for whistlers in each group varies with time. In these curves the ordinate represents the numbers of whistlers observed over 10 min intervals with the abscissa giving the time in IST. It is seen from *Fig. 6* that the occurrence rate in each group shows a periodicity [16]. Actually, this periodicity is of the order of an hour which predicts duct lifetime.

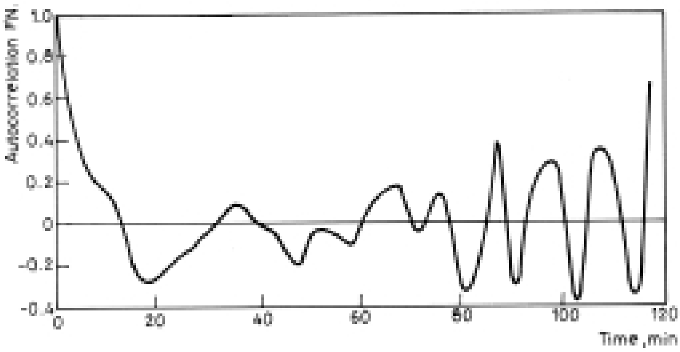

Fig. 3. Variation of auto-correlation function with time

3. Results and Discussion

The periodicities observed in the occurrence rate of whistlers observed at Varanasi may find their origin in the growth and decay of ducts as envisaged by OKUZAWA et al. [12]. The power spectrum shows peaks at different frequencies separated by a constant frequency having the time interval of $\sim$ 70 minutes, which may be considered as the lifetime of the ducts. PARK and CARPENTER [17] suggested that the average time for which the individual ducts might stay within the viewing area

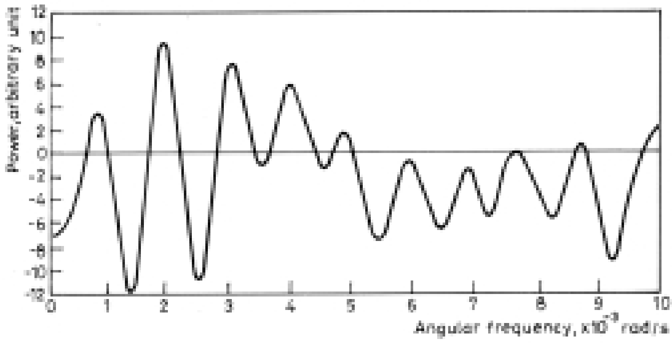

Fig. 4. Power spectrum of occurrence rate of whistlers recorded at Varanasi

was about 2 h. HAYAKAWA et al. [18], using real-time whistler analyser at Moshiri ($L = 1.6$), showed that it took less than one hour for a duct to be formed and duct lifetime is of the order of one hour or less. They also suggested the successive growth and decay of ducts. Using power spectrum analysis of whistlers recorded at Gulmarg and Nainital, RAO and LALMANI [16] evaluated duct lifetime of the order of one hour. Simultaneous observations of whistlers from adjacent stations have yielded duct life as short as 30 min for mid-latitudes.

Ideally, the minima in power spectra should go to zero, in order that our interpretation is perfectly valid. Yet, we do not observe such a behaviour. The finite value of power spectrum at the minima may be due to the differences in the time histories of individual ducts. Furthermore, it is also possible that the whistlers might have propagated in an extensive system of ducts, well spread in L value [17,19,20].

The power spectral analysis was based entirely on the occurrence rate. To quantify our conclusions that the periodicity is due to growth and decay of ducts, dispersion analysis was performed to establish that individual ducts actually existed during the period of observation. The dispersion varied between 25 and 35 sec$^{1/2}$, but a large number of whistlers could be grouped with dispersion of 28 sec$^{1/2}$, 29 sec$^{1/2}$, 31 sec$^{1/2}$. The dispersion measurement indicates some spread in dispersion around a well peaked value suggesting the existence of single component whistlers. In fact, whistlers at low latitudes are single component whistlers which means that whistlers propagate along a single L-shell. Thus, the whistler occurrence rate is a quasi-Gaussian shaped distribution. Furthermore, it was observed that whistlers with a particular dispersion were present during certain periods only. If each dispersion corresponds to the existence of a duct, then we find that a number of ducts exist during certain periods. The dispersion plot as a function of time shows a well peaked value in all the three cases. Thus, at least three ducts existed overlapping each other. Furthermore, whistlers are also present with other dispersion values, hence, the number of ducts during the period of interest becomes much more than three.

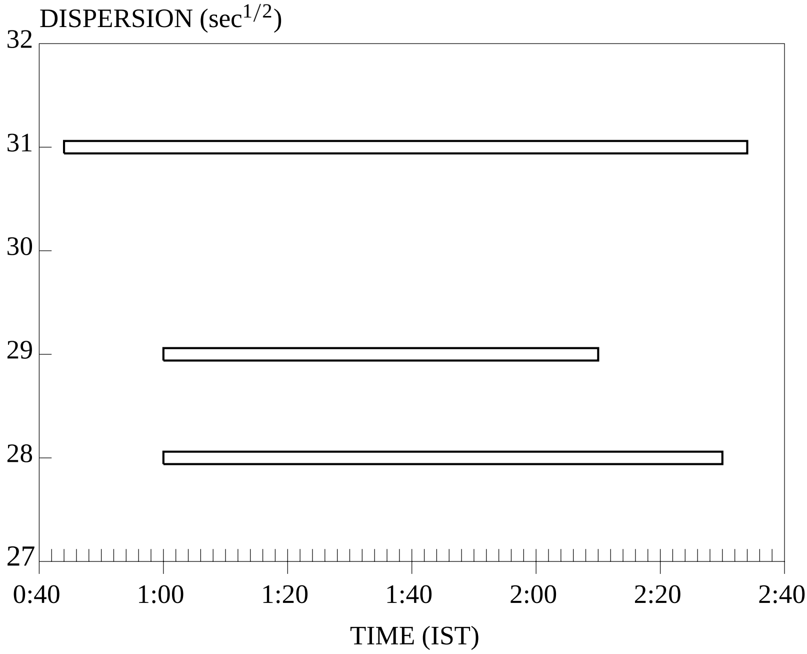

Fig. 5. Durations over which whistlers of a given dispersion are observed

Fig. 6 shows the variation of occurrence rate of whistlers with time. In these curves, the ordinate represents the number of whistlers observed over ten-minute intervals. The occurrence rate shows periodicity with periods ranging between 55 and 60 minutes lending support to the results obtained by power spectrum analysis, viz., that a definite periodicity existed in the whistler occurrence rates, although, the time period determined from the dispersion analysis is slightly different. In the dispersion analysis, some observations have been left over, which may have large periods and, hence, resultant periodicity present in the power spectrum analysis becomes variable and large as compared to that obtained from the dispersion analysis. When large numbers of ducts are more or less simultaneously excited, the net rate may not show any periodicity even though individual ducts grow and decay in quick succession and in such a situation, the power spectrum analysis may fail because of the high ‘noise level’ in the data.

The estimated lifetime of the ducts based on dispersion analysis and power spectrum analysis comes out to be about 60 minutes and 70 minutes, respectively. These results are in close agreement with that of RAO and LALMANI [16] for low latitude whistlers where they have estimated duct lifetime to be of the order of one hour or less and have also presented evidence for the successive growth and decay of ducts. The duct lifetime of the order of one hour is comparable in order of magnitude with the estimates of other researchers [4,12,17,21].

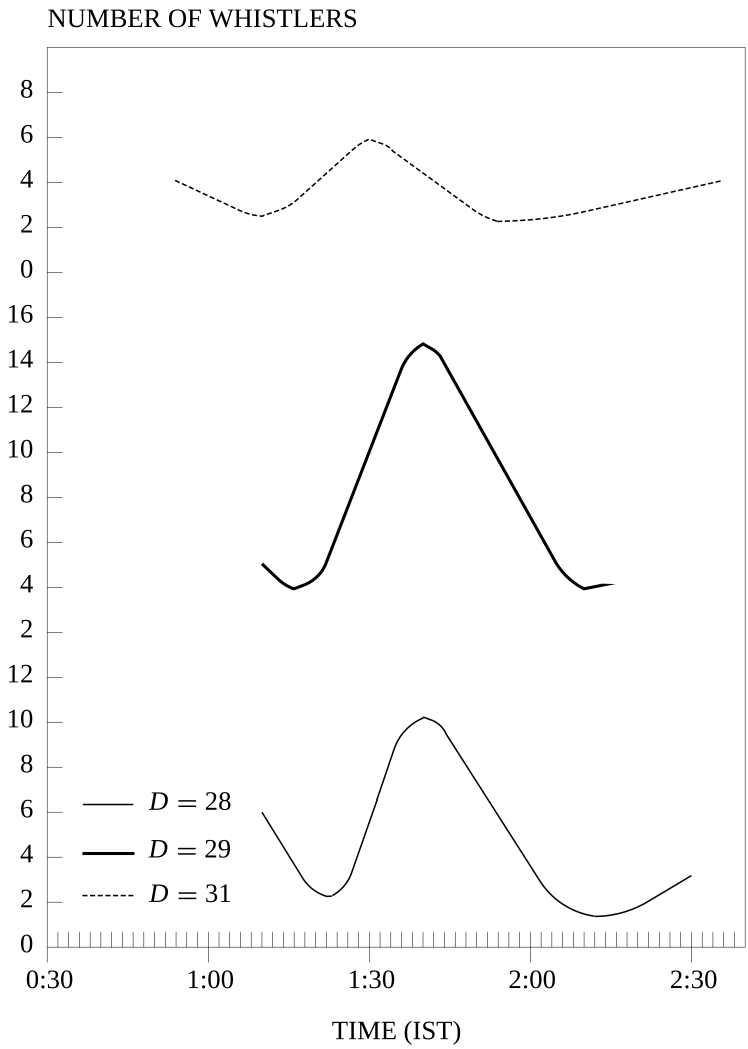

Fig. 6. Variation of whistler occurrence rate with time for different dispersions. Ordinates indicate number of whistlers occurred over 10-min. intervals

Here, it is important to note that the observed periodicity in occurrence rate has been attributed only to the propagation effects, not in the source. This point could be answered only when the periodicity is searched in the lightning discharge rate causing the observed whistlers. In the absence of direct in-situ measurements, we can use general features of lightning discharges. It is noted that, in general, at low latitudes, the number of whistlers observed is much less as compared to mid/high latitudes whereas latitudinal distribution of lightning discharges clearly shows higher occurrence rate at low latitudes and it decreases with latitudes [1]. LALMANI and SINGH [22] have discussed that the whistler occurrence rate is not only governed by the source but it is more controlled by the properties of the medium and propagation conditions. In other words, any modulation of occurrence rate at the source is unlikely to be detected in the whistler observations at low latitudes.

4. Conclusions

The occurrence rate shows periodicity at an interval of 70 minutes, which may be attributed to a cyclic process in the growth and decay of ducts. The whistler dispersion analysis predicts periodicity of the order of 60 minutes and suggests that more than one duct are present simultaneously. Based on our results, we conclude that the duct lifetime is of the order of an hour and the present estimates are consistent with those of other researchers. Furthermore, it is to be noted that by recording whistlers at low latitudes, we have derived information about mid-latitude ducts.

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References

[1] HELLIWELL, R. A.: Whistlers and Related Ionospheric Phenomena, Stanford Univ. Press, California (1965).

[2] HAYAKAWA, M. – TANAKA, Y.: On Propagation of Low Latitude Whistlers, *Rev. Geophys. Space Phys.*, Vol. 16 (1978), p. 111.

[3] SINGH, R. P.: Whistler Studies at Low Latitude, *Ind. J. Radio and Space Phys.*, Vol. 22 (1993), p. 139.

[4] SMITH, R. L.: Propagation Characteristics of Whistlers Trapped in Field-Aligned Columns of Enhanced Ionization, *J. Geophys. Res.*, Vol. 66 (1961), p. 3699.

[5] ANGERAMI, J. J.: Whistler Duct Properties Deduced from VLF Observations Made with the OGO-3 Satellite Near the Magnetic Equator, *J. Geophys. Res.*, Vol. 75 (1970), p. 6115.

[6] ONDOH, T.: Magnetospheric Whistler Ducts Observed by ISIS Satellites, *J. Radio Res. Labs. Tokyo*, Vol. 23 (1976), p. 139.

[7] HAYAKAWA, M. – IWAI, A.: Magnetospheric Ducting of Low Latitude Whistlers as Deduced from the Rocket Measurement of their Wave Normal Directions, *J. Atmos. Terr. Phys.*, Vol. 37 (1975), p. 1211.

[8] SMITH, R. L. – ANGERAMI, J. J.: Whistler Propagation in Magnetospheric Ducts, *ESSA Conjugate Point Symposium, Institute of Environmental Research, Boulder, Colorado, Technical Memorandum*, Vol. 2 (1967).

[9] PARK, C. G.: Whistler Observations of the Interchange of Ionization between the Ionosphere and the Protonosphere, *J. Geophs. Res.*, Vol. 75 (1970), p. 4249.

[10] SOMAYAJULU, V. V. – RAO, M. – TANTRY, B. A. P.: Whistlers at Low Latitude, *Ind. J. Radio and Space Phys.*, Vol. 1 (1972), p. 102.

[11] SINGH, R. P. – SINGH, A. K. – SINGH, U. P. – SINGH, R. N.: Wave Ducting and Scattering Properties of Ionospheric Irregularities, *Adv. Space Res.*, Vol. 14 (1994) p. 225.

[12] OKUZAWA, T. – YAMANAKA, K. – YOSHINO, T.: Characteristics of Low Latitude Whistler Propagations Associated with Magnetic Storms in March, *Rept. Ionosphere and Space Res. Japan*, Vol. 25 (1971), p. 17.

[13] MADDEN, T.: Spectral, Cross-Spectral and bi-Spectral Analysis of Low Frequency Electromagnetic Data, in: *Natural Electromagnetic Phenomena below 30 Kc/s* (Ed.: D.F. Bleil) Plenum, New York, (1964), p. 429.

[14] DOWDEN, R. L. – ALLCOCK, G. M.: Determination of Nose Frequency of Non-Nose Whistlers, *J. Atmos. Terr. Phys.*, Vol. 33 (1971), p. 1125.

[15] SINGH, U. P. – SINGH, A. K. – LALMANI – SINGH, R. P. – SINGH, R. N.: Hybrid-Mode Propagation of Whistlers at Low Latitudes, *Ind. J. Radio and Space Phys.*, Vol. 21 (1992), p. 246.

[16] RAO, M. – LALMANI: An Evaluation of Duct Lifetimes from Low Latitude Ground Observations of Whistlers, *Planet. Space Sci.*, Vol. 23 (1975), p. 923.

[17] PARK, C. G. – CARPENTER, D. L.: Whistler Evidence of Large Scale Electron Density Irregularities in the Plasmasphere, *J. Geophys. Rs.* Vol. 75 (1970), p. 3825.

[18] HAYAKAWA, M. – TANAKA, Y. – OKADA, T. – OHTSU, J.: Time Scales for the Formation, Lifetimes and Decay of Low Latitude Whistler Ducts, *Ann. Geophys.*, Vol. 1 (1983), p. 515.

[19] LESTER, M. – SMITH, A. J.: Whistler Duct Structure and Formation, *Planet. Space Sci.*, Vol. 28 (1980), p. 645.

[20] CORCUFF, P. – CORCUFF, Y.: Structure et dynamique de la plasmapause-plasmasphere les 6 et 14 juillet 1977; étude a l'aide des données des sifflements secus an sol et des données des satellites ISIS et GEOS-1. *Ann. Geophys.*, Vol. 38 (1982), p. 1.

[21] SHIMAKURA, S. – MORIIZUMI, M. – HAYAKAWA, M.: Propagation Mechanism of Very Unusual Low Latitude Whistlers with Additional Traces of the Earth-ionosphere Waveguide Propagation Effect, *Planet. Space Sci.*, Vol. 39 (1991), p. 611.

[22] LALMANI – SINGH, R. P.: Whistler Occurrence Rate Variation with Geomagnetic Latitude, *J. Scientific Res., B.H.U.*, Vol. 2 (1978), p. 317.