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Estimation of magnetospheric electron densities from low latitude whistlers

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Abstract : Dispersion analysis of whistler waves recorded at the low latitude stations have been used to estimate electron density in the equatorial region and electron contents in the flux tube aligned along the dipolar geomagnetic fields lines This is possible only when waves have propagated along the field lines In this paper, we report some examples of whistler waves recorded at the ground station Jammu (geom lat 22° 26′ N, L = 1 17) India, whose analysis yield path of propagation in the range $1\ 62 \leq L \leq 4\ 39$ The matched filtering and parameter estimation technique has been used to analyze these whistlers and the error in estimating the path of propagation is less than 3% However, the computed electron densities and electron tube contents based on the analysis of these whistlers are found to be one order of magnitude smaller than the values reported by the other workers This shows that the matching of simulated and observed dynamic spectra need not necessarily yield correct path of propagation and hence correct value of electron density As a result either the propagation mechanism at low latitude or the analysis method of whistlers recorded at low latitudes has to be reconsidered

Keywords : Matched filtering, zero frequency dispersion, wave-normal, whistler mode, electromagnetic wave propagation, ionosphere-magnetosphere interaction

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1. Introduction

The analysis of whistler dispersion yields information about the medium parameters such as electron density, total electron content of flux tube [1–9], electron temperature [10–13], magnetic field and large-scale electric field [14–16,2]. In the estimation of these parameters it is assumed that the whistler mode signal has propagated in the ducted mode along the dipolar geomagnetic field lines and the plasma distribution

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follows a given model. The most widely used model is the diffusive equilibrium model [17]. Using the usual technique of dispersion analysis some efforts were made to estimate the equatorial electron density and total electron contents in the plasmasphere by analyzing whistlers recorded at the low latitude Indian stations [18–20,9,16]. Singh *et al* [21,22] analyzed some selected whistlers recorded at Varanasi using the matched filtering and parameter estimation technique and showed the validity of the technique in analyzing whistler signals recorded at low latitudes. In this technique also it is assumed that the wave has propagated along the dipolar geomagnetic field line The accuracy depends on the accurate reproduction of the observed dynamic spectra using initial parameters such as zero frequency dispersion, initial time delay and nose frequency. However, using the same technique the results of analysis in some cases show anomalous behavior as far as the relation between L-value and dispersion is concerned [23]. In the normal case dispersion is proportional to the length of path covered by the wave *i.e.* L-value. As L-value increases dispersion increases.

At this stage we are not able to improve either the model of electron distribution, when compared with that used by [21,22,24] or the measurement accuracy of whistler parameters for low latitudes based on the analysis to a limited number of whistlers recorded at other low latitude Indian ground stations. However, it seems useful to extend the analysis to a larger number of whistlers recorded at Jammu in order to get some feelings about the probing potentiality of whistlers recorded at the low latitudes and their applicability. In this paper we present the variation of equatorial electron density and total electron contents with L-value derived from the analysis of 22 whistlers recorded at Jammu during the night hours. An example of whistler spectrograms of a typical event used in the present study is shown in Figure 1, which occurred in the pre-midnight sector on June 5, 1997 during deep quieting period (average $K_P \sim 1$). Whistler data used in the dispersion analysis are presented in Section 2. Results of the analysis are discussed in Section 3. The main conclusion of the paper is given in Section 4.

2. Whistler data and analysis

Jammu station is well equipped for the measurements of VLF waves from natural sources. Broad band VLF signals are received by a T-type antenna, amplifiers and tape recorder with bandwidth from 50 Hz to 15 kHz. The antenna is erected at a suitable distance from the main building to reduce the power line hum and any other type of man made noises. Between the antenna and pre/main amplifier, an active filter unit is introduced to reduce the local noise to a minimum in the frequency range from 100 Hz to 500 Hz. The gain of the pre/main amplifier is varied form 0 to 40 dB to avoid over loading of the amplifier at the time of intense whistler activity. The observations were taken continuously during day and nighttimes under AICPITS program and whistlers in large numbers were observed during night hours. The

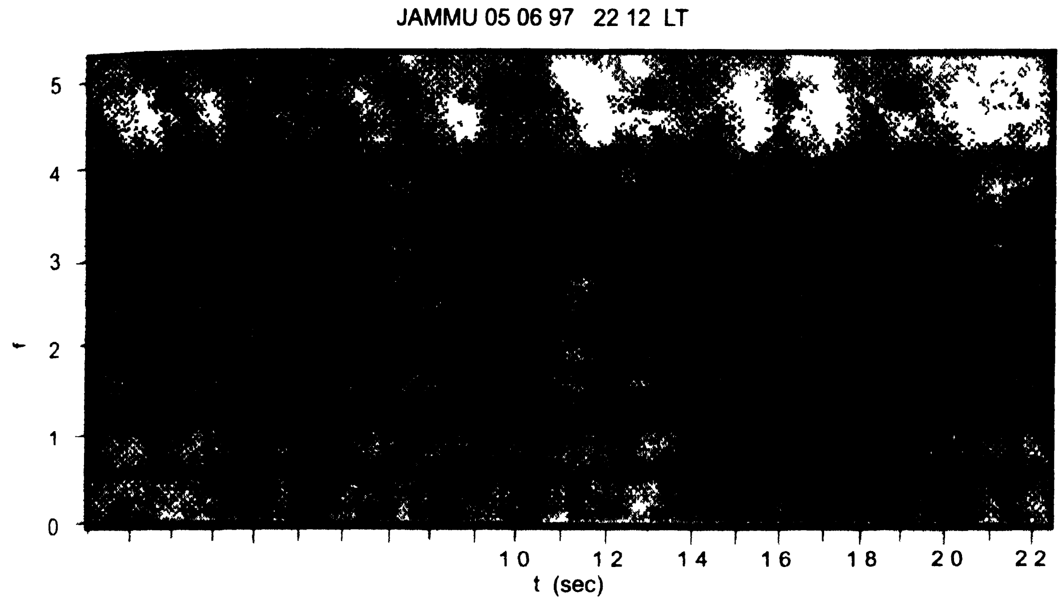

Figure 1 Spectrogram of one of the whistler events (as an example) received at Jammu on June 5 1997 at 22 12 IST which are analysed in this paper alongwith other whistler events Whistlers numbered 1–7 in Table 1 are marked by A, B C, D, E, F and G

whistler data were stored in analog form on magnetic tapes, which were analyzed using a digital sonograph having variable frequency range from 100 Hz to 40 kHz During the span of seven years of recording periods, we could observe several hundreds of whistlers during night hours The dates and times of 22 short whistlers recorded at Jammu, which we used in the present study are shown in Table 1 Short whistlers are analyzed using matched filtering and parameter estimation technique [21 22,24,25] and various magnetospheric parameters are derived The results are also shown in Table 1

3 Results and discussions

Dispersion values of analyzed whistlers reported in Table 1 lies between 11 9 and 88 9 $s^{1/2}$ whereas the corresponding L-value lies between 1 6 and 4 4 This shows that the reported whistlers belong to mid latitude phenomena From Table 1, we find discrepancy between the dispersion of whistler waves and corresponding derived L-value [23] The L-value of the Jammu station is 1.17. Therefore, the derived L-value greater than 1 2 implies that the waves may have propagated along higher L-value, and after exiting form the duct, might have penetrated the ionosphere and were trapped in the earth-ionosphere wave guide. The wave-normal at the entrance into the wave guide was such that they propagated towards the equator and were received at low-latitude station Jammu [26,8]. Some of the whistlers for which the L-value and dispersion do not match, may have leaked from the duct in the magnetosphere and followed another path in the magnetosphere and propagated to the recording station It clearly shows

The variation of total electron content in a flux tube (NT) with L-value derived from whistler data of Jammu, Varanasi, Tihany and Siple is presented in Figure 3 I is clearly seen that the total electron content derived from the data of Varanasi and Jammu is lower than those of Tihany and Siple The four data point of Jammu show higher value and in the range of Siple data when extended to L ~ 4 4. Analyzing whistler data recorded at low latitude Indian stations, Indian Scientists [9,19,20 29 have reported that the total electron content in a flux tube $\sim 10^{13}$ electrons cm tube [1] during night times The analyses of whistlers always yield the electron density

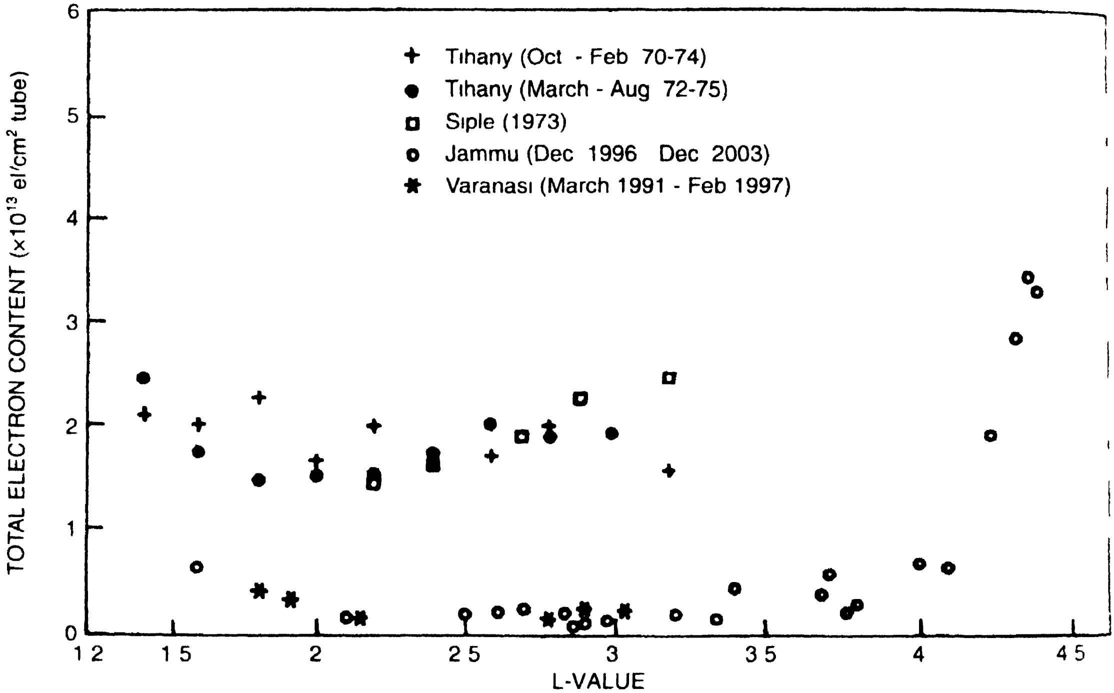

Figure 3. Variation of total electron content (electrons cm ^{2} tube ^{1}) in a flux tube with L-value

of the ducting structures At L $\geq$ 2, density enhancements of the order of 10% are sufficient to produce ducted propagation, whereas at low latitudes (L < 2) enhancement factors of $\sim$100% are required for the ducted propagation of whistlers [30,31] As the propagation at low latitudes is in the non-ducted mode, the estimation of electron density and total electron contents in a flux tube becomes erratic Because if the signals have propagated strictly along the dipolar field lines in prolongitudinal mode then the method of estimation of electron density could be used and estimated value truly represents the electron density and total electron contents along the path of propagation. The derived lower value suggests a relook in the propagation mechanism of whistler mode signals, which has been suggested by others [27,23]. Ferencz *et al* [27] have analyzed a large number of whistlers recorded at mid latitude station Bornholm Island and showed that there was mismatch in the L-value of recording and derived L-value from the analysis of whistlers using Match Filtering and Parameter Estimation Technique (MFPE) which is also used in the present analysis However, they have not estimated electron density Singh *et al*, [23] have analyzed whistlers recorded at Jammu using Match Filtering and Parameter Estimation Technique (MFPE) and have discussed only discrepancy in L-value and dispersion values

4 Conclusion

In the present paper we have derived the electron density distribution and total electron content in the flux tube using Match Filtering and Parameter Estimation Technique (MFPE) and found that these parameters are about one order of magnitude smaller than those derived from the whistlers recorded at mid and high latitudes This shows that the analysis method is based on field aligned propagation is not capable to depict correct picture of VLF propagation at low latitudes Therefore, a proper analysis method should be developed Further, the propagation mechanism of whistler mode signals at low latitudes should be studied in detail including the effect of inhomogeneity in the medium parameters and the curvature in the geomagnetic field lines

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