Indian J. Phys. 64B (1), 34-41 (1990)

An analysis of low latitude whistlers observed at Nainital

P N Khosa, Lalmani and K Kishen
Department of Physics, Regional Engineering College,
Hazratbal, Srinagar, Kashmir-190 006, India

Received 22 December 1988, accepted 25 January 1989

Abstract : Analysis of low latitude whistlers observed at low-latitude ground station Nainital (geomagnetic lat., 19° 1'N) with unknown nose frequency and causative sferic is presented. The method used in the present paper permits an accurate estimation of errors. Our results on the equatorial electron density (n_e) and tube content (N_T) are based on the analysis of more than 100 observed whistlers. Further the ionosphere-plasmasphere coupling fluxes are determined which are found to be in good agreement with those reported by other workers.

Keywords : Whistlers, causative sferic, nose frequency, ionosphere, plasmasphere, electron density.

PACS No : 94.30.

1. Introduction

Since the pioneering work of Storey (1953), the observation and analysis of whistlers have been pursued throughout the globe over a wide range from high to low latitudes (Allcock 1960, Helliwell 1965, Iwai and Ohtsu 1967, Somayajulu *et al* 1972, Cerisier 1973, Singh *et al* 1977, Hayakawa and Tanaka 1978, Carpenter 1983, Khosa *et al* 1981, Wang and Wang 1984, Ondoh *et al* 1979, Boskova *et al* 1984). Over the last decade, whistlers have become a very important tool for studying the morphology and dynamics of the plasmasphere, the magnetospheric electric fields and ionosphere-plasmasphere coupling fluxes (Carpenter 1966, Carpenter *et al* 1972, Park 1970, Mathur and Rycroft 1972). At low latitudes one of the main problems in whistler analysis faced by workers is to obtain the nose frequency (f_n) and nose time delay (t_n) with a reasonable degree of precision. This is due to the fact that the whistler spectrograms do not exhibit the portion of the whistler near the nose frequency at low latitudes. In the recent past however, different methods have been proposed to obtain the nose frequency in the case of such whistlers (Smith 1961, Dowden and Allcock 1971, Corcuff and Corcuff 1973, Bernard 1973, Ho and Bernard 1973). Recently, another method for determining the nose frequency of whistlers recorded at low latitudes based on Bernard's approximations has been developed by Tarcsai (1975). This method involves the determination of the parameters in Bernard's (1973) approximation and of a further parameter locating the causative sferic by a least-square curve fitting procedure developed by Tarcsai (1975). We should be using this method for the analysis of whistlers recorded at our low latitude ground station Nainital. In what follows, we first present a brief outline of the Tarcsai (1975) method used in the present analysis. This is followed by a presentation of whistler data recorded at Nainital. Finally, the results are discussed and compared with those reported by others.

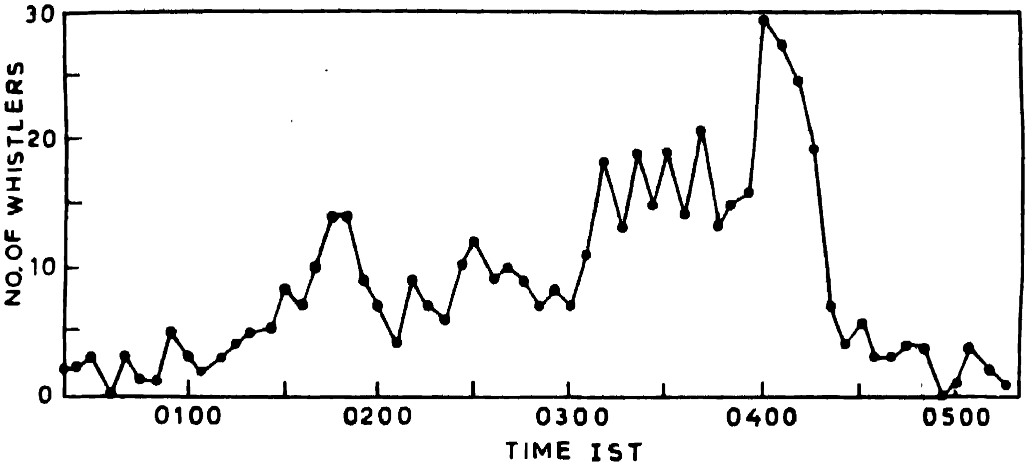

Figure 1. Showing the variation of whistler occurrence rate at Nainital on 25th March 1971. The ordinate indicates number of whistlers heard over 5 min. intervals.

Using the computer program of Tarcsai (1975) we have so far analysed about 800 whistlers traces, out of which the results for about 100 whistlers are discussed here. It is to be emphasized that contrary to other studies, the results to be presented here refer to routine analysis of non-nose whistlers with known causative sferic observed at our low latitude ground station Nainital. There are no experimental observations of the interchange of ionization between ionosphere and protonosphere reported from whistler studies at low latitudes. However, our results show that there is an average night time downward flux of 2.9×10^8 electrons/cm^2 sec. between 0020 IST to 0520 IST on 25 March 1971.

2. Brief outline of the parameters involved in curve fitting method

The approximate expression proposed by Bernard (1973) and used by Tarcsai (1975) for obtaining the dispersion of ducted whistlers can be written as

$$D(f)=t(f)\sqrt{f}=D_c\,\frac{f_{HE}-Af}{f_{HE}-f} \qquad (1)$$

where

$$\Lambda=\frac{3\Lambda_n-1}{\Lambda_n(1+\Lambda_n)} \text{ and } \Lambda_n=\frac{f_n}{f_{HE}} \tag{2}$$

In the above expressions D_0 is zero dispersion, f is the wave frequency, f_{HE} represents equatorial electron gyrofrequency, $t(f)$ is the travel time at frequency f. Combining eqs. (1) and (2), the travel time at nose frequency is calculated as

$$t_n=\frac{D_0}{\sqrt{f_n}}\frac{2}{1+\Lambda_n} \tag{3}$$

It is necessary to introduce a new parameter T which gives the difference in time between the chosen origin and the actual causative sferic. The measured travel time t^* can be written as :

$$t^*(f)=t(f)-T=\frac{D_0}{\sqrt{f}}\frac{f_{HE}-\Lambda f}{f_{HE}-f}-T \tag{4}$$

There are four unknown parameters : D_0, f_{HE}, T and Λ (or f_n) in eq. (4). Following Tarcsai (1975) we shall search for those values of D_0, f_{HE} and T which give a close fit to the measurements in a least square sense i.e. which minimize the sum of the weighted squares of the residuals

$$M=\sum_{k=1}^{n} W_k(t^*_{mk}-t^*_{ck}(D_0, f_{HE}, T))^2 \tag{5}$$

where the subscripts m and c refer to the measured and computed t^* values respectively, W_k are the weights given to the individual measurements, and the summation is to be taken over the points of the whistler trace scaled at frequence f_k. The values of D_0 and f_{HE} (or f_n and t_n), obtained from the curve fitting method are used by us, following the procedure suggested by Tarcsai (1975). Further, the expressions used for computing the electron density at geomagnetic equator (n_e) and tube electron content (N_T) after Park (1972) are written as :

$$L=(8.736\times 10^5 f_{HE}^{-1})^{1/3} \text{ (where } f_{HE} \text{ in Hz)} \tag{6}$$

$$\eta_e=K_e f_n t_n^2 L^{-5}=K'_e D_0 f_{HE}^{5/3} \tag{7}$$

$$N_T=K_T f_n t_n^2 L^{-1}=K'_T D_0^2 f_{HE}^{1/3} \tag{8}$$

where the quasi-constants K'_e, K'_T are weakly dependent of f_n and Λ_n.

3. Data selection and analysis

The whistlers used in this study have been recorded at the U. P. State Observatory, Nainital (geomag. lat. 19°1′N, $L=1.16$), India.

The whistlers recorded at Nainital were of very high quality, and the number of whistlers recorded during magnetic storms was always large enough to be of statistical significance. During the period under report, the whistler data was characterized by a consistently good whistler intensity with well defined components. On 25th March 1971, whistlers in great numbers (Figure 1) were observed at our field station, Nainital. The spurt in activity started around 0020 IST and lasted for about 5 hours, ending finally at day break 0520 IST. During this period, the K_p index varied between 2 and 5. The mere occurrence rate itself was interesting and altogether several hundred whistlers were recorded. The whistler traces were manually scaled from sonograms (Kay-Electric Sonograph) between 0-8 KHz in steps of 0.3 KHz. Thus, we obtained 20 points per trace on the average. The mean frequency of the scaled traces was about 4.7 KHz. The measured travel times and the other data (e.g. f_0F_2 values for ionospheric correction) have been stored on magnetic tapes together with the results obtained.

4. Results and discussion

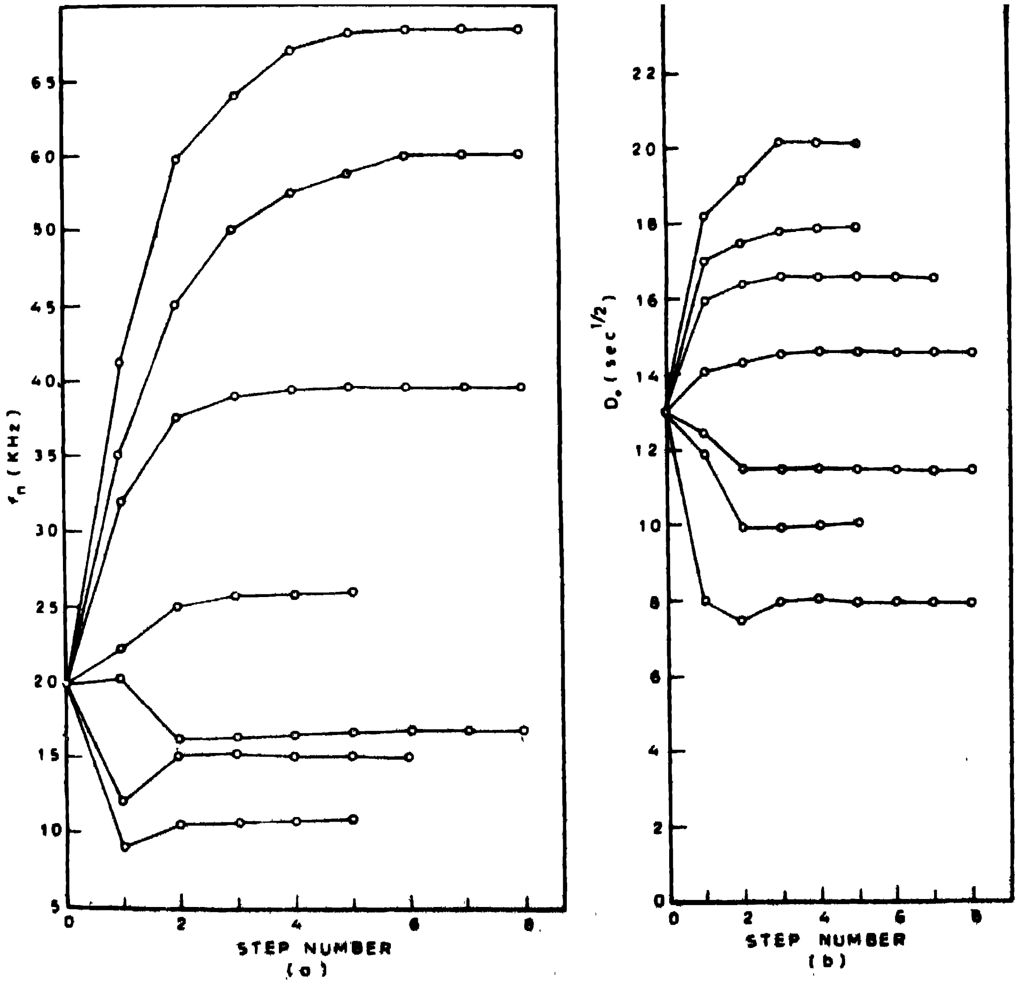

Figure 2:(a, b). Showing the convergence of f_n and D_0 as function of the step number, for seven typical whistlers.

The starting values of the parameters D_0, f_{HE}, T and f_n used in our computation have to be rapidly convergent. In the iteration procedure, these values were determined from the extended Q-method (Dowden and Allcock 1971) as pointed out by Tarcsai (1975). We show in Figures 2(a, b) the convergence of f_n and D_0 as function of the step number for seven typical whistlers, the average number of iteration steps was about eight. The ratio of the corrections obtained in

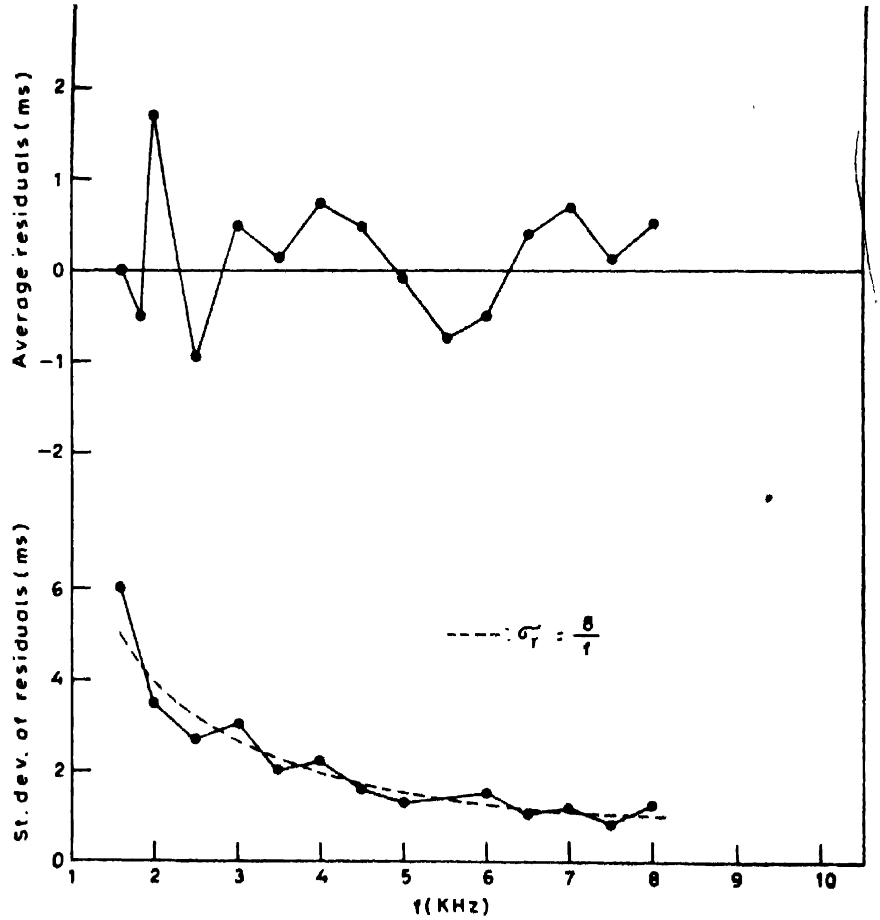

Figure 3. Showing average residuals in travel times for 50 whistlers analysed with the FIT method, and the standard deviations of residuals, plotted vs frequency.

successive steps was generally much less than 1/2 at the last 3-4 steps. This clearly indicates that the iteration procedure consisting of finite number of steps, approximated the limiting (true) values of D^0, f_{HE}, f_n (and f_n) to an accuracy of better than 0.2%. This accuracy is quite satisfactory but can be increased further if needed. For parameter *T*, the accuracy of iteration is generally better than 0.1 m sec.

We have performed the analysis of residuals by computing the averages and standard deviations of travel time residuals at different frequencies of the analysed whistlers to study the closeness of curve fitting and the average measurements errors. The average residuals for whistlers analysed with accurate curve fitting method (without weighting) is shown in the upper part of Figure 3. It is clear that the accurate curve fitting method provides the close values of the parameters of the measured whistlers. The average residuals are having absolute values of

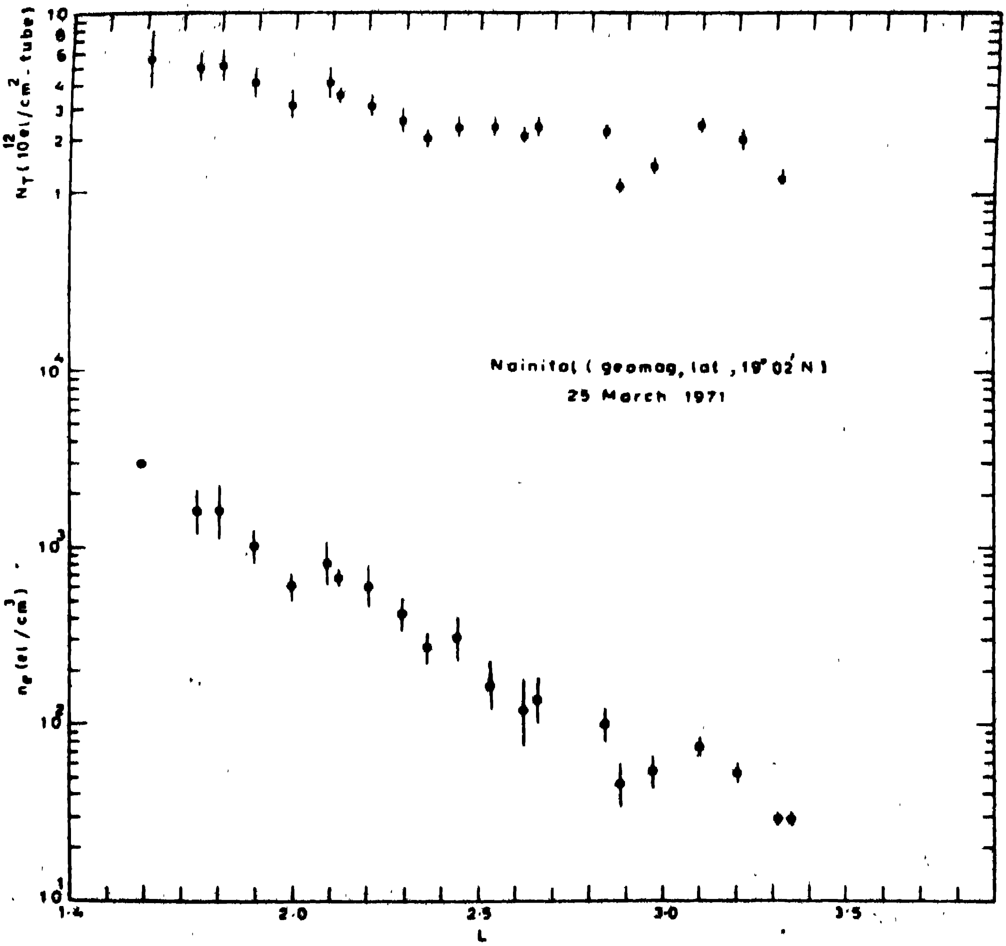

Figure 4. An example for measured n_e and N_T profiles, the error bars indicate one sigma error limits.

6

less than 2 m sec and within their three sigma error limits all of them are nearly equal to zero. A systematic pattern is exhibited around zero so far as the distribution of the residuals is concerned which could be due to the approximate character of the eq. (1). The lower part of Figure 3 depicts the standard deviation of the residuals at different frequencies. The expression $\sigma_{\tau}(f)=\frac{8}{f}$ (dashed curve) could be employed to set the reasonably approximate values of $\sigma_{\tau}(f)$.

In Figure 4, we present N_T and η_e vs L profiles measured on 25 March 1971. The error-limits represent one sigma deviations. The day 25th March 1971 was magnetically disturbed while 24th March was magnetically quiet. During the five hours period on 25th March 1971, the K_p index varied between 2 and 5. If the changes of tube content were entirely attributed to ionosphere-plasmasphere coupling fluxes, then our measurements demonstrate an average downward flux of 2.9×10^8 electrons/cm^2 sec between 0020 IST, and 0520 IST 25 March 1971. These fluxes during magnetic storm across the 1000 km level are in good agreement, observed mainly at higher latitudes (Park 1970, Chappell *et al* 1970).

5. Conclusion

It can be concluded that the method used in the present study is applicable to the reliable, routine analysis of whistlers at low latitudes with unknown nose frequency. The method permits an accurate estimation of errors. Further, the results for some whistlers showed that the equatorial electron density and the tube content can be determined to the greatest accuracy.

Acknowledgments

The authors are grateful to the Principal, Regional Engineering College, Srinagar, for his constant encouragement and keen interest in this work. The authors are also thankful to Dr S S Agarwal, CEERI, Extension Centre, New Delhi, for providing computer and sonograph facilities.

References

Allcock G M 1960 *IGY Whistler results report to URSI 13th general assembly Commission, London* **4**

Bernard L C 1973 *J. Atmos. Terr. Phys.* **35** 871

Boskova J, Jiricek F and Trisha P 1984 *Proc. Conf. Achievements of the IMS.* 217

Carpenter D L 1966 *J. Geophys. Res.* **71** 693

——1983 *Science* **18** 917

Carpenter D L, Stone K, Siren J C and Crystal T L 1972 *J. Geophys. Res.* **77** 2819

Cerisier J C 1973 *J. Atmos. Terr. Phys.* **35** 77

Chappell C R, Harris K K and Sharp G W 1970 *J. Geophys. Res.* **75** 50

Corcuff P and Corcuff Y 1973*Sol. Am. Geophys.* **29** 273

Dowden R L and Allcock G M 1971 *J. Atmos. Terr. Phys.* **33** 1125

Hayakawa M and Tanaka Y 1978 *Rev. Geophys. Space Science* **16** 111

Helliwell R A 1965 *Whistlers and Related ionospheric Phenomena* (Standford : Standford Press, California)

Ho D and Bernard L C 1973 *J. Atmos. Terr. Phys.* **35** 881

Iwai A and Ohtsu J 1967 *Proc. Res. Inst. Atmos. Nagoya University* **14** 14

Khosa P N, Lalmani, Rausaria R R and Ahmad M M 1981 *Indian J. Radio and Space Phys.* **10** 209

Mathur A and Rycroft M J 1972 *J. Geophys. Res.* **77** 1982

Ondoh T, Kotaki M, Murakami J, Watanebe S and Nakamura Y 1979 *J. Geophys. Res.* **84** 2097

Park C G 1970 *J. Geophys. Res.* **75** 4249

——1972 *Radio Science Lab. Tech. Rept. Standford Electronics Lab.* (Standford University) 3454

Singh R N, Lalmani and Singh R P 1977 *Nature Phys. Sci.* **266** 40

Smith R L 1961 *J. Geophys.* **66** 3709

Somayajulu V V, Rao M and Tantry B A P 1972 *J. Radio Space. Phys.* **1** 102

Storey L R O 1953 *Phil. Trans. Roy. Soc. London* **A246** 113

Tarcsai Gy 1975 *J. Atmos. Terr. Phys.* **37** 1447

Wang S and Wang Y 1984 *Proc. Conf. of the IMS 26-28 June, 1984*