WHISTLER OBSERVATIONS OF THE QUIET TIME PLASMASPHERE–IONOSPHERE COUPLING FLUXES AT LOW LATITUDE

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Abstract. Observations of whistlers during quiet times made at low-latitude ground station Nainital (geomag. lat. $19^\circ 1' $ N) are used to deduce plasmasphere–ionosphere coupling fluxes. The whistler data from 3 magnetically quiet days are presented that show a smooth decrease in dispersion with time. This decrease in dispersion is interpreted in terms of a corresponding decrease in electron content of tubes of ionization. The electron densities, electron tube contents (10^{16} el/m^2-tube) and coupling fluxes (10 el m^{-1} s^{-2}) are computed by means of an accurate curve fitting method developed by Tarcsai (1975) and are in good agreement with the results reported by other workers.

Key words: atmospheric plasma, ionosphere

1. Introduction

The usefulness and various advantages of the whistler method of determining electron density in the magnetosphere are well documented in the literature (Carpenter and Smith, 1964, Helliwell, 1965; Park, 1970; Corcuff, 1975; Sazhin *et al.*, 1992). The technique has been applied successfully to many problems in magnetospheric plasma structure and dynamics, plasmasphere – ionosphere coupling, plasmaspheric electric fields etc. Plasmasphere–ionosphere coupling fluxes play an important role in the large scale behaviour of the inner magnetosphere. Plasma flows between the ionosphere and plasmasphere are of importance as most of the ionization in the plasmasphere originates in the ionosphere, whilst downward flows of plasma may contribute to the maintenance of the nocturnal ionosphere (Bailey *et al.*, 1987). Considering the interchange of cold plasma between the ionosphere and the plasmasphere the experiments seem to lag behind theory and model computations. Coupling fluxes have mainly been inferred from incoherent scatter observations (Evans, 1975), topside soundings and satellite beacon measurements (Poulter *et al.*, 1981a,b). Whistlers represent an inexpensive and effective method for obtaining coupling electron fluxes, but the experimental results published upto now refer mainly to higher latitudes (Park, 1970; Tarcsai, 1975; Andrews *et al.*, 1978; Andrews, 1980; Saxton and Smith, 1989).

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In this paper, an attempt has been made to determine the equatorial electron density, total electron content in a flux tube and coupling fiuxes using whistlers recorded at low-latitude station Nainital during quiet days. The specific problem dealt with in this paper may be described as follows.

The Whistlers in great numbers were observed at Nainital (geomag. lat., 19°1′ N; L = 1.12) under quiet magnetic conditions on March 7, April 18 and 19, 1971. The data contains a continuous 24 h set of whistlers and showed a smooth decrease in dispersion with time. This decrease in dispersion is interpreted in terms of a corresponding decrease in the electron content of tubes of ionization. At low latitudes the main difficulty in whistler analysis is to obtain the nose frequency (f_n) and nose time delay (t_n) with a reasonable degree of precision. This is because of the fact that the whistler spectrograms do not exhibit the portion of the whistler near nose frequency at our low latitudes. Such a nose frequency will have to be inferred by extrapolation techniques. For the analysis of non-nose whistlers, a number of methods have been proposed (Smith and Carpenter, 1961; Dowden and Allcock, 1971; Ho and Bernard, 1973; Bernard, 1973; Rycroft and Mathur, 1973; Tarcsai, 1975). The nose frequency of the whistler data used in estimating equatorial electron density n_{eq}, electron tube content N_T and coupling fluxes has been computed by means of accurate curve fitting method developed by Tarcsai (1975) based on the least squares estimation of the two parameters, zero frequency dispersion D_0, equatorial electron gyrofrequency f_{He} in Bernard's approximation. Although this method gives good results at mid-latitudes, its validity at low-latitudes may be questioned. In this method diffusive equilibrium model (DE-1) has been used (Park, 1972). At low L-values the curve fitting method of Tarcsai (1975) would not change too much the equatorial electron density and total electron content N_T values compared to the systematic errors which are inherent in all of the existing nose extension methods. These systematic errors originate from the approximations used for the refractive index and for the ray path in the derivation of the analytic expressions for the dispersion and from the difference between the theoretical and actual distribution plasma along the field lines. Therefore, the systematic errors in the results of analysed whistlers will have different magnitudes depending mainly on the L-value and the actual plasma distribution (Tarcsai, 1981; Tarcsai *et al.*, 1989). To examine its validity, we analysed few whistlers recorded at Nainital using this method and Dowden-Allcock linear Q-technique (Dowden and Allcock, 1971). Both methods yielded results within ±10%. Further it is to be noted that the Tarcsai's method has successfully been used in the analysis of low-latitude whistlers (Lalmani *et al.*, 1992).

The whistler traces were processed by a reliable curve fitting technique (Tarcsai, 1975) for the estimation of equatorial electron density n_{eq}, electron tube content N_T and coupling fluxes. In the determination of electron density, electron tube contents and coupling fluxes from whistler data, it is assumed that the whistlers have propagated along geomagnetic field lines. This hypothesis at low latitudes particularly due to inhomogeneities of electron density over most of the whistler path has been discussed in detail by Singh *et al.* (1993).

In the following we first present the whistler data used for the analysis recorded at Nainital during quiet periods. This is followed by a presentation of an outline of the method developed by Tarcsai (1975) from which tube flux content N_T (defined as the number of electrons in a geomagnetic flux tube of 1 cm^2 cross sectional area at 1000 km altitude and extending to magnetic equator) and electron density are evaluated. Finally the results are discussed and compared with those reported by other workers.

2. Data Selection and Method of Analysis

A geomagnetically quiet period was chosen for this study, with the aim of determining the quiet day behaviour of coupling fluxes; this could then be used as a reference for the study of a more disturbed time at low latitudes. At low latitudes, the whistler occurrence rate is low and sporadic. But once it occurs, its rate of occurrence becomes comparable to that of mid-latitudes (Hayakawa *et al.*, 1988). Similar behaviour has also been observed at our low-latitude Indian station Nainital. For the present study, we have chosen whistlers recorded during quiet periods at our low-latitude ground station Nainital (geomag. lat., $19^\circ 1'$ N) because a large number of whistlers was observed. The whistler data chosen correspond to March 7, April 18 and 19, 1971. Altogether more than a hundred whistlers were recorded at Nainital during quiet periods of March 7, April 18 and 19, 1971 which clearly show a smooth decrease in dispersion. The variation of dispersion with local time is shown in Figure 1. About 100 whistlers were chosen for the present analysis. The whistler data are available in the form of sonograms in the frequency range of 0–8 KHz, which show the variation of frequency with time.

On March 7, 1971, a significant number of whistlers were recorded at our low latitude ground station Nainital ($19^\circ 01'$ N; $149^\circ 45'$ E). The whistler activity started at about 0100 IST and showed a drift from 0122 to 0321 IST. The observed whistlers show a smooth decrease in dispersion. On this day the period was magnetically quiet with total K_p index 8 (average $K_p \sim 1$). On April 18, 1971, the whistler ducts showed no drift until about 2215 IST and the spurt in activity started around 2210 IST ending finally at 2344 IST. The day was magnetically quiet with K_p index 19^- (average $K_p \sim 1$) and whistler duct showed an inward drift from 2215 to 2344 IST. The observed whistlers show a smooth decrease in dispersion. On April 19, 1971, the spurt in activity started around 0100 IST ending finally at 0331 IST. The day was observed magnetically quiet with total K_p index 15 (average $K_p \sim 1$). The observed whistlers show a smooth decrease in dispersion as shown in Figure 1.

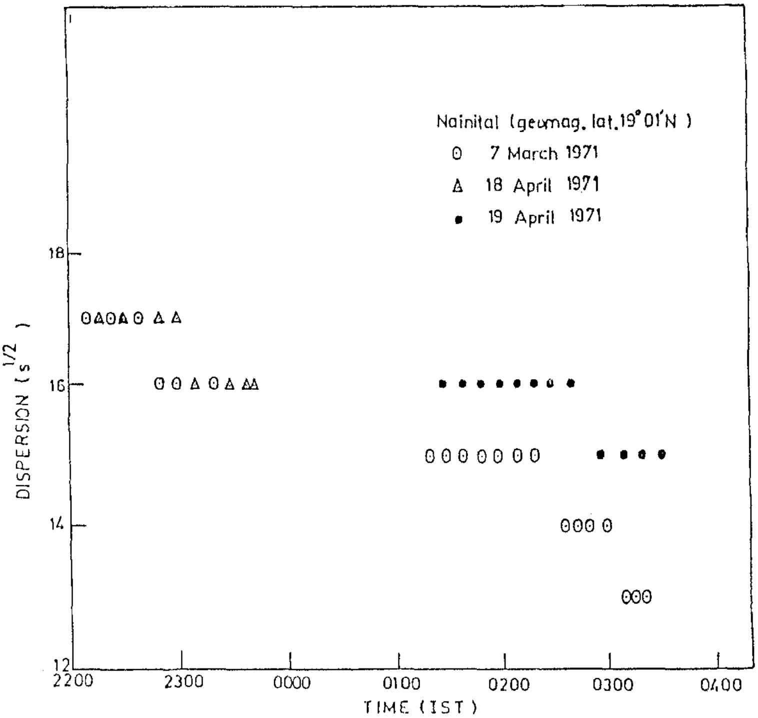

Figure 1. Variation of whistler dispersion with time recorded at Nainital during quiet periods.

The whistlers are known to propagate along geomagnetic field lines in ducted mode. The dispersion function under suitable approximation is written as (Bernard, 1973)

$$D(f) = t(f)\sqrt{f} = D_0(f_{He} - Af)/(f_{He} - f). \tag{1}$$

Where D_0 is zero-frequency dispersion, f_{He} is equatorial electron gyrofrequency, $t(f)$ travel time at frequency f, and

$$A = \frac{3\Lambda_n - 1}{\Lambda_n(1 + \Lambda_n)}, \quad \Lambda_n = \frac{f_n}{f_{He}} \tag{2}$$

f_n is the nose frequency for which travel time t_n is written as

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

Sometimes the causative atmospherics is not known. In such cases the travel time is measured from a chosen origin and a correction parameter T is introduced (which gives the time difference between the chosen origin and the actual sferic). Using Equation (1) and (2), the measured travel time $t^*(f)$ is written as

$$t^*(f) = t(f) - T = \frac{D_0}{\sqrt{f}} \frac{f_{He}}{f_n} \frac{f_n(f_{He} + f_n) - f(3f_n - f_{He})}{(f_{He} - f)(f_{He} + f_n)} = T \tag{4}$$

In this equation there are four unknown parameters, D_0, f_{He}, T and f_n Tarcsai (1975) has developed a computer program to solve Equation (4) for the unknown using successive iteration method. In this method those values of D_0, f_{He}, T and f_n are searched which give best fit to the measured parameters. After Park (1972) and using Equation (3) for t_n.

$$t_n = 8.736 \times 10^5 \times f_{He}^{-1/3}, \quad \text{(where } f_{He} \text{ in Hz)}$$

$$n_{eq} = K_e f_n t_n^2 L^{-5} = K_e' D_0^2 f_{He}^{5/3} \tag{5}$$

$$N_T = K_T f_n t_n^2 L^{-1} = K_t' D_0^2 f_{He}^{1/3}$$

where the constants K_e' and K_T' are weakly dependent on f_n and f_{He}. Using Equation (5) and analysing a large number of whistlers recorded at Nainital, equatorial electron density n_{eq} and total electron content N_T in a flux tube of unit cross section has been evaluated.

3. Results and Discussion

Figure 1 shows the variation of dispersion of whistlers observed at Nainital during quiet periods with time. The dispersion smoothly decreases with the increase in time for the all three days. The decreasing dispersion with time could be due to changing magnetospheric path, or to changing electron content of a fixed tube, or due to both. The analysis of the data shows that the whistler path remained almost fixed. Thus, the decreasing dispersion with time could be attributed to changing electron contents of a fixed tube. Figure 2 shows the variation of equatorial electron density n_{eq} and electron density N at the 1000 km altitude with time. It is clearly seen that the majority of whistlers propagated in the range L = 1.6 to L = 3.3. The equatorial electron density for Nainital varies between 3×10^3 cm^{-3} and 7×10^1 cm^{-3}. The results derived from whistlers recorded at low-latitude station Nainital are in agreement with those reported by Park *et al.* (1978) and Tarcsai *et al.* (1988). Park *et al.* (1978) obtained an average density of 3×10^3 cm^{-3} at L = 2, whereas Tarcsai *et al.* (1988) has reported 2×10^4 cm^{-3} at L = 1.4 and 5×10^2 cm^{-3} at L = 3.2. Ralchovski (1976) observed night-time equatorial density 5×10^3 cm^{-3} at L = 1.6.

Figure 3 shows the half hourly median value of N_T which exhibits a systematic variation in the afternoon through morning period, with a maximum of 5.4×10^{16} el m^{-2} tube and a minimum of 1.7×10^{16} el m^{-2}-tube. The computed coupling electron fluxes (given by the rate of change of tube content N_T) are shown in Figure 3. The fluxes of about 1–3 $\times 10^{12}$ m^{-2} s^{-1} presented here may be compared with previously published work, which used whistler mode signals or the satellite beacon technique. Andrews (1980) used whistler mode signals received in

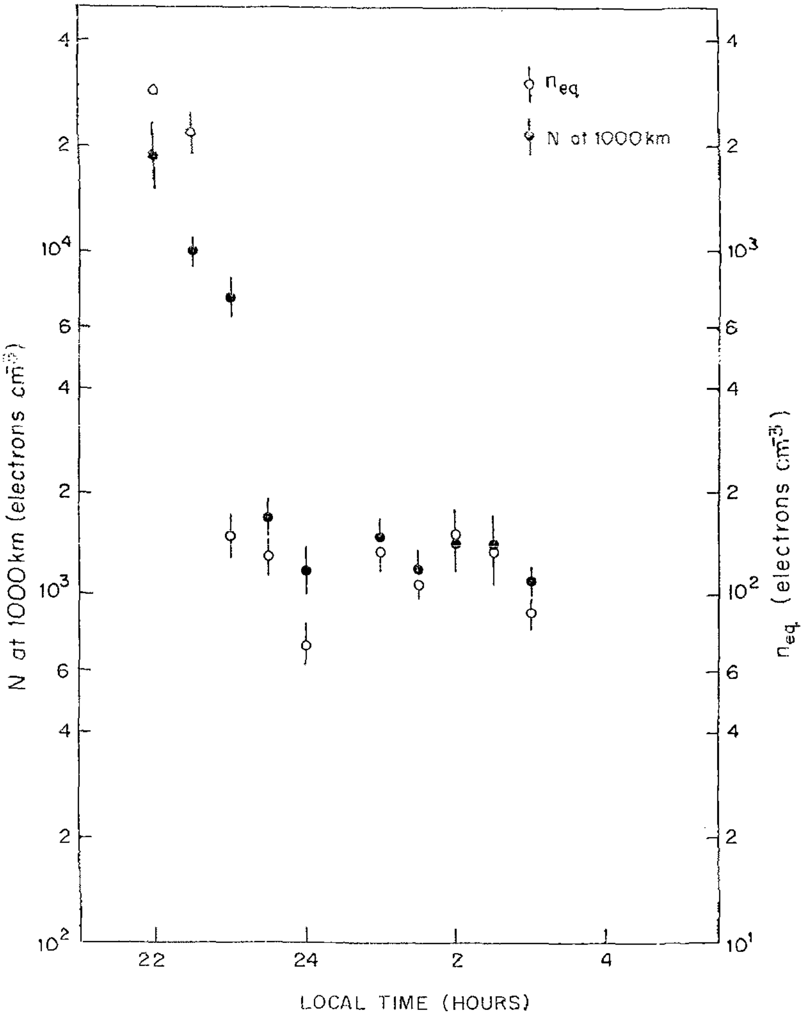

Figure 2. Variation of computed electron density N at 1000 km altitude and equatorial electron density n_{eq} with time for Nainital with error bars. Data points shown are averaged over 0.5 h.

New Zealand from the transmitter NLK in Seattle, U.S.A., to study fluxes and radial plasma drifts near $L = 2.3$; the fluxes were of magnitude 1–3 × 10^{12} m^{-2} s^{-1} and in the late evening, the fluxes were directed downwards into the ionosphere (emptying of the flux tube). Poulter *et al.* (1981a,b) used data from AST-6 satellite beacon experiment to study field-aligned plasma flows in the plasmasphere. They obtained fluxes of about 0.8–3 × 10^{12} m^{-2} s^{-1} directed downwards in the night and upwards in the day for quiet days. Recently Saxton and Smith (1989) used whistler mode signals from the VLF transmitters NAA and NSS in the Northeast U.S.A., made of Faraday, Antarctica to deduce plasmasphere–ionosphere coupling fluxes near $L = 2.5$ during quiet time. They found fluxes of magnitude 1–3 × 10^{12} m^{-2} s^{-1},

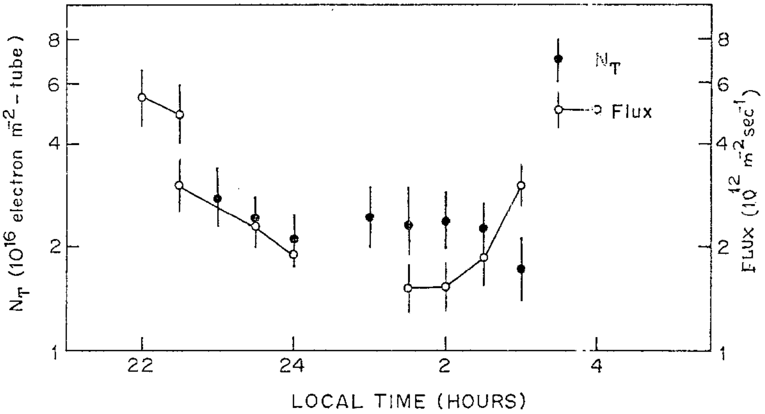

Figure 3. Variation of total electron content N_T and coupling flux with time for Nainital with error bars. Data points are averaged over 0.5 h.

in good agreement with our values. Park (1970) used whistler data near $L = 4$ to obtain rates of change of tube content he found upward fluxes in the day of about 5×10^{12} m^{-2} s^{-1} and downward fluxes in the night of 3×10^{12} m^{-2} s^{-1}. Fluxes have also been reported from incoherent scatter radar data (Vickrey *et al.*, 1979; Evans, 1975; Evans and Holt, 1978), but it is not meaningful to compare these results with ours (Saxton and Smith, 1989). Thus our results show a downward flux of ionization of the order of 1–3 × 10^{12} m^{-2} s^{-1} which is in remarkable agreement with that of Saxton and Smith (1989). It must be admitted that the present estimates for the equatorial electron density n_{eq}, tube electron content N_T and flux of ionization are not all that accurate. The main factors which render the present results inaccurate is that at low latitudes nose whistlers are not observed. Not withstanding these limitations the present exercise of studying the transport of ionization in the top-side F-region during quiet time is still worthwhile. Indeed, if simultaneous measurements of the F-region by other methods (such as incoherent scatter) are available, the present studies would have yielded much more valuable and physically significant results.

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