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Whistler evidence of downward movement of ionization at low latitudes*

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सार — निम्न अक्षांशों वाले फील्ड स्टेशन नैनीताल में शांय-शांय की आवाज करने वाली पवन (हि्वस्लर) का संपूर्ण पथ F क्षेत्र की ऊपरी सीमा के भीतर की ओर पाया गया है। नैनीताल में रात के समय में शांय-शांय करने वाली पवनों की भारी संख्या काल के साक्षेप विक्षेपण में कमी प्रकट करती है। विक्षेपण की इस कमी को आयनीकरण नलिका में विद्यमान इलेक्ट्रानों में लगातार कमी के संदर्भ में व्यक्त किया गया है। गणना के आधार पर प्राप्त परिणाम 500 कि. मी. के आधारीस्तर पर आयनीकरण के नीचे के ओर के अभिवाह को दर्शाते हैं और इनकी कोटि 2.8×10^8 इलेक्ट्रान/से. मी.^{2}/से० हैं।

यह भी दर्शाया गया है कि निचले अंक्षाशों में F क्षेत्र के शीर्ष की ओर उभय ध्रुवीय विसरण अकेला की आयनीकरण के परिवहन को स्पष्ट नहीं कर सकता, अपितु उसमें $\mathbf{E} \times \mathbf{B}$ के विचलन जैसी कुछ अन्य प्रक्रियाओं का भी महत्व है।

ABSTRACT. The entire path of whistlers observed at our low latitude field station Nainital lies well within the upper boundary of the F-region. Large number of whistlers recorded during nighttime at Nainital show a smooth decrease in dispersion with time. This decrease in dispersion is interpreted in terms of corresponding decrease in the electron content of tubes of ionization. The computed result shows a downward flux of ionization at the base level of 500 km to be in the order of 2.8×10^8 electrons/cm^2/sec.

It is also shown that the ambipolar diffusion alone cannot explain the transport of ionization in the topside F-region at low latitudes but some other processes such as $\mathbf{E} \times \mathbf{B}$ drifts are also important.

1. Introduction

One of the important problems which is engaging the attention of many investigators is the maintenance of the nocturnal F-layer. Several effects are supposed to contribute for the maintenance of the nighttime F-layer. The winds in the neutral atmosphere drive the ionization up the magnetic field lines where the loss rate of the ionization by dissociative recombination is reduced, Rishbeth (1968) postulated a nighttime production rate of 1/cm^3 /sec to contribute to the maintenance of the nighttime F-layer to go along with the critical flux (Geisler 1967) of 1.5×10^7 cm^{-2} sec^{-1}. Whatever may be the other effects, it appears that the nocturnal F-layer cannot be explained satisfactorily without invoking downward diffusion of ionization from the exosphere. A downward flux of ionization of the order of 10^8 cm^{-2} sec^{-1} appears to be sufficient for the nighttime production rate of ionization of 1 cm^{-3} sec^{-1} due to the charge exchange with hydrogen ions from the plasmasphere (Carpenter and Bowhill 1971). Park (1970) for the first time, from the detailed mid-latitude whistler study of the electron content of magnetospheric tubes of ionization reported the usual daytime flux of $\sim 3 \times 10^8$ electrons cm^{-2} sec^{-1} across 1000 km level and downward flux at night of the order of $\sim 1.5 \times 10^8$ electrons/cm^2/sec, an amount which is sufficient to maintain the nocturnal F-layer. However, there are no experimental observations of the interchange of ionization between ionosphere and protonosphere reported from the whistler studies at low latitudes. In this paper an attempt has been made to determine the downward flux of ionization from the whistlers recorded at Nainital (Geomagnetic latitude 19°1′ N).

An important feature of low latitude whistler propagation is the low value of the maximum height reached by the whistler wave in the equatorial plane. For the whistlers recorded at Nainital, the maximum equatorial height attained is approximately 760 km ($L = 1.2$), which is well within the lower boundary of the plasmasphere ($\sim$1000 km). Thus a study of whistlers observed at Nainital is likely to give information on the top of F-region of ionosphere.

2. Description of data

Generally, whistlers in large numbers are recorded during nighttime on magnetically disturbed periods at

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*This work is an extension of the study done and presented at the National Space Science Symposium, 1982 held at Bangalore in February 1982.

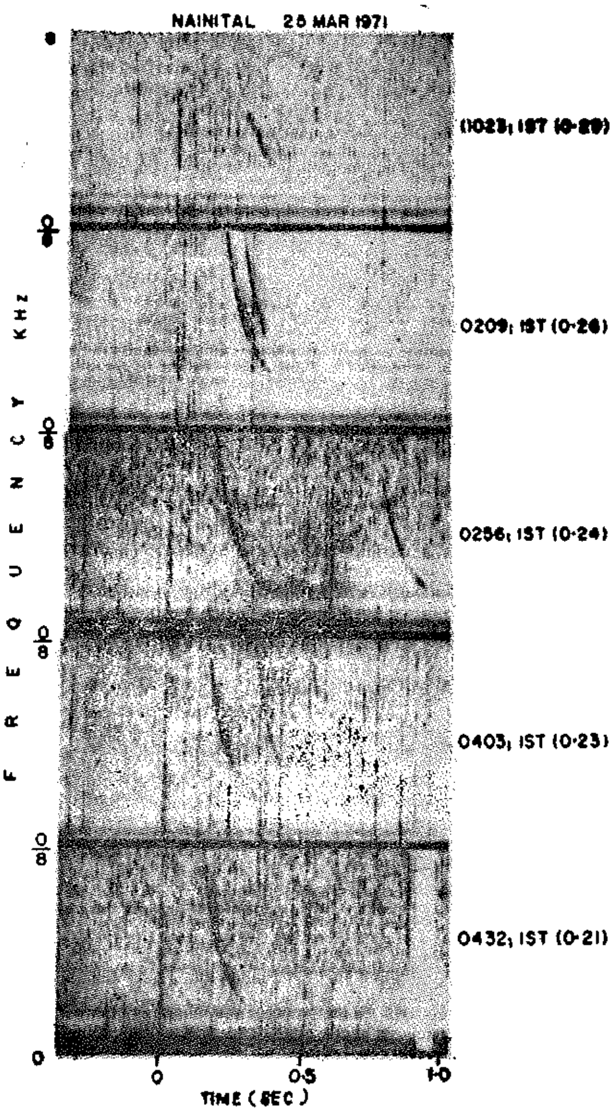

Fig. 1. Sonograms of whistlers showing the variation of dispersion with time at Nainital (Figures shown by the side of time indicate the time delay at 5 KHz)

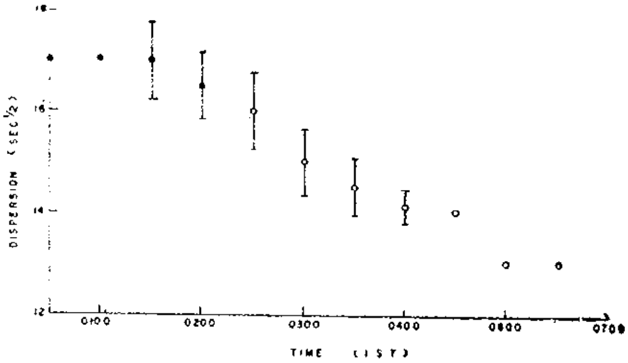

Fig. 2. Variation of dispersion with time (Nainital, 25 March 1971)

low latitudes (Somayajulu 1968; Dikshit 1973). On 25 March 1971, whistlers in great numbers were observed at our field station in Nainital. The spurt in activity started around 0020 IST and lasted for about five hours, ending finally at day break at 0520 IST. During this period, the K_p index varied between 2 and 5. The mere occurrence rate itself was interesting in the sense that it showed a feeble but clearly discernible periodicity (Rao *et al.* 1973). Altogether, several hundred whistlers were recorded. When dispersion analysis were made, a very interesting result emerged. The dispersion showed a remarkably smooth decrease within the observation period of five hours.

In Fig. 1 a sequence of five sonograms have been shown corresponding to different times of occurrence. These sonograms have been arranged in such a way that the causative sferics lie on a single vertical line. The figures shown in brackets by the side of time of occurrence, indicate the delay at 5 KHz. It is evident from Fig. 1 that the delay time at 5 KHz decreases smoothly with time from 0.29 seconds to 0.21 seconds. This, of course, corresponds to a similar decrease in dispersion. The dispersions of all the several hundreds whistlers recorded during the five-hour interval have been deduced by standard methods and the results are shown in Fig. 2. All the whistlers are grouped into half hour intervals and the mean dispersion in each group is determined. Thus Fig. 2 shows the variation in dispersion as a function of time. Each point indicates the mean value in the half hour group and the flags suggest spread in values. The maximum and minimum half hourly mean values are 17 $sec^{1/2}$ and 13 $sec^{1/2}$ respectively.

3. Calculation of tube content

The dispersion in the whistler wave is caused by the presence of ionization along the path of propagation. The ionization in the F-region and below also contributes to the observed dispersion, the magnitude of this contribution can be easily estimated from the F-region profiles (Helliwell 1965). While the lower ionospheric contribution to the whistler dispersion observed at high and middle latitudes is a small fraction of the total dispersion, at low latitude the fraction is considerably higher. Especially, for Nainital, as already mentioned, the entire dispersion is due to the ionization in the F and in the top F-regions.

The electron density has been calculated as a function of distance along the lines of force (or as a function of height) by using the well known $1/R^3$ model incorporating necessary corrections for low latitudes (Somayajulu 1968). Once the electron density is determined, the total content in a tube of force can be easily estimated. For this, the variation in the magnetic field strength along the line of force can be calculated as :

$$B(\phi) = B_0 (\cos\phi_0/\cos\phi)^6 (1+3\sin^2\phi)^{1/2} \qquad (1)$$

where B_0 is the induction at the earth's equator ($B_0 = 0.238 \times 10^4$ webers/m^2). A unit tube of flux is, by definition, that tube which encloses a flux of one weber everywhere. Thus the cross-sectional area of the tube of force varies inversely as $B(\phi)$.

To calculate the total content, the flux tube is divided into a number of elementary volumes $v_1, v_2, v_3, \ldots v_n$ and average electron densities in these elemental volumes $N_1, N_2, N_3, \ldots\ldots N_n$ are determined from the density profiles obtained earlier. Then the total content (N_T) is given by :

$$N_T = \sum_{i=1}^{n} v_i N_i \qquad (2)$$

4. Some numerical results

To calculate the tube contents at 0020 and 0500 IST from the observed dispersion of 17 sec$^{1/2}$ and 13 sec$^{1/2}$ at these times, one must first specify the altitude above which the presumed $1/R^3$ model holds. From an examination of the earlier attempts of deducing electron density distributions from the low latitude whistlers (Somayajulu 1968), it is concluded that a height of 500 km is appropriate. Below this altitude it is assmued that standard F-region profiles are valid. Thus the observed dispersion at any time can be written as :

$$D_{obs} = D_i + K \int_{\phi=0}^{\phi=10.8^\circ} \cos\phi\,(1+3\sin^2\phi)^{1/4}\, d\phi \qquad (3)$$

where $\phi = 10.8^\circ$ corresponds to a height of 500 km for the geomagnetic field line terminating at Nainital. The quantity D_i is the dispersion contributed by the ionization lying below 500 km. An approximate value of D_i can be obtained from the expression (Helliwell 1965) :

$$D_i = 2 \times \frac{f_0 F_2}{2c\,(f_H)^{1/2}} \times 150\,\pi \qquad (4)$$

where $f_0 F_2$ is the critical frequency of the F_2-region the factor 2 accounts for the double passage through the ionosphere. Eventhough the F_2-region shows considerable variation during the post night periods, it is assumed that a single value of $f_0 F_2$ is valid for the period of observations. If the value of $f_0 F_2$ is taken to be as 4 MHz, D_i comes out to be ~6 sec$^{1/2}$. It, the refore, follows that the dispersions due to the ionization above 500 km at 0020 and 0520 IST respectively are 11 sec$^{1/2}$ and 7 sec$^{1/2}$, with these values of dispersions and with the help of the Eqn. (3) of the scale factor K can be easily obtained.

Having thus determined the ionization distributions corresponding to the two times mentioned above, the tube contents are calculated. The electron contents in a tube of flux which has an area of 1 square cm, at an altitude of 500 km and which extends upto the equatorial plane are computed with the following results :

At 0020 IST : $N_T = 1.35 \times 10^{13}$ electrons/cm^2—tube

At 0520 IST : $N_T = 8.58 \times 10^{12}$ electrons/cm^2—tube

Since this change in electron content occurs within a duration of about five hours, the flux of ioniaztion is :

$$\frac{(13.5 - 8.58) \times 10^{12}}{5 \times 60 \times 60} = 2.8 \times 10^8 \text{ electrons cm}^{-2}\text{ sec}^{-1}.$$

5. Discussion of results

It is instructive to compare the above results of total electron contents and flux with those of Park (1970) whose computations refer to L-values in the range of 3.5 to 5. The total contents of tubes lying in the above range of L-values are, according to Park (1970, 1972) in the order of 10^{13} electrons/cm^2—tube. In this connection it is to be recorded that the electron tube content of Park is different from this case. His electron tube content consists of total number of electrons in a tube of force that has a cross-sectional area of 1 cm^2 at 1000 km base level and extends from 1000 km altitude to the geomagnetic equator (L~4). Since the tube of force corresponding to Nainital latitude will not reach the height of 1000 km equatorial height a tube of force with a cross-sectional area of 1 cm^2 at 500 km altitude has been considered. Thus a direct comparsion cannot be made between the electron tube contents obtained by us and with those of Park, because both the electron number density within the tube of force and its volume are significantly different in two cases. However, if we assume that there is an interchange of ionization between protonosphere and ionosphere during nighttime and if we further assume that there is a downward flux of ionization even at 500 km height, a comparison can be made between the downward flux of ionization at mid-latitude observed by Park at the base of level 1000 km and similar downward flux of ionization observed in the present study at the base level of 500 km from the low latitude whistler records.

Our result shows a downward flux of ionization in the order of 2.8×10^8 electrons cm^{-2} sec^{-1}. Though the present estimates of the flux of ionization are very crude and have several handicaps, but being the first experimental evidence the present exercise of studying the transport of ionization in the top-side F-region is well worth the trouble.

6. Ambipolar diffusion and transport of ionization

In an ordinary gas, if we create a spatial density gradient, the particles tend to flow from a region of high concentration to that of low concentration. In a plasma which contains electrons and ions, the situation is complicated. The electrons are lighter and hence tend to diffuse faster than the ions. This results in charge separation which in turn gives rise to electric fields. The direction of this field is such as to decelerate the fast moving electrons and accelerate the slow moving ions. The net result is that both the electrons and ions tend to move with the same velocity. In other words, the ionization, as a whole, moves with a single velocity. This is called ambipolar diffusion. In a magnetoplasma, diffusion across the magnetic field line is inhibited. Hence only the ambipolar diffusion along the magnetic field line is important.

It has now to be seen whether ambipolar diffusion alone can explain the observed flux of ionization at 500 km. The ambipolar diffusion coefficient D_a, the gradient of electron density ∇N and the flux of ionization **G** are related as follows (Carpenter and Bowhill 1971) :

$$\mathbf{G} = -D_a \, . \nabla N \tag{5}$$

The ambipolar diffusion coefficient D_a is approximately given by:

$$D_a \approx D_i \, (1 + T_e/T_i) \tag{6}$$

where,

D_i = Diffusion coefficient of ions = $KT_i/m_i \, \nu_{in}$

T_e = Electron temperature

T_i = Ion temperature

K = Boltzman's constant

m_i = Mass of ion

ν_{in} = Collision frequency between ions & neutral particles.

With reasonable profiles of T_e, T_i and ν_{in}, the magnitude of D_a can be evaluated easily. A representative value (Okuzawa *et al.*, 1971) of D_a at a height of 500 km is 2×10^{11} cm^2/sec. To compute **G** the magnitude of ∇N has to be known, which can be obtained from the electron density distributions derived from whistler observations. This gradient at a height of about 500 km is found to be around 2.2×10^{-4} cm^{-4}. Thus the magnitude of flux **G** comes out about 4.4×10^7 cm^{-2} sec^{-1}, which is within one order of magnitude less than the value 2.8×10^8 cm^{-2} sec^{-1} obtained earlier. This evidently shows that ambipolar diffusion alone cannot explain the observed results. This result is consistent with that of Okuzawa *et al.* (1971) who attempted to explain the duct spreading in terms of the diffusion process. It is, therefore, concluded that other transport processes such as $\mathbf{E} \times \mathbf{B}$ drifts must be operating at these altitudes. Indeed, most of the mid-latitude observations of whistlers strongly suggest that $\mathbf{E} \times \mathbf{B}$ drifts play a dominant role in the transport of ionization (Park 1970, 1971, 1972; Park and Carpenter 1970).

7. Conclusions

The contents of this paper enable us to draw the following conclusions:

(1) Under favourable conditions, low latitude whistler observations yield information on the transport of ionization in the top F-region during magnetically disturbed periods.

(2) The flux of ionization at an altitude of 500 km at low latitudes is in the same order of magnitude as that deduced for high latitudes ($L \sim 4$) at the base of the plasmasphere.

(3) Ambipolar diffusion alone cannot explain the transport of ionization in the topside F-region at low latitudes. Other processes such as $\mathbf{E} \times \mathbf{B}$ drifts are also important.

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