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Study of Electron fluxes in Ionosphere-Plasmasphere coupling from whistlers observed at low latitude ground station Jammu L= 1.17

Abstract:- The downward flux of the ionization are measured by whistlers recorded at low latitude ground station Jammu (geomag lat 22^0 26$^/$) and L= 1.17, on 5 June 1997. The whistler data shows a variation in dispersion with time. This decrease in dispersion is interpreted in terms of a corresponding decrease in the electron content of tubes of ionization and is compared with that obtained by Park (1972, Technical Report, Stanford university) for mid latitudes. By Park's (1972) expressions the equatorial electron density and electron tube content N_T values were computed. Our measurements from whistlers show an average downward flux 2.8×10^8 electrons cm^{-2} S^{-1}. The simple diffusion equation which relates the flux to the ionization gradient by the ambipolar diffusion coefficient is again computed shows that the flux computed is within an order of magnitude less than that derived from the dispersion data. It is, therefore, argued that other processes like E × B drifts should play a dominant role in controlling the transport of ionization at low latitudes.

Keywords:- flux of the ionization, equatorial electron density, electron tube content, Plasmasphere, Ionosphere, dispersion

Introduction:-

An important characteristic of low latitude whistler propagation is the low value of the max. Heights reached by the associated L-values are very low. Thus for Gulmarg L=1.2, for Nainital L=1.12 and Jammu L =1.17 . It shows that the path for whistlers observed at Jammu is within the upper boundary of the F-layer, this boundary is not well defined but is identified as the level where light ions (hydrogen, helium) becomes more numerous than the heavier ions (Chiefly oxygen). Even though, this upper boundary is found to exhibit diurnal and geographical height variations in the range of 600-2000 km (Mayer et al., 1967, Somayajulu, 1968, Brinton et al., 1969). It is fact to identify it at 1000 km, which is taken as the lower boundary of the plasmasphere. Thus, a study of whistler at Jammu gives us information about the top of the F-layer of the ionosphere.

In addition to the production and loss mechanism, the important problem is the study of the upper F-layer is the transport of ionization. In general, transport of ionization in the top side F-region may result from (1) E × B drifts (2) ambipolar diffusion along the magnetic field (3) interaction between ionization and neutral winds. The combination at the equator of (1) and (2) explains the well known anomaly called the "equatorial anomaly".

The important problem is the maintenance of the nocturnal F-layer, and several effects are supposed to contribute to this. The wind in the neutral atmosphere drive the ionization up the magnetic field lines where the loss rate of ionization by dissociative recombination is reduced (Hansen and Patterson, 1964, Park 1970, Carpenter and Bowhill, 1971, Risbeth, 1968). It is found that a night-time production rate of 1 cm-3 s-1 to contribute to the maintenance of the night-time F-layer to go along with the critical flux of 1.5× 107 cm-3 s-1 (Risbeth, 1968). It appears that the nocturnal F-layer cannot be explained satisfactorily without involving downward diffusion of ionization of the order of 108 cm-3s-1 appears to be sufficient for the night-time production rate of ionization of 1 cm-3 s-1 due to the charge exchange with H-ions from plasmasphere (Carpenter and Bowhill, 1971). In many techniques, whistler methods yield reliable data on the morphology and dynamics of the plasmasphere, on magnetospheric electric fields and on coupling fluxes between ionosphere-plasmasphere (Carpenter, 1966, Park, 1972). Mid-latitude whistler study of the electron content of magnetospheric tubes of ionization reported the upward daytime fluxes of 3× 108 electrons cm-2 s-1 across 1000km level and downward flux at night of the order of ~ 1.5 × 108 electrons cm-2 s-1, an amount is sufficient to maintain the nocturnal F-layer (Park, 1970). The propagation characteristics and association of plasma behavior of law latitude whistlers have been extensively studies by Hayakawa and Tanaka (1978). Low latitude whistlers are very useful for studying the unsolved problem in this field due to more susceptible to propagation conditions like duct excitation, ionospheric transmission etc. Hayakawa et.al (1990) on night time low latitude whistlers and their propagation mechanism, pointed out that the propagation of whistlers in the earth-ionosphere wave-guide after ionospheric transmission is more likely to be towards higher latitudes than towards the equator, and subionospheric propagation seems to exhibit a horizontal beaming around the magnetic meridian plane. These characteristics of the observation have interpreted either in terms of non-ducted or field aligned propagation and are strongly of the opinion that this is inductive of field-aligned propagation for very low latitude whistlers localized in geomagnetic latitude of 10o – 14o.

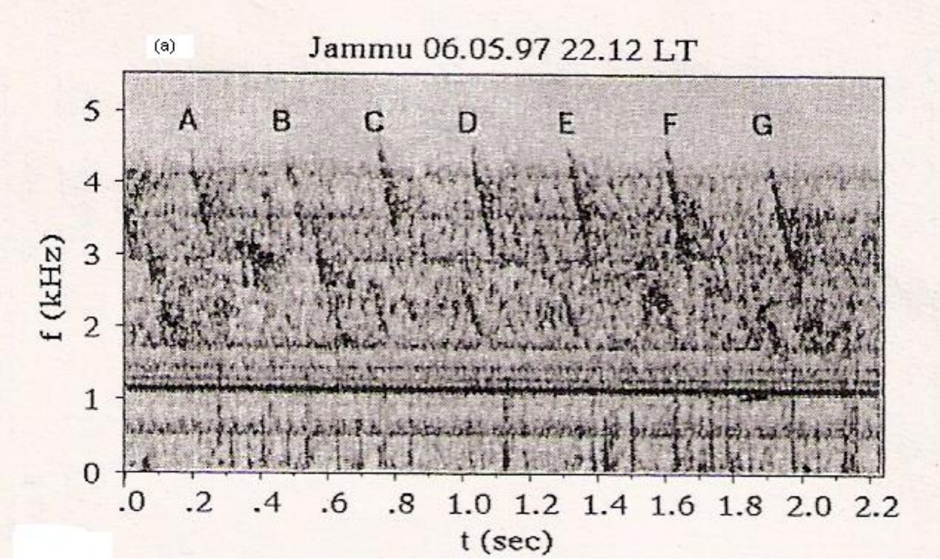
In this paper an attempt has been made to determine the downward flux of ionization from the whistler studies at low latitude. The data showed a smooth variation in dispersion with time. This variation in dispersion is interpreted in terms of a corresponding decrease in the electron content of tubes of ionization. At low latitudes the main difficulty in whistler analysis is to determine the nose frequency (fn) and nose time delay (tn) with a reasonable degree of precision.

For the analysis of non nose whistlers, the downward flux of ionization is computed by means of an accurate curve fitting method developed by Tarcsai (1975) from the whistlers recorded on 5 June 1997 at our low latitude Jammu and is compared with that obtained by Park (1972) for mid latitudes. The magnetospheric electric field along with protonosphere coupling fluxes using simultaneous phase and group path measurements on whistler mode signals (Andrews et al. 1978). The flux of ionization is computed again from the simple diffusion equation which relates the flux to ionization gradient through the ambipolar diffusion coefficient. It is shown that the flux computed is within an order of magnitude less than that derived from the dispersion data. It is argued that the E × B drifts play a very important role in controlling transport of ionization at low latitudes.

Data Selection and Method of Analysis

At low latitudes, the whistler occurrence rate is low and sporadic. But once it occurs, its occurrence rate becomes comparable to that of mid- latitudes (Hayakawa et al., 1988). Similar behavior has also been observed at our low latitude Indian stations. All the Indian stations are well equipped for measurements of VLF waves from natural sources. For the present study, the whistler data chosen corresponds to June 5, 1997 for Jammu, On 5 June 1997 at Jammu station whistler activity started around 2140 h IST (Indian Standard Time) and lasted upto 2245h IST. During this period about 100 whistlers have been recorded (Lalmani et al., 2001). Altogether more than hundred whistlers were recorded and the occurrence rate showed a feeble but discernible periodicity (Rao and Lalmani, 1975). During this period several whistlers were recorded (Singh et al., 2000).

Fig.1 (a) presents dynamic spectrum of short whistlers (marked A, B, C, D, E, F and G, selected for the analysis) in the frequency band 3-4.5 KHz recorded at Jammu at 2212 IST on June 5, 1997. In the frequency band 1.7-3 KHz large number of frequency components are missing and signals resemble more like emissions rather than whistlers. Further, VLF waves in both the frequency bands do not appear simultaneously, rather they appear alternately. Fig.1 (b) shows dynamic spectrums of short whistlers (marked 1, 2, 3 and 4, selected for the analysis) and VLF emissions recorded at Jammu at 2147 IST. Whistlers are banded and diffused in the frequency range 2.7-3.7 KHz and are repeated in time. The time interval between the 55 events is not constant. Unusual VLF noises are also seen in the spectrum.



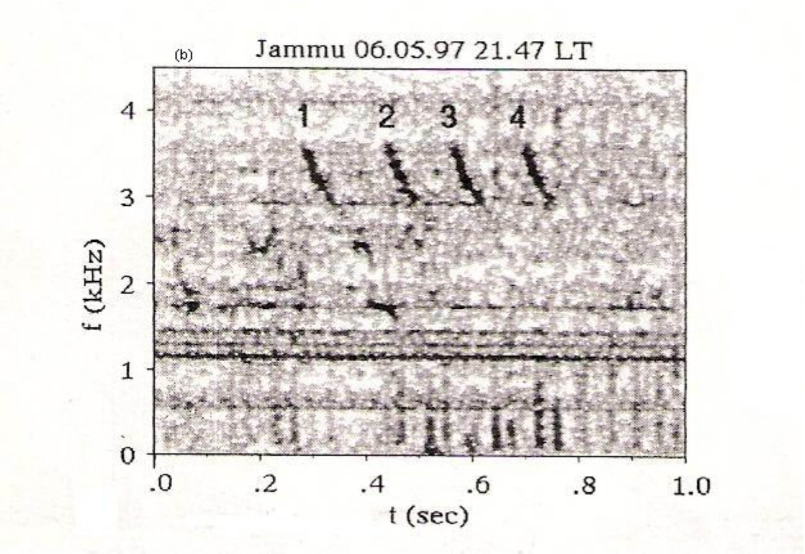


Fig. 1. (a) Dynamic spectrum of whistlers recorded at Jammu June 5, 1997. Whistlers are marked by A,B,C,D,E,F and G. (b) Dynamic spectrum of whistler recorded at Jammu June 5, 1997. Whistlers are marked by 1, 2, 3 and 4.

Tarcsai (1975) has developed a curve fitting technique for the analysis of middle and high latitude whistlers. This technique has also been applied successfully to those low latitude whistlers whose propagation path are low below L = 1.4 (Singh, 1997; Sonwalker and Inan, 1995; Ohta et al., 1996;Tarcsai, 1975). Further technique is found suitable not only for long and good quality whistlers but also for short and faint whistlers. The computer programme written for the purpose requires input data such as frequency time (f, t) values scaled at several points along whistler trace appropriate for F2, zero frequency dispersion (Do), and a suitable ionospheric model etc. The output results include the L-value of propagation, equatorial electron density, total tube content etc. we have adopted this programme for the analysis of nighttime whistlers recorded at our station Nanital, Varanasi and Jammu during quiet days.

At low L-values, the curve fitting method of Tarcsai (1975) would not change too much the equatorial electron density and total electron content 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 (Tarcsai et al., 1989). To examine its validity we analyzed few whistlers recorded at Jammu using this method as Dowden Allcock (1971) Q- technique. 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 (Singh et al., 1992).

For the determination of Do fn and tn Ho and Bernards (1973) approximate function for the dispersion of whistlers is given by (Tarcsai 1975)

$$D(f)=t(f)\,f^{1/2}=D_o\left[\frac{(f_{Heq}-Af)}{f_{Heq}-f}\right]$$

(1)

Where

D_o = zero frequency dispersion

f_{Heq} = equatorial electron gyrofrequency

f = Wave frequency

t(f) = travel time at frequency f, and

$$A=\frac{3\Lambda_n-1}{\Lambda_n(1+\Lambda_n)}$$

(2)

Here

$$\Lambda_n = \frac{f_n}{f_{Heq}}$$

Where fn is the nose frequency for which travel time tn is written as

$$t_n = \left[\frac{D_o}{f_n^{1/2}}\right]\left[\frac{2}{(1+\Lambda_n)}\right]$$

(3)

If the causative sferic is unknown, and the travel times at different frequencies of the whistler traces are measured with respect to an arbitrary time origin, then it is necessary to introduce a new parameter T, which gives the difference in time between the chosen origin and the actual causative sferic. Using T and equation (1) the measured travel time t*(f) can be written as

$$t^*(f) = t(f) - T = \frac{D_o}{\sqrt{f}}\frac{(f_{Heq}-Af)}{(f_{Heq}-f)} - T$$

$$= \left[\frac{D_o}{\sqrt{f}}\frac{f_{Heq}f_n(f_{Heq}+f_n)-f(3f_n-f_{Heq})}{f_n(f_{Heq}-f)(f_{Heq}+f_n)}\right]-T$$

(4)

In this equation there are four unknown parameters; Do, fHeq,,T and fn . In the following we proceed in two different ways; either we assume fn to be an independent parameter or we adopt a model for the electron density distribution. This helps us in reducing the number of unknowns to three. In the present study, the latter procedure is followed. Thus those values of Do fHeq, and T searched for, which fit best to the measurements in the least square sense, i.e, which minimize the sum of the weighted squares of residuals

$$M = \sum_{k=1}^{n} W_k\left[t^*_{mk} - t^*_{ck}(D_o, f_{Heq}, T)\right]^2$$

(5)

Where the subscripts m and c refer to the measured and computed t*values, respectively, wk the weights given to the individual measurements, and the summation is to be taken over the points of the whistler trace scaled at frequency fk.

As is known from the theory of least squares estimation, in a nonlinear case the determination of the parameters which correspond to the condition M= minimum, can be accomplished through linearization by expanding the residuals into a Taylor series and then using an iteration procedure (Tarcsai, 1975), we have done exactly this. Let us introduce the vector X whose components are

$$X_1 = D_o$$

$$X_2 = f_{Heq}$$

(6)

$$X_3 = T$$

Then assuming that the values of Do , fHeq and T are known at iteration (i-1), the improved solutions at the ith step can be obtained as

$$X_1 = X_{i-1} + \Delta X_1$$

(7)

Where the vector differential corrections ΔX1 is given in each step of the iteration by

$$\Delta X = A^{/}WY(A^{/}WY)^{-1}$$

(8)

In equation (8) the prime indicates matrix transposition A is then n×3 matrix of the partial derivatives of t* with respect to the unknown parameters, whose elements can be computed, using equation (4)

$$a_{kj} = \left(\frac{\partial t^*}{\partial x_j}\right)_{f=f_k}$$

(9)

W is n×n square matrix of the measurement weights, which is diagonal for uncorrected measurement errors, and Y is the column vector of residuals with elements

$$Y_k = t^*_{mk} - t^*_{ck}$$

(10)

In evaluating the matrix formula of equation (8), those values of Do ,fHeq and T are to be used, of course, which have been obtained in the previous step of the iteration. No weighting has been used in general (wkk = 1, wkj = 0, k ≠ j). The value of fn has also been improved in each step, in the following manner. According to Park (1972) for typical diffusive equilibrium model, (DE-1) of the electron density distribution, Λn can be calculated from fn as

$$\Lambda_n = (3.5475 - 0.47351F + 0.065879F^2)^{-1}$$

(11)

Where F = $\log_{10} f_n$

Also as $\Lambda_n = f_n/f_{Heq}$, we can write

$$f_{n,i+1} = \Lambda_{ni} \quad f_{Heq,i+1}$$

(12)

Where, Λni is computed from equation (11) with fni obtained in the preceding step of the iteration. Thus, for a converging, fni, the nose frequency also converges. From this it is clear that in the course of iteration the value of A is also changed successively but in general rather weakly, and it converges very fast.

The iteration procedure outlined can be stopped, if the magnitude of the corrections decreases below a certain fixed level, or the sum of weighted squares of the residuals stabilizes. After the criterion of convergence has been fulfilled, i.e., the iteration has been finished, tn can be computed from equation (3)

In order to ensure the procedure against divergence it is necessary to introduce a multiplicater m into equation (7) we have

$$X_1 = X_{i-1} + m\Delta X_1$$

(13)

Where 0 < m ≤ 1 and the actual value of m is properly varied in the course of iteration. Generally m ≤ 0.1 – 0.3 at the first two steps and it is increased to unity.

Using values of Do and fHeq (or fn and tn) obtained by the curve fitting method, we can compute the equatorial radius of the whistler duct (L) the local electron density at the geomagnetic equator (neq) and at a height of 1000km (N) ; and the tube electron content (NT). After Park (1972) and Tarcsai (1975), and using equation (3) for tn we can write

$$L = 8.735 \times 10^5 f_{Heq}^{-1/3}$$

(14)

Where f_{Heq} is in Hz

$$n_{eq} = K_e f_n t_n^2 L^{-5} = K_e^{/} D_o^2 f_{Heq}^{5/3}$$

(15)

$$N_T = K_T f_n t_n^2 L^{-1} = K_T^{/} D_o^2 f_{Heq}^{1/3}$$

(16)

$$N = K_1 f_n t_n^2 L^{-5} = K_1^{/} D_o^2 f_{Heq}^{5/3}$$

(17)

Where the constants K/e and K/T are weakly dependent on fn and Λn Tracsai (1975).

TABLE 1. Parameters of whistlers observed at Jammu ground station estimated from the whistler dispersion analysis using accurate curve fitting technique. W is the whistler number, IST is the Indian Standard Time, D_o is the dispersion of whistler, f_n is the whistler nose frequency, f_{Heq} is equatorial gyro frequency , L-value is in earths radii, n_e is the equatorial electron density.

W	Station	Dates&Year	IST	D_o (sec$^{1/2}$)	f_n (KHz)	f_{Heq} (KHz)	L Value	n_e(cm^{-3})	N_T(cm^{-2})

1	Jammu	05June 1997	21:40:25	65.5±1.0	4.2±0.03	11.37±0.07	4.25±0.01	159±3	1.9×10^{13}
2	Jammu	05June 1997	21:47:42	81.9±1.1	3.39±0.013	10.59±0.034	4.35±0.005	220±5	2.9×10^{13}
3	Jammu	05June 1997	22:47:50	88.9±1.8	3.82±0.02	10.27±0.05	4.39±0.07	247±8	1.9×10^{13}
4	Jammu	05June 1997	22:47:55	87.6±1.4	3.85±0.01	10.37±0.03	4.38±0.00	244±6	3.4×10^{13}
5	Jammu	05June 1997	22:12:20	28.8±1.2	8.15±0.72	21.98±1.95	3.41±0.10	93±6	3.3×10^{12}
6	Jammu	05June 1997	22:12:51	28.9±0.9	6.29±8.21	16.96±0.55	3.72±0.04	61±1	4.5×10^{12}
7	Jammu	05June 1997	22:13:22	35.5±1.7	6.13±0.25	16.51±0.66	3.75±0.05	88±2	4.2×10^{12}
8	Jammu	05June 1997	22:13:53	38.3±1.9	4.61±0.10	12.42±0.28	4.12±0.03	63±4	6.3×10^{12}
9	Jammu	05June 1997	22:14:24	26.1±0.6	5.76±0.13	15.53±0.35	3.83±0.02	43±4	3.3×10^{12}
10	Jammu	05June 1997	22:14:55	22.8±1.7	5.99±0.41	16.17±1.10	3.78±0.08	35±1	2.6×10^{12}
11	Jammu	05June 1997	22:15:26	38.9±1.2	5.06±0.09	13.62±0.24	4.00±0.02	76±3	7.1×10^{12}

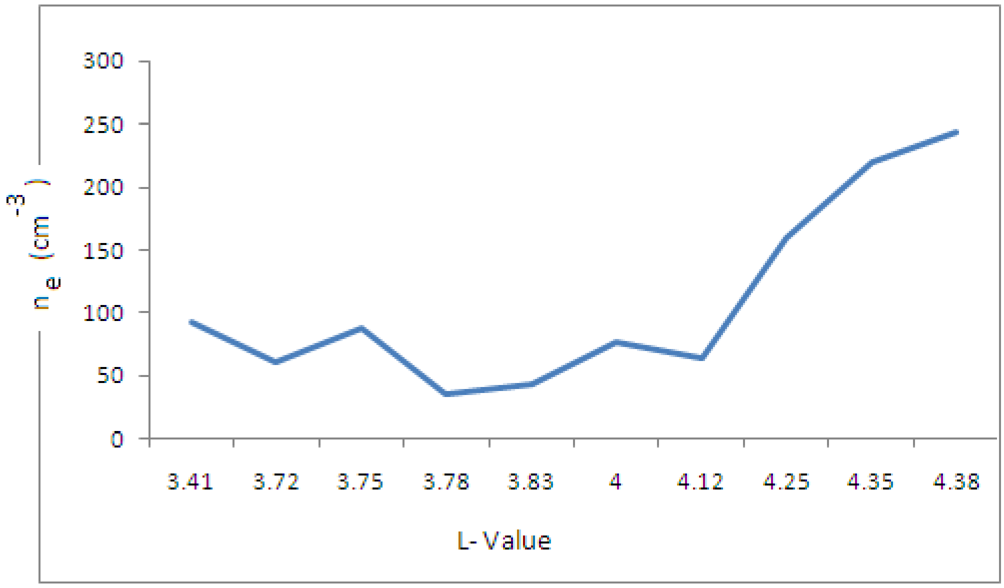


Fig. 2. Variation of equatorial electron density (ne) with L.

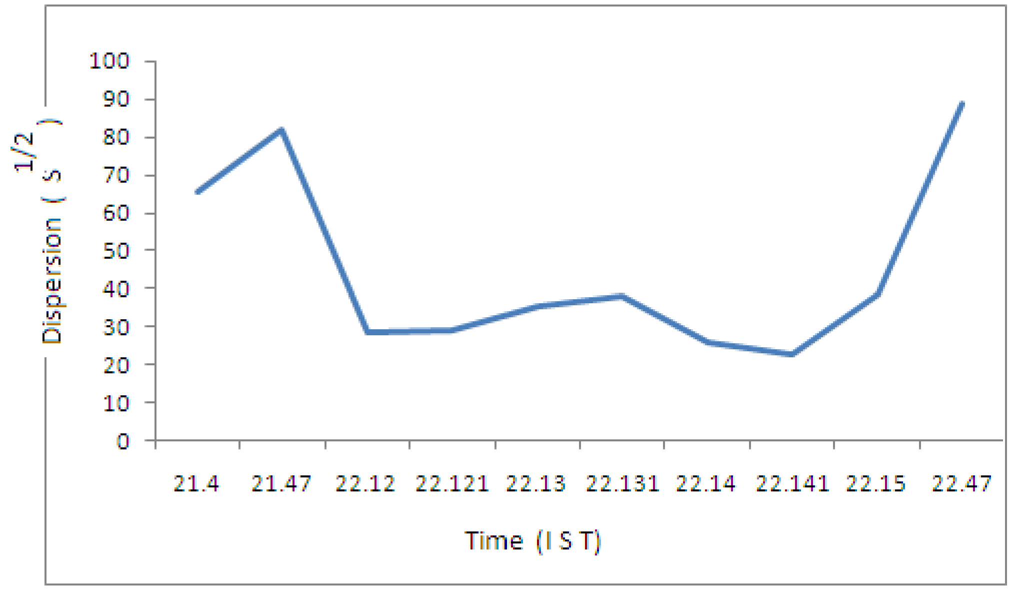


Fig.3. Variation of dispersion with time.

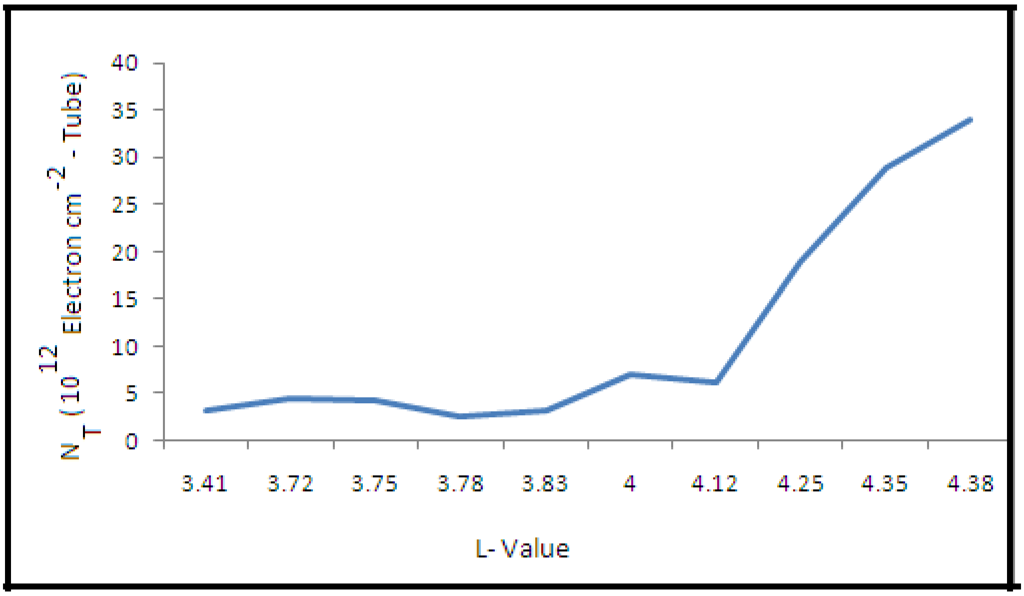


Fig. 4. Variation of Electron tube content with L- Value

Transport of Ionization and Ambipolar Diffusion:-

The observed flux of ionization at 500km can be explained by ambipolar diffusion. The ambipolar diffusion coefficient (δa) , the gradient of electron density (∇n) and the flux of ionization (F) are related by (Carpenter and Bowhill, 1971)

$$F = \delta_a \cdot \nabla n \quad (18)$$

The ambipolar diffusion coefficient δa (i.e parallel to magnetic field) is approximately given by

$$\delta_a \approx \delta_i \left(1 + \frac{T_e}{T_1}\right) \quad (19)$$

Where δa = diffusion coefficient of ions = K(Ti/mi νin), Here Te = electron Temperature, Ti = Ion temperature, K = Boltnman Constant, mi = mass of ion and νin = collision frequency between ions and neutral particles.

The value of δa can be easily calculated with the reasonable values of Te , Ti and νin. The determined value of δa at a height of 500 km is 2 × 1011 cm2 s-1 (Okuzawa et al, 1971). To compute the magnitude of ∇n which can be determined from the electron density distributions derived from whistler observatiobs. At a height of 500km this gradient is around 5.4 × 10-3 cm-3 . Thus the magnitude of flux is about 14.6 × 107 cm -2 s-1 which is within one order of magnitude less than the value of 2.8 × 108 cm-2 s-1 obtained earlier.

Discussion of Results:-

It is useful information to compare the above results of total electron content and the flux with the values of Park (1970) whose computations for the L- values between 3.5 – 5. The total electron content of tubes for the given L- values are , according to Park (1970, 1972)of the order of 1013 electrons cm-2 . Our results are shown in the Table 1. Can not make any direct camparison with Park (1970, 1972). For the L-values between 3.8 – 4.4, of our observations, the equatorial electron density (ne) and tube electron content (NT) are 2×102 electron cm -3 and 1012 - 1013 electron cm-2 – tube respectively.This eror at low latitudes as compared with high latitudes may be due to the use of the nose entension method of a non nose whistlr recorded at our low latitude station Jammu. During the night time due to interchange of ionization between the ionosphere and protonosphere and downward flux of ionization from 500 km to 1000km at mid latitude. Similar downward flux of ionization is observed by our observations recorded at low latitude station.

As per our calculations a downward flux of ionization is of the order of 2×108 electron cm-2 S-1 which is in agreement with Park (1970).The main factor which render our result inaccurate is due to the non-nose low latitude whistlers are observed. In the top-side F-region the present studying of the transport of ionization is still worthwhile. If the measurements of the F-layer by other methods similtaneously (Such as inchorent scatter) are available then our studies would have found much more valuable and physically significant results.However, the value of flux of ionization obtained by ambipolar diffusion process is 14.4×107 electron cm-2 S-1 which is less one order of magnitude than the value of 2×108 electron cm-2 S-1 .This shows that ambipolar diffusion alone can not explain the observed results. The conclusion is consistent with that of Okuzawa et. al. (1971) who attempted to explain the duct spreading in terms of the diffusion process.

However, most of the mid-latitude observations of whistlers suggest strongly that E×B drifts plays an important role in the transport of ionization (Angerami and Carpenter, 1966, Park, 1970,1972). There fore, it is concluded that the transport processes like E×B drifts must be operating at these latitudes. In terms of E×B drifts the downward movement of ionization have been interpreted and the electric fielf inferred are westward in the morning sector (Park and Meng, 1971, Altaf and Ahman, 2014). Tube content profiles undergo complex and rapid changes during the substorm (Park,1970,1971, 1972) probabily because of combination of E×B drifts and fluxes along field lines , for this a westward electric field of ~ 1mVm-1 is required. The westward electric field estimated by whistler data is about 1 mVm-1 (Misra, 1979, Altaf and Ahmad, 2014) from the radial motions of discrete field-aligned whistler ducts as indicated by changes in nose frequency (Block and Carpenter, 1974; Hayakawa and Tanaka, 1978) studied in favour of ducted propagation of low latitude whistlers on the basis of theoretical and experimental results.In the geomagnetic latitude of 10-14o Hayakawa et. al (1990) have shown that the localization of field-aligned propagation of low latitude whistlers with the help of a speed direction finding method. The computed results reported by other workers lie well within the range (Carpenter et. a., 1972, Block and Carpenter, 1974, Andrews et. al, 1978, Park, 1978) from the ground based observations, although their result refer to higher latitudes. This study shows the important relationship between vertical drifts and protonospheric fluxes and shows both are important in the night-time ionosphere. Hence, it shows that E×B drifts plays an essential role in controlling transport of ionization at low latitudes.

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