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SMART SENSING OF MAGNETOSPHERIC PLASMA BY MEANS OF WHISTLER MODE SIGNALS OBSERVED AT A LOW LATITUDE INDIAN GROUND STATION SRINAGAR

(L = 1.28)

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ABSTRACT

The dispersion analysis of the whistlers recorded at our low latitude ground station Srinagar (geomag. lat., 24^{o} $10^{/}$ N; L = 1.2) are used to derive the magnetospheric plasma parameters. The estimated parameters are in agreement with the results reported by other workers. The dispersion analysis of the whistlers recorded at Srinagar is also used to deduce information about ducts and for the determination of maximum electron density at the height of ionosphere. The maximum electron density at the height of ionosphere obtained from whistler dispersion comes out to be higher than that of the background, which is in accordance with characteristics of whistler duct. The equalvient width of the whistler duct at the maximum height of its path is found to be close to the obtained value from satellite and ground based observations. The width of ducts estimated from the diffuseness of the whistler trace observed at Srinagar is found to lie in the range of about 50-150 km.

KEYWORDS: Smart Sensing, Magnetospheric Plasma, Whistler Mode Signals Observed, Low Latitude Indian Ground Station Srinagar, (L = 1.28)

INTRODUCTION

It is well known that near - Earth environment is occupied by electromagnetic noises over a wide frequency range from DC to VHF (Hayakawa et al.2004). Noises of higher frequencies include solar radiations, galactic noise and also there is terrestrial noises generated near earth at lower frequencies. The important electromagnetic phenomena very close to us are summarized as follows:(1) electromagnetic phenomena associated with lightning discharge in the atmosphere,(2) electromagnetic phenomena in the ionosphere/magnetospheric plasma, and (3) electromagnetic phenomena originating in the lithosphere (Hayakawa et al. 2004). The first and second phenomenon which is concerned to us, are not so new and there have been many new discoveries about them at mid/high latitudes. But, in comparison to high latitudes, these phenomena at low latitudes have not been well understood. Although recent studies of VLF waves observations at low latitudes have led us to some new discoveries of whistlers and VLF/ELF emissions such as first observation of day-time Hiss triggered chorus emissions.(S. A Sheikh, et al. 2010), unexpected simultaneous observation of daytime whistlers and VLF/ELF emissions, etc. (Lalmani et al. 1999, 2000; Singh and Singh 1997; Singh et al. 1999 2004a, 2008, 2009). The return strokes of lightning generate electromagnetic waves a wide frequency range from few Hz to MHz frequencies. Under suitable conditions these waves penetrate the ionosphere & propagate along the geomagnetic field lines to the opposite hemisphere where they can be recorded by receiving systems. The waves propagating through the plasma medium is dispersed, high frequencies preceding the low frequencies, and the entire signals are called whistlers. The analysis of whistler dispersion yields information about the plasma medium parameters such as electron density, total electron content of flux tube ,electron temperature , Magnetic field & large scale convective electric field.Whistler mode waves & their interaction with energetic particle has been a subject of interest since the discovery of radiation belts.The wave particle interaction occurring in the magnetosphere generates a variety of emission in the VLF/ELF range. Although the VLF/ELF emissions of different types are often observed at different times during day & nights hours at low altitude ground station in Japan & India (Hayakawa et al.1975; Khosa et al.1981; Singh et al.1981, 1999) .We report here nighttime Whistlers recorded during magnetically quite period in our routine observation of VLF waves at Srinagar. These observed whistlers at Srinagar are used to estimate the parameter of the plasma medium such as electron density, total electron content of a flux tube, electron temperature, and large scale convective electric fields.

OBSERVATIONAL RESULTS AND DISCUSSIONS

Srinagar station is well equipped for the measurements of VLF waves from natural sources. The conventional experimental set up employed at our low latitude ground station Srinagar consists of T-type antenna, pre and main amplifiers having bandwidth of 50 Hz-15 kHz, and magnetic tape recorder. The VLF data stored in analog form on magnetic tapes are analyzed using a digital sonograph machine. .The huge amount of VLF data accumulated on magnetic tapes was analyzed. Out of this analysis we obtain a very unique & very interesting result of the occurrence of nighttime whistlers at our newly setup ground based station Srinagar on April25, 2009. One of the most interesting things is to see that almost all varieties of emission known to us are observed on this night. Figure 1 shows two examples of ducted short whistlers observed at Srinagar on April 25, 2009 during nighttime. The analyzed dispersions of whistlers W1, and W2, are 35.5 and 28.5 sec respectively. The different dispersions of the whistlers show that these whistlers have been propagated in different ducts.

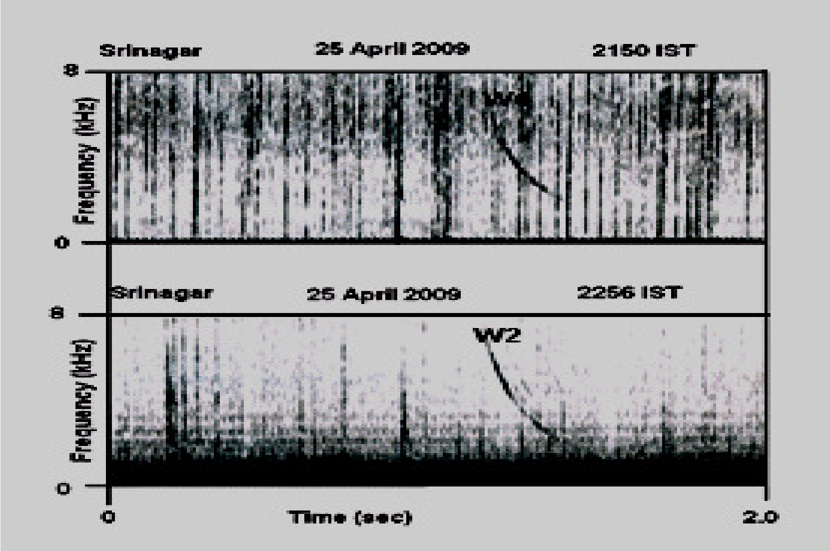

Figure 1: Dynamic Spectrograms of Whistlers Recorded at Srinagar Kashmir

The form of whistler dynamic spectra is determined by the group delay time of the whistler wave propagating at different frequencies from the source to the receiver. At low latitude 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 latitude. 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 197 I; Ho and Bernard 1973; Rycroft and Mathur 1973; Tarcsai 1975).

In the present paper, we use the Dowden and Allcock (1971) linear Q-technique for the determination of nose frequency $\boldsymbol{f_n}$ and the minimum group delay time of non-nose whistlers recorded at our low latitudes ground station Srinagar on April 25, 2009 during quiet period. In this technique, $\boldsymbol{f_n}$ and $\boldsymbol{t_n}$ are determined from measurements of group delay at many frequencies along the observed whistler trace. The plot of the reciprocal of the dispersion

$$\mathbf{Q}\,(f) = (\mathbf{t}\,.f^{1/2})^{-1} \qquad (1)$$

Where t is the group propagation time per hop at frequency f, and it gives a straight line. This straight line intercepts the Q = 0 axis at $\boldsymbol{f_0}$ = 3.06 times the nose frequency, the value of Q at $\boldsymbol{f_n}$ then also allows calculation of $\boldsymbol{t_n}$ the group propagation time per hop at the nose frequency.

In terms of $\boldsymbol{f_0}$ and the slope

$$\mathbf{Q}' = \mathbf{d\,Q / d}\,f \qquad (2)$$

We get

$$f_n = f_0 / 3.1 \qquad (3)$$

$$t_n = -\,(2.1\,\mathbf{Q}' / f_n^{3/2})^{-1} \qquad (4)$$

Thus, from (3) and (4) we determine f_n and t_n for the required non-nose whistlers recorded at our low latitude ground station Srinagar.

If group delay measurements (t) are made at N different frequencies (f) the error in the deduced f_n due to the random errors (Δt) is determined by standard least square regression theory (Dowden and Allcock 1971) as

$$\Delta f_n / f_n = \gamma\,\Delta Q / Q$$

$$\Delta f_n / f_n = \gamma\,\Delta t / t \qquad (5)$$

Where

$$\gamma^2 = N^{-1}\,(\beta + 1)\,/\,(\beta - 1)$$

Where β is the frequency mean square to square mean ratio.

$$\beta = \frac{\overline{f^2}}{\overline{f}^2}$$

Thus by this theory the maximum error in nose frequency deduced in the present study is about 10%.

The plasmaspheric parameters are derived by determining the nose frequency f_n the corresponding arrival time t_n, and group delay time of the signal at different frequencies in the whistler mode from the source to the receiver (Singh et al. 1993) for field aligned propagation can be written as

$$t = \frac{R_E L}{2}$$

$$\times \int_0^{\varphi_t} \frac{f_p(\varphi)\, f_{He} \cos^6\varphi_0 (1 + 3\sin^2\varphi)\, d\varphi}{f^{1/2}\cos^5\varphi \left[f_{He} \frac{\cos^6\varphi_0}{\cos^6\varphi} (1 + 3\sin^2\varphi)^{1/2} - f \right]^{3/2}} \qquad (6)$$

where **t** is time delay for each magnetospheric path, φ_t is the geomagnetic latitude of the station above the ionosphere (reference height), φ_0 is the geomagnetic latitude of the station, f_p is the plasma frequency, f_{He} is the equatorial electron gyro-frequency, f is the wave frequency, L is the McIlwain parameter, R_e is the earth radius and c is the velocity of light. Equation (6) is derived under the assumption that the whistlers travels on the same L which contains the point above the station at the reference altitude. Similar expression for the time delay has been obtained and discussed by Sazhin et al. (1990). At low latitudes $f_{He} >> f$ and considering electron density distribution along dipolar geomagnetic field line to be $N = K^2 R^{-3}$ where K is a constant, (6) in terms of dispersion is written as

$$D = D_{obs} - D_{ionos}$$

$$= \frac{9LR_e^{-1/2}K}{2cf_{He}^{1/2}} \int_0^{\varphi_t} \cos\varphi(1+3\sin^2\varphi)^{1/4} d\varphi \tag{7}$$

Where D_{obs} is the measured dispersion and $D_{ionos.} = t_{ions.} f^{1/2} = 7.0$ (Singh et al. 1993). Thus, for a given station, K is determined by integrating equation (7) and using the measured dispersion of the recorded whistler. Once K is known, the electron density distribution along a geomagnetic field line is determined.

PROPAGATION PATH OF WHISTLERS

The nose frequency f_n (= 0.37 f_{He} to 0.4 f_{He}) of the whistler is used to determine the path of propagation (Helliwell : 1965; Sazhin et al. 1992). The present estimation of f_n has an error of about 10%. For diffusive equilibrium $fn = 0.38 f_{He}$ (Sagredo et al. 1973). Sazhin et al. (1990) estimated this multiplying parameter to vary between 0.38 and 0.40. The L-value along which the whistler wave has propagated is given by

$$L = \frac{9.56}{f_{He}^{1/3}} \tag{8}$$

Where f_{He} *is* measured in kHz. Thus the propagation path L of whistlers recorded at Srinagar on April 25, 2009 is determined from (8).

ELECTRON DENSITY IN THE PLASMASPHERE

Integrating (7) for the given L-value (whistler path), the scale factor K is determined, which is further used in the evaluation of electron density by using the measured dispersion of the recorded whistler at Srinagar. Usually part of sub-ionospheric path at low latitudes lies in the Earth-ionosphere waveguide and a corresponding correction to the propagation delay should be taken into account.

The correction would vary from event to event and can be evaluated only when the source location and ionospheric exit location from the duct are precisely known. At Srinagar such a facility does not exist. Hence, there is possibility of systematic error introduced into the data analysis of low latitudes in general and Srinagar station in particular.

ELECTRIC FIELD

The nose frequency derived from whistler spectrograms specifies the path of whistler wave propagation in terms of L-value. Thus, measuring the nose frequency f_n for successively recorded whistlers, the variation of L with time in the equatorial plane is determined. Using the "frozen in field" concept, the plasma drift velocity derived from whistler data is related with the magnetospheric plasma drift caused by large scale East-West electric field E. The central dipole is used to represent the geomagnetic field. The whistler nose frequency and the minimum equatorial gyro-frequency along the path of propagation are related (Smith 1960, 1961; Angerami 1970; Block and Carpenter 1974) as

$$f_n \approx K f_{He} \approx K f_{Ho}(R_o/R)^3 \tag{9}$$

Where $K = 0.38$ for a diffused equilibrium model of the field-line distribution of ionization f_{He} and f_{Ho} are the functional gyro-frequencies at geocentric distances R and R_o (Earth's surface) respectively.

Specializing the hydro-magnetic drift relation $V = \mathrm{E} \times \mathrm{B}/B^2$ to the magnetic equator, we obtain (in MKS units)

$$dR/dt = -(E_w/B_o)(R_o/R)^{-3} \tag{10}$$

Where B_0 represents the geomagnetic field strength at the Earth's surface and Eω is the westward component of the magnetospheric electric field.

From (9) and (10) the convection electric field, in a dipole model, in the equatorial plane (Block and Carpenter 1974; Park 1976) is given as

$$E = 2.07 \times 10^{-2} \frac{d(f_n^{2/3})}{df} \mathrm{V\,m^{-1}} \tag{11}$$

Thus, from (11) one can directly estimate the convection electric field from the slope of $f_n^{2/3}$

The estimated plasma parameters: equatorial electron density ($\approx 7\times 10^4$ cm^{-3}), and large scale convection electric field (~0.1 – 0.2 mV m^{-1}) are of the same order of magnitude as reported by other workers (Lalmani et al., 1992; Mishra et al., 1980; Sazhin et al., 1992, 1993; Singh et al., 1998, 2004, 2008).The L-value of the path of propagation of the whistlers shown in Fig.1.1are found to be in the range of 3.75..

CONCLUSIONS

The results relating to electron density, total electron content, and large scale convection electric field derived from the whistler dispersion analysis of the whistlers recorded at Srinagar are in agreement with results reported by other workers. Further, the derived magnetospheric parameters are in accordance with the characteristics of whistler duct.

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