Magnetospheric Plasma Parameters Deduces from Analysis of Multiple-Whistlers Detected by Automatic Whistlers Detector (AWD) at Low Latitude Varanasi

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Whistlers are exotic electromagnetic phenomena produced by lightning discharges and have been regarded as cheap and effective tool for the case studies of plasmasphare diagnostic since the early years of whistler research. Recently, at Indian low latitude station Varanasi (geomag. lat. $=14°55'$ N, long. $= 153° \ 54'$ E) an Automatic Whistler Detector (AWD) has been installed in Dec, 2010 for detection and analysis of whistlers. This instrument has two main propose (i) to automatically detect and collect statistical whistlers data for the investigation of whistlers generation and propagation and (ii) to provide plasmasphere electron densities extracted from whistlers. In the present paper, we have analyzed the multiple whistlers recorded on 21 Feb. 2011 and computed the various magnetospheric parameters.

I. INTRODUCTION

Whistlers are electromagnetic phenomena produced by the propagation of the radio energy from lightning-generated sferics through the ionospheric and magnetospheric plasma [1]. Whistlers are identified as audio-frequency radio signals that usually begin at high frequencies (on the order of 10 kHz) and typically fall in frequency to ∼1 kHz in about 1 s [2].

Lightning strokes produce sferics, which are intense impulses of electromagnetic energy with a spectrum dominated by the very low frequency (VLF: 3-30 kHz) range. Some fraction of this energy penetrates up through the ionosphere and travels through the magnetospheric plasma in the whistler mode [3]. As the electromagnetic wave travels through the plasma environments of the ionosphere and magnetosphere, it undergoes dispersion. Because the propagation velocity decreases with frequency, the lower frequency components of the wave arrive later than the higher frequency components [4]. When the waves have penetrated into the magnetosphere there are two options: the waves can follow a duct of enhanced plasma density which is aligned with the magnetic field lines, or take another curved path that does not perfectly follow the field lines [5].

The formation of whistler ducts has also been studied by many workers theoretically, and it has been suggested that VLF ducts may be formed by flux-tube interchange under the influence of localized transverse electric fields [6-8]; however, the origin of these fields is still controversial. Whistler mode waves are approximately guided by the Earth's static magnetic field. If, in addition, the waves are trapped in a duct of either enhanced or depleted plasma density then the wave normal is confined to a relatively small range of angles with respect to the magnetic field [9]. In the absence of a duct the wave normal deviates progressively from the magnetic field. Due to the increased presence of ions at lower altitudes, the wave is eventually reflected at the lower hybrid resonance (LHR) frequency, generally at some significant height above the ionosphere [10]. When electromagnetic waves reach the ionosphere in the conjugate hemisphere they are either reflected back into the magnetosphere or infiltrate the Earth-ionosphere waveguide, where they may be detected by receivers on the ground [3].

At very low latitudes the inclination of the magnetic field is not favorable for trapping whistlers in ducts. So even though lightning is most prevalent here, whistlers are very rare. At medium latitudes whistlers become far more common. Whistlers recorded in this region have the general characteristics of higher frequencies arriving before the lower frequencies. These whistlers propagate mainly through the plasmasphere. At higher latitudes the whistlers have a distinct nose-frequency. Since night and daytime whistlers have different occurrence and dispersion characteristics, their propagation mechanisms must also be different [11]. The specific shape of a whistler is determined by the plasma density and strength of the magnetic field in the duct.

In the present study, we have presented the multiple whistlers observed at our low latitude station Varanasi on 21 February 2011. The details about the experimental setup of newly installed Automatic Whistler Detector (AWD) at Varanasi are presented in section 2 and the theory of and formulation for computation of magnetospheric parameters are presented in section 3. The results of this study with discussions are presented in section 4. Finally, the conclusion of the study is presented in section 5.

II. EXPERIMENTAL SETUP

This paper presents the first result obtained by the Automatic Whistler Detector (AWD) installed at Indian low latitude station Varanasi. A detailed description of the system operation and algorithm development can be found in Lichtenberger et al [12]. The incoming VLF data stream is sampled at a rate of 44.1 kHz using a 16-bit soundcard in a standard personal computer. The data stream is taken from the magnetic North-South and East-West loop antenna. While the operational system can independently sample from the data streams provided from both the NS and EW loops.

The AWD system has been installed and working at Varanasi since December, 2010 and has collected a lots of VLF data which consists of variety of whistlers. The detectors algorithm is based on image correlation where the target image is preprocessed spectrogram of raw VLF signals and the pattern is a model whistler. The development philosophy of the whistler detection algorithm was to "over trigger" i.e., to attempt to capture all possible whistlers but accept some events will be captured which do not represents whistlers. The whistler detector output is then manually examined "by eye" to determine if the 4 s captured record contains a whistler.

III. PLASMASPHERIC PARAMETERS

For longitudinal propagation the whistler mode dispersion relation is given as [5]

$$\mu^2 = \frac{\Pi^2}{\omega(\Omega - \omega)} \quad (1)$$

where m is the refractive index, P and W are the plasma and gyrofrequency, and w is the wave frequency. Since the refractive index depends on frequency, the whistler mode is dispersive, which is commonly characterized by the dispersion

$$D_0 = T\sqrt{f} \quad (2)$$

where$\omega = 2\pi f$ and T is the time delay of the signal at frequency f. The dispersion and group delay are primarily dependent upon the cold plasma electron density and the McIlwain L-shell of the whistler duct.

Dowden and Allcock [13] found that the nose whistler gave a mean ratio of zero-Q frequency (f_0) to observed nose frequency of 3.090.04. This property was used to determine the nose frequency (f_n) of the whistlers, which do not exhibit nose by extrapolating the Q(f) regression line obtained from t(f) measurements within the available frequency range. Thus, f_n is determined by using the relation

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

and hence f_{Heq}, the equatorial gyrofrequency along the field line, through the relation $f_n = 0.4 f_{Heq}$[14].

Various models have been used to calculate the electron-density variation such as: Dungey Model (N = N_0 $e^{2.5R}$), Johnssin-Smith Model (N = $N_0 f_H$ $e^{2.5R}$), Gyro-frequency Model (N = $N_0 g f_H$) [5]. Smith [15] has derived an average model based on the gyro- frequency and is given as:

$$N = 1.2 \times 10^4 f_H \quad (4)$$

where N is the number of electron cm^{-3} and f_H is the gyro-frequency in Hz. Plasmaspheric electron densities are an important parameter for describing the condition of the near-Earth plasma and the waves that propagate through this plasma. Plasmaspheric electron densities strongly determine the resonant energy for energetic electrons resonating with VLF waves [16].

The frequency of minimum time delay which dependent on the strength of the Earth's magnetic field along the path of propagation was a particular interest since it provide for the first time a means of determining the latitude or the path of propagation [17]. The variation of L-value with time in the equatorial plane can be determined from measuring the nose frequency and written as

$$L = 9.56/f_{He}^{1/3} \quad (5)$$

where f_{He} in kHz.

Plasma drift velocity is related with the magnespheric plasma drift caused by large scale East-West electric field. The central dipole is used to present the geomagnetic field. The convection electric field, in a dipole model, in the equatorial plane [17]

$$E = 2.07 \times 10^{-2} \frac{d}{dt}(f_n^{2/3}) V m^{-1} \quad (6)$$

where f_n in Hz. Hence from this equation we can derive the convection electric field.

IV. RESULTS & DISCUSSION

Large no-umber of whistlers has been observed during routine recording of VLF data by AWD at

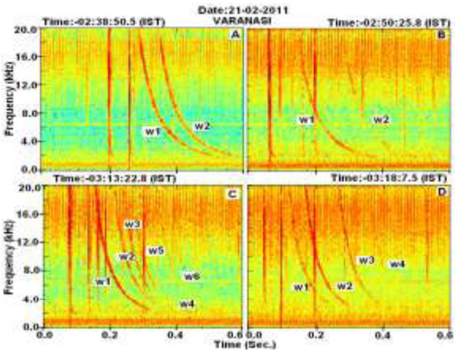

FIG. 1: Typical Example of Doublet as well as Multiple Whistlers.

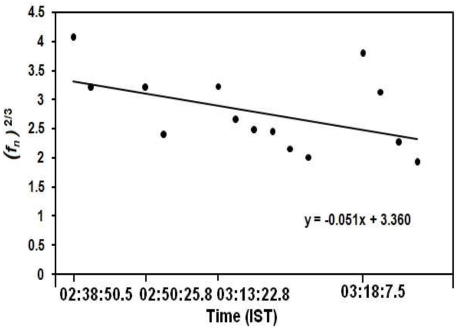

FIG. 2: Variation of the $(f_n)^{2/3}$ with time.

Varanasi in the month of February 2011. Figure 1 shows typical example of multiple whistlers observed on 21 February 2011. Figure 1 is made up four sub-figures A, B, C and D. There are doublet whistlers in the sub-figure A and B recorded at 02:38:50.5 and 02:50:25.8 IST respectively. Sub-figure C contains six whistlers observed at 03:13:22.8 IST. Similarly the sub-figure D observed at 03:18:7.5 IST shows four whistlers.

The characteristic plasmaspheric parameters are computed using Figure 1 and the equations (1) - (6). These plasmaspheric parameters of the discussed doublet as well as multiple whistlers shown in Figure 1 are tabulated in Table 1.

The whistler propagation path and plasmaspheric parameters are derived by determining the nose frequency f_n of the recorded whistlers using the nose extension method of Dowden and Allcock [13]. Dispersions of whistlers have been calculated by equation (2). We have computed the electron density at equatorial height of the duct and nose-frequency with the help of equation (4) and equation (3).

We have computed the paths of propagation i.e. L-value of analyzed whistlers of the sub figure A as 3.4 and 3.9. For the figure B, L-values are 3.9 and 4.5.; for the figure C it lies between 3.9 and 4.9. Similarly calculated L-value for the figure D is 3.6, 3.9, 4.6 and 5.07 respectively.

Dispersion for the whistlers varies between 12 and 17 $\text{sec}^{1/2}$. The dispersion of the whistlers observed at the Indian stations range from 10 $\text{sec}^{1/2}$ to 70 $\text{sec}^{1/2}$ [11]. Thus our computed results are comparable to the other reported results at low latitudes. Dispersion of the whistler depends upon the path length, electron density and magnetic field distribution along the path of propagation. Low dispersion may arise if the propagation path is small. In that case the total propagation path may lie in the ionosphere [17].

The equatorial electron densities of the observed whistlers varies between 10.09×10^2 cm^{-3} and 95.70×10^2 cm^{-3}. The equatorial electron gyrofrequency varies between 6.23 to 20.49 kHz and the nose frequency of these observed whistlers lie between 2.3 to 8.9 kHz. The variation of $f_n^{2/3}$ with time is shown in the Figure 2. The slop of the trend line gives the electric field as 0.051 mVm^{-1}. Singh et al. [18] shown that the quiet time electric fields usually lie between 0.05 mVm^{-1} and 0.15 mVm^{-1}. Thus our results derived from the whistlers observed at Varanasi during quiet period of 21 February 2011 lie well within the range reported by other workers.

CONCLUSION

Whistlers are very useful means for exploring the ionosphere and magnetosphere and play an important role in the physics of magnetospheric plasma waves and particle and are responsible for the estimation of many atmospheric parameters. Whistlers acquire their characteristic frequency-time structure as they propagate through the magnetospheric plasma by virtue of the dispersive nature of the whistler-mode. The large numbers of doublet and multiple whistlers observed at our low latitude station Varanasi on 21 February, 2011 have been analyzed using Dowden-Allcock linear Q-technique. Our dispersion analysis shows that the observed whistlers have propagated in ducted mode along higher L values and after exiting from the duct they penetrate the ionosphere and are trapped in Earth ionosphere waveguide and are received at Indian low latitude station, Varanasi. The electron densities varies 10 to 95 10^2 cm^{-3}. The electric field is found to be 0.051 mVm^{-1}. The electron density and electric field derived from whistler data at Varanasi compare well with the

Date: 21-03-2011		Dispersion D_O ($Sec^{1/2}$)	Nose Frequency f_n (kHz)	Equatorial Electron Gyrofrequency f_{Heq} *(kHz)*	L-value	Equ. electron Density n_{eq} x 10^2 cm^{-3})
A	**W1**	12.19±1.3	8.19±0.4	20.49±0.8	3.49±0.2	24.59
	W2	17.35±0.75	5.76±0.8	14.40±0.9	3.92±0.3	17.28
B	**W1**	17.30±01.9	5.7±00.7	14.40±02.3	3.9±0.2	17.33
	W2	27.04±3.5	3.69±0.6	9.24±1.9	4.5±0.2	10.09
C	**W1**	17.19±4.5	5.81±0.8	14.54±2.1	3.9±0.3	17.45
	W2	23.12±6.8	4.32±1.1	10.81±2.9	4.32±0.3	12.97
	W3	25.73±8.2	3.88±0.8	9.71±2.05	4.48±0.4	11.65
	W4	26.13±6.8	3.82±0.7	9.56±1.8	4.50±0.3	11.47
	W5	31.34±2.7	3.19±0.1	7.97±0.4	4.7±0.1	95.70
	W6	34.97±8.7	2.86±0.7	7.15±1.9	4.96±0.4	85.88
D	**W1**	13.52±1.1	7.39±0.2	18.48±0.6	3.61±0.1	22.18
	W2	17.98±3.8	5.55±0.7	13.89±1.9	3.97±0.2	16.67
	W3	29.36±6.7	3.40±1.1	8.51±2.8	4.68±0.3	10.21
	W4	37.36±9.8	2.67±1.7	6.23±4.2	5.07±0.4	80.29

other measurements made by other techniques.

REFERENCES

[1] L. R. O. Storey, "An investigation of whistling atmospherics", Phil. Trans. Roy. Soc. (London), 246A, 113 - 141, (1953).

[2] J Rodger, J. Lichtenberger,G.. McDowell1, J.R.P. Downs, N. R. Thomson, "Automatic Whistler Detection Operational Results From New Zealand", Radio Science, 44, RS2004, 10, (2008).

[3] B. Collier, J. Lichtenberger, M. A. Clilverd, C. J. Rodger, P. Steinbach, "Source region for whistlers detected at Rothera, Antarctica", J. Geophys. Res, 116, A03219, (2011).

[4] Evan Jeng, "Detection of Whistler Waves", Stanford.edu/Proj. (2010).

[5] R. A. Helliwell, "Whistlers and Related Ionospheric Phenomena", Stanford University Press, Stanford, 43-51, (1965).

[6] G.. Park and R. A. Helliwell, "The Formation by Electric Fields of Field Aligned Irregularities in the Magnetosphere," Radio Sci. 6 (2), 299-304 (1971).

[7] D. M. Walker," Formation of whistler ducts", Planetary and Space Science, 26, 375-379, (1978).

[8] R. J. Thomson, "The formation and life time of whistlers ducts", Planetary and Space Science, 26, 423-430, (1978).

[9] A. D. M. Walker, "The theory of whistler propagation", Reviews of Geophysics, 14, 629-638, (1976).

[10] F. Walter and. J. J. Angerami, "Non ducted mode of VLF Propagation between conjugate hemispheres; Observations on OGO's 2 and 4 of the 'Walking?Trace' Whistler and of Doppler Shifts in Fixed Frequency Transmissions", J. Geophys. Res., 74(26), 6352-6370, (1969).

[11] B. Singh and M. Hayakawa, "Propagation modes of low- and very-low-latitude whistlers", Journal of Atmos. Sol-Terr. Phys., 63, 1133-1147, (2001).

[12] J. Lichtenberger, C. Ferencz, L. Bodnr, D. Hamar, and P. Steinbach, "Automatic Whistler Detector and Analyzer system: Automatic Whistler Detector", J. Geophys. Res, 113,A12201, (2008).

[13] B. L. Dowden and G. M. Allcock, "Determination of nose frequency of non-nose whistlers", J. Atmos and Terr. Phys, 33, (1125-1129), (1971).

[14] S.S. Sazhin, M. Hayakawa, and K. Bullough, "Whistler diagnostics of magnetospheric parameters": A review, Ann. Geophys, 10(5), 293-308, (1992).

[15] J. Smith, Jr. P. J. Colman, D.L. Judge, and C.P. Sonett, "Characteristics of the extraterrestrial current system: Explorer V1 and Pioneer V", J. Geophys. Res, 65, 1858-1861, (1960).

[16] H. C Chang and U. S. Inan, "Quasi-relativistic electron precipitation due to interactions with coherent VLF waves in the magnetosphere", J. Geophys. Res., 88, 318-328, (1983).

[17] S. B. Singh, Usha. Kumari, K.M. Singh, A. K. Singh, "Probing of Magnetospheric Parameters by Whistlers Analysis at Varanasi", Earth Science India, 4(IV), 201 - 211, (2011).

[18] R. P. Singh, A. K. Singh, D. K. Singh, Plasmaspheric parameters as determined from whistler spectrogram: a review. J. Atmos. Sol.-Terr. Phys. 60, 495-508 (1998).