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The relationship between the polarization of whistlers and their dispersion

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Abstract. It is found, based on the whistler data obtained at Moshiri, that there exists a definite relationship between the phase difference (Φ) of wave magnetic fields of daytime whistlers on two crossed loop aerials and the dispersion (D); Φ (deg) $= -3.34 \times D(\text{s}^{1/2}) + 82.2$. This relation in conjunction with our previous empirical formula relating the dispersion with path latitude will suggest a diagnostic tool of inferring the path latitude of VLF emissions only by using the simple polarization measurement for those waves.

Key words: Magnetosphere – Whistlers – Dispersion – Phase difference measurement – Polarization

1. Introduction

The ground-based measurement of polarization of VLF waves; the measurement of amplitude ratio and phase difference of VLF signals on crossed loop aerials, provides useful information on the ionospheric transmission mechanism of VLF waves after having propagated through the magnetosphere (Tanaka et al., 1976; Okada et al., 1977, 1981; Machida and Tsuruda, 1984). The present paper deals with the polarization characteristics of whistlers as a function of dispersion value, and points out that the phase difference of whistler wave fields on the crossed loops can be extensively used to infer the latitude where whistlers emerge from the ionosphere.

2. Polarization characteristics as a function of dispersion

The present study is based on the whistler data obtained at a middle latitude station of Moshiri, Japan (geomagnetic latitude $= 34.5°$ N; $L = 1.59$). The measurement of polarization is made as follows. The wideband (0–10 kHz) VLF signals, together with calibration signals, recorded on analogue magnetic tapes are digitized by means of an A/D converter, and those digitized data are analyzed by a computer to deduce the amplitude ratio and phase difference of the signals on crossed loop aerials over the full frequency range of whistler spectrum (see Okada et al., 1983, for the detailed procedure). The polarization is defined as $p(= -H_{NS}/H_{EW}$, where H_{NS} and H_{EW} are the wave magnetic field components in the geomagnetic NS and EW directions) $= re^{i\Phi}$. In the following, we use the information of phase differences in a narrow frequency band from 3.0–4.0 kHz where the whistler energy is maximized in the spectrum.

Figure 1 illustrates the final result in the form of the relationship between the phase difference and dispersion value. This figure is concerned with daytime whistlers as termed by Hayakawa and Tanaka (1978) which occurred during the local time interval of 17 h through 20 h and is based on the data obtained from three daytime occurrence peaks at 14:00–14:05 on 14th January 1983, 17:25–17:30 on 24th January 1984 and 19:55–20:00 on 13th February 1985. Only strongest whistlers are used to deduce reliable polarization data. Each dot represents the mean value of the occurrence distribution of phase differences for the frequency range from 3.0 to 4.0 kHz for a specific whistler. Open dots refer to the whistlers on 14th January 1983, black dots those on 24th January 1984, and triangles those on 13th February 1985. A horizontal arrow indicates the average value of phase differences for each dispersion value. As seen from the figure, we understand that there exists a clear and definite relationship between the phase differences Φ and dispersion value D. The following regression line is obtained with an extremely high correlation coefficient of -0.93 and is shown in the figure in full line.

$$\Phi(\text{deg}) = -3.34 \times D(\text{s}^{1/2}) + 82.2.$$

The previous direction finding study (Hayakawa et al., 1981) has found that the ionospheric exit points of whistlers with dispersion for which we have the highest occurrence number, are very close to the observing station. So, we have examined the distribution of dispersion value measured in every 5 $\text{s}^{1/2}$ in the local time intervals from 17:00 to 20:00 for two Januaries in 1983 and 1984 and for February 1985, and the result is that the most probable dispersion is close to, but slightly larger than 40 $\text{s}^{1/2}$. The use of this most probable dispersion ($D = 41 - 42$ $\text{s}^{1/2}$) in our previous experimental formula, $D(\text{s}^{1/2}) = 1.22\ (\Lambda - 0.72)$ (Λ: geomagnetic latitude) (Hayakawa and Tanaka, 1978) has yielded $\Lambda = 34.3 - 35.1°$, which is in good agreement with the actual latitude of the station of Moshiri. Hence, the use of Hayakawa and Tanaka (1978)'s empirical formula enables us to infer the path latitude of the whistlers, and so at the top of Fig. 1, the corresponding path latitude is also indicated. For example, $D = 75$ $\text{s}^{1/2}$ in the figure corresponds to the path latitude of $\Lambda = 58.1°$, about 2,460 km away from the station of Moshiri in the magnetic meridian plane. For larger dispersion such as 57.5 and 75 $\text{s}^{1/2}$, the

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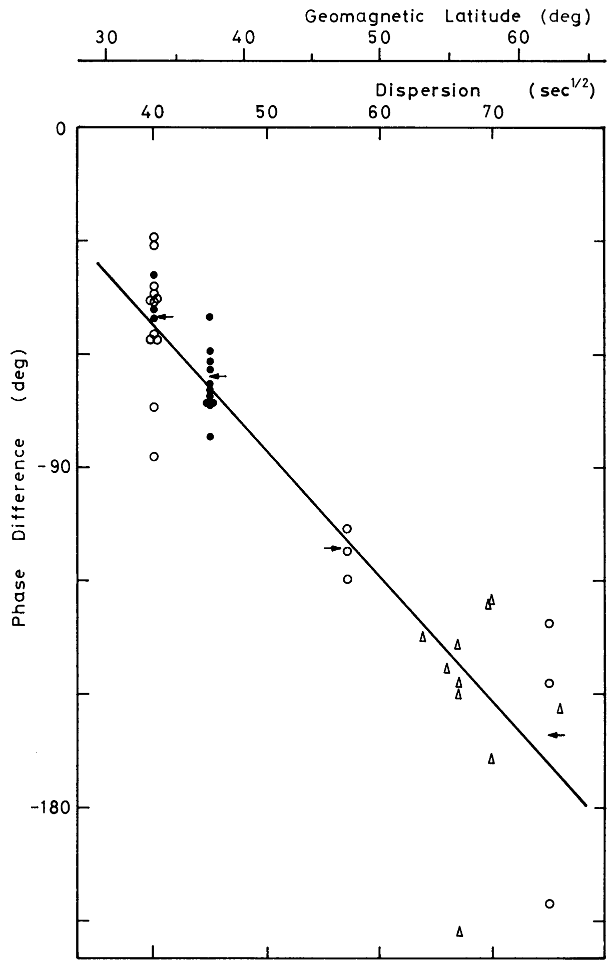

Fig. 1. The relationship between the phase difference and the dispersion value. The regression line is indicated in *full line*

azimuth of arrival is considered to be close to the magnetic meridian plane, because the propagation distance becomes larger for off-meridional whistlers, suggesting more absorption in the Earth-ionosphere waveguide propagation. Actually, we have tried to deduce the azimuths of whistlers with dispersions of 57.5 and 75 $s^{1/2}$, by using a rough estimation of Θ(azimuth) $= \tan^{-1} r$ on the assumption of linearly polarization, and we find that all of those whistlers have propagated from a small range of azimuth (less than 30°) around the magnetic meridian plane. For whistlers with larger D's having propagated over great distances in the Earth-ionosphere waveguide, the waves will be more linearly and vertically polarized so that $\phi \sim -180°$, which is roughly consistent with Fig. 1. On the contrary, one would expect ϕ closer to $-90°$ for $D \sim 40$ $s^{1/2}$ because circularly polarized whistler-mode waves are incident nearly from the vertical directions and also the scatter in ϕ may indicate the reception of off-meridional whistlers.

3. Conclusion and future application

A clear tendency as found in Fig. 1 will be useful for the future study of whistlers based on the polarization measurement. Furthermore, we can propose a useful diagnostic for magnetospheric VLF/ELF emissions such that when we apply the relationship as obtained in the present paper, to VLF emissions such as hiss and chorus whose path latitudes are difficult to determine, we may be able to infer the approximate path latitude of those emissions on the assumption of meridional propagation only by using the simple polarization measurement.

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