Hybrid-mode propagation of whistlers at low latitudes

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Whistlers recorded at Varanasi (geomag. lat. 14°55'N) during the period Jan. 1976-Aug. 1978 have been analysed. It is shown that the nighttime whistlers are characterized by extremely small dispersion of less than 15 s⁻¹². This feature supports the hypothesis of combined ground-ionosphere waveguide and field-aligned propagation known as hybrid mode of propagation. The lower cut-off frequencies of these whistlers have been evaluated and majority of these whistlers are found to lie in the low frequency range of 1.7-3.4 kHz.

1 Introduction

It is well known that the occurrence frequency of whistlers decreases with decreasing geomagnetic latitudes. At Varanasi (geomag. lat. 14°55'N) whistlers were first recorded by Singh et al. The low latitude whistlers have certain special features in that they have low dispersion and occur only when field-aligned irregularities or enhanced ionization is present along the propagation path. The path length is relatively shorter but curvature of the magnetic field is large. Many of the low latitude whistlers diffract away from the field line path and are not received at the conjugate points. On the other hand, whistlers along the higher geomagnetic latitudes may also get diffracted and may propagate along lower geomagnetic field lines. In most of these cases, the low dispersion whistlers are recorded. We have chosen whistlers with clear causative atmospherics in order to ascertain the propagation path along the geomagnetic field, and discuss some of their features.

The hybrid types of whistlers are a combination of propagation along geomagnetic field lines in ducted mode and a guided mode wave propagation in earth-ionosphere. The lower cut-off frequencies of whistler are determined. The analysis of accompanying tweeks is carried out to compute the location of the whistler source. The distribution of lower cut-off frequencies and location of the causative atmospherics provide evidence of hybrid type of the propagation for extremely small dispersion (ESD) whistlers.

2 Propagation of tweeks and whistlers

Tweeks and whistlers are part of the VLF spectrum generated by the lightning discharges. Depending upon the orientation of the lightning the tweeks propagate in the earth-ionosphere waveguide to long distances. Part of the VLF energy may leak from the waveguide and propagate along geomagnetic field line in ducted mode and is received as whistlers at the conjugate points. Examples of tweeks and ESD whistlers are shown in Fig. 1. It is seen that tweeks have very small dispersion near the lower cut-off frequency of each mode (fundamental and second harmonics). On the other hand such features are not seen in whistlers.

The important feature of propagation of whistlers is described by magneto-ionic theory. Using well known approximation, the group velocity of whistler is written as

$$V_g = \frac{2C \left[ \omega (\omega_h \cos \theta - \omega) \right]^{3/2}}{\omega_h \omega \cos \theta} \ldots (1)$$

where $C$ is the velocity of electromagnetic waves in vacuum, $\omega$ the whistler wave frequency, $\theta$ the wave-normal angle made with the geomagnetic field, and $\omega_h$ and $\omega$ are respectively the angular electron gyro and plasma frequencies.

The time taken by the whistler wave along the geomagnetic field line is
group velocity for perfectly conducting earth and ionosphere is written as

\[ V_n = C \left[ 1 - \frac{C^2 n^2}{4 h^2 f_1^2} \right]^{1/2} = \frac{d}{t_n} \]  \hspace{1cm} \ldots (4)

where \( n \) is the mode number and \( h \) is the height of the earth-ionosphere waveguide. If \( t_1 \) and \( t_2 \) are the times taken corresponding to frequencies \( f_1 \) and \( f_2 \) of the fundamental of tweeks, then the propagation distance \( d \) from Eq. (4) is written as

\[ d = (t_1 - t_2) C \left[ 1 - \frac{C^2}{4 h^2 f_1^2} \right]^{-1/2} - \left[ 1 - \frac{C^2}{4 h^2 f_2^2} \right]^{-1/2} \]  \hspace{1cm} \ldots (5)

Further, using \( f-t \) variation of whistler wave, dispersion is calculated from Eq. (3). When the light-
ning source is located far from the conjugate points, then for certain orientation of the lightning channel the wave may propagate in the earth-ionosphere waveguide and subsequently aligns itself at an appropriate point along the geomagnetic field lines.

3 Results and discussion

The data recorded at Varanasi during nighttime (0000 to 0530 hrs) from Jan. 1976 to Aug. 1978 have been examined. The general features observed during continuous monitoring of whistlers and tweeds are: (i) whistlers have not been recorded during daytime but they have frequently been observed during nighttime, (ii) the occurrence rate was found to be higher between midnight and early morning hours, and (iii) the maximum occurrence rate at Varanasi was found to be during February and March months. The dispersion analysis of whistlers from sonograms has been carried out, and the results are shown in Fig. 2. It is noted that most of the whistlers had dispersion smaller than 15 s$^{1/2}$, with a peak around 10 s$^{1/2}$. A few cases with dispersion greater than 20 s$^{1/2}$ were also recorded. The higher dispersion of recorded whistlers perhaps corresponds to field-aligned propagation, and the 10 s$^{1/2}$ corresponds to a combined path consisting of field-aligned and ionosphere-waveguide mode propagation alone. The lower dispersion may correspond to ionosphere-waveguide mode propagation alone. The small dispersion features of these whistlers lead us to conclude that most of the whistlers recorded at Varanasi might have followed a combined path. Such whistlers are called hybrid whistlers$^3$. We find that the lower cut-off frequencies of ESD whistlers lie between 1.7 and 3.4 kHz, as shown in Fig. 3. These frequencies are invariably higher than the earth-ionosphere waveguide cut-off frequency which is approximately 1.67 kHz. The location of a dominant peak around low frequency as seen in Fig. 3 shows that for a large number of whistlers only a small part of propagation path is along the ionized plasma which enhances the occurrence around the earth-ionosphere waveguide cut-off frequency. The occurrence rate distribution is seen to increase with decreasing cut-off frequency as shown by the lower and higher envelopes drawn and shown by the hatched region in Fig. 3. The hatched region contains 20 observations and five observations are either above or below this hatched region.

We have also evaluated the location of the causative atmospherics for a few cases as shown in Table 1. From the table it is evident that for 10 whistlers, the sources are located near the magnetic equator (3°S to 3°N). In the remaining cases the location of the source is widely distributed and most of these are away from the conjugate points of Varanasi. Thus, we find that most of the
low latitude whistlers correspond to a mixed path of propagation with varying fractions from event to event and all these are known as hybrid whistlers. The dominance of low frequency noise limits the nature of dispersion at lower frequency cutoff. An effort should be made to improve the system to suppress noise and ascertain the nature of dispersion at low frequency end.

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References