DAY TIME OBSERVATIONS OF PRECURSORS AT LOW LATITUDE

U. P. SINGH, ASHOK KUMAR SINGH, D. P. SINGH* and R. P. SINGH
Atmospheric Research Lab., Physics Department, Banaras Hindu University, Varanasi-221005, India
**Physics Department, Govt. College, Adampur, Hisar-125052, India*

(Received 17 April, 1996; Accepted in final form 11 June, 1996)

Abstract. Whistler precursors observed during day time at low latitude ground station Gulmarg (Geomag. Lat. 24° 10′ N) and their morphological features are reported. Transverse resonance interaction between whistler mode wave and counter streaming energetic electrons as the probable generation mechanism has been worked out. Minimum anisotropy required for wave amplification, parallel energy of resonating electrons and wave growth rate relevant to generation mechanism is studied.

Key words: Earth atmosphere, ionosphere, whistlers

1. Introduction

Precursors are the most intriguing naturally occurring phenomena discussed by various authors (Dinger, 1957; Dowden, 1972; Laaspere and Wang, 1968; Reeve and Rycroft, 1976a,b). Recently Paschal (1990) reported whistler precursors from a VLF transmitter which were similar to ordinary precursors in their timing with respect to their causative sferic and the two hop-whistler echo, but they occurred at the nose frequency of the whistler instead of at lower frequencies. Phase analysis showed that the precursors consisted of the amplification and advance in phase of components in the transmitted signal, together with the generation of coherent side bands. Further, he showed that precursors were generated during a sudden but momentary increase in wave-particle growth activity in the interaction region instead of triggering mechanism discussed by earlier authors. If growth activity is sufficiently enhanced, the threshold condition for triggering may decrease enough so that even existing magnetospheric noise can initiate a precursor, and no initial triggering signal may be required.

Dowden (1972) explained the generation of precursors involving transverse resonance interaction between hybrid whistler and energetic electrons. Based on this theory one expects to observe one hop hybrid whistler, but Laaspere and Wang (1968) have reported that, of the several hundred precursor events studied, none showed any evidence of a one-hop hybrid whistler. Reeve and Rycroft (1976a) have raised objections concerning the hybrid whistler itself. They have argued that rather than propagating first under the ionosphere and then back to the original hemisphere in the whistler mode, the reverse is more likely. Further, the hybrid theory relies on the time delay and frequency shift predicted by the consistent wave theory, the detailed mechanism of wave-particle interaction is not well understood.

Earth, Moon and Planets **73:** 267–275, 1996.

Reeve and Rycroft (1976a) proposed two new mechanisms for the generation of precursors. In one case (beating frequency model), two frequency components of a whistler having the same group delay time, interact to trigger a precursor at the difference frequency. This model requires ducted wave propagation (one-hop whistler) which is not observed and hence this mechanism is ruled out. In the unducted model, part of the energy from the causative lightning stroke travels in an unducted mode, undergoes one magnetospheric reflection and refraction from the inner edge of the plasmapause, arrives in the equatorial plane with its wave vector parallel to the geomagnetic field and triggers precursors. Using ray tracing computations for different magnetospheric models, Reeve and Rycroft (1976a) have successfully explained the appearance of single and multiple precursors to whistlers. Reeve and Rycroft (1976a) have also shown that the VLF energy from tropical lightning may follow an unducted path in which, after one magnetospheric reflection and one reflection from the inner edge of the plasmapause, it arrives in the equatorial plane just inside the plasmapause with the correct properties to interact in transverse resonance mode with energetic electrons. VLF emissions may be triggered which will, in the presence of a duct appear on the ground as spontaneous emissions. Since triggering signal is unducted it will not be received.

Park and Helliwell (1977) presented frequency-time spectrums purporting to show that precursors observed in North America start at frequencies which are multiples of 60 Hz. They argued that this is evidence of the effects of power line harmonics. They proposed a model in which the outgoing whistler undergoes longitudinal resonance with costreaming energetic electrons and perturbs the electron energy distribution. This perturbed distribution then amplifies, through cyclotron resonance, a power line harmonic moving in the opposite direction. The amplified power line harmonic triggers an emission which arrives before the two-hop whistlers echo. Molchanov and Chmyrev (1970) and Reeve and Boswell (1976) suggested parametric decay as a possible mechanism for precursor's generation.

In the present paper we have reported some events of whistler precursors recorded at Gulmarg. The observed features are explained by considering transverse resonance interaction between whistler mode waves by counter streaming energetic electrons. The resonance energy of electrons, required anisotropy in the distribution function and growth rate have been computed. It is argued that the finite growth rate could amplify the weak signals which in turn may trigger the whistler precursors. An attempt is made to explain the frequency spectrum of the precursors.

2. Data Analysis

The whistler precursors were observed during whistler recording using an isotropic antenna, pre-amplifier (kept at the base of the antenna), main-amplifier (in the laboratory) and a tape recorder. On March 29, 1972, we observed about thirty precursors between 1100 and 1600 hours IST. During this period K_p index varied

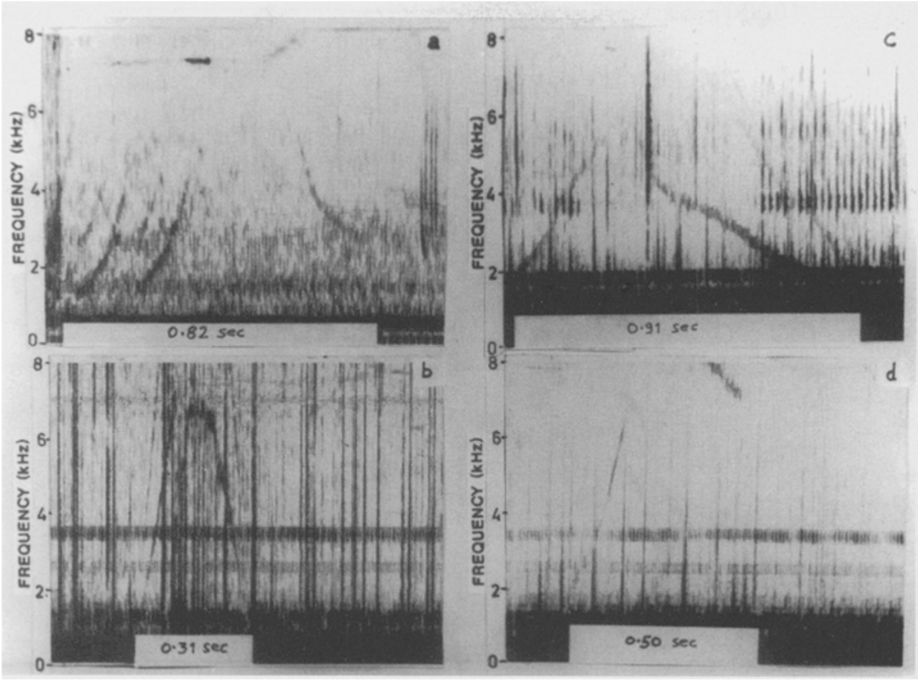

Figure 1. Whistler precursors.

between 4 and 3_+. Figure 1 shows some events. White labels at ordinate refer to start and end of the events. Precursors observed at Gulmarg can be classified into four categories: multicomponent precursors (Figure 1a), precursors containing a small number of discrete components ($n > 4$, n is the number of components; Figure 1b), diffuse precursors (Figure 1c) and single-component precursors (Figure 1d). Figure (1a) shows five rising tones preceding the originator whistler with some time delay. The rising tones have the lower cut-off frequency at about 1.0 kHz and upper cut-off frequency at about 4.5 kHz, whereas the falling tone (whistler wave) has the lower cutoff at about 2.7 kHz and upper cutoff at about 5.5 kHz. The measured dispersion of whistler in Figure 1a was found to be about 18 $s^{1/2}$, a dispersion typical to Gulmarg station for one-hop whistlers. Figure (1b) shows another example of whistler precursor with almost no time delay in which rising tone has the lower cutoff frequency at about 1.4 kHz and upper cutoff frequency at about 7.2 kHz. The dispersion of whistler in Figure (1b) was found to be 16 $s^{1/2}$. Figure 1c shows one rising tone having the lower cut-off frequency at about 2.0 kHz and upper cut-off frequency at about 6.0 kHz and two traces of falling tones in the frequency range 2.0–5.9 kHz. Figure 1d shows another typical example of whistler precursor in which rising tone has the lower and upper cut-off frequencies 1.9 and 7.0 kHz respectively, whereas the falling tone has the lower and upper cutoff frequencies 7.0 and 8.0 kHz respectively. The measured dispersion of the

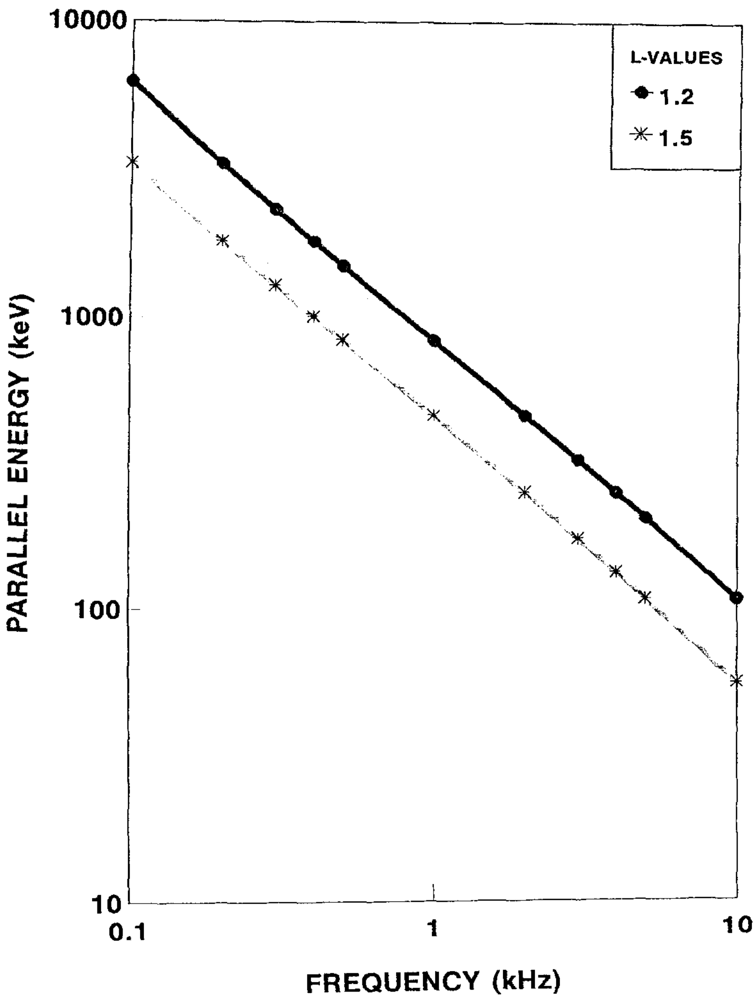

Figure 2. Variation of parallel energy of resonating electrons with wave frequency for different L-values.

associated whistler was found to be about 60 $s^{1/2}$. In this case the whistler energy is confined only in the frequency range 7.0–8.0 kHz. It appears that the lower frequency portion of the whistler trace has been attenuated during propagation through the ionosphere. The whistler seems to be two-hop whistler.

During this period large number of discrete chorus emissions also were recorded (Singh, 1993; Singh *et al.*, 1993, 1994). Singh (1993) pointed out that the unusual VLF emissions are observed under magnetically disturbed conditions. During the observation period, the possibility of electrical noise generated by electric discharges/motors/any other sources, to the authors' best knowledge are ruled out.

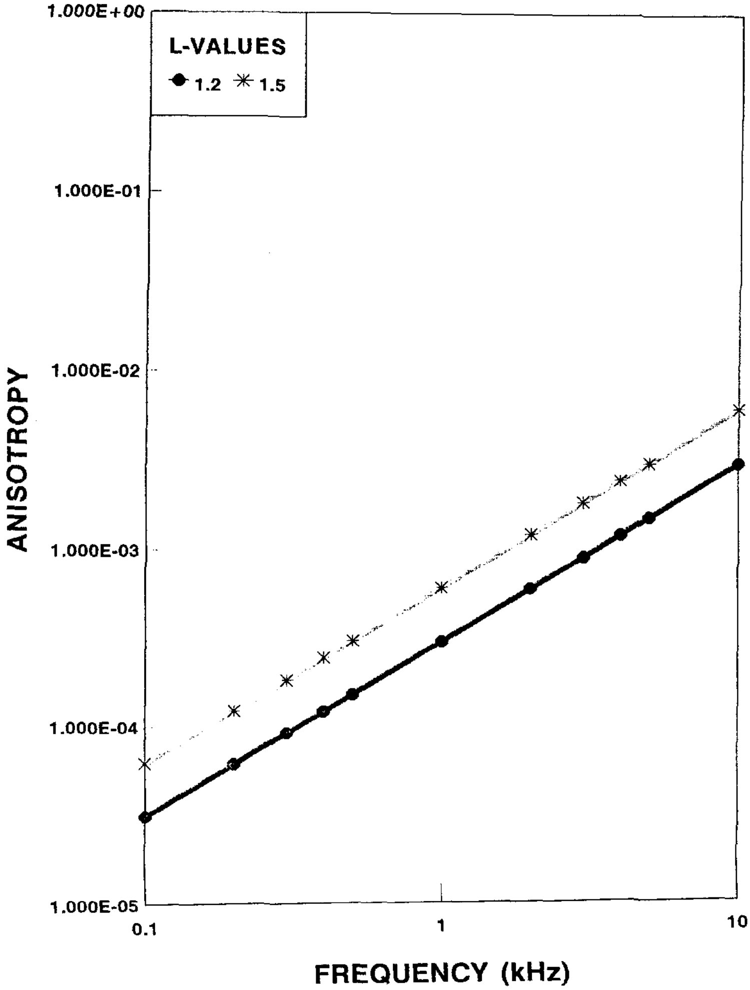

Figure 3. Variation of minimum anisotropy required for amplification of wave with frequency for different L-values.

3. Generation Mechanism

Transverse resonance interaction between inner zone energetic electrons and extremely low frequency (ELF)/very low frequency (VLF) waves propagating along geomagnetic field line is the most probable mechanism for the generation of whistler precursors and hence in the following we shall briefly discuss the relevant portion of the phenomena. The VLF wave propagating through a medium having index of refractionn $\mu \sim \omega_p^2/\omega_{\rm He}(\omega + \omega_{\rm Hi})$, interact resonantly with costreaming energetic electrons satisfying resonance condition $\omega - k \cdot v = \omega_{\rm He}(1 - v^2/c^2)^{1/2}$. Where ω_p is electron plasma frequency, $\omega_{\rm H}$ is gyrofrequency, suffice $e(i)$ refer to

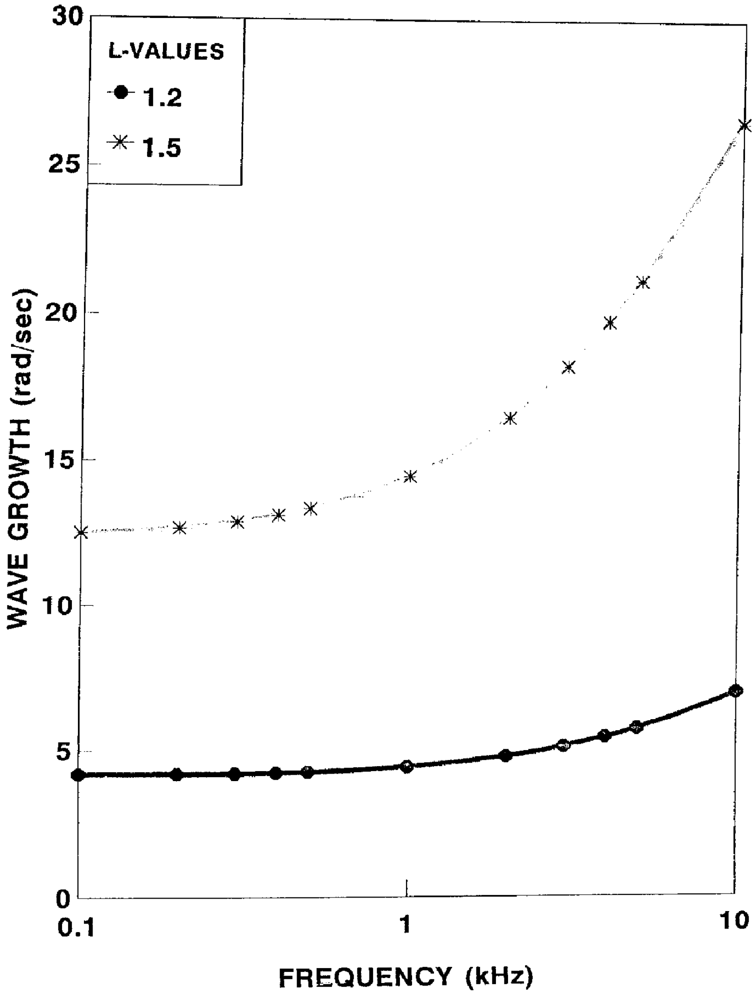

Figure 4. Variation of wave growth rate with frequency for different L-values.

electron (ion). These expressions are combined to obtain parallel component of the energy of resonating electrons as

$$E_{\parallel} = (\gamma_r - 1)m_0c^2, \tag{1}$$

where m_0 is the rest mass of the electron and γ is relativistic factor $= (1 - v^2/c^2)^{-1/2}$. In Equation (1), γ_r is determined from the relation (Tsurutani *et al.*, 1975).

$$\gamma_r^2 - 1 = \left(\frac{\omega_{\mathrm{He}}}{\omega_p}\right)^2 \left(\frac{\omega_{\mathrm{He}}}{\omega}\right) \left(1 + \frac{\omega_{\mathrm{Hi}}}{\omega}\right). \tag{2}$$

Equations (1) and (2) are used to evaluate parallel energy of resonating electrons.

The interacting waves under favourable conditions are amplified. For wave amplification, the high-energy tail of the velocity distribution function should have some finite anisotropy $A = (T_\perp/T_{||}) - 1$, where $T_\perp$ and $T_{||}$ are the temperatures of the electrons perpendicular to and parallel to the geomagnetic fields respectively. In the regime of linear theory, the growth rate of the wave for $\omega \ll \omega_{\mathrm{He}}$ is given by (Kennel and Petschek, 1966)

$$\Gamma = \pi\omega_{\mathrm{He}}\left(1 - \frac{\omega}{\omega_{\mathrm{He}}}\right)^2 \frac{J(> E_R)}{2V_R N_T}\left\{A(V_R) - \frac{1}{\frac{\omega_{\mathrm{He}}}{\omega} - 1}\right\}, \tag{3}$$

where $J(> E_R)$ is the omnidirectional flux of electrons having energy greater than the resonance energy. V_R is the resonance velocity and N_T is the total number density of electrons.

Equatorial region of the magnetosphere is the most suitable region for the occurrence of the transverse resonance instability. We have evaluated parallel component of resonating electron energy for the L values near $L = 1.2$ (corresponding to Gulmarg). It is found that the energy of resonating electrons decreases as L value increases for a given frequency band.

We found that the resonant energy of electrons for precursors having frequency in the range 1–10 kHz lies in the range 0.1–0.8×10^5 MeV. The computed energy corresponds to triggering wave propagating along geomagnetic field lines. If the wave propagates at certain angle to the geomagnetic field lines then the required resonant energy increases considerably. The measured velocity distribution shows that the electron flux density decreases as energy increases, hence the probability of resonance decreases as wave normal direction θ increases, especially for $\theta > 45°$.

Equation (3) shows that the wave growth rate linearly increases with anisotropy A in the velocity distribution function. Further Γ is positive only when $A > \omega/(\omega_{\mathrm{He}} - \omega)$. Thus, there is a minimum anisotropy which is required for the instability to occur and hence for the generation of VLF emission. Figure 3 shows the variation of this minimum anisotropy as a function of wave frequency for different L values. It is seen that the gyroresonance leading to extremely low frequency signals requires only small values of A, however, on a particular field line, this requires resonance with electrons of much higher energy. The anisotropy A increases with frequency as well as L values.

For numerical evaluation of wave growth, the density of energetic electrons at different L values are derived from the measurements of Katz (1966) who has reported the variation of electron flux as a function of energy for different L-values in the inner zone radiation belt. The variation of wave growth rate with excited frequency for $L = 1.2$ and $L = 1.5$ is shown in Figure 4. The growth rate is large and it increases with frequency. This large amplification causes significant enhancement in wave amplitude and in turn trigger waves which are observed on the ground station.

The rising frequency spectrum of precursor observed at Gulmarg can be explained by considering the interaction region to start from the equator and extend to some finite length in the southern hemisphere along the geomagnetic field line. It is noted that after moving away from the equator, the local electron gyrofrequency becomes too large for the resonance condition to be still met and the generation of rising tone (precursor) ceases. The geomagnetic field gradient and the feedback delay due to the finite wave group and electron velocities cause a characteristic rate of change of frequency of the emission as the electron traverses the interaction region (Helliwell, 1967; Rycroft, 1972).

4. Conclusion

Precursors have been observed during day time at low latitude Indian station. Morphological features are described. It is shown that these emissions could be generated during resonant cyclotron interaction in the equatorial zone of the inner magnetosphere.

Acknowledgement

One author (UPS) thanks C.S.I.R. for financial support.

References

Dinger, H. E.: 1957, 'Periodicity in Dawn Chorus', IRS-URSI symp., May 22–25.
Dowden, R. L.: 1972, 'Trigger Delay in Whistler Precursors', *J.Geophys. Res.* **77**, 695–699.
Helliwell, R. A.: 1967, 'A Theory of Discrete VLF Emissions from the Magnetosphere', *J. Geophys. Res.* **72**, 4773–4790.
Katz, L.: 1966, 'Electron and Proton Observations', in *Radiation Trapped in Earth's Magnetic Field*, D. Reidel, Holland, p. 129.
Kennel, C. F. and Petschek, H. E.: 1966, 'Limit on Stably Trapped Particle Fluxes', *J. Geophys. Res.* **71**, 1–28.
Laaspere, T. and Wang, C. Y.: 1968, 'Whistler Precursors', *Radio Sci.* **3**, 213.
Molchanov, O. A. and Chmyrev, V. M.: 1970, 'Possible Generation Mechanism of the Precursors of Whistlers', *Geomag. Aeron.* **10**, 816.
Park, C. G. and Helliwell, R. A.: 1977, 'Whistler Precursors: A Possible Catalytic Role of Power Line Radiation', *J. Geophys. Res.* **82**, 3636–3642.
Paschal, E. W.: 1990, 'Whistlers Precursors on a VLF Transmitter Signal', *J. Geophys. Res.* **95**, 225–231.
Reeve, C. D. and Boswell, R. W.: 1976, 'Parametric Delay of Whistlers – A Possible Source of Precursors', *Geophys. Res. Lett.* **3**, 405.
Reeve, C. D. and Rycroft, M. J.: 1976a, 'A Mechanism for Precursors to Whistlers', *J. Geophys. Res.* **81**, 5900–5910.
Reeve, C. D. and Rycroft, M. J.: 1976b, 'Unducted VLF Energy from Tropical Lightning as a Possible Source of Midlatitude VLF Emissions and Electron Precipitation', *J. Geophys. Res.* **81**, 6201–6202.
Rycroft, M. J.: 1972, 'VLF Emissions in the Magnetosphere', *Radio Sci.* **7**, 811–830.

Singh, R. P., Lalmani, and Singh, U. P.: 1993, 'Discrete Emissions and Whistler Precursors Recorded at Low Latitude Ground Station Gulmarg', *Earth, Moon and Planets* **60**, 225–232.
Singh, R. P., Singh, U. P., Singh, A. K., and Singh, D. P.: 1994, 'Daytime Observations of Chorus Emissions at Low Latitude', *Canad. J. Phys.* **72**, 73–79.
Singh, U. P.: 1993, 'Whistlers/VLF Emissions and Related Phenomena', Ph.D. Thesis, Banaras Hindu University, Varanasi, India.
Tsurutani, B. T., Smith, E. J., and Thorne, R. M.: 1975, 'Electromagnetic Hiss and Relativistic Electron Losses in the Inner Zone', *J. Geophys. Res.* **80**, 600–607.