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Some aspects of whistler duct lifetimes at low latitudes

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Abstract. Naturally occurring low-latitude whistlers provide a powerful ground-based technique for probing the inner magnetosphere. Whistler data recorded during a 5-h period at our low-latitude ground stations, Gulmarg ($L = 1.28$), Nainital ($L = 1.16$) and Varanasi ($L = 1.11$), were used to determine the lifetime of whistler ducts. Duct lifetimes as short as 50 min were observed, a result which has an important implication for current theories of ducts at low latitudes.

Key words: Whistlers – Magnetosphere – Ducts – Ionosphere – Plasmapause – Dispersions – Causative sferics – Electric field.

Introduction

Over the last decade, whistlers have become a very important tool for probing the plasmaphere and beyond. Since the pioneering work of Storey (1953), the observation of whistlers has been continued over a wide range of high-to-low latitudes (Allcock, 1960; Helliwell, 1965; Iwai and Ohtsu, 1967; Somayajulu et al., 1972; Cerisier, 1973; Singh et al., 1977; Hayakawa and Tanaka, 1978; Carpenter, 1983). It is now well established that most ground-observed whistlers are guided between opposite hemispheres by magnetic field-aligned enhancements of ionization termed "whistler ducts". The theory of trapping and propagation of whistlers in ducts has been discussed by several authors (e.g. Smith, 1961; Walker, 1972; Laird and Nunn, 1975). By using these ducted whistlers the dynamics and structure of the magnetospheric thermal plasma have been studied (Carpenter and Park, 1973; Y. Corcuff, 1975). However, Walker (1976) recently showed that there remain many unsolved problems in the whistler propagation itself, especially in the lower exosphere and ionosphere, such as the excitation of ducts and their lifetimes, leakage from them, and the transmission properties through the ionosphere.

Determination of duct lifetimes is important for evaluating theories of duct formation at low latitudes. On the basis of detailed sonographic study, Somayajulu and Tantry (1968) have found that it might take less than 1 h for ducts to form and that once the duct has been formed, it might stay alive for a few hours to a few days. Ducts at mid-latitudes have been observed to persist for 10–20 h (Park and Carpenter, 1970) in the vicinity of the plasmapause. Recently duct lifetimes at mid-latitudes as short as 30 min have been reported by making simultaneous observations from adjacent whistler stations (Hansen et al., 1983). The lifetime of ducts deduced by the low-latitude workers seems to be widely distributed from 30 min to a few days. Therefore, further study is needed of the lifetime of the ducts at low latitudes.

As a result of the increasing importance and versatility of the whistler technique it has become clear that improved understanding of some aspects of whistler propagation is necessary at low latitudes. The purpose of this paper is to determine the lifetime of whistler ducts by making continued whistler data recorded at our low-latitude ground stations, Gulmarg ($L = 1.28$; 24°26′N, 147°09′E) and Nainital ($L = 1.16$; 19°02′N, 149°45′E) from 0020 to 0500 I.S.T. (Indian Standard Time) on 25 March 1971, and at Varanasi ($L = 1.11$; 15°06′N, 159°33′E) from 0020 to 0300 IST on 19 March, 1977. Briefly, our approach is as follows. Suppose we consider an ideal situation in which only one duct is contributing to the whistler occurrence rate at a station and also suppose that this duct takes a finite time to grow to its mature state and to decay, finally merging with the background ionization. We should then expect the whistler occurrence rate recorded on the ground to show the corresponding rise and fall with time. If, as suggested by Okuzawa et al. (1971), the growth and decay of ducts are cyclic, it follows that the whistler occurrence rate shows a kind of periodicity. This ideal case can, in favourable conditions, be extended to a realistic situation in which a few active ducts are simultaneously contributing to the occurrence rate. The presence of any periodicity in the combined occurrence rate can be detected by the standard technique of power spectrum analysis, as suggested by Madden (1964). We find that whistler-duct lifetimes can be as short as 50 min, a result which has important implications for current theories of ducts at low latitudes.

Observations

The whistlers recorded at Gulmarg, Nainital and Varanasi were always of very high quality, and the number of whistlers recorded during magnetic storms was always large enough to be of statistical significance. During the mentioned period the whistler data were characterized by a consistently good whistler intensity and rate with well-defined components.

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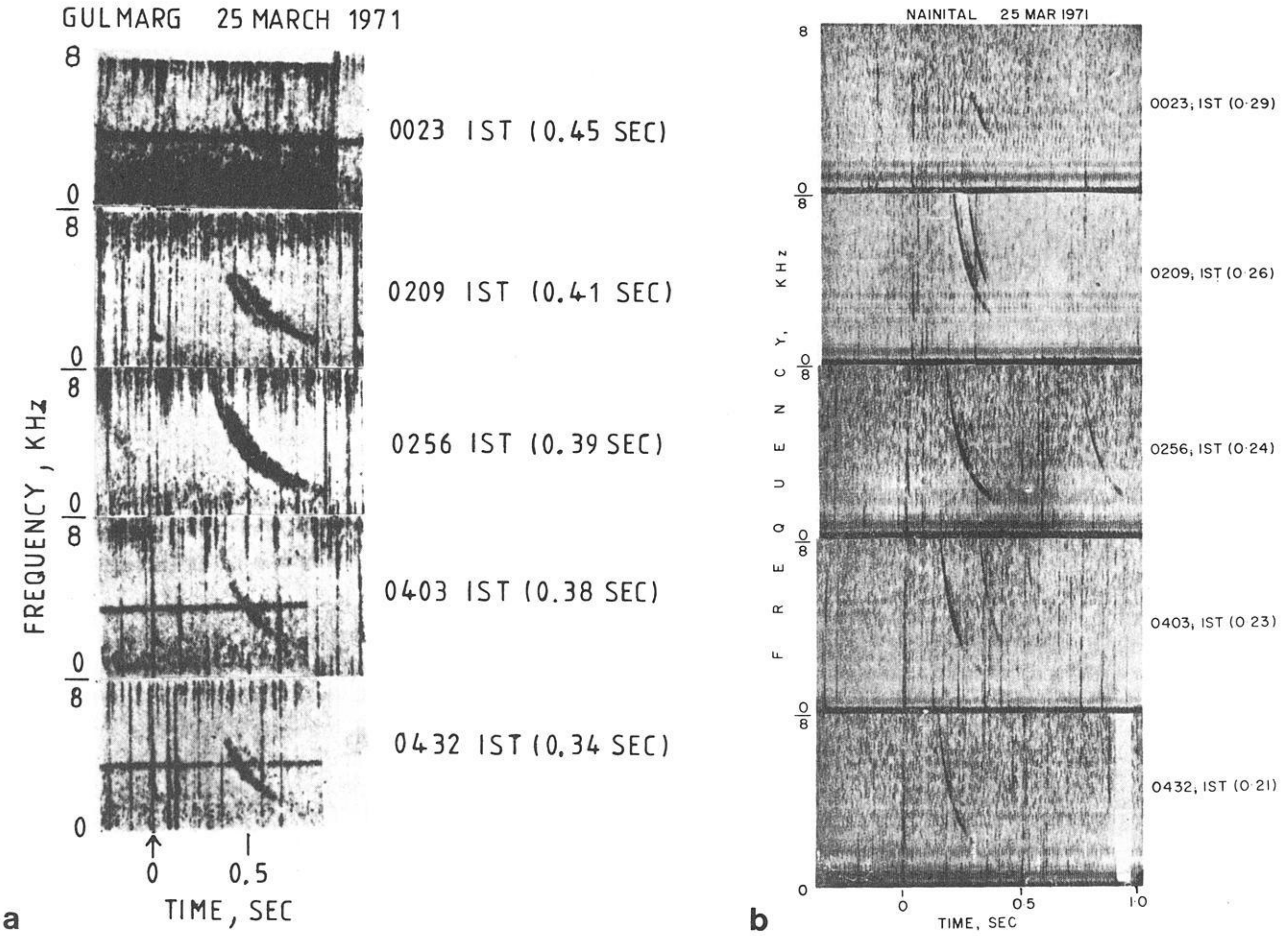

Fig. 1 a + b. An example of spectrograms of whistlers recorded simultaneously at **a** Gulmarg and **b** Nainital on 25 March 1971, showing the variation of dispersion with time (figures shown by the side of time indicate the time delay at 5 kHz)

On 25 March 1971, whistlers in great numbers were observed at our field stations in Gulmarg and Nainital. The spurt in activity started around 0020 IST and lasted for about 5 h, ending finally at day break at 0520 IST. During this period the Kp index varied between 2 and 5. The mere occurence rate itself was interesting and altogether several hundred whistlers were recorded and dispersion analyses made. The dispersion showed a remarkably smooth decrease within the observation period of 5 h.

In Fig. 1 we show a sequence on five sonograms corresponding to different times of occurrence recorded on 25 March 1971 at Gulmarg and Nainital. The first sonogram (0023 IST) shows a single trace, with energy limited to a frequency band of 3–5 kHz. This is a typical feature of low-latitude whistlers during magnetic disturbances. The first whistler to arrive, after the sudden commencement of the storm, has energies concentrated mainly around 4.5 kHz. This is probably a reflection of the concentration of energy in the mentioned frequency range at the source itself.

All the above sonograms have been arranged in such a way that causative sferics lie on a single vertical line. The figures shown in brackets by the side of time of occurrence indicate the delay at 5 kHz. It is at once evident from Fig. 1 that the delay time at 5 kHz decreases smoothly with time. This, of course, corresponds to a similar decrease in dispersion.

In Fig. 2 we show a sequence of five sonograms corresponding to different times of occurrence during magnetic storms recorded at our low-latitude ground station Varanasi on 19 March 1977. Similar characteristics of smooth decrease in dispersion can also be seen in Fig. 2. The spurt in activities started around 0000 IST and lasted for about 5 h, and several hundred whistlers were recorded during this period.

The decrease in dispersions shown in Figs 1 and 2 (discussed later) indicate that some ducts formed within that portion of fields of view. Flux tube interchange has been proposed as a possible mechanism for duct formation, so it was of interest to determine whether the ducts are subject to any cross-L drift. Hence nose frequencies (f_n) of the non-nose whistlers recorded at our low-latitude stations were determined using the method of Ho and Bernard (1973) and plotted $f_n^{2/3}$ instead of f_n against IST, as shown in Fig. 3, so that the slope of the data points can be directly related to the convection electric field (Block and Carpenter, 1974; Park, 1976).

Results and discussions

In Fig. 4 we show the power spectrum analysis of the whistler occurrence rate at Gulmarg, Nainital and Varanasi on 25 March 1971 and 19 March 1977 to estimate duct lifetime. It is at once clear from Fig. 4 that the power spectra show peaks at certain selected frequencies. Thus, the time interval corresponding to the frequency separation between peaks

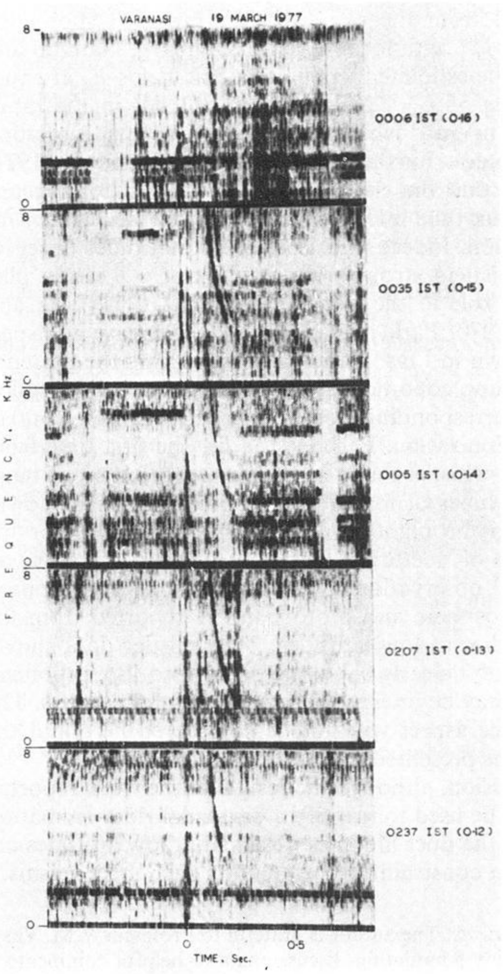

Fig. 2. An example of spectrograms of whistlers recorded at Varanasi on 19 March 1977, showing the variation of dispersion with time as in Fig. 1

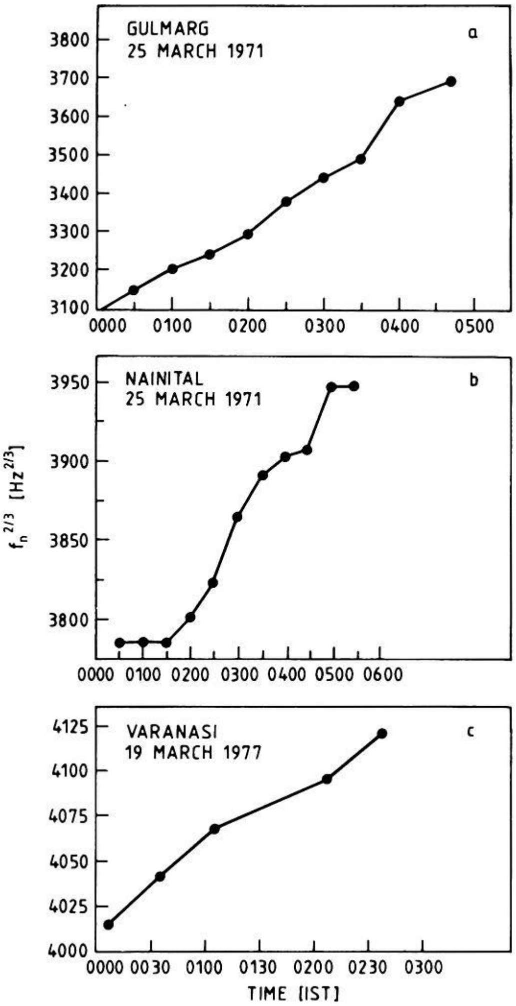

Fig. 3. Variation of whistler nose frequency (plotted on a linear scale in the two-thirds power of nose frequency), with local time observed at (a) Gulmarg, (b) Nainital and (c) Varanasi to estimate the westward component of electric field

is remarkably constant and is around 50 min. This result seems to indicate that some physical process with a periodicity of about 50 min is present in the whistler occurrence rate recorded at Gulmarg, Nainital and Varanasi. We wish to suggest that this periodicity signifies the continuous process of growth and decay of ducts as envisaged by Okuzawa et al. (1971). The spectrum corresponding to the data obtained at Nainital (Fig. 4b) and Varanasi (Fig. 4c) shows peaks at a frequency of about 2×10^{-3} rad/s and 1×10^{-3} rad/s and its harmonics respectively, having the constant time interval corresponding to the frequency separation between peaks. The power spectrum in Fig. 4a also shows peaks but the frequency separation between peaks is rather variable. In this case the average time interval corresponding to the frequency separation between peaks is about 1 h. Considering the fact that all the individual ducts which contribute to the whistler occurrence rate at a given station do not grow or decay in unison, we expect the frequency interval between peaks in the power spectrum to be variable. In this sense, the remarkable constancy of the frequency interval in the power spectrum shown in Fig. 4b and c should be regarded as fortuitous. It is also perhaps probable that at Nainital and Varanasi, which are at lower latitudes than Gulmarg, only very few ducts contribute to the occurrence rate. Such a conclusion is at least qualitatively in agreement with the fact that the "viewing area" of a ground station decreases with latitude (Carpenter, 1966). The period of about 50 min obtained from the data in Fig. 4 can be taken to represent the order of lifetime of ducts. The above value of about 50 min for the duct lifetime is comparable in order of magnitude with the estimate of other workers (Smith, 1960; Okuzawa et al., 1971; Park and Carpenter, 1970; Hansen et al., 1983). Especially Fig. 12 of Park and Carpenter (1970) seems to suggest that the average time for which the individual ducts may stay within the viewing area is around 2 h. Furthermore, the number of whistlers recorded at our low-latitude ground station is much less than the available sources (lightning flashes). This shows that the occurrence rate of whistlers at low latitudes is controlled more by the properties of the medium than by source effects.

Several duct-formation mechanisms have been proposed to date (Park and Helliwell, 1971; Cole, 1971; Walker, 1978; Thomson, 1978; Lester and Smith, 1980). An essential point common to several theories is that electric fields perturbing the magnetospheric plasma play a dominant role

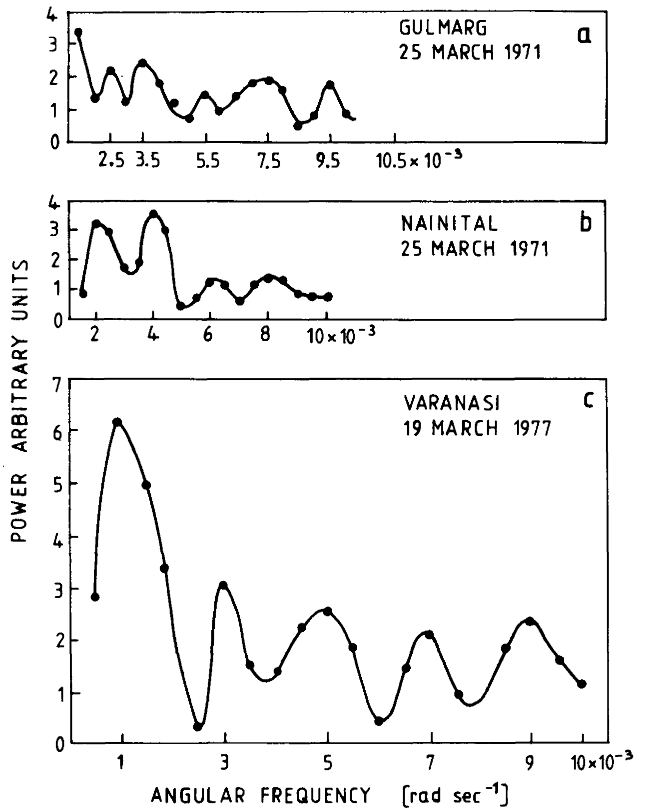

Fig. 4. Power spectra of the whistler occurrence rate observed at (a) Gulmarg, (b) Nainital and (c) Varanasi for whistler-duct lifetimes at low latitudes

in duct formation. Therefore, in the present paper an attempt was made to estimate the magnetospheric electric field during magnetic storm periods, using whistlers observed at Gulmarg, Nainital and Varanasi (shown in Figs. 1 and 2), from radial motions of discrete field-aligned whistler ducts, as indicated by changes in nose frequencies (Block and Carpenter, 1974). Park (1976) has shown that the observed changes in whistler nose frequency, f_n, were due to cross-L drift of ducts. The whistler nose frequency and the minimum equatorial gyrofrequency $f_{\mathrm{H_{eq}}}$, along the path of propagation are related (Block and Carpenter, 1974; Park, 1976) as

$$f_n \simeq k f_{\mathrm{H_{eq}}} = k f_{\mathrm{H_0}} (R_0/R)^3 \qquad (1)$$

where $k = 0.38$ for diffusive equilibrium model of field-line distribution of ionization, and $f_{\mathrm{H_{eq}}}$ and $f_{\mathrm{H_0}}$ are the equatorial gyrofrequencies at geocentric distances R and R_0 (earth's surface) respectively.

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

$$dR/dt = -(E_\omega/B_0)(R_0/R)^{-3} \qquad (2)$$

where B_0 represents the geomagnetic field strength at the earth's surface and E_ω is the westward component of the magnetospheric electric field. From Eqs. (1) and (2) the convection electric field in the post mid-night sector, in a dipole model, in the equatorial plane is given (Block and Carpenter, 1974; Park, 1976) as

$$E_\omega = 2.07 \times 10^{-2} \frac{d(f_n^{2/3})}{dt} \mathrm{Vm}^{-1} \qquad (3)$$

Thus, from Eq. (3) one can directly estimate the convection electric field from the slope of $f_n^{2/3}$. Figure 3 shows the variation of $f_n^{2/3}$ with local time for Gulmarg, Nainital and Varanasi. The estimated value of electric fields E_ω at equatorial heights of $L = 1.28$, 1.16 and 1.11 lies in the range of 0.1 to 0.7 $\mathrm{mVm^{-1}}$ which are sufficient for duct formation at low latitudes. Furthermore, Park and Helliwell (1971) have shown that the electric fields in the equatorial plane will cause flux tube interchange, a possible mechanism for duct formation. Indeed, most of the mid-latitudes observations of whistlers strongly suggest that $\vec{E} \times \vec{B}$ drifts play a dominant role in the transport of ionization (Park and Carpenter, 1970; Park, 1970, 1972). The decrease in dispersion, as shown in Figs. 1 and 2, clearly shows the presence of plasma-flow conditions because decrease in dispersion gives the corresponding decrease in the electron content of tubes of ionization. Park (1970), for the first time from mid-latitude whistler study of the electron content of magnetospheric tubes of ionization, reported the usual downward flux in the night-time across 1000 km level for the maintenance of nocturnal F-layer. However, there are no experimental observations of the interchange of ionization between ionosphere and protonosphere reported from the whistler studies at low latitudes. The whistler data shown in Figs. 1 and 2 clearly show the downward flux of ionization which may be interpreted in terms of $\vec{E} \times \vec{B}$ drifts. The details of this aspect will not be considered here and the results will be presented in a future report.

In conclusion, although the results of the work reported here cannot be used to identify a particular duct-formation mechanism, the duct lifetimes observed at low latitudes are an important constraint in formulating such mechanisms.

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References

Allcock, G.M.: IGY whistler results, paper presented at 13th General Assembly, Union Radio Sci. Int. London, 1960

Block, L.P., Carpenter, D.L.: Deviation of magnetospheric electric fields from whistler data in a dynamic geomagnetic field. J. Geophys. Res. **79**, 2783, 1974

Carpenter, D.L.: Whistler studies of the plasmapause in the magnetosphere – I. Temporal variations in the position of knee and some evidence on plasma motions near the knee. J. Geophys. Res. **71**, 693, 1966

Carpenter, D.L.: Some aspects of plasmapause probing by whistlers. Radio Sci. **18**, 917, 1983

Carpenter, D.L., Park, C.G.: On what ionospheric workers should know about the plasmapause-plasmasphere. Rev. Geophys. Space Phys. **11**, 133, 1973

Cerisier, J.C.: A theoretical and experimental study of non-ducted VLF waves after propagation through the magnetosphere. J. Atmos. Terr. Phys. **35**, 77, 1973

Cole, K.D.: Formation of field-aligned irregularities in the magnetosphere. J. Atoms. Terr. Phys. **33**, 741, 1971

Corcuff, Y.: Probing of the plasmapause by whistlers. Ann. Geophys. **26**, 363, 1975

Hansen, H.J., Scourfield, M.W.J., Rash, J.P.S.: Whistler duct lifetimes. J. Atmos. Terr. Phys. **45**, 789, 1983

Hayakawa, M., Tanaka, Y.: On the propagation of low-latitude whistlers. Rev. Geophys. Space Phys. **16**, 111, 1978

Helliwell, R.A.: Whistlers and related ionospheric phenomena. Stanford Univ. Press, Stanford, Calif., 1965

Ho, D., Bernard, L.C.: A fast method to determine the nose frequency and minimum group delay of a whistler when causative sferic is unknown. J. Atoms. Terr. Phys. **35**, 881, 1973

Iwai, A., Ohtsu, J.: Long-term variation of whistler dispersion. Proc. Res. Inst. Atmos. Nagoya Univ. **14**, 51, 1967

Laird, M.J., Nunn, D.: Full wave VLF modes in a cylindrically symmetric enhancement of plasma density. Planet. Space Sci. **23**, 1949, 1975

Lester, M., Smith, A.J.: Whistler duct structure and formation. Planet. Space Sci. **28**, 645, 1980

Madden, T.: Spectral, cross-spectral and bispectral analysis of low frequency electromagnetic data, in Natural Electromagnetic phenomena below 30 kc/s (Ed. Bleil, D.F.) p. 429, Plenum, New York, 1964

Okuzawa, T., Yamanaka, K., Yoshino, T.: Characteristics of low-latitude whistler propagations associated with magnetic storms in March 1970. Rep. Ionos. Space Res. Jap. **25**, 17, 1971

Park, C.G.: Whistler observations of the interchange of ionization between the ionosphere and the protonsphere. J. Geophys. Res. **75**, 4249, 1970

Park, C.G.: Methods of determining electron concentrations in the magnetosphere from nose whistlers. Radiosci. Lab. Stanford Univ. Tech. Rep. No. 3454-1, 1972

Park, C.G.: Substorm electric fields in the evening plasmasphere and their effects on the underlying F layer. J. Geophys. Res. **81**, 2283, 1976

Park, C.G., Carpenter, D.L.: Whistler evidence of large scale electron-density irregularities in the plasmasphere. J. Geophys. Res. **75**, 3825, 1970

Park, C.G., Helliwell, R.A.: The formation by electric fields of field-aligned irregularities in the magnetosphere. Radio Sci. **6**, 299, 1971

Singh, R.N., Lalmani, Singh, R.P.: Whistlers recorded at Varanasi. Nature Phys. Sci. 266, **40**, 1977

Smith, R.L.: Guiding of whistlers in a homogeneous medium. J. Res. Nat. Bur. Stand. Sect. D. **64**, 505, 1960

Smith, R.L.: Propagation characteristics of whistlers trapped in field-aligned columns of enhanced ionization. J. Geophys. Res. **66**, 3699, 1961

Somayajulu, V.V., Tantry, B.A.P.: Effect of magnetic storms on duct formation for whistler propagation. J. Geomagn. Geoelect. **20**, 21, 1968

Somayajulu, V.V., Rao, M., Tantry, B.A.P.: Whistlers at low latitude. Indian J. Radio Space Phys. **1**, 102, 1972

Storey, L.R.O.: An investigation of whistling atmospherics. Phil. Trans. Roy. Soc. London, Ser. **A246**, 113, 1953

Thomson, R.J.: The formation and lifetime of whistler ducts. Planet. Space Sci. **26**, 423, 1978

Walker, A.D.M.: The propagation of very low frequency waves in ducts in the magnetosphere, 2. Proc. R. Soc. London. **A239**, 219, 1972

Walker, A.D.M.: The theory of whistler propagation. Rev. Geophys. Space Phys. **14**, 629, 1976

Walker, A.D.M.: Formation of whistler ducts. Planet. Space Sci. **26**, 375, 1978

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