EFFECT OF EQUATORIAL ANOMALY ON WHISTLER WAVE PROPAGATION AT LOW LATITUDES

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ABSTRACT

Effect of equatorial anomaly on the propagation characteristics of whistlers observed in low latitude ground stations during magnetically quiet and disturbed periods is studied with the help of ray tracing computations. It is shown that the propagation characteristics of night-time whistlers are affected during disturbed periods only. The propagation characteristics of day-time whistlers are almost similar during both quiet and disturbed periods.

1. INTRODUCTION

BULLOUGH *et al.*[1] have studied in detail the occurrence and intensity of VLF signals at low, middle and high latitudes with the help of experiments aboard arial 3 satellite. They have reported that the intensity of VLF waves is greatly enhanced in the low latitude region (< 30° latitude) particularly during afternoon and evening hours. They have attributed this enhancement to trapping and ducted propagation of these signals in the equatorial anomaly. Later on, Hayakawa and Tanaka[2] and Hayakawa and Iwai[3] have also assumed the same phenomena for afternoon and evening hour whistlers observed at Moshiri and Sakushima low latitude ground stations in Japan.

Although the trapping and ducted propagation of day-time low latitude whistlers in equatorial anomaly are not yet studied thoroughly, there are certain objections which rule out the above phenomena to occur. First, the electron density distribution with the anomaly peak at the field line is not exactly the Gaussian type at all the altitudes as found in actual ducts, with the result of which, the trapped whistler waves can not be guided throughout the field, line upto the base of the F region ionosphere. Second, since the whistlers are also observed during night-time when the day-time type anomaly does not exist, the question arises as to how the whistlers are propagated to low latitude ground stations during this time. In the present paper, we have carried out ray tracing computations to study the propagation characteristics of day and night-time whistlers observed both during quiet and disturbed periods. For this purpose, we make the assumption that the day-time whistlers are not ducted in the equatorial anomaly but propagated under the influence of its negative horizontal density gradients. This assumption is based on the results of Aubry[4] who has found the wave normals of the downcoming whistler waves oriented towards the equator in the low latitude ionosphere possibly as a result of horizontal density gradients of the equatorial anomaly.

2. IONOSPHERIC MODEL AND THE COMPUTER PROGRAMME

2.1. *Background Electron Density Model*

The background electron density model employed by us in the present study is similar to that employed by Singh[5] and Singh *et al.*[6], earlier.

2.2. *Equatorial Anomaly Model*

Topside sounder data have shown that the electron density distribution around the equator is highly variable. This has been named as equatorial anomaly[7,8]. During day-time the anomaly indicates two peaks confined to a particular field line. During night-time the two peaks coalesce into one that lies on the equator and the anomaly is limited to a very small latitudinal range (± 5°)[9]. In order to simulate such a model of the equatorial distribution in our calculation, we employ an expression for the horizontal density gradients given by Singh[5].

$$N\theta = Neo\ e^{a(\sin\theta - \beta)}. \quad (1)$$

Here Neo is the reference level electron density, a, an arbitrary constant whose value depends on the magnitude of the gradient to be applied, θ, the colatitude, and β, a constant whose value is given by the cosine of the latitude at 120 Km where the horizontal density gradient becomes zero. For quiet periods, the value of a is taken to be 13 between the latitude range 22° to 11° and −2 from 11° to the equator such that, at 400 Km, electron density distribution is similar to that shown by profile 'A' in Fig. 1. For disturbed periods, the value of a is taken to be 11 between the latitude range 22° to 5° and zero from 5° to the equator. This distribution is shown by 'B' in Fig. 1. The 18° field line is shown by dotted curve along which peaks of the anomaly exist. These profiles fit well with the experimentally observed integrated electron content profiles of King *et al.*[9].

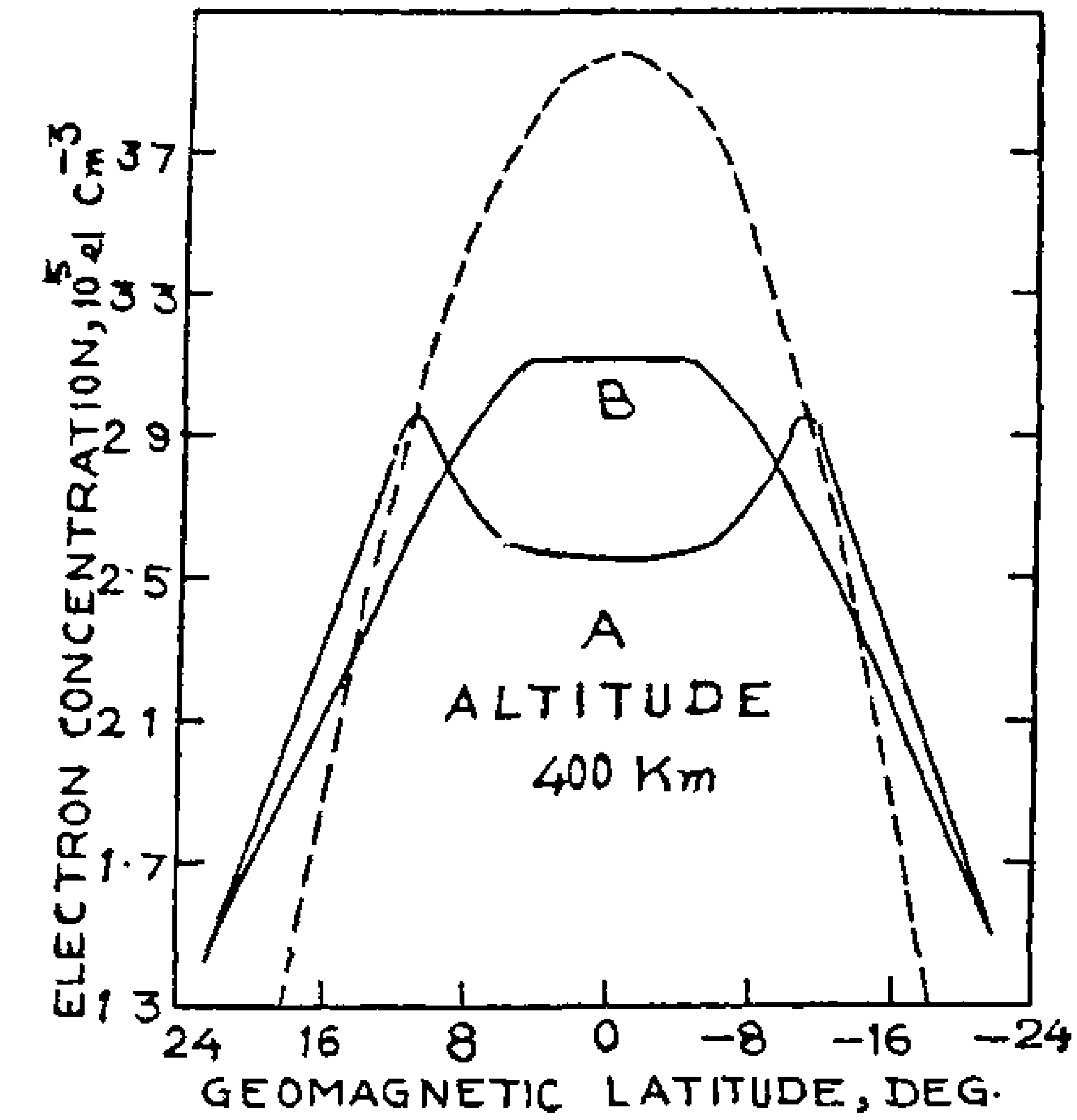

FIG. 1. Electron density distribution of the equatorial anomaly during quiet (A) and disturbed (B) periods simulated in the computations of whistler ray paths. The dotted curve indicates the field line along which quiet time equatorial anomaly exists.

2.3. *Computer Programme*

The ray tracing equations and the computer programme used by us in our calculations are similar to those employed by Taylor and Shawhan[10]. The programme was run at the IBM 360/44 computer installed at the Delhi University, Delhi.

3. Results and Discussion

3.1. *Propagation Characteristics of Day-time Whistlers*

Initially we calculate the raypaths for the waves of frequency 5 KHz in the background electron density model 2.1 which does not include equatorial anomaly. The initial latitude is chosen to be 20° at 120 Km and the initial wave-normal angle $\Delta_0 = 0°$ (Δ_0 is the angle between the vertical and the wave-normal, positive in the clockwise direction and negative in the anticlockwise direction). The computed ray path is shown in Fig. 2. We find that the initial and final latitudes (final latitude means the arrival latitude in the opposite hemisphere) of this ray path are much different from each other. Further, the final wave-normal angle (wave-normal angle at 120 Km in the opposite hemisphere) is found to be +110° which indicates that the waves corresponding to this ray path cannot penetrate the lower ionosphere to be observed on the ground.

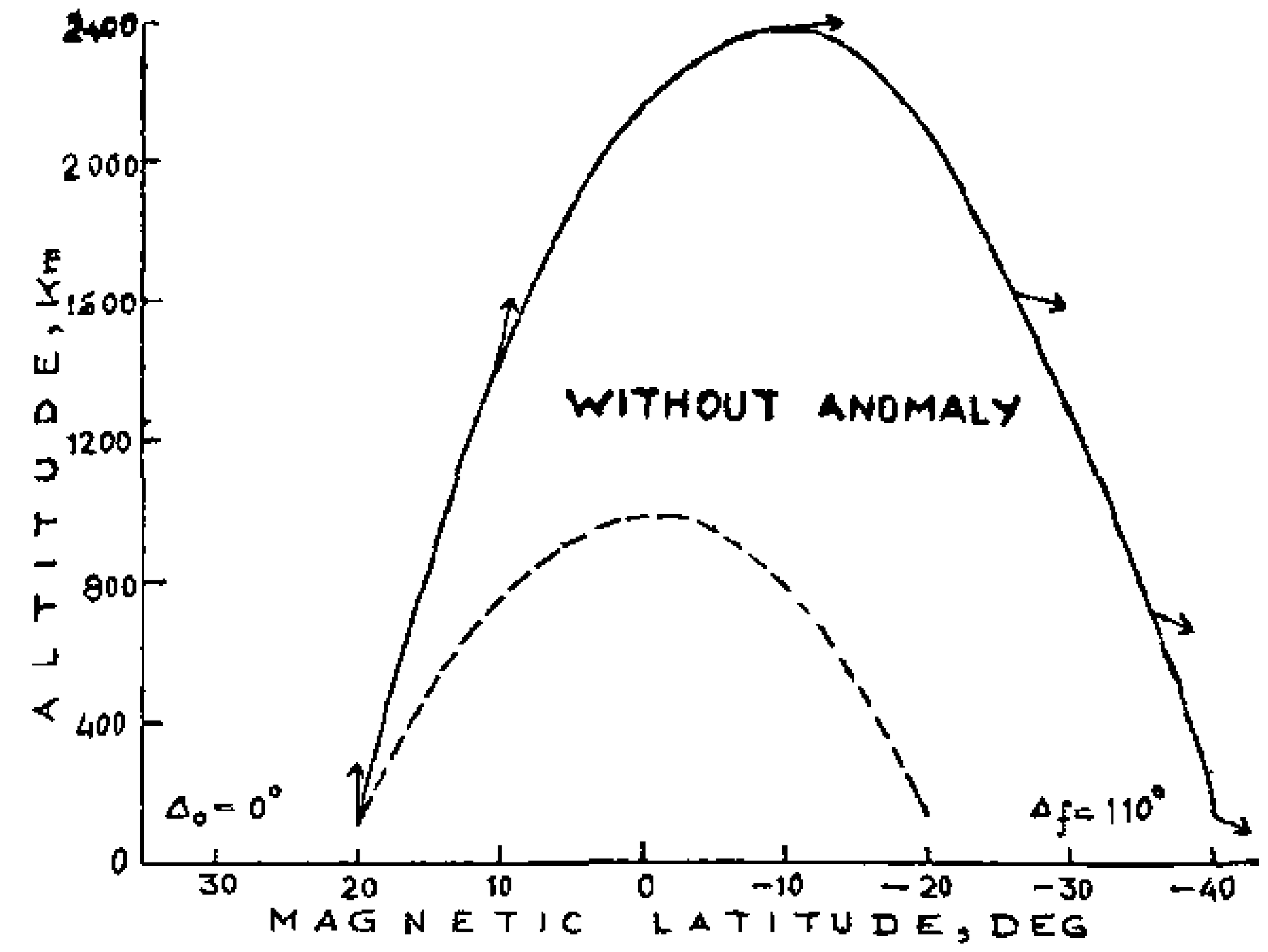

FIG. 2. The ray path for the waves of frequency 5 KHz computed in the background electron density model 2.1. The initial latitude is 20° and the initial wave-normal angle $\Delta_0 = 0°$. Arrows indicate the wave-normal directions. Dashed curve indicates the magnetic field line.

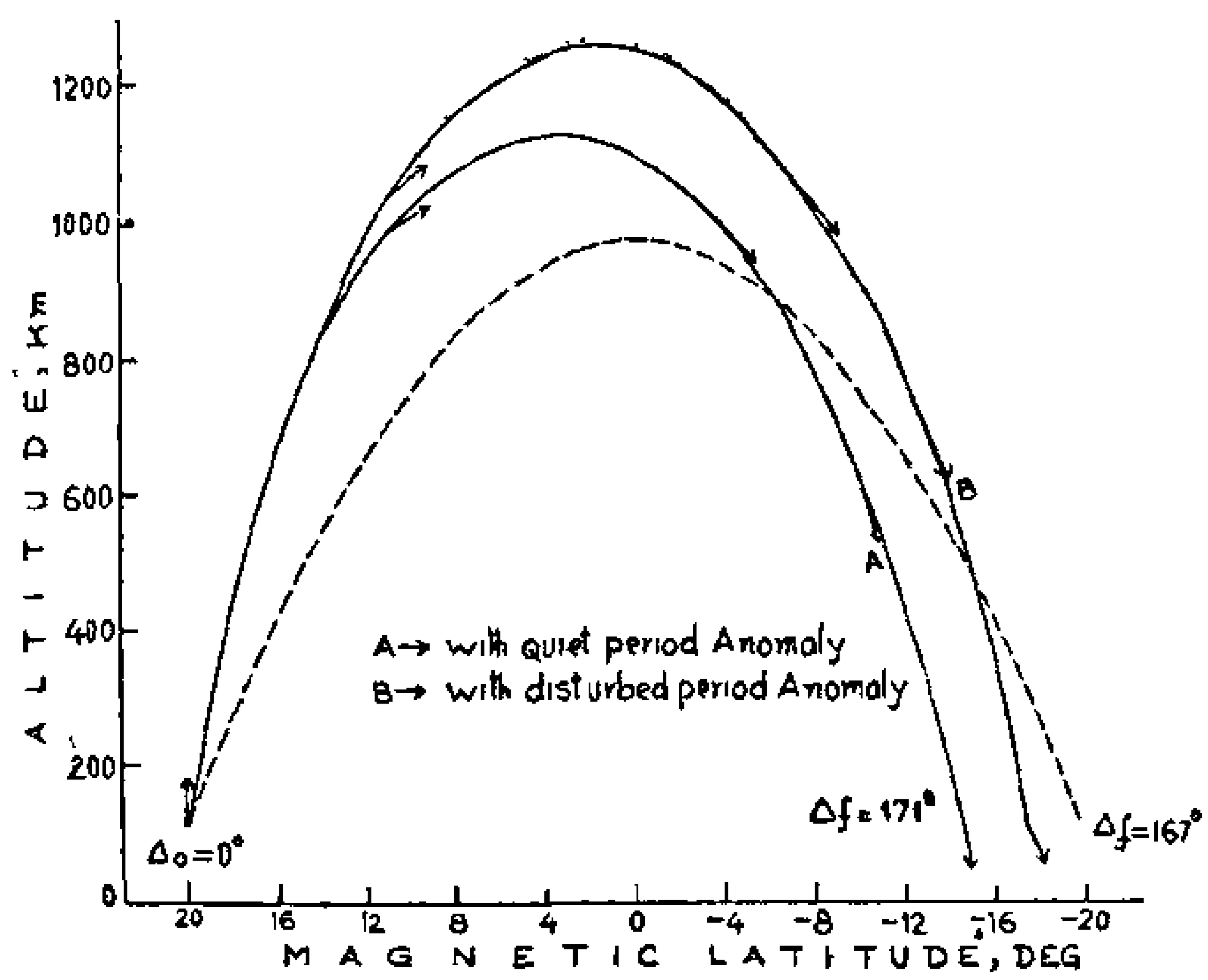

FIG. 3. The ray paths for the waves of frequency 5 KHz computed in equatorial anomaly model 'A' and 'B' for quiet and disturbed periods respectively. The initial conditions are the same as shown in Fig. 2.

Now we calculate the ray path for the same frequency in the day-time equatorial anomaly models 'A' and 'B' which correspond to the electron density distribution during quiet and disturbed periods. The initial latitude and the initial wave-normal angle are the same as taken in the calculation of the ray path of Fig. 2. The computed ray paths are shown in Fig. 3. We find that the final arrival latitudes of these ray paths are much closer to the conjugate point in the opposite hemisphere as compared to that of the ray path shown in Fig. 2. Further, the final wave-normal angles (Δf) of these ray paths are much higher than that of the ray path shown in Fig. 2. Since the necessary condition for the ground observation of such waves is that their final wave-normal angles should be about $\pm 180°$ [11], this condition is nearly satisfied by the ray paths of Fig. 3 as their final wave-normal angles are approaching this value. A small change in the value of a in equation 1 would make these wave-normal angles almost $\pm 180°$ and the corresponding waves would be observed on the ground.

3.2. *Propagation Characteristics of Night-time Whistlers*

Since the equatorial anomaly during night-time is limited to very narrow latitude range around the equator, perhaps it may not influence the propagation characteristics of low latitude whistlers. Then the question arises how the low latitude whistlers are propagated to ground stations during night-time. If these whistlers are not influenced by any horizontal density gradients existing in the ionosphere, then their propagation paths will be similar to those as shown in Fig. 2 and, as discussed earlier, such waves will not be observed on the ground. In order to solve this problem we mention here the results of Singh and Tantry[12] who have computed the ray paths of multi-flash whistlers observed in the low latitude ground station of Nainital in an ionospheric model which did not include any horizontal density gradients, but the initial wave-normal angle was chosen to be non-vertical ($\Delta_0 = 6°$). Although the wave-normals of the up-going whistler waves are normally upward at 120 Km, they may be sometimes non-vertical also as a result of refraction from sporadic E layers or from any other small scale irregularity existing in the lower region of the ionosphere[4]. Perhaps on account of these reasons, the whistler activity at low latitude ground stations during night-time and quiet periods is very low[13].

Experimental evidence has shown that during magnetically disturbed periods large negative horizontal density gradients in the ionization of the F region ionosphere exist during night-time at low latitudes[6]. Singh[5] has calculated the ray paths of whistler waves including these gradients in his ionospheric model and has explained the propagation characteristics of low latitude whistlers at the ground stations. He has also correlated the high whistler activity at the ground with the existence of negative horizontal density gradients of the ionization during the periods of magnetic disturbances. We also feel that the night-time equatorial anomaly which is limited to a narrow latitude range during quiet periods extends to a wide latitude range during disturbed periods and produces a negative horizontal density gradients in the ionization. Under the influence of such gradients the low latitude whistlers will be propagated in a manner similar to that as shown by Singh[5].

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1. Bullough, L., Hughes, A. R. W. and Kaisher, T. R., *Proc. Roy. Soc. London, A.*, 1969, **311**, 563.
2. Hayakawa, M. and Tanaka, Y., *Rep. Ion. Space Res. Japan*, 1973, **27**, 213.
3. — and Iwai, A., *J. Atmos. Terr. Phys.*, 1975, **57**, 1211.
4. Aubry, M. P., *Annals Geophys.*, 1967, **23**, 467.
5. Singh, B., *J. Geophys. Res.*, 1976, **81**, 2429.
6. Singh, D. P., Jain, S. K. and Singh, B., *Annals Geophys.*, 1978, **34**, 37.
7. Eccles, D. and King, J. W., *Proc. Roy. Soc. London, A*, 1964, **281**, 464.
8. King, J. W., Reed, G. C., Olatunji, E. O. and Legg, A. J., *J. Atmos. Terr. Phys.*, 1967, **29**, 1355.
9. Rastogi, R. G., *J. Geophys. Res.*, 1959, **64**, 729.
10. Taylor, W. W. L. and Shawhan, S. D., *J. Geophys. Res.*, 1974, **79**, 105.
11. Helliwell, R. A., *Whistlers and Related Ionospheric Phenomena*, Stanford University Press, Stanford, 1965.
12. Singh, B. and Tantry, B. A. P., *Indian J. Radio and Space Phys.*, 1972, **1**, 277.
13. Somayajulu, V. V., Rao, M. and Tantry, B. A. P., *Ibid.*, 1972, **1**, 102.