THREE-DIMENSIONAL RAY TRACING OF VERY LOW LATITUDE WHISTLER

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1. Introduction

There are two different types propagation of whistlers in the magnetosphere: the propagation trapped by field-aligned ducts, and the nonducted propagation based solely on Shell's law [1]. The ray paths of nonducted whistlers are known to deviate from the magnetic field lines. Further, the nonducted whistlers do not follow the same propagation path, so it is very difficult to explain echo-train whistlers by means of nonducted propagation[2].

Thus it is concluded that the ground-based whistlers observed at high and low latitudes are attributed to the propagation trapped in field-aligned ducts . By contrast, the enhancement factor for ordinary ducts to trap whistlers at very low latitudes is required to be much more than 100 percent, and this kind of high enhancement factor seems to be very unrealistic .

As a result, the propagation mechanism of very low latitude whistlers has recently been studied by several researchers. In 1979, Ondoh et al. concluded that the whistlers at the geomagnetic latitude of 15.3° are attributed to ducted propagation as a result of observing a considerable number of echo-train whistlers at Okinawa in Japan [3].

On the other hand, Liang et al. made the multistation network observations in South China and found that whistlers are detected during the nighttime even at the geomagnetic latitude of 5.5°. Also, they concluded that exists a favorable nonducted propagation channel at ~10° [4].

We conducted the observations at the three stations in South China, Zhanjiang (geomag. lat. 10.0° N), Guilin (14.1° N), and Wuchang (19.4° N)—covering the geomagnetic latitude range from 10° to 20° N during the period of the 5th and 11th of January 1988. This spaced direction finding measurement has shown that there exists a stable geomagnetic latitude for ionospheric penetration of whistlers, no frequency dependence on the ionospheric exist region, and strong tendency for those whistlers to propagate toward higher latitudes after the ionospheric transmission. It also was suggested that nighttime whistlers taking place at the geomagnetic latitudes of 10° to 14° are due to the field-aligned propagation [5],[6].

If we assume the ordinary ducted propagation, the enhancement factor necessary for trapping whistlers at very low latitudes is more than 100 percent. However, such an enhancement factor is never observed. So we used the three-dimensional ray tracing, including the realistic ionospheric profile with equatorial anomaly and on the IGRF magnetic field model.

2 Ionospheric model

The ionospheric model used in the ray tracing is based on the diffusive equilibrium model by assuming the ion composition and temperature at the reference height of 500 km. The electron density distribution can be described by the following general form

$$N_e(r, \theta, \phi) = N_{DE}(r) \times N_\theta \times N_L \qquad (1)$$

with the effect of the lower ionosphere. In this form $N_{DE}(r)$ is the diffusive equilibrium model , r is geocentric distance , θ and ϕ are the geographic colatitude and longitude, respectively. The factor N_θ is the negative latitude gradient given by next form.

$$N_\theta = 1.0 + C(r)\exp\{\alpha(\sin\theta - \sin\theta_0) \qquad (2)$$

Then N_L is the E-W asymmetrical distribution of density given by next form.

$$N_L = 1.0 + LG \times (\pi / 180) \times (\phi - \phi_0) \qquad (3)$$

Thought LG shows the rate of longitudinal gradient of density, we pay no attention to this parameter in this paper. Because our observation of whistlers in South China was made at mid-night. The background diffusive equilibrium model is given by T=1000°K, η_{O^+}=98.85%, η_{He^+}=1.1%, η_{H^+} =0.05%[7].

3. Ray tracing computation

We have assumed that the wave normal of the incident whistler in one hemisphere with the cone of 3 degree to vertically upward at the height of 120 km. Whether the wave propagated to the opposite hemisphere is able to penetrate through the ionosphere is determined by the analysis of wave normal direction there by the means of Shell's law. Transmission cone i is given by next form.

$$i = \cos^{-1}(\cos\delta \times \cos\varepsilon) \qquad (4)$$

Where $+\delta$ is the latitudinal angle to ward South and $+\varepsilon$ is the longitudinal angle of toward East from vertically upward, respectively.

The transmission cone is evaluated by putting $|n \sin i| < 1$, where n is refractive index at the height of 120 km and whether or not the final wave normal is within the transmission cone, determines whether or not the downgoing whistler penetrates through the ionosphere .

4. Computational results of nonducted propagation

Figure 1 illustrates the relationship between start points and penetrat point (lower figure), also indicates the condition of incident angle (upper figure), The wave started from the point of geographic latitude 0.5°S , geographic longitude 110.0°E (marked ×) penetrates with incident angle 0.1° at the opposite hemisphere, 17.23°N, 109.9°E. Another hand the wave from 0.5°S, 109.8°E (marked ◎) reflects with incident angle 1.6 ° at the same point of the opposite hemisphere. From this figure, we can easily understand there are many kind of incident waves at one point of the lower ionosphere. Some waves penertate in the lower ionosphere and another reflect. And also these source points originated from sferics are very close each other.

5. Echo-train whistler by ray tracing

As the ray paths of nonducted whistlers are deviated from the magnetic field lines, both wave normals of short whistler and echo-train whistler can not always penetrate through the ionosphere. Further the ray paths of one hop and two hops whistler are different each other, the dispersion of echo-train whistler is not three times the value of short whistler. So it is very difficult to explain echo-train whistlers by means of nonducted propagation.

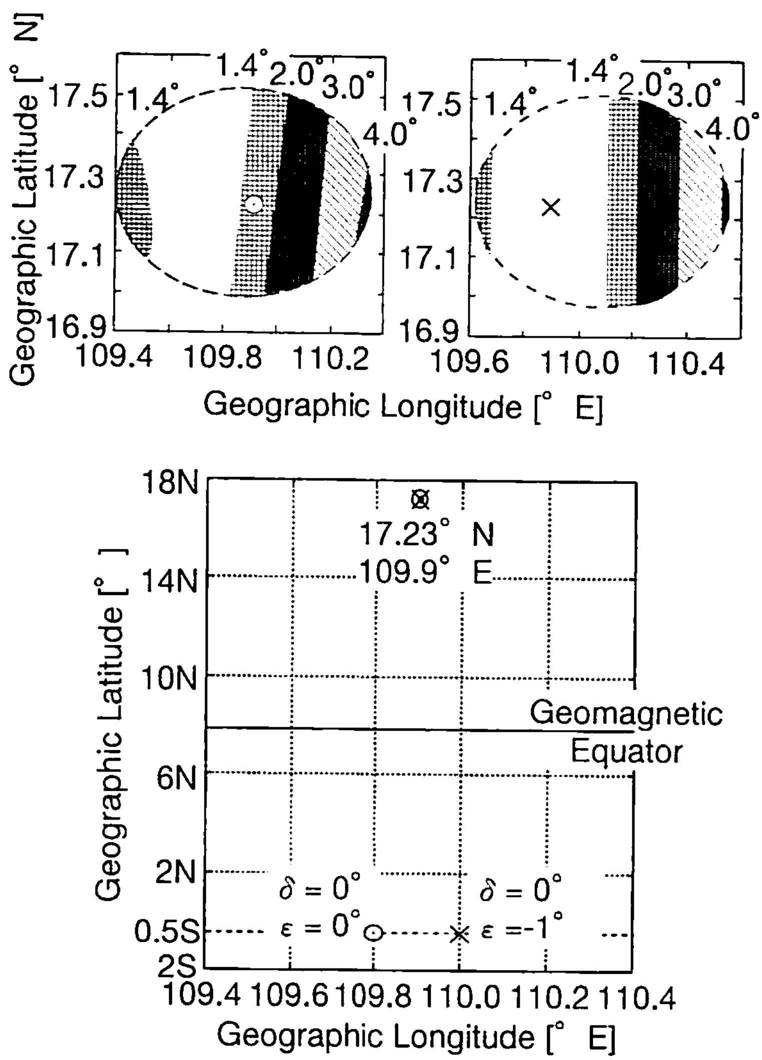

Fig.1. Relationship between initial point and final point with incident angle.

But, we consider many incident angles at 120 km ionospheric height, the possibility of echo-train whistler is occurred by three-dimensional ray tracing.

At the point of geographic latitude 0.45°S, geographic longitude 110.0°E, one whistler wave with to vertically upward (δ =0, ε =0) at the height of 120 km penetrates at the opposite hemisphere of geographic latitude 17.22°N, geographic longitude 110.1°E. The dispersion of this one hop whistler is 14.1 $s^{1/2}$. Another hand, at the point of geographic latitude 1.00°S , geographic longitude 110.0°E, another whistler wave with to vertically upward (δ =1.80°, ε =-1.60°) at the height of 120 km does not penetrate at the opposite hemisphere of geographic latitude 17.49°N, geographic longitude 109.8°E.

This whistler wave reflects with δ =5.46°, ε =0.33° at ionospheric height of 120 km, and propagates to the south hemisphere again and reaches at geographic latitude 0.56°S, geographic longitude 109.9°E. This whistler reflects at this point with δ =3.43°, ε =-1.17° and goes again to the north hemisphere as echo-train whistler. This echo-train whistler penetrates at the point of geographic latitude 17.56°N, geographic longitude 109.8°E with the incident angle of δ =-0.93°, ε =-0.10°. The dispersion of this echo-train whistler is 42.3 $s^{1/2}$. The ratio of these dispersion is just 1:3.

6. Conclusion

Three-dimensional ray tracing computations of nonducted whistlers have been made to investigate whether or not the ground-based whistlers at very low latitudes are propagated along magnetic field lines.

1.Considering the waves with the cone angle to vertically upward at the ionospheric height of 120 km by three-dimensional ray tracing, we can show the possibility of echo train whistler.

2. While nonducted whistler by two-dimensional ray tracing cannot penetrate through ionosphere at the frequency components below 2.5 kHz, the frequency components of whistler from 1 to 8 kHz calculated by this three-dimensional ray tracing can penetrate. This result supports our observational data at very low latitude in South China [8].

Using this three-dimensional ray tracing, the propagation characteristic of whistlers observed at very low latitudes (geomag.lat.,10° to 14°) in South China are well considered to be due to nonducted propagation.

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