GEOMAGNETISM AND AERONOMY, English Translation, VOL. 35, NO. 6, JUNE 1996
Russian Edition: NOVEMBER–DECEMBER 1995

Model for the height of the ionosphere maximum in main ionospheric trough zone

P. V. Kishcha and N. A. Kochenova
Institute of Terrestrial Magnetism, Ionosphere and Radio Wave Propagation, Russian Academy of Sciences

Abstract. A model for spatial-temporal variations in the height of the ionospheric $F2$ region maximum in the main ionospheric trough (MIT) zone was developed via statistical analysis of data of external sounding of the subauroral ionosphere, obtained by the Intercosmos 19 satellite. This model is based on the IRI 90 model for h_mF2 and on a set of correcting factors depending on the level of magnetic activity and invariant latitude. Correction of the global ionosphere model IRI for the MIT zone allows us to reduce modeling error by half.

Introduction

Although many papers deal with investigations of the main ionospheric trough (MIT) [*Ben'kova and Zikrach*, 1983; *Besprozvannaya et al.*, 1990; *Dedeney et al.*, 1983; *Moffett and Quegan*, 1973; *Rodger et al.*, 1992], relatively little attention is paid to variations in the height of the $F2$ region maximum h_mF2. Evidently, this lack of attention is related to the fact that capabilities of the network of ionosphere stations are limited because of the small number of stations in this region and the need for more frequent sounding when satellite data are employed. In the literature [*Ben'kova and Zikrach*, 1983; *Besprozvannaya et al.*, 1990], experimental data for h_mF2 in the MIT region are given without general analysis of h_mF2 variations. *Dedeney et al.* [1983] gave a typical scheme for isolines of the electron density in the MIT region for the southern hemisphere; however, they did not reveal any peculiarities of the h_mF2 variations. The goal of this paper is to study spatial-temporal variations in h_mF2 on the basis of the external sounding data and also to construct an analytical model.

Experimental Data

The data from external sounding from aboard the Intercosmos 19 satellite for 1980–1982 (high solar activity, Wolf number $W > 120$) were used for periods from winter to equinox in the northern hemisphere in the longitudinal sector 20 70°E. Ionograms were taken every 8 s, i.e., in intervals of about 40 km along the Earth's surface, which allowed the position and form of the MIT to be reliably determined. A total of 62 satellite flights through the MIT regions were studied, and each flight gave 20–45 ionograms, i.e., a total of 2000. We calculated altitude profiles of electron density and the height of the $F2$ region maximum via the procedure given by *Indyukov and Serebryakova* [1986], using the modified method of *Jackson* [1969].

Peculiaries of the Determination of h_mF2 From External Sounding Ionograms

Usually the height of the $F2$ region maximum is determined from the external sounding ionograms as a true height at the last frequency which can be obtained from ionograms by the procedure given by *Indyukov and Serebryakova* [1986] and *Jackson* [1969]. The obtained estimates systematically exceed the h_mF2 values determined from ionograms of vertical sounding (VS) procedure [*Gulyayeva*, 1978], in which a parabolic extrapolation of a profile form near the $F2$ region maximum is adopted [*Ben'kova et al.*, 1988]. This excess increases with latitude (see Table 1), mainly for two reasons. The first is the existence of thick $F2$ layers with small or

Table 1. Parameter Δh_m versus latitude

VS station	Geographic latitude, deg	Mean Δh_m, km
Yugorskiy Shar	70	+29
Arkhangel'sk	65	+30
Yakutsk	62	+18
Sofia	43	+18
Ashkhabad	38	+17
Tashkent	41	+17
Havana	23	+8

0016-7932/96/3506-0011$18.00/1

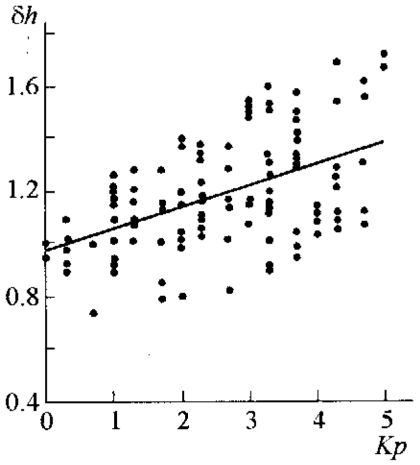

Figure 1. The $\delta h = (h_mF2)_{\text{exp}}/\overline{h_mF2}$ versus Kp index within the range $-0.5° \leq \Delta\Phi_s \leq 0.5°$ in the vicinity of the MIT minimum. Solid circles represent experimental data; the solid line demonstrates the linear approximation through the least squares procedure.

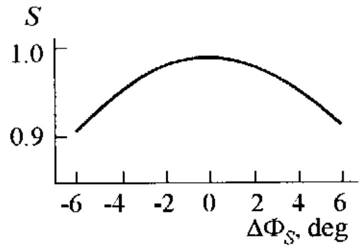

Figure 2. The function S, which demonstrates the latitudinal variations in relative values of δh, versus the MIT minimum position.

zero vertical plasma frequency gradients in the vicinity of MIT. In this case a radio pulse from an onboard ionosonde is reflected from the topside of this region, and a pulse from a ground-based ionosonde is reflected from the bottom part of the region. As a result, the difference Δh_m is dominantly positive. The second reason for overestimation of h_mF2 is high diffusivity of external ionograms. Thus the procedure suggested by *Indyukov and Serebryakova* [1986] was supplemented by a parabolic extrapolation of the form of the external ionosphere profile, as was done by *Gulyayeva* [1978], and this allowed the systematic overestimation to be reduced. To extrapolate h_mF2, we used the following formulas:

$$h_mF2 = \overline{h_mF2} + (X1 - 1)\frac{h_{30} - \overline{h_mF2}}{X1 - X2}$$

$$X1 = 1 - \sqrt{1 - \frac{\overline{N_mF2}}{N_mF2}}$$

$$X2 = 1 - \sqrt{1 - \frac{N_{30}}{N_mF2}}$$

where $\overline{h_mF2}$ is the height of the $F2$ region maximum without extrapolation and $\overline{N_mF2}$, N_mF2 and N_{30}, are the electron densities at the heights $\overline{h_mF2}$, h_mF2, and $\overline{h_mF2} + 30$ km, respectively.

Results of Statistical Analysis

Statistical analysis of h_mF2 variations, based on the external sounding data, and correlation between the experimental data and the data computed by the global ionosphere model IRI 90 permitted the following conclusions.

1. The model gives systematically underestimated values for h_mF2 in the vicinity of the MIT minimum, the average error increasing with magnetic activity.

2. In the vicinity of the MIT minimum the ratio δh of the experimental values of $(h_mF2)_{\text{exp}}$ to the calculated values $\overline{h_mF2}$ depends linearly on the magnetic activity level, characterized by a value of the Kp index. Figure 1 shows the δh distribution within the range $-0.5° \leq \Delta\Phi_s \leq 0.5°$ in the vicinity of the MIT minimum. Here $\Delta\Phi_s$ is the deviation of the invariant latitude of the sounding point from the MIT minimum position. The line demonstrates the linear approximation performed by the least squares procedure.

3. The latitudinal dependence of h_mF2 has a pronounced maximum near the MIT minimum position. Figure 2, which presents the ratio $S = \delta h/\overline{\delta h}$ dependence on $\Delta\Phi_s$, clearly demonstrates this finding. Here δh is determined at the current sounding point along the satellite orbit, and $\overline{\delta h}$ is associated with the MIT minimum position. This profile is in agreement with a typical diagram of a two-dimensional MIT section [*Dedeney et al.,* 1983] as well as with theoretical results [*Bryunelli and Namgaladze,* 1988; *Rodger et al.,* 1992; *Watkins and Richards,* 1979].

The initial heating of the thermosphere in the auroral zone, together with the increase of magnetic activity, resulting from the intensification of auroral electrojets and the absorption of energy from injected particles, forms a system of thermospheric winds directed from the heated region toward the equator. Under the action of a horizontal wind the plasma rises along the geomagnetic field lines, thereby increasing the height of the $F2$ region maximum in the MIT zone.

Analytical Model

Results of the statistical analysis form the basis for a model of spatial-temporal variations in the height of the $F2$ region maximum in the MIT zone. This model

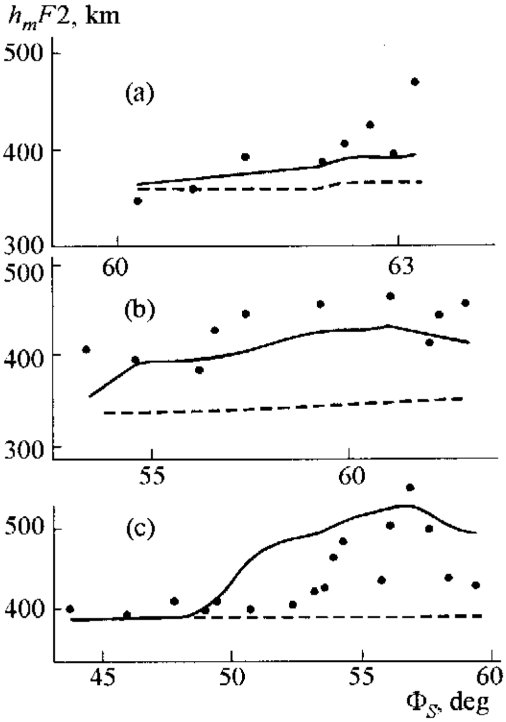

Figure 3. The h_mF2 variations versus an invariant geomagnetic latitude along the Intercosmos 19 orbit: (a) October 30, 1980, $Kp = 1+$; (b) March 18, 1981, $Kp = 3+$; and March 3, 1982, $Kp = 5-$. Circles represent experimental data; dashed lines show the data from the IRI 90 model; and solid lines show the data from the IRI model corrected for the MIT region.

uses the following analytical expressions:

$$h_mF2 = \overline{h_mF2}(\alpha + \beta Kp)S(\Delta\Phi_s)$$

$$S(\Delta\Phi_s) = \alpha_1(\Delta\Phi_s)^{\beta_1}\exp(\gamma_1\Delta\Phi_s)$$

where $S(\Delta\Phi_s)$ is a function describing latitudinal variations in relative quantities δh within the range $-6° \leq \Delta\Phi_s \leq 6°$; $\alpha = 0.971$; $\beta = 0.081$; $\alpha_1 = 0.2896 \times 10^{-1}$; $\beta_1 = 1.783$; and $\gamma_1 = -0.9006 \times 10^{-1}$. This model can be easily included in the IRI 90 model, which was done by a smooth transition from the subauroral to the middle latitudes. Figure 3 presents samples of experimental measurements of h_mF2 variations along the satellite orbit and also their simulation using the original IRI 90 model, corrected for the MIT zone at various levels of magnetic activity. We can see that the correcting procedure decreases by half the relative error of simulation.

Conclusion

A model for spatial-temporal variations in the height of the $F2$ region maximum in the MIT zone was developed as a result of statistical analysis of data from external sounding of the subauroral ionosphere. The model is based on the IRI model for h_mF2 and on a set of correcting factors depending on the magnetic activity level. The corrected model for the MIT zone allows the simulation error to be reduced by half.

Acknowledgments. This work was supported by the Russian Fund for Basic Research (grant 94-05-17352).

References

Ben'kova, N. P., and E. K. Zikrach, Main ionospheric trough from ground-based observations in the Yakutsk region, in *Physical Processes in the Main Ionospheric Trough Zone*, p. 7, GFU CSAN, Praga, 1983.

Ben'kova, N. P., et al., Altitude profiles of electron density in the auroral zone from the data of IK 19 satellite and the Yugorskiy Shar Station, *Rep. 48(802)*, 16 pp., IZMIRAN, Moscow, 1988.

Besprozvannaya, A. S., O. N. Boytman, O. M. Pirog, and T. I. Shchuka, Features of the two-dimensional electron density distribution in the high latitude ionosphere, *Issled. Geomagn. Aeron. Sol. Phys., 90*, 3, 1990.

Bryunelli, B. Y., and A. A. Namgaladze, *Ionosphere Physics*, 527 pp., Nauka, Moscow, 1988.

Dedeney, J. R., A. S. Rodger, and M. J. Jarvis, Radio studies of the main F region trough in Antarctica, *Radio Sci., 18*, 6, 927, 1983.

Gulyayeva, T. L., Fortran program for fast iterative $N(h)$ analysis of ionograms, *Rep. 1460-78*, 39 pp., Dep. VINITI, Moscow, 1978.

Indyukov, A. Y., and M. V. Serebryakova, Program for calculations of the $N(h)$ external ionosphere profiles, *Rep. 2907-B86*, 10 pp., Dep. VINITI, Moscow, 1986.

Jackson, J. E., The reduction of topside ionograms to electron density profiles, *Proc. IEEE, 57*, 6, 960, 1969.

Moffett, R. G., and S. Quegan, The midlatitude trough in the electron concentration of the ionospheric F layer: A review of observations and modeling, *J. Atmos. Terr. Phys., 35*, 2, 207, 1973.

Rodger, A. S., R. G. Moffett, and S. Quegan, The role of ion drift in the formation of ionization trough in the mid- and high-latitude ionosphere: A review, *J. Atmos. Terr. Phys., 54*, 1, 1, 1992.

Watkins, B. J., and P. G. Richards, A theoretical investigations of polar F-region ionosphere, *J. Atmos. Terr. Phys., 41*, 2, 179, 1979.

(Received January 18, 1995.)