INTERNATIONAL JOURNAL OF GEOMAGNETISM AND AERONOMY
VOL. 6, GI2006, doi:10.1029/2005GI000112, 2006

Causes of longitude-latitudinal variations in the ionospheric *F2*-layer maximum in summer nighttime conditions

A. T. Karpachev, and N. A. Gasilov[1]

Institute of Terrestrial Magnetism, Ionosphere, and Radio Wave Propagation, Troitsk, Moscow Region, Russia

Received 28 April 2005; revised 29 November 2005; accepted 20 December 2005; published 28 February 2006.

[1] The causes of longitudinal and latitudinal variations in the $F2$-layer maximum in the summer nighttime ionosphere at middle, subauroral, and auroral latitudes are investigated. To do this the following problems are solved in sequence. The longitudinal variations in h_mF2 are studied in the belt of invariant latitudes between 40° and 65° according to the Intercosmos 19 satellite data. It is shown that the longitudinal effect in the quiet ionosphere is rather stable but differs by its character in the Southern and Northern hemispheres. Considerable discrepancies between Intercosmos 19 data and International Reference Ionosphere (IRI) model are detected at high latitudes. On the basis of the longitudinal variations in h_mF2 using the servo model of the ionosphere and the Mass Spectrometer Incoherent Scatter thermosphere model, variations in the vertical drift velocity, W, caused by neutral wind are calculated. In terms of the Tikhonov regularization method, the approach to a solution of the inverse problem on deriving meridional and zonal components of the neutral wind from the longitudinal variations in W is developed. A comparison with the Horizontal Wind Model (HWM) neutral wind model is performed and an attempt to correct this model for the considered conditions is made. Estimation of the contribution of the neutral wind, composition and temperature into longitudinal and latitudinal variations in h_mF2 is performed. The causes of the asymmetry between the Northern and Southern hemispheres are discussed. *INDEX TERMS:* 2443 Ionosphere: Midlatitude ionosphere; 2481 Ionosphere: Topside ionosphere; 0355 Atmospheric Composition and Structure: Thermosphere: composition and chemistry; *KEYWORDS:* $F2$-layer dynamics; $F2$-layer height; Latitudinal variations.

Citation: Karpachev, A. T., and N. A. Gasilov (2006), Causes of longitude-latitudinal variations in the ionospheric *F2*-layer maximum in summer nighttime conditions, *Int. J. Geomagn. Aeron., 6,* GI2006, doi:10.1029/2005GI000112.

1. Introduction

[2] The longitudinal variations in the height of the midlatitudinal ionospheric $F2$ layer in both hemispheres for summer midnight conditions were revealed and studied in detail using the data of the topside sounding onboard the Intercosmos 19 satellite [*Deminov and Karpachev*, 1988; *Karpachev and Gasilov*, 1998]. Using theoretical models of the ionosphere [*Ben'kova et al.*, 1986; *Buonsanto et al.*, 1989; *Miller et al.*, 1997; *Rishbeth*, 1967; *Rishbeth et al.*, 1978], the variations in the plasma vertical drift velocity, W, induced by the neutral wind were derived from the longitudinal variations in h_mF2. Then, applying the empirical model of the thermosphere Mass Spectrometer Incoherent Scatter (MSIS), the contributions of the neutral wind, composition and temperature into the longitudinal effect (LE) were estimated [*Karpachev and Gasilov*, 1998]. Since the reliability of the repeatedly tested ionospheric models and MSIS model is beyond any doubt [see *Titheridge*, 1995], one can believe in reliability of the estimates of the contributions obtained on the basis of these models. Further, the problem of a determination of the contributions of both components of the neutral wind (zonal and meridional) was formulated [*Karpachev and Gasilov*, 2000, 2001]. It turned out that for the classical solution of this problem, the availability of h_mF2 measurements in the both coordinate systems (geomagnetic and geographic) and some additional physical assumptions are required. To overcome these difficulties, the Tikhonov reg-

[1] Also at Faculty of Engineering, Baskent University, Ankara, Turkey

1524–4423/06/2005GI000112$18.00

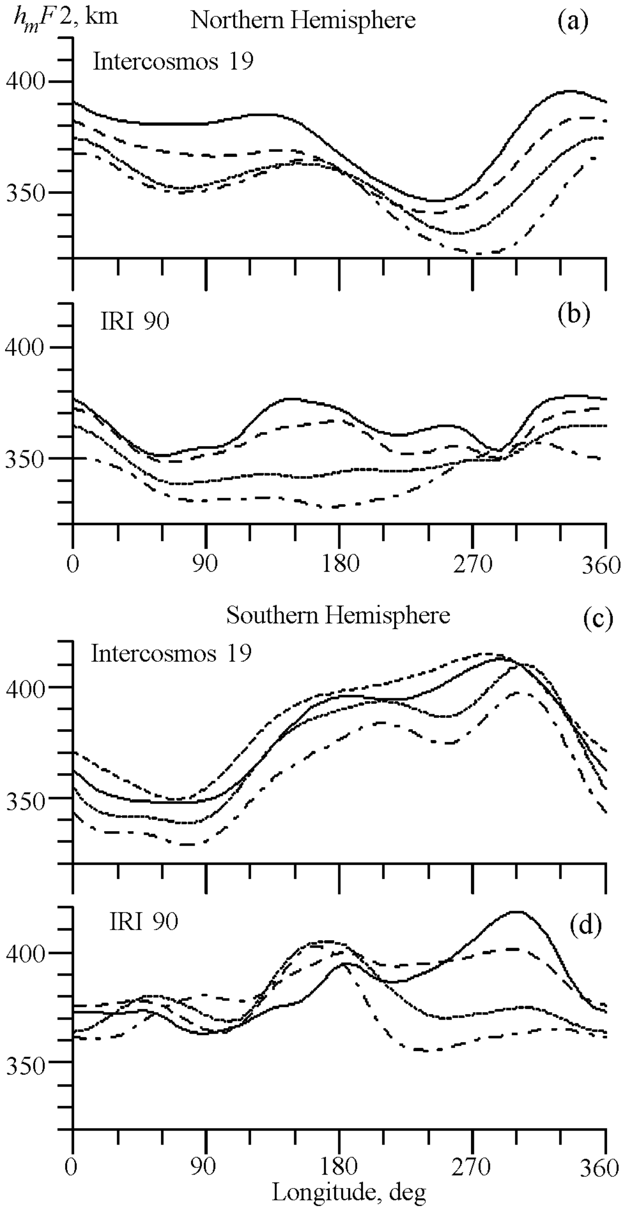

Figure 1. Longitudinal variations in h_mF2 derived from the Intercosmos 19 data for the summer near-midnight conditions at high solar activity at invariant latitudes of 40°Λ (solid curves), 50°Λ (dashed curves), 60°Λ (dotted curves), and 65°Λ (dash-dotted curves) in the (a) Northern and (c) Southern hemispheres and (b, d) from the IRI model.

ularization method [*Tikhonov and Arsenin*, 1986] was used. The approach developed on the basis of this method makes it possible to determine fairly accurately the meridional component of the neutral wind and much less reliably to determine the zonal component. In this paper we try to apply the developed approach to the analysis and evaluation of the contribution of various factors into the longitudinal and latitudinal variations in the height of the summer nighttime $F2$ layer in a broad belt of latitudes from middle to auroral ones. To estimate the contribution of the zonal component and to compare with the calculations, the neutral wind model Horizontal Wind Model (HWM) [*Hedin et al.*, 1991] is used.

2. Data of the Measurements

[3] The distributions of h_mF2 in the belt of the invariant latitudes between 40° and 65° according to the Intercosmos 19 data were built. The data cover conditions of the local summer in the Northern and Southern hemispheres during the solstices for the period with high solar activity ($F_{10.7} \sim 200$) since 1979 till 1981. The data for very quiet conditions ($AE < 300$ nT) were chosen in order to minimize the influence of the electric fields and acoustic gravity waves (AGW) and therefore to reduce the data scatter and to increase the accuracy of the representation of the h_mF2 distribution. As a result, the stable background state of the quiet ionosphere determined (as one of the factors) by the undisturbed wind system was found. About 100 and more than 60 orbits were chosen in the Northern and Southern hemispheres, respectively. The satellite orbits in both hemispheres are oriented in such a way that the local time increases with a latitude increase from ∼ 2300 LT (40°Λ) to ∼ 0100 LT (65°Λ). The local time at the fixed invariant latitude changes with the longitude also. In order to eliminate this weaker dependence, the data were corrected taking into account the diurnal variations in h_mF2 from the International Reference Ionosphere (IRI) model. The correction was carried out to the nearest hour in local time: 2300 LT for 40°Λ, 2330 LT for 50°Λ, 2400 LT for 60°Λ, and 0100 LT for 65°Λ. Thus the obtained distribution is not a LT map in a literal sense; however, all data fall into a narrow interval of the near-midnight hours, and this does not complicate strongly the analysis. The other circumstance is more important: the auroral ionosphere at 0100 LT at ∼70% of longitudes is sunlit, so in the period when at a latitude of 40°Λ purely night conditions are realized, some intermediate conditions are maintained at 65°Λ, that should be taken into account in the calculations.

[4] The data on the electron temperature T_e obtained from in situ measurements on board the Cosmos 900 satellite were also used in calculations. The measurements were conducted almost in the same conditions as the measurements of h_mF2 at altitudes of ∼370 km and ∼470 km in the Northern and Southern hemispheres, respectively [*Karpachev et al.*, 1997]. A correction of the T_e values on the altitude using the IRI model was performed in the Southern Hemisphere. The T_e distribution in the latitude belt from 40°Λ to 65°Λ was obtained by averaging of 70 and 100 satellite orbits in the Northern and Southern hemispheres, respectively.

[5] Let us consider longitude-latitudinal variations in h_mF2 at middle (40°Λ and 50°Λ), subauroral (60°Λ), and auroral (65°Λ) latitudes (see Figure 1). One can see in Figure 1 that the mean value of h_mF2 decreases at the transition from 40°Λ to 65°Λ. This decrease would be even stronger at a fixed local time, because at its change from 2300 to 0100 LT the $F2$ layer (at all latitudes) vice versa

ascents by ∼10 km compensating the h_mF2 decrease with latitude. The analysis of the Intercosmos 19 data shows that the character (amplitude and shape) of the averaged longitudinal variations in h_mF2 is very stable at the fixed latitude in spite of quite large day-to-day variations. The stability of LE is mainly a manifestation of the undisturbed wind system stability. At a transition from middle latitudes to auroral ones LE changes weakly by the amplitude which is about 45–50 km and 65–70 km in the Northern and Southern hemispheres, correspondingly. The changes in the shape of the LE are also small and manifest in an eastward shift of the phase. Let's compare the longitudinal variations in h_mF2 obtained from the Intercosmos 19 data with the h_mF2 variations according to the IRI model [*Bilitza*, 1990] obtained for the same conditions from the ground-based sounding data. The zonally averaged values of h_mF2 obtained from the topside and ground-based sounding differ only slightly (no more than 5 km). However, at some particular longitudes the difference may be considerable. The strongest discrepancies (20–30 km) occur in the Southern Hemisphere at longitudes of the Indian Ocean and Pacific Ocean, where there are no ionospheric stations. As a result IRI model does not adequately reproduce the shape of the longitudinal variations in h_mF2 in both hemispheres for the considered conditions, therefore analyzing these variations one cannot determine their causes. This can be done only using the Intercosmos 19 data what cover homogeneously all longitudes and latitudes in both hemispheres. It is worth noting, however, that both data sets distinctly reproduce a local maximum in h_mF2 at longitudes of about $150-210^\circ$ in the Southern Hemisphere.

3. Formulation of the Problem

[6] The variations in the height of the $F2$-layer maximum are mainly determined by variations in the parameters of the neutral atmosphere and plasma vertical drift induced by the thermospheric wind. The effects of the meridional and zonal components of the wind differ considerably. We will try to estimate the contribution of each factor into the longitudinal and latitudinal variations in h_mF2. We will solve the inverse problem. At the first stage we determine the variations in the velocity W of the plasma vertical drift from the known variations in h_mF2. To do this we first calculate the longitudinal variations of the balance height h_{m0} related to variations in the composition and temperature of the thermosphere. At the second stage, using the calculated longitudinal variations in W we determine the components of the neutral wind.

4. Determination of the Variations in *W* From the Variations in h_mF2

[7] The calculations were performed using the main principles ionospheric model which has been developed by *Rishbeth* [1967] and *Rishbeth et al.* [1978] and which is usually called a servo model. According to the servo model, the variations in the velocity W of the plasma vertical drift in quasi-stationary conditions are related to the variations in h_mF2 by the following formula [*Buonsanto et al.*, 1989]:

$$W = \frac{D_{am}\sin^2 I}{2H}\times$$

$$\left[\exp\frac{h_mF2 - h_{m0}}{H} - \exp\frac{-k(h_mF2 - h_{m0})}{H}\right]$$

where D_{am} is the ambipolar diffusion coefficient D_a at the h_mF2 height, H is the scale height for atomic oxygen which controls the diffusion, I is the Earth's magnetic field inclination, and k represents the scale height for the effective recombination coefficient and is equal to 1.875. The balance height, h_{m0}, is determined as a height where the following relation between the recombination and diffusion processes is fulfilled:

$$\beta = \frac{sD_a\sin^2 I}{H^2}$$

The constant s is taken equal to 0.160 and 1.077 for the nighttime and daytime conditions, respectively. The values of the atmospheric parameters for calculation were taken from the MSIS model [*Hedin*, 1991], and the values on T_e were taken from the Cosmos 900 data [*Karpachev et al.*, 1997].

[8] The variations in the balance height h_{m0} are mainly determined by the changes in the composition and temperature of the thermosphere and are described in the following way [*Karpachev and Gasilov*, 1998]:

$$h_{m0} = h_0 + c_1T_n\left[\ln\frac{[\mathrm{O}]_0\beta_0T_n^2(T_n+T_i)^{1/2}}{(T_e+T_i)\sin^2 I} - c_2\right] \qquad (1)$$

where h_0 is some reference height (in the calculations it was taken $h_0 = 300$ km), β_0 is the recombination coefficient at the height h_0, and c_1 and c_2 are constants. Since all the parameters in (1) depend on longitude, h_{m0} depends on longitude also. Taking into account that one can rewrite (1) in a form more simple and convenient for the analysis:

$$h_{m0} = h_0 + c_1T_n\left[\ln\frac{[\mathrm{O}]_0[\mathrm{N}_2]_0T_n^{7/2}}{\sin^2 I} - c_3\right]$$

[9] Determination of the balance height h_{m0} raises no difficulties for purely daytime or nighttime conditions, when according to the servo model the coefficient s takes the values 1.077 or 0.160, correspondingly. However, as it has been noted above, the auroral ionosphere in summer near-midnight conditions is partly sunlit ($Z_\odot \le 95^\circ$). So in calculations of h_{m0} for invariant latitudes 60° and 65°, the values of the coefficient s were determined depending on the illumination level using a linear interpolation between the daytime and nighttime values. Such procedure provides smooth variations in h_{m0} with longitude, because transferring from the nighttime to the daytime conditions the average value of h_{m0} decreases but the character of its longitudinal variations does not change strongly.

5. Determination of the Meridional and Zonal Wind From the Longitudinal Variations in *W*

[10] The velocity of the plasma vertical drift caused by the neutral wind is described by the known relation:

$$W = -0.5(U \sin D + V \cos D) \sin 2I \quad (2)$$

where U is the zonal (positive eastward) and V is the meridional (positive northward) components of the wind, and I and D are the inclination and declination of the magnetic field, correspondingly. Then one can try to solve the inverse problem: using the known variations in the plasma vertical drift W with longitude, λ, to determine both components of the neutral wind with the accuracy up to the first Fourier harmonics. To do this, we expand the right-hand and left-hand parts of equation (2) into a finite Fourier series:

$$V = V_0 + V_c \cos \lambda + V_s \sin \lambda$$

$$U = U_0 + U_c \cos \lambda + U_s \sin \lambda \quad (3)$$

[11] It is known that the geomagnetic field parameters are well enough determined by two harmonics of the Fourier expansion:

$$0.5 \sin 2I \sin D =$$

$$s_0 + s_1^c \cos \lambda + s_1^s \sin \lambda + s_2^c \cos 2\lambda + s_2^s \sin 2\lambda$$

$$0.5 \sin 2I \cos D =$$

$$c_0 + c_1^c \cos \lambda + c_1^s \sin \lambda + c_2^c \cos 2\lambda + c_2^s \sin 2\lambda \quad (4)$$

[12] Then according to (2), the variations in the plasma vertical drift W should be described by three harmonics of the Fourier series. If one substitutes relations (3) and (4) into equation (2) and equalizes the corresponding terms, we obtain the equation system:

$$A\mathbf{v} = \mathbf{w} \quad (5)$$

where $\mathbf{v} = (V_0, V_c, V_s, U_0, U_c, U_s)^T$, $\mathbf{w} = (W_0, W_1^c, W_1^s, W_2^c, W_2^s, W_3^c, W_3^s)^T$ and A is the matrix of the 7×6 dimension, its elements depend only on the magnetic field parameters.

[13] System (5) consists of 7 linear algebraic equations in 6 unknowns. In a classical sense it can have an infinite number of solutions, one solution (when one of the equations is a linear combination of 6 others) or no solutions at all. Note that vector $\mathbf{w}$ is determined experimentally and contains some errors. As a result, the classical solution of the system (even if it does exist) may describe the physical situation inadequately. However, we can try to find a normal solution [*Tikhonov and Arsenin*, 1986]. The vector with a minimal norm among those vectors for which the difference between the right-hand and left-hand parts of the system is minimal (such vectors are called pseudosolutions) is called a normal solution. It is known [*Tikhonov and Arsenin*, 1986] that the normal solution for system (5) exists and is unique. However, a determination of the normal solution is an incorrect problem: small changes (errors) in the input data (i.e., in the $\mathbf{w}$ vector) may cause rather large changes in the solution. To find a normal solution stable to small perturbations of the right-hand side of system (5), the Tikhonov regularization method [*Tikhonov and Arsenin*, 1986] was applied.

[14] The calculations performed have shown that the regularization method provides a stable solution for the meridional component of the wind V in the entire latitudinal belt considered, whereas for adequate determination of the zonal component U the accuracy in determination of the longitudinal variations in h_mF2 is not sufficient. Therefore the neutral wind model HWM [*Hedin et al.*, 1991] is used in subsequent calculations. Currently, it is the only global empirical model of the neutral wind so it is often used for calculations and comparisons with measurements. As a rule, a good agreement with both calculations and other measurements is noted. That raises some doubts, taking into account large inaccuracy of measurements of the wind velocity (by all methods) and insufficiently large data set used for the model elaboration (especially in the Southern Hemisphere) [*Hedin et al.*, 1991]. Therefore the calculations were performed in order to determine how accurate the winds components obtained from the HWM model describe the longitudinal and latitudinal variations in h_mF2. For this purpose the direct problem was solved: first longitudinal variations in the vertical drift W were calculated on the basis of the model values of the wind components, and then, using the servo model the longitudinal variations in h_mF2 were calculated. The results of the calculations are shown in Figures 2 and 3. Comparing Figures 2a and 3a to Figures 1a and 1c, correspondingly, one can see that the longitudinal variations in h_mF2 obtained on the basis of HWM model differ strongly in shape from the experimental ones (especially at high latitudes of the Southern Hemisphere) as one could have expected. Thus the HWM model, on the whole, inadequately reproduces the longitudinal variations in the neutral wind. On the other hand, the considered average values of h_mF2 are similar, and the local maximum in the meridional wind at longitudes about $180 - 240°$ in the Southern Hemisphere is again observed (see Figure 3c).

[15] We tried to correct the HWM model using reliable measurements of h_mF2 and applying the thermospheric and ionospheric models well recommended. We used the fact that the main contribution into the h_mF2 variations is provided by the meridional component, whereas even strong changes in the zonal component of the wind weakly influence these variations [*Karpachev and Gasilov*, 2000]. The longitudinal variations in the zonal component of the wind calculated using the HWM model, were presented by one first harmonic, because taking into account the higher harmonics would exceed the measurement accuracy. Using the smoothed zonal wind and applying the regularization method, we determined the variations in the meridional component of the wind describing most accurate the experimental values of h_mF2.

[16] Figures 4 and 5 show the longitudinal variations in

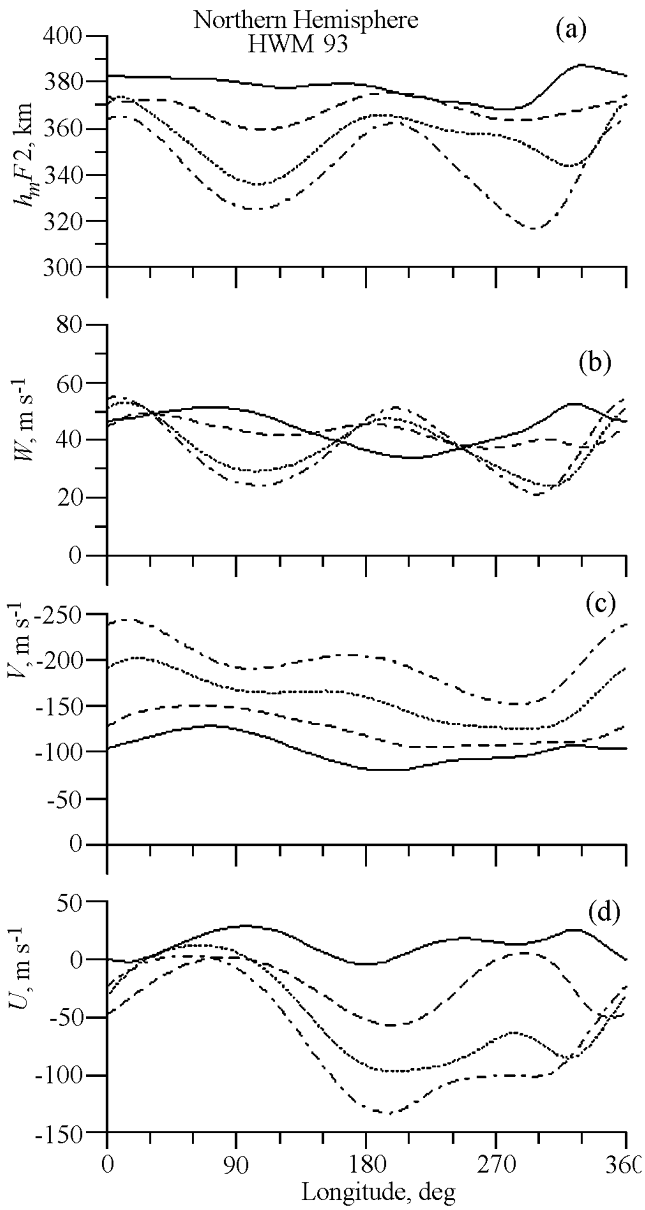

Figure 2. Longitudinal variations in (a) h_mF2 and (b) velocity of the plasma vertical drift, W, at latitudes of 40°Λ (solid curves), 50°Λ (dashed curves), 60°Λ (dotted curves), and 65°Λ (dash-dotted curves) in the Northern Hemisphere calculated taking into account (c) the meridional V and (d) zonal U wind according to the HWM model.

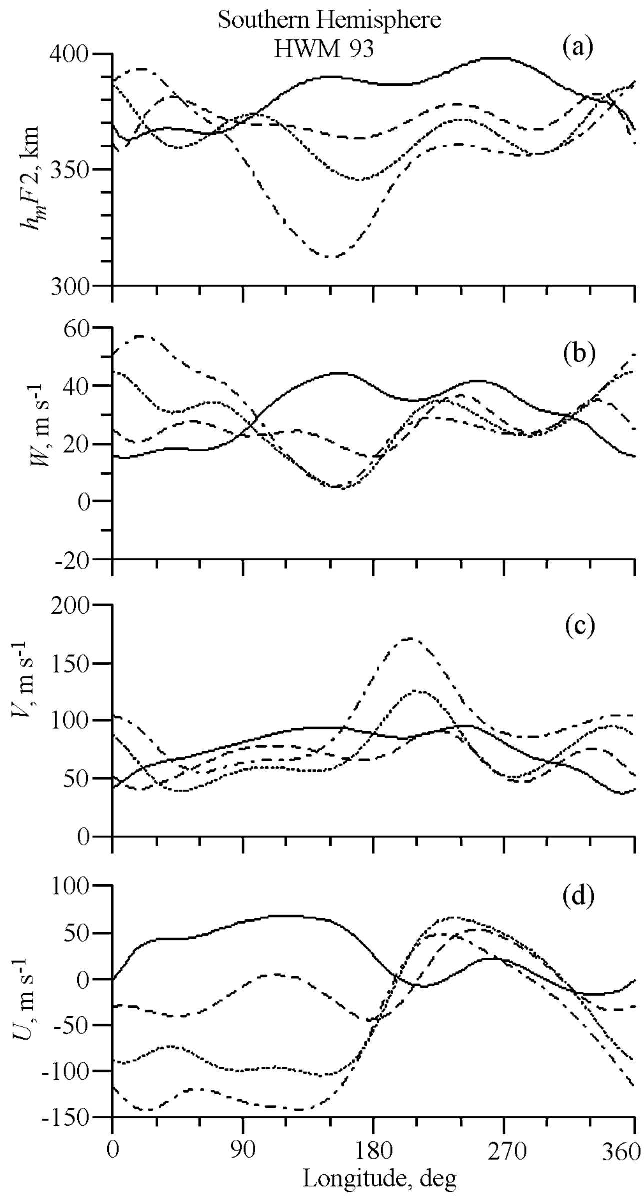

Figure 3. Same as in Figure 2 but for the Southern Hemisphere.

h_mF2 according to the data of the Intercosmos 19 satellite (Figures 4a and 5a), calculated longitudinal variations in W (Figures 4b and 5b), calculated meridional component of the wind (Figures 4c and 5c), and smoothed zonal component of the wind for invariant latitudes 40°, 50°, 60° and 65° in the Northern and Southern hemispheres, respectively (Figures 4d and 5d). The obtained system of the winds reproduces the longitudinal variations in h_mF2 in the entire region of the considered latitudes fairly well. For comparison, Figure 4b shows also the value of W obtained for the considered conditions at the Millstone Hill radar (54°Λ, 289°E) [*Buonsanto and Witasse*, 1999]. This value is approximately in the middle between the values calculated for 50°Λ and 60°Λ, that is a partial proof of the correctness of the calculations performed. Thus the global topside sounding data can be used for a correction of the neutral wind model.

6. Discussion

[17] The $F2$-layer height may be approximately presented as $h_mF2 = h_{m0} + \alpha W$. The α coefficient varies from 0.95 to

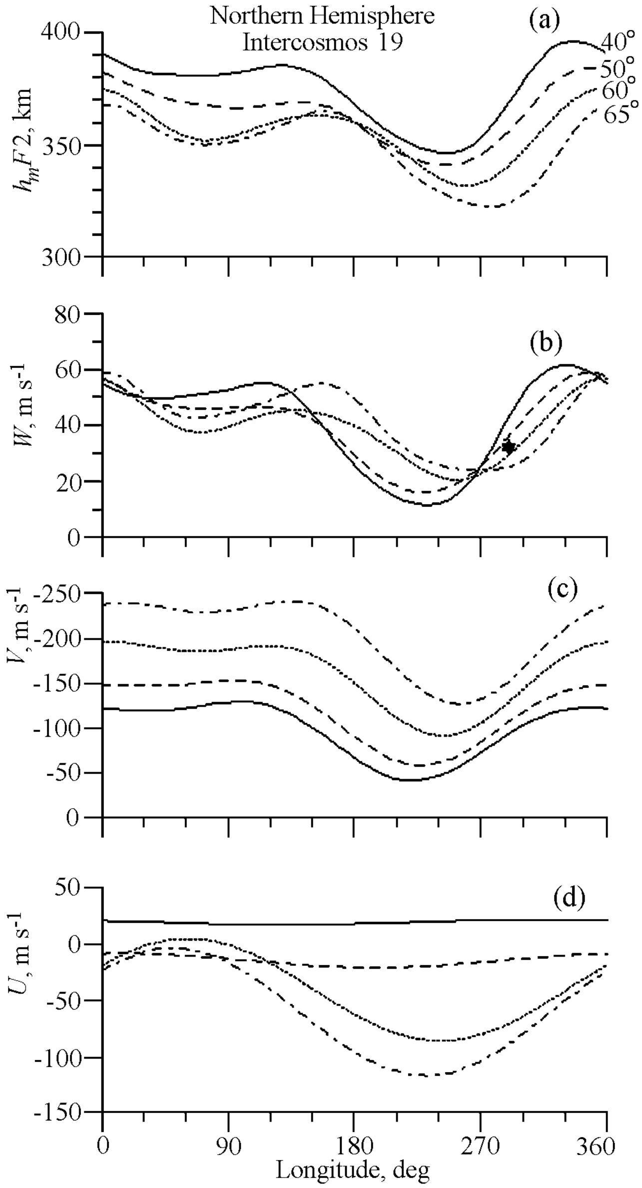

Figure 4. Longitudinal variations in (a) h_mF2 derived from the Intercosmos 19 data, calculated on the basis of these data variations in (b) the vertical drift W and (c) meridional wind V and (d) smoothed first harmonic of the variations in the zonal wind U from the HWM model at latitudes of 40°Λ (solid curves), 50°Λ (dashed curves), 60°Λ (dotted curves), and 65°Λ (dash-dotted curves) in the Northern Hemisphere. Asterisk shows the value obtained from the Millstone Hill radar data [*Buonsanto and Witasse*, 1999].

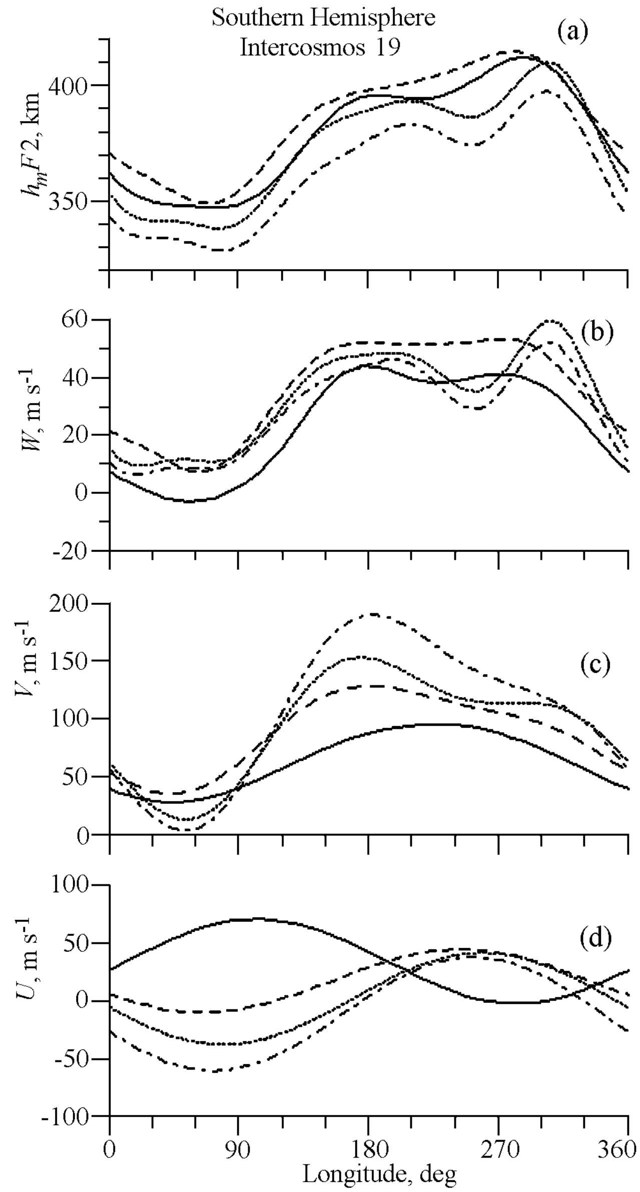

Figure 5. Same as in Figure 4 but for the Southern Hemisphere.

1.17 and therefore weakly influences the contribution of W. We analyze first the effect of the thermospheric parameters on the h_mF2 variations. To do this we consider the longitudinal variations in T_n, [O], [N_2], and the balance altitude h_{m0} for fixed invariant latitudes 40°, 50°, 60° and 65° by the example of the Southern Hemisphere (Figure 6). Zonally averaged values of the parameters we will denote by the line on the top. The averaged values of h_mF2, h_{m0}, and αW for the Southern and Northern hemispheres are presented in Table 1.

[18] One can see from Figure 6 that the average values of T_n (i.e., $\overline{T_n}$) in the Southern Hemisphere increase with an increase in latitude from 40° to 65° by ∼180 K, whereas the product $\overline{[O]} \times \overline{[N_2]}$ almost does not change, because $\overline{[N_2]}$ increases with latitude and $\overline{[O]}$ decreases proportionally. In spite of the increase in $\overline{T_n}$, the balance altitude $\overline{h_{m0}}$ decreases with latitude by 26 km (see Table 1) as a result of the transition from the nighttime conditions to the daytime conditions. The height $\overline{h_mF2}$ decreases by 18 km, this fact demonstrates that the contribution of the vertical drift

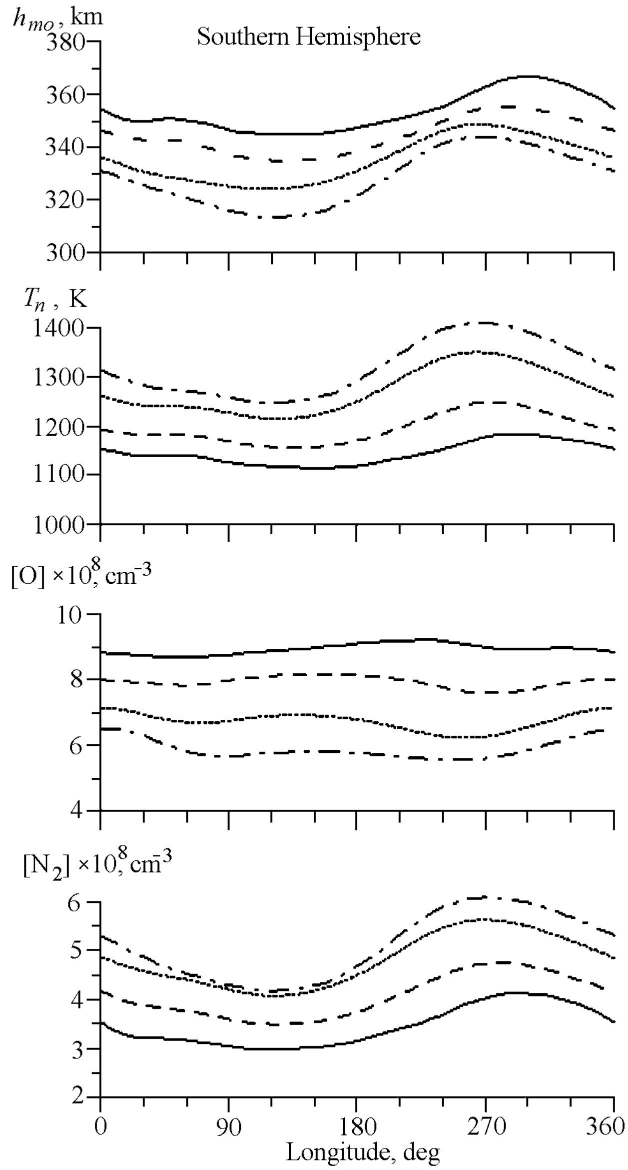

Figure 6. Longitudinal variations in the calculated (a) balance altitude h_{m0}, (b) temperature T_n, and concentrations of (c) [O] and (d) [N_2] at a height of 300 km according to the MSIS model for the summer near-midnight conditions at invariant latitudes of 40°Λ (solid curves), 50°Λ (dashed curves), 60°Λ (dotted curves), and 65°Λ (dash-dotted curves) in the Southern Hemisphere.

into $\overline{h_mF2}$ increases by 8 km. In the Northern Hemisphere, $\overline{h_mF2}$ decreases by 26 km at the transition from middle to high latitudes, $\overline{h_{m0}}$ decreases by 32 km and therefore the contribution of the wind into $\overline{h_mF2}$ increases by 6 km (see Table 1).

[19] The value $\overline{\alpha W} \simeq \overline{V \cos D \sin 2I}$, so the average velocity of the meridional wind $\overline{V}$ increases strongly at approaching high latitudes to compensate the decrease in the average value of the product $\overline{\cos D \sin 2I}$ (by factors of 2.4 and 1.9 in the Northern and Southern hemispheres, respectively) and to provide the increase in $\overline{W}$. That is what is actually observed in Figures 4c and 5c.

[20] The longitudinal variations in the temperature of the thermosphere T_n follow by shape the variations of the geographic latitude φ at a fixed invariant latitude, they are small in amplitude and insignificantly increase with an increase in latitude (from $0.06\overline{T_n}$ to $0.14\overline{T_n}$) (Figure 6). Almost the same is true for the longitudinal variations in the product [O] × [N_2] what determines the contribution of the thermospheric composition into variations in h_mF2 and also slightly increases with an increase in latitude (from 35% to 38% relative to the mean value of [O] × [N_2]). Therefore the increase in the LE amplitude in h_{m0} (from ~22 km at 40° to ~31 km at 65°) is not determined by these factors, but is related mainly to the variations in the illumination conditions both with latitude and longitude. In the Northern Hemisphere the difference between the geomagnetic and geographic poles is less, so these variations are also less and the amplitude of LE in h_m0 changes slightly (from 13 to 16 km). At such values of the LE amplitude in h_{m0}, its contribution into the longitudinal variations in h_mF2 in the Northern Hemisphere is about 25% and almost does not change with latitude, whereas in the Southern Hemisphere this contribution increases with latitude from 30% to 40%. Thus the changes in the average value of h_mF2 with latitude are mainly provided by variations in the balance height, whereas the longitudinal variations in h_mF2 are caused for the most part by the drift.

[21] Now we consider changes with latitude in the contribution of the both wind components into the longitudinal variations in h_mF2. According to (2) the contribution of the meridional wind component may be presented as $\overline{a}\tilde{V} + \tilde{a}\overline{V} + \tilde{a}\tilde{V} \sim \overline{a}\tilde{V} + \tilde{a}\overline{V}$, where $\overline{V}$ is the zonally averaged value of V, $\tilde{V}$ is its variations with longitude, and similar designations are introduced for the value $a = 0.5 \cos D \sin 2I$. The product $\overline{a}\tilde{V}$ provides the most significant contribution into the longitudinal variations in h_mF2. However, in the Northern Hemisphere it decreases sharply toward high latitudes since the mean value of $\cos D \sin 2I$ decreases in amplitude by a factor of 2.4 and the amplitude of LE in the meridional wind component increases insignificantly. The weakening of the effect of $\tilde{V}$ in the Northern Hemisphere is partly compensated by the effect of $\overline{V}$, because both multipliers of the product $\tilde{a}\overline{V}$, increase toward high latitudes. The wind in the Southern Hemisphere behaves in such a way that the contributions of $\overline{V}$ and $\tilde{V}$ almost do not change with latitude.

[22] The neutral wind is generated by the solar heating of the thermosphere and is governed by the ion drag. Since $N_i \sim \sin D$, one may assume that the longitudinal variations in the meridional wind in the geomagnetic coordinate system are determined as some combination $c\varphi + d \sin D$, where φ is geographic latitude. The analysis shows that one can adjust the c and d coefficients in such a way that the dependencies similar to those in Figure 4c would be obtained. However, those are only quantitative considerations. Determination of the causes of LE in the neutral wind velocity needs a special analysis. The longitudinal variations in the meridional wind in the Southern Hemisphere calculated on the basis of h_mF2 data differ rather strongly by shape from the variations in

Table 1. Variations in the Average Ionosphere Parameters With Latitude

Latitude	Northern Hemisphere			Southern Hemisphere		
	$\overline{h_mF2}$	$\overline{h_{m0}}$	$\overline{\alpha}\overline{W}$	$\overline{h_mF2}$	$\overline{h_{m0}}$	$\overline{\alpha}\overline{W}$
40°	375	335	40	379	354	25
50°	364	324	40	385	345	40
60°	355	313	43	373	335	38
65°	349	303	46	361	328	33

the HWM model; however, in the longitudinal variations of all parameters in Figure 5, a local maximum at longitudes of 150–210° is clearly pronounced. Thus a regional peculiarity in the wind system in the Southern Hemisphere takes place and needs explanation.

[23] Similarly, the contribution of the zonal component of the wind is determined by the expression $\overline{b}\tilde{U} + \tilde{b}\overline{U} + \tilde{b}\tilde{U} \sim \tilde{b}\overline{U} + \tilde{b}\tilde{U}$ where $b = 0.5 \sin D \sin 2I$. The longitudinal variations in the product $\sin D \sin 2I$ slightly vary with latitude by both the shape and amplitude, therefore the changes of the contribution of the zonal component are determined mainly by its own changes. In both hemispheres with an increase in latitude, the direction of the zonal wind changes from the eastward to westward. As a result, the contribution of the zonal wind into drift variations is positive at middle latitudes but at high latitudes becomes negative and causes to a decrease of the LE amplitude (especially strong in the Southern Hemisphere). Thus, though the average values of the amplitude of the longitudinal variations in the neutral wind components increase at a transition from middle latitudes to high latitudes, the relative contribution of the wind into the longitudinal variations in h_mF2 slightly decreases. In the Northern Hemisphere it is mainly due to the decrease of the contribution of the longitudinal variations in the wind meridional component, whereas in the Southern Hemisphere it is related to the change in the zonal wind direction. This decrease in the contribution of the wind is compensated by the increase of the contribution of $\tilde{h}_{m0}$, so finally the LE amplitude in h_mF2 almost does not change with latitude.

[24] The comparison of the variations in h_mF2 in the Northern and Southern hemispheres shows the presence of a strong asymmetry. The longitudinal variations in the height of the $F2$-layer maximum are stronger by amplitude in the Southern Hemisphere and at the first approximation are described by one first harmonic, whereas in the Northern Hemisphere they are described by two harmonics comparable by magnitude. The obtained results make it possible to understand more clearly the causes of the asymmetry. At a fixed geomagnetic latitude, the variations in geographic latitude govern the longitudinal variations in the thermospheric composition. These variations are stronger in the Southern Hemisphere than in the Northern Hemisphere and differ by the sign, this determines the great difference in the h_{m0} variations. The asymmetric action of the wind is mainly determined by the magnetic field declination D. The variations in $\sin D$ determine domination of the first harmonic in the Southern Hemisphere and the presence of two harmonics in the Northern Hemisphere. In the Northern Hemisphere, atmospheric parameters are often characterized by two harmonics too; this is evidence of an inverse influence of the ionosphere on the thermosphere, probably, via ion drag. Finally, a strong impact is provided by the longitudinal variations in the neutral wind velocity. However, the causes of the longitudinal variations in the both components of the wind are not known, so the problem of the asymmetry is not solved completely.

7. Conclusions

[25] The representative data of the Intercosmos 19 satellite and the technique of calculations developed make it possible to find the main factors and to estimate the contribution of each into variations in h_mF2 at middle, subauroral, and auroral latitudes. The approach is tested using the summer near-midnight conditions, but one can solve similar problem for any other conditions. Now we formulate the main results of the studies carried out.

[26] The distributions of the height of the $F2$-layer maximum within the invariant latitude belt from 40° to 65° in the both hemispheres for the summer nighttime conditions were built. The data from the topside sounding onboard the Intercosmos 19 satellite were carefully selected for very quiet conditions to minimize the influence of the electric fields and AGW. This made it possible to derive stable longitudinal variations in h_mF2 related to the stable system of neutral winds. The character of LE in h_mF2 varies slightly at the transition from middle to auroral latitudes and its amplitude is about 45–50 km in the Northern Hemisphere and 65–70 km in the Southern Hemisphere. The IRI model does not adequately reproduce the h_mF2 variations at high latitudes and needs further correction.

[27] On the basis of the approach developed by *Karpachev and Gasilov* [2000] the inverse problem was solved: using the longitudinal variations in the plasma vertical drift velocity W calculated from h_mF2 by means of the servo model of the ionosphere, the meridional and zonal components of the neutral wind for the fixed invariant latitudes 40°, 50°, 60°, and 65° were calculated with the accuracy up to the first harmonic. The approach is based on the expansion into the finite Fourier series of the longitudinal variations in W, geomagnetic field parameters, and wind velocity and on solution of the obtained system of algebraic equations by the Tikhonov regularization method. The calculations performed by this method show that there is a stable solution

for the meridional wind, whereas the accuracy of derivation of the longitudinal variations in h_mF2 is not enough for an adequate determination of the zonal wind.

[28] The direct problem was also solved: using the HWM model of the neutral wind, servo model of the ionosphere, and MSIS thermospheric model, variations in h_mF2 for the considered conditions were calculated. It was shown that the HWM model inadequately reproduces the h_mF2 variations, especially in the Southern Hemisphere where the model is based on a limited set of data. A correction of the HWM model for the considered conditions was performed: the zonal component of the wind was smoothed by one first harmonic and the meridional component was calculated by the regularization method. The wind system obtained in such a way reproduces fairly accurately the longitudinal and latitudinal variations in h_mF2 in the entire belt of the latitudes considered. Therefore the global data of the topside sounding can be used for correction the neutral wind model, such correction being an actual task because of a serious lack in the wind velocity measurements.

[29] The analysis performed makes it possible to find the main factors which determine the longitudinal and latitudinal variations in h_mF2 in the summer nighttime conditions and to estimate the contribution of each factor into these variations. At middle latitudes, the temperature of the neutral atmosphere T_n and plasma vertical drift W induced by the neutral wind are the main factors. The contributions of these factors are from 25% to 30% and from 70% to 75% correspondingly. The meridional wind component provides a larger contribution into the wind effect than the zonal component ($\sim$ 80% and $\sim$ 20%, correspondingly). With an increase in latitude, the relative contribution of the wind into the longitudinal variations in h_mF2 decreases slightly, although both the mean values of the neutral wind components and the amplitudes of their longitudinal variations increase. This is mainly due to a decrease of the contribution of the wind meridional component into the drift longitudinal variations in the Northern Hemisphere, whereas in the Southern Hemisphere this is related to the reverse of the zonal wind direction. However, the decrease of the wind contribution is compensated by the increase in the contribution of $\tilde{h}_{m0}$; so finally the LE amplitude in h_mF2 almost does not change with latitude.

[30] The results obtained promote a deeper understanding of the causes of the asymmetry between the ionospheric parameters in the Northern and Southern hemispheres. In the geomagnetic coordinate system the different geometry of the magnetic field in different hemispheres manifests mainly in the effect of the neutral wind via the variations in the magnetic field inclination. The difference between the geomagnetic and geographic coordinates manifests mainly in variations in h_{m0} via the longitudinal variations in the composition and temperature of the thermosphere. As for the longitudinal variations in the wind velocity, they are practically unexplored and so it is too early to consider a complete understanding of a problem of the asymmetry.

References

Ben'kova, N. P., M. G. Deminov, and N. A. Kalifarska (1986), *Analytical model of the night-time mid-latitude F2-region, Preprint 17 (631)* (in Russian), 14 pp., IZMIRAN, Moscow.

Bilitza, D. (1990), *International Reference Ionosphere 1990, Rep. 90-22,* Natl. Space Sci. Data Cent., Greenbelt, Md.

Buonsanto, M. J., and O. G. Witasse (1999), An updated climatology of thermospheric neutral winds and F-region ion drifts above Millstone Hill, *J. Geophys. Res., 24*(11), 24,675.

Buonsanto, M. J., J. E. Salah, K. L. Miller, W. L. Oliver, R. G. Burnside, and P. G. Richards (1989), Observations of neutral circulation at mid-latitudes during the equinox transition study, *J. Geophys. Res., 94*(12), 16,987.

Deminov, M. G., and A. T. Karpachev (1988), Longitudinal effect in the night-time mid-latitude ionosphere according to the Intercosmos 19 satellite data, *Geomagn. Aeron.* (in Russian), *28*(1), 76.

Hedin, A. E., M. A. Biondi, and R. G. Burnside (1991), Revised global model of thermospheric winds using satellite and ground-based observations, *J. Geophys. Res., 96*(5), 7657.

Karpachev, A. T., and N. A. Gasilov (1998), Variations in the plasma vertical drift with longitude in the night-time summer ionosphere calculated on the basis of the h_mF2 measurements, *Geomagn. Aeron* (in Russian), *38*(5), 89.

Karpachev, A. T., and N. A. Gasilov (2000), Derivation of the zonal and meridional components of the neutral wind from the longitudinal variations in h_mF2, *Geomagn. Aeron.* (in Russian), *40*(4), 79.

Karpachev, A. T., and N. A. Gasilov (2001), Zonal and meridional wind components derived from Intercosmos 19 h_mF2 measurements, *Adv. Space Res., 27*(6–7), 1245.

Karpachev, A. T., V. V. Afonin, and Ya. Shmilauer (1997), Distribution of the electron temperature in the region of the ionospheric trough in summer night-time conditions, *Geomagn. Aeron.* (in Russian), *37*(1), 96.

Miller, K. L., M. Lemon, and P. G. Richards (1997), A meridional wind climatology from a fast model for the derivation of meridional winds from the height of the ionospheric $F2$ region, *J. Atmos. Sol. Terr. Phys., 59*(14), 1805.

Rishbeth, H. (1967), The effect of winds on the ionospheric $F2$ peak, *J. Atmos. Terr. Phys., 29*(1), 225.

Rishbeth, H., S. Ganguly, and J. C. G. Walker (1978), Field-aligned and field-perpendicular velocities in the ionospheric $F2$-layer, *J. Atmos. Terr. Phys., 40*(7), 767.

Tikhonov, A. N., and V. Ya. Arsenin (1986), *Methods of Incorrect Problem Solutions* (in Russian), 287 pp., Nauka, Moscow.

Titheridge, J. E. (1995), The calculation of neutral winds from ionospheric data, *J. Atmos. Terr. Phys., 57*(9), 1015.

N. A. Gasilov and A. T. Karpachev, Institute of Terrestrial Magnetism, Ionosphere, and Radio Wave Propagation, 142190 Troitsk, Moscow Region, Russia. (karp@izmiran.rssi.ru)