Midlatitude Ionospheric *F*2 layer at Sunrise

Beibit Zhumabayev, Artur Yakovets, and Galina Gordienko

Institute of Ionosphere, National Center for Space Research and Technology, Almaty, Kazakhstan

(beibit.zhu@mail.ru)

Abstract. **The behavior of the F2 layer at sunrise has been studied based on vertical-incidence ionospheric sounding data in Almaty (76 55′E, 43 15′N). Records with small amplitudes of electron density background fluctuations were selected in order to exactly estimate the onsets of a pronounced increase in the electron density at different altitudes. It has been indicated that the electron density growth rate is a function of altitude; in this case, the growth rate at the F2 layer maximum is much lower than such values at fixed altitudes of ~30–55 km below the layer maximum. The solar zenith angle (χ) and the blanketing layer thickness (ho) at the beginning of a pronounced increase in the electron density at altitude h are linearly related to the h value, and these quantities vary within ∼ 90 < χ < 100 and 180 km < ho < 260 km, respectively.**

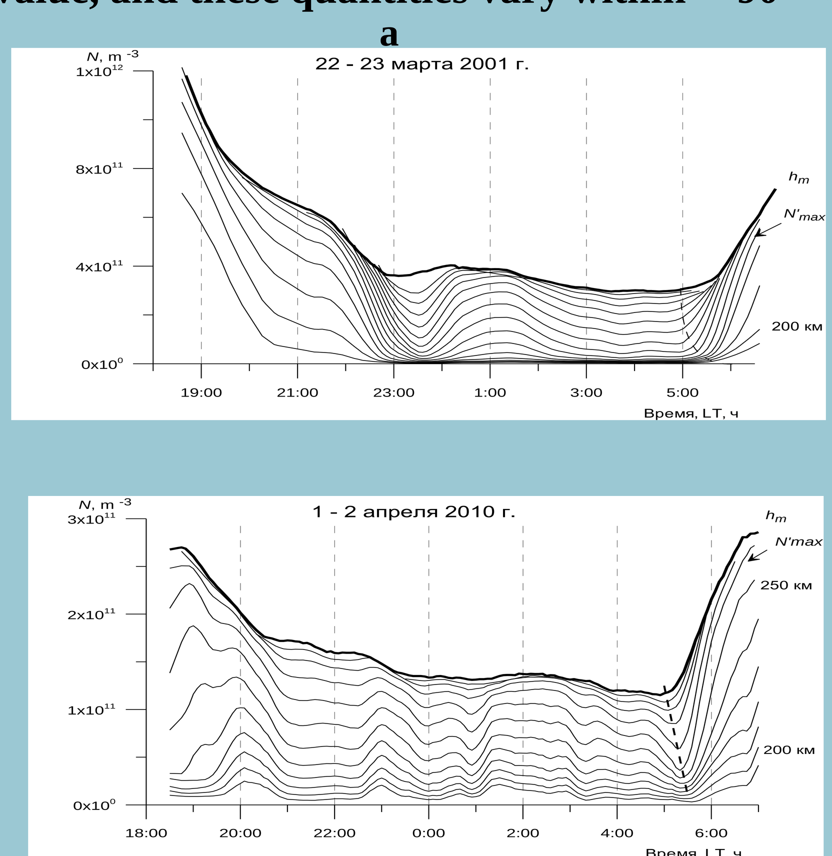

Figure 1. Behavior of the ionospheric electron density at several fixed altitudes and the F2 layer maximum altitude (hm) at night and in the morning on March 22–23, 2001, and on April 1–2, 2010.

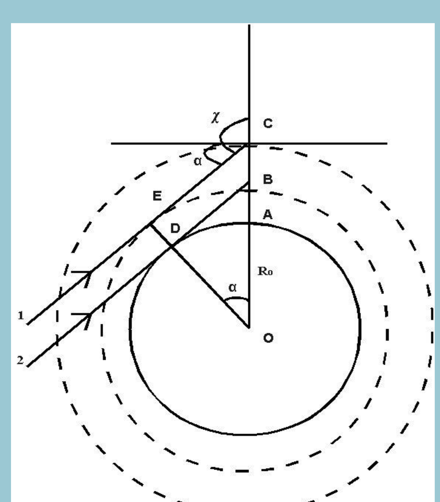

Figure 2 Ionizing solar radiation trajectory in the Earth's atmosphere: (1) the onset of a pronounced increase in the electron density; (2) the ray that touches upon the Earth's surface.

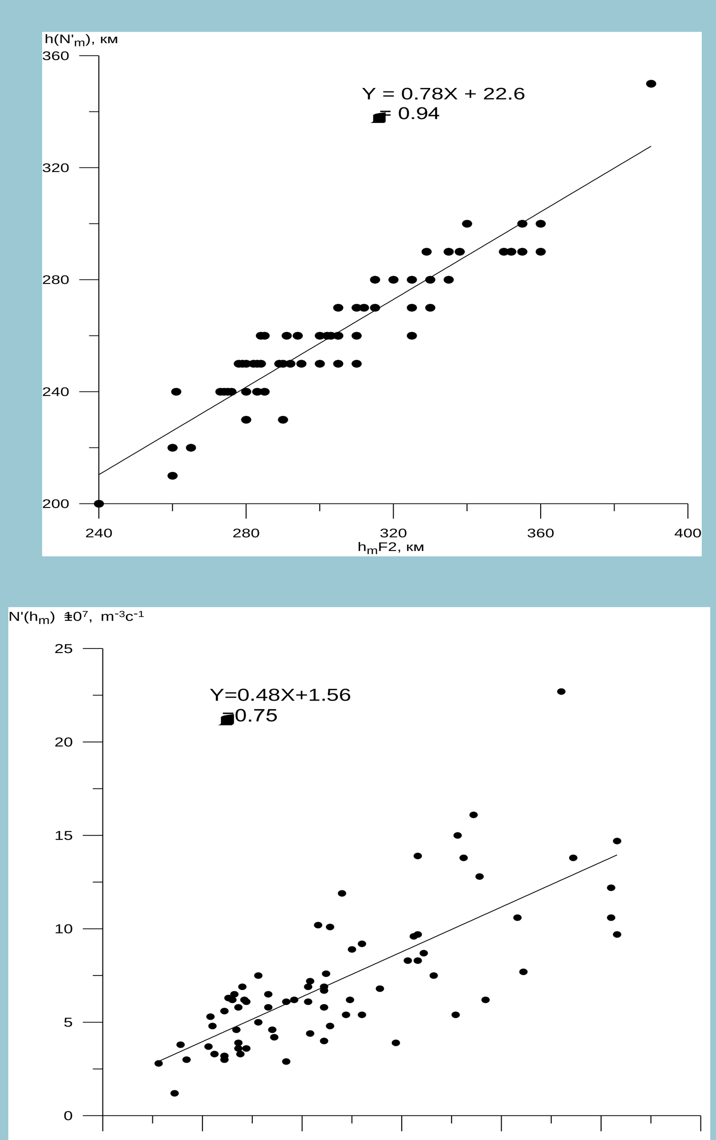

Figure 3. Scatter diagrams between the altitude where the electron density growth rate is maximal (h(N'$_m$)) and the F2 layer maximum altitude (hmF2) (upper panel) and between the electron density growth rate at a layer maximum (N'(hm)) and the maximal electron density growth rate (N'$_m$) (lower panel); the regression lines are shown by solid lines.

1 Introduction. **Researchers started studying the behavior of the ionosphere at sunrise at the very beginning of regular ionospheric sounding. The main experimental results of these studies were generalized in [1]. Note that the quantitative parameters of the F2 layer behavior obtained by different researchers have a considerable spread in values and the data on the electron density growth rate (N') and solar zenith angle (χ), at which the electron density starts increasing pronouncedly, were mostly obtained for the layer maximum. Virtual heights directly read from ionograms were used to analyze the N(t) behavior at altitudes below the layer maximum. The aim of this work is to study the F2 layer behavior at sunrise using the data of vertical-incidence ionospheric sounding over Almaty in 2000–2010 and the F2 layer dynamics in the entire layer thickness at fixed true altitudes by converting ionograms into vertical electron density profiles (N(h) profiles).**

2 Description of equipments and observation results **The vertical ionospheric sounding was conducted in the Institute of the Ionosphere (Alma-Ata) using the "Parus" digital ionosonde. The information needed for calculations of various parameters of the F2 layer was read from the ionograms using the semiautomatic method with the participation of an experienced operator.**

Data processing included obtaining N(h) profiles from the ionograms, using the POLAN conversion program [2]. The sequence of N(h) profiles made it possible to obtain the behavior of several layer parameters, including the electron density at fixed altitudes (N) and at the layer maximum (NmF2).

Examples of the N(t) variations at several altitudes differing by 10 km, obtained on March 22–23, 2001, and April 1–2, 2010, are presented in Figs. 1a and 1b, respectively. The lower curve in the figures corresponds to a 190 km altitude, and the upper (thick) curve corresponds to the variations at the layer maximum. The N(t) variations presented in Fig. 1 bear features typical of all measurement sessions, namely, (a) the instants of the beginning of a pronounced increase observed later on the lower altitudes; (b) the electron density growth rates (N') differ at different altitudes, and the growth rate is maximal at altitudes below the layer maximum altitude. For the observation sessions presented in Figs. 1a and 1b, these altitudes are 230 and 260 km, respectively.

We consider the order of determining the solar ionizing radiation trajectory in the atmosphere at sunrise when the electron density started increasing pronouncedly at point C located at altitude h (Fig. 2). Here point A represents the ionosonde position, and angle α is the Sun height above the mathematical horizon for this instant. The angle α varies from 90 , when the Sun is at the zenith, up to –90 , when the Sun is at the nadir. In the latter case, α is negative since the Sun is below the mathematical horizon line. The solar zenith angle (χ) is related to the Sun's height (α) by the expression

$$\chi = 90 - \alpha.$$

We obtained the Sun's height (α) for the Almaty geographic coordinates, specific date, and the time of the day from the available site http://www.osno.navy.mil/USNO/astronomical-applications/data-services/alt-az-world, where interactive calculations of the Sun's height and azimuth are performed.

The thickness of the blanketing layer (ED = ho), which almost completely absorbs ionizing radiation, was the main parameter of the ionizing radiation trajectory in the atmosphere that made it possible to estimate the atmospheric absorbing capacity. The geometry of solar radiation propagation to point C at the altitude h = AC, where the beginning of a pronounced increase in the electron density is registered (Fig. 2, ray 1), indicates that ho is the smallest distance of the ray trajectory to the Earth. We can neglect the effect of the ionizing solar radiation refraction on the solar zenith angle for altitudes h0 satisfying the relationship ρ(ho) « ρ(o), where ρ(h) is the atmospheric density at altitude h (Pavlov and Pavlova, 2010). From the OEC right triangle, we obtain the following expression:

$$R + ho = (R + h)\cos\alpha,$$

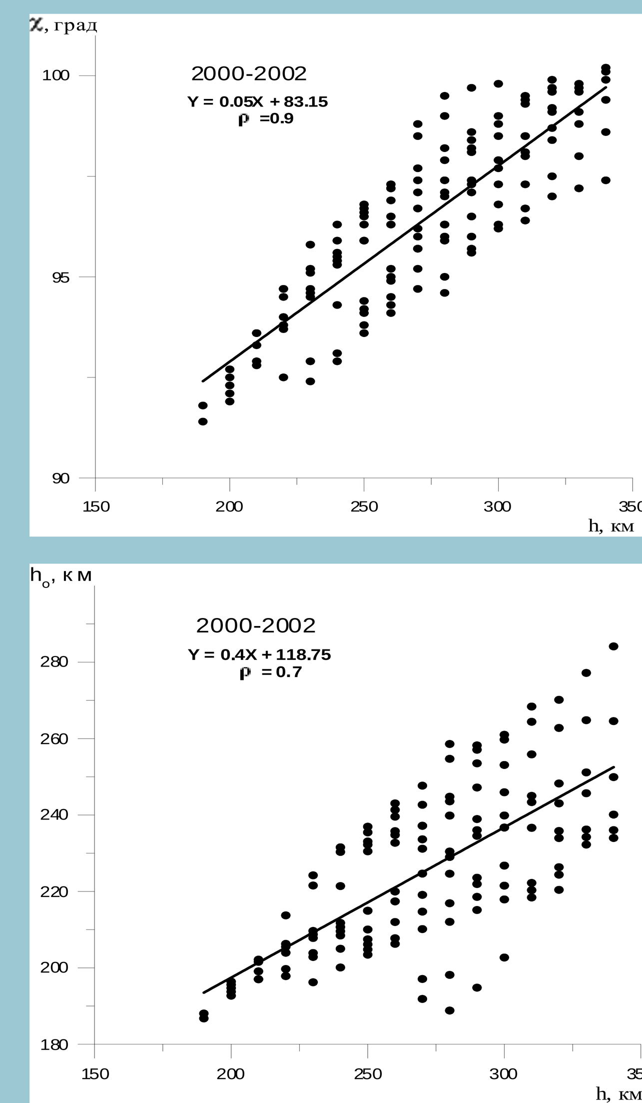

Figure 4. Scatter diagrams between the solar zenith angle (χ) and altitude h (upper panel) and between the altitude of the blanketing layer upper boundary (ho) and altitude h (l.p.) for the spring equinox months at a solar activity maximum.

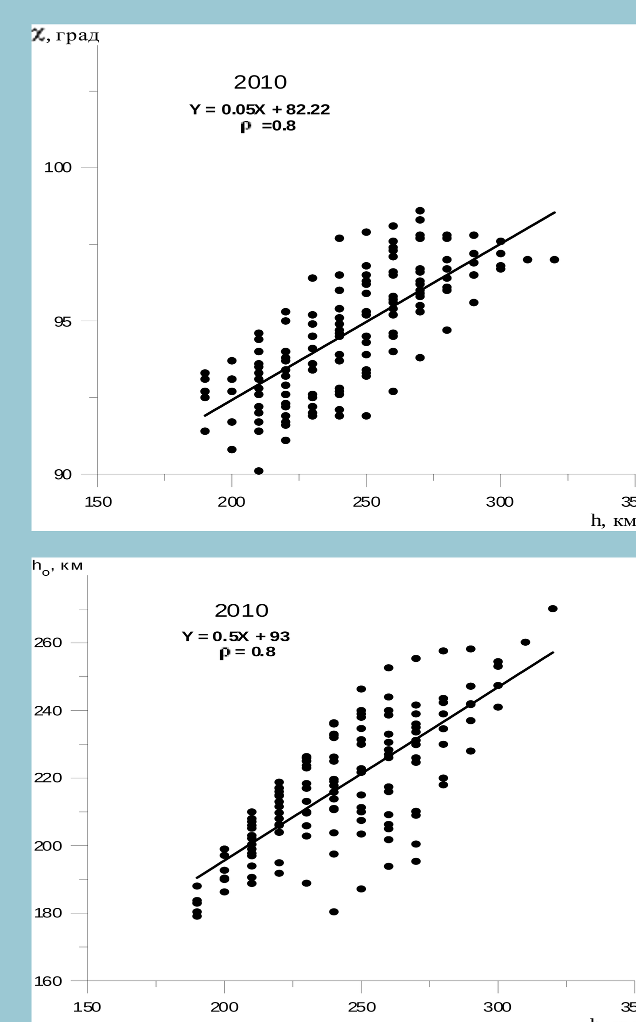

Figure 5. Same as in Fig. 4 but for a solar activity minimum.

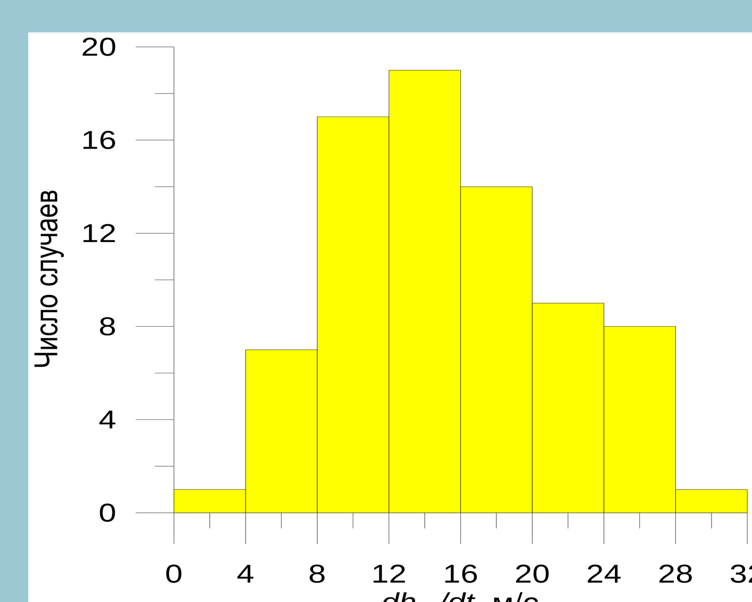

Figure 6. Distribution of the rate of decrease in the F2 layer maximum altitude (dhm/dt) at sunrise.

from which we can estimate ho for a specific h value and tabulated α, corresponding to the time when the electron density starts increasing pronouncedly at a given h altitude obtained from experimental records. Here R = OA is the Earth's radius.

The records presented in Figs. 1a and 1b illustrate the difference in the electron density growth rates at different altitudes. It is clear that the maximal N' value corresponds to altitudes below the layer maximum altitude. The N' value increases with decreasing altitude, reaches a maximal value at a certain altitude, and then decreases to small values near the layer bottom. To quantitatively estimate the vertical behavior of N', we presented in Fig. 3 scatter diagrams (constructed using the data for 2000–2010) between the altitude where the electron density growth rate was maximal (h(N'm)) and the layer maximum altitude (hmF2) (Fig. 3a) and such diagrams between the electron density growth rate at the N'(hm) layer maximum and the maximal electron density growth rate (N'm) (Fig. 3b). The layer maximum altitude was calculated at the instant when the electron density started increasing at altitude hm.

The vertical profiles of the solar zenith angle and the altitude of the blanketing layer upper boundary were calculated for the spring equinox months in the years of a solar activity maximum (Fig. 4) and minimum (Fig. 5). Figures 4 and 5 indicate that the corresponding solar zenith angle and altitude of the blanketing layer upper boundary increase with increasing altitude h where the electron density starts increasing pronouncedly. The formulas for the regression lines (solid lines) presented in the upper left-hand side corner of Figs. 4 and 5 indicate that the slope of the average vertical profile of the zenith angle is identical in the years when solar activity is maximal and minimal and the average χ value at an activity maximum is larger than the corresponding value at an activity minimum by approximately one degree at all altitudes. Figure 6 presents the distribution of the rate of decrease in the F2 layer maximum altitude (dhm/dt) at sunrise, constructed based on the hm(t) time variations. The most probable values vary from 8 to 20 m/s. Such an hm behavior explains why the Nm growth rate is always lower than the N growth rate at fixed altitudes below hm.

3 Summary

The main results of the work can be formulated as follows:

1. Based on vertical-incidence ionospheric sounding data, we indicated that the electron density at altitudes of the ionospheric F region increases rapidly at sunrise and a positive correlation exists between the altitude where the growth rate is maximal (h(N'$_m$)) and the layer maximum altitude (hmF2), on the one hand, and between the electron density growth rate at the h(N'$_m$) layer maximum and the maximal electron density growth rate (N'$_m$), on the other hand.

2. We indicated that the solar zenith angle, corresponding to the instant when the electron density starts increasing pronouncedly, and the corresponding altitude of the blanketing layer upper boundary increase with increasing altitude h where the electron density starts increasing pronouncedly. We established that the slope of the average vertical profile of the zenith angle is identical at a solar activity maximum and minimum and the average χ value at an activity maximum is larger than the corresponding value at an activity minimum by approximately one degree at all altitudes.

References

[1] Rishbeth, H., Jenkins, B., and Moffett, R.J., The F Layer at Sunrise, Ann. Geophys., 1995, vol. 13, pp. 367–374.

[2] Titheridge, J.E., Ionogram Analysis with the Generalised Program POLAN, National Geophysical Data Center. Boulder. CO USA, 1985.