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ANOMALY OF THE COMPOSITION OF THE F-2 EQUATORIAL REGION OF THE IONOSPHERE DURING THE HOURS AFTER SUNSET ACCORDING TO DATA FROM THE MASS-SPECTROMETER EXPERIMENT ON THE "COSMOS-274"

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16. Abstract

A mass spectrometer on board Cosmos-274 measured concentrations of light atoms and ions. While traversing the geomagnetic equator during the evening hours it recorded an anomalous drop in ionized molecular oxygen and ionized atomic oxygen and nitrogen. A similar, less dramatic, decline was observed in the concentration of neutral atomic oxygen. A possible explanation for this and previously observed behavior is an ascent in altitude of the F layer in the hours after sunset, a possibility which is supported by calculations.

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ANOMALY OF THE COMPOSITION OF THE F-2 EQUATORIAL REGION OF THE IONOSPHERE DURING THE HOURS AFTER SUNSET ACCORDING TO DATA FROM THE MASS-SPECTROMETER EXPERIMENT ON THE "COSMOS-274"

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A series of special features of the equatorial ionosphere /3* --the anomalous electron density [1], the appearance of ions in the wake of meteors and the fall in the concentration of charged particles at the altitude of the night-time F layer [2,3], the generation of plasma inhomogeneities responsible for the F-layer dispersion in the equatorial ionosphere [4]--have usually been related to the disturbing action of the $\vec{E} \times \vec{H}$ -drift of ionization close to the geomagnetic equator. In order to explain the role of fields of equatorial electric flow in the formation of the equatorial ionosphere and to evaluate the contribution of $\vec{E} \times \vec{H}$ -drift to the distribution of ionization in the equatorial regions, one must have data concerning the distribution of the neutral and the ionized components, the electric fields, and the dynamical regimes, of the equatorial ionosphere.

The present study considers certain anomalous special features of the distribution of ionic and neutral components of the equatorial F2 region in the period after sunset. It relies on the results of the mass-spectrometer experiment on the "Cosmos-274" satellite and introduces the results of calculations which explain the creation of the observed anomaly in the ionic component in terms of peculiarities of the night-time dynamical conditions in the equatorial ionosphere.

*Numbers in the margin indicate pagination in the foreign text.

Measurement Apparatus and Methods

For our investigation of the ionic and neutral composition of the equatorial ionosphere we used the data from the mass-spectrometric experiment conducted on board the space satellite "Cosmos-274" during the period from 25 to 31 March 1969. The satellite had been launched into an orbit with the following parameters: perigee--213 km, apogee--323 km, inclination to the equator--65°.

The measurement of the composition was performed by means of a modified MKh 6407 P radio-frequency mass spectrometer [5]. The particular apparatus used in the experiment had the following fundamental characteristics: range of mass, 1-4 a.m.u. to 12-48 a.m.u.; sensitivity to ionic concentration, 20-30 cm^{-3}; scanning time of the spectrum of mass during the period of measurement (the results of which are examined below), 2.5 sec. The absolute concentration of ions was evaluated by three different means, all of whose values agreed in the experiment: 1) a computational method using approximations and known relationships at the altitude of the probe [6], 2) an approximation based on the absolute calibration under laboratory conditions of an identical apparatus [7], and 3) a comparison of the sum total of ion concentrations with the value of N_e according to a semi-empirical model of the ionosphere [8]. The absolute concentration of the neutral component in the experiment was not determined because of the uncontrolled decline in the sensitivity of the mass spectrometer after unsealing. /4

During the course of the experiment the ionic and neutral compositions were measured in succession following a program which conformed to the bloc of automated instruments within the apparatus. The mass analyzers were oriented in the direction of motion of the satellite. The field of view of the analyzers contained no surfaces of gas canisters or construction elements of the satellite. The specific procedure [9] used in the experiment made it possible to separate atmospheric components from the components of the satellite's gas separators and mass analyzers.

Because of the limited dynamic range of the apparatus--about 10^3 in ionic measurement--the concentration of O^+ ions, $n(O^+)$, prevailing at the altitude of the orbit of the satellite was, in certain cases when the measurement of $^{16}O^+$ saturated the amplifier current, determined by the measurement of the isotopic $^{18}O^+$ ion concentration using an assumed ratio of isotopes $^{18}O/^{16}O$ equal to 0.002.

During the analysis of the neutral composition, the amounts of O, N_2, and O_2 were regularly recorded. The mass peak at O_2 /5
significantly exceeded the peak at O, while the CO_2 peak was not less than 10-15 times smaller than the O_2 peak. This testified to the almost complete recombination of atomic oxygen within the mass analyzer into O_2, which made it possible to evaluate the relative change in the O concentration along the orbital path of the satellite from the change in the O_2 peak, assuming that the recombination rate of O during the course of the experiment did not appreciably change. The correctness of that assumption under the conditions of this experiment was considered in [10].

Some Results of the Measurement of the Composition of the Equatorial F2 Region

The results of the measurement of the ionic composition of the F2 region obtained by the experiment of the "Cosmos-274" satellite were considered in [11], while some of the data on the neutral composition is given in [10]. One of the most interesting features of this experiment is that in a whole series of instances, a significant anomaly in the latitudinal distribution of the ionic and neutral composition was observed when the satellite traversed the equatorial region during the hours after sunset (21.00 - 23.00 LT). By way of example, figure 1 presents the data on the distribution of the ionic composition in the equatorial F2 region in the hours after sunset on one particular day, and figure 2 presents the data on the distribution of atomic oxygen under the same conditions. The experimental value of n(O) was normalized in fig. 2 with reference to the n(O) values predicted for the experimental conditions by the 1971 Jacchia model [12]. The distribution of the ionic and neutral composition shown in figs. 1 and 2 corresponds to undisturbed conditions ($K_p = 2\text{-}3^+$).

It follows from fig. 1 that in the F2 region near the geomagnetic equator there is a significant decline in the concentrations of the atomic ions H^+, N^+, and O^+ during the hours /6
prior to midnight. Besides the fundamental drop, there is also a noticeably significant inhomogeneity of ionic concentration localized immediately adjacent to the geomagnetic equator, in the northern pre-equatorial region--a "subdrop" in O^+ concentration. The distributions of the H^+ and N^+ ions in the equatorial F2 region, in general, mimic the O^+ ion distribution.

The distributions of the molecular NO^+ and O_2^+ ions shown in fig. 1 display a gradual decline in the concentrations of these ions, which is related to the increasing orbital altitude of the satellite. In the region of the fundamental drop in $n(O^+)$, however, a decrease in $n(NO^+)$ and $n(O_2^+)$ is observed, and the decline in $n(O_2^+)$ is more marked than that of $n(NO^+)$.

An essential aspect of the equatorial anomaly in ionic composition is the fact that ions of mass number 28+ a.m.u. are observed in areas of a drop in O^+ ions. These ions may be identified either as N_2^+ or Si^+, since the mass numbers of those two ions are so close that the mass analyzers do not distinguish them. We must point out, however, that it is difficult to account for the appearance of N_2^+ ions in the night-time F2 region in substantial quantities, considering the particular equatorial drop of $n(O^+)$ in the ionic composition. In particular, as the results of the mass-spectrometer measurements of the ionic composition of the night-time F2 region performed on the "Salyut-4" orbiting space station have shown [13], the appearance of N_2^+ ions in the night-time F2 region should be accompanied by an increase in the $n(NO^+)$, as a result of the fast reaction $N_2^+ + O \rightarrow NO^+ + N$ [14]. During the declines in $n(O^+)$ observed in the experiment with increases in the concentration of ions of 28 a.m.u., $n(NO^+)$, on the contrary, declined.

It is more probably correct to identify the 28+ ions as Si^+ ions. This hypothesis is confirmed by the results of direct /7 mass-spectrometer [3] and optical [15] measurements, which have been explained by the presence of larger volume ions of meteoric origin--Fe^+, Mg^+, and Si^+--in the night-time equatorial ionosphere at altitudes of 250-500 km. The measurement of Fe^+ and Mg^+ ions was not performed in our experiment due to the limited mass range of the apparatus (<48 a.m.u.) and the presence of harmonic peaks of molecular ions in the spectrum, which prevented the reliable measurement of Mg^+ ions.

In the part of the measurements of the neutral composition in the equatorial thermosphere, we observed, as fig. 2 implies, a significant deviation of the experimentally measured distribution of atomic oxygen from that calculated according to the

Jacchia model. In addition, by comparing the data presented in figs. 1 and 2 we discover a noticeable correlation between the distributions of n(O) and $n(O^+)$: in the region of a basic drop in $n(O^+)$ there is a minimum in n(O), beyond which, despite the increasing altitude of the satellite orbit, there is an increase in n(O), correlated with a rise in $n(O^+)$. It is difficult to evaluate the N_2 variation in the equatorial thermosphere from the data on the direct measurements, since the value of the N_2 measurement is at the limit of the sensitivity of the apparatus. By indirect evidence, however, in particular from the measurement of the concentration of NO^+ ions, which in the first approximation is proportional to $k \cdot N_2$ (where k is the ratio of the rate of formation of NO^+ ions to their rate of destruction, which in these conditions changes very little), we can conclude that while a significant anomaly exists in the n(O) distribution, it does not exist in the latitudinal course of $n(N_2)$, at least within the conditions of the experiment.

Thus, the resulting data provide evidence of the existence of an anomaly in the distributions both of charged and of neutral components in the equatorial and low-latitude ionosphere during the hours after sunset. We emphasize that the detected /8
special variations in the neutral and ionic composition characterize a latitudinal dependence in the distribution of charged and neutral components, so long as the altitude and local time of the passage of the satellite through the region of the anomaly are not essentially changed.

It was suggested earlier [3], in order to explain a similar anomaly in the ionic composition detected by the mass-spectrometer experiment in the orbital space station "Salyut-1", that the anomaly might be caused by an ascent of the equatorial F layer in the hours after sunset. Such an ascent of the F layer has actually been detected in the results of direct measurements of the vertical drift in the equatorial ionosphere [16]. It was indicated in [3] that the ascent of the F layer should be accompanied by appreciable changes in the ionic composition at the altitude of the F2 region in connection with the existence of a significant gradient in the ion concentration below the maximum of the F layer. In order to corroborate the possibility of the formation of an anomaly in the ionic composition of the equatorial ionosphere as a result of a post-sunset ascent of the F layer, we present below the results of calculations of the altitude distributions of O^+ and O_2^+ ions in the night-time ionosphere, assuming an ascending drift of ionization.

Methods and Results of Calculation

The calculation of the distribution of ions in the night-time ionosphere was performed over the altitude interval 160-400 km on the basis of a numerical solution to the equation of continuity for O^+ and O_2^+ ions:

$$\frac{\partial n_i}{\partial t} = P_i - L_i - \frac{\partial (n_i v_i)}{\partial z}$$

where n_i is the ion concentration; t is time; P_i is the rate of formation and L_i the rate of destruction of ions; V_i is the vertical velocity of ions; z is the altitude. A night-time source of O and O_2 ionization is not taken into account. The arrangement of photochemical cycles of O^+ and O_2^+ at the altitudes of the F2 region were taken in correspondence with [17]. The distributions of O and O_2 with altitude were determined for a Jacchia model with T_∞ = 1000 °K, which corresponds to the conditions of the experiment. The temperatures of the charged and neutral particles were taken to be equal in the calculations. The values of V_i needed for the calculations were taken from the data of direct measurements of the vertical velocity of the $\vec{E} \times \vec{H}$ -drift in the night-time equatorial ionosphere under /9 conditions similar to conditions of the experiment we conducted [18]. When performing the calculations we used the difference arrangement considered in [19]. From the equilibrium condition the solution internal consisted of 10 sec of time and 10 km of altitude. The initial profiles of $n(O^+)$ and $n(O_2^+)$, adjusted to the conditions of the experiment, were taken from [20]. The changes of $n(O^+)$ and $n(O_2^+)$ at the boundaries were assumed to be exponential, with different values of exponents.

The results of the calculation of the distributions of O^+ and O_2^+ ions in the night-time ionosphere with an ascending F layer are shown in figure 3. This graph implies that the ascent of the F layer should be accompanied by significant changes in the absolute and relative concentrations of O^+ and $O_2{}^+$ ions at altitudes below the layer maximum. Figure 4 shows a particular aspect of the relative changes of $n(O^+)$ and $n(O_2{}^+)$ at an altitude of 260 km during the ascent of the layer. The reduced values were used to normalize the calculated values of ion concentration to their initial values, corresponding to the beginning of the ascent.

It is clear from fig. 4 that $n(O^+)$ in the night-time ionosphere below the maximum of the F layer rapidly declines during the ascent of the layer. At the same time $n(O_2{}^+)$ changes in a more complicated fashion. So in the lower part of the F layer, at an altitude of 260-270 km, where the measurements of our experiment were conducted, barely 1.5 hours after the beginning of the ascent of the layer, a decline occurred in the $n(O_2{}^+)$ which was also observed in the experiment. The results of calculation, however, show that $n(O_2{}^+)$ increases at altitudes > 300 km more than 2-3 hours after the beginning of the ascent. This agrees with the results of the experiment on the OGO-6 satellite [21], where an increase in the concentration of molecular ions was detected in the equatorial decline at an altitude of 450 km during the pre-midnight hours.

Thus, the results of calculation at least qualitatively support the possibility of the creation of an anomaly in the ionic composition in the equatorial ionosphere by means of a drift ascent of the F layer in the period after sunset. Divergence of the experimental from the calculated values can be explained by the simplified nature of the calculations.

Conclusion

The totality of the data we have presently concerning the ionic composition of the equatorial ionosphere [2,3,23] indicates that the phenomenon of a drop in atomic ions at altitudes below the maximum of the F layer is a characteristic aspect of the night-time equatorial ionosphere. The generation of the drop, as was shown above, may be satisfactorily explained by the ascent of the equatorial F layer which is generally observed in the hours after sunset.

Supplementary confirmation of the connection of the anomaly of the ionic composition with ascent in the ionization is the appearance of ions of meteoric origin--Fe^+ [23], Mg^+ [3,15], and Si^+ [15, and in our experiment]--in the region of the equatorial drop. The possibility of the ascent of ions of meteoric origin at the altitude of the F layer because of the $\vec{E} \times \vec{H}$ drift in the equatorial region was demonstrated in [22]. Particularly impressive is the close correlation between the distribution of Si^+ ions and the drop in O^+ ions, detected in the experiment, which confirms the dependence between the distribution of Fe^+ ions of meteoric origin and inhomogeneities in the ionization of the night-time equatorial ionosphere considered in [2].

We must point out the longitudinal dependence of the appearance of the equatorial anomaly in ionic composition, /10 which according to the data of our experiment is drawn to the Afro-Asian sector. We can assume that the longitudinal dependence of the appearance of the equatorial anomaly serves to reflect the longitudinal variation of the equatorial electron flow [24].

The results of this experiment as well as the results of measurements conducted earlier [25], provide evidence of the existence of an anomaly in the neutral composition of the equatorial thermosphere. The correlation of the anomaly of the neutral composition with the anomaly in the distribution of charged particles points up the close connection between the distributions of neutral and ionized components in the equatorial ionosphere.

REFERENCES

1. Rishbet, G., and O. Garriot, Vvedenie v fiziku ionosfery [Introduction to the Physics of the Ionosphere], Leningrad, Gidrometizdat, 1975, 184 pp.

2. Hanson, W.B., and S. Santini, J. Geophys. Res., 75, 5503 (1970).

3. Romanovshiy, Yu.A., L.I. Pogulyaevskiy, I.A. Lubov, and E.G. Ul'yanov, DAN SSSR 224/6, 1312 (1975).

4. McClure, J., and W.B. Hanson, J. Geophys. Res. 31, 3431 (1973).

5. Rafal'son, A.I., and A.M. Shereshevskiy, Mass-spektrometricheskie pribory [Mass-spectrometric Devices], Moscow, Atomizdat, 1968.

6. Harris, K.K., G.W. Sharp, W.C. Knudsen, J. Geophys. Res. 72, 5939 (1967).

7. Evlanov, E.N., V.A. Ershova, Preprint Pr-75, IKI USSR Academy of Sciences, Moscow, 1971.

8. Nisbet, J.S., Penn. Univ. Sci. Report No. 355, 1970.

9. Istomin, V.G., Geomagnetizm i aeronomiya [Geomagnetism and Aeronautics] 1/3, 359 (1961).

10. Katyushina, V.V., and Yu.A. Romanovskiy, DAN SSSR 217/5, 1057 (1974).

11. Romanovsky, Yu., V. Katjushina, and V. Istomin, Space Res. 15, 351 (1975).

12. Jacchia, L., SAO Special Report, 1971.

13. Loevsky, A., L. Pogulaevsky, Yu. Romanovsky, and E. Ul'janov, Paper presented at 19th COSPAR Meeting, Philadelphia, USA, 1976.

14. McFarland, D., D. Albitton, F. Fehsenfeld, E. Ferguson, and A. Schmeltkopf, J. Geophys. Res. 79, 2925 (1974).

15. Bocksenberg, A., J.G. Gerard, J. Geophys. Res. 78, 4641 (1973).

16. Balsley, B., J. Atmosph. Terr. Phys. 35, 1035 (1973).

17. Ferguson, E.E., Rev. Geophys. Space Phys. 12, 703 (1974).

18. Woodman, R., WDC A UAGR, 12 (2), 194 (1971).

19. Balakin, V., Zh. matem. vychisl. matemat. 10, 1512 (1970).

20. Howard, K., J. Vanderslice, and S. Tilford, Plan. Space Sci. 18, 145 (1970).

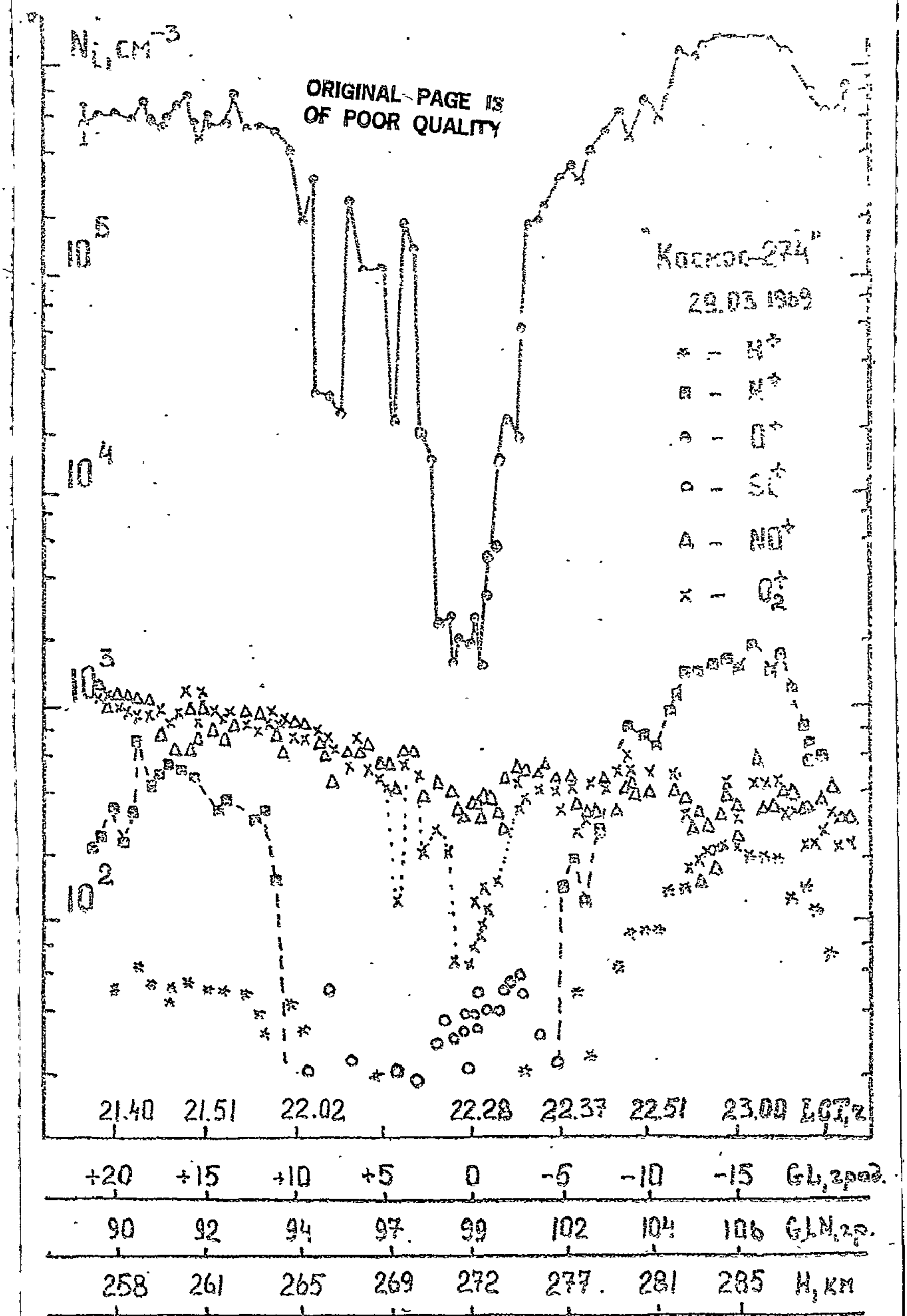
21. Hanson, W., S. Santini, D. Zuccaro, and T. Flowerday, J. Geophys. Res. 75, 5483 (1970).

22. Hanson, W., D. Sterling, and R. Woodman, J. Geophys. Res. 77, 5530 (1972).

23. Hanson, W., S. Santini, J. Geophys. Res. 76, 7761 (1971)

24. Sugiura, M., and D.I. Poros, J. Geophys. Res. 74, 4025 (1969).

25. Hedin, A., and H. Mayr. J. Geophys. Res. 78, 1688 (1973).



Ni, см-3
10 5
10 4
10 3
10 2
"Космос-274"
29.03.1969
H+
N+
O+
Si+
NO+
O2+
21.40 21.51 22.02 22.28 22.37 22.51 23.00 LGT, ч
+20 +15 +10 +5 0 -5 -10 -15 GL, град.
90 92 94 97 99 102 104 106 GLM, гр.
258 261 265 269 272 277 281 285 H, км

Рис. I

(Caption from previous page)
Fig. 1. Data on ionic composition from "Cosmos-274" flight of 29 March 1969, plotted logarithmically as no. of ions per cm^3 over time of flight. The four scales identify parallel aspects of the flight across the equatorial ionosphere. Top, local time is given in hours; second, geomagnetic latitude in degrees; third, geomagnetic longitude in degrees; bottom, altitude in kilometers.

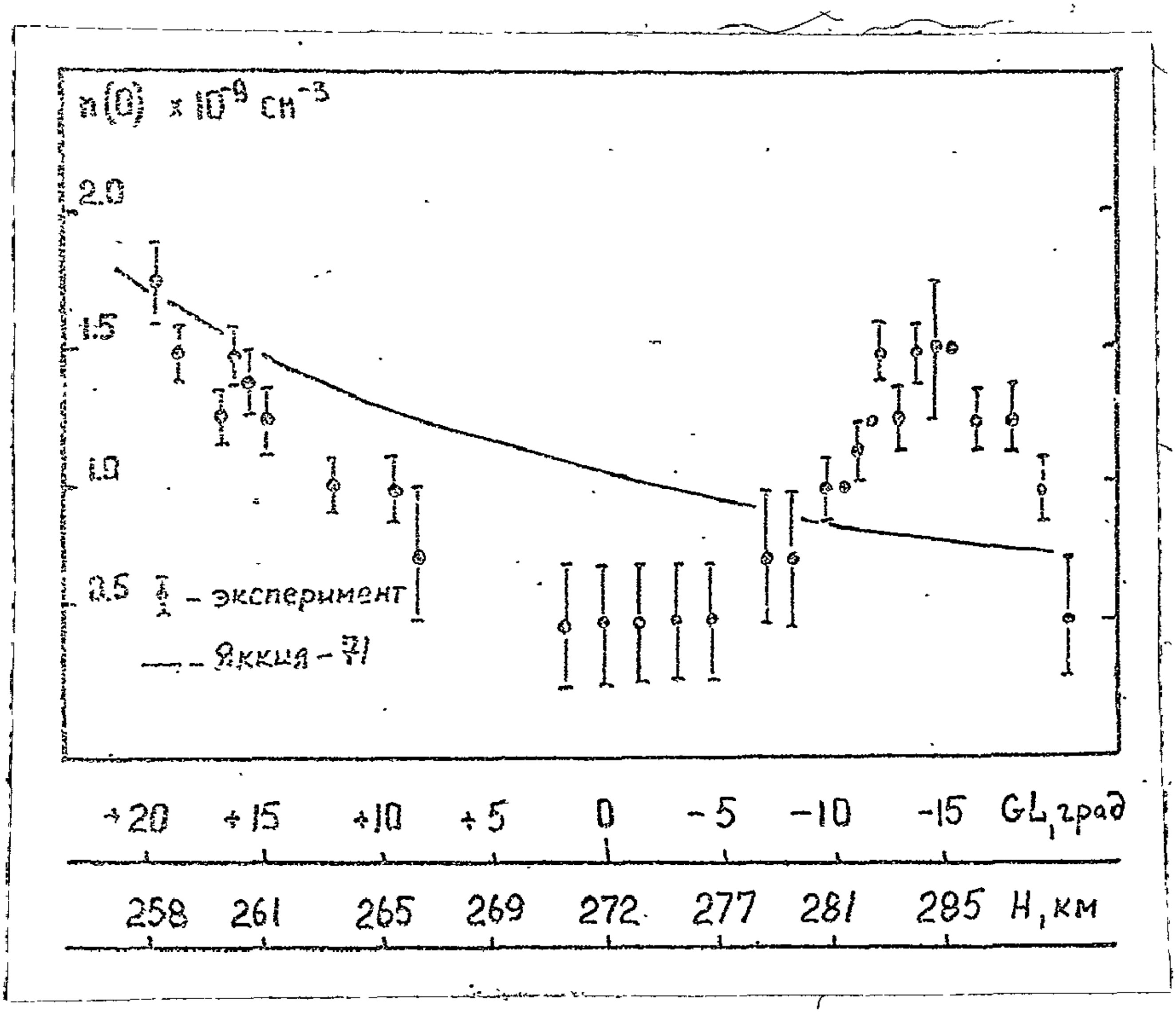


Fig. 2 Distribution of atomic oxygen in the night-time equatorial thermosphere. Barred dots are experimental data and the solid line the Jacchia-71 prediction. Bottom scales give geomagnetic latitude in degrees and altitude in kilometers.

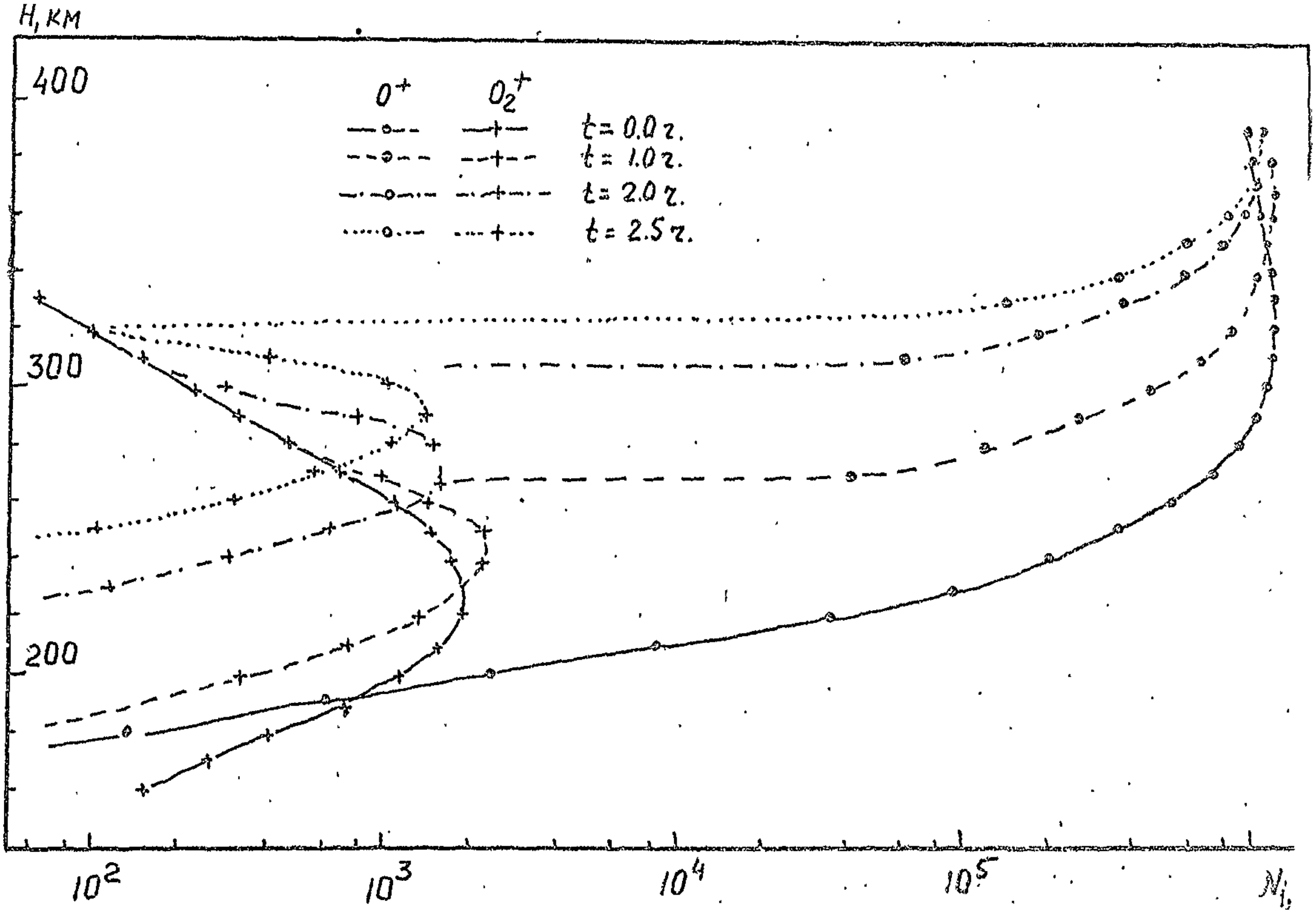


Fig. 3. Changes in the distributions of O^+ and O_2^+ ions during a night-time upward drift of the F layer[2] Calculations of concentration, N, for various altitudes, H, are given for t = 0.0, 1.0, 2.0, and 2.5 hours.

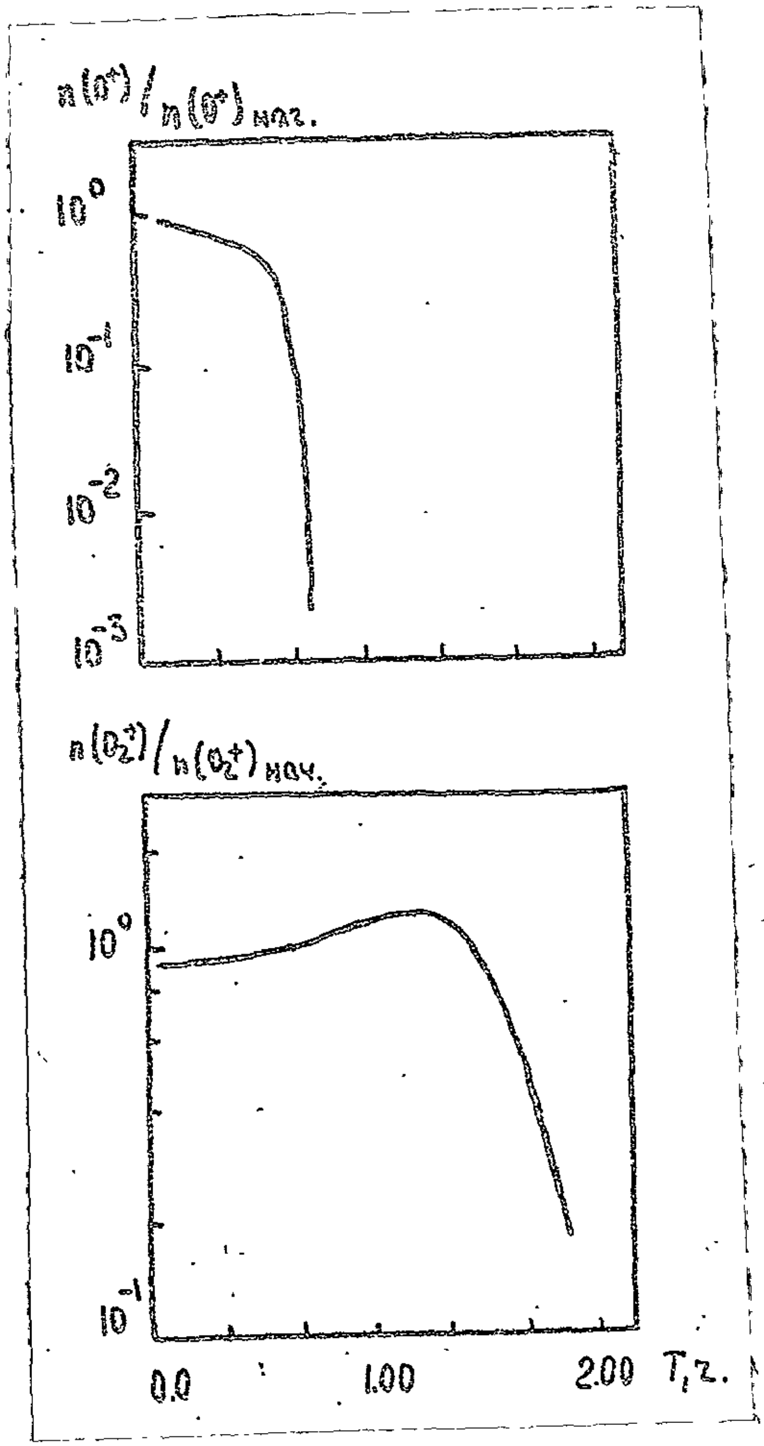


Fig. 4 Relative fractions $n(O^+)/n(O^+)_{initial}$ and $n(O_2^+)/n(O_2^+)_{initial}$ at an altitude of 260-270 km in the F layer while it rises over time T, in hours.