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ROCKET STUDIES OF THE IONIZATION RATE, ELECTRON CONCENTRATION, NEUTRAL COMPOSITION AND WINDS IN THE F REGION

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As a result of rocket experiments carried out from 1965 to 1971, information has been obtained on the ultraviolet flux, the composition and temperature of the neutral upper atmosphere, the electron concentration n_e and electron temperature T_e. All experiments were performed in middle latitudes, from the same geographical point, early in the morning at solar zenith angles $\sim 82°-78°$.

The variations of the neutral composition observed are semi-annual; for a quiet ionosphere variations with solar and geomagnetic activity are slight. Variations of the neutral gas composition are likely to influence the $n_e(h)$ profile mainly above the F2 region maximum. For the F2 region maximum in autumn and winter the $n_e(h)$ profile is determined mainly by the neutral winds, which affect both the altitude distribution of the effective recombination coefficient and its absolute value.

As a result of rocket experiments carried out from 1965 to 1971 at altitudes 80—500 km information on the solar ultraviolet flux, the composition and temperature of the neutral upper atmosphere [1—4], electron concentration n_e [5] and electron temperature T_e [6] was obtained. All experiments were performed from middle latitudes of the European part of the USSR from the same geographic point early in the morning at solar zenith angles 82°—78°. A detailed review of these experiments is contained in [7].

Before discussing the interconnection between the ionized and neutral components of the upper atmosphere it is worth considering the primary experimental data and the behaviour of the measured parameters separately.

In Fig. 1a are given the normalized values of the photoelectric saturation currents showing variations of the absorption of solar radiation at altitudes 100 to 400 km due to the variations of the neutral atmospheric density and composition.

Information on the altitude dependence of the solar radiation in different spectral bands (Fig. 1b) was used for the definition of the neutral particle concentrations: [O] and $[M] = [O_2] + [N_2]$ according to the procedure described in [4]. Variations of both the total concentration and the composition were observed from experiment to experiment: comparatively low concentrations were noted on 20 September 1965 at altitudes $h > 250$ km. The experiment on 28 November 1970 is characterized by the highest relative values of molecular concentrations.

Comparison of the results with data on solar and geomagnetic activities showed that no correlation existed between the variation of the concentrations of neutral particles or their composition and solar and geomagnetic activities. Comparing the results of the summer experiment on 20 August 1971 with the others carried out during the autumn it can also be noted that these results show neutral gas seasonal variations larger than expected.

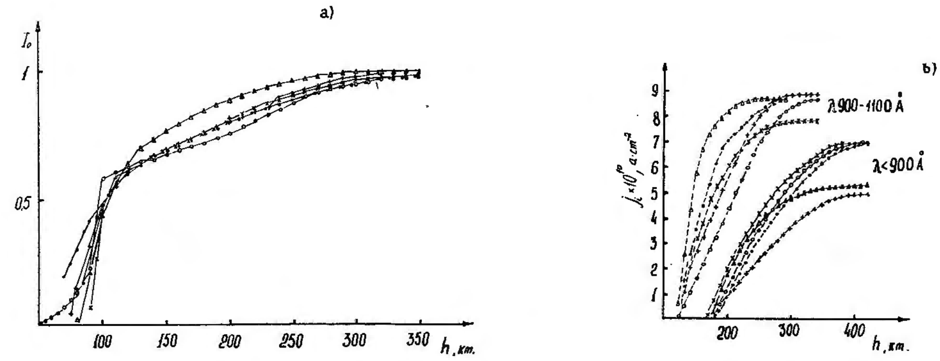

Fig. 1. a) variations with height of the normalized intensity of solar ultraviolet radiation observed during five morning flights; b) variations with height of the saturation photocurrent j_1 observed in two different spectral bands in the UV region.

△ △ △, 20 September 1965, +++ 13 October 1966, • • • 3 October 1970, ○ ○ ○ 28 November 1970, × × × 20 August 1971.

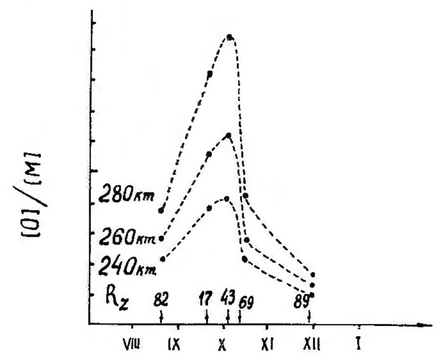

Fig. 2. Variation with month of year of the [O]/[M] ratio at different heights. R_Z, Zurich sunspot number.

In Fig. 2 is seen a rather clear increase of both the total neutral gas density and the [O]/[M] ratio during the autumn. It is known that variations of density and composition with a period of 6 months are observed in the atmosphere and that the maximum values fall within the spring-autumn periods [8]. The observed variations of the concentration and composition of the neutral particles reflect the semi-annual variations of upper atmospheric structure which are practically independent of solar activity [8, 9].

For a comparison of the data obtained in experiments on the ionized and neutral components the dependences of electron concentration $n_e(h)$ [5] and the ionization rate $q(h)$ are given in Fig. 3. It is seen that above the F2 layer maximum $q(h)$ values are proportional to the absolute concentration of all neutral particles $n(h)$. Neutral atmosphere variations do not explain the observed difference in the $n_e(h)$ profiles near the maximum of the F region. The relative concentration of molecular particles was, for example, highest on 28 November 1970 with the smallest values of $n_e(h)$ and $q(h)$. It may be that on 28 November 1970 $n_e(h)$ values were smaller because of a higher loss rate. This shows that $n_e(h)$ profiles cannot in all cases be explained only by photochemical processes, i.e. that for the description of recombination processes in the F2 region use of the well-known expression for an effective electron-loss coefficient [10] $\beta_{eff} = K_1[O_2] + K_2[N_2]$, where K_1 and K_2 are the corresponding reaction rate coefficients, is incomplete.

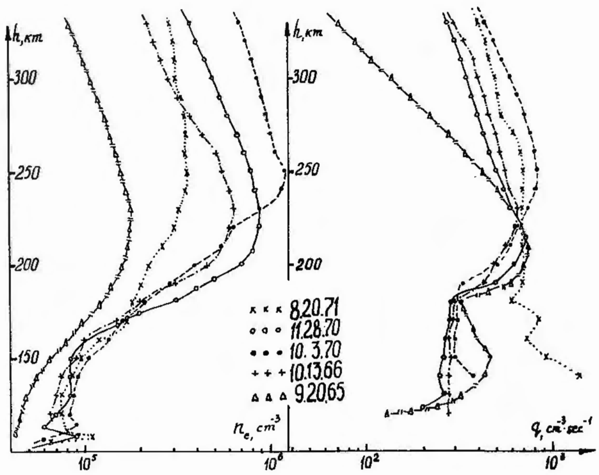

Fig. 3. Variation with height of electron density n_e and electron production rate q for five flights. Key as for Fig. 1.

Drifts influence the structure of the ionosphere at altitudes 180—400 km [11]. Calculations of the vertical distributions of the neutral wind velocities and ionization drifts for these experiments showed that in all cases at $\sim$ 180—400 km in autumn the horizontal neutral wind velocities were higher than in summer. Higher values of the vertical velocity of the ionospheric plasma drift were also observed in autumn. It should also be noted that the vertical components of the neutral wind velocity were small ≤ 1.5 m s^{-1}, and were greatest on 28 November 1970. At present the observed increase of the atomic oxygen concentration in winter is explained by its transfer from the southern to the northern hemisphere under the action of the vertical velocity of the neutral wind [12]. The values of the neutral wind vertical velocity obtained give evidence that during the measurements performed such an additional flux of atomic oxygen was not observed.

The $n_e(h)$ profiles obtained agree well with the $q(h)$ profiles when taking into account the directions and the velocities of the charged particle drifts. There is a rather clear correlation between the F2 layer form and the value of the downward ionization drift below 400 km altitude. Fig. 4 gives the altitude dependence of β_{eff} defined by solving the ionization balance equation using $n_e(h)$ and $q(h)$

experimental values and the results of calculations [11]. It was found that β_{eff} depends inversely on the drift velocity. For the experiment on 20 August 1971, when the drift velocity did not exceed $10\,m\,s^{-1}$, the drift motions practically do not influence β_{eff}. It is significant that in the 250—350 km interval, and independently of the ionization drift values, β_{eff} varies by less than a factor of 2 which differs from the height profiles calculated theoretically [10].

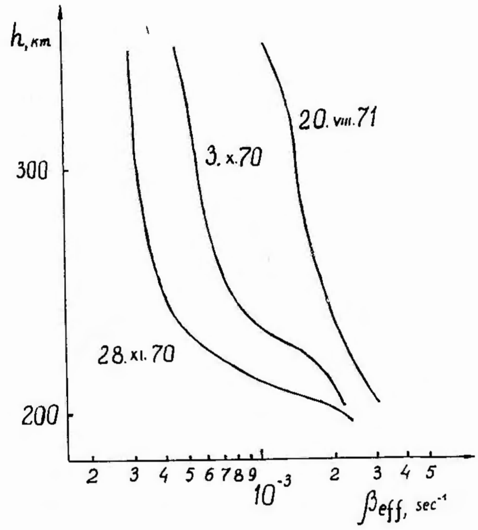

Fig. 4. Variation with height of effective recombination coefficient for electrons, defined in the text.

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