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Rocket study of ionization and recombination rates in the *F*-region taking account of charged particle drift

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Abstract—The information on neutral and ionized components of the upper atmosphere is obtained as a result of simultaneous measurements performed with Soviet geophysical rockets by means of the dispersion interferometer, the photoelectron analyser and probe instruments. The height profile of the effective recombination coefficient in the *F2*-region was calculated with each of three following assumptions: (1) the motion term was ignored in the ionization balance equation; (2) the motion term was accounted for the vertical diffusion; (3) the vertical diffusion and the neutral wind effect calculated by J. W. King was taken into account. Evaluations showed that in some cases the charged particle transfer essentially affects both the altitude distribution of the effective recombination coefficient and its absolute values above the *F2*-region maximum. Variations of these values can reach a factor of 2 if the charged particle transfer is taken into account.

1. INTRODUCTION

ON A NUMBER of Soviet vertical geophysical rockets, experiments were performed to study basical ionospheric processes and their interrelations: GRINGAUZ *et al.* (1968), GDALEVICH and GUBSKY (1972), RUDAKOV and KNORIN (1972), SHUTTE (1972). Height distributions of fluxes of the ionizing solar radiation by means of the photoelectron analyzer (it gave information on the neutral upper atmosphere composition and its temperature), the electron density n_e by means of the dispersive radiointerferometer and also the electron temperature T_e by means of probes were measured to accomplish this.

The combination of results of these measurements allowed to estimate the height distribution of the ionization rate and effective recombination coefficient β_{eff} (GRINGAUZ *et al.*, 1968; SHUTTE and KNORIN, 1969) and also the heat influx to the electron gas Q_e and the efficiency of the electron gas heating $\mathscr{X}$ (GDALEVICH and SHUTTE, 1972). In evaluating recombination process rates it was considered that the term div $(n_e \cdot \mathbf{V})$ describing the charged particle motion is determined only by the vertical diffusion (SHUTTE and KNORIN, 1969); the charged particle drift due to ionospheric winds was ignored.

In 1965–1971 a number of papers were published KING *et al.* (1965, 1967, 1971); KOHL *et al.* (1967, 1968); GEISLER (1966); CAHILINOR (1970a, 1970b); MAYER and MAHAJAN (1971); ECCLES *et al.* (1971) which were devoted to *F*-region ionization drifts caused by atmospheric winds. In particular, KOHL and KING (1967), KING and KOHL (1965) developed the technique of calculations of ionospheric drift velocities W for the height range 100–700 km. This allowed to estimate W for any concrete day, geographical latitude and local time in the mentioned height range. On special request of authors of the present paper Dr. J. King performed calculations of vertical distributions of ionospheric drift velocities for concrete conditions under which Soviet geophysical rockets were launched on 3 October 1970, 28 November 1970 and 20 August 1971. Results of calculations by Dr. King were used to solve the equation of the ionization balance with taking into account of the ionospheric drift in the term div $(n_e . \mathbf{V})$.

The purpose of this paper is to present results of the determination of β_{eff} height distributions (up to ~ 400 km), the comparison of them with corresponding β_{eff} height profiles obtained with the ignoring of the ionospheric drift and the estimation of the influence of the latter on recombination processes in the F-region.

2. THEORY

The height distribution of the effective recombination coefficient was calculated from the equation of the ionization balance

$$\frac{\partial n_e}{\partial t} = q - \beta_{\text{eff}} \cdot n_e + D \left(\frac{\partial^2 n_e}{\partial h^2} + \frac{3}{2H} \frac{\partial n_e}{\partial h} + \frac{n_e}{2H^2} \right) - w \frac{\partial n_e}{\partial h} \tag{1}$$

where

q—the ionization rate,
D—the vertical diffusion coefficient,
w—the vertical velocity of the ionization drift.

Used values of n_e and q are presented in Fig. 1.

Let us note that values of n_e are determined by a radiomethod during a vertical rocket flight and q—from neutral atmosphere parameters and from the intensity of the ionizing solar radiation which were obtained from measurements on the same rocket by means of the photoelectron analyzer (GRINGAUZ *et al.*, 1968; SHUTTE, 1972).

The data of the neutral composition structure throughout period of these experiments are shown in Fig. 2, which are necessary to estimate the coefficient D and the scale height H. The ratio of concentrations of the atomic oxygen [O] and major molecular particles [M] = $[O_2] + [N_2]$ are presented in the right part of this picture.

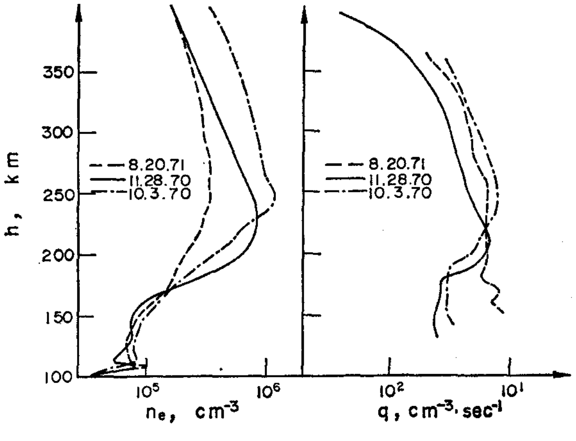

Fig. 1. $n_e(h)$ and $q(h)$ distributions.

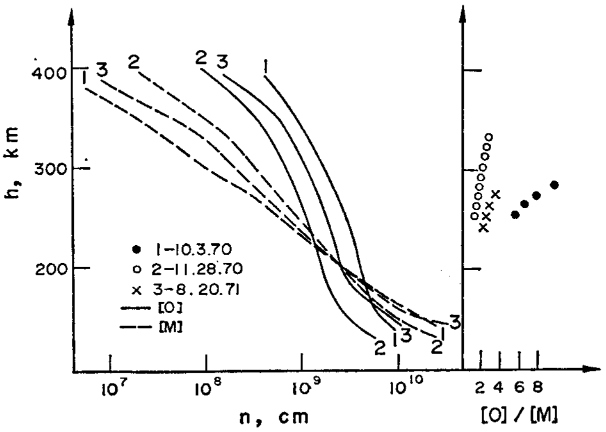

Fig. 2. Results for the neutral composition.

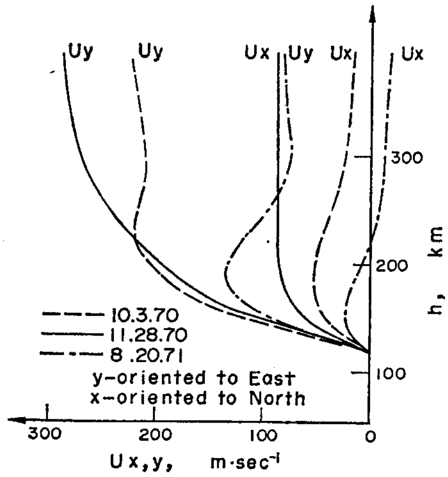

Fig. 3. Components of the neutral wind horizontal velocity (calculated by J. W. King).

Components of the neutral wind horizontal velocity calculated by J. King are shown in Fig. 3. In these calculations it was assumed that neutral winds formed by pressure gradients are mainly controlled by Coriolis force, the viscous force, inertial forces and by the ion deceleration due to neutral particle and ion collisions, In this relation calculations of the kinematic viscosity by Matuura and Nagata (1962) were used. Ionograms and corresponding models of the *F*-region with the ignoring of the ionization in the *E*-region were used in calculations of the ion deceleration for selected values of the ion concentration. Moreover it was assumed that the collision frequency of a neutral particle with all ions, ν_i, is much less than the ion gyrofrequency and masses of ions and neutral particles are equal. The parameter ν/n is assumed to be 7×10^{-10} cm^{-3} sec^{-1} according to estimations by

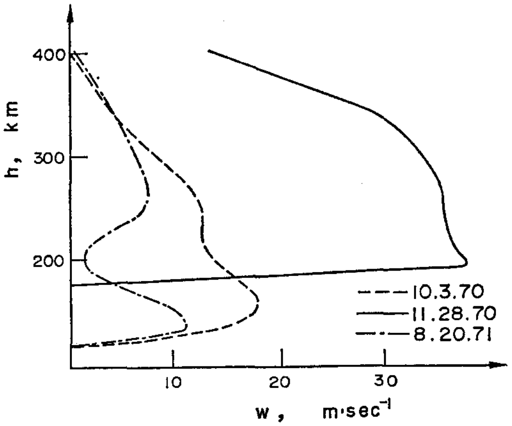

Fig. 4. Vertical component of the ionospheric drift velocity.

Dalgarno (1964). These estimations were made under the assumption that over all height range of the F-region one can take into consideration only collisions between O^+ and O.

When calculating pressure gradients $\nabla p/p$ (so-called 'motive forces') the atmospheric data by JACCHIA (1965) were used for conditions of the moderate solar activity and the equinax.

If one suggests that the ion motion is only due to neutral winds (i.e. the contribution of forces caused by ion pressure gradients and electric fields is relatively unimportant) (HINES, 1965; BRAMLEY, 1971; RUSTER, 1971) then the value of the ionization drift velocity will be determined by the projection of the neutral wind velocity vector on a field line. Values of the vertical component of the ionospheric drift velocity obtained from mentioned experiments are presented in Fig. 4. One can note that the vertical component of the neutral wind velocity is negligible and the component U_y directed from the east to the west considerably exceed the component U_x in all cases. At heights $h < 400$ km the ionospheric drift (see Fig. 4) was directed downwards and reached maximum values on 11.28.70. Let us note that values of drift velocities presented in this figure are in good agreement with results by EVANS (1971) obtained by the method of radiowave incoherent back scattering. In accordance with these results at daytime fluxes of charged particles at $h < 400$ km are directed downwards and at $h > 400$–600 km—upwards.

3. RESULTS

From the comparison of Figs. 1 and 2 it follows that at $h > 200$ km in the experiments under consideration:

(i) Absolute concentration values of neutral particles were different each from another by less than a factor of 2.

(ii) Differences in values of $q(h)$ practically correspond to to differences in values of $n(h)$;

(iii) The relative concentration of molecular particles was maximum on 28 November 1970.

One would think that on 23 November 1970 values of n_e should be minimum because in this time minimum values of $q(h)$ and (O)/[M] were observed over all the period of this experiment. However, it can be seen from Fig. 1 that on 28 November 1970 values of n_e were considerably higher than, for instance, on 20 August 1971. Thus one can suggest that observed profiles of $n_e(h)$ cannot be always explained only by photochemical processes.

To analyse the influence of the ionization motion term in the equation (1) on the character of recombination processes this equation was solved under each of three following assumptions (i) the motion term was ignored; (ii) only the vertical diffusion was considered taking into account the motion term; (iii) the vertical diffusion and the charged particle drift due to the neutral wind was taken into account (the effect of electric field was ignored).

4. DISCUSSION

Results of calculations presented in Fig. 5 allowed to draw the following conclusions: absolute values of β_{eff} and height dependence of $\beta_{\text{eff}}(h)$ are only slightly varied under the action of the vertical diffusion. The taking account of charged particle drift considerably changed the character of profiles $\beta_{\text{eff}}(h)$ on 3 October 1970 and 28 November 1970. Instead of an anomalous increase of β_{eff} values at $h \geqslant 230$ km a monotonic decrease is now observed. Besides, in come cases (28 November 1970) absolute values of β_{eff} are changed by a factor of 2. The downwards high velocity of the ionospheric drift on 28 January 1970 caused the minimum value of h_mF2 over all period of this experiment. In summer, on 20 August 1971 the drift velocity did not exceed 10 m/sec and this did not practically influence the values of $\beta_{\text{eff}}(h)$. It is now more clear why in the F-region the good coincidence of the form of $n_e(h)$ and $q(h)$ profiles took place during the period of this experiment (see Fig. 1). Observed height distribution of values of ionization drift velocities $n_e(h)$ are apparently indicative of the seasonal effect of the meridional wind influence on the electron

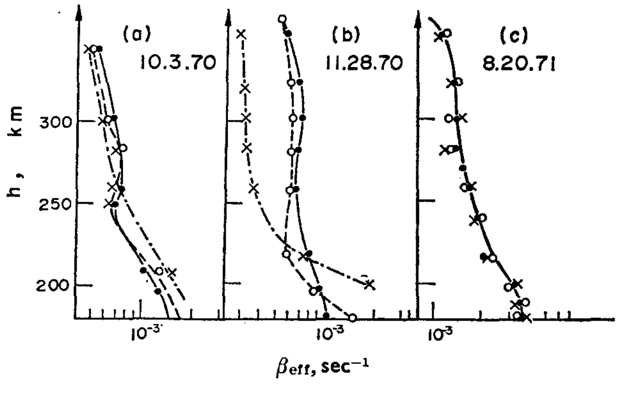

Fig. 5. Height distributions of the effective coefficient of recombination.

—●—●—● div $(n_e \,.\, \mathbf{V}) = 0$; $w = 0$
—○—○—○ div $(n_e \,.\, \mathbf{V}) \neq 0$; $w = 0$
—×—×—× div $(n_e \,.\, \mathbf{V}) \neq 0$; $w \neq 0$.

concentration distribution in the region. As a result of these effects the *F2*-region is observed as more 'compact' in winter (Strobel and McElroy, 1970).

The comparison of absolute values of $\beta_{\mathrm{eff}}(h)$ also showed that values of β_{eff} decrease with the increase of the wind velocity. In this case variations of the neutral composition structure apparently influence β_{eff}—values to a lesser extent than the drift does. Really maximum relative concentrations of atomic oxygen were observed on 10.3.70. From point of view of aeronomical reaction rates on 10.3.70 minimum values of $\beta_{\mathrm{eff}}(h)$ should by observed and on 11.28.70—maximum ones. In practice maximum values of β_{eff} were observed on 8.20.71 when values of the ratio [O]/[M] were substantially less than, for instance, on 10.3.70. It is worth to note that typical seasonal variations of the neutral composition were not observed in this case (Mayer and Mahajan 1971; Strobel and McElroy, 1970; Shimazaki, 1972). The relatively scanty number of measurements does not allow to explain unambiguously the cause of the observed disagreement. It is known that in winter the seasonal increase of the atomic oxygen concentration is mainly observed at the daytime (i.e. at lesser zenith angles than it took place in the mentioned experiments).

5. CONCLUSION

The above mentioned considerations showed that in a number of cases the charged particle drift substantially influences both the character of the height distribution of the effective recombination coefficient in the ionosphere and its absolute values. The most influence of meridional winds is observed in the winter experiment. When the ionospheric drift velocity exceeded 10 m/sec the charged particle drift influenced the rate of ionization losses to a greater extent than variations of the neutral compostition.

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