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STRUCTURAL PARAMETERS OF THE IONOSPHERE BY THE DATA OF GROUND-BASED AND ROCKET EXPERIMENTS AND PHOTOCHEMISTRY OF THE LOWER PART OF F-REGION

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ABSTRACT

From rocket and ground-based measurements during flights of"Vertical-3" and "Vertical-4" geophysical rockets in 1975 and 1976, electron density and collision frequency profiles have been obtained. Neutral particles concentrations of O, O_2 anl N_2 have been determined too.

It is shown, that photo chemical theory of the ionosphere formation based on modern conceptions of its constants and on processes in which excited ions are present, explain satisfactory height changes of electron concentration observed below F-region maximum.

I. Introduction

Simultaneous complex measurements of basic parameters height distribution of the upper atmosphere made when rockets are launched give valuable information required for solving problems of the ionosphere physics and updating processing and interpretation procedures of experimental data. One of the modern problems, that of building a theoretical model of the atmosphere, needs a question to be solved of whether constants of photochemical processes measured in laboratory can be applied to real conditions in the upper atmosphere.

Given below are the results of simultaneous measurements of the neutral composition (N_2, O_2, O), electron density n_e and the effective electron collision frequency ν_e . Experiments were carried out according to the rocket studies of the upper atmosphere program, begun in 1965 [1-4] . The VERTICAL rockets were launched at mid-latitudes in the European part of the USSR on September 2, 1975 (for the Sun's zenith angle $\chi = 67^{\circ}$, 10,7 cm - solar radio radiation flux $F_{10.7} = 83\cdot10^{-22}$ $W\cdot m^{-2}.Hz^{-1}$, VERTICAL-3) and on October 14, 1976 ($\chi = 63^{\circ}$, $F_{10.7} = 73\cdot10^{-22}$ $w\cdot m^{-2}.Hz^{-1}$, VERTICAL-4).

The data obtained were used to up-data the information on the ionization processes in the lower F-region, and to check the now used photochemical theory and the assumed constants of the processes.

2. Results of measurements

2.1. n_e (h) and ν_e -(h)-profiles

$n_e(h)$ - profiles were measured by a rocket dispersion radiointerferometer (frequencies 144 and 48 MHz) and a ground-based ionosond recording separately o and x-components of ionograms. The measuremental procedure was given in [4] together with $n_e(h)$ profiles for 2.09.1975. On October 14, 1976 ground-based measurements gave the $n_e(h)$-profile from 63 km and up to the F-region maximum, rocket measurements for the range 82 to 1300 km.

The accuracy of rocket measurements of $n_e(h)$ in the upper part of the rocket trajectory depends on the ionospherical non-stationarity $\dot{N}_e = \frac{\partial N_e}{\partial t} = \frac{\partial}{\partial t}\int_0^h n_e(h)\,dh$, where N_e is the total content of electrons [5]. The error in n_e measurements exceeded 10% at heights of $h > 600$ km for October 14, 1976. To take into account the contribution from the ionospherical non-stationarity $\dot{N}_e \sim N_e$ was assumed, at each fixed height. Then for any height $\dot{N}_e(h) = [N_e(h)/N_e(h_{max})]\dot{N}_e(h_{max})$, where $\dot{N}_e(h_{max}) = 1.5\cdot 10^9$ cm^{-2}s^{-1} is the instability in the peak of the rocket trajectory calculated from our measurements.

Fig. 1 shows the results of rocket measurements of electron density n_e on October 14, 1976. The feature of the $n_e(h)$-profile is the two strata recorded by the ionosond in the E-region. The height corresponding to the maximum electron concentration, $h_{max}F$ is 226 km.

The $n_e(h)$ profile from ground-based measurements was calculated as follows. The $n_e(h)$-distribution in D- and the base of E-region was assumed exponential $n_e(h) = 100\times\exp[(h-h_0)/H]$. The scale height H and the initial height in the ionosphere h_0

were at O-trace of the ionogram, taking into account radiowaves absorption measured at 2.00 MHz [6] . In E- and F-regions the method of least squares was used to calculate the $n_e(h)$-profile for both the ionogram components.

Fig. 1 gives the results of calculations for October 14, 1976. Maximum discrepancy of n_e-values from rocket and ground-based data is 12%. This difference can be caused both by non-simultaneous rocket and ground-based measurements and by horizontal gradients of n_e in the ionosphere. The h_{max} F-value calculated from the ionograms is 6 km lower than that from rocket measurements.

The procedure of determining $\nu_e(h)$-profile from the ground-based measurements of the radiowave absorption frequency dependence L(f) and the rocket-measured $n_e(h)$-profile is given in [4] together with the $\nu_e(h)$-profile for September 2, 1975. In the experiment of October 14, 1976 polarization measurements of L(f) were carried out at 8 frequencies in the range 2.00 to 4.25 MHz and the amplitudes of pulses received were averaged over the frequency range [7] . It allowed, for the experiment considered, the period over which signals were averaged to be reduced down to 15 min and the maximum error for the profile down to 20%, $\nu_e(h)$-profile and error limits are shown in Fig.2.

2.2. Neutral composition

The density and composition of neutral particles N_2, O_2 and O were determined from height dependences of the spectral intensity of solar UV-radiation recorded by a photoelectron analyzer on-board the rocket in six wavelength ranges: I - $\lambda \leq 600$Å, II - 600 to 900Å, III - 900 to 1100Å; IV - 1100 to 1350Å; V - - 1350 to 1500Å; VI - $\lambda > 1550$Å. The measuremental procedure and instrumentation are described in [8] .

Fig. 3 shows the $[N_2]$, $[O_2]$ and $[O]$ profiles obtained. On September 2, 1975 the results were obtained for the rocket ascent (heights $h > 150$ km) and on October 14, 1976 for the rocket descent (heights, $h > 120$ km). For comparison Fig. 3 gives also height dependences of neutral particles, according to Jaccia's 71-model [9]. Good agreement should be mentioned between the measured and model profiles, excluding the $[O_2]$ data in the 2.09.75 experiment. The latter is obviously due to the effect of the running rocket engine on the medium. The experimental conditions on September 2, 1975 did not yield data on the descending branch of the trajectory, hence density data from the model were used for O_2 above 150 km and for all particles below 150 km [9].

3. Aeronomic calculations

It was assumed for aeronomic processes below $h_{max}F$ that the major source of N_2^+, N^+, O_2^+ and O^+ ions is the direct ionization of neutral gas by solar UV-radiation. Table I summarizes chemical reactions of ion generation and their further transformation.

Vibrational temperature was taken equal to that of neutral gas [21] – [23]. The densities of $[N]$ and $[NO]$ not calculated in our experiments were taken from [24]. Transfer processes were not taken into account, equilibrium conditions were assumed since in the day time the contribution from diffusion transfer at the heights considered was much less than that from direct ionization and recombination processes.

The values of ion production rate were obtained from the experimental data about the neutral composition and intensity of UV-radiation for $\lambda > 400$Å. For $\lambda < 400$Å Hinteregger's data for low solar activities were used [25]. In the given paper Te-dat from the experiment of September 2, 1975 were used for both cases [26] since the final experimental Te-values for VERTICAL-4 have not been obtained until the calculations under discussions, while the Sun's zenith angles and $F_{10.7}$ fluxes are close in both experiments.

In these approximations equations for ion concentrations $[O^+(^2P)], [O^+(^2D)], [O^+(^4S)], [N^+], [N_2^+], [O_2^+], [NO^+]$, were obtained (see Table I). These equations at quasi-neutrality condition $\sum_i [X_i^+]=[e]$ form a system of non-linear equations which can be solved for ion $[X^+]$ and electron $[e]=n_e$ densities by using iteration procedure.

Fig. 1 and 4 show the electron density calculated values, the fig. 4 shows the ion composition also.

Thus obtained distributions of $[N_2]$, $[O_2]$, $[O]$ and n_e were used for gas-kinetic calculations of $v_e(h)$-profiles. The number of electron-ion collisions was determined by method [27]. The rate of electron collisions with neutrals was derived from [28]. Fig. 2 is the $\nu_e(h)$-profile calculated for October 14, 1976.

4. Discussion

Coincidence of $n_e(h)$-profiles directly measured and based on the aeronomic calculations can be a criterion of whether the scheme of photochemical processes responsible for the lower F-region formation, used in the paper is adequate. Fig. 1 and 4 also show profiles for October 14, 1976 and September 2, 1975. $n_e(h)$-curves in Fig. 1 (14.10.1976) show that there is a good agreement of theoretical and experimental data (errors less than 15%) in the height range 130-220 km. For $h < 130$ km the discrepancy is somewhat larger and can be explained by inaccuracies in the assumed concentrations of minor components N and NO (see reactions 16, 17, Table I).

For the experiment carried out on September 2, 1975 the discrepancy between the theoretical and measured electron concentrations does not exceed 10% while it grows up to 35% below 130 km which can be attributed to inaccuracies both in the T_e (h)-profile used and in the assumed concentrations of minor components. Inaccuracy in Te(h) over the range 120 to 130 km can be revealed by comparison of gas-kinetic and experimental values of ν_e (see Fig. 2). If over the height range 120 to 130 km Te values are taken to be 250°K higher than those we got from [26] , the measured and calculated values of ν_e may fit well to an accuracy of 10% and the rocket and theoretical profiles of n_e(h) can be made fully coincident within this range. Above 130 km agreement between both experimental and calculated values of n_e and ν_e cannot be obtained due to Te changings. Here experimental values of ν_e are higher than gas-kinetic and for h 160km the discrepancy is of an order of magnitude. The observed discrepancy was earlier recorded [4,29-31] .

Conclusions

1. By way of comparison of the data which have been obtained simultaneously in ground-based and rocket experiments and characterize both the ionized and neutral components of the upper atmosphere, it was shown that the dayside ionosphere below the F-region maximum could be fairly well described by the adopted photochemical model.

2. The values of density n_e, obtained on photochemical calculations essentially depend on the temperature coefficients of major aeronomic processes was shown for heights $h < 130$ km.

3. The using of measured n_e(h)-profiles and data on neutral components allows to make more accurate gas-kinetic calculations of electron collision frequency ν_e.

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Table 1

NN	Reaction	Reaction rate coefficient*)	Reference
1	$O + h\nu \rightarrow O^+(^2P) + e$	$0{,}2\, q_O$	[10]
2	$O + h\nu \rightarrow O^+(^2D) + e$	$0{,}4\, q_O$	[10]
3	$O + h\nu \rightarrow O^+(^4S) + e$	$0{,}4\, q_O$	[10]
4	$O_2 + h\nu \rightarrow O_2^+ + e$	q_{O_2}	[11]
5	$N_2 + h\nu \rightarrow N_2^+ + e$	q_{N_2}	[11]
6	$N_2 + h\nu \rightarrow N^+ + N + e$	$0{,}1\, q_{N_2}$	[12]
7	$N + h\nu \rightarrow N^+ + e$	q_O	[12]
8	$O^+(^2P) \rightarrow O^+(^2D) + h\nu$	$0{,}318\ sec^{-1}$	[13]
9	$O^+(^2D) + e \rightarrow O^+(^4S) + e$	$3{,}0 \times 10^{-8}\ cm^3 sec^{-1}$	[14]
10	$O^+(^4S) + O_2 \rightarrow O_2^+ + O$	$2{,}0 \times 10^{-11}\, \varphi_1(T_n)$	[15]
11	$O^+(^4S) + N_2 \rightarrow NO^+ + N$	$\varphi_2(T_v, T_n)$	[16]
12	$O^+(^2D) + O_2 \rightarrow O_2^+ + O$	$2{,}0 \times 10^{-10}\ cm^3 sec^{-1}$	[17]
13	$O^+(^2D) + N_2 \rightarrow N_2^+ + O$	$1{,}0 \times 10^{-9}\ cm^3 sec^{-1}$	[18]
14	$O^+(^2P) + O_2 \rightarrow O_2^+ + O$	$2{,}0 \times 10^{-10}\ cm^3 sec^{-1}$	[17]
15	$O^+(^2P) + N_2 \rightarrow N_2^+ + O$	$1{,}0 \times 10^{-9}\ cm^3 sec^{-1}$	[18]
16	$O_2^+ + N \rightarrow NO^+ + O$	$1{,}8 \times 10^{-10}\ cm^3 sec^{-1}$	[19]
17	$O_2^+ + NO \rightarrow NO^+ + O_2$	$4{,}5 \times 10^{-10}\ cm^3 sec^{-1}$	[15]
18	$N_2^+ + O \rightarrow NO^+ + N$	$1{,}3 \times 10^{-10}\, \varphi_3(T_n)$	[20]
19	$N_2^+ + O \rightarrow O^+ + N_2$	$1{,}0 \times 10^{-11}\, \varphi_4(T_n)$	[20]
20	$N_2^+ + O_2 \rightarrow O_2^+ + N_2$	$4{,}2 \times 10^{-11}\, \varphi_5(T_n)$	[15]
21	$N^+ + O_2 \rightarrow O_2^+ + N$	$3{,}6 \times 10^{-10}\, \varphi_6(T_n)$	[15]
22	$N^+ + O_2 \rightarrow NO^+ + O$	$2{,}4 \times 10^{-10}\, \varphi_7(T_n)$	[15]
23	$NO^+ + e \rightarrow N + O$	$4{,}5 \times 10^{-7}(300/Te)$	[12]
24	$O_2^+ + e \rightarrow O + O$	$2{,}2 \times 10^{-7}(300/Te)$	[12]
25	$N_2^+ + e \rightarrow N + N$	$2{,}7 \times 10^{-7}(300/Te)^{0{,}7}$	[12]

*) where q - ion production rate,

T_n - neutral gas temperature,

T_v - vibrational temperature,

T_e - electron temperature.

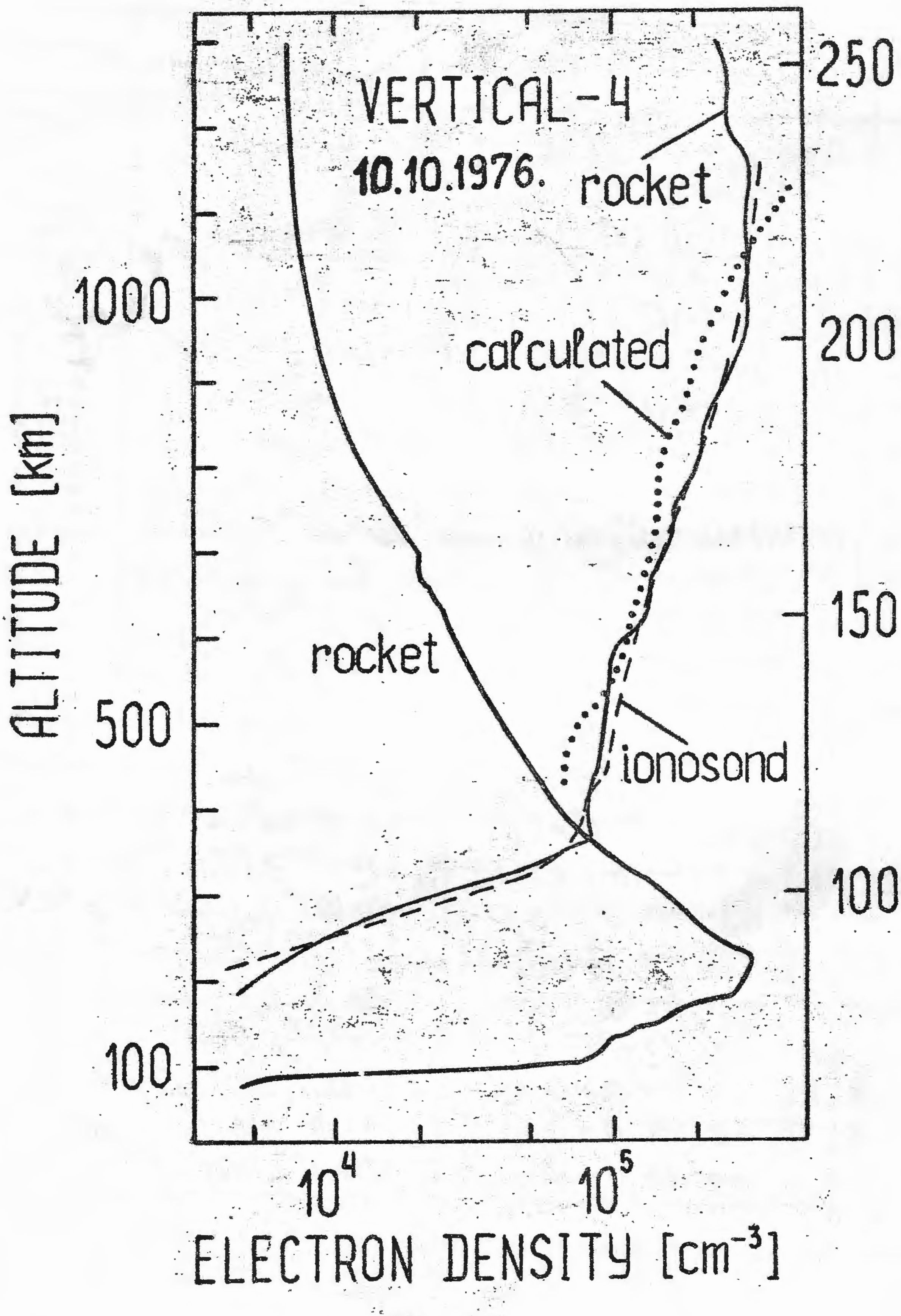

VERTICAL-4
10.10.1976.
rocket
calculated
rocket
ionosond
ALTITUDE [km]
1000
500
100
250
200
150
100
10^4
10^5
ELECTRON DENSITY [cm^{-3}]

Fig.1

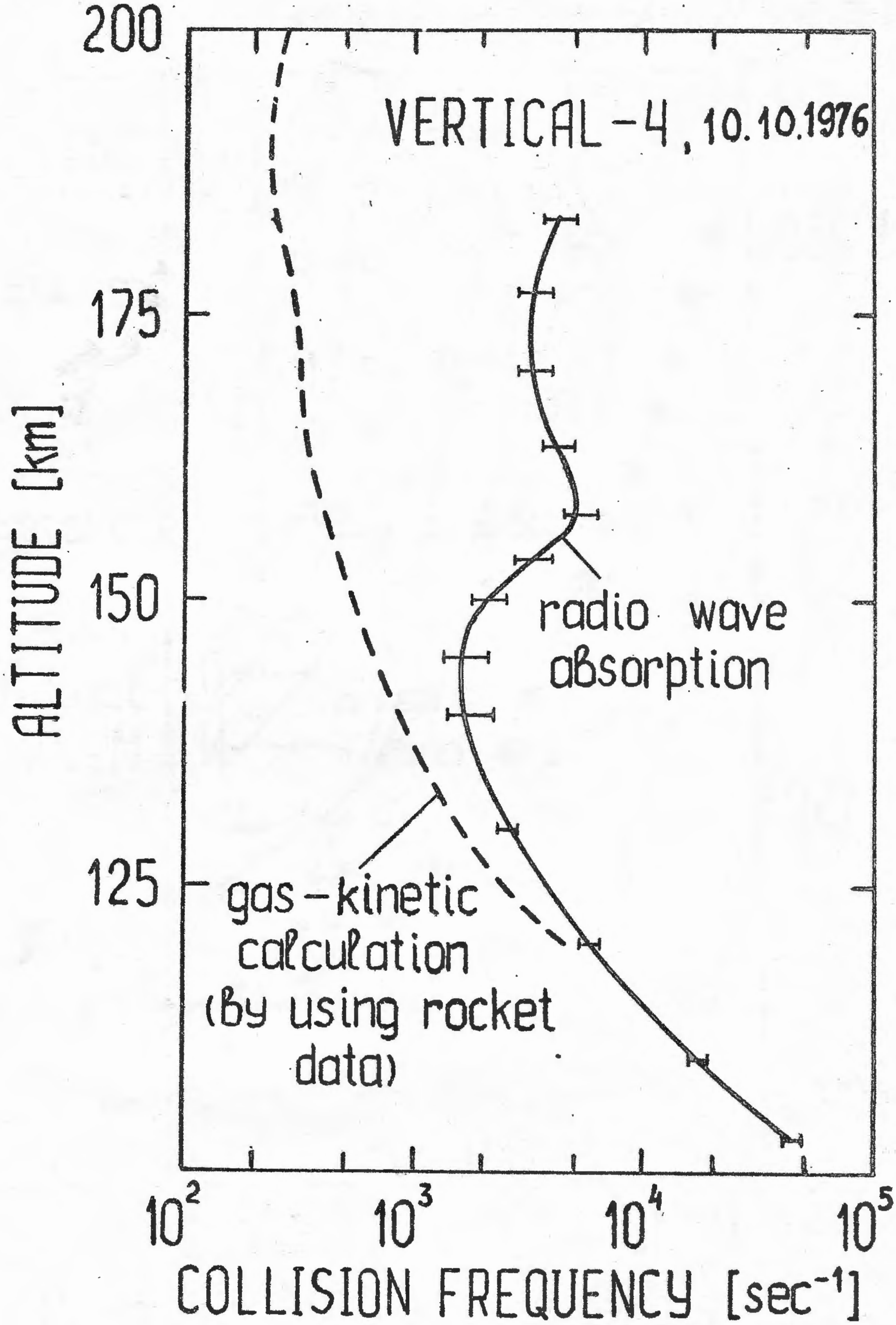
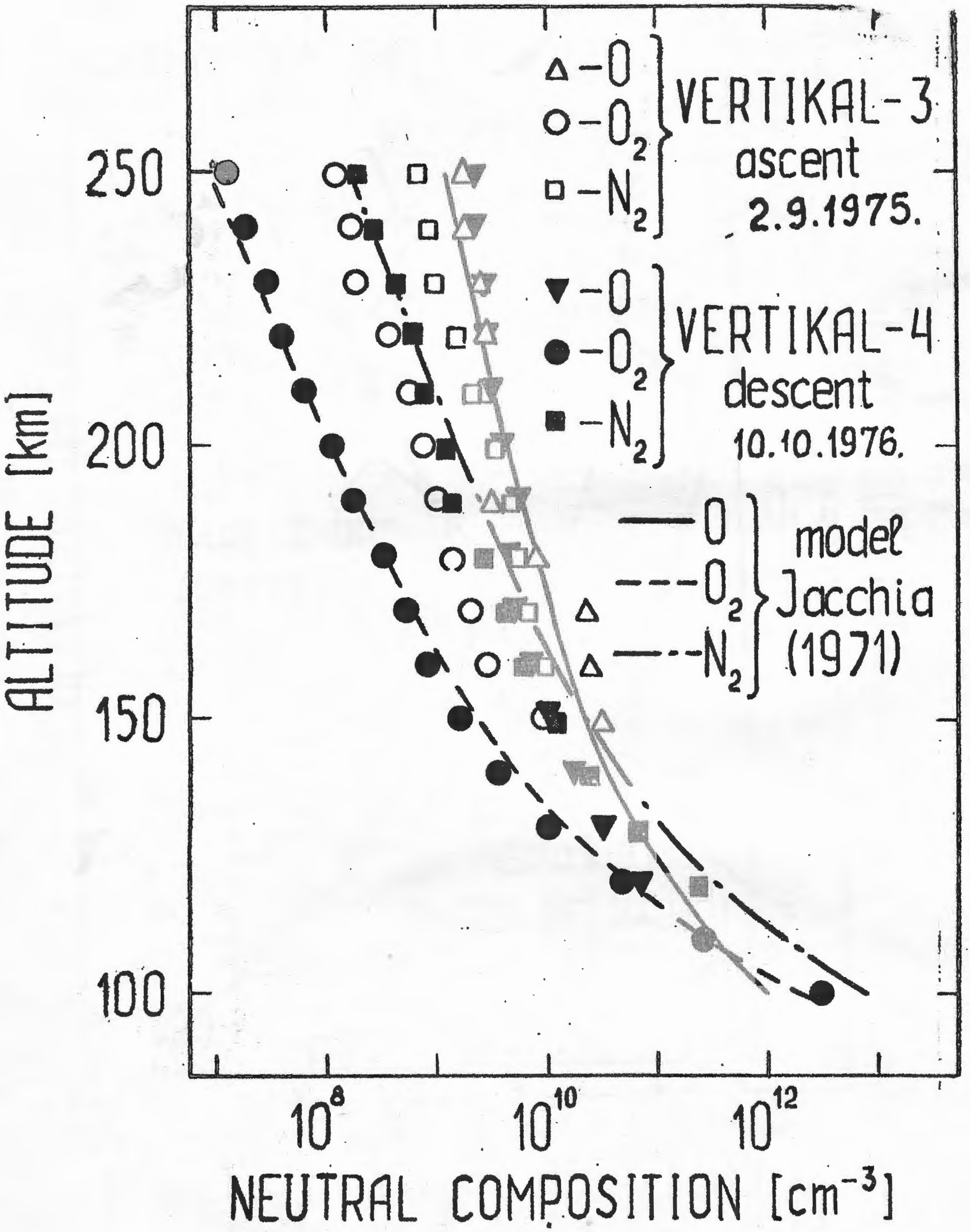

200
175
150
125
ALTITUDE [km]
VERTICAL-4, 10.10.1976
radio wave absorption
gas-kinetic calculation (by using rocket data)
10^2
10^3
10^4
10^5
COLLISION FREQUENCY [sec^-1]

Fig. 2



ALTITUDE [km]
250
200
150
100
10^8
10^{10}
10^{12}
NEUTRAL COMPOSITION [cm^{-3}]
△ – O
○ – O_2
□ – N_2
VERTIKAL-3
ascent
2.9.1975.
▼ – O
● – O_2
■ – N_2
VERTIKAL-4
descent
10.10.1976.
—— O
- - - O_2
–·– N_2
model
Jacchia
(1971)

Fig.3

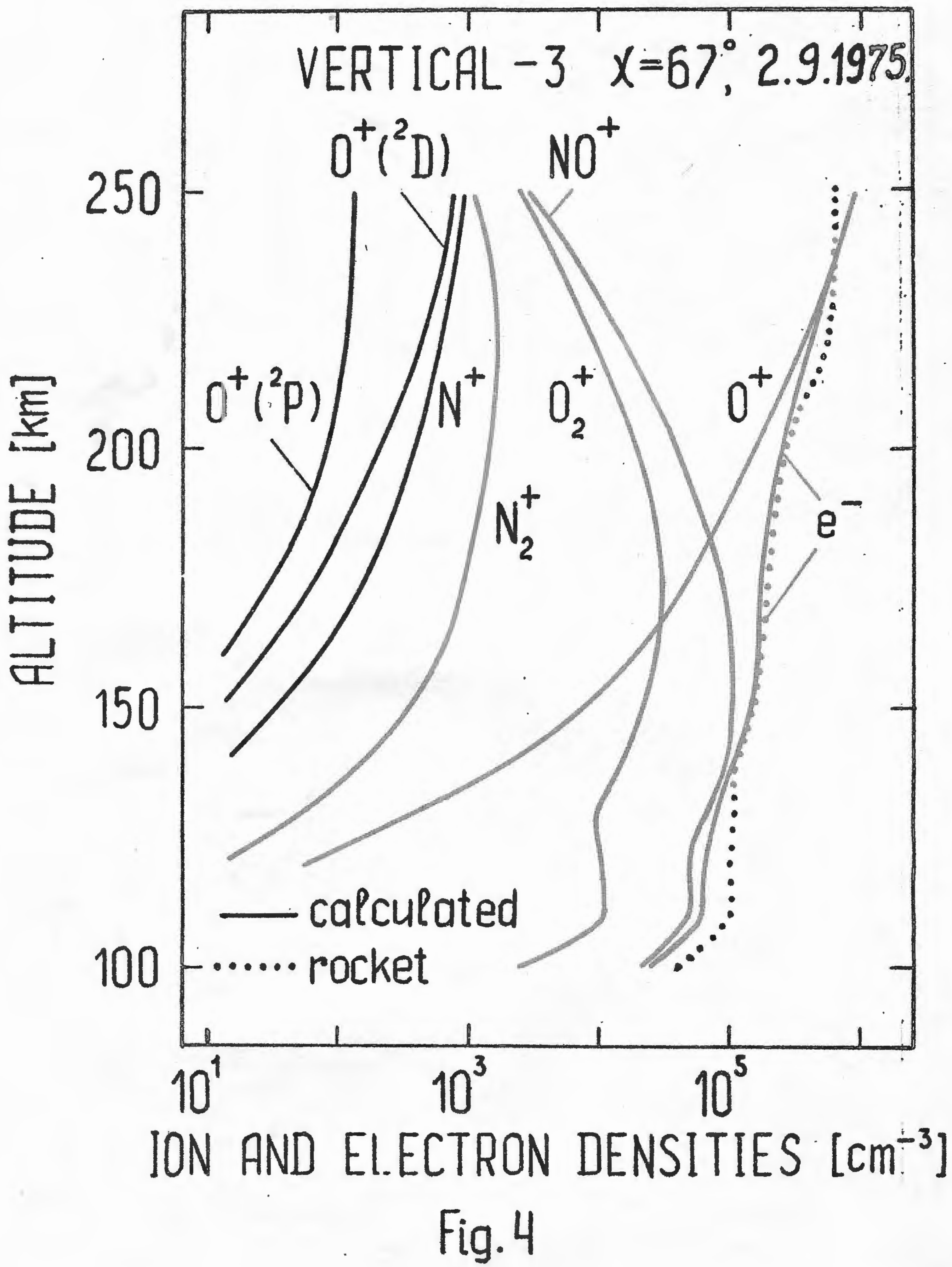

VERTICAL-3 χ=67°, 2.9.1975
O⁺(²D)
NO⁺
O⁺(²P)
N⁺
O₂⁺
O⁺
N₂⁺
e⁻
calculated
rocket
ALTITUDE [km]
250
200
150
100
10¹
10³
10⁵
ION AND ELECTRON DENSITIES [cm⁻³]

Fig. 4