DIRECT BALLOON MEASUREMENTS OF THE STRATOSPHERIC AEROSOL

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A balloon-borne impactor and measurements of the vertical profile of the number density and particle size distribution of aerosol particles at altitudes ranging from 10 to 30 km are described. The measurements were performed in the town of Ryl'sk during the summer of 1987–1988.

Many calculations of the optical, thermodynamic, physical, and chemical parameters and characteristics of the stratosphere have been performed based on models of the stratospheric aerosol. The models in turn must be checked experimentally and refined based on direct measurements of the stratospheric aerosol. Impactor measurements of the aerosol component are most informative in this respect; such measurements enable determining the number density of aerosol particles and the size distribution, morphological characteristics, and elemental composition of the particles. Very few direct impactor measurements of the stratospheric aerosol have been performed, so that new measurements could be useful and interesting to a wide range of investigators of the atmosphere.

The aerosol particles are sucked into the impactor through a thin tube with an inner diameter of 1.8 mm and an outer diameter of 2 mm. A rotating plate for deposition of aerosol particles from the gas flow is positioned 1 mm below the exit opening of the tube. Particles are collected on a fine copper grids coated with a thin carbon film, usually employed in electron microscopy. The plate is displaced under the nozzle and the pump is switched on and off at a prescribed flight altitude of the balloon automatically.

Electron-microscopic analysis of the obtained samples makes it possible to determine the number density of aerosol particles per unit area of the plate in any prescribed particle-size interval and also to obtain a morphological description of the collected particles.

The flow rate of air through the device at pressures ranging from 10 to 265 mbar was determined on a laboratory apparatus based on the pressure drop at the ends of the suction tube. The calculations showed that the volume flow rate of air through the entry section of the suction tube varies from 15.4 liters/min at an altitude of 10 km up to 3.4 liters/min at an altitude of 30 km.

To evaluate how effectively aerosol particles are deposited on the plate by means of inertial deposition we employed the results of numerical calculations of the equations of motion of the particles in the velocity field formed as the rarefied gas effuses from the nozzle.[1] The calculations showed that for an impactor at an altitude of 15 km particles with a radius of 0.05 μm are deposited with an efficiency of 50% and particles with a radius exceeding 0. 1 m are deposited with an efficiency of 100%. Above 18 m particles whose radius exceeds 0.05 μm are also deposited with 100% efficiency.

The efficiency with which aerosol particles are sucked into a thin-walled tube was calculated on the basis of a model of a point sink in a uniform rectangular flow.[2] Under the conditions of a balloon experiment, for particles whose radius is less than 1 μm, the suction factor is close to 100% at all sampling altitudes.

The error in measuring the concentration of aerosol particles with radius greater than 0.1 μm does not exceed 60% at all measurement altitudes, and for the finest particles it reaches a factor of 2.

The measurements of the vertical distribution of aerosol particles with $r \geq 0.05$ μm at altitudes in the range 13 ... 27 km, performed in September 1987 in the town of Ryl'sk, are presented in Table I. The data were obtained as the balloon was rising as well drifting at the maximum altitude, and were averaged over 3-km layers (the altitude at the center of the layer is shown in the tables). The total particle number density varies from 1.0 to 2.3 cm^{-3}, and for particles with $r < 0.3$ μm a relative maximum of the number density is observed at an altitude of 25.5 km. Figure 1a shows the particle-size distribution at different altitudes.

The particle-size spectra obtained are close to Junge's power-law distribution $dN/d\log r = Cr^{-\nu}$ (or to a superposition of power laws) and drop off quite steeply for large radii, so that particles with radius $r > 1$ μm are virtually never observed. The parameter ν depends on the altitude randomly, and its values at different altitudes range from 2.2 to 5.3.

Measurements of the vertical, aerosol particle distribution performed in June 1988 are presented in Table II and in Figs. 1b and c. The data were obtained as the balloon was rising at altitudes ranging from 10 to 30 km and are averaged over 1.5-km layers. The total number density of particles with $r \geq 0.05$ μm ranges from 0.4 to 3.0 cm^{-3}. Compared with the 1987 data at altitudes $H > 20$ km the number density of large particles was higher and their percentage in the particle-size distribution was higher. The parameter ν ranges from 1.7 to 3.9 at different altitudes.

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TABLE I.

The vertical particle size distribution N ($r > r_0$), cm^{-3}. *(Town of Ryl'sk, September 3, 1987).*

r_0 μm	H km				
	14.8	18.4	22.0	25.5	26.2
0.05	1.5(0)	2.3(0)	7.0(-1)	1.7(0)	1.0(0)
0.1	3.0(-1)	2.9(-1)	2.9(-1)	7.6(-1)	1.8(-1)
0.15	9.5(-2)	1.9(-1)	1.9(-1)	5.4(-1)	7.9(-2)
0.2	7.1(-2)	1.3(-1)	1.3(-1)	3.5(-1)	2.7(-2)
0.25	4.7(-2)	5.2(-2)	6.8(-2)	2.0(-1)	7.8(-3)
0.3	2.5(-2)	8.1(-3)	3.0(-2)	5.2(-2)	3.1(-3)
0.35	1.4(-2)	4.6(-3)	1.1(-2)	2.1(-2)	—
0.4	9.0(-3)	—	7.6(-3)	6.5(-3)	—
0.45	7.6(-3)	—	4.4(-3)	—	—
0.5	2.8(-3)	—	2.5(-3)	—	—

Note. The number in parentheses denotes a power of 10.

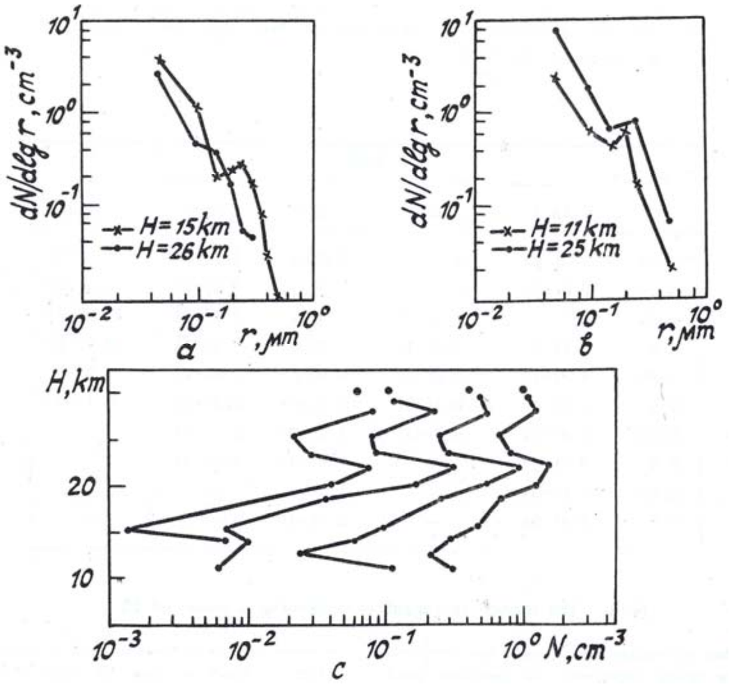

FIG. 1. The results of impactor measurements of aerosol in the town of Ryl'sk. a, b) Particle size distribution at different altitudes. The distributions were measured on September 3, 1987 and June 21, 1988, respectively. c) Vertical profiles of the number density of particles with $r > r_0$; the profiles were obtained on June 21, 1988.

The morphological composition of the particles is virtually identical for all particle sizes and measurement altitudes in both flights. More than 90% of the particles collected are burr-shaped, their optical density is substantially nonuniform, and the particles evaporate easily in the beam of an electron microscope; the latter property could be responsible for the distortions of the size spectra of real stratospheric particles occurring during laboratory analysis of aerosol samples. Many finely dispersed particles have halos. Particles of other morphological types constitute no more than 3 to 4% of the total number of particles. Optically dense large particles of irregular form are encountered among them most often, while needles, chains, and multilayer particles are encountered less often.

TABLE II.

The vertical particle size distribution N ($r > r_0$), cm^{-3}. (Town of Ryl'sk, June 21, 1988).

r_0 μm	H km							H km			
	11.3	12.6	13.9	15.3	18.5	20.2	21.9	23.7	25.3	27.0	28.4
0.05	4.2(-1)	7.5(-1)	1.1	1.5	1.7	3.1	3.0	3.0	3.1	3.0	1.7
0.1	3.2(-1)	2.1(-1)	3.0(-1)	4.8(-1)	6.7(-1)	1.3	1.6	8.2(-1)	7.3(-1)	1.3	1.2
0.15	2.5(-1)	1.1(-1)	1.8(-1)	2.8(-1)	4.7(-1)	8.8(-1)	1.4	5.4(-1)	4.1(-1)	8.8(-1)	8.8(-1)
0.2	1.9(-1)	5.0(-2)	1.2(-1)	1.8(-1)	3.5(-1)	7.1(-1)	1.2	4.2(-1)	3.2(-1)	7.2(-1)	7.1(-1)
0.25	1.2(-1)	2.4(-2)	6.1(-2)	9.6(-2)	2.6(-1)	5.6(-1)	1.0	3.0(-1)	2.5(-1)	5.9(-1)	5.3(-1)
0.3	2.4(-2)	6.2(-3)	2.7(-2)	2.6(-2)	1.0(-1)	3.0(-1)	5.7(-1)	1.5(-1)	1.4(-1)	3.6(-1)	2.5(-1)
0.35	5.9(-3)	—	1.0(-2)	6.8(-3)	3.6(-2)	1.7(-1)	3.5(-1)	8.3(-2)	8.2(-2)	2.4(-1)	1.2(-1)
0.4	—	—	6.7(-3)	1.4(-3)	7.2(-3)	8.6(-2)	1.9(-1)	6.1(-2)	3.8(-2)	1.6(-1)	4.7(-2)
0.45	—	—	—	—	1.4(-3)	7.0(-2)	1.3(-1)	5.0(-2)	2.6(-2)	1.3(-1)	4.0(-2)
0.5	—	—	—	—	—	4.0(-2)	8.3(-2)	2.8(-2)	2.1(-2)	8.3(-2)	—

Note. The number in parentheses denotes a power of 10.

It should be noted that the experimental data presented above on the aerosol-particle number density in the lower stratosphere are lower than some data obtained by other methods.[3,4] The greatest discrepancy is observed at altitudes below 20 km in the case of data obtained by optical methods, in particular, with the help of a photoelectric counter. In this case, the measurements can differ by more than an order of magnitude. At the same time, the disagreement with data from impactor measurements made by other authors is small and falls within the measurement error at virtually all altitudes.

The disagreements with the data obtained by optical methods are partially of a methodical character — underestimation of the particle sizes owing to partial evaporation of the particles from the plate in the beam of an electron microscope and losses of large particles owing to deposition on the inner walls of the suction tube. In addition, the efficiencies of inertial deposition and suction must be determined more accurately (this is now being done).

Experience in developing and using a balloon-borne impactor has shown that the device developed can be used in scientific research for measuring the background contents of the stratospheric aerosol. These data will form the starting point for regular observations, which are being conducted at the Central Aerological Observatory. Repeated use of the impactor will make it possible to investigate the long-period variability of the stratospheric aerosol. The existing systematic errors in the measurements can be reduced in the process of laboratory calibration.

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