OPTICAL MANIFESTATIONS OF NONCONDENSATION AEROSOL CLOUDS

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The spectral coefficients of the attenuation and lidar ratio were calculated from the experimental data on the microstructure and chemical composition of clouds of noncondensation origin. Comparing the calculations of the scattering coefficients with direct measurements made it possible to change the method of evaluation of the optical characteristics. The analysis performed shows that noncondensation clouds can be easily detected and identified by multi frequency laser sounding (most efficiently in the near-IR region of the spectrum).

The development of remote optical methods for studying the atmosphere and the underlying surface and their successful application are strongly dependent on the level of knowledge about the entire range of spatial-temporal variability of the characteristics of aerosol.[1]

In this respect the atmospheric-optical formations whose microphysical parameters and therefore also optical manifestations differ substantially from the "typical" parameters and manifestations, i.e., the most characteristic properties of aerosol systems forming the basis for modeling and interpretation of observational data are of great Interest.

Clouds of noncondensation origin which were detected during airborne sounding of the atmosphere must certainly be referred to situation of precisely this type.[2–4] The essence of this phenomenon lies in the fact that during clear dry atmospheric conditions (relative humidity of less than 40%) localized regions with an elevated aerosol concentration and a horizontal size of several tens of kilometers are observed at altitudes above 1 km (as a rule, above the inversion layer). The aerosol concentration in such a cloud is usually four to ten times higher than in the surrounding medium, though a number of cases when the aerosol concentration was several tens (up to 60) times greater were observed. The vertical size of such formations ranges from several hundreds of meters up to several kilometers and the vertical distribution of the aerosol is quite complicated.

Our studies of the microstructure and chemical composition of noncondensation aerosol clouds showed that they were distinguished by the presence of a distinct medium-dispersed particle fraction with d = 1–4 μm originating in the soil.[2–4]

This phenomenon, though comparatively rare (one observation over approximately 150 flying hours), is of definite interest from the optical viewpoint for the following reasons.

First, finite regions of space whose optical characteristics are different from those of the surrounding air can strongly affect the operation of optical devices and the interpretation of optical observations. In particular, in aerial photographic surveys performed from high altitudes ($H \geq 5$ km) in clear weather photographs are often rejected owing to the presence of spatially localized regions which do not admit precise photometric measurements. Some of these cases can apparently be explained by the presence of noncondensation aerosol clouds along the survey path which attenuate and scatter solar radiation but cannot always be detected visually owing to their high optical density.

Second, the character of the particle-size distribution function strongly distinguishes noncondensation clouds from the optical properties of atmospheric haze assumed In modeling.[3,4] The fact that the chemical composition is close to that of a soil aerosol[4] suggests that the optical manifestations of such a formation will be appreciably different from those usually given in models of clouds.

To evaluate the optical properties of noncondensation aerosol clouds, we shall examine the results of calculations of the optical characteristics performed under the assumption that the particles are spherical and isotropic based on measurements of the microstructure with a photoelectric counter for radial sizes ranging from 0.2 to 5 μm.

Based on information about the chemical composition and taking into account the fact that this phenomenon is observed when the relative humidity is low the complex refractive index of the particles . was set in the calculations in accordance with a synthetic model for humidity of f = 18–25%.[5]

To analyze the spectral behavior of the aerosol attenuation coefficients, we shall study three cases recorded on February 5, 1986, September 20, 1985, and May 14, 1987. The first realization is the thickest cloud (the ratio of the total particle concentration N_0 at the center of the cloud to the particle concentration N_n at the periphery of the cloud $N_0/N_n \sim 65$); the second realization is close to the most often encountered situations ($N_0/N_n \sim 10$); and, the third realization is the case of a tenuous cloud ($N_0/N_n \sim 4$). Figure 1 shows the spectral dependences of the aerosol attenuation coefficients α(λ), normalized to the values of α (0.55 μm) calculated for these realizations. The figure also shows for comparison the spectral behavior of this dependence for a background model of atmospheric haze.[6] Table 1 gives the quantitative values of the coefficients α(λ) calculated for the central part and periphery of the clouds in these realizations.

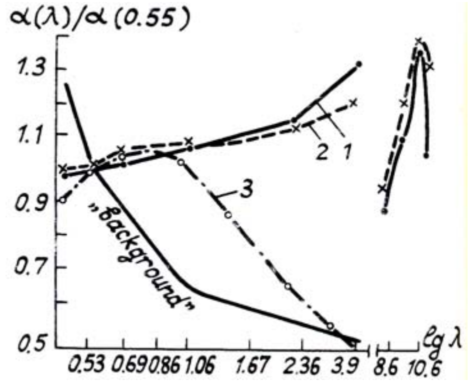

FIG. 1. The normalized spectral behavior of the aerosol attenuation coefficient according to the "background" model[6] and in noncondensation clouds: 1 – February 5, 1986; 2 – September 20, 1985; 3 – May 14, 1987.

TABLE I.

Aerosol attenuation coefficients (km^{-1})

Data	λ, μm				Cloud
	0.55	1.06	3.9	10.6	
05.02.86	0.086	0.093	0.113	0.09	center
05.02.86	$0.21\cdot10^{-2}$	$0.20\cdot10^{-2}$	$0.14\cdot10^{-2}$	$0.08\cdot10^{-2}$	periphery
20.09.85	$0.15\cdot10^{-1}$	$0.16\cdot10^{-1}$	$0.18\cdot10^{-1}$	$0.2\cdot10^{-1}$	center
20.09.85	$0.39\cdot10^{-2}$	$0.4\cdot10^{-2}$	$0.45\cdot10^{-2}$	$0.58\cdot10^{-2}$	periphery
14.05.87	$0.74\cdot10^{-3}$	$0.72\cdot10^{-3}$	$0.26\cdot10^{-3}$	$0.1\cdot10^{-3}$	center
14.05.87	$0.34\cdot10^{-3}$	$0.37\cdot10^{-3}$	$0.15\cdot10^{-3}$	$0.08\cdot10^{-3}$	periphery

It is obvious from the data in Fig. 1 and Table I that the spectral behavior clearly distinguishes aerosol noncondensation clouds from the background model of a cloudless sky and most strongly in the IR-region of the spectrum, as expected based on their microstructure. It should be noted that for the first and second realizations, where α(λ) differ by more than an order of magnitude the spectral dependences α(λ)/α(0.55) are close in the entire spectral region from 0.4 to 11.6 μm. In the weak case, which is apparently characteristic for such formations at the dissipation stage and which is consequently already depleted of large particles, appreciable differences in the spectral behavior of α(λ)/α(0.55) from the background model are observed only in the visible and near-IR regions of the spectrum, and at λ > 1.06 μm the aerosol attenuation coefficients drop off rapidly. The realization recorded on May 14, 1987 is of definite interest, since in this case the vertical structure of the cloud could be studied. Figure 2 shows the calculations, based on the data, of the microstructure of a vertical section of an aerosol noncondensation cloud for three wavelengths λ = 0.55, 3.9, and 10.6 μm (the isolines show the regions of different values of the attenuation coefficients). As we can see, such a formation has a quite complicated spatial structure which is appreciably different in different sections of the spectrum. Therefore in photometric measurements performed with transillumination of an aerosol noncondensation cloud in different sections of the spectrum the spatial configuration of the cloud will be significantly different.

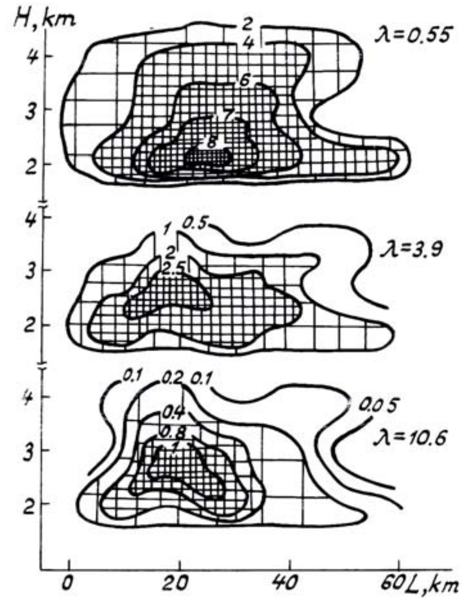

FIG. 2. The results of calculations of a vertical section of a noncondensation cloud (May 14, 1987), α(λ) · 10^4 km^{-1}.

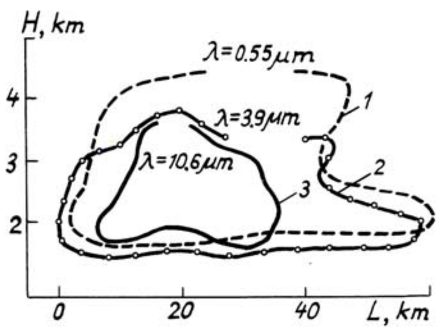

FIG. 3. Vertical section of a cloud observed on May 14, 1987. The boundary of the cloud is taken to be the level where the aerosol attenuation coefficient is equal to 0.25 of the maximum value. λ = 0.55 μm (1), 3.9 μm (2), and 10.6 μm (3)

Figure 3 illustrates this effect in the case when the boundary of the cloud is taken to be the level where the attenuation coefficient is equal to 25% of the maximum value observed in the corresponding spectral region. Based on the character of the spectral behavior of the scattering and backscattering coefficients for these clouds and the fact that the main attenuation is determined by scattering by aerosol particles one would expect that such a picture will also be observed in the case of reflected light.

Before analyzing the spectral behavior of the lidar ratio which depends more strongly than does $\alpha(\lambda)$ on the microphysical characteristics of aerosol particles we shall study some methodological questions. All results presented above were obtained by calculations directly based on data, obtained with a photoelectric detector for particle radii ranging from 0.2 to 5 μm, on the microstructure of aerosol particles. Based on the character of the microphysical parameters and the assumed nature of such aerosol formations (see Ref. 4) we must stress the fact that the calculations illustrate the optical manifestations of particles which are most characteristic for aerosol noncondensation clouds, but they cannot pretend to give a complete description of their optical image, since it cannot be excluded that at the moment of detection particles whose size falls outside the range of measurements of the photodetector are present in the atmosphere. To evaluate their contribution Table II compares the computed values of the attenuation coefficients for $\lambda = 0.55$ μm with the data from simultaneous measurement of the scattering coefficients with the help of a nephelometer at $\lambda = 0.53$ μm. It is obvious that the computed values of the attenuation coefficients are much smaller than the measured values of the scattering coefficients. It should be noted that this result is not nexpected; it is quite typical for most attempts to compare directly the optical characteristics computed based on microstructural data obtained with AZ-5 photodetectors and the directly measured values of the attenuation or scattering coefficients. This discrepancy, as a rule, arises for the following reasons: the limited range of the spectrum of particle sizes measured with the photodetector ($r \geq 0.2$–5) and the effect of the relative humidity, which changes the refractive index of the particles in the course of their condensation growth or drying.[7]

TABLE II.

Aerosol attenuation coefficients (km^{-1}) computed and measured ($\lambda = 0.55$ μm) in a n aerosol noncondensation cloud on May 14, 1987

height	1800 m	2800 m	4000 m
theory	$7.8 \cdot 10^{-4}$	$7.3 \cdot 10^{-4}$	$4.6 \cdot 10^{-4}$
experiment	$2.66 \cdot 10^{-2}$	$8.87 \cdot 10^{-3}$	$9.12 \cdot 10^{-3}$

In our case the second factor can be neglected without greatly affecting the accuracy of the evaluation, since noncondensation clouds are observed under conditions of low relative humidity when the refractive index of dry particles (see the analysis of the chemical composition in Ref. 3) is close to that of the particles used to calibrate the photoelectric detectors. Therefore for further analysis the contribution of particles whose radius is less than 0.2 μm, which play an important role in the formation of the optical characteristics in the visible region of the spectrum, must be taken into account. For this purpose the method developed in Ref. 6 for evaluating the content of different fractions by weight from data on the microstructure was employed.

TABLE III.

Temporal section of a cloud recorded on February 5, 1986.

time	Readings of nephelometer, km^{-1}	Coefficient of attenuation, km^{-1}								
		λ, μm								
		0.53	0.69	0.86	1.06	1.07	2.36	3.39	5.3	10.6
22^h57^m	0.020	0.0166	0.0144	0.0130	0.0119	0.0105	0.0095	0.0089	0.0064	0.0065
23^h04^m	0.045	0.0499	0.0499	0.0492	0.0489	0.0495	0.0451	0.0382	0.0203	0.0201
23^h17^m	0.14	0.160	0.164	0.166	0.171	0.179	0.165	0.140	0.174	0.072
23^h21^m	0.3	0.595	0.621	0.637	0.668	0.722	0.676	0.572	0.268	0.270

Table III gives the results of calculations, based on the method of Ref. 6, of the attenuation coefficients of the strongest aerosol cloud recorded on February 5, 1986. The table also gives for comparison (column 2) data obtained with simultaneous nephelometric measurements for $\lambda = 0.53$ μm.

The good agreement between the calculations and the measurements in the visible region of the spectrum gives a basis for believing that the optical characteristics of aerosol noncondensation clouds can be determined most accurately in this case. In this variant the spectral behavior of $\alpha(\lambda)/\alpha(0.53)$ remains nearly neutral in the wavelength range from 0.4 to 3.9 μm; then this quantity drops off rapidly and, based on the character of the spectral dependence in the region $\lambda > 5$ μm, is now virtually identical to the background model.

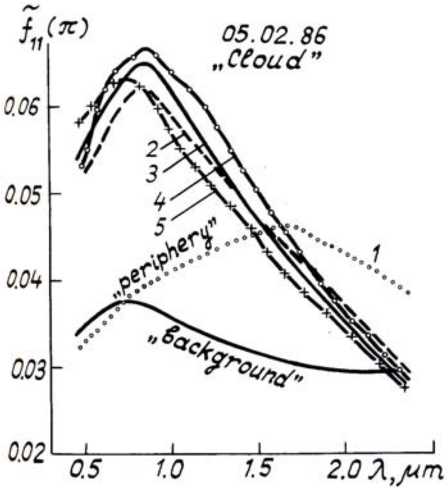

FIG. 4. The change in the lidar ratio accompanying the passage of a noncondensation cloud on February 5, 1986: 22^h57^m LT (1); 23^h04^m LT (2); 23^h17^m LT (3); 23^h21^m LT (4); 23^h26^m LT (5).

Figure 4 shows the computed spectral dependences of the lidar ratio in the wavelength range $\lambda = 0.4$–2.6 μm for different times of passage of an aerosol noncondensation cloud. It is interesting that the spectral dependences of the lidar ratio are stable for all data obtained Inside the cloud, though the quantitative values of the attenuation and backscattering coefficients differ by more them a factor of ten. The lidar ratio in the range 0.4–2 μm appreciably exceeds in absolute magnitude the values which are observed in the background aerosol model and models of condensation clouds.

Summarizing the results of the foregoing analysis of calculations and measurements it is worth noting that aerosol noncondensation clouds are optically quite specific formations, a number of whose spectral properties exhibit characteristic differences from those of atmospheric haze and liquid-drop clouds.

Depending on their optical density and vertical size such clouds can play an appreciable role in the attenuation of solar radiation in the entire spectral region. Even tenuous formations which are visually indistinguishable against the background of the illuminated sky make a large contribution to the attenuation of radiation in the visible and infrared regions of the spectrum on separate sections of the photometrically scanned space. At the same time the foregoing analysis shows that noncondensation clouds can be easily detected and identified by means of multifrequency laser sounding (most efficiently in the near-IR region of the spectrum).

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