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RADIATION TRANSFER IN DISPERSION MEDIUM IN SEPARATING

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The influence of a degree of separating dispersion medium layer on radiation balance regarding its optical dimensions, scattering phase function shape and albedo of single scattering was investigated. It was stated that the bleaching effect occurring at dispersion medium separating has certain space boundaries. The classical concept of the «infinitely extended dispersion medium» was clarified.

Air radiation balance is substantially determined by the presence of cloudiness [1, 2]. Therefore, studying mechanisms of radiation transfer in a cloudy atmosphere was always traditional [3–9] and became especially urgent recently due to global warming hypothesis [10, 11]. The existing computing methods of radiation transfer in a cloudy atmosphere are used for various cloudiness models depending on the required accuracy and immediacy of results obtaining. Certain peculiarities of radiation transfer in broken clouds (BRN) were studied, in particular, bleaching effect of dispersion medium layer in separating. The increase of transmittance in separating the dispersion medium layer of constant optical thickness into separate parts of the same optical thickness with retaining light and observation conditions is understood as bleaching effect. The dispersion medium layer is simulated by a set of rectangular parallelepipeds of different optical dimensions, the upper edge of which is commonly lit by parallel flux of radiation. The interaction between separate parts of the broken dispersion medium was not examined here. In this case we assume that the safe layer transmittance will be equal to the sum of transmittances of its parts due to the principle of additivity as, for example, in the model of dispersion medium in the form of screens [12]. It is known, that principle of additivity in this model cannot be observed in case of energy exchange between screens.

In the process of investigation the following parameters were determined: $I^{+}(\tau,\Lambda,g)$ is the flux of radiation passed and scattered into lower hemisphere; $I^{-}(\tau,\Lambda,g)$ is the flux of radiation scattered into upper hemisphere; $I_{\Lambda}(\tau,\Lambda,g)$ is the part of radiation absorbed by the cloudy medium. Here τ is the optical radius-vector of dispersion medium point in the form of parallelepiped with optical length τ_{x_0}, optical section $\tau_{y_0}\times\tau_{z_0}$ and lit uniformly by collimated flux of radiation normal directed to plane yz in rectangular coordinate system; g is the asymmetry parameter defining the degree of scattering phase function elongation; Λ is the albedo of single scattering; N is the degree of separation of the dispersion medium layer into separate parts in the form of parallelepiped. Degree of dispersion medium separation N is characterized by the optical section $\tau_{y_1}\times\tau_{z_1}$ of one part of the medium to that one of $\tau_{y_0}\times\tau_{z_0}$ ratio of the whole medium. The intensity of incident radiation is I_0=1. In this case values $I^{+}(\tau,\Lambda,g)$, $I^{-}(\tau,\Lambda,g)$, $I_{\Lambda}(\tau,\Lambda,g)$ are transmittance T, reflectance factor R and absorption factor A with normalization $T+R+A=1$.

Let us consider the radiation transit through a separate parallelepiped in changing its optical dimensions. Such consideration is trivial. However, certain peculiarities of radiation propagation which are determinative in estimating radiation balance in dispersion medium at its separation become obvious. The results obtained in this case show that when changing lateral optical dimensions of dispersion medium the deformation of angular distribution radiation of multiply diffused light occurs [10] that results in changing radiation balance spreading in limited volume of dispersion medium and, respectively, transmission value. As at computing radiation balance the fluxes of radiation into upper and lower hemispheres are calculated, at dispersion medium splitting into separate non-commuted parts the increase of radiation transmission specified by the growth of a part of multiply diffused light into lower hemisphere should be occurred.

The results of calculations (Fig. 1, 2) show the bleaching effect in specific situations. The analysis of the data presented in Figures results in following conclusion. There is a certain area of optical dimensions of dispersion medium at which a degree of separation influences significantly the radiation balance and, correspondingly, the large interval of optical dimension values at which transmission does not practically depend on medium separation. These conclusions are valid at different scattering phase functions as well as at absorption occurring in the dispersion medium. Dependences of reflection value radiated by the dispersion medium in separating are presented in Fig. 3. It should be noted, that the reflection value at dispersion medium separation anomalously changes at absorption in the medium (Fig. 3, curve 1).

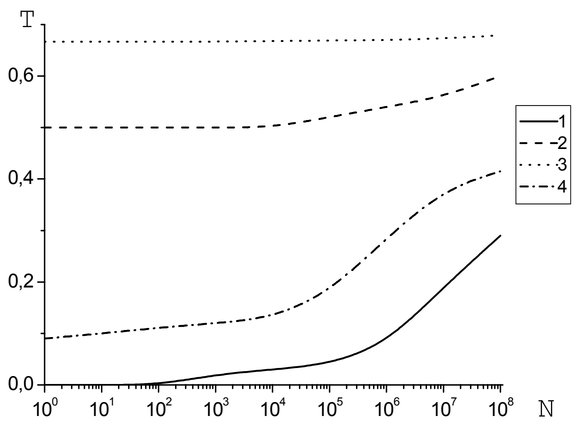

Fig. 1. *Dependence of transmittance on separation range of dispersion medium. Spherical scattering phase function. Λ=0,7: 1) τ_x=20, 2) τ_x=1; Λ=1: 3) τ_x=1, 4) τ_x=20*

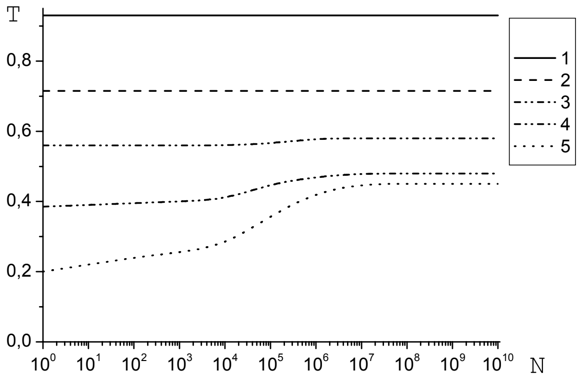

Fig. 2. *Dependence of transmittance on separation range of dispersion medium. Scattering phase function C1, Λ=1, τ_x: 1) 50, 2) 20, 3) 10, 4) 5, 5) 1*

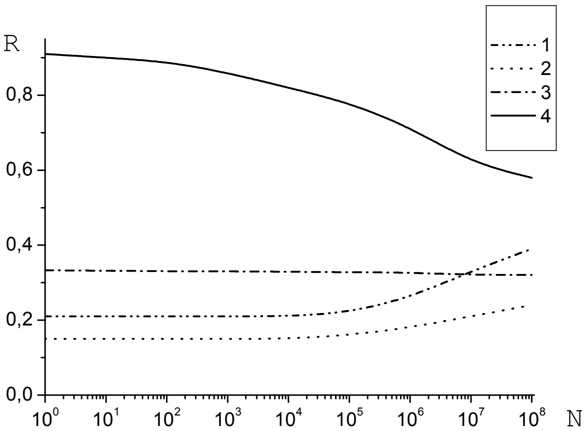

Fig. 3. *Reflectance dependence on separation range of dispersion medium. Spherical scattering phase function. Λ=0,7: 1) τ_x=20, 2) τ_x=1; Λ=1: 3) τ_x=1, 4) τ_x=20*

Dispersion medium separation in presence of absorption results in one more effect significant for the atmosphere energy. It is a matter of abrupt decrease of absorbed radiation share at increasing number of clouds accompanied by decreasing lateral optical dimensions of a separate cloud. This change has certain special limits (Fig. 4).

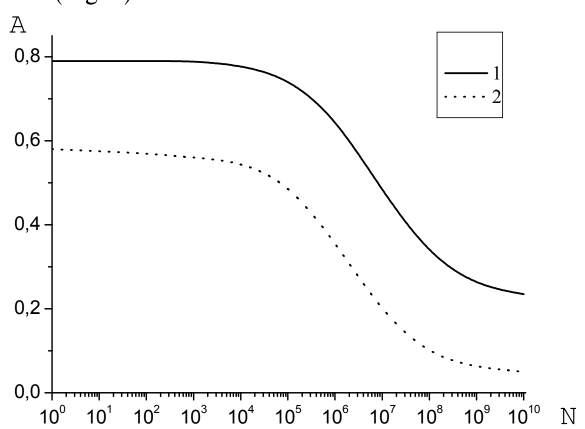

Fig. 4. *Dependence of absorbed energy value on a degree of separation of dispersion medium. Spherical scattering τ_x=20, Λ: 1) 0,7, 2) 0,9*

The boundary curves for two scattering phase functions are presented in Fig. 5. The boundary curve determines such area of optical thickness of spatially limited dispersion medium at which the medium may be considered as a semi-infinite one with the corresponding value Λ. For example, at optical diameter equaling to two, and spherical scattering phase function with optical thickness of $\tau_x \geq 5$, accuracy not less than 1 %, the medium can be considered as semi-infinite. In this case the principle of Ambartsumyan is fulfilled [13]: augmentation of additional layer to the semi-finite medium does not change its reflection factor which in this case equals to 0,57 that corresponds to the spatially unlimited medium with Λ=0,957. This result follows from the exact solution of the radiative transfer equation [3] and may be calculated by the formula [10].

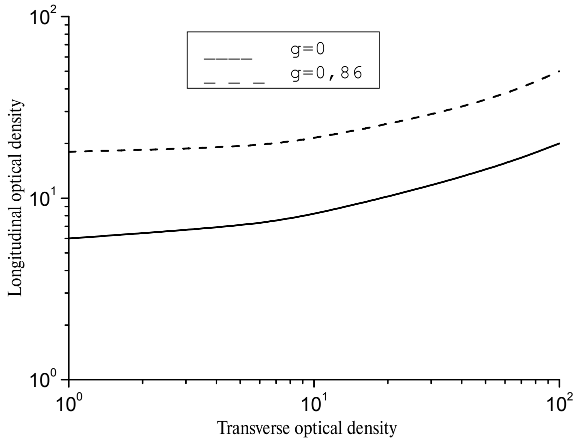

Fig. 5. *Boundary curves*

The same compliance is observed with other optical diameters of dispersion medium, and the value of saturation boundary increases in optical diameter increasing, i. e. such value of lateral optical thickness is achieved at which dispersion medium are considered to be as infinitely thick while the obtained values are far from infinity. For example, at optical diameter 20, the boundary optical thickness of dispersion medium equals to 10 that corresponds to the infinite medium with Λ=0,992.

The increasing of the elongation range of scattering phase function results in boundary curve shift towards the area of large optical thicknesses when occurs the saturation by the spatially limited dispersion medium in the change of radiation reflection factor and transmittance meanings.

The criterion of determining dispersion medium infinity also follows from the principle of Ambartsumyan. For dispersion medium with the scattering phase function C1 [14], each point on the boundary curve obtained for spatially limited dispersion media may correlate with the value of albedo of single scattering ? determined for semi-infinite medium that is equivalent to the statement about radiation balance equivalence of finite and infinite dispersion media.

The reflection factor value can be obtained from the exact solution of radiation transfer equation, in $P_0(\Lambda)$ for cloudy scattering phase function C1 equaling:

$$P_0(\Lambda)=$$
$$=\frac{(1-\Lambda)\left\{(1-\Lambda)^2+4\Lambda\mu\begin{bmatrix}3(1-\Lambda)-3\mu(1-4\Lambda)-\\-4\mu^2(1+4\Lambda)\end{bmatrix}\right\}}{(1-\Lambda)^2+4\Lambda\mu(2-2\Lambda-\mu+4\Lambda\mu)}.$$

The integral parameter μ of the scattering phase function $f(\theta)$ is determined by formula $\mu=2\int_0^{\pi} f(\theta)\sin^2\theta d\theta$, where is the scattering angle. For the scattering phase function C1 μ=0,03.

Thus, a practically important conclusion for climatology may be drawn from the data obtained. This conclusion is about the fact that there is a large category of scattering objects whose optical thickness change does not influence the radiation balance of atmosphere, i. e. beginning from a certain meaning of optical density, the cloudiness thickness becomes somewhat similar despite the significant physical processes connected with formation and transformation of clouds. The same common conclusion can be drawn on the basis of the results given in Fig. 1–3: within the certain range of optical thicknesses the sizes of clouds do not influence the change radiation balance of the atmosphere.

On the basis of results of this work, one can note some peculiarities of radiation propagation in a cloudy separating atmosphere. The magnitude of radiation absorption at certain values of optical density does not depend on longitudinal optical thickness. It depends only on lateral optical medium dimensions and, therefore, on the degree of separation. There are also limiting values of lateral optical thickness of dispersion medium at which further increase or decrease of lateral optical medium dimensions does not result in absorption increasing or decreasing. It means that the bleaching effect of dispersion medium at its separation appears only in a certain area of optical dimensions and depends on albedo of single scattering.

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