THE OPTICAL RADIATION TRANSFER IN LAYERED ATMOSPHERE

B. V. Goryachev[1], G. Y. Grigoriev[2], A. A. Averkiev[1]

[1]National research Tomsk Polytechnic University
[2]National research centre "Kurchatov Institute"
634050, 30, Lenin Ave., Tomsk, Russia

ABSTRACT

Consider the transfer of radiation in a stratified atmosphere. The analytical expressions for the calculation of transmittance, reflection and absorption ability of dispersed layered environment were obtained. It is established that the conservative scattering of radiation regime of the atmosphere is practically independent of altitude stratification of the aerosol. It is shown that the reflectivity of the atmosphere is only weakly dependent on the optical density of the surface layer with the absorption at any value of optical density of the upper layer and the single scattering albedo. The essential dependence of the absorptivity of the atmosphere from high-altitude parameters stratified atmosphere were established.

Key words: radiation, transfer, atmosphere, layer

1. INTRODUCTION

The radiation balance of the atmosphere is a key element in the models that are the basis for forecast weather and climate [1]. The accuracy of the estimate of the radiation balance components depends on the accuracy of the methods used [2-12], and detailed consideration of all effects influencing the result.

The aim of this work is to solve the problem of radiation transfer in an analytical form and determination of the radiation balance components in a stratified atmosphere. Analytical solution is obtained using the method of multiple reflections [4]. The stratified atmosphere is presented in the form of three flat layers, at normal incidence of the radiation flux on the surface of the dispersed medium. Within each layer the optical parameters of the medium are considered constant. The analytical expressions for determining the transmittance of $A_{123}(\tau,a,\Lambda)$, reflectivity $B_{123}(\tau,a,\Lambda)$ and absorption capacity $C_{123}(\tau,a,\Lambda)$ a stratified atmosphere.

2. THEORY

We introduce the notation: optical sizes $\tau=\alpha l$ (α – attenuation coefficient, l – the geometrical sizes dispersion medium)) of the first layer of a parallelepiped (the radiation propagates along the x-axis, the transverse optical dimensions are the same for all layers and equal $\tau_{1y_0}\times\tau_{1z_0}$), in the second layer $\tau_{2x_0}\times\tau_{1y_0}\times\tau_{1z_0}$; the third layer $\tau_{3x_0}\times\tau_{1y_0}\times\tau_{1z_0}$; scattering phase function radiation, characterized by the degree of elongation $a=(\eta+2\mu)/(\beta+2\mu)$, where

η, β, μ are integral parameters of the scattering phase function [4]; the single scattering albedo is Λ_1, Λ_2 and Λ_3 in the first, second and third layers, respectively. The underlying surface is characterized by transmittance factor t and reflection coefficient r. In the stratified atmosphere model under consideration which was used for calculation of the atmosphere radiation characteristics, the parameters of each layer are constant in each layer. This parameters can be determined as a result of atmospheric research [1-3]. Based on the multiple reflection method, the following formulae were derived:

$$A_{123} = \frac{F_1 A_3}{F_5};\; B_{123} = B_1 + \frac{A_1^2 (A_2^2 B_3 + B_2 F_5)}{F_2 F_5};\; C_{123} = C_1 + \frac{A_1}{F_2}\left[F_6 + \frac{A_2\left(F_2 F_7 + B_3 F_6\right)}{F_5}\right].$$

Notation:

$$F_1 = A_1(\tau,a,\Lambda) A_2(\tau,a,\Lambda);\; F_2 = 1 - B_1(\tau,a,\Lambda) B_2(\tau,a,\Lambda);$$

$$F_3 = 1 - B_1(\tau,a,\Lambda) B_3(\tau,a,\Lambda);\; F_4 = A_1^2(\tau,a,\Lambda) B_2(\tau,a,\Lambda) B_3(\tau,a,\Lambda);$$

$$F_5 = F_2 F_3 - F_4;\; F_6 = C_2(\tau,a,\Lambda) + C_1(\tau,a,\Lambda) B_2(\tau,a,\Lambda);$$

Radiation characteristics of each layer $A_i(\tau,a,\Lambda), B_i(\tau,a,\Lambda), C_i(\tau,a,\Lambda)$ where i = 1, 2, 3, are determined by any method specified in [1–4].

3. RESULTS

Let us consider some results of calculations according to the formulas of the fluxes of monochromatic radiation in a stratified atmosphere.

For calculations use the following parameters: two layers have spherical scattering phase function (a=1), conservative scattering (Λ=1) and the same optical density. The third layer has an anisotropic scattering phase function (a=10), different single scattering albedo and variable optical density.

The results are shown in Fig. 1-4. The transverse dimensions of the optical dispersion medium are equal $\tau_{1y_0} \times \tau_{1z_0} = 10^5$.

In Fig. 1 shows the dependences of transmission coefficient A_{123} three-layer dispersion medium from the optical density of the absorbent layer dispersion medium.

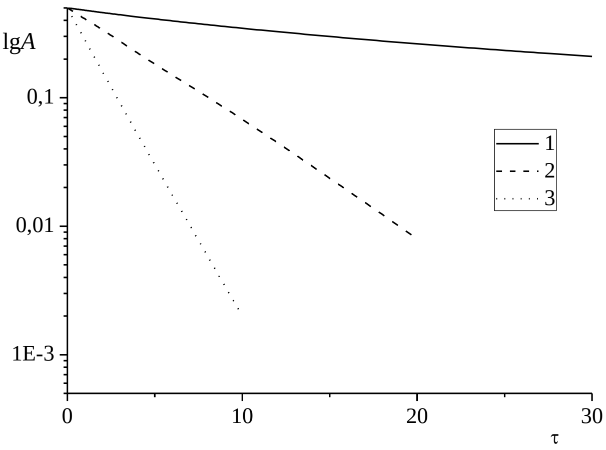
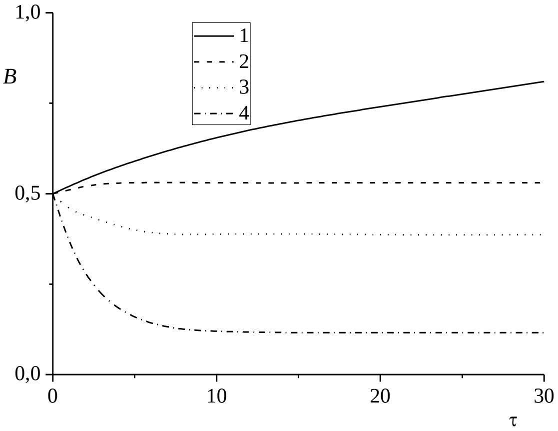


Fig. 1. The dependence of the transmittance of A_{123} three-layer dispersion medium from the optical density of the absorbent layer dispersion medium.

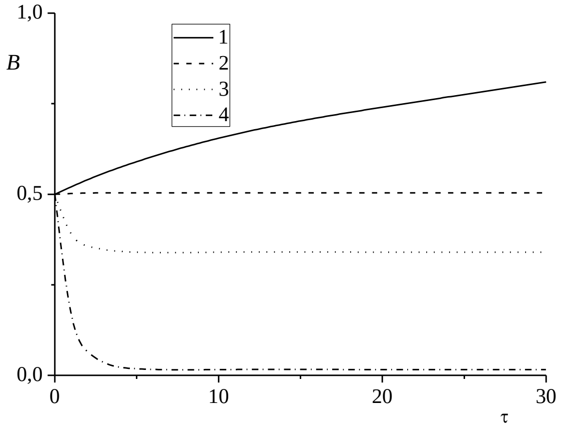
1 – the single scattering albedo $\Lambda=1$; the degree of elongation of the scattering phase function $a_1=a_2=1$, $a_3=10$;

2 – $\Lambda=0{,}9$; $a_1=a_2=1$, $a_3=10$; 3 – $\Lambda=0{,}5$; $a_1=a_3=1$, $a_2=10$; the optical density of the dispersion medium layers $\tau_{1x_0}=\tau_{2x_0}=\tau_{3x_0}=1$

In Fig. 2 the dependence of the reflectivity B_{123} three-layer dispersion medium from the optical density of the absorbent layer dispersion medium for three values of the single scattering albedo and the same optical density of all three layers.



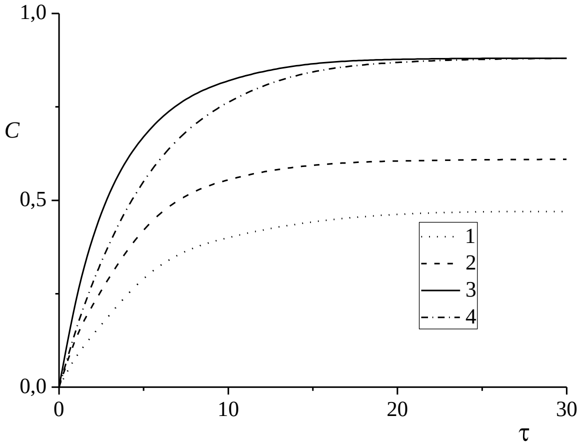
a)



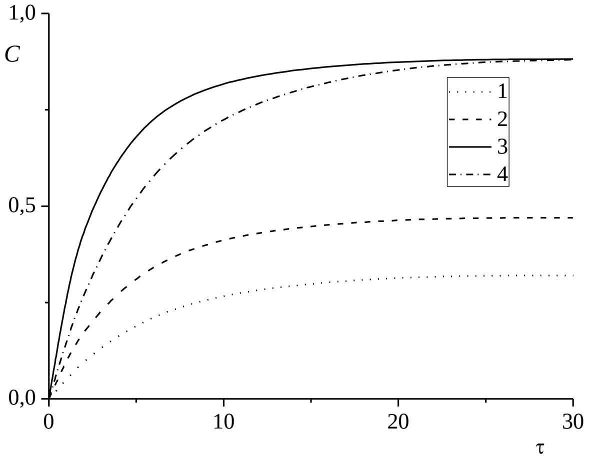
b)

Fig. 2. The dependence of the reflectivity B_{123} three-layer dispersion medium from the optical density of the absorbent layer dispersion medium. The single scattering albedo (a) Λ=0,9; (b) Λ=0,5. 1 – Λ=1; the degree of elongation of the scattering phase function a_1=a_2=1, a_3=10; 2 – a_1=a_2=1, a_3=10; 3 – a_1=a_3=1, a_2=10; 4 – a_2=a_3=1, a_1=10; the optical density of the dispersion medium layers $\tau_{1x_0} = \tau_{2x_0} = \tau_{3x_0} = 1$

In Fig. 3 the dependence of absorption capacity C_{123} three-layer dispersion medium from the optical density of the absorbent layer dispersion medium. The single scattering albedo in the absorbing layer Λ=0,9. Figures a) and b) correspond to the values of optical density of the layers is equal to 1 and 2.



a)

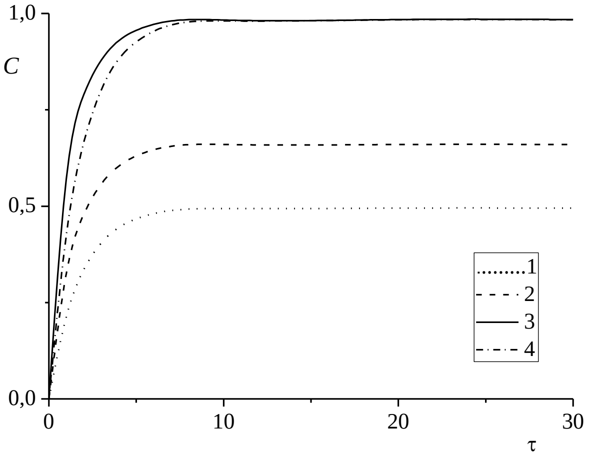


b)

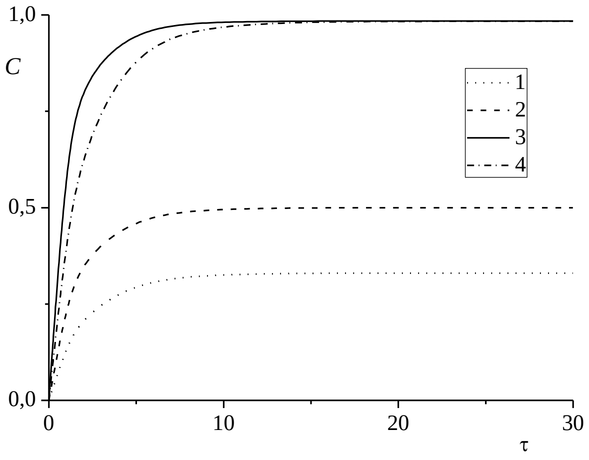
Fig. 3. The dependence of absorption capacity C_{123} three-layer dispersion medium from the optical density of the absorbent layer dispersion medium. The single scattering albedo Λ=0,9. 1 – a_1=a_2=1, a_3=10; 2 – a_1=a_3=1, a_2=10; 3 – a_2=a_3=1, a_1=10; 4 – a single layer a =10;

a) the optical density of the dispersion medium layers $\tau_{1x_0} = \tau_{2x_0} = \tau_{3x_0} = 1$; *b*) $\tau_{1x_0} = \tau_{2x_0} = \tau_{3x_0} = 2$

In Fig. 4 shows the same data as in Fig. 3, but for Λ=0,5.



a)



b)

Fig. 4. The dependence of absorption capacity C_{123} three-layer dispersion medium from the optical density of the absorbent layer dispersion medium. The single scattering albedo Λ=0,5. 1 – a_1=a_2=1, a_3=10; 2 – a_1=a_3=1, a_2=10; 3 – a_2=a_3=1, a_1=10; 4 – a single layer a =10.

a) the optical density of the dispersion medium layers $\tau_{1x_0} = \tau_{2x_0} = \tau_{3x_0} = 1$; *b*) $\tau_{1x_0} = \tau_{2x_0} = \tau_{3x_0} = 2$

4. CONCLUSIONS

Thus, the results of the work we can draw the following conclusions.

1. Analytical expressions were derived for calculation of transmittance, reflectivity and absorptivity of stratified atmosphere.
2. The radiation regime of the atmosphere is practically independent from altitudinal stratification of aerosol in case of conservative scattering.
3. The reflectivity of the atmosphere is only weakly dependent on the optical density of the surface layer with the absorption at any value of optical density of the upper layer.
4. The transmittance of a stratified atmosphere depends weakly on the altitude distribution of atmospheric parameters at any value of the single scattering albedo in the absorbing layer.
5. The absorptive capacity of the atmosphere heavily depends on the altitudinal stratification of atmospheric parameters and can be more (or less) of the absorption coefficient of one layer with the absorption depending on its height.
6. The reflectivity of the atmosphere is only weakly dependent on the distribution of the absorbing substance in the height at any value of the single scattering albedo.
7. The absorptive capacity of the atmosphere has a pronounced dependence of the saturation from the values of the

optical thickness of the absorbing layer (for example, when τ > 5 the absorption capacity of the atmosphere does not depend on the value of optical density).

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B.V. Goryachev[1], A/Prof. - bvg@tpu.ru; G.Y. Grigoriev[2], Prof. - grigoriev_gy@nrcki.ru;
A.A. Averkiev[1] – averkiev_95@mail.ru