ON THE EFFECT OF SOME FACTORS ON THE DETERMINATION OF THE OPTICAL SCATTERING THICKNESS FROM THE SKY BRIGHTNESS

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The question of the effect of the absorption of light on the determination of the aerosol optical thickness from sky brightness observations is studied. Empirical formulas, which take into account the circumsolar aureole in the integration of the brightness angular distribution, are constructed.

We have already studied the question of how to determine the aerosol optical scattering thickness from measurements of the absolute brightness angular distributions $f(\varphi)$ in a clear atmosphere.[1] We derived, based on the numerical results of the solution of the radiation transfer equation, approximation relations which relate τ_a^*, the secants of the zenith distances of the sun $\sec Z_0$, and the difference τ'_α :

$$\tau_a^* = \frac{-\left(\delta + \beta \sec Z_0\right)}{2\left(\gamma + \varepsilon \sec Z_0\right)} + \frac{\sqrt{\left(\delta + \beta \sec Z_0\right)^2 + 4\left(\gamma + \varepsilon \sec Z_0\right)\tau'_a}}{2\left(\gamma + \varepsilon \sec Z_0\right)}, \quad (1)$$

where

$$\tau'_a = 2\pi \int_0^{\pi/2} f(\varphi) \sin\varphi \, d\varphi - 2\pi \int_{\pi/2}^{\pi} f(\varphi) \sin\varphi \, d\varphi. \quad (2)$$

The numerical values of the parameters δ, β, γ, and ε, which determine the dependence of τ_a^* (the aerosol scattering thickness) on the wavelength and the turbidity of the atmosphere, are presented in Ref. 1. (In Ref. 1, in the final formula the cosine is given incorrectly instead of the correct secant in the square root.) We investigated the case of pure scattering, and we showed that the quantities τ_a^* agree well with the true aerosol optical thicknesses τ_α, incorporated in the calculations of $f(\varphi)$.

In this paper we estimate the effect of absorption of light on the quantity τ_a^*.

It is well known[2] that under the conditions of single scattering of light the absorption, within the limits of the plane-parallel approximation, has no effect on the directed scattering coefficient $f_1(\varphi)$ referred to the solar almucantar. Absorption also will not effect $f(\varphi)$ if the scattering and absorbing substances form layers at different altitudes. An example of this is the ozone layer above the main scattering mass; this makes it much easier to interpret the observations of sky brightness in the ultraviolet region of the spectrum.[3] It can be expected that significant mixing of the absorbing and scattering components of the atmosphere will change $f(\varphi)$.

In order to determine what these changes are, we calculated the sky brightness at the almucantar of the sun by solving the radiation transfer equation. The scattering and absorbing substances were assumed to be uniformly mixed. The values of the optical parameters adopted in Ref. 1 were used, and to them we added the absorption optical thicknesses τ_{abs} in accordance with the values of the photon survival probability for aerosol particles $\omega = \tau_\alpha/\tau_a + \tau_{abs}$, equal to 0.9 and 0.65. The first value is characteristic for the background aerosol,[4] and the second value is characteristic for urban pollution.[5] The transfer equation was solved by the method of spherical harmonics. In this case the formula for calculating $f(\varphi)$ is

$$f(\varphi) = \frac{I(\varphi)}{\pi \exp\left(-\tau \sec Z_0\right) \sec Z_0}, \quad (3)$$

where $I(\varphi)$ is the intensity of the scattered radiation in units of S (πS is the spectral solar constant) and

$$\tau = \tau_R + \tau_\alpha + \tau_{abs} \quad (4)$$

is the total optical thickness of the atmosphere (τ_R is the Rayleigh component).

Figure 1 shows the results obtained by comparing the true values of τ_α with the optical scattering thicknesses τ_a^* determined using the formula (1). It is obvious that taking absorption into account with ω = 0.9 decreases the aerosol thickness by not more than 5%, even in the case of significant atmospheric turbidity. In practice this means that the relation (1) can be used to determine the scattering thickness at

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locations far from industrial centers. If ω is equal to 0.65, then τ_a^* is 3 to 17% less than τ_α. Thus the corrections required to determine τ_a by the method of Ref. 1 in cities and industrial centers are insignificant.

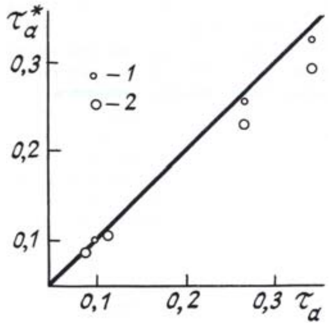

FIG. 1. Comparison of the aerosol optical thicknesses τ_a and τ_a^* with ω = 0.9 *(1) and* 0.65 *(2). The straight line corresponds to the case of pure scattering.*

In order to be able to use the formula (2) in practice, it is necessary to have measurements of the brightness angular distribution at small angular distances from the sun. Such measurements present well-known difficulties. We decided to simplify the integration process by choosing the appropriate empirical relations for the aureole section of the angular distribution. The first integral was represented in the form

$$2\pi \int_0^{\pi/2} f(\varphi)\,\sin\varphi\, d\varphi = 2\pi \int_0^{10^\circ} f(\varphi)\,\sin\varphi\, d\varphi + \int_{10^\circ}^{\pi/2} f(\varphi)\,\sin\varphi\, d\varphi \tag{5}$$

and

$$2\pi \int_0^{10^\circ} f(\varphi)\,\sin\varphi\, d\varphi = k(\varphi_i) f(\varphi_i). \tag{6}$$

The coefficients $k(\varphi_i)$ were calculated for two values of φ_i from the observed values of $f(\varphi)$ with small angles in the spectral range 0.4–0.7 μm: $k(5°) = 0.09 \pm 0.01$ and $k(10°) = 0.22 \pm 0.08$.[6–7] The standard deviations shown are primarily determined by the variations of the coarsely dispersed and submicron fractions of the aerosol in the atmosphere. Model calculations[1] give values that are close to the experimental values: $k(5°) = 0.11$ and $k(10°) = 0.22$. The additional error in determining τ_a' owing to substitution of Eq. (6) into Eq. (2) in determining τ_a' is 6% ($\varphi_I = 5°$) and 15% ($\varphi_I = 10°$) with a confidence probability of 0.95.

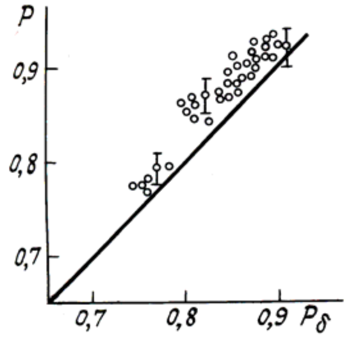

FIG. 2. Comparison of the Bouguer transmittances P with the values determined from the sky brightness under the assumption that there is no absorption P_δ.

In conclusion we shall illustrate the applicability of this method for determining the optical scattering thickness in a clear atmosphere. Tabular data from simultaneous measurements of the absolute brightness angular distributions $f(\varphi)$ and transmittances of the atmosphere P_δ by the Bouguer method in the visible region of the spectrum are presented in Refs. 2 and 6. The latter were determined from observations of the intensity of the direct sunlight with different atmospheric masses and characterize the extinction of radiation owing to absorption and scattering. With the help-of the relations (1)—(2) and (6) we obtain from the observed brightness angular distributions $f(\varphi)$ values of τ_a^* that are virtually identical, according to what was said above, with the aerosol optical scattering thickness τ_a. We add to them the Rayleigh components τ_R and compare the quantities $P = \exp(-(\tau_R + \tau_a^*))$ with P_δ. The results of this comparison are given in Fig. 2. One can see that P is ~ 2–4% greater than P_δ. This is due to the weak absorption of light in the ozone bands (Chappeau bands) and by atmospheric aerosol.

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