Analysis of the daytime sky brightness in the range of nephelometric scattering angles

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Data of observation of the day cloudless sky brightness in solar almucantar in the south-east of Kazakhstan within 30–60° scattering angles have been analyzed. Spectral dependence of the coefficients entering into relations for determination of the scattering optical thickness by the nephelometric method is found. The obtained results can be used in separation of the vertical thickness of light extinction into the absorption and scattering components at high positions of the sun above the horizon.

One of the urgent problems of modern atmospheric physics is separation of the aerosol optical thickness τ_a, determined by the Bouguer method from observations of the spectral fluxes of direct solar radiation, into absorption $\tau_{a.a}$ and scattering $\tau_{a.s}$ components. The problem can be solved only by means of attracting additional data on scattering properties of the atmosphere obtained from parallel measurements of the absolute brightness phase function $f(\varphi)$ in the solar almucantar.[1–3] The following numerically determined integral is commonly used when solving the problem on reconstruction of the thickness $\tau_{a.s}$:

$$\tau_n = 2\pi \int_0^{\pi} f(\varphi)\,\sin\varphi\,d\varphi. \quad (1)$$

Since the scattering angle φ is related to the zenith distance Z_0 and azimuth of the observed sky point ψ counted from the solar vertical by

$$\cos\varphi = \cos^2 Z_0 + \sin^2 Z_0 \cos\psi, \quad (2)$$

then the value of the maximum angle φ_{max} is equal to $2Z_0$ at $\psi = 180°$. The experience of numerical integration of experimental functions in different spectral ranges suggests that such a procedure can be more or less reliably performed if the values $f(\varphi)\sin\varphi$ for φ_{max} not less than 120–130° are available. Therefore, series of observations obtained at atmospheric masses $m < 2$ remain outside the analysis of the value τ_a for absorptivity. The range $1 \le m \le 2$ covers the principal part of daytime in summer in midlatitudes and, especially, south latitudes. Just in the period the photochemical reactions, forming aerosol from the gas phase, proceed most actively, the greatest amount of pollutants come into the urban atmosphere, etc. Therefore, a search for the ways for determining the thickness $\tau_{a.s}$ from observations of $f(\varphi)$ at $Z_0 < 60°$ is somewhat reasonable. In this paper we study a possibility of determining τ_n by nephelometric method using the relationships of the form

$$\tau_n = k(\varphi_i)\, f(\varphi_i) \quad (3)$$

for scattering angles $30° \le \varphi_i \le 60°$ in the wavelength range $0.34 \le \lambda \le 1.01$ μm, using the observational data for $f(\varphi)$ obtained in different years at the Astrophysical Institute of the Academy of Sciences of Kazakhstan and in Kirbaltabai village of Almaty Region (the south-east Kazakhstan) in summer and autumn seasons.

First the possibility of using the relationship (3) for determining τ_n, and then, after correction, the coefficient of spectral transparency of the atmosphere by the "short method" was noted by E.V. Pyaskovskaya-Fesenkova.[4] She revealed that minimum variations of $k(\varphi_i)$ from day to day in the visible spectral range at high transparency occur near the scattering angle $\varphi_i = 60°$. The coefficient $k(60°)$ turned to be equal to 13.1. It should be noted here that measurements of $f(\varphi)$, made by E.V. Pyaskovskaya-Fesenkova, were limited below by the angle $\varphi \ge 10°$, i.e., the solar aureole was not taken into account. Even first measurements of the brightness phase function $f(\varphi)$ at small angles $\varphi \ge 2°$ have shown that taking into account of the aureole in the red wavelength range increases the value τ_n by 10%, in average.[5] Further investigations of the sky brightness in IR spectral range have led the authors of Ref. 6 to the conclusion that in practice the angle $\varphi_i = 60°$ is more preferable than $\varphi_i = 30°$ in the IR range due to minimum scatter of values $k(\varphi_i)$. When measuring the light scattering coefficients in some local atmospheric layer, in particular, near-ground layer, using an artificial light source, one usually takes the angle $\varphi_i = 45°$ as nephelometric. Therefore, spectral dependence of the coefficients $k(\varphi_i)$ in this wavelength range must be studied more carefully.

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First, we consider, at which scattering angle φ_0 the observed function $f(\varphi)$ crosses the absolute spherical brightness phase function $f = \tau_n/4\pi$. The values of φ_0 in 10 spectral intervals from 0.34 to 1.01 μm were determined, using the expanded series of published data[1,3,7] and the results of our observations of $f(\varphi)$ in Kirbaltabai village, by means of graphical interpolation. More than 350 brightness phase functions $f(\varphi)$ measured in the range of scattering angles $2 \le \varphi \le 150–160°$ were analyzed. The results are shown in Fig. 1.

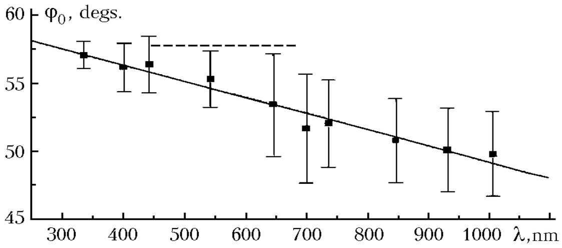

Fig. 1. Dependence of the angle φ_0 on the wavelength λ.

It is well seen that the value of the angle φ_0 systematically and linearly decreases with the wavelength λ. The dotted line shows the result obtained by E.V. Pyaskovskaya-Fesenkova: $\varphi = 57°$ independently of λ. The deviation can be easily explained by taking into account the aureole when calculating τ_n and by considering the cases of great turbidity of the atmosphere in present research. Only in the UV range, when the molecular and multiple scattering prevail over the aerosol one, and contribution of the aureole into calculations of τ_n is insignificant, the angle φ_0 is equal to 57°.

Spectral dependences of the mean coefficients $k(\varphi_i)$ with corresponding rms deviations at the scattering angles of 30, 40, and 60° obtained from the data of the same measurements are shown in Fig. 2. The scatter of $k(\varphi_i)$ increases with wavelength from 3–4% in UV range to 9–10% in IR range. As the error in measurement $\delta f(\varphi)$ is 3–4%, and the error in determining $\delta\tau_n$ by numerical integration does not exceed 1.5%,[4] the values of the scatter $\delta k(\varphi)$ are principally caused by variations of the aerosol scattering phase function from day to day, which are the most well pronounced in the longwave range on the background of molecular component. So, in order to increase the accuracy of determination of τ_n it seems to be expedient to use three (or more) values of the coefficients $k(\varphi_i)$. The histogram of deviations of τ_n from

$$\tau_n^* = 1/3\,[k(30°)\,f(30°) + k(40°)\,f(40°) + k(60°)\,f(60°)], \quad (4)$$

where the values $k(\varphi_i)$ correspond to the data shown in Fig. 2, is shown in Fig. 3. The results in visible and IR wavelength ranges are presented. The step of the histogram is accepted to be equal to 4% according to the accuracy of determination of $f(\varphi)$. The result is obvious: the rms deviations of τ_n^* from τ_n decrease from 10 to 5%.

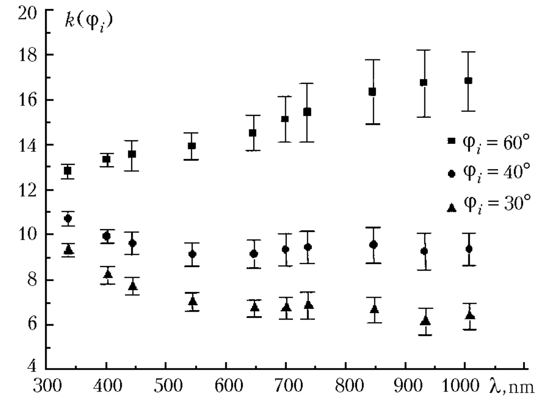

Fig. 2. Spectral dependence of the coefficients $k(\varphi_i)$.

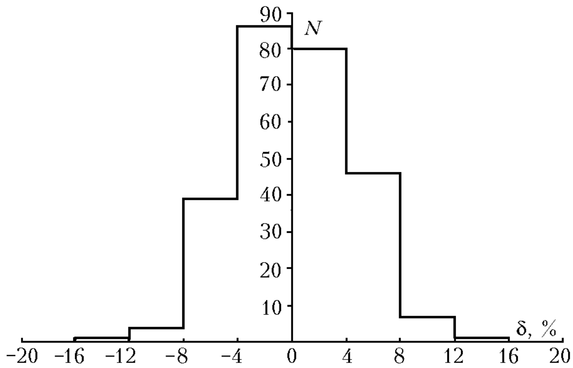

Fig. 3. Histogram of the deviations of τ_n from τ_n^*.

Thus, instead of calculating the value τ_n by formula (3) one can use the nephelometric method and determine it by means of the relationship (4) with the accuracy of $\delta\tau_n \sim 5\%$. Then the possibility is provided of dividing the optical thickness τ_a of light extinction into components of absorption $\tau_{a.a}$ and scattering $\tau_{a.s}$ at the Sun zenith angles of $30° \le Z_0 \le 60°$. To do it, it is necessary to attract the numerical data of solving the radiation transfer equation. As for the question, to what extent the values of the coefficients $k(\varphi_i)$ have regional character, it requires a special study.

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