Sky brightness at nephelometric scattering angles in arid regions of the Earth

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The data on sky brightness near the nephelometric scattering angles of 30, 40, and 60° at points situated in arid regions of Tinga Tingana (Australia), Solar Village (Arabia), and Dalanzadgad (Mongolia) are analyzed. Mean nephelometric coefficients are calculated and the accuracy of calculating the brightness optical thickness is estimated.

The problem of construction of radiation models of the atmosphere over arid zones becomes urgent due to desertification of vast territories of the Earth occurring everywhere due to the climate change, forest fires, and human activity. Aerosol optical thickness of scattering τ_{as} and absorption τ_{aa} are important characteristics entering the models. They can be determined from observations of the intensity of the direct solar radiation and the daylight sky brightness $B(\varphi)$ in the solar almucantar.[1–3] In this case the integral value (the so-called brightness optical thickness) is used for calculation of τ_{as}:

$$\tau_n = 2\pi \int_0^{\pi} \frac{B(\varphi)\sin\varphi}{E_0\, e^{-\tau m}\, m} d\varphi, \quad (1)$$

where E_0 is the spectral solar constant,[4] $\tau = \tau_m + \tau_{as} + \tau_{aa} + \tau_{oz}$ is the total optical thickness including, in addition to the aforementioned components, the optical thickness due to molecular scattering τ_m and the optical thickness due to absorption of light by ozone τ_{oz} (in the visible wavelength range); m is the Bemporad function.

Because of a specific feature of the relation of the scattering angle φ to the zenith angle of the Sun Z_0 and azimuth ψ measured from the direction toward the Sun

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

the maximum angle φ_{max}, at which the sky brightness $B(\varphi_{max})$ can be measured, is equal to $2Z_0$. It makes difficult to calculate τ_n at $Z_0 \le 60°$. In this case it seems reasonable to use nephelometric method in determining τ_n:

$$2\pi \int_0^{\pi} \frac{B(\varphi)\sin\varphi}{E_0\, e^{-\tau m}\, m} d\varphi = k(\varphi_i) B(\varphi_i), \quad (3)$$

where φ_i are the angles within the range $30 \le \varphi \le 60°$.[5] The values $k(\varphi_i)$ for South-West Kazakhstan determined from observations of the sky brightness are presented in Ref. 6.

The values $k(\varphi_i)$ calculated from the data of AERONET at three sites in arid zones of the Earth: Australia (Tinga Tingana), Arabian Peninsula (Solar Village), and Mongolia (Dalanzadgad) are presented in this paper.

The cases were selected from the AERONET data on brightness, in which the values $B(\varphi)$ at the fixed φ angles on the left and on the right of the Sun (except for the aureole range $2 \le \varphi \le 4°$) at $m \ge 2$ differed by not more than 10%. Then the homogeneity of distribution of turbidity along a horizontal direction was guaranteed to some extent. The values τ_n were calculated by means of numerical integration at reliable graphic interpolation of $B(\varphi)\sin\varphi$ in the angular range $\varphi_{max} \le \varphi \le 180°$ ($\varphi_{max} = 2Z_0$), then the values of the coefficients $k(\varphi_i)$ were calculated for φ_i equal to 30, 40, and 60° in four wavelength ranges. The total number of 973 angular distributions of brightness was used in calculations. Then the values $\bar{k}(\varphi_i)$ and corresponding rms deviations $\Delta k(\varphi_i)$ were determined. The final results are summarized in the Table. The values of the angles $\bar{\varphi}_0$ and $\Delta(\varphi_0)$, for which the following condition was fulfilled, are also presented there:

$$\tau_n = 4\pi \frac{B(\varphi_0)}{E_0\, e^{-\tau m}\, m}. \quad (4)$$

It follows from the Table that the values $\bar{k}(\varphi_i)$ in each wavelength range change weakly when passing from one observation site to another, that makes an evidence of the similarity of the shapes of spectral scattering phase functions in all three regions. Good agreement of $\bar{k}(\varphi_i)$ is observed with the data of observations in South-West Kazakhstan presented in Ref. 6.

Considering the histogram shown in Fig. 1, one can judge on the deviations of τ_n values calculated by means of integration from

$$\tau_n^* = \frac{\bar{k}(30°)B(30°) + \bar{k}(40°)B(40°) + \bar{k}(60°)B(60°)}{3E_0\, e^{-\tau m}\, m}, \quad (5)$$

determined by means of using the coefficients $\bar{k}(\varphi_i)$ at all three angles in each specific case.

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Table. The values of nephelometric coefficients $\bar{k}$ (φ_i) and the angles φ_0

λ, μm	$\bar{k}(30°)$	$\Delta k(30°)$	$\bar{k}(40°)$	$\Delta k(40°)$	$\bar{k}(60°)$	$\Delta k(60°)$	$\bar{\varphi}_0$	$\Delta\varphi_0$
				Australia				
0.44	8.7	0.6	10.2	0.4	13.3	0.3	55.5	1.7
0.67	7.3	0.5	9.3	0.6	14.0	1.0	54.5	3.5
0.87	6.8	0.5	9.3	0.6	15.1	1.4	52.2	3.4
1.02	6.4	0.7	9.3	0.6	16.2	1.6	50.4	2.9
				Arabian Peninsula				
0.44	8.3	0.3	10.4	0.5	14.5	0.7	50.8	2.8
0.67	7.2	0.6	10.2	0.9	16.3	1.6	48.3	3.5
0.87	6.6	0.7	9.9	1.0	16.9	1.9	48.5	4.0
1.02	6.3	0.7	9.6	1.0	17.0	2.3	49.0	4.3
				Mongolia				
0.44	8.0	0.7	9.7	0.6	13.4	0.4	55.3	2.3
0.67	7.0	0.8	9.2	0.9	14.4	1.1	53.6	3.5
0.87	6.8	0.9	9.4	1.0	15.6	1.4	50.7	3.6
1.02	6.4	0.7	9.1	0.7	15.8	1.3	51.4	3.0

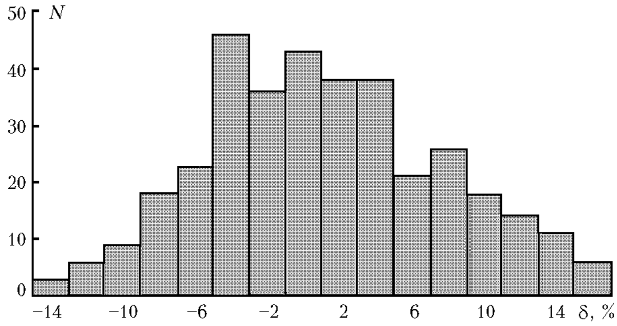

Fig. 1. Histogram of deviations of τ_n from τ_n^* (Mongolia).

The deviations δ(%) for observation of brightness in Mongolia in all wavelength ranges are also presented there. Here N is the number of considered cases. Analogous results were obtained for other sites (Figs. 2 and 3). The accuracy of determination of τ_n by the nephelometric method is obtained to be equal to 6.0% (Tinga Tingana), 7.7% (Dalanzadgad), and 8.5% (Solar Village). The $k(\varphi_i)$ values characteristic of each particular region were used in calculations.

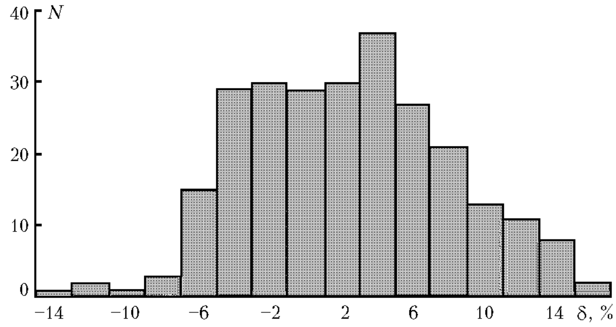

Fig. 2. Histogram of deviations of τ_n from τ_n^* (Arabian Peninsula).

The scattering angle $\bar{\varphi}_0$, for which the relationship (4) is fulfilled, decreases as the wavelength increase, and differs from the value $\bar{\varphi}_0 = 57°$ obtained by E.V. Pyaskovskaya-Fesenkova.[5] Possible causes for such deviations were discussed earlier.[6]

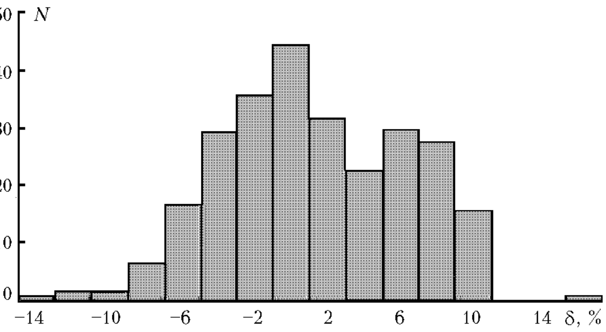

Fig. 3. Histogram of deviations of τ_n from τ_n^* (Australia).

Thus, application of nephelometric method to calculating τ_n values, and then, using the radiation transfer equation, for calculating τ_{as} makes it possible to analyze atmospheric turbidity at atmospheric masses $m < 2$, when it is impossible to use the relationship (1) because of the condition (2). Thus, the possibility has been confirmed of considering and analyzing the observations conducted during the most part of the daylight time.

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