DETERMINATION OF THE ATMOSPHERIC TRANSPARENCY COEFFICIENT FROM THE POLARIZATION OF SKY LIGHT

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Abstract

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DETERMINATION OF THE ATMOSPHERIC TRANSPARENCY COEFFICIENT FROM THE POLARIZATION OF SKY LIGHT

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Observations of the brightness of the sky through a polaroid and without it, using the visual photometer described in ([1]), were carried out by the author in 1956 and 1957 at the mountain observatory ($h = 1450$ m above sea level) and at the Aksenger state farm ($h = 500$ m) in the vicinity of Alma-Ata, as well as in the Libyan Desert of the Egyptian region of the UAR ($h = 200$ m). The measurements were made along the Sun' s almucantar. At the same time, measurements were made of solar radiation, as well as of the brightness of the circumsolar halo, using a halo photometer with a selenium photocell at different zenith distances of the Sun ([1]). Observations with the halo photometer were carried out at the mountain observatory by N. I. Ovchinnikova, at the Aksenger state farm by P. N. Boiko, and in the Libyan Desert by V. M. Kazachevsky and P. N. Boiko.

Observations with both photometers were carried out with yellow Schott filters cut from the same plate. The effective wavelengths λ_0 of the eye-yellow-filter system were calculated by the formula

$$\lambda_0 = \frac{\int_0^\infty E_\lambda p'_\lambda \varepsilon_\lambda \lambda \, d\lambda}{\int_0^\infty E_\lambda p'_\lambda \varepsilon_\lambda \, d\lambda}, \tag{1}$$

where E_λ is the energy distribution in the spectrum of the light source, p'_λ is the transparency of the filter, and ε_λ is the spectral sensitivity of the eye. Light sources with different energy distributions in the spectrum were considered: an absolutely black body with $T = 20\,000$°K and $T = 4000$°K, the Sun at the boundary of the atmosphere ($T = 6000$°K), and a light source with $E_\lambda = \text{const}$. The following results were obtained:

	20000	6000	4000	$E_\lambda = \text{const.}$
T in °K	20000	6000	4000	$E_\lambda = \text{const.}$

	20000	6000	4000	$E_\lambda = \text{const.}$
λ_0, in mμ	560	565	568	567

The effective wavelengths of the selenium photocell–yellow-filter system were calculated by the formula

$$\lambda_0 = \frac{\displaystyle\int_0^\infty E_\lambda p'_\lambda \varepsilon_\lambda p_\lambda^m \lambda \, d\lambda}{\displaystyle\int_0^\infty E_\lambda p'_\lambda \varepsilon_\lambda p_\lambda^m \, d\lambda}; \tag{2}$$

here E_λ is the energy distribution in the spectrum of the Sun at the boundary of the atmosphere, ε_λ is the spectral sensitivity of the photocell, p_λ is the spectral coefficient of atmospheric transparency, and m is the atmospheric mass in the direction

to the Sun. The following results were obtained:

m	1	5.6
λ_0, mμ	577	582

On the basis of the observations indicated, the degrees of polarization P and the atmospheric transparency coefficients p were determined. The degree of polarization was determined by the method of V. G. Fesenkov, which consists in measuring the brightness of the sky at the point under consideration through a polaroid three times in succession (B_1, B_2, B_3), at three positions of the polaroid separated from one another by 60°. The degree of polarization was obtained from the formula

$$P = \frac{2\sqrt{B_1(B_1 - B_2) + B_2(B_2 - B_3) + B_3(B_3 - B_1)}}{B_1 + B_2 + B_3}. \tag{3}$$

The transparency coefficients were determined by three methods: 1) from measurements of direct solar radiation by the Bouguer method; 2) from measurements of the sky brightness $B(60^\circ)$ on the Sun' s almucantar at an angular distance from it $\vartheta = 60^\circ$, by the method proposed by the author, from the formula

$$p = 0.973 - 9.80 \, \frac{B(60^\circ)}{E_m m}, \tag{4}$$

Fig. 1

Figure 1: Fig. 1

where E_m is the solar illumination on a perpendicular surface at the observing site for the atmospheric mass in the direction of the Sun m; 3) from measurements of the near-solar aureole at the moment of maximum brightness, by the method proposed by the author, from the formula

$$\lg p = -\frac{M}{m_{\max}}, \tag{5}$$

where M is the modulus of logarithms, $m_{\max}$ is the atmospheric mass in the direction of the Sun at the moment of maximum brightness of the near-solar aureole ([1]).

Fig. 1

For determining the atmospheric transparency coefficient by these three methods, the difference in the effective wavelengths for the eye-filter and photoelement-filter systems is of no significance. Indeed, for the extreme values of the effective wavelengths, 568 and 582 mμ, the values of the transparency coefficients from observations at Mount Wilson are respectively 0.885 and 0.890, i.e., a difference of about 1/2%.

Let us consider the dependence between the atmospheric transparency coefficient p and the degree of polarization P for scattering angles $\vartheta = 40^\circ$, 60°, and 90°. Fig. 1 shows such a dependence: a (observations at the mountain observatory), (at the Aksenger state farm), and (in the Libyan Desert). The observations were made in the summer and autumn months at various zenith distances of the Sun, within the range from 44° to 87°, on the Sun' s almucantar.

Taking into account that the error in determining the degree of polarization and the atmospheric transparency coefficient is of the order of 1-2%, from consideration of Fig. 1 it may be concluded that for $\vartheta = 90^\circ$ there is a definite single-valued nonlinear dependence between these two quantities, independently of the observing site. For $\vartheta = 60^\circ$ and $\vartheta = 40^\circ$ no such clear dependence is observed, since the scatter of the points in these cases exceeds the limits of the errors of both quantities.

Taking into account that $\rho = e^{-\tau}$, where τ is the optical thickness of the atmosphere, along the abscissa axis one may plot not the atmospheric transparency coefficients but $\lg \tau$. Then, for $\vartheta = 90^\circ$, a definite unambiguous linear dependence is obtained between the degree of polarization P and $\lg \tau$ (Fig. 2). The correlation coefficient with probable error is $r = -0.97 \pm 0.01$.

For $\vartheta = 60^\circ$ and $\vartheta = 40^\circ$, the scatter of the points somewhat exceeds the limits of error, but nevertheless a linear dependence between P and $\lg \tau$ is present. The

Fig. 2

Figure 2: Fig. 2

correlation coefficients are, respectively, $r = -83 \pm 0.05$ and $r = -0.63 \pm 0.10$.

Fig. 2

The presence of a clear functional dependence between P and $\lg \tau$ for $\vartheta = 90^\circ$ can be used to determine the atmospheric transparency coefficient. The equation relating these two quantities is as follows:

$$\lg \tau = 0.035 - 1.344\, P. \tag{6}$$

Thus, by measuring the degree of polarization on the Sun' s almucantar at an angular distance from it of $\vartheta = 90^\circ$, one can quickly and accurately determine the atmospheric transparency coefficient at any moment of time. This formula is applicable only in the absence of snow cover. In addition, it is necessary to obtain observational material in regions with high air humidity, with different albedos of the underlying surface, and also for different wavelengths.

If all three straight lines are extrapolated in the direction of increasing τ, the intersection of these straight lines with the abscissa axis will occur near one and the same point, namely near $\lg \tau = 0$, or $\tau = 1$. Thus, if such an extrapolation is permissible, then at $\tau \approx 1$ the degree of polarization should be equal to zero.

If extrapolation is allowed in the other direction, toward decreasing τ, then at $\lg \tau \approx -1.3$, or $\tau \approx 0.050$, and, consequently, at a transparency coefficient $\rho \approx 0.95$, the degree of polarization for $\vartheta = 90^\circ$ reaches 100%, for $\vartheta = 60^\circ$ 60%, and for $\vartheta = 40^\circ$ 26%. As is known, in a molecular atmosphere, if the anisotropy of the molecules is not taken into account, for ϑ equal to 90, 60, and 40°, the values of the degree of polarization are precisely 100, 60, and 26%, respectively. Thus, if such an extrapolation is allowed, one may suppose that in a Rayleigh atmosphere the degree of polarization can reach 100% when the transparency coefficient is not less than 0.95. If one accepts the ef-

If the effective wavelength of the eye-filter system is equal to 564 mμ, then the transparency coefficient of the molecular atmosphere for sea level is 0.92, and for a mountain observatory, where the mean atmospheric pressure $B =$ 640 mm, it is 0.93. Consequently, in a molecular atmosphere the degree of polarization on the Sun' s almucantar at $\vartheta = 90^\circ$ cannot be greater than 83% at sea level, or greater than 87% at a mountain observatory. And only at an altitude with atmospheric pressure of 455 mm does the degree of polarization in a molecular atmosphere reach 100%. It may be that the reason for the incomplete polarization at atmospheric pressure $B > 455$ mm is the depolarizing influence of higher-order scattering of light, which only for $p \geq 0.95$ is so small that it no longer has a noticeable effect on the degree of polarization.

These last conclusions have been drawn only under the assumption that rectilinear extrapolation of the straight lines in Fig. 2 is permissible.

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Note: Figure translations are in progress. See original paper for figures.