COLOR TEMPERATURE OF THE ATMOSPHERE AND THE AEROSOL OPTICAL THICKNESS

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Analysis of the angular distributions of the color temperature arid the pseudoemissivity, which were obtained from results of field measurements as well as simulations, showed that these parameters can be useful indicators for determining the optical state of the atmosphere, in particular, its optical thickness, as well as for selecting and identifying objects and phenomena observed in the atmosphere against the background formed by the scattered solar radiation.

For many practical problems in atmospheric optics it is often necessary to have some idea of the general character of the spectral distribution of the emitted or reflected (scattered) energy, and it is important that the form of this distribution be fixed by one or two parameters that cam be easily monitored.

The spectral energy distribution of a real source of thermal radiation can be represented by the relation[1]

$$B(\lambda,\ \varepsilon,\ T) = \frac{1}{\pi}\,\varepsilon(\lambda,\ T)\cdot M(\lambda,\ T), \qquad (1)$$

where λ is the wavelength of the radiation, B is the brightness of the real source, T is the temperature of the source, ε is the emissivity of the real source relative to the emissivity of an absolutely black body at the same temperature, and M is the luminosity of an absolutely black body (determined by Planck's law).

The relation (1) can be formally used for objects which can be classified as secondary sources of optical radiation. But then the physical parameters ε and T must be replaced by pseudoparameters: the color temperature T_c and the pseudoemissivity ε_p.[1] This approach has already been used for a long time in the study of natural resources.[2]

In Ref. 3 the results of theoretical investigations of the variations of the parameters ε_p and T_c for the earth's Rayleigh atmosphere in the plane of the solar vertical of the observer are presented. Analysis of these results shows that large gradients of ε_p and T_c exist near the horizon, this is in agreement with the character of the angular distribution of the optical thickness. The purpose of this work is to investigate the dependence of the parameters ε_p and T_c on the aerosol optical thickness and the effect of the latter on the character of the angular distribution of the color temperature and the pseudoemissivity.

Figure 1 shows estimates made of the color tensperature at the zenith of clear daytime sky color temperatures were recorded when the atmosphere above the observer was clear (i.e., the optical thickness was small). Conversely, the lowest color temperatures were recorded when the optical thickness was greatest (in the presence of clouds at the zenith). Thus, Fig. 2 shows an inverse relationship between the observed color temperature at the zenith and the optical thickness of the aerosol in time agreed with the commenced advection of moist air, which, according to synoptic data, occurred above the 1500 m level above the point of observation. Intense cloud formation started two to three hours after the observations were completed.

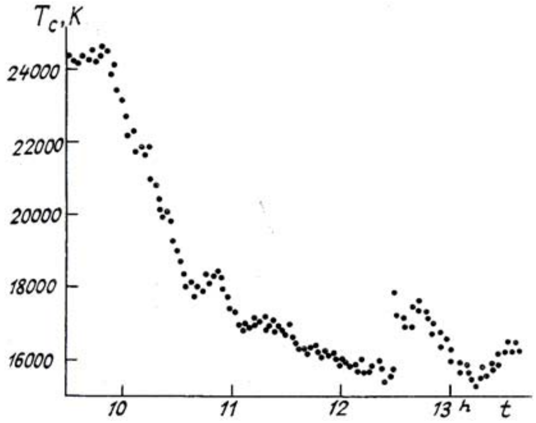

FIG. 1. Example of a realization of the color temperature of clear daytime sky. The sharp drop in the values of T_c in time coincided with the commenced advection of moist air.

Figure 2 shows (for a fixed position of the sun) the characteristic values of the color temperature, which were obtained from observations of the spectral brightness at the zenith for a clear atmosphere (sequence of points 1), a turbid atmosphere (2), and in the presence of clouds (3, 4); here N is the number of readings made with the photometer. The results show that the color temperature at the zenith in the presence

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of clouds differs significantly from the color temperature at the zenith when there are no clouds (approximately by a factor of 5). The highest based on results of photometric observations. These estimates are based on time series of the values of the brightness at the zenith at the wavelengths $\lambda_1 = 0.42$ and $\lambda_2 = 0.69$ μm. The measurements were performed with the help of a stellar-solar photoelectric photometer.[4] The significant (~ 8000 K) change in the values of the color temperature over ~ 4 hour of observations is interesting. The sharp drop in the values of T_c.

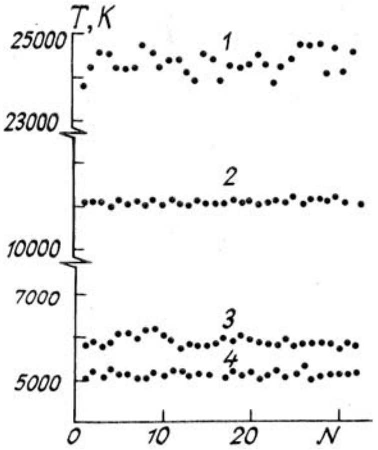

FIG. 2. The values of the color temperature of the atmosphere for different atmospheric states based on data from observations performed at the zenith.

The mechanism of formation of the brightness of the earth's spherical daytime atmosphere under conditions of single scattering is studied in Ref. 5. The relations obtained there make it possible to estimate the spectral brightness in a given angular direction as a function of the singular coordinates of the sun and the altitude dependence of the attenuation (scattering and absorbing) properties of the atmosphere. Algorithms and programs for calculating the spectral brightness, the color temperature, and the pseudoemissivity of the daytime and twilight sky have been developed based on these relations at the Institute of Atmospheric Optics of the Siberian Branch of the Academy of Sciences of the USSR. In what' follows the results obtained with the help of the computational programs mentioned above are discussed.

Figure 3 shows the results of calculations of the color temperature based on data on the values of the spectral brightness of the atmosphere for $\lambda_1 = 0.42$ and $\lambda_2 = 0.69$ μm. The model given in Ref. 6 for the altitude dependence of the scattering coefficient was employed in the calculations; the aerosol scattering phase function did not depend on λ in the indicated wave length range $\lambda_1 - \lambda_2$. The angular distribution of the color temperature in the plane of the solar vertical of the observer is presented for the zenith angle of the sun equal to 30° for different values of the aerosol optical thickness; $\tau_a = 0$ (curve 1), 0.03 (2), and 0.32 (3). The figure also shows the values of T_c, which were calculated based on the results of photometric observations, taken from Ref. 7 with $\tau_a = 0.15$. The figure shows that as aerosol optical thickness increases the angular dependence of the color temperature becomes smoother and the dynamic range of the color temperature decreases. The Rayleigh atmosphere (curve 1) has a small range of values of T_c at a given position of the sun in the sky.

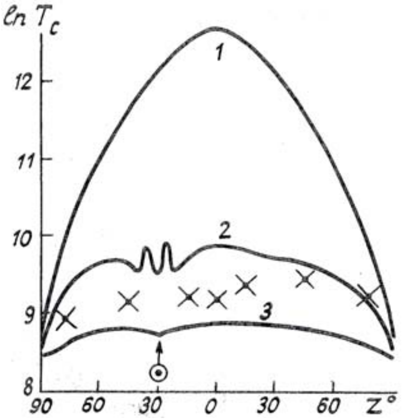

FIG. 3. The angular distribution of the color temperature in the plane of the solar vertical of the observer with the zenith angle of the sun equal to 30° and different values of the optical thickness of the atmospheric aerosol at $\lambda_1 = 0.42$ *and* $\lambda_2 = 0.69$ μm. $\tau_a = 0$ *(1),* 0.03 *(2), and* 0.32 *(3); the dots with crosses indicate the values of* T_c *calculated from the results of observations*[7] *with* $\tau_a = 0.16$. *The encircled dot marks the position of the sun.*

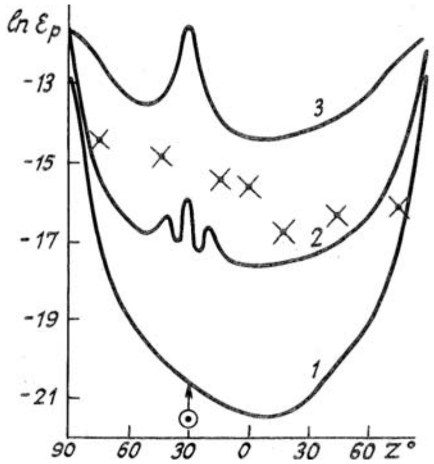

FIG. 4. The angular distribution of ε_p *in the plane of the solar vertical of the observer for the same conditions and using the same notation as in Fig. 3.*

Figure 4 shows the results of calculations of the emissivity ε_p for the same starting data and using the same notation as in Fig. 3. Here the increase in the optical thickness results in an increase in ε_p, and the dynamic range of the values decreases; this can be seen especially clearly by comparing with the values of the pseudoemissivity ε_p calculated for a Rayleigh atmosphere (curve 1). The figure shows that as the aerosol optical thickness Increases the angular dependence of ε_p becomes smoother. Comparing the values presented in Figs. 3 and 4 shows that for small values of τ_a (from 0 to 0.03) the dynamic range of the color temperature at the zenith is larger than for the parameter ε_p. For values of τ_a ranging from 0.03 to 0.3 the reverse dependence is observed.

Summarizing, we can conclude that in the plane of the solar vertical of the observer, for small values of the zenith angles of the sun, the angular distribution of the color temperature and of the pseudoemissivlty in the visible region of the electromagnetic spectrum has the following properties:

1. As the aerosol optical thickness of the atmosphere z increases from 0 to 0.3, T_c decreases and ε_p increases.
2. As the aerosol optical thickness of the atmosphere increases, the dynamic range of the values of T_c and ε_p decreases and their angular distributions become smoother.
3. In the presence of weak atmospheric turbidity the color temperature is the more sensitive indicator of the optical state of the atmosphere, while under conditions of high turbidity ε_p is the more sensitive indicator.

In conclusion, it should be noted that the high sensitivity of T_c and ε_p to a change in the aerosol optical thickness of the atmosphere and the comparatively simple method for estimating the values of these parameters make these parameters very useful as indicators for determining the optical state of the atmosphere.

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