# Effect of thin cloudiness on spectral behavior of the atmosphere effective height

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The problem is considered of the effect of thin cloudiness on the spectral dependence of the atmospheric effective height in a wavelength range 0.44–12 μm. It is shown that the presence of thin cloudiness results in anomalous spectral behavior of the effective height of the atmosphere, i.e., in appearance of a global minimum in the above wavelength range. Besides, thin cloudiness can lead to the appearance of a local maximum in the visible wavelength range. The contribution of thin cloudiness into the aerosol optical thickness of the atmosphere is estimated.

## Introduction

The effective height of the atmosphere (EHA), or the height of homogeneous atmosphere, is the ratio of aerosol optical depth to the aerosol extinction coefficient of the ground atmospheric layer. The technique is suggested and model estimates of EHA are obtained[1] for the aerosol extinction coefficient of the atmosphere and its components within a 1.07–12 μm range, where experimental data were lacking. The mean value of the effective height of the cloudless atmosphere is shown to monotone decrease from about 1 km in the Visible to about ~0.2 km in a “transparency window” of 8–12 μm.

The air condition, when sky is considered as absolutely meteorologically clear is very rare (about 1%).[2] The meteorological method of cloudiness control cannot serve as a criterion of the absence of cloudy particles at a measurement path. Therefore, values of aerosol optical depth of the atmosphere measured in real conditions are usually affected by thin cloudiness, which is understood as a small decrease in cloudiness (zenithal optical depth is less than 0.2). According to the data from Ref. 3, the presence of high clouds can result in overestimation of monthly average values of aerosol optical depth by 0.02–0.05.

In this work, a possibility is considered to determine the optical depth of the thin cloudiness on the base of studying its effect on the spectral dependence of EHA within a range 0.44–12 μm.

## Analysis of input data and their correction

The results of experimental investigations of aerosol extinction coefficients (β) in the ground layer and aerosol optical depths (τ) of the atmosphere within 0.44–3.9 μm range[4] are used as input data for model calculations of the spectral behavior of EHA. To obtain the model estimates of EHA in a range 0.44–12 μm, the spectral behaviors of β and τ are presented as a sum of two terms:

$$\beta(\lambda) = \beta_{\mathrm{sm}}(1)\cdot\lambda^{-n_1} + \beta_{\mathrm{cd}},\ \tau(\lambda) = \tau_{\mathrm{sm}}(1)\cdot\lambda^{-n_2} + \tau_{\mathrm{cd}}, \quad (1)$$

where $\beta_{\mathrm{sm}}(1)$ and $\tau_{\mathrm{sm}}(1)$ are the submicron components of β and τ at λ = 1 μm; $\beta_{\mathrm{cd}}$ and $\tau_{\mathrm{cd}}$ are the coarsely dispersed components of β and τ; $n_1$ and $n_2$ are the exponents of the Angström formulae (the first terms in Eq. (1)).

The first attempt to describe the spectral behavior of optical depth of the atmosphere by Eq. (1) with the RMS method failed, because the coarsely dispersed component $\tau_{\mathrm{cd}}$ was negative. Therefore, spectral behaviors of aerosol optical depths and aerosol extinction coefficients of the atmosphere were tested for accordance with correction method from Ref. 5. It turned out that there were systematic inaccuracies in the input data, which were eliminated by this method.

Figure 1 shows the spectral behaviors of aerosol extinction coefficients on a horizontal path (Fig. 1*a*) and of aerosol optical depths on a slant path (Fig. 1*b*) within 0.44–3.9 μm spectral range, corrected by Eqs. (1) from Ref. 5, and experimental ones from Ref. 4. The solid lines correspond to model spectral behaviors of β and τ for the data, corrected by Eq. (1). Fitting parameters for them are the following: $\beta_{\mathrm{sm}}(1) = 0.047$ km$^{-1}$; $\beta_{\mathrm{cd}} = 0.038$ km$^{-1}$; $n_1 = 1.1$; $\tau_{\mathrm{sm}} = 0.024$; $\tau_{\mathrm{cd}} = 0.046$; $n_2 = 1.8$.

It turned out that aerosol extinction coefficients much better agree with the correction technique from Ref. 5 than aerosol optical depths of the atmosphere. Thus, the maximum difference between experimental and corrected values of aerosol extinction coefficients does not exceed 0.004 km$^{-1}$, while it attains 0.03 for aerosol optical depths. Also, aerosol optical depth essentially changes not only in value, but in the character of its spectral behavior. Thus, a local

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maximum appears in a 1.06 μm region, and a fall of the corrected data appears instead of the increase in input values of aerosol optical depths within 1.06–3.9 μm. The appearance of the local maximum can be caused by the presence of medium fraction of aerosol particles.[6] Such spectral behavior of $\tau$ is verified by similar behavior of $\beta$. So, if there is a medium fraction in the input data for aerosol extinction coefficients of the ground layer, it is to appear in the spectral behavior of aerosol optical depth, essentially determined by aerosol of the lower troposphere. On correcting the input data,[5] values and spectral behavior of EHA noticeably changed.

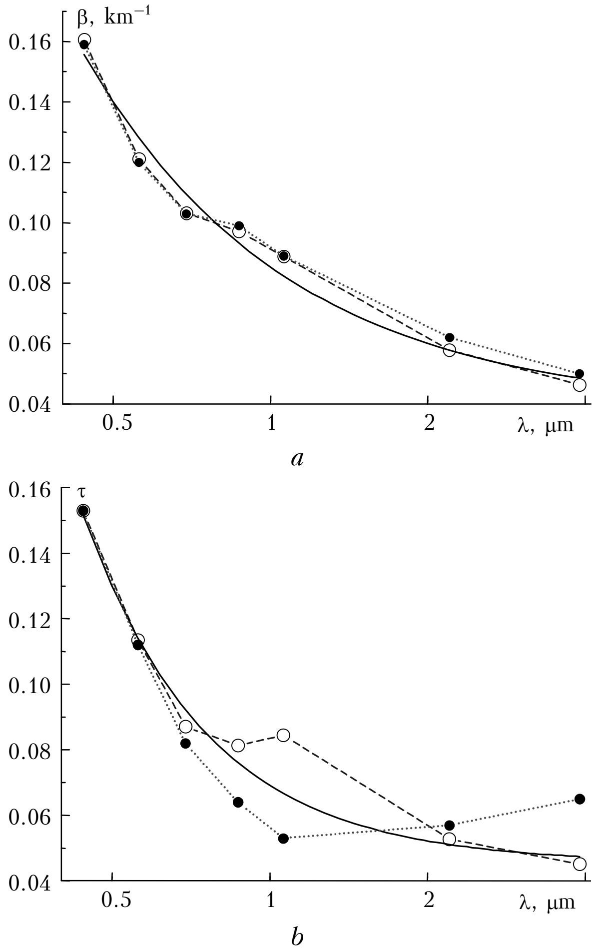

**Fig. 1.** Spectral behaviors of mean values of the corrected[5] (empty circles) and experimental[4] data (solid circles).

Figure 2 shows the spectral behaviors of EHA within 0.44–3.9 μm range for the corrected and input data.

First of all, the local $H_0$ maximum for the corrected data within 1.06 μm region is noticeable. If it is not connected with crude errors in the input data, then, as was mentioned above, it can be explained by the presence of the medium-size aerosol fraction.[6] In other aspects, the spectral behaviors of $H_0$ for input and corrected data are similar, but the variability range of the latter is much narrower.

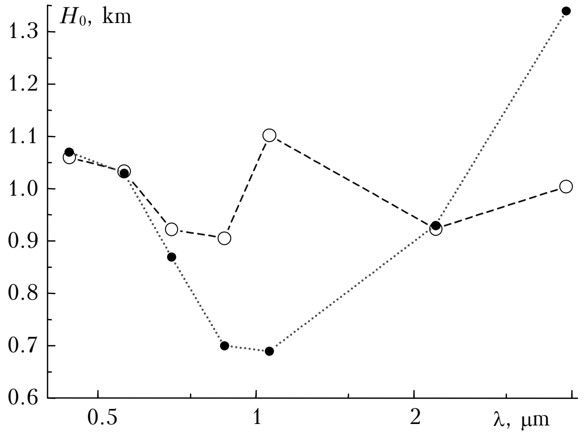

**Fig. 2.** Spectral behaviors of EHA for corrected[5] (empty circles) and input[4] data (solid circles).

## Effect of thin cloudiness on the spectral behavior of EHA

Note that the coarsely dispersed component of the aerosol optical depth $\tau_{cd}$ is the sum of the optical depth of coarsely dispersed aerosol ($\tau_{cd.a}$), the source of which is mainly the ground air layer, and the optical depth of thin cloudiness ($\tau_{cd.c}$), forming at the cloud-formation height. To estimate the optical depth of thin cloudiness, the effect of the coarsely dispersed component $\tau_{cd}$ of optical depth on the spectral behavior of EHA was studied for model (1) and corrected data. It was assumed that thin cloudiness has a quasi-neutral spectral behavior within 0.44–12 μm range.

Figure 3 shows the model spectral behaviors of EHA within a range 0.44–12 μm for mean corrected values of aerosol parameters of the atmosphere (solid circles) and other parameters of the coarse component $\tau_{cd}$ (0.006, 0.013, 0.026, 0.066, 0.086, 0.106, 0.126).

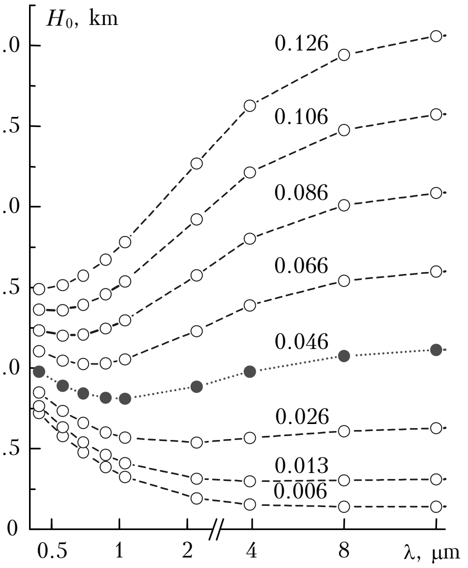

**Fig. 3.** Model spectral behaviors of EHA.

As is seen, a decrease in EHA with increasing wavelength is observed at small $\tau_{cd}$ throughout a 0.44–12 μm spectral range. A global minimum appears at moderate $\tau_{cd}$ and shifts from the long-wave toward the shortwave spectral range as $\tau_{cd}$ increases. At large $\tau_{cd}$, the increase in EHA with the wavelength is observed throughout a 0.44–12 μm range.

It is expected, that EHA for the aerosol extinction coefficient for the troposphere aerosol, not affected by cloudiness, decreases with an increase in wavelength, since the free-atmosphere effective height for the concentration of the aerosol, having close physical and chemical properties, decreases with an increase in particle size.[7,8] Such assumption is confirmed by calculation of the effective height of the aerosol atmosphere, performed with the data from Ref. 9 for background and medium-cycle models within a 0.35–5.3 μm range. In view of this, the optical depth of thin cloudiness can be estimated.

The technique for determination of the optical depth of thin cloudiness is based on the assumption that EHA, except for the effect of cloudiness extinction component, decreases with increasing radiation wavelength. Therefore, excluding $\tau_{cd.c}$ (at which the minimum of model EHA at a certain extreme wavelength is observed) from $\tau_{cd}$, an estimate of the optical depth of thin cloudiness can be obtained. The choice of the extreme wavelength is a discussion question, because it can be chosen in a range, where EHA does not decrease essentially.

The analysis has shown that a 4–12 μm range can be used for this. Here the estimate does not essentially depend on the choice of extreme wavelength. EHA for extreme wavelengths of 4 and 12 μm is of 0.3 and 0.14 km in these ranges. Such result is in a good agreement with the effective height estimate equal to 0.2 km and obtained for clear air in 8–12 μm range.[1] From the analysis of the data, shown in Fig. 3, the optical depth of cloudiness is estimated as 0.033–0.04 μm at extreme wavelengths of 4 and 12 μm.

Figure 4 shows the corrected spectral behaviors of EHA within 0.44–3.9 μm spectral range for mean values of aerosol parameters of the atmosphere (solid circles) and other parameters of $\tau_{cd}$ (0.006, 0.026, 0.066, 0.086, 0.106, 0.126).

Excluding spectral regions 0.56 and 1.06 μm from the analysis of Fig. 4, we observe the same regularities as in Fig. 3. Besides, the above-noted maximum of EHA is observed in a 1.06 μm region at small $\tau_{cd}$, which disappears at large $\tau_{cd}$. At moderate $\tau_{cd}$, a local maximum appears in the visible spectral range at $\lambda$ = 0.56 μm. This is shown by data from Ref. 4 for a separated subarray of 14 days with thin cloudiness.

On the base of Fig. 4 data, the minimum estimate of the optical depth of thin cloudiness ($\tau_{cd.c}$) can be obtained from the condition of equality of EHAs at wavelengths of 2.2 and 3.9 μm, which is observed at $\tau_{cd.a} = 0.029$. Then the minimal estimate is

$$\tau_{cd.c} = \tau_{cd} - \tau_{cd.a} = 0.046 - 0.029 = 0.017,$$

while the true estimate of $\tau_{cd.c}$ is within a 0.017–0.046 range.

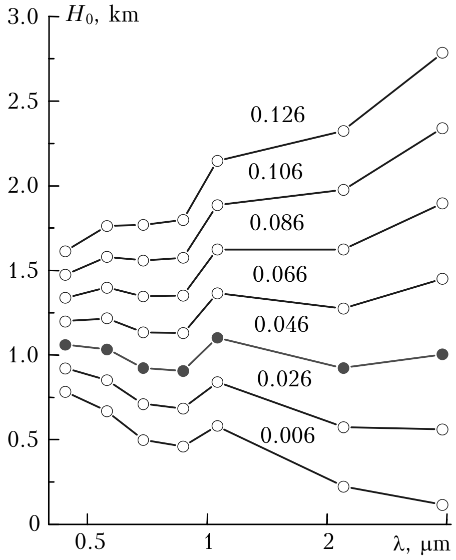

**Fig. 4.** Corrected spectral behaviors of EHA.

## Conclusion

The thin cloudiness leads to essential variations of model spectral behavior of the effective height of the atmosphere. In the absence or small values of the optical depth of thin cloudiness, a decrease in EHA is observed with increasing the wavelength throughout a 0.44–12 μm spectral range. At average and large values of the optical depth of thin cloudiness, the spectral behavior of EHA becomes anomalous. Thus, a global minimum appears at its moderate values, which shifts from the long-wave spectral range toward the shortwave one, when increasing the optical depth. At large values, an increase in EHA with wavelength is observed throughout 0.44–12 μm spectral range. In addition, thin cloudiness can result in appearance of a local maximum in the visible spectral range and its disappearance at a wavelength of 1.06 μm.

An anomalous spectral behavior of EHA can be one of criteria of the presence of thin cloudiness on a slant path. A technique for estimation of the optical depth of thin cloudiness has been suggested; its average value has been estimated as 0.033–0.04, which is in a good agreement with the data from Ref. 3, where this estimate is equal to 0.02–0.05.

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