On the Estimate of the Contribution of Submicron Aerosol into the Extinction of IR Radiation

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Introduction

Accounting for the extinction of radiation in the atmospheric transparency window from 8 μm to 12 μm is important for solving climatic problems. Apart from the continuum absorption of water vapor and selective absorption of trace gases, aerosol particles of different size can make some contribution here.

An attempt is undertaken in this paper to estimate the contribution of submicron aerosol into the absorption of infrared (IR) radiation on the basis of some arrays of spectral aerosol extinction coefficients $\alpha(\lambda)$ obtained on the long near-ground paths.

Characteristics of the Data

Five arrays of the coefficients $\alpha(\lambda)$ were processed. One of them was obtained at the Black Sea coast, three were in continental hazes of West Siberia (haze 1, haze 2, and haze 3), and the last was obtained in fall 1997 under conditions of smoke haze originated from big forest and peat fires. Table 1 presents the mean values and root mean square (rms) errors of the principal meteorological parameters of the atmosphere: temperature (t, °C); relative humidity (RH, %); partial pressure of water vapor (e, mbar), as well as the number of measurements N in each case. Then, it is necessary to select the submicron component from the total aerosol extinction.

Table 1. Mean values and root mean square errors of atmospheric meteorological parameters.

Parameter	Haze 1 (Summer 1997)	Haze 2 (Summer 1998)	Haze 3 (Fall 1998)	Smoke Haze (Fall 1997)	Coastal Haze
t, °C	10.4 ± 4.0	19.4 ± 5.3	8.6 ± 9.1	9.4 ± 6.6	20.0 ± 3.3
RH, %	71.1 ± 18.8	62.7 ± 18.6	76.6 ± 16.3	57.1 ± 18.4	73.6 ± 12.4
e, mbar	8.8 ± 2.0	13.9 ± 3.3	9.1 ± 3.9	6.6 ± 2.1	17.4 ± 4.1
N	145	394	298	141	168

Technique for Selection of the Submicron Aerosol Component

To solve this complicated problem, we used the statistical method for dividing the coefficients of aerosol extinction into components caused by particles of different size. The method is based on the linear multiple regression analysis (Pkhalagov et al. 1999). The regression equation has the following form:

$$\alpha_{i\lambda} = K_{0\lambda} + K_{1\lambda}\Delta_{i1} + K_{2\lambda}\Delta_{i2} + K_{3\lambda}\alpha_{i,c} + \delta_{\alpha} \quad (1)$$

where $\alpha_{i\lambda}$ are the measured aerosol extinction coefficient at the wavelength λ; Δ_{i1}, Δ_{i2}, and $\alpha_{i,c}$ are the input parameters of the equation related to the variations of fine, middle-disperse, and coarse aerosol fractions, respectively; $K_{0\lambda}$, $K_{1\lambda}$, $K_{2\lambda}$, and $K_{3\lambda}$ are the regression coefficients determined by means of minimization of the error δ_{α}. The values Δ_{i1}, Δ_{i2}, and $\alpha_{i,c}$ were calculated from the measured values $\alpha_{i\lambda}$ as follows.

$$\Delta_{i1} = (\alpha_{i,\,0.44} + \alpha_{i,\,0.48} + \alpha_{i,\,0.55})/3 - (\alpha_{i,\,0.69} + \alpha_{i,\,0.87} + \alpha_{i,\,1.06})$$

$$\Delta_{i2} = (\alpha_{i,\,0.69} + \alpha_{i,\,0.87} + \alpha_{i,\,1.06})/3 - (\alpha_{i,\,1.6} + \alpha_{i,\,2.2} + \alpha_{i,\,3.9})$$

$$\alpha_{i,c} = (\alpha_{i,\,1.6} + \alpha_{i,\,2.2} + \alpha_{i,\,3.9})$$

Let us note that each parameter is averaged over three wavelengths in order to decrease the error. Then the regression coefficients $K_{0\lambda}$, $K_{1\lambda}$, $K_{2\lambda}$, and $K_{3\lambda}$ were determined. The component of aerosol extinction related to the submicron fraction was calculated by the following formula:

$$\alpha_i(\lambda)_{sm} = K_1(\lambda)\Delta_{i1} + K_2(\lambda)\Delta_{i2} = \alpha_i(\lambda) - K_3(\lambda)\alpha_{i,c} - K_0(\lambda) \quad (2)$$

If one supposes that all extinction of radiation in the range of 1.6 μm to 3.9 μm is caused only by scattering by coarse particles, one can assume that the coefficients $\alpha_i(\lambda)_{sm}$ in the range of 8 μm to 12 μm obtained in such a way are the coefficients of absorption of IR radiation by submicron aerosol. The errors of the obtained values $\alpha_i(\lambda)_{sm}$ are determined by a random (δ_{α}) and systematic error. The last can be estimated by the value $K_0(\lambda)$, which is not statistically related to the input parameters of Eq. (1).

Results

Quantitative data on the coefficients $\alpha_i(\lambda)_{sm}$ in the wide wavelength range were obtained from statistical processing of all five arrays. Mean spectral dependencies of the coefficients $\alpha_i(\lambda)_{sm}$ in all ranges from 0.44 μm to 12 μm are shown in Figure 1a. The values $\alpha_i(\lambda)_{sm}$ in the transparency window from 8 μm to 12 μm are shown in Figures 1b and 1c. It is seen that the value of the absorption coefficient of submicron aerosol fraction in this window varies in the limits from 0.01 km^{-1} to 0.03 km^{-1}.

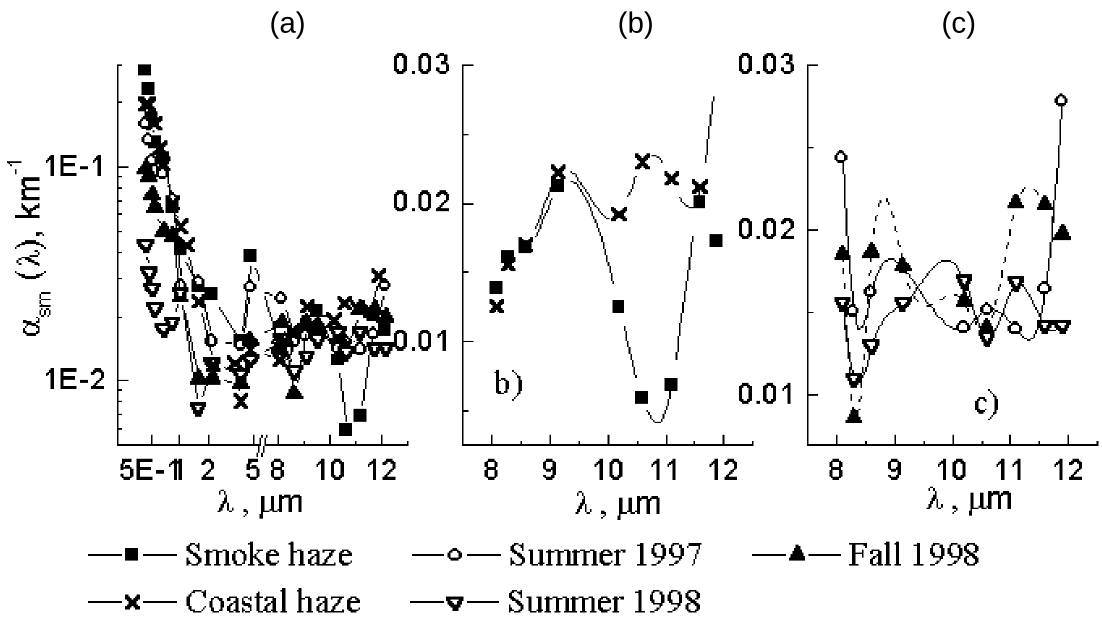

Figure 1. Spectral behavior of the mean absorption coefficients of submicron aerosol fraction.

In general, the character of the spectra $\alpha_i(\lambda)_{sm}$ in the IR range is chaotic and does not allow conclusions to be drawn about the absorption bands of submicron aerosol. The maximums near $\lambda = 9$ μm and 11 μm are well pronounced in coastal haze. The maximum near $\lambda = 9$ μm is also seen in smoke haze, but the sharp minimum is observed near $\lambda = 11$ μm, and maximum is at $\lambda = 11.5$ μm. The situation with absorption bands in summer and fall hazes in Siberia is very ambiguous because the spectrum of the coefficients $\alpha_i(\lambda)_{sm}$ vary noticeably for different data arrays.

The obtained values of the coefficients $\alpha_i(\lambda)_{sm}$ in the range of 8 μm to 12 μm are in good agreement with the numerical estimates of the contribution of submicron aerosol fraction into the absorption of IR radiation performed by Kabanov et al. (1988) on the basis of the single-parameter model of microphysical and optical characteristics of atmospheric haze and the Rayleigh formula for the case $\kappa << 1$.

$$\alpha_i(\lambda)_{sm} = 36\pi m \kappa_d V_d (m^2 + 2)^{-2} \lambda^{-1} \quad (3)$$

where m and κ_d are real and imaginary parts of the complex refractive index of particles at the wavelength λ, and V_d is the specific volume of the aerosol particle matter (the index d is related to the dry matter). It is known that the content of water in the composition of aerosol particles increases as relative humidity increases, which leads to the decrease of the real part of the complex refractive index of particles. It follows from the aforementioned formula that the increase of the absorption of IR radiation should be observed as relative humidity increases. In this connection, it is interesting to analyze the effect of relative humidity of air on the character of the change of the spectral dependence of the coefficients $\alpha_i(\lambda)_{sm}$. Figure 2 shows the mean spectral dependencies of the coefficients $\alpha_i(\lambda)_{sm}$ in

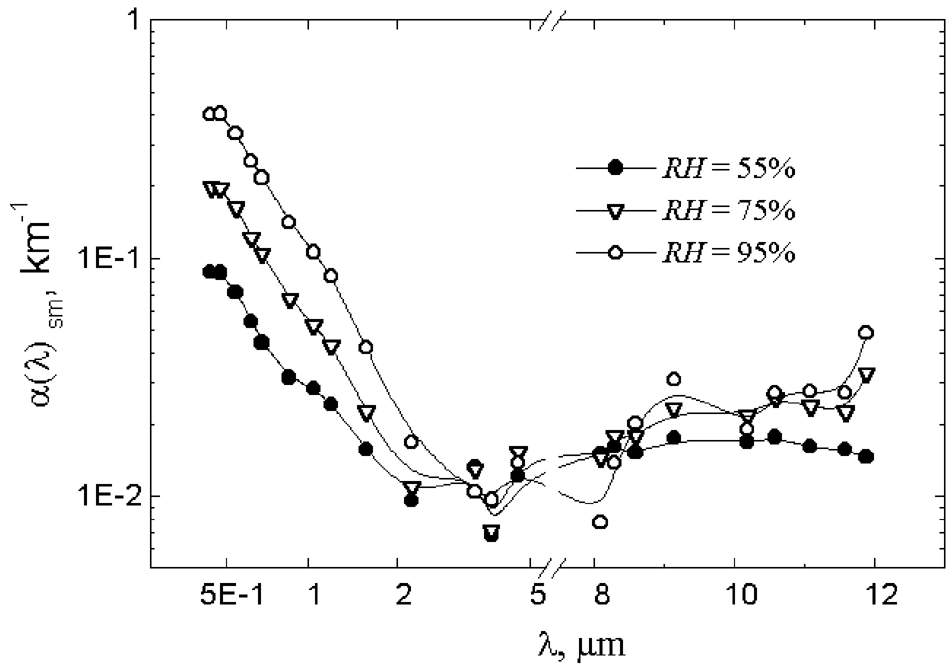

Figure 2. Transformation of the spectral dependence of the mean extinction coefficients of submicron aerosol fraction in coastal haze at the change of relative humidity.

narrow (±5%) humidity ranges for the coastal haze, where RH is the principal factor of the variability of submicron aerosol. Indeed, the coefficients $\alpha_i(\lambda)_{sm}$ in IR wavelength range increase as relative humidity increases.

We have not succeeded in performing an analogous analysis for the continental region, because relative humidity is not the determining factor of variability of submicron aerosol in the weakly turbid atmosphere of West Siberia.

Conclusion

The quantitative estimates of the absorption coefficients of IR radiation in the atmospheric transparency window from 8 μm to 12 μm are obtained using the statistical approach of dividing the total aerosol extinction coefficients into components caused by particles of different size. The absorption coefficient values in this range are 0.01 km^{-1} to 0.03 km^{-1}; that is in good agreement with the available numerical estimates. In general, the revealed absorption by submicron aerosol makes a small contribution into the total extinction of IR radiation in the atmosphere. For comparison, the mean value of the coarse aerosol extinction in this wavelength range in different seasons and in different geographical zones varies from 0.05 km^{-1} to 0.1 km^{-1}, and the continuum absorption of water vapor in summer in the mid-latitudes can exceed 0.2 km^{-1}.

References

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