Estimation of the Single Scattering Albedo from the Data on the Content of Submicron Aerosol, Absorbing Substance, and the Parameter of Condensation Activity In a Local Volume

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Introduction

Regional models that describe the spatial-temporal variability of atmospheric aerosol parameters are necessary to solve many radiative and climatic problems. An important area of study is the content of the main absorbing substance, soot (black carbon), in aerosol particles. Soot determines the non-selective absorption of radiation in the visible wavelength range by aerosol. It is an important radiative-climatic factor because of its significant effect on the atmospheric transparency, albedo of clouds and snow cover.

The results estimating the single scattering albedo of submicron aerosols are analyzed in this paper based on the routine simultaneous measurements of the directed scattering coefficient of the dry matter of aerosol particles at the wavelength of 0.52 μm, mass concentration of soot and the parameter of aerosol condensation activity.

Instrumentation and Technique for Measurement

The aerosol characteristics in the near-ground air layer were measured round-the-clock every-hour from 1998 to 2000 at the stationary Aerosol Monitoring Station (Kozlov et al. 1997) situated at the eastern outskirts of the city of Tomsk. The aerosol came in optical cells of the devices in flux mode through the samples mounted at the height of ~ 9 m.

The FAN nephelometer with heating of the air flux by about 30°C was used for the directed scattering coefficient of the dry matter of aerosol particles $\mu_0(45°)$, $km^{-1}ster^{-1}$, at the wavelength of 0.52 μm. The devices were calibrated by scattering pure gases. The mass concentration of soot, M_S $\mu g/m^3$, was measured by the modified aethalometer, which was analogous to that used by Hansen et al. (1984). The aethalometer realizes the method for measurement of diffuse attenuation of light by a layer of aerosol particles directly during the process of collection on the aerosol filter. Absolute calibration of the device was performed in laboratory conditions using the pyrolysis generator of soot particles and comparing the data of simultaneous optical and gravimetric measurements of soot using the pyrolysis generator of soot particles from 50 nm to 200 nm (Baklanov et al. 1998). The sensitivity of the aethalometer is about

0.1 $\mu g/m^3$ when pumping 20 to 30 liters of air. Duration of individual air sampling for the nephelometer and the aethalometer is 10 minutes. The available URL for the data arrays is http://aerosol1.iao.ru/.

The station contained the active nephelometric polarization setup consisting of the nephelometer and the devices for artificial moistening of aerosol up to 95 percent and heating up to 300°C. The device was used for recording the aerosol scattering coefficient as a function of relative humidity and temperature. The parameter of aerosol condensation activity and the content of volatile species in the composition of aerosol particles were determined from these measurements.

Technique for Estimating the Single Scattering Albedo of Aerosol

The single scattering albedo is the important optical characteristic of absorbing properties of aerosol particles, which determines the ratio between scattering and absorption in the total extinction:

$$\omega = \sigma / (\sigma + \alpha) \tag{1}$$

where σ is the scattering coefficient, and α is the absorption coefficient. The data obtained on the directed aerosol scattering coefficient $\mu_0(45°)$, mass concentration of soot M_S and the parameter of condensation activity γ were used for estimating the single scattering albedo ω. The scattering coefficient of the dry matter of aerosol particles was determined from the measured directed scattering coefficient

$$\sigma_0 = K \times \mu_0 \, . \tag{2}$$

For our data processing, we used the value of the transition constant K equal to 9. The results of the comparison of our data with the data of measurements at a long path show that this value satisfactorily corresponds to the majority of haze conditions (Panchenko et al. 1994). The error in determining the total scattering coefficient σ using this value is ~ 20 percent. To calculate the scattering coefficient at ambient relative humidity, the Kasten–Hanel formula was used:

$$\sigma(R) = \sigma_0(1 - R)^{-\gamma} \tag{3}$$

where R is relative humidity and γ is the parameter of condensation activity of aerosol particles. The aerosol absorption coefficient was determined from the data on the soot concentration:

$$\alpha = \alpha_m \times 10^{-3} \times M_S \tag{4}$$

where α_m is the specific cross-section of absorption. According to the results of theoretical calculations for finely dispersed soot particles (approximation of the presence of soot as a component of external mixture), as well as according to literature data for many atmospheric situations (Clarke et al. 1987; Gundel et al. 1984; and Wolff 1984) one can use the value $\alpha_m \sim 10\ m^2g^{-1}$ as an estimate for the visible wavelength range. We also considered the cross-section of absorption of Rayleigh particles $\alpha_m = 6.3\ m^2g^{-1}$ as a limit case of very small particles (at the complex refractive index of soot m = 1.7 - i 0.7 and the particle density $\rho = 1.5\ g/cm^3$).

The formulas (1) to (4) allow us to estimate the single scattering albedo. One can reduce Eq. (1) to the obvious form

$$\omega = [1 + 0.3\alpha_m P_S(1–R)^{\gamma}]^{-1} \tag{5}$$

where $P_S = M_S / M_A$ is the relative content of soot in dry particles, M_A is the mass concentration of the aerosol dry matter. According to the one-parameter model (Gorchakov and Sviridenkov, 1981), the aerosol scattering coefficient in conditions of atmospheric haze correlate well with the mass concentration of finely dispersed aerosol, which makes it possible to pass to the value of the aerosol mass concentration in Eq. (3):

$$M_A \approx 300 \times \sigma, \tag{6}$$

where M_A is measured in $\mu g/m^3$, and σ is in km^{-1}. Then, from Eq. (5), one can obtain the formula for estimating the single scattering albedo:

$$\omega(R) = \{1 / [1 + (\omega_0^{-1} - 1)]\}\times(1 - R)^{-\gamma} \tag{7}$$

Formulas (5) and (7) was used for the statistical estimates of the annual behavior of the single scattering albedo taking into account seasonal peculiarities of the variations of the relative content of soot and the parameter of condensation activity of aerosol particles. At first, the daily, monthly, and seasonal mean values of the single scattering albedo of dry particles were calculated from the hourly data on P_S. Then the corresponding values of the single scattering albedo at certain relative humidity of air were determined. The results obtained allowed us to investigate the peculiarities of the annual behavior and the limits of variation of the albedo, as well as to consider the effects of the particle dispersity and of relative humidity on the variations of albedo.

Results

Analysis of the experimental data on the relative content of soot in the aerosol dry matter P_S (Figure 1) and the parameter of condensation activity γ (Figure 2) shows that their annual behaviors are similar to each other. The year-to-year stability of the principal peculiarities of the annual behaviors of two parameters is observed. Maximum in winter and minimum in summer are the most well pronounced. The monthly mean values P_S decrease from 10 to 3 - 4 percent, and the respective values γ decrease from 0.6 to 0.2. Annual behaviors of the aerosol and soot mass concentrations are characterized by analogous shape. Hence, the seasonal behavior of P_S is caused by stronger variations of the mass concentration of soot compared to aerosol. As for the annual behavior of the parameter of condensation activity γ, possibly, seasonal variations of the chemical composition and microstructure of particles affect it. Local extremes are also observed in the annual behaviors. In particular, one possible reason for the appearance of local peculiarities is the effect of forest fire smoke. As a rule, the relative content of soot decreases at intrusions of the smoke plumes of forest fires. It is seen in Eq. (7) that the peculiarities of the annual behaviors of P_S and γ compete with each other in the change of the single scattering albedo.

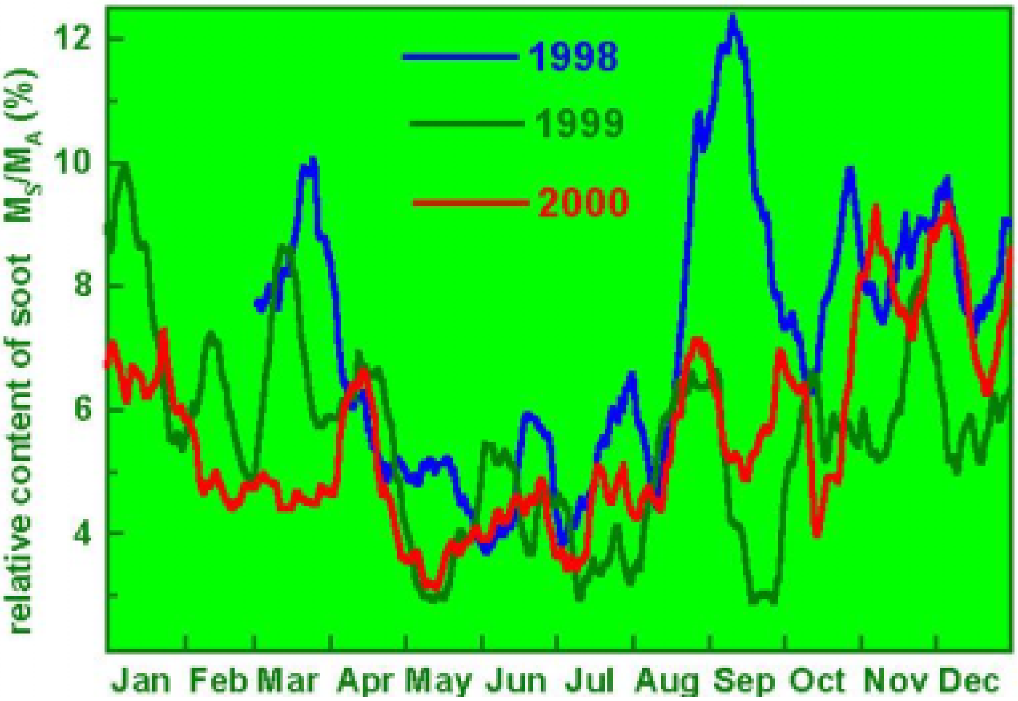

Figure 1. Annual behavior of the relative content of soot.

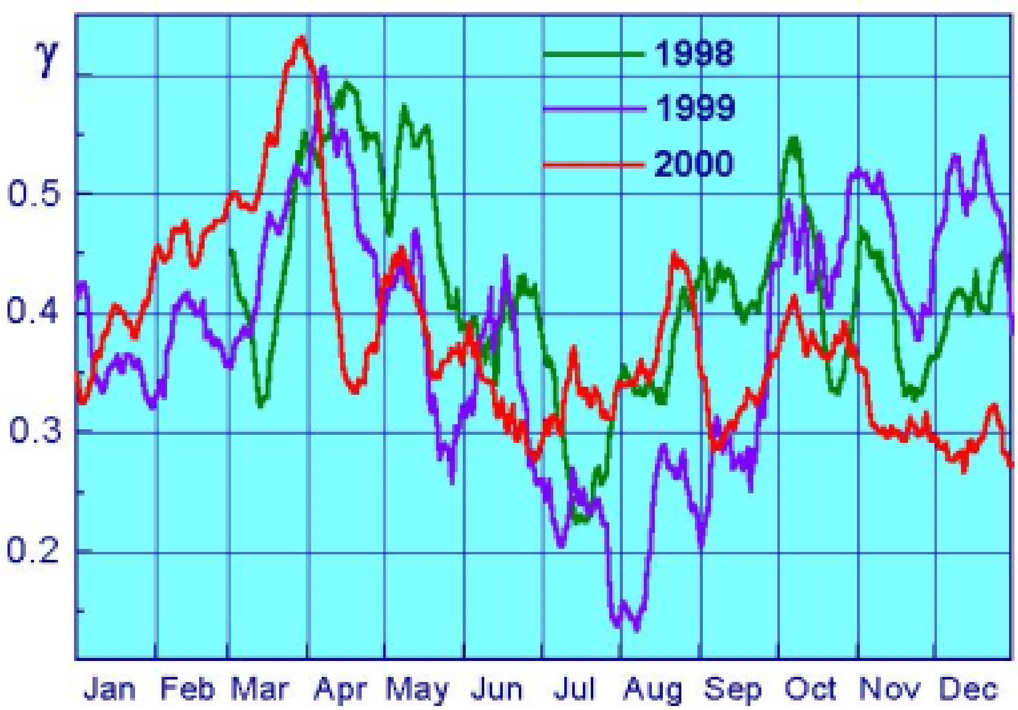

Figure 2. Annual behavior of the parameter of condensation activity of aerosol particles.

Annual behavior of the single scattering albedo of «dry» particles is shown in Figure 3. Minimum of its value is observed in winter and maximum is in summer. The values of albedo increase as relative humidity increases, but the peculiarities of the seasonal variations are smoothed.

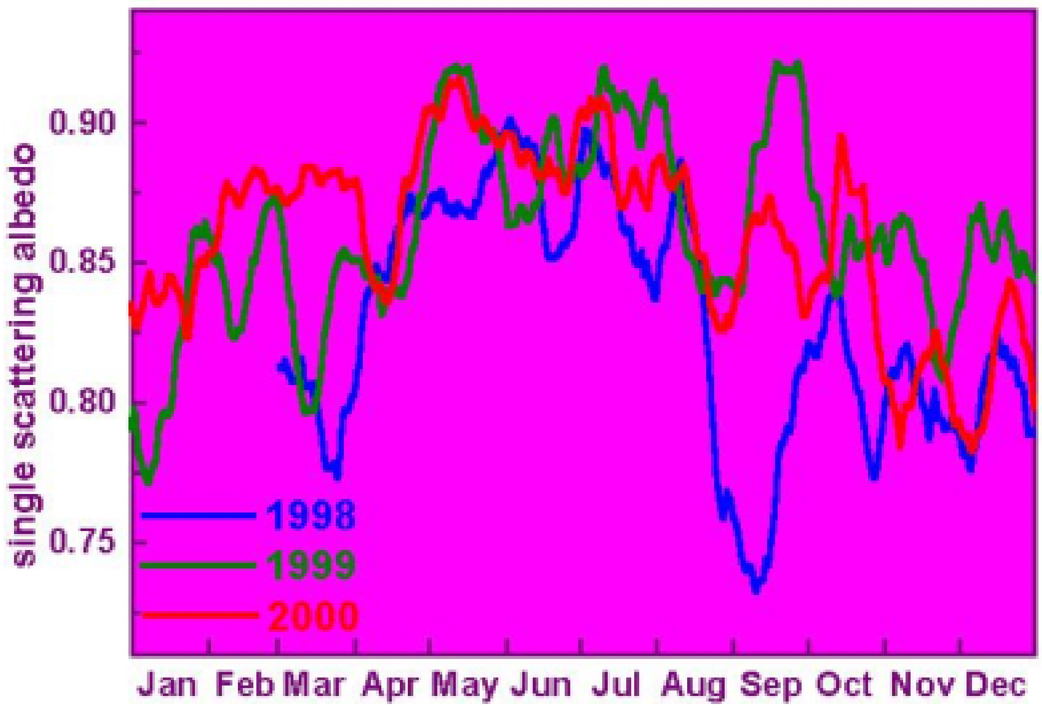

Figure 3. Annual behavior of the single scattering albedo of dry aerosol.

The effect of the disperse composition of particles is more significant in fall and winter, and at small relative humidity. The albedo of Rayleigh soot particles here can be 6 percent greater than that of larger particles. As a whole, the total limits of variations of the single scattering albedo of dry particles are $\omega = 0.79–0.93$ for the considered parameters of particles. At relative humidity R ~ 90 percent, the range of variations becomes narrower $\omega = 0.89–0.96$.

Conclusion

The statistical estimates based on the aerosol and soot mass concentration and the parameter of condensation activity makes it possible to reveal the stable peculiarities of seasonal variability of the single scattering albedo of aerosol particles in the visible wavelength range. Such investigations are important for creating a model of the composite aerosol particles (soot as a component of internal admixture).

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