Investigation of Absorption Properties of Submicron Aerosol in the Troposphere Over West Siberia

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Introduction

Improving radiative climate models for the cloudless atmosphere depends largely on the correct way to simulate single-scattering albedo of atmospheric aerosol. Solving this problem requires performing detailed experiments on the study of the aerosol absorption characteristics in the troposphere. The principal absorbing substance in aerosol is soot. Studying the dynamics of the change of aerosol absorption under the effect of geophysical factors becomes more and more urgent.

The results of the approximate estimation of the single-scattering albedo and the relative content of soot in particles based on measurements of the scattering coefficient of submicron aerosol and the concentration of soot in the troposphere are considered in this paper.

Instrumentation and Technique for Measurements and Calculations

Simultaneous measurements of the scattering coefficient of the dry matter of aerosol particles at the wavelength of 0.52 μm (nephelometer) and the mass concentration of soot (aethalometer) in the troposphere up to 7 km were carried out regularly during 1999 – 2002 from on board an aircraft-laboratory over the Novosibirsk region. The devices, as well as the peculiarities of their calibration and operation on board the aircraft-laboratory, are described by Panchenko et al. (2000). Flights were performed every month during the daytime. The mean duration of one flight was 3 hours. When analyzing the results, attention was paid to the measurement data at the heights of 0.5, 1.0, 1.5, 2.0, 3.0, 4.0, 5.5, and 7.0 km. The duration of each of these flights was about 10 minutes.

The measurements of the aerosol scattering coefficient σ (km^{-1}) and the mass concentration of soot M_s ($\mu g/m^3$) were used for approximate estimation of the vertical profiles of the relative content of soot in particles P and the single-scattering albedo ω:

$$\omega = \sigma / (\sigma + \alpha), \qquad (1)$$

The aerosol absorption coefficient α in Eq. (1) was calculated using the data on the soot concentration

$$\alpha(km^{-1}) = \alpha_m(m^2/g) * 10^3 * M_S\ (\mu g/m^3), \qquad (2)$$

The value α_m = 4.61 m^2/g (at the wavelength of 0.53 μm) obtained in simultaneous measurements of the aerosol absorption coefficient by optical-acoustic spectrometer and the mass concentration of soot by aethalometer in the near-ground layer of the atmosphere (Kozlov et al. 2002) was used for calculations. The aerosol mass concentration was determined from the data on σ using the formulas of the one-parameter model of atmospheric aerosol (Gorchakov and Sviridenkov 1981):

$$M_a\ (\mu g/m^3) = 2 * \rho\ (g/cm^3) * 10^2 * \sigma\ (km^{-1}), \quad (3)$$

where ρ is the density of the particulate matter. We took the value ρ = 1.8 g/cm^3 characteristic of continental aerosol. Then the relative content of soot was calculated $P = M_s/M_a$.

Equations (1-3) give only approximate estimates of the vertical profiles of ω and P, because the values α_m and ρ used for calculations are the model assumptions, which can be the source of errors. The estimates show that, at mean errors in measuring σ and M_s, about 20% of the relative error in determine-ing albedo dω/ω is 1% to 3% at the values ω>0.90 and increases up to 8.5% as ω decreases to 0.70.

Results of Measurements

The results of airborne measurements allowed us to study the dynamics and ranges of variations of the vertical profiles of the aerosol characteristics. The analysis shows the year-to-year stability of the principal peculiarities of the vertical profiles of the aerosol and soot concentrations, single-scattering albedo, and the relative content of soot. It is seen in the synchronous manner of variations of the concentrations of aerosol and soot and in the stable peculiarities of seasonal transformation of the vertical profiles.

Vertical profiles of the aerosol characteristics obtained in 2001–2002 are shown in Figures 1-4. Figure 1 illustrates the profiles of the mass concentration of soot, aerosol, and air temperature in different months. As shown, the total range of variations of the mass concentration of soot is, in average, from 5 to 0.02 $\mu g/m^3$ and the range of variations of the mass concentration of aerosol is from 50 to 0.5 $\mu g/m^3$, i.e., variations can exceed two orders of magnitude. Local maximums of concentrations at different heights are often observed on the background of the monotonic decrease (Figure 1). The most probable reason of appearance of the maximums can be the effect of such factors as temperature inversions, cloud layers, transfer and change of air mass, and forest fire smoke. The important peculiarity observed in the majority of events is the similarity of the profiles of the mass concentrations of aerosol and soot (Figure 1). The considered vertical profiles of aerosol are in qualitative agreement with mean seasonal profiles of the aerosol scattering coefficient obtained earlier in airborne measurements in West Siberia at heights ranging up to 5 km (Panchenko et al. 1994). The shape of the vertical profiles of the mass concentration of soot is also characterized by significant seasonal variations closely related to the temperature stratification of the boundary layer of the atmosphere (Figures 1 and 2). Temperature inversions in the height range 0.5 to 1.5 km (Figure 1a) characteristic of West Siberian region in cold season lead to the most pronounced dynamics of the vertical profile of the soot concentration.

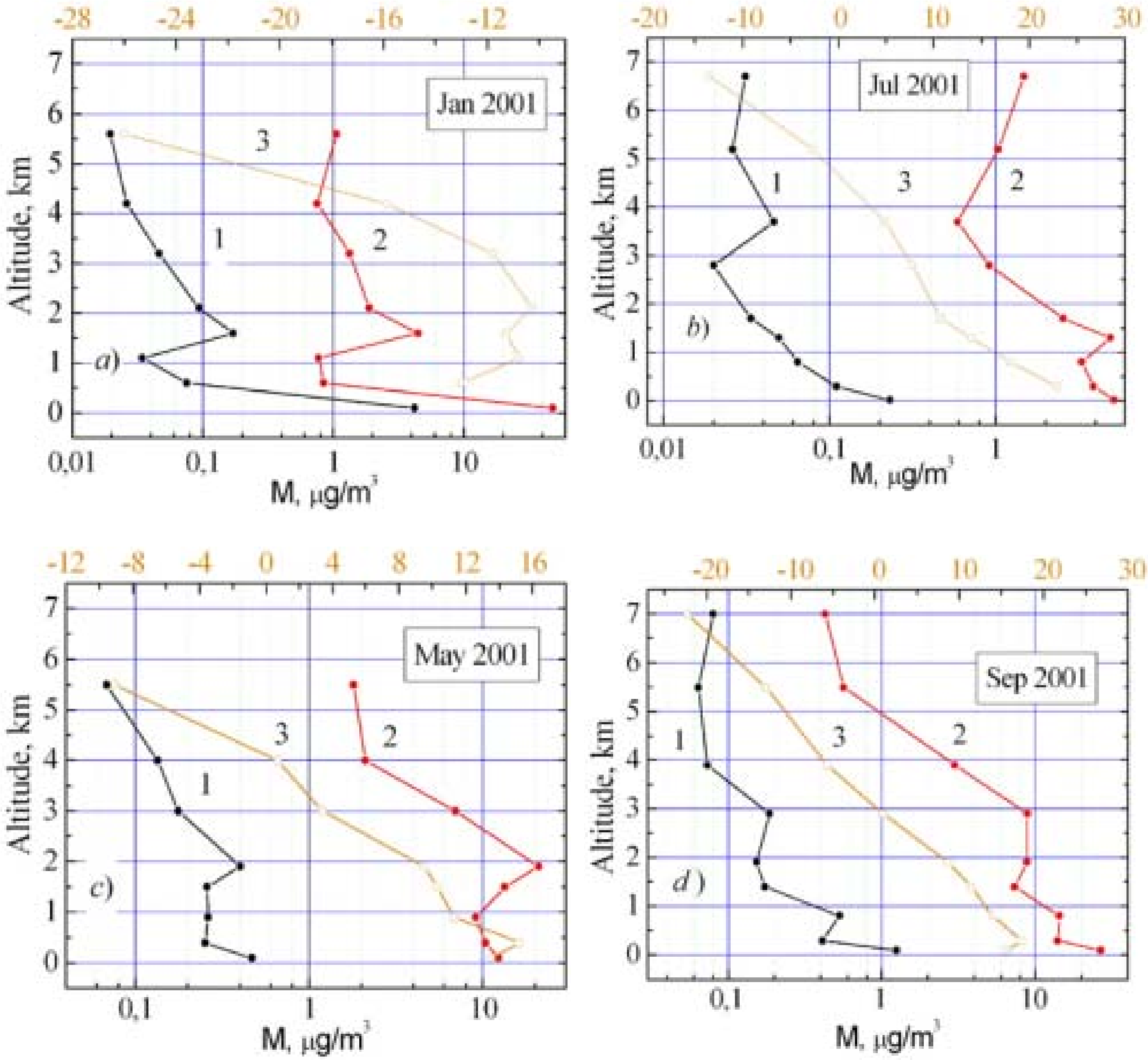

Figure 1. Vertical profiles of the mass concentrations of soot (1) and aerosol (2); and air temperature (3) in different months of 2001.

The greatest rate of variations of the soot concentration is observed in the under-inversion layer. The concentration decreases here from 3 to 5 μg/m^3 to 0.1 μg/m^3 (curve 1 in Figure 2). Above the inversion layer, the values M_s decreases to 0.01 to 0.02 μg/m^3. Rarity of temperature inversions during daytime in summer (Figures 1b, c, d), together with a seasonal decrease in the intensity of sources of soot lead to the decrease in soot concentration in the near-ground layer. Then the range of variations becomes narrower, and the vertical profile becomes smoother (curve 3 in Figure 2). The profiles with enhanced soot concentration in height ranging from 1 to 4 km are often observed in spring (curve 2).

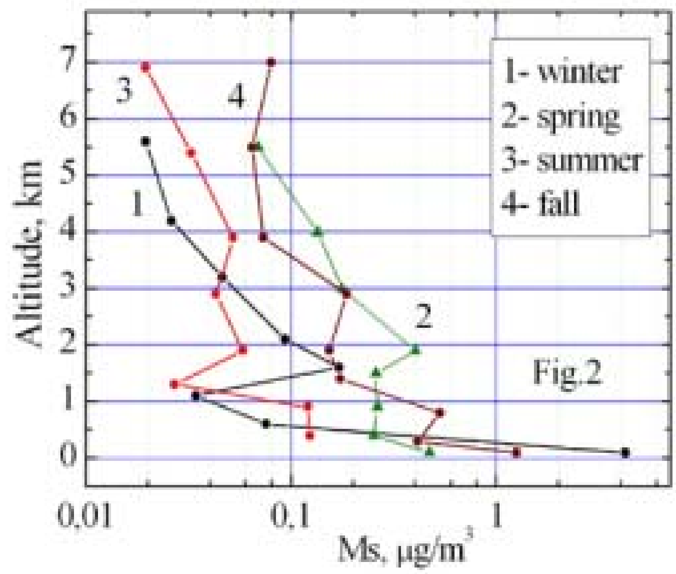

Figure 2. Vertical profiles of the mass concentration of soot in different seasons on example of the data during 2001–2002).

An analogous increase of the aerosol concentration in spring is explained by the effect of remote westward transfer of air mass (Panchenko et al. 1994). Profiles with enhanced concentrations of soot and aerosol caused by the smoke of forest fires were also observed in the warm season (Figure 3).

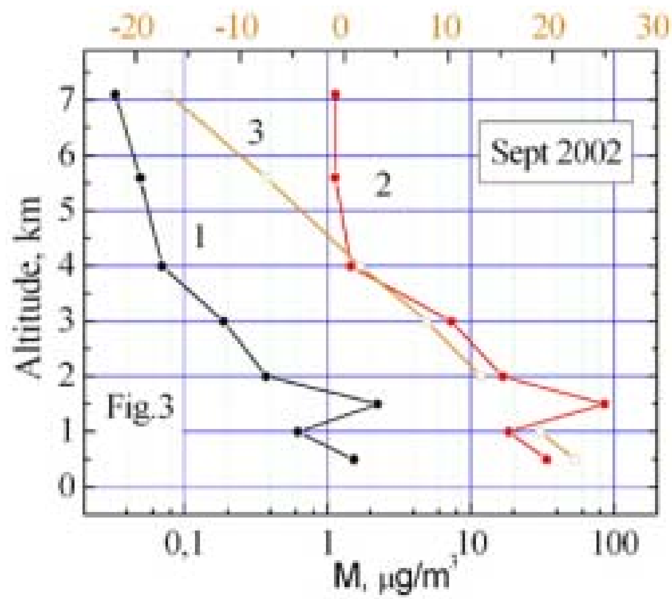

Figure 3. The effect of the smokes of forest fires on the vertical profiles of the mass concentrations of soot (1) and aerosol (2) in September 2002. Curve 3 shows air temperature.

Vertical profiles of P and ω also are characterized by significant seasonal variability and their peculiarities are qualitatively similar to the peculiarities of the profiles of the soot concentration. It follows from Eqs. (1-3) that P and ω are related by the inversely proportional dependence. So let us consider only the dynamics of albedo. Note that the decrease of P with height is characteristic of the profiles of the relative content of soot. The greatest variations of P are observed in the cold season. It decreases in the under-inversion layer from 0.08–0.15 to 0.04–0.07 and then to 0.01–0.02 at increased heights. The rate of variation in P is less in the warm period, and the range of variations narrows to 0.06-0.01.

Vertical profiles of the single-scattering albedo of dry aerosol in different seasons are shown in Figure 4. In general, the value ω increases as the height increases. This is caused by the decrease of P. The greatest dynamics of albedo are observed in fall and winter (Figures 4a, d). The value ω in winter varied from 0.75 to 0.98. The characteristic peculiarity of these profiles is that the greatest variations in ω are observed at heights up to 1 km (decrease to 0.9). The rate of variations of albedo above the inversion layer dramatically decreases (curves 1–3, 5, 7 in Figure 4a). Sometimes the decrease of albedo is observed at big heights. One such profile (curve 4) was obtained under conditions of multi-layer cloudiness at the heights of 3 to 7 km. The characteristic range of variations of albedo during the warm season is 0.9 to 0.98 (Figures 4b, c), and the dynamics of variation is smoothed. Principal seasonal differences in the single-scattering albedo are observed in the lower layer of the troposphere below 1 km. The shape of the vertical profile of ω and the ranges of its variations above 1 km weakly depend on the season.

Conclusion

The vertical profiles of the concentrations of aerosol and soot obtained in 1999–2002 in the troposphere of West Siberia up to 7 km are analyzed. The peculiarities of the dynamics of the single-scattering albedo and the relative content of soot are studied. The characteristic ranges of variations of the aerosol absorption characteristics are revealed, and the peculiarities of their seasonal variability are analyzed. The year-to-year stability of the vertical profiles and their seasonal dynamics is observed. Seasonal differences in the single scattering albedo and the relative content of soot are mainly observed in the lower layer of the troposphere below 1 km. Seasonal differences in the higher layers are weakly pronounced.

Acknowledgment

This work was supported by Atmospheric Radiation Measurement Contract No. 5012 and Russian Foundation for Basic Researches (Grant No. 03–05–64787).

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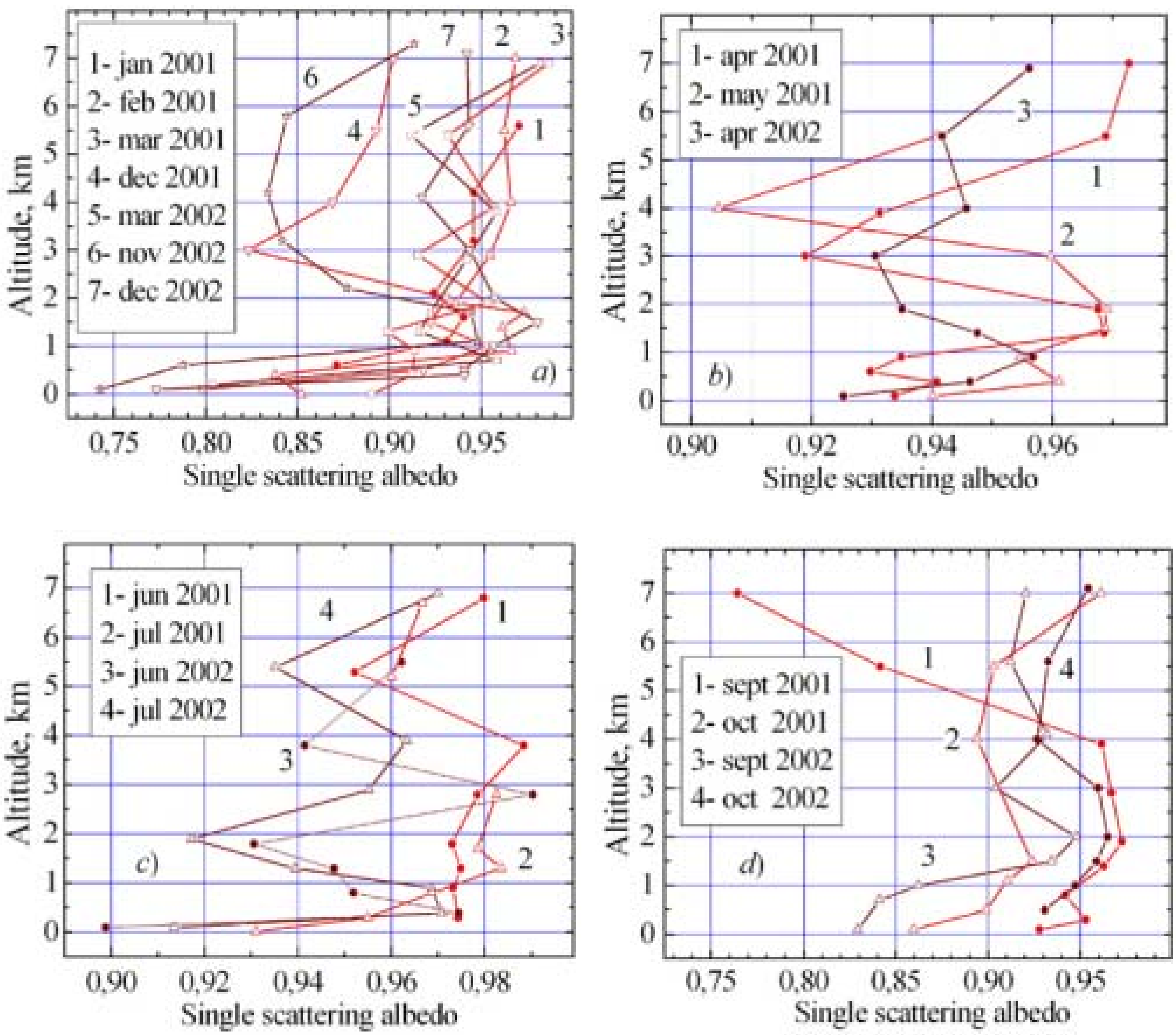

Figure 4. Vertical profiles of the single scattering albedo of the dry matter of submicron aerosol in different seasons 2001–2002: a) winter, b) spring, c) summer, and d) fall.

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