SEASONAL FACTORS OF THE VARIABILITY OF THE SUBMICRON AEROSOL CHARACTERISTIC. II. DIURNAL BEHAVIOR (VERTICAL PROFILE)

M.V. Panchenko and S.A. Terpugova

Institute of Atmospheric Optics,
Siberian Branch of the Russian Academy of Sciences, Tomsk
Received January 26, 1996

This paper continues the series of publications devoted to the analysis of seasonal features in the variability of submicron aerosol in the atmospheric layer up to 5 km over Western Siberia. In this paper we analyze the diurnal behavior of the vertical profile of aerosol scattering coefficient in different seasons. It is shown that in winter there are practically no regular transformations of the aerosol content during a day, however, the transport of aerosol layers by vertical motions is possible. Diurnal behavior of aerosol profile is the most pronounced in summer. Its characteristic features are the decrease of the total aerosol content in the layer under inversion (100–400 m) *during nighttime and the increase of the height of mixing layer and its filling with aerosol during daytime. We did not manage to reveal any diurnal behavior of aerosol in spring and fall from the bulk of data analyzed, because of a strong day-to-day variability of all atmospheric processes.*

Along with the variability of aerosol characteristics caused by the processes of synoptic scale,[1] the aerosol state is also subject to quick variations during a day.

Of the processes that govern the aerosol variability, the main physical processes determining diurnal behavior of the aerosol content and transformation of its optical properties are understood best of all.[2,3]

At the same time, when trying to quantitatively describe the diurnal behavior of aerosol characteristics under some specific conditions, the geophysical nature of aerosol is put in the forefront, and it is necessary to take into account all the variety of external synoptic, geophysical and local factors, prehistory of the specific air mass, the state of underlying surface, insolation, etc. As a result, at present the possibility of creating a theoretical (quantitative) model describing all the variety of factors and their relationships is too problematic even for describing the diurnal behavior. So it seems to be more realistic to introduce them into the model based on the data of experimental observations.

For these reasons, in this paper we try to describe the diurnal variability of the vertical profile of aerosol characteristics (up to 5 km) that manifests itself in the mean values of representative arrays of data that can make a basis for the empirical model of aerosol over the region under investigations.

In order to decrease the effect of seasonal variations in the formation of the vertical profiles of atmospheric parameters, the analysis was carried out for each season separately. The data arrays were divided into “morning,” “day,” “evening” and “night” depending on the time of sunrise and sunset at the latitude of the specific geographical site in each month.

According to the approach we develop, to reveal the role of various processes in the diurnal behavior, let us remove the effect of relative humidity (that has its own diurnal behavior) and consider the variability of dry aerosol (i.e. the processes explicitly connected with formation, generation and sink of particles from the atmosphere).

Vertical profiles of the scattering coefficient $\sigma_d(H)$ of the dry matter of aerosol particles for winter, spring and fall are shown in Fig. 1.

In winter no transformation of aerosol content is observed along the vertical direction during a day. Despite of the existence of diurnal behavior of temperature in the lower (< 1 km) atmospheric layers, the average temperature profile is inverse[8] and that suppresses the interlevel aerosol exchange.

In this case one can take into account only the relative humidity variations when modeling diurnal behavior of optical characteristics in the mixing layer. Only motions of aerosol layers are observed in some realizations in winter. They do not cause any noticeable variations of the aerosol optical thickness, but they are important for solving a number of practical problems such as optical detection and ranging, estimation of the background of natural and artificial sources, and so on.

0235-6880/96/06 464-05 $02.00

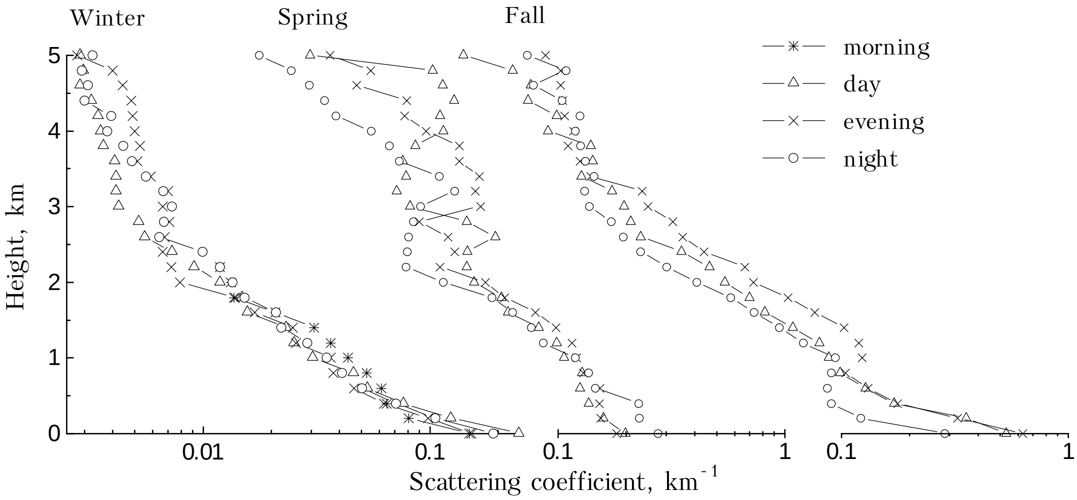


FIG. 1. Diurnal behavior of the vertical profile of the scattering coefficient of dry matter of aerosol particles in winter, spring and fall.

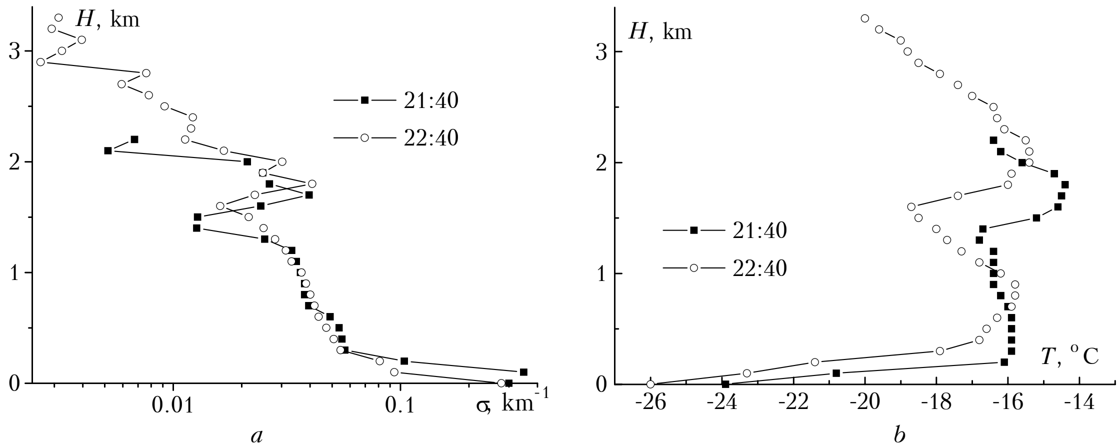


FIG. 2. Vertical profiles of aerosol scattering coefficient (a) and temperature (b) measured on January 14, 1986, over the town of Kolpashevo with the time interval of 1 hour.

Let us analyze such a dynamics by an example shown in Fig. 2 that presents the vertical profiles of the scattering coefficient $\sigma_d(H)$ and air temperature T measured over the town of Kolpashevo with 1-hour intervals on January 14, 1986, under anticyclonic conditions.[4]

As is seen from Fig. 2*a*, the aerosol layer, which was observed at the altitude H_1 = 1700 m, moved to the altitude H_2 = 1800 m during an hour.

It was shown earlier in the papers co-authored by B.D. Belan[4,5] that one can ignore many aerosol processes determining the variability of $\sigma_d(H)$ at the altitudes considered under the conditions analyzed. Measurements were performed under clear weather conditions, hence, there were no aerosol washing out by clouds and precipitation in the region under consideration. One can ignore the generation of new aerosol particles due to photochemical reactions during dark time. The rates of sedimentation and coagulation of the submicron particles are small, and it is not necessary to take into account this processes for the time interval between two soundings (~ 1 hour). Strong temperature inversions of the order of a several degrees were observed during the measurements at the altitudes up to 400 m and from 1.5 to 2 km, what is evidence of the fact that the turbulent exchange within the aerosol layer is significantly suppressed.

Thus, we should take into account only the horizontal and vertical motions of aerosol, what is expressed by the following equation:

$$\frac{\partial \sigma_d}{\partial t} = v\,\frac{\partial \sigma_d}{\partial x} + w\,\frac{\partial \sigma_d}{\partial z}\,, \qquad (1)$$

where v and w are the horizontal and vertical components of the wind velocity, respectively.

Analysis of the data on the scattering coefficient along the flight path (about 1000 km long) of the instrumented aircraft shows that we may ignore the term $v\dfrac{\partial\sigma_{\rm d}}{\partial x}$ in Eq. (1) because its value is about two orders of magnitude less than $w\dfrac{\partial\sigma_{\rm d}}{\partial z}$. As a result, in our case the aerosol transfer is mainly caused by regular vertical motions:

$$\frac{\partial\sigma_{\rm d}}{\partial t} = w\,\frac{\partial\sigma_{\rm d}}{\partial z}.. \qquad (2)$$

In order to check this conclusion obtained through certain simplifications, we have estimated the velocity of vertical motion w. To do this, we used the adiabatic method of calculation,[6] because the altitudes of measurements were between the principal isobaric surfaces. The profiles of temperature used for calculating w are shown in Fig. 2*b*.

The results of calculations gave the value of $w = 97$ m/hour that is in a good agreement with the data on the aerosol-optical and microstructural characteristics observed.

Thus, one can conclude that the effective transfer of aerosol by regular ascending and descending motions of air is possible in the case when the turbulence is suppressed.

Spring and fall are characterized by the enhanced dynamics of the day-to-day variability of all atmospheric processes (frequent changes of air mass, great number of days with precipitation, and so on). This makes the analysis difficult and significantly hides the peculiarities of the diurnal behavior. Principal features of the daily transformations of the vertical profile $\sigma_{\rm d}(H)$ in spring and fall are similar to the summer diurnal behavior, but the amplitude of variations is much less. Let us also note that in the spring bulk of data there are many data where the accumulation of aerosol was observed in the near-ground atmospheric layer during nighttime.

In summer the diurnal behavior of the aerosol vertical profile is most explicit. The average summer profile $\sigma_{\rm d}(H)$ is shown in Fig. 3.

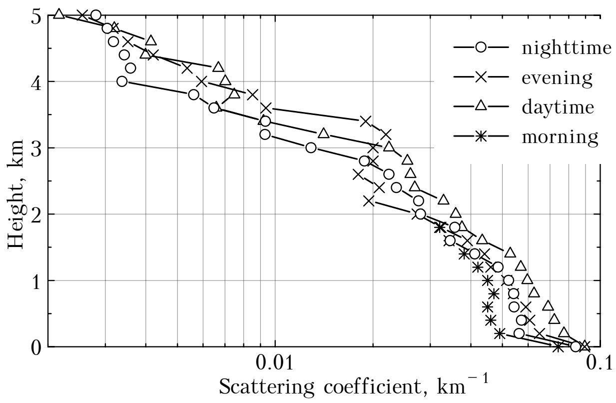


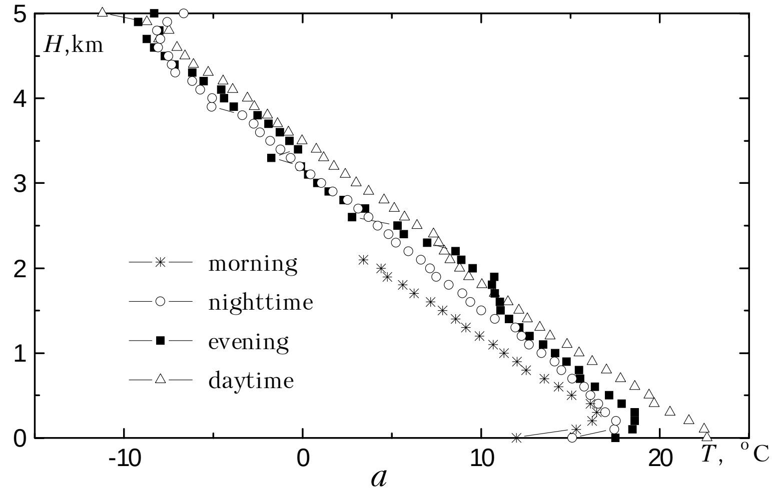
FIG. 3. Diurnal behavior of the vertical profile of the scattering coefficient of dry matter of aerosol particles in summer.

Before describing the principal processes of variability of the vertical profile of aerosol dry matter, it is necessary to assess the “qualityB[7] of the array of nephelometric data obtained. To do this, let us consider the result of measurements of meteorological parameters of the atmosphere and consider the diurnal behavior of the vertical profiles of temperature and specific humidity shown in Fig. 4. As is seen, diurnal behavior of the average profiles $\bar{T}$ and $\bar{Q}$ in the subarrays “night,B “dayB and “eveningB is in a good agreement with the existing conceptions and quantitatively well agrees with the mean climatic data for summer.[8] At the same time, temperature $\bar{T}(H)$ and, especially, specific humidity $\bar{Q}(H)$ in the “morningB array of data goes out of the general ensemble. It is clear that this occurs due a weak statistical representativity of the “morningB data. Therefore, this subarray is possible to be used only for the analysis of the vertical stratification, but not for quantitative estimations of the diurnal behavior of $\sigma_{\rm d}(H)$ analyzed.

In summer from the evening and during nighttime, the formation of the temperature inversion is usually observed. Its height can reach 400–500 m in the morning (see Fig. 4*a*). This leads to a decrease in the total aerosol content in the layer under the inversion (100–400 m). Minimum values in the morning are observed at the height ~ 300 m.

Because of the warming of the underlying surface and the atmosphere during a day, the height of the mixing layer increases, and it is filled with aerosol. In the evening (possibly, at the change of the sign of the radiation balance, as shown in Ref. 9) the aerosol emission from the near-ground layer stops, and the lower atmospheric layers (below $H \sim 1.5$ km on the average) loose aerosol. Above this layer up to $H \sim 3.5$ km some increase of the height of the mixing layer continues. The maximum of the scattering coefficient $\sigma_{\rm d}$ is well pronounced in the evening near its upper boundary. The estimates show that about 15–20 mg of aerosol substance per every square meter of the surface is emitted into the atmosphere during a summer day, that is in a good agreement with the results of Ref. 9. The analysis of seasonal mean data on $\sigma_{\rm d}(H)$ does not allow to reveal the day-to-day accumulation of aerosol and to accurately estimate what portion of aerosol particles come back to the underlying surface during a night, and what portion is emitted into the free atmosphere. According to our rough estimates, one can expect that about $0.5 \div 1$ mg/m^2 of dry aerosol matter is emitted into the free atmosphere under the so-called radiative type of weather.[2,3]

The mean rates of variation of the content of submicron aerosol $\dfrac{1}{M}\dfrac{\partial M}{\partial t}$ in different atmospheric layers during a day (per cent per hour) are presented in Table I.



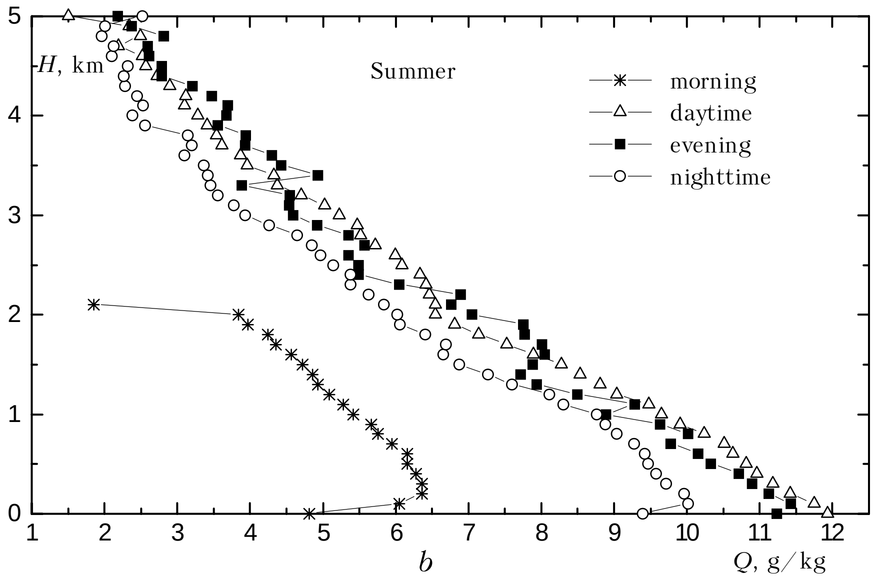


FIG. 4. Diurnal behavior of the vertical profile of temperature(a) and specific humidity (b) in summer.

TABLE I.

H, km	Night to day	Day to evening	Evening to night
0–0.6	+16%	−0.5%	−4%
0.6–3	+15%	0	−4%
3–3.5	+55%	+5%	−27%
3.5–5	+34%	+2%	−14%

It is clear that the averaged data we present here may give only an idea of the main tendencies in the processes occurring in the atmosphere. The aerosol dynamics is pronounced best of all in some particular cases under the radiative type of weather. Let us illustrate this by an example from the data obtained under anticyclonic conditions over the city of Novosibirsk with the time interval of ~4 hours and over the city of Tomsk with the time interval of ~1 hour.

Vertical profiles of changes in the scattering coefficient $\Delta\sigma_d(H)$, temperature ΔT and specific humidity ΔQ during the time between two soundings are shown in Fig. 5. It is seen from the figure that heating of practically the entire mixing layer occurs during the observation periods (near-ground layers over Tomsk are already cooled in the evening). Aerosol and water vapor increase simultaneously along all the profile, but the increases of these parameters are maximum at the altitude lower than the maximum heating. Moreover, as is obvious from the evening data (Tomsk), the splitting of the altitudes of the maxima in the parameters under consideration is well pronounced (T, Q and σ in the order of decreasing altitude).

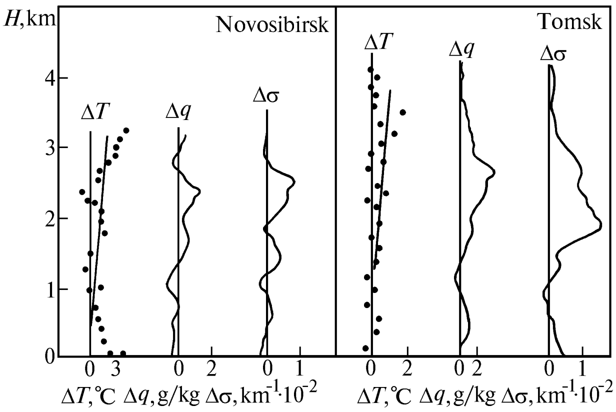


FIG. 5. Vertical profiles of changes in the scattering coefficient, temperature and specific humidity occurring during the time between two cycles of sounding during a summer day under anticyclonic conditions.

It is clear that the diurnal behavior of the aerosol dry matter is the result of a competition among the following processes: generation of new aerosol particles due to photochemical and chemical gas–to–particle transformations, lifting of "oldB aerosol (of the same origin) and the particles produced by the dispersion process from the underlying surface, motion of aerosol particles from the altitude of observations to the above layers or their income from the above layers due to the vertical flows and sedimentation of particles on the underlying surface.[3] It is also obvious that the intensity of each process under specific conditions depends on the whole complex of different factors such as insolation, the state of the underlying surface, etc. It follows therefrom, as well as from the airborne data we have analyzed, that the diurnal behavior should be most well pronounced in the near-ground atmospheric layer. We are planning to devote our next paper to the analysis of the data of near-ground measurements.

ACKNOWLEDGMENTS

This work was supported in part by the Russian Foundation of Fundamental Research (Grant No.95–05–14195).

REFERENCES

1. M.V. Panchenko and S.A. Terpugova, Atmos. Oceanic Opt. **8**, No. 12, 977–980 (1995).
2. V.N. Sidorov, G.I. Gorchakov, A.S. Emilenko and M.A. Sviridenkov, Izv. Akad. Nauk SSSR, Fiz. Atmos. Okeana **20**, No. 12, 1156–1164 (1984).
3. L.S. Ivlev, *Chemical Composition and Structure of Atmospheric Aerosols* (State University Publishing House, Leningrad, 1982), 370 pp.
4. B.D. Belan, G.O. Zadde, M.V. Panchenko et al., in: *Abstracts of Reports at the All–Union Conference on Transformation and Remote Transfer of Gaseous and Aerosol Admixtures in the Atmosphere*, Vilnius (1986), pp. 112–113.
5. B.D. Belan, M.V. Panchenko, T.M. Rasskazchikova and V.V. Pol'kin, in: *Abstracts of Reports at IX All–Union Symposium on Laser and Acoustic Sounding of the Atmosphere*, Tomsk (1987), Part 1, pp. 130–135.
6. S.P. Khromov, *Principles of Synoptic Meteorology* (Gidrometeoizdat, Leningrad, 1948), 700 pp.
7. M.V. Panchenko, S.A. Terpugova, A.G. Tumakov et al., Atmos. Oceanic Opt. **7**, No. 8, 546–551 (1994).
8. S.D. Koshinskii, L.I. Trifonova and Ts.A. Shver, eds., *Climate of Tomsk* (Gidrometeoizdat, Leningrad, 1982), 176 pp.
9. A.F. Kovalev, Trudy Inst. Eksp. Meteorol., No. 51, 83–87 (1990).