SEASONAL FACTORS OF THE VARIABILITY OF THE SUBMICRON AEROSOL CHARACTERISTICS. I. AIR MASSES

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Received July 3, 1995

This paper analyzes the effect of air masses of different types on the content of submicron aerosol particles in the lower 5 km *atmospheric layer over Western Siberia. It is shown that in winter and spring Arctic air masses above the mixing layer contain a larger aerosol amount than mid-latitude air masses. In summer, the aerosol content in Arctic air masses is less practically within the entire altitude range. The main processes determining such character of differences have been discussed. The aerosol amount accumulated in the Arctic in different seasons has been estimated.*

This paper continues a series of papers devoted to an analysis of nephelometric data obtained from onboard the aircraft-laboratory during 1986–1988. Measurement technique and results of analysis of the obtained data array have been described in detail in Ref. 1. It has been shown that seasonal ensembles of data obtained in Western Siberia adequately reflect the regularities of the variability of the parameters of the submicron aerosol that are characteristic of the region as a whole. In Ref. 2, the factors affecting the annual variability of the total content of the submicron aerosol in the troposphere of Western Siberia and the formation of its vertical stratification in different seasons were analyzed.

This and next papers are devoted to an analysis of seasonal differences in the aerosol vertical stratification.

Based on the data available in the scientific literature (see, for example, Ref. 3) and on our own experience, we can suppose that the main factors that essentially affect the variability of the aerosol characteristics for each season are the changes of air masses.

It follows from the general ideas[4] that in addition to the principal parameters considered in meteorology (temperature and air humidity), air masses may differ in the aerosol characteristics. Moreover, at the very beginning of regular observations meteorologists paid attention to the fact that air masses differ in air color and meteorological visibility range.[5] However, the data on aerosol parameters of different air masses, including only the data of optical measurements in the ground atmospheric layer[6] and optical spectral thickness of the atmosphere $\tau(\lambda)$ (Ref. 7), are insufficient for some applications.

The weather in Western Siberia is determined by air masses of two types, namely, by continental Arctic and continental mid-latitude ones.[8]

Using the approach developed by us, we analyze the scattering coefficients of the dry matter of aerosol particles σ_d, because it is the parameter that characterizes the total content of particles in the air mass and is connected with its prehistory, nature, and intensity of aerosol sources.[2]

Average vertical profiles of σ_d in the continental mid-latitude (*a*) and the Arctic (*b*) air masses for different seasons are shown in Fig. 1. As is seen, behavior of the vertical profile and aerosol loading in each air mass in going from season to season shows the features that have been already discussed in Ref. 7 for general seasonal data ensembles.

A more interesting problem of identification of discriminating parameters of air mass for creation of dynamical aerosol models is a search for differences between air masses for one season. Leaving aside evident differences in the height of the mixing layer connected with a thermal regime of air masses of two types[8] (which have been discussed in ample detail in Ref. 7), we focus our attention on an analysis of the differences in aerosol content at different altitudes.

The results of comparison of the vertical profile of σ_d in mid-latitude and Arctic air masses are shown in Fig. 2 for each season. The altitude ranges where the profiles are reliably different by the Student criterion with probability >0.9 are hatched. As is seen, the generally accepted idea that Arctic air masses bring the clear transparent air into the region of observations is right only for the summer conditions (Fig. 2*c*) when the aerosol loading of mid-latitude air mass is greater than that of the Arctic one almost at all altitudes. In fall (Fig. 2*d*) there are no reliable differences between Arctic and mid-latitude air masses.

In winter (Fig. 2*a*) at altitudes above ~ 500 m Arctic air contains, on average, more aerosol particles than mid-latitude air masses.

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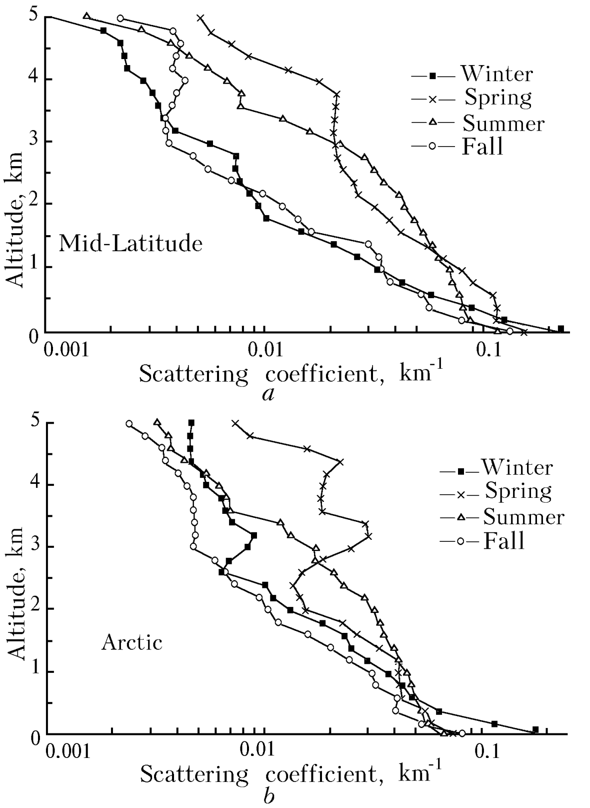

FIG. 1. Average profiles of the scattering coefficient of the dry matter of the aerosol in continental mid-latitude (a) and Arctic (b) air masses for different seasons.

In spring at altitudes above 2.5 km the differences in characteristic of the winter conditions retain, whereas in the lower 1 km layer the character of differences becomes similar to the summer ones.

The facts we revealed for the winter and spring data arrays are, at first sight, unexpected, so let us consider them in more detail.

Systematic study of the Arctic aerosol has been started since 1972, though the phenomenon of "arctic hazeB[9–11] has been observed already in the 50's. Now the widespread attention of specialists is called to the aerosol problems of Arctic air. The papers devoted to these problems are generalized in Refs. 12 and 13.

Based on the data of these investigations, the main reasons for winter and spring accumulation of the aerosol in Arctic air are clear. From fall till spring, as the ground surface is cooled, the temperature difference between the pole and the equator (ocean and continent) increases. That leads to intensification of meridian component of air flow circulation in the northern hemisphere. And on the contrary, as the atmosphere is heated from spring till summer, principal direction of the motion of air flows acquires zonal character.[14] It is clearly seen from the map of mean pressure and wind field distributions in January and July[15] drawn in Fig. 3. It is seen that in winter the mid-latitude air passing over industrial areas, being loaded by aerosol during its motion, penetrates the Arctic region. The state of the atmosphere and underlying surface in the cold season favors aerosol accumulation.[13] Then the Arctic air mass enriched with the aerosol comes to Western Siberia (let us remind that 2/3 of time the region under investigation is under the impact of mid-latitude air masses, and 1/3 - of Arctic air masses).

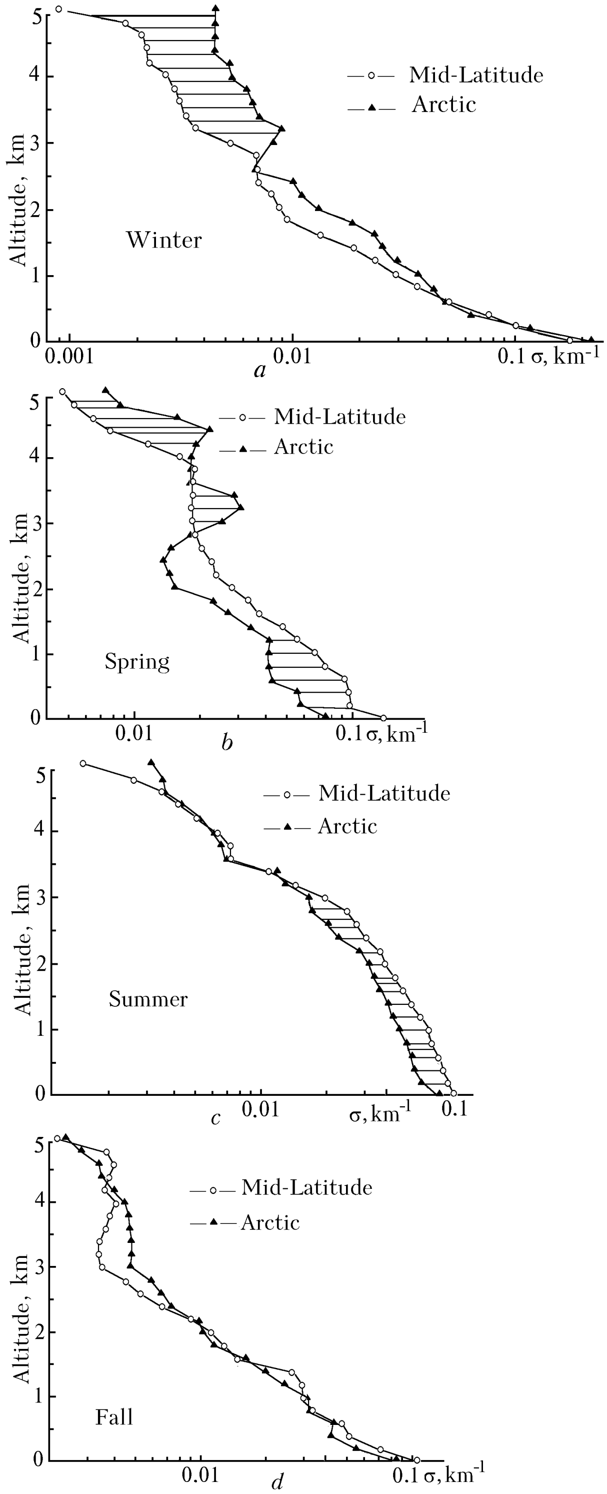

FIG. 2. Comparison of the vertical profiles of σ_d in mid-latitude and Arctic air masses for each season.

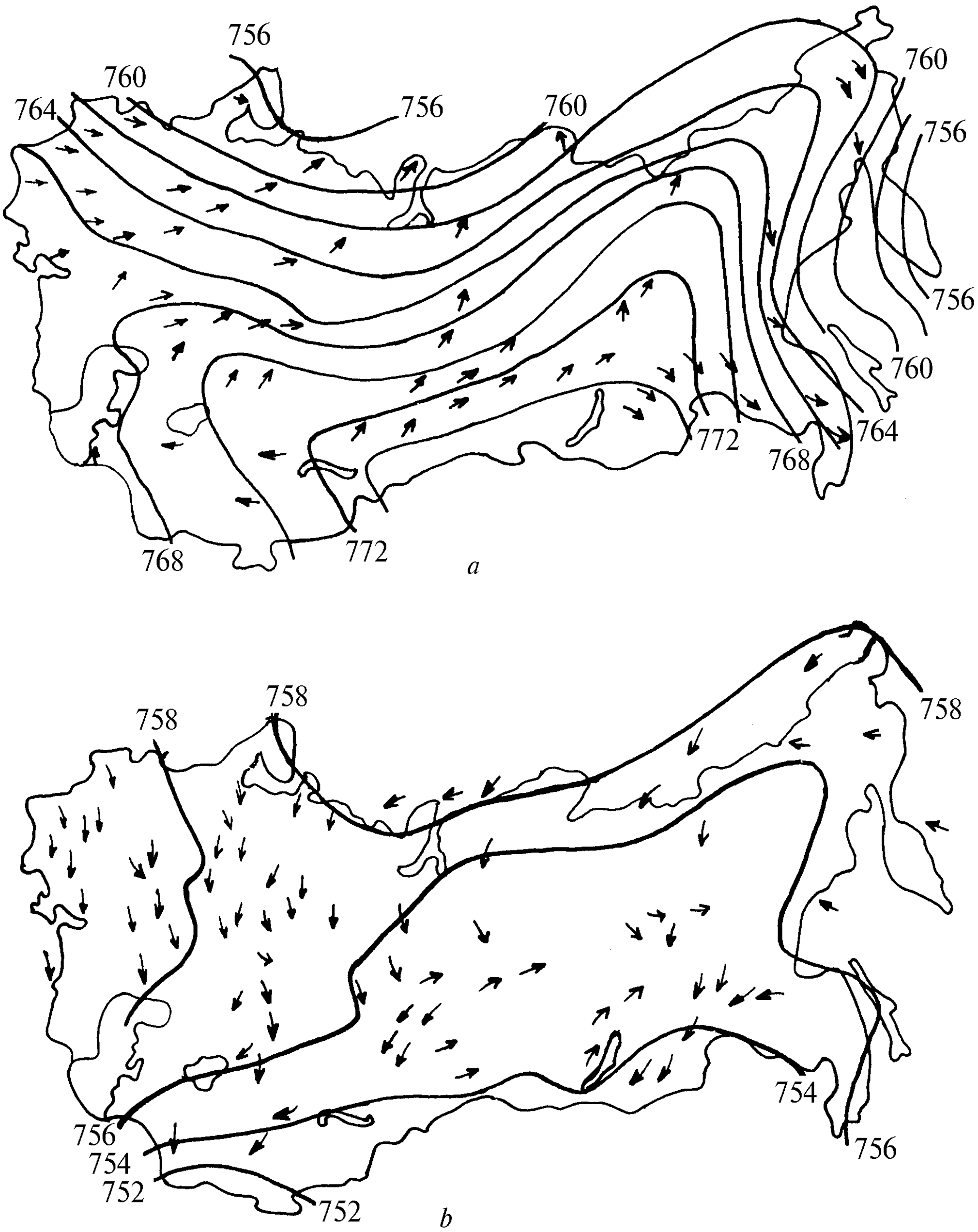

FIG. 3. Average pressure and wind fields[15] in January (a) and July (b).

The latitudinal orientation of Arctic and polar fronts in winter and spring also favors the access of mid-latitude air to the Arctic, because the fronts are zones of precipitation and intensive mixing,[13] and hence they are impenetrable for the aerosol from the south. As the underlying surface and the atmosphere are cooled, these fronts are shifted southwards and cover larger area over Northern America and Eurasia. In spring and summer the inverse pattern is observed.

An additional factor is that the intensification of anthropogenic emissions of the aerosol in the cold season primarily causes its enhanced content in industrial regions of the northern hemisphere.

As is seen, there is a complex of objective processes that favor the access and accumulation of the aerosol in Arctic air in the cold season, and contrary impede its access in the warm season.

This is the reason why we observe such a seasonal behavior of the principal differences between vertical profiles $\sigma_d(H)$ in mid-latitude and Arctic air masses over Western Siberia.

It is seen that in winter and spring practically at all altitudes above the mixing layer height (above 500 m in winter and above 2000 m in spring[2]) Arctic air masses are more loaded with the aerosol than the mid-latitude ones. In spring, as everything is heated, the effect of the underlying surface as an aerosol source is enhanced, and the height of the mixing layer increases, which strongly favors the increase of the content of aerosol particles in the lower atmospheric layers (i.e., the processes are analogous to the summer ones). So the differences between $\sigma_d(H)$ in different air masses acquire the summer character.

In summer, entrainment of continental air into the Arctic is less probable, and so the Arctic air masses contain fewer aerosol particles at altitudes up to 5 km than mid-latitude air masses. In fall, when it often rains and the underlying surface is wet, there are no differences between Arctic and mid-latitude air masses.

The revealed seasonal regularities of aerosol loading of Arctic air masses enable us to estimate the annual behavior of submicron aerosol accumulation in the Arctic atmosphere. It can be estimated by two methods.

1. First, we consider the fall vertical profile $\sigma_d(H)$ as a background one. Then we subtract it from $\sigma_d(H)$ for other seasons in the altitude range where the differences are reliable by the Student criterion. Using the relation between σ_d and the specific volume of aerosol particles and setting their density $\rho = 2$ g/cm^3, we estimate the mass concentration of the submicron aerosol for each season. Such estimates yield the values of the increase of the mass concentration ΔM given below.

Season	Altitude range, km	ΔM, μg/m^3
Winter	2–5	0.7
Spring	2–5	5.7
Summer	3.5–5	0.47

2. The second method is analogous to the first one, but the difference is calculated between $\sigma_d(H)$ of Arctic and mid-latitude air masses for each season. With this approach we have the estimates given below.

Season	Altitude range, km	ΔM, μg/m^3
Winter	3–5	2
Spring	4.5–5	3.3

It is seen that the estimates of the mass concentration obtained by two methods give close values and indicate that the maximum aerosol loading of Arctic air occurs in spring. Our estimates of ΔM are very close to the mass concentration values observed in the Arctic region in this period.[13]

In conclusion it should be emphasized that the reliable differences we revealed in the vertical profile $\sigma_d(H)$ in different air masses over the region under investigation show that taking into account the type of air mass in the regional models will improve the quality of prediction of the aerosol characteristics.

ACKNOWLEDGMENT

The work was supported in part by Russian Foundation of Fundamental Research (Grant No. 95-05-14195).

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