Diurnal Behavior of Aerosol and Water Vapor in Summer

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Introduction

The strong effect of the diurnal rhythm of income of the solar radiation on the dynamics of meteorological and aerosol characteristics is well known. The important consequence is the feedback, i.e., the diurnal behavior of transparency results in the change of the radiation income.

In this paper, we analyze the diurnal variations of the characteristics of atmospheric aerosol and water vapor in Western Siberia in summer. The analysis is based on the long-term experimental data obtained from onboard an aircraft (vertical profile of the scattering coefficient and absolute humidity of air) and under ground-based conditions (aerosol optical thickness and columnar water vapor).

Diurnal Behavior of Aerosol Scattering Coefficient

It is clear that the diurnal behavior of the aerosol optical characteristics is caused by two principal processes. The first is the change of the quantity of particles in different layers of the atmosphere under the effect of aerosol sources, and the second is the diurnal behavior of relative humidity. Therefore, it is possible to perform a more detailed analysis of these processes by considering the variability of "dry" aerosol and aerosol "in situ" separately.

Figure 1 presents the diurnal behavior of the vertical profile of the scattering coefficient of the dry matter of submicron aerosol particles in summer. From the evening and during the nighttime, the formation of the temperature inversion is usually observed. Its height can reach 400 m to 500 m in the morning. This leads to a decrease in the total aerosol content in the layer under the inversion (100 m to 400 m). Minimum values in the morning are observed at the height of ~300 m.

Because of the warming of the underlying surface and the atmosphere during the day, the height of the mixing layer increases, and it is filled with aerosol. In the evening, at the change of the sign of the radiation balance, the aerosol emission from the near-ground layer stops, and the lower atmospheric layers (below H ~ 1.5 km) lose aerosol. Above this layer, up to H ~ 3.5 km, some increase of the height of the mixing layer continues. The maximum of the scattering coefficient σ_d is well pronounced in the evening near its upper boundary.

The estimates show that about 15 mg to 20 mg of aerosol substance per every square meter of the surface is emitted into the atmosphere during a summer day. The analysis of seasonal mean data on $\sigma_d(H)$ does not allow the day-to-day accumulation of aerosol to be revealed or to accurately estimate

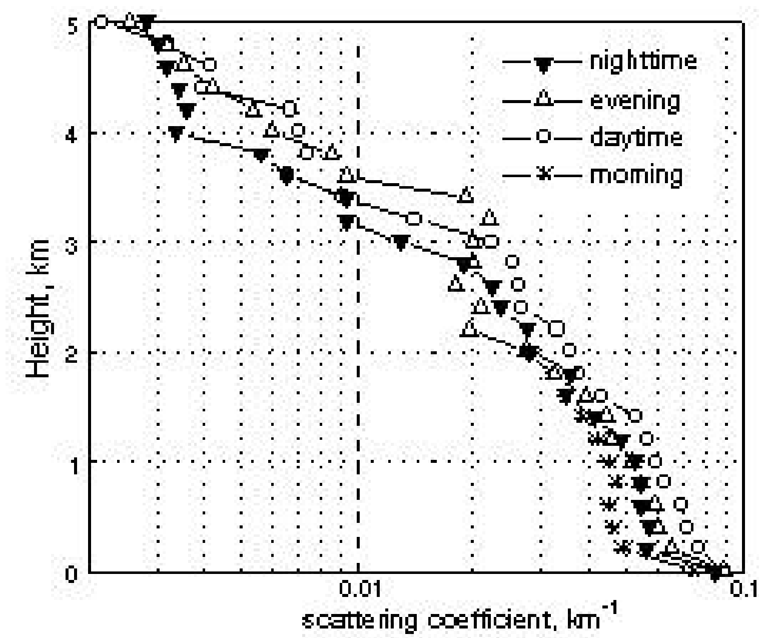

Figure 1. Diurnal behavior of the vertical profile of the scattering coefficient of dry matter of aerosol particles in summer.

what portion of aerosol particles come back to the underlying surface during the night, and what portion is emitted into the free atmosphere. According to our rough estimates, one can expect that about 0.5 mg/m^2 to 1 mg/m^2 of dry aerosol matter is emitted into the free atmosphere under the so-called radiative type of weather.

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

Table 1. Mean rates of submicron aerosol in different atmospheric layers.

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%

Aerosol Optical Thickness of the Atmosphere

As for the principal characteristics of the total transparency, the aerosol optical thickness and the columnar water vapor, one should expect the hidden display of the diurnal behavior due to the difference in the conditions at different altitudes and the complicated (sometimes inverse) effect of various factors. The mechanisms of convection, turbulence, transformation of aerosol properties (or the condensation of water vapor) during the vertical motion additionally complicate the final result. Also, the regular component is distorted due to the synoptic oscillations of the atmospheric transparency (the change of air mass). So one can select the diurnal behavior only if you average the data over the positive period and then normalize it to the daily mean values. (For example, aerosol optical thickness in the form $\tau_n(t)=\tau^h/\tau^d$).

It was shown earlier that there is some diurnal behavior of aerosol optical thickness in the visible wavelength range under the average summer conditions in Western Siberia. In this paper, we analyze the peculiarities of the transparency variations in some wavelength ranges on the basis of longer observations. The results of the calculation of $\tau_n(t)$ and the Angstrom parameter α, which characterizes the spectral behavior, are shown in Figure 2. It is seen in the figure that three periods can be selected in the diurnal behavior of τ. The first one is in the morning until 10 a.m. to 11 a.m. and it is characterized

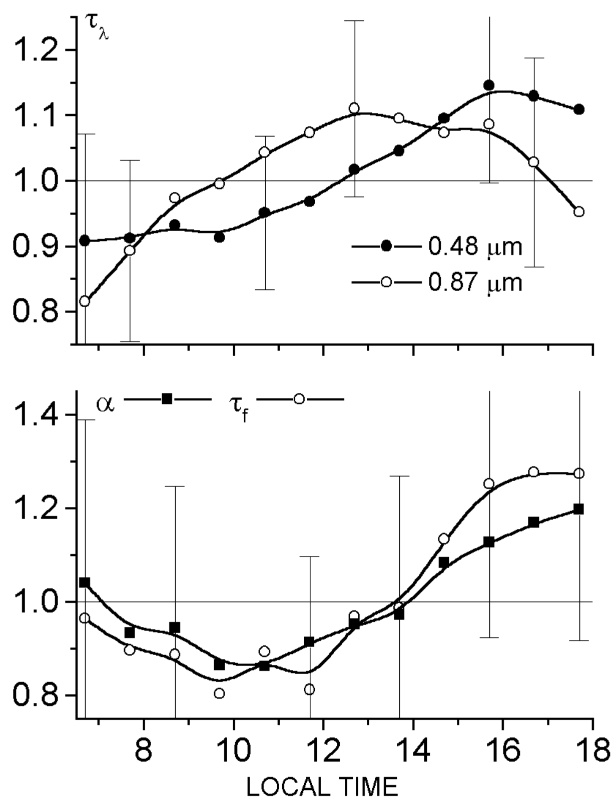

Figure 2. Diurnal behavior of aerosol optical thickness τ_λ normalized to the daily mean value, and Angstrom parameter α.

by the small values τ^h and hourly variations. The increase of turbidity by approximately 3% per hour is observed during a day until 4 p.m.; and the decrease of τ^h down to the mean value τ^d is observed in the evening. The statistical significance of the extremes in diurnal behavior of τ and other parameters was estimated by the confidence probabilities P_S calculated upon the student criterion.

The analogous peculiarities of $\tau_n(t)$ are also revealed at other wavelengths, but the maximum in the infrared (IR) range (0.87 μm) is observed earlier and is better pronounced. The consequence of spectral differences is the diurnal behavior of the parameter α, which is minimum at noon. Such a behavior of τ and α is explained by the diurnal transformation of fine and coarse aerosols. The change of $\tau_{0.87}(t)$ occurs mainly because of the effect of emission of coarse particles from the surface that is observed at the increase of temperature during the day (development of turbulence and convection). The change of $\tau_{0.48}(t)$ is caused primarily by the fine fraction which occurs under the effect of the contrary process of aerosol generation and "drying" of aerosols as the relative humidity decreases. As our investigations of condensation activity of atmospheric aerosol and its temporal behavior show, the change of this parameter can significantly affect the variability of optical characteristics. The diurnal behavior of the "fine" component of the aerosol optical thickness $\tau_f(t) = \tau_{0.48} - \tau_{0.87}$ is shown in Figure 2 separately. The effect of humidity becomes weaker in the afternoon, and the contribution of the fine particles is "reconstructed." In the evening, while the convection becomes weaker, the filling of the atmosphere by aerosol stops, and the sink process becomes prevalent. Sedimentation of the coarse particles is more intensive, this causes the increase of the parameter α in the evening.

To estimate the possible effect of the local (urban) conditions, we analyzed the data on aerosol optical thickness obtained over a forest 60 km from the city. Comparison of the data obtained at two sites show that in spite of some differences (appearing because of the difference in time and duration of observations performed in two regions), the general manner of the diurnal behavior is the same.

Columnar Water Vapor of the Atmosphere

The problem of the diurnal behavior of columnar water vapor W(t) is not studied well due to the insufficient regularity of aerological observations (2 to 4 sensing per day). Application of the differential method of measuring the spectral transparency of the atmosphere (in the region of the transparency band of 0.94 μm) made it possible to analyze the peculiarities of the columnar water vapor variations. Two maxima are observed in the diurnal behavior W(t) at 8 a.m. and 4 p.m. (Figure 3). The first maximum shows the fact of "switching on" the mechanism of evaporation after the sunrise and filling of the atmosphere with water vapor. The minimum W(t) before noon is related with the process of condensation of water vapor while it is transported to the upper layers and the formation of clouds. The presence of the second maximum characterizes the continuation of the effect of the daytime evaporation and its decrease in the evening.

One can add here the peculiarity of the diurnal variation of the height of homogeneous layer $H_0 = W/a_0$. This value characterizes the peculiarities of the vertical distribution of humidity a(h). Let us note that one can approximately assume $H_0 = 1/\beta$, where β is the index of the smoothed exponential profile of humidity in the troposphere. In the morning the process of evaporation passes ahead of vapor spreading

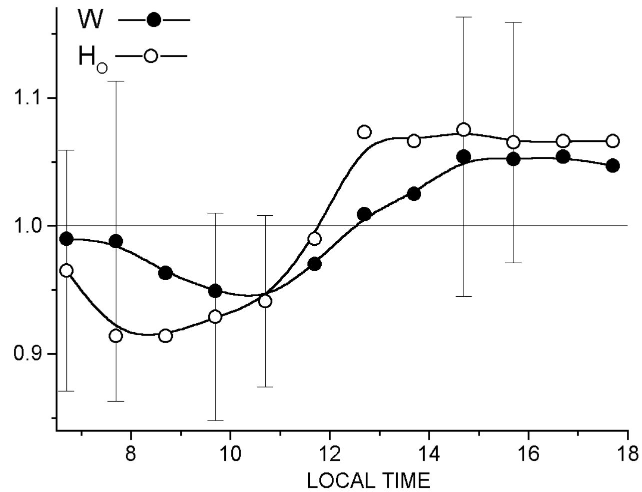

Figure 3. Diurnal behavior of columnar water vapor (W) and the height of the homogeneous atmosphere (H_0).

in the atmosphere. So, in comparison with the nighttime conditions, the profile a(h) becomes sharper, and the mean value of the height H_0 is about 1.7 km to 1.8 km. Moreover, the raise of vapor is not accompanied by smoothing of the profile (increase of H_0), because the process of condensation and expense of moisture for the formation of clouds occur. The height H_0 reaches its "daytime" level only near noon ($H_0 \geq 2$ km). Thus, one can select two periods in the diurnal behavior of the vertical distribution of water vapor: $\beta \approx 0.56$ km^{-1} before noon and $\beta \approx 0.49$ km^{-1} in the afternoon.

Total Transparency

The peculiarities of the diurnal behavior of $\tau_\lambda(t)$ and W(t) cause the behavior of the total transparency of the atmosphere T_Σ (Figure 4). Transparency was calculated by the LOWTRAN-7 model for the 0.35 μm to 3.5 μm wavelength range and "optical airmass" m = 2 in the form:

$$T_\Sigma = \frac{\int S_{0\lambda} T_\lambda^A T_\lambda^W T_\lambda^R d\lambda}{\int S_{0\lambda} d\lambda}$$

where $S_{0\lambda}$ is the spectral solar constant, T_λ^A

and T_λ^W are the aerosol and water vapor components of transparency, respectively, and T_λ^R is the constant component of the Rayleigh scattering and absorption by other gases. The calculations show that the diurnal behavior of transparency is principally determined by the aerosol component $\tau_\lambda(t)$ and has a minimum near 4 p.m.

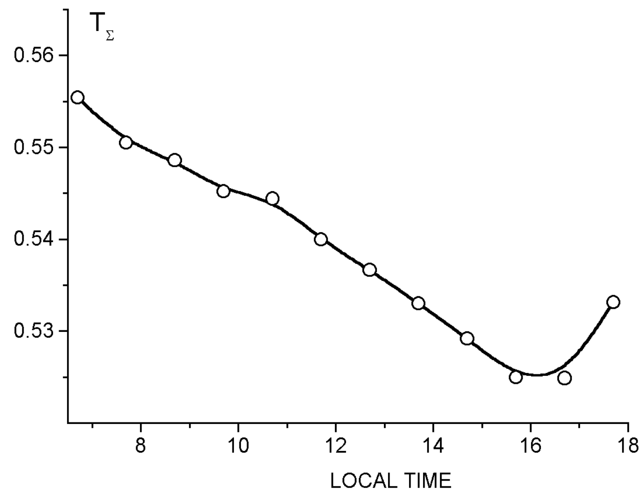

Figure 4. Diurnal behavior of the total atmospheric transparency.

Acknowledgments

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