Investigation of relations between optical and electric characteristics of the surface atmosphere

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The results of simultaneous investigations into variations of the optical aerosol extinction coefficients, atmospheric electric field strength, and UV flux (280–320 nm) in June 2004 near Tomsk are considered. The effect of the antiphase dynamics of the aerosol extinction coefficient at $\lambda = 0.45$ μm and the electric field strength, observed for 10 days, is discussed. It is shown that this effect coincides in time with minimum of sunspots. A physical hypothesis taking into account all the observed experimental facts is proposed to explain this phenomenon. The temporal dynamics of the coefficient $\alpha(0.45)$ and the UV flux in June 1–24 is analyzed. The presence of an in-phase low-frequency oscillation component with close periods in the both cases suggests the existence of a weak, but still noticeable influence of the solar UV radiation on optical characteristics of aerosol in the lower troposphere.

Introduction

It is well known now that the atmospheric aerosol (both submicron-sized and coarse) is an important climate-forming factor, and this circumstance is taken into account in all modern climate models.[1–3] Moreover, Ref. 3 presents model estimates, according to which the mean global radiative forcing due to aerosol is close to that due to greenhouse gases. This circumstance and a deficit of available data about the extremely variable properties of aerosol determine the urgency and importance of experimental optical-microphysical investigations of aerosol both in the upper atmosphere and surface layer.

Optical characteristics of aerosol are known to depend on many factors. In particular, the value and spectral structure of the aerosol extinction coefficient $\alpha(\lambda)$ in the visible and IR spectral regions in atmospheric hazes significantly depend on the geographic region, season, and time of day. However, within the same season, the diurnal dynamics of $\alpha(\lambda)$ can vary markedly, thus indicating the manifestation of some other hidden factors, which can contribute significantly to variability of optical properties of aerosol under certain conditions.

The study of such factors in the atmospheric surface layer is of undoubted interest. According to the conclusions of Refs. 4–7, these factors may include: *atmospheric electric field strength, intensity of the UV radiation flux, and solar activity.*

These factors are selected on the following counts. If we assume that a significant part of the submicron aerosol in atmosphere is formed as a result of aging of the fine photochemical aerosol, produced from the gas phase under the effect of the UV radiation,[4] then the variations of the UV flux due to change in the number of sunspots[5] can lead to changes in the concentration of the submicron-sized aerosol and the corresponding changes of the aerosol extinction in the shortwave spectral range. In its turn, the increase of the fine aerosol is mostly caused by condensation of the supersaturated water vapor on condensation nuclei, that is, on particles, whose size is greater than some critical value. The appearance of an elementary charge on such a neutral particle leads to decrease in the critical size of particles, water vapor can condense on, and, consequently, to increase of the number of optically active particles.[6]

In addition, the presence of a charge on particles increases the efficiency of coagulation processes (especially, for oppositely charged particles). Aerosol particles can be charged as a result of the diffusion sink of light ions upon their motion in the atmospheric electric field.[7] This allows the atmospheric electricity to be considered as one of the factors affecting optical properties of atmospheric aerosol.

The first experimental results of investigations in this field were published[8] in 2002. In particular, it was shown that in a fine day the distribution function of the fine aerosol transforms with the change in the UV flux intensity. This conclusion was drawn based on analysis of temporal dynamics of the size spectrum and number density of fine particles in the period from 10:00 to 16:00 LT at one of the measurement days. It turned out that if at 10 LT the aerosol fraction with the maximum (in diameter) within 12–13 nm and the number density of about 4000 cm^{-3} was observed in the region of measurements, then the maximum of the distribution gradually shifted to the 20 nm range at 12 LT and to

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35–40 nm by 16 LT. The maximal particle number density (8000–9000 cm^{-3}) was observed from 11 to 13 LT and fell on the rising branch of the diurnal behavior of the UV flux intensity. The regularities revealed in the daytime dynamics of the size spectrum and the number density of fine particles under fine weather conditions unambiguously evidence the influence of the UV solar radiation on the process of atmospheric aerosol generation.

In addition, some unusual regularity has been revealed, which consists in the fact that at small amount of clouds the electric field strength decreases with increase of the UV flux ($\lambda = 0.353$ μm) at the correlation coefficient $\rho = -0.67$. Principally, this means that, with the increase of the UV flux, the number of light ions, being main contributors to the air conductivity,[7] in the lower atmosphere increases, which leads to decrease of the field strength. Note that the UV radiation at $\lambda > 0.3$ μm cannot directly generate the ionization in a molecular medium, because the ionization potentials of the major and trace atmospheric molecules lie in the shorter-wave UV region, whose radiation is absorbed by ozone and thus does not reach the Earth's surface. To explain this fact, we assume that the ionization potential of molecules decreases during a day under the effect of the UV radiation in the presence of organic pollutants in the troposphere, and light nanometer-sized ions are generated.

This paper continues the investigations, which were reported in Ref. 8.

Note that such investigations can be also of interest for the study of physical causes of the influence of solar activity variations on the Earth weather and climate, which are under intensive discussion during the last 20–30 years.[9–11]

Description of the experiment

This work was carried out in June 1–24 of 2004 at the eastern outskirts of Tomsk. The combined field investigations included the round-the-clock synchronous measurements of spectral aerosol extinction coefficients in surface hazes (in the 0.44–12 μm region), the atmospheric electric field strength, the UV-B solar radiation flux intensity, and the disperse composition and number density of aerosol particles (radius > 0.2 μm).

The atmospheric transmittance was measured with the interval of 2 h with a two-channel automated filter photometer,[10] operating in the wavelength range $\lambda = 0.44$–12 μm in 22 spectral regions. The photometer operated by a reflection scheme with a baseline of ~ 415 m (the total length of the measurement path was ~ 830 m). A mirror cat's eye with main mirror of 500 mm in diameter and a focal length of 1500 mm was used as a reflector at the path end. One measurement cycle lasted 30 min with 20-s averaging of signals at every wavelength. For one cycle, six atmospheric transmission spectra were recorded and then averaged during the processing (if no pronounced temporal trend of this parameter was observed).

The obtained atmospheric transmission spectra were used to calculate the spectral aerosol extinction coefficients $\alpha(\lambda)$ by the technique described in Ref. 10. A random error in determination of the extinction coefficient at a single measurement was 0.02–0.03 km^{-1}.

The field strength E was measured every minute with a Pole-2 stationary electrostatic fluxmeter. The net UV-B flux ($\lambda = 0.28$–0.32 μm) was measured with a serial UVB-1 pyranometer (manufactured in USA) at the TOR station of the Institute of Atmospheric Optics. The measurements were carried out round-the-clock with the 1 h interval. The disperse composition and the number density of aerosol particles in atmosphere were measured with an AZ-5 automatic optical aerosol counter, also located at the TOR station and operating with the 1 h interval. Unfortunately, the diffusion spectrometer of nanometer-sized particles did not operate during these measurements because of some technical problems.

As a result, we have compiled a combined data array, containing 150 joint averaged realizations.

Experimental results

Figure 1*a* shows temporal behavior of $\alpha(0.45)$ and the atmospheric electric field strength for the whole period of measurements. It can be seen that in the range $N = 10$–95, corresponding to the time period of about June 2–12, $\alpha(0.45)$ and E vary in antiphase: the electric field strength decreases with increase of atmospheric aerosol turbidity and *vice versa*. Further, in the range $N = 95$–150, this regularity is already absent.

The normalized coefficient of correlation between $\alpha(0.45)$ and E variations, $\rho = -0.70$, shown in Fig. 1*b*, can serve as a quantitative estimate of negative correlation between these parameters. It should be emphasized that the obtained negative correlation of the aerosol turbidity of the atmosphere and the electric field strength contradicts the well-known electrooptical relation,[11] following which the field strength increases with the increase of the atmospheric turbidity under conditions of fine weather due to absorption of a fraction of light ions on aerosol particles.

To explain the revealed contradiction, we have analyzed thoroughly the measurement conditions, including solar activity in the period under consideration. As a quantitative characteristic of solar activity, we took the number of sunspots.[12] Figure 1*c* shows the temporal behavior of the sunspot number for June 2004. As can be seen, just in the period of June 2–12, when a pronounced negative correlation was observed between $\alpha(0.45)$ and E in our measurements, the sunspot number was minimal, that is, it was the period of a calm sun. This fact is very interesting, and it is still to be interpreted. The duration of the event allows us to hope that it is not a simple coincidence.

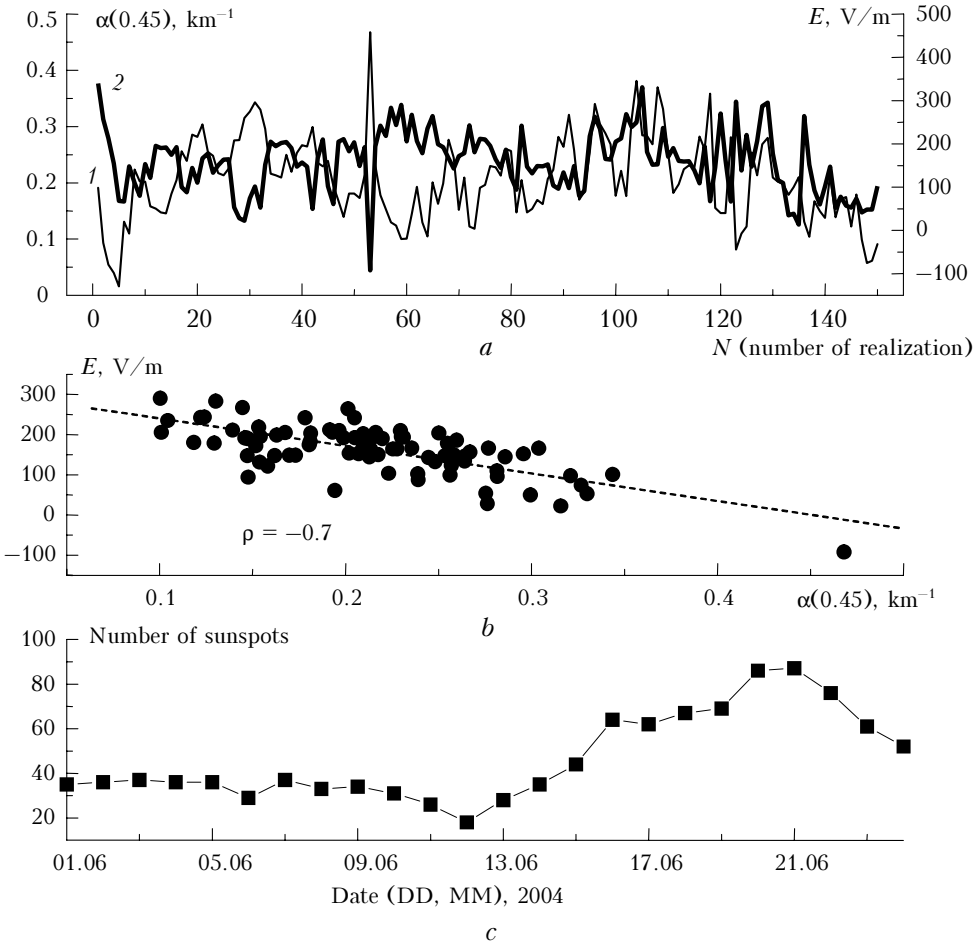

Fig. 1. Temporal behavior of α(0.45) (curve *1*) and the atmospheric electric field strength (*2*) for the whole period of measurements (*a*); statistical correlation between E and α(0.45) in the period of June 2–12 (*b*); temporal behavior of the sunspot number for the whole period of measurements (*c*).

To understand the physical essence of the negative correlation between the dynamics of aerosol extinction at $\lambda = 0.45$ μm and the electric field strength, it is necessary to reveal, first of all, the nature of temporal variations of α(0.45).

For this purpose, we present in Fig. 2 the temporal behavior of α(0.45) and α(3.91) in June 1–12. Absolutely synchronous variations of these coefficients indicate that almost all variability of α(0.45) in this case is determined by the coarse aerosol. What's more, it is seen that the variations of the coarse aerosol not only fully form the dynamics of aerosol extinction in the visible region, but also significantly determine its level, especially, in the period of June 2–7. The role of the submicron-sized aerosol in this period was very small. This means that the revealed negative correlation of the atmospheric electric field strength at α(0.45) is caused, essentially, by the dynamics of coarse particles.

To estimate this conclusion quantitatively, we have calculated the aerosol extinction components caused by the submicron-sized ($\Delta\alpha_{sm}$), medium ($\Delta\alpha_m$), and coarse ($\Delta\alpha_c$) aerosol particles. The values of $\Delta\alpha_{sm}$, $\Delta\alpha_m$, and $\Delta\alpha_c$ were found as differences of the linear combinations (averaged over the spectral range) of α(λ):

$$\Delta\alpha_{sm} = [\alpha(0.45) + \alpha(0.48) + \alpha(0.55)]/3 - [\alpha(0.69) + \alpha(0.87) + \alpha(1.06)]/3, \quad (1)$$

$$\Delta\alpha_m = [\alpha(0.69) + \alpha(0.87) + \alpha(1.06)]/3 - [\alpha(1.6) + \alpha(2.17) + \alpha(3.91)]/3, \quad (2)$$

$$\Delta\alpha_c = [\alpha(1.6) + \alpha(2.17) + \alpha(3.91)]/3. \quad (3)$$

Then the correlation coefficient of variations of these components with variations of the electric field strength was calculated.

The variation correlation of the field strength with the submicron-sized component of α(0.45) turned out to be +0.29, with the medium component −0.42, and with the coarse component −0.62.

As expected, the main fraction of the correlated variations of α(0.45) and E falls on the coarse component of α(0.45). At the same time, the submicron-sized component has a weak positive correlation with the electric field, which well corresponds to the existing idea about the deposition of light ions on small particles.

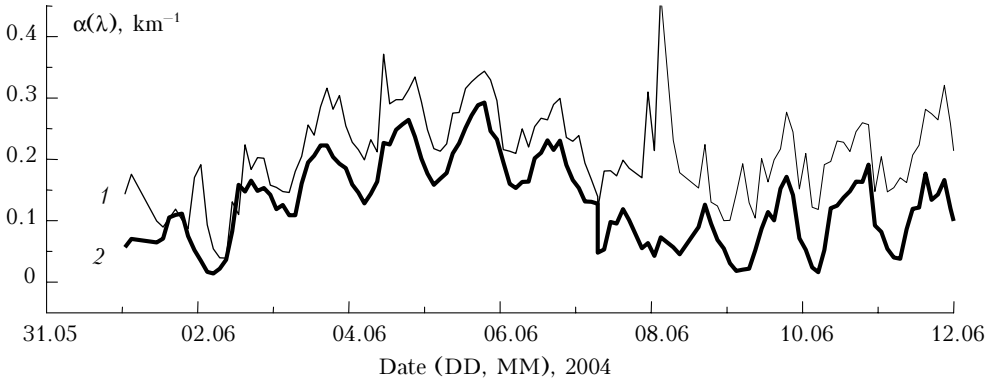

Fig. 2. Time dynamics of α(0.45) and α(3.91) in the period of June 1–12: λ = 0.45 (*1*) and 3.91 μm (*2*).

Figure 3 shows a pronounced morning minimum, falling on 4–5 LT, and a daytime maximum near 16–20 LT. This figure also shows the diurnal behavior of *E*, averaged over the whole data array, which has a weakly pronounced morning maximum and evening minimum.

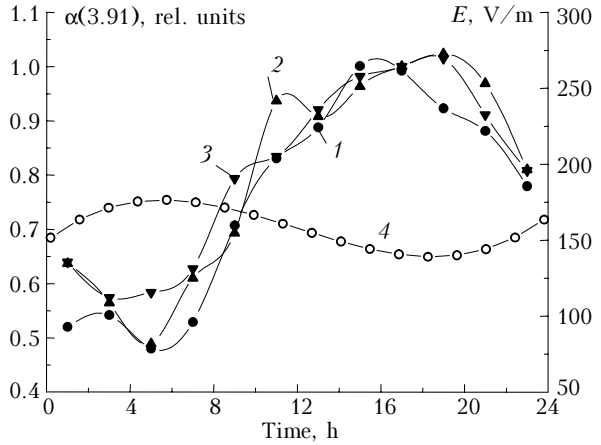

Fig. 3. Diurnal dynamics of the aerosol extinction coefficient at λ = 3.91 μm for June 3, 4, and 5 of 2004 (curves *1*, *2*, and *3*, respectively) and the electric field strength *E* (*4*), averaged over the whole data array.

The character of the diurnal behavior of α(3.91) suggests that it is connected with the insolation intensity, which, along with other factors, determines the surface temperature and the convective transport of the coarse aerosol. The diurnal dynamics of the electric field may also be connected with insolation through some parameter as well. Supposedly, such a parameter may be the degree of air ionization in the surface layer, which is known to be higher in summer than in winter and at fine weather than at overcast. If to accept these assumptions, it becomes possible to construct the following logic sequence of events.

In the period of a calm sun, when the UV flux intensity is minimal, the photochemical processes of aerosol formation are retarded. This leads to a deficit of the submicron-sized aerosol in the surface layer, and the variability of α(0.45) is almost fully determined by the diurnal dynamics of the coarse aerosol. The latter, in its turn, is determined by the temperature convection with the morning minimum and afternoon maximum. At a deficit of the submicron-sized aerosol, the electric field varies, on the average, only due to the diurnal variation of the degree of air ionization due to the insolation and has, correspondingly, the nighttime maximum (minimum of air ions) and daytime minimum (maximum of air ions). This explains the presence of the negative correlation between the aerosol extinction coefficient α(0.45) and the electric field strength.

Certainly, this scheme is still speculative to a large extent.

In conclusion, let us see whether there is some correlation between the aerosol extinction of optical radiation and solar UV radiation. Certainly, this correlation should be sought for in the shortest-wave part of the spectrum. For this purpose, we present in Fig. 4 the smoothed time behavior of α(0.45) and the daily average UV flux for the whole period of measurements.

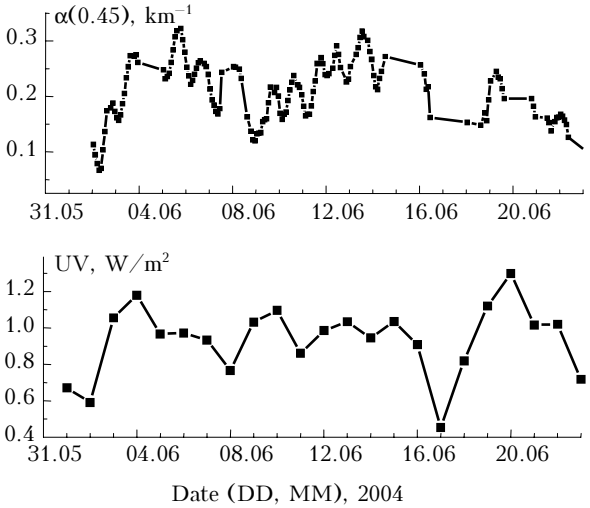

Fig. 4. Time dynamics of the aerosol extinction coefficient α(0.45) and the UV-B flux for the whole measurement period.

Note that the temporal behavior of $\alpha(0.45)$ was smoothed using the moving average over 5 points, and the UV flux for a particular day was determined by averaging the UV pyranometer data for the period from 10 to 17 LT. Against the background of the considered diurnal variations of $\alpha(0.45)$ caused by the temperature dynamics, we can clearly see the lower-frequency component with the period of about 8 days. The qualitative analysis of the temporal behavior of the UV flux shows that a similar in-phase low-frequency component is also seen, though not so distinctly, in the dynamics of this parameter. Thus, the presence of the in-phase low-frequency components with the close periods in the both cases is indicative of existence of a weak, but still marked influence of the solar UV radiation on the optical characteristics of aerosol in the lower troposphere.

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