Electro-optical interconnections in the atmosphere under smog conditions

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Interconnections between variations of aerosol extinction coefficients for optical radiation and the atmospheric electric field strength under haze and smog conditions are analyzed based on complex field measurements. It has been found that under smog conditions, a significant (almost by an order of magnitude) decrease of the field strength is observed at increasing turbidity of the atmosphere. This contradicts the well-known electro-optical relation and gives grounds for a supposition that the number of charged particles in smog significantly increases, and the electro-optical relations drastically change. Large number of fires occurring on the Earth makes one to consider this fact in models of climate and in analyzing mechanisms of the solar activity influence on the weather and climate.

Introduction

It is known that tropospheric aerosol, along with greenhouse gases (GG), is the important climate forming factor affecting the radiative budget of the Earth.[1,2] Aerosol affects the radiative budget through the cloud formation processes, and under cloudless conditions – through extinction of solar radiation and the change of the atmosphere–underlying surface system albedo. In some particular cases, aerosol can either intensify the greenhouse effect caused by GG or partially compensate for it. The sign of the aerosol forcing depends on the aerosol microstructure and chemical composition, as well as on meteorological conditions forming its vertical distribution. Events of the presence of smoke in the atmosphere due to forest and peatbog fires regularly occurring in different regions of the Earth and emitting a lot of smoke aerosol into the atmosphere[3] are especially important in the context of the problem of the aerosol forcing of climate. As smoke aerosol takes part in the cloud formation process, the efficiency of which essentially depends on the presence or absence of the electric charge on particles at heterogeneous condensation,[4] it seems important to reveal the peculiarities of interaction of smoke aerosol with the electric field of the atmosphere in field experiments.

Within the frameworks of the problem discussed, it would be interesting to study the variations of the aerosol extinction coefficient in the optical region and the strength of the electric field under conditions when there is a smoke from forest fires in the atmosphere.

The preliminary results of such investigations carried out in the region of Tomsk in 2004 are discussed in this paper.

Description of the experiment

The experiment was carried out since May 5 until May 25, 2004 when forest fires, usually related to burning dry last year's grass, occurred in the region. Simultaneous round-the-clock measurements of the spectral transmission of the atmosphere $T(\lambda)$ in the wavelength range from $\lambda = 0.44$ to 12 μm along a near-ground path and the strength of the electric field E were organized during this period.

Measurements of the atmospheric transmission were performed every two hours (odd hours) with the automated filter photometer[5] containing two measurement channels, one of which covered the wavelength range from $\lambda = 0.44$ to 1.06 μm (8 wavelengths) and the second one from 1.06 to 12 μm (15 wavelengths). The photometer was operated with a reflector at 415 m distance making the total length of the measurement path to be equal to 830 m. The mirror cat's eye with the diameter of the main mirror of 500 mm and focal length of 1500 mm was used as a reflector. Measurements in both channels were performed in parallel. Duration of the measurement cycle was 30 min. Six spectra in the first channel and four in the second channel were recorded during this time, which then were averaged in processing.

The transmission of the atmospheric layer $T(\lambda)$ and the total spectral extinction coefficient $\varepsilon(\lambda)$ were determined using the technique proposed in Ref. 6. The aerosol extinction coefficients $\beta(\lambda)$ were calculated from thus obtained values of the total extinction coefficients $\varepsilon(\lambda)$ using the statistical model[7] based on the apparatus of multiple linear regression.

Measurements of the electric field strength were performed every minute with a "Pole-2" stationary

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electrostatic fluxmeter installed on the metal netting at the end of the measurement path. To form the common data array, the E values obtained were averaged over 30 minutes also at odd hours. All optical and electric measurements were accompanied with standard meteorological observations, as well as with measurements of the concentration of carbon monoxide (CO), the mass concentration of the aerosol containing soot (M_s), and the gamma radiation background, carried out at permanently operating stations of the Institute of Atmospheric Optics SB RAS.

The data array of 140 realizations of all aforementioned parameters was obtained during the period of measurements.

The results measured

On the whole, strongly variable weather typical for May was observed during the measurements. Air temperature t varied from 1 to 35°C, relative humidity from 20 to 97%, and meteorological visibility range from 3 to 30 km.

The change of the temperature-humidity regime in the region during the period of measurements is shown in Fig. 1 that presents the time behavior of the parameters t and RH smoothed by the sliding average in order to smooth the diurnal dynamics.

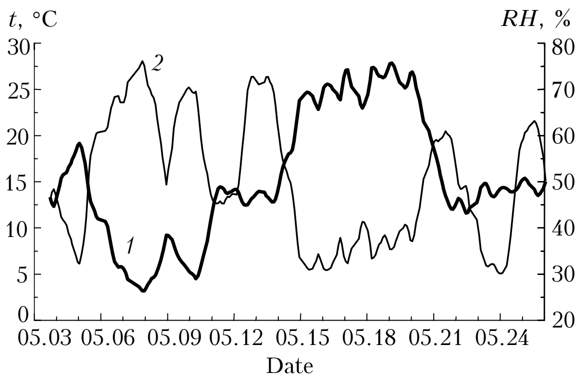

Fig. 1. Smoothed daily variation of temperature (*1*) and relative humidity of the air (*2*) during the measurements.

It is seen that air temperature during measurements varied very strongly, and its maximum values were observed from May 15 until May 21. Hence, relative humidity of air in this period took minimum values (RH = 33–50%). The heaviest smoke was observed in the atmosphere just in this hot and dry period.

It is seen from Fig. 2 that the maximum in the temporal behavior of the coefficients $\beta(\lambda)$ is observed in the period from May 15 until May 21 at all wavelengths being most pronounced in the visible (λ = 0.45 μm) spectral range.

The fact that variations of the coefficients $\beta(\lambda)$ in visible and IR spectral ranges are synchronous attracts one's attention. The quantitative measure of the revealed synchronous variations are the coefficients of correlation between the parameter $\beta(0.50)$ and the parameters $\beta(1.06)$, $\beta(3.9)$ and $\beta(10.6)$ shown in Fig. 3 and taking the values of 0.91, 0.83, and 0.86, respectively.

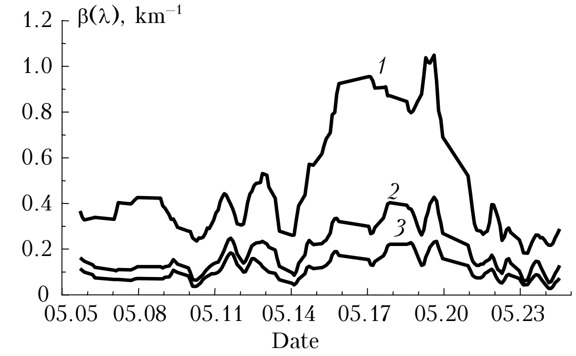

Fig. 2. Temporal behavior of the aerosol extinction coefficients at λ = 0.45 (curve *1*), 1.06 (*2*), and 3.9 μm (*3*) during the period from May 5 until May 25, 2004.

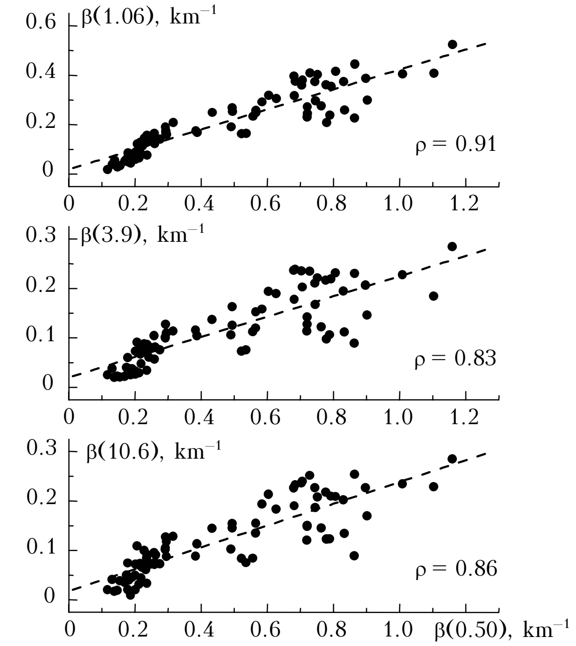

Fig. 3. Statistical correlation between variations of the aerosol extinction in the visible and IR ranges; ρ is the normalized correlation coefficient.

That high correlation coefficients evidence of the presence of the common factor in aerosol extinction for the visible and IR radiation under conditions formed by the forest fire smoke. Most likely, this common factor is that smoke particles generated from gaseous phase and larger particles emitted into the atmosphere from the underlying surface in the fire location simultaneously come to the atmosphere during fire.

Temporal behaviors of the carbon monoxide concentration and the mass concentration of aerosol containing soot M_s (Fig. 4) also have well pronounced maximum in the period from May 15 until May 21, that unambiguously indicates the smoke-caused origin of the maximum in the aerosol extinction (see Fig. 2).

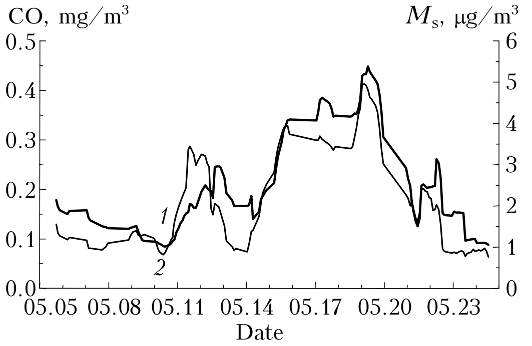

Fig. 4. Temporal behaviors of the CO concentration (curve *1*) and aerosol containing soot M_s (*2*).

Correlation between the variations of the aerosol extinction coefficient and the strength of the electric field E under smoke conditions is shown in Fig. 5, from which it follows that significant decrease of the electric field strength is observed during the strongest smoke in the atmosphere, i.e., during smoke the parameters $\beta(0.50)$ and E vary in antiphase.

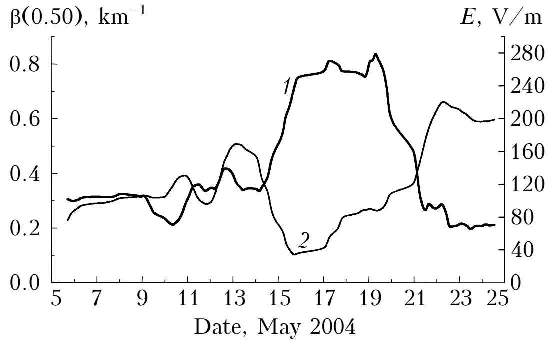

Fig. 5. Smoothed temporal behaviors of the aerosol extinction coefficient $\beta(0.50)$ (curve *1*) and the strength of the atmospheric electric field E (*2*) during the measurements.

This contradicts the well-known electro-optical relation,[8] according to which the field strength under good weather conditions should increase with the increasing atmospheric turbidity.

To explain the effect revealed, the normalized correlation coefficients ρ were calculated between E and $\beta(\lambda)$ coefficients in the visible and IR wavelength regions. The calculated results are shown in the Table.

It is seen that the correlation coefficients between E and $\beta(\lambda)$ at fire are negative and quite close to each other in the entire wavelength range. The correlation coefficients between E and $\beta(\lambda)$ presented in the last column of the Table obtained in Ref. 9 at variations in the fall haze are absolutely different. They are positive and decrease with wavelength that evidences of the fact that the main sink of light air ions under fair weather conditions occurs on small aerosol particles, and this mechanism under these conditions governs the variability of the atmospheric electric field. So, it is absolutely clear that electro-optical relations in the atmosphere under smoke conditions are caused by another mechanisms.

Mean values of $\beta(\lambda)$ coefficients, their rms deviations $\sigma_\beta(\lambda)$, and the normalized correlation coefficients between $\beta(\lambda)$ and the field strength E under conditions of smoke haze

λ, μm	$\overline{\beta}(\lambda)$, km^{-1}	$\sigma_\beta(\lambda)$, km^{-1}	$\rho_{\beta(\lambda), E}$	
			Present paper	Ref. 9*
0.45	0.529	0.31	−0.67	0.51
0.50	0.467	0.276	−0.67	0.51
0.55	0.416	0.246	−0.67	0.50
0.63	0.344	0.205	−0.66	0.49
0.69	0.315	0.189	−0.67	0.49
0.87	0.246	0.146	−0.64	0.47
1.06	0.208	0.122	−0.62	0.42
1.6	0.158	0.094	−0.62	0.34
2.17	0.134	0.078	−0.57	0.38
3.91	0.116	0.068	−0.55	0.31
8.18	0.121	0.073	−0.6	0.06
10.6	0.121	0.071	−0.59	0.14

* Measurements were carried out under fall haze conditions.

The effect of the electric field strength decrease during smoke haze revealed indicates, in fact, that, as the aerosol concentration in the atmosphere increases, the number of charged particles in smokes does not decrease, but, on the contrary, significantly increases. It gives one good grounds to assume that either intense increase of the number of light air ions occurs in the region of fire, which leads to the decrease of the electric field strength, or the fine photochemical aerosol generated in the fire is initially charged, and the dynamics of the field is caused by absolutely other mechanisms.

It is known that the increase of the number of light air ions can occur due to the increase of gamma-radiation background in the region.[8,10] As was mentioned above, the gamma-radiation background in the region was measured in the experiment among many parameters. It occurred that the gamma-radiation background changed during the period of measurements from 16 to 17 μR/h that is significantly less than the measurement error for this parameter. This means that variations of the gamma-radiation background in the region could not affect the concentration of light air ions in the atmosphere.

If one assumes that fine aerosol generated in the zone of fire is initially charged, then the most probable mechanism explaining the decrease of the electric field strength during smoke haze can be the formation of negative volume charge in the near-ground layer of the atmosphere, which can partially compensate for the initial electrostatic field.[8,11]

Conclusions

The effect has been revealed of a significant decrease in the strength of the electric field (from

200 to 30–60 V/m) during smoke haze at increasing aerosol concentration in the atmosphere. It obviously contradicts the well-known electro-optical relation and is evidence of the fact that as the number of the aerosol particles increases, the number of light air ions in the atmosphere does not decrease, but, on the contrary, significantly increases. It was assumed that the fine photochemical aerosol particles generated at fire are charged, thus forming the negative volume charge in the near-ground layer of the atmosphere that can partially compensate for the initial electrostatic field.

The obtained result is evidence of the very strong effect of fires on electro-optical characteristics of the lower troposphere. At big number of fires on the Earth, it is necessary to take into account this fact in climatic models, as well as in considering the physical mechanisms of the effect of solar activity on weather and climate.

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