STUDY OF CORRELATION BETWEEN AEROSOL EXTINCTION OF OPTICAL RADIATION AND ATMOSPHERIC ELECTRIC FIELD STRENGTH

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Simultaneous field measurements of aerosol extinction coefficients α(λ) in the visible and IR spectral regions and the atmospheric electric field strength E are treated in the paper. Statistic correlation between α(λ) in different wavelength regions and E under conditions of atmospheric haze are analyzed. It is shown that, in the general case correlation between these parameters in realistic atmospheric hazes is insignificant. The maximum normalized correlation coefficients (~0.5) are found to occur in the visible spectral region and under conditions of increased relative air humidity. This allows the conclusion that the electric field strength in hazes is mostly influenced by fine-disperse moistened particles on which the sink of light air ions is more efficient.

As known, the atmospheric electric field generated by thunderstorm clouds exists continuously and is characterized by a wide spectrum of natural variations caused by different factors (see Refs. 1 and 2, and references therein). Under the atmospheric haze conditions (if fogs and precipitation are absent) change in the concentration of ionized air molecules (light ions) due to their sink on the atmospheric aerosol is an important factor of variability of the atmospheric electric field strength E. Note that ionization of air molecules occurs principally due to natural radioactivity and space radiation. The decrease in the concentration of light ions at their sink on the atmospheric aerosol leads to the decrease in the air electric conductivity (γ) and, hence, to the increase in the electric field strength.

The existence of a determined relation between the electric field strength and the meteorological range $S_{\rm m}$ was suggested for the first time in the basic review by I.M. Imyanitov and K.S. Shifrin[1] devoted to problems of the atmospheric electricity. The relation has been assumed in the following form:

$$E = C\, S_{\rm m}^{-1}, \qquad (1)$$

where C is a constant.

Expression (1) was derived from the general considerations supposing that $E \sim \gamma^{-1}$, and $\gamma \sim N^{-1}$ (N is the number density of neutral particles in the near-ground atmospheric layer). Then the electric field strength should be proportional to the number of particles, i.e. $E = \sim N$. Taking into account that $S_{\rm m} \sim N^{-1}$, we obtain Eq. (1).

Using the well-known relationship $S_{\rm m} = 3.91 \times \alpha(0.55)^{-1}$, where $\alpha(0.55)$ is the aerosol extinction coefficient at the wavelength $\lambda = 0.55$ μm, the electric field strength can be represented in the form:

$$E = C_1\, \alpha(0.55). \qquad (2)$$

Equations (1) and (2), relating the electrical and optical characteristics of the atmosphere, are derived on the assumption that variations of the parameters $S_{\rm m}$ and $\alpha(0.55)$ are caused only be change in the concentration of particles. However, in fact, these parameters depend not only on the number of particles, but also on their size and chemical composition that can significantly vary depending on meteorological conditions.

The purpose of this paper is to ascertain what is the relation between these parameters under the conditions of real atmospheric hazes, and what is the role of particles of different size in the mechanism of sink of light ions on the aerosol. Of course, to solve these problems, it is necessary to carry out special investigations into statistical relations between variations of the atmospheric electric field strength under different weather conditions and the aerosol extinction coefficients in the wide wavelength region.

Toward this end, we have carried out a 20-day cycle of round-the-clock simultaneous measurements of the spectral transmittance $T(\lambda)$ of the surface atmosphere in the wavelength region $\lambda = 0.44-12.2$ μm on the 800-m long path, the electric field strength E, the relative air humidity RH, and the air temperature t. The measurements were performed every 4 hours in August–September 1997 near Tomsk. The electric field strength was measured with a string dynamic sensor.[3] Spectral measurements of $T(\lambda)$ were carried out with an automated filter two-channel system.[4] The total extinction coefficients $\varepsilon(\lambda)$ were found from the obtained values of $T(\lambda)$, and then the aerosol extinction coefficients $\alpha(\lambda)$ all over the wavelength range were calculated by the multiple linear regression technique.[5] Note that measurements of $T(\lambda)$ in the

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specified wavelength range allow the optical characteristics to be used to assess contributions from particles of different size (from submicron to coarse-disperse ones) into the extinction.

During the period of observation, we have obtained the data array containing a total of 91 realizations of optical, meteorological, and electrical parameters of the atmosphere. The variability range was: 0.07–0.35 km^{-1} for α(0.55) (what corresponds to variation of the meteorological range from 55 to 11 km), 0.1–19°C for the air temperature, 33–95% for the relative humidity, and 8–132 V/m for the electric field strength. The mean values of these parameters, their rms deviations, and normalized correlation coefficients for the period of observations are presented in Table I. It should be noted that the significant positive correlation of the electric field strength with the coefficient α(0.55), characterizing the atmospheric turbidity, and the relative air humidity is observed in this data array. The similarity of variations of these three parameters is well seen in their diurnal behavior shown in Fig. 1. The analysis of these data allows us to conclude that in atmospheric hazes in the absence of fogs and precipitation there is a statistical correlation between the air turbidity and the electric field strength. This correlation shows itself in the fact that the electric field strength in the atmosphere increases as the haze density in the moist atmosphere increases. The last circumstance related to the air humidity may prove very important for physical interpretation of the effect of atmospheric aerosol on the electric field strength.

It is known that diurnal variations of the air humidity mostly affect the degree of moistening and, hence, the size of aerosol particles, rather than their number density.[6,7] So, possibly, just the moistening of particles is the key factor that determines the efficiency of sink of light ions on the aerosol and affects change of the electric field strength. Taking into account that the submicron aerosol in continental hazes is more hygroscopic than the coarse-disperse one, we can suppose that light ions must sink mostly on the submicron aerosol.

TABLE I. The mean values, rms deviations, and normalized correlation coefficients of the parameters: α(0.56), *RH, t, and e for the total data array. The level of significant correlation is* ~ 0.20.

Measured parameter	Mean value	RMS dev.	Correlation coefficients			
			α(0.56)	*RH*	*t*	*e*
α(0.56), km^{-1}	0.141	0.053	1.00	–	–	–
RH, %	69.97	18.43	0.41	1.00	–	–
t, °q	9.55	3.42	−0.016	−0.710	1.00	–
e, V/m	76.13	34.01	0.50	0.727	−0.38	1.00

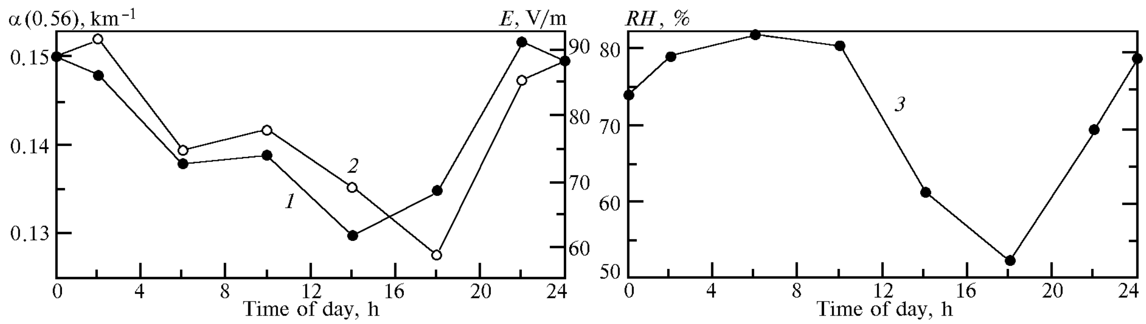

FIG. 1. Mean diurnal behavior of the extinction coefficient α(0.56) *(curve 1), the atmospheric electric field strength E (curve 2), and the relative air humidity RH (curve 3) during the period of measurements.*

TABLE II. The mean values and rms deviations of the parameters α(0.56), *RH, t, and e, corresponding to averaged spectra of the aerosol extinction coefficients shown in Fig. 2 (N is the number of realizations).*

No. of a curve in Fig. 2	$\overline{\alpha(0.56)}$, km^{-1}	$\overline{RH}$, %	σ_{RH}, %	$\overline{t}$, °C	σ_t, °C	$\overline{E}$, V/m	σ_E, V/m	*N*
1	0.103	63.6	15.9	8.36	2.82	55.0	21.9	18
2	0.153	69.1	18.1	9.87	3.64	76.8	33.6	64
3	0.302	91.3	7.8	4.41	1.93	117.3	5.3	9

To exam this supposition, let us analyze the mutual variation dynamics of the coefficients $\alpha(\lambda)$ at different wavelengths and the electric field strength E in hazes of different density. For such an analysis the total data array was divided into three subarrays by the degree of atmospheric turbidity. The extinction coefficient at the wavelength of 0.56 μm was taken as an estimate of the degree of turbidity. The first subarray incorporated spectra recorded at $\alpha(0.56) < 0.11\ km^{-1}$, those recorded at $\alpha(0.56) = 0.11–0.2\ km^{-1}$ form the second subarray, and spectra recorded at $\alpha(0.56) > 0.2\ km^{-1}$ form the third one. The mean values and rms deviations of the parameters $\alpha(0.56)$, RH, t, and E in every subarray are presented in Table II. It is seen that the increase of the air turbidity, which occurs as the relative humidity increases, results in significant increase of the mean strength of the atmospheric electric field. The increase rate of $\alpha(0.56)$ and E rises sharply at the humidity higher than 70%.

The averaged spectral behaviors of the aerosol extinction coefficients corresponding to these subarrays are shown in Fig. 2. It is seen that most significant variations of the coefficients $\alpha(\lambda)$ occur in the wavelength range of 0.44 to 12 μm, where submicron particles contribute mostly into the aerosol extinction. In the region of 8 to 12 μm, where the most contribution comes from the coarse-disperse aerosol, variations are smaller. Comparison of the amplitudes of variation of the coefficients $\alpha(\lambda)$ at different wavelengths and the electric field strength in hazes of different density confirms the supposition of the prevalent role of submicron particles in the process of light ion sink on the atmospheric aerosol.

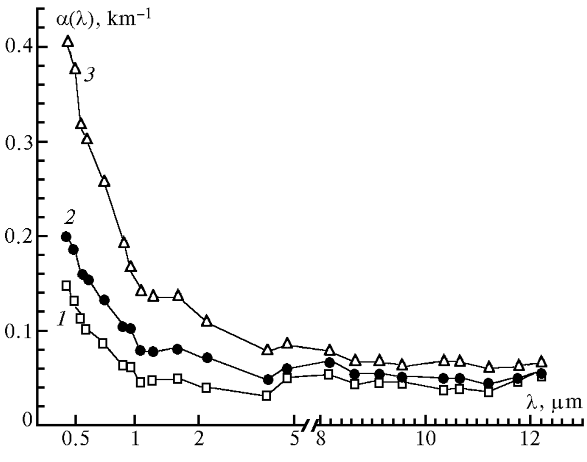

FIG. 2. Transformation of the spectral structure of the aerosol extinction coefficient $\alpha(\lambda)$ in atmospheric hazes of different density (the values of the parameters $\overline{\alpha(0.56)}$, $\overline{RH}$, $\overline{t}$, and $\overline{E}$ for the curves 1, 2, and 3 are given in Table II).

To estimate quantitatively the role of aerosol particles of different size in their interaction with the electric field, consider the data of Table III that presents the mean values of the coefficients $\alpha(\lambda)$ in the wavelength range of 0.44 to 12 μm, their rms deviations $\sigma_{\alpha(\lambda)}$, and the normalized correlation coefficients between $\alpha(\lambda)$ and the parameters RH, t, and E in the total data array.

TABLE III. The mean values of the coefficients $\alpha(\lambda)$, their rms deviations $\sigma_{\alpha(\lambda)}$, and the normalized correlation coefficients between $\alpha(\lambda)$ and the parameters RH, t, and e in hazes for the fall period in West Siberia. The total data array.

λ, μm	$\overline{\alpha(\lambda)}$, km^{-1}	$\sigma_{\alpha(\lambda)}$, km^{-1}	$\rho_{\alpha(\lambda),RH}$	$\rho_{\alpha(\lambda),t}$	$\rho_{\alpha(\lambda),E}$
0.44	0.2087	0.0770	0.461	−0.118	0.511
0.48	0.1933	0.0719	0.459	−0.098	0.511
0.52	0.1639	0.0612	0.423	−0.051	0.502
0.56	0.1406	0.0526	0.413	−0.016	0.498
0.69	0.1353	0.0506	0.406	−0.003	0.495
0.87	0.1066	0.0403	0.327	0.125	0.471
1.06	0.0801	0.0320	0.222	0.203	0.423
1.22	0.0789	0.0315	0.149	0.205	0.342
1.60	0.0816	0.0325	0.160	0.196	0.337
2.17	0.0700	0.0284	0.165	0.233	0.381
3.97	0.0503	0.0221	0.079	0.232	0.308
4.69	0.0623	0.0258	−0.158	0.315	0.112
8.18	0.0682	0.0276	−0.277	0.496	0.056
8.66	0.0564	0.0241	−0.267	0.435	0.048
9.12	0.0569	0.0242	−0.259	0.405	0.056
9.55	0.0550	0.0235	−0.337	0.436	−0.017
10.34	0.0522	0.0228	−0.198	0.417	0.096
10.66	0.0518	0.0226	−0.193	0.444	0.141
11.21	0.0459	0.0206	−0.197	0.337	0.121
11.76	0.0549	0.0234	−0.378	0.422	−0.071
12.19	0.0606	0.0247	−0.448	0.405	−0.137

As seen, the coefficients $\alpha(\lambda)$ in the wavelength range $\lambda = 0.44–3.97$ μm have the significant positive correlation with the electric field strength. It is interesting that it is just the spectral range, where the positive correlation of the coefficients $\alpha(\lambda)$ with the relative humidity is observed. In the range, where it becomes negative ($\lambda > 4$ μm), the correlation between $\alpha(\lambda)$ and E is broken. These data, as a whole, confirm the supposition about the prevalent influence of small particles on the atmospheric electric field strength.

The negative correlation between $\alpha(\lambda)$ in the range $\lambda > 4$ μm and the relative air humidity is observed not often, and in this case it is probably related to a peculiarity in the diurnal behavior of the coarse aerosol number density, which decreases in the nighttime and in the morning due to weakening of upwelling fluxes, while the relative air humidity increases at this time. In the daytime, the relative humidity decreases as the temperature increases, but the number density of coarse particles in the surface atmospheric layer increases due to intensification of upwelling fluxes caused by turbulent diffusion.

Similar mechanisms of aerosol escape likely determine the character of the spectral structure of the correlation coefficients between $\alpha(\lambda)$ and the air temperature. A very weak negative correlation of these parameters in the visible wavelength region is possibly related with the daytime arrival of the fine-disperse aerosol into the upper atmospheric layers, while the number density of fine-disperse aerosol has no time to restore due to photochemical processes. The significant positive correlation between $\alpha(\lambda)$ in the range $\lambda > 4$ μm and t is rather caused by the daytime arrival of the coarse-disperse soil aerosol into the surface atmospheric layer. It is important to note here that the correlation between $\alpha(\lambda)$ in this wavelength range and the electric field strength remains lower than the level of significance, i.e. change of the number density of the coarse-disperse aerosol in atmospheric hazes weakly affect the electric field strength. This fact is evidently related to the low number density of coarse particles in the atmosphere.

In general, the experimental data obtained show that even in the visible wavelength region the correlation coefficient between variations of the aerosol extinction and the electric field strength is relatively low ($\rho_{\alpha(\lambda),E} \sim 0.5$). This means that, in the general case, there is no unambiguous relation between these parameters in real atmospheric hazes. However, some effect of the atmospheric aerosol on the electric field strength evidently exists. This effect is more noticeable under the conditions of dense hazes at the enhanced relative air humidity.

In conclusion note that in order to use electric field strength sensors as indicators of the technogenic load on the environment in problems of ecological monitoring (as suggested, in particular, in Ref. 8), it is necessary to continue this studies to refine existing models, which relate optical and electrical parameters of the atmosphere.

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REFERENCES

1. I.M. Imyanitov and K.S. Shifrin, Uspekhi Fiz. Nauk **LXXVI**, No. 4, 593–642 (1962).
2. I.M. Imyanitov and V.P. Kolokolov, in: *Proceedings of the First All-Union Symposium on Atmospheric Electricity* (Gidrometeoizdat, Leningrad, 1976), pp. 5–22.
3. V.A. Donchenko, M.V. Kabanov, V.T. Kalaida, et el., Izv. Vyssh. Uchebn. Zaved., Ser. Fizika (1998) (in press).
4. Yu.A. Pkhalagov, V.N. Uzhegov, and N.N. Shchelkanov, Atmos. Oceanic Optics. **5**, No. 6, 423–426 (1992).
5. Yu.A. Pkhalagov and V.N. Uzhegov, Opt. Atm. **1**, No. 10, 3–11 (1988).
6. G.I. Gorchakov, A.S. Emilenko, and M.A. Sviridenkov, Izv. Akad. Nauk SSSR, Fiz. Atmos. Okeana **17**, No. 1, 39–49 (1981).
7. M.V. Kabanov, M.V. Panchenko, Yu.A. Pkhalagov, et al., *Optical Properties of Coastal Atmospheric Hazes* (Nauka, Novosibirsk, 1988), 201 pp.
8. V.P. Kobets, "*Natural and anthropogenic variations of the atmospheric electric field,*" Author's Abstract of Cand. Phys-Math. Sci. Dissert., Industrial Institute, Bratsk (1998), 24 pp.