AEROSOL EXTINCTION OF OPTICAL RADIATION IN SUMMER HAZES OF WEST SIBERIA

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This paper presents some results obtained during two periods of measurements of the aerosol extinction coefficients carried out in the outskirts of Tomsk and in rural area during summer season. High level of the aerosol extinction has been revealed in the IR under conditions of urban haze. A physical interpretation of this fact is proposed. It is shown that the mean spectral dependence of the aerosol extinction coefficients at the wavelengths from 0.44 *to* 1.06 μm *in a rural haze is more pronounced as compared to that in an urban haze. Strong influence of the air relative humidity on the aerosol extinction of optical radiation under background conditions is observed.*

One of the most important problems in atmospheric optics is the study of regularities of the aerosol extinction of the visible and infrared radiation in the near ground hazes of different regions. Quantitative data on spectral aerosol extinction coefficients $\alpha(\lambda)$ in hazes are necessary, in particular, for improving accuracy of radiation calculations in climatology, for making improvements of the algorithms for spaceborne sounding data processing as well as for various applied problems the like.

By now the statistical data on the coefficients $\alpha(\lambda)$ in summer hazes have been obtained only for the mid-latitudes of Russia,[1–5] coastal zone of the Black Sea[6–8] and arid zone near the Lake Balkhash.[9–11] The above investigations have revealed the basic distinctions of the optical characteristics of hazes in different regions what underlines the need for regional approach when studying the near ground hazes. In this connection the performance of such investigations is of great importance in the vast areas of West Siberia. A distinguishing feature of this region is the existence of large forest areas and numerous marches.

It should be noted that the first short cycle of complex investigations of spectral transmission of hazes in the vicinity of Tomsk was carried out in early 1970s during fall seasons. The results of these investigations have made it possible to reveal a considerable difference in composition of particles of fine and coarse aerosol fractions in the ground hazes and to detect first from the optical data the aerosol absorption bands in the wavelength range of 9 to 12 μm (Ref. 12).

A new cycle of investigations of optical characteristics of hazes of West Siberia started in 1991 in the framework of the complex ecological program on stratospheric and tropospheric ozone (SATOR).

This paper describes some results of the two cycles of measurements of spectral atmospheric transmission carried out in 1992. The measurements were performed using an automated multiwave meter for spectral transmission of the ground atmospheric layer. This meter is described in Ref. 13. It should be noted here that this device consisted of two separate meters mounted on one rotating platform. One of them operated in the wavelength range from 0.44 to 1.06 μm (eight spectral regions) and the second meter operated in the wavelength range from 1.06 to 12 μm (15 spectral regions). In this version both meters operate with reflection. One mirror cat's eye for both channels was used as a reflector.

The first three-week cycle of 24-hour measurements in the wavelength range from 0.44 to 12 μm was carried out from May 25 till June 15 along the path of 1 km length in the vicinity of Tomsk. The second short cycle of 24-hour measurements was carried out from July 17 till July 23 at a distance of 80 km from Tomsk under conditions close to the background ones. The path of 1.2 km length (with reflection) passed above a grassland in the riverside of the river Ob. Here the measurements were carried out only in the wavelength range 0.44–1.06 μm because there were some obstacles beyond our control.

During the first cycle of measurements we have obtained 212 averaged spectra of the total extinction coefficient and during the second cycle of measurements 62 spectra of the above value have been obtained. It should be noted that the aerosol extinction coefficients $\alpha(\lambda)$ in the IR spectral range were separated out using the statistical method.[14] The obtained coefficients $\alpha(\lambda)$ were formed in the corresponding large data arrays for the first and second cycles of measurements.

For brevity of the presentation in the subsequent consideration we assume that the measurements of the first cycle were performed under conditions of urban haze and those of the second cycle were performed in the rural area.

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MEASUREMENT RESULTS

Table I gives the statistical characteristics of the arrays of meteorological parameters, which took place during the first and second measurement cycles. Here R is the air relative humidity; e is the water vapor partial pressure; t is the air temperature; $\bar{X}$ are the mean values of the above parameters; σ_X are their rms deviations; ρ_{XX} are the coefficients of crosscorrelation between the meteorological parameters.

A comparison of the data from Table I shows an essential difference of meteorological conditions in the first and second measurement cycles. It is clear that in the second cycle the mean values of temperature, relative and absolute air humidity were much higher than in the first cycle at lesser values of the variance. This fact does not allow clear identification of the characteristics of urban and rural hazes since the measurements were performed under quite different conditions. Besides the mean values and variances the periods discussed greatly differ in the crosscorrelation coefficients between the meteorological parameters. Thus, in particular, a strong negative correlation should be noted in the second cycle of measurements between the relative humidity and air temperature ($\rho_{Rt} = -0.85$) and a comparatively rarely observed negative correlation between R and e ($\rho_{Re} = -0.23$).

The above peculiarities of meteorological conditions during the measurements were exhibited by the optical properties of aerosol in both measurement cycles that follows from Tables II and III, presenting the statistical characteristics of the data arrays of the aerosol extinction coefficients $\alpha(\lambda)$ for urban and rural summer hazes. The spectral structure of the mean values of coefficients $\alpha(\lambda)$ for these two types of haze is given in Fig. 1.

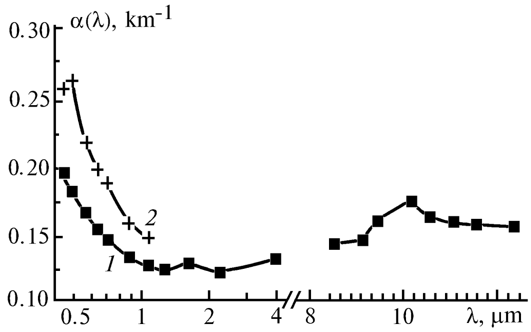

FIG. 1. Spectral structure of aerosol extinction coefficients under conditions of urban (1) and rural (2) hazes.

TABLE I. Statistical characteristics of meteorological parameters during the two measurement cycles.

X	Cycle 1					Cycle 2				
			ρ_{XX}					ρ_{XX}		
	$\bar{X}$	σ_X	R	e	t	$\bar{X}$	σ_X	R	e	t
R, %	58.2	20.0	1.0	0.57	−0.47	81.9	13.84	1.0	−0.23	−0.85
e, mb	7.68	3.01	–	1.0	0.41	18.7	2.49	–	1.0	0.70
t, °C	10.8	5.33	–	–	1.0	19.8	3.97	–	–	1.0

TABLE II. Statistical characteristics of the aerosol extinction coefficients in summer urban haze.

λ, m	$\bar{\alpha}$, km^{-1}	σ_α, m^{-1}	$\rho_{\alpha(0.44)\alpha(\lambda)}$	$\rho_{\alpha(1.06)\alpha(\lambda)}$	$\rho_{\alpha(\lambda)R}$	$\rho_{\alpha(\lambda)e}$	$\rho_{\alpha(\lambda)t}$
0.44	0.196	0.101	1.00	0.76	0.29	0.42	0.14
0.48	0.183	0.095	0.95	0.81	0.26	0.37	0.12
0.55	0.168	0.086	0.92	0.80	0.22	0.31	0.10
0.63	0.155	0.080	0.87	0.84	0.19	0.22	0.05
0.69	0.149	0.077	0.84	0.86	0.19	0.22	0.05
0.87	0.135	0.068	0.77	0.85	0.05	0.18	0.14
1.06	0.128	0.065	0.76	1.00	0.14	0.14	0.12
1.25	0.125	0.063	0.75	0.96	0.09	0.23	0.22
1.6	0.131	0.066	0.62	0.86	−0.04	0.17	0.32
2.2	0.123	0.062	0.59	0.82	−0.03	0.17	0.32
3.9	0.135	0.068	0.55	0.77	−0.053	0.20	0.36
4.6	0.161	0.080	0.54	0.67	−0.07	0.26	0.42
8.1	0.163	0.081	0.44	0.50	−0.014	0.31	0.50
8.6	0.146	0.073	0.49	0.59	−0.014	0.28	0.50
9.2	0.149	0.074	0.51	0.63	−0.013	0.27	0.49
9.5	0.163	0.081	0.53	0.72	−0.05	0.23	0.39
10.2	0.178	0.088	0.56	0.73	0.03	0.25	0.32
10.5	0.166	0.082	0.55	0.68	−0.03	0.26	0.39
11.1	0.162	0.081	0.55	0.67	−0.02	0.30	0.42
11.6	0.161	0.080	0.54	0.68	0.02	0.31	0.38
12.4	0.159	0.078	0.46	0.56	−0.14	0.29	0.53

TABLE III. Statistical characteristics of the aerosol extinction coefficients in summer rural haze.

λ, μm	$\bar{\alpha}$, km^{-1}	α_α, km^{-1}	$\rho_{\alpha(0.44)\alpha(\lambda)}$	$\rho_{\alpha(\lambda)R}$	$\rho_{\alpha(\lambda)e}$	$\rho_{\alpha(\lambda)t}$
0.44	0.258	0.166	1.00	0.51	–0.19	–0.45
0.48	0.262	0.168	0.95	0.56	–0.17	–0.48
0.55	0.217	0.139	0.94	0.56	–0.18	–0.48
0.63	0.199	0.127	0.93	0.58	–0.23	–0.52
0.69	0.186	0.119	0.93	0.57	–0.19	–0.50
0.87	0.157	0.100	0.88	0.54	–0.34	–0.56
1.06	0.149	0.095	–0.88	0.61	–0.36	–0.62

URBAN HAZE

From the analysis of Fig. 1 (curve *1*) and Table II it follows that the urban haze is characterized by a very flat spectral dependence of the mean aerosol extinction coefficient $\alpha(\lambda)$. If we conditionally take the level $\alpha = 0.125$ km^{-1} (at $\lambda = 1.25$ μm) as the contribution from the coarse aerosol fraction to the extinction, one can see that the fine aerosol fraction contribution is only 0.07 km^{-1} in the range of $\lambda = 0.44$ μm. This contribution rapidly decreases and becomes insignificant already at $\lambda = 1.06$ μm as the wavelength increases.

Thus, it follows therefrom that in this measurement period the urban haze was characterized by the deficit of the fine aerosol fraction. The most probable reason for this deficit is the fact that the major portion of measurements of this cycle was carried out under conditions of arctic air masses. Besides, a very high level of the coefficients $\alpha(\lambda)$ in the IR spectral range (from 0.12 to 0.18 km^{-1}) have attracted our attention to, which substantially exceeds the known mean data on aerosol extinction in summer hazes in mid-latitudes (0.05–0.10 km^{-1}).[1–5]

In the general case such a level of aerosol extinction in the IR spectral range may be a consequence of a systematic error when separating the aerosol component from the total extinction or this level is due to the radiation absorption by particles of the fine fraction or the extinction by the coarse aerosol fraction. The absorption by fine fraction particles can be excluded because of their small concentration (as it was mentioned above).

In order to determine the most probable factor from the rest two factors, we consider, in addition to the mean values, the data on the autocorrelation coefficients between aerosol extinction at different wavelengths and cross-correlation coefficients of optical-meteorological parameters. As one can see from Table II, in the urban haze the correlation coefficients $\rho_{\alpha(0.44)\alpha(\lambda)}$ decrease rapidly with the increase of the wavelength up to $\lambda = 4.6$ μm and then they remain practically invariable, varying from 0.50 to 0.55. Such a behavior of the parameter $\rho_{\alpha(0.44)\alpha(\lambda)}$ and its level are indicative of the existence, in the atmosphere, of a common factor causing synchronous variations of aerosol extinction in the visible and IR spectral ranges. The neutral character of the spectral dependence $\rho_{\alpha(0.44)\alpha(\lambda)}$ in the IR range uniquely indicates that this factor is the existence of huge aerosol particles in the atmosphere. Really, if the obtained values of the coefficients $\alpha(\lambda)$ in the IR spectral range were the result of a systematic error, we should certainly failed to obtain such a level of correlation with the visible spectral range. We can draw similar conclusions when analyzing the spectral structure of the parameter $\rho_{\alpha(1.06)\alpha(\lambda)}$.

As was mentioned above, the mean values of the aerosol extinction coefficients in the IR spectral range in hazes are usually equal to 0.05–0.1 km^{-1}. And in our case this value is practically twice as large. Rough estimates show that the increase of the aerosol extinction level by 0.07–0.08 km^{-1} obtained from our data can be a consequence of the optical radiation scattering by particles of biological origin (multiple bits of poplar seeds, aspen, pussy-willow, dandelion, and so on), which during this period were almost constantly present on the measurement paths. In particular, this assumption is supported by the character of spectral dependence of the correlation between the aerosol extinction coefficients and the relative air humidity $\rho_{\alpha(\lambda)R}$ (see Table II).

From this table we can see that at the wavelengths from 0.44 to 1.25 μm the correlation between these two parameters is positive (although being very weak), and at $\lambda \geq 1.6$ μm the correlation is negative everywhere. Simple fact that negative correlation appears between α and R from the point of view of interaction of commonly encountered aerosol with the atmospheric humidity cannot be explained. However, assuming that the optical radiation extinction is due to the poplar seeds, the negative correlation between α and R can be interpreted under conditions of periodic rains. Really, when it is raining (when the air relative humidity, as a rule, increases) the seeds become wet and their concentration in the air decreases. And after rain (when the air humidity is falling) the seeds dry off and their concentration in air gradually increases. Since during the first cycle of measurements the rains precipitated regularly, the occurrence of negative values of $\rho_{\alpha(\lambda)R}$ in the IR range is quite possible. It should be noted that the above mechanism, describing the implicit connection of the seeds concentration and the air relative humidity, makes an insignificant contribution to the variability of $\alpha(\lambda)$ (see the correlation level

$\rho_{\alpha(\lambda)R}$ in Table II). The above mechanism is used by the authors only for revealing the tendencies.

RURAL HAZE

From the analysis of Fig. 1 (curve *2*) and Table III follows that the rural haze is characterized by larger values of the aerosol extinction coefficients α at wavelengths ranging from 0.44 to 1.06 μm and also by a more pronounced spectral dependence $\alpha(\lambda)$ as compared with the urban haze. It is evident that these distinctions are due to not only different measurement areas but also due to different meteorological conditions of these measurements and, first of all, the relative air humidity R (see Table I). It should be kept in mind that with the increase of relative air humidity the spectral dependence of the coefficients $\alpha(\lambda)$ in hazes becomes more pronounced, and the absolute values of $\alpha(\lambda)$ in this case increase over the entire wavelength range.[8]

Since the measurement path is located near the river, then at night and especially in the morning the fogs of different density are often observed. In this case the relative air humidity is often higher than 95% (in fogs it is 100%). This results in the fact that the condensation processes involving aerosol are very active. This fact is clearly seen from the correlation coefficients between $\alpha(\lambda)$ and R varying from 0.51 to 0.61 that well exceeds the corresponding coefficients for urban haze. Practically neutral character of the correlation coefficients $\rho_{\alpha(\lambda)R}$ over the entire wavelength range leads to a clearly seen synchronous variation of the coefficients $\alpha(\lambda)$ at all wavelengths and is in full accordance with the time variation of R. It is evident that this experimental fact should be attributed to the peculiarity of rural haze, when in the absence of foreign pollution the natural aerosol of different size changes its optical and physical properties only as a result of interaction with the atmospheric moisture.

Analysis of spectral dependence of the autocorrelation coefficients $\rho_{\alpha(0.44)\alpha(\lambda)}$ (Table III) shows a very close connection of variations of aerosol extinction at all wavelengths. The general and very strong factor of synchronous variations of $\alpha(\lambda)$ is most likely the relative humidity of air. This assumption is supported, in particular, by the data from Figure 2, which shows the averaged spectral variations of aerosol extinction coefficients in rural haze for the three values of the relative air humidity. The fact that with the increase of humidity the increase of aerosol extinction coefficients, comparable in value, is observed (in both the wavelength ranges near 0.44 μm and 1.06 μm) is indicative of an equal influence of the air humidity in rural haze on the optical properties of particles of different size.

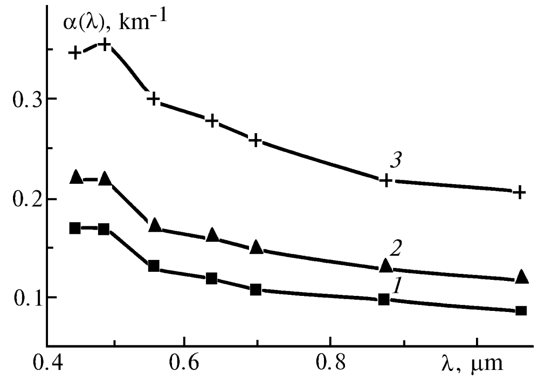

FIG. 2. Spectral structure of aerosol extinction coefficients in rural haze at relative humidity R = 63 *(curve 1),* 80 *(curve 2), and* 96 *per cent (curve 3).*

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