Obtaining the most probable value of the aerosol extinction coefficient of atmospheric haze from long-term series of observations along a near-ground horizontal path

R.F. Rakhimov, V.N. Uzhegov, E.V. Makienko, and Yu.A. Pkhalagov

Institute of Atmospheric Optics,
Siberian Branch of the Russian Academy of Sciences, Tomsk

Received December 14, 2004

Based on the long-term series of observations of the aerosol extinction of the atmosphere along a surface horizontal path near Tomsk, we analyze the interannual variability of the aerosol extinction coefficient $\beta_\varepsilon(\lambda)$ in the spectral region from 0.44 to 3.91 μm. The interannual stability of the most probable values is revealed. It is shown that the distribution of the frequency of occurrence for the aerosol extinction coefficient $N(\beta_\varepsilon)$ measured in the spectral region wavelength range from 0.44 to 3.91 μm is close to lognormal. Specific features of the annual observation series manifest themselves mostly in the range of the increased values of the aerosol extinction coefficient. The most significant fluctuations of the spectral values of the aerosol extinction coefficient in the region under study are caused by smoke of forest fires. The interannual variation of the left branch of the dependence approximating distribution of the frequency of occurrence $N(\beta_\varepsilon)$ are caused by variations in the statistics of arctic air mass invasions into the region under study.

Introduction

The specific features of the seasonal and diurnal variations of the optical and microphysical parameters of the disperse component of the atmosphere have been studied[1] based on the results of many-month spectral measurements of the aerosol extinction coefficient of the atmosphere $\beta_\varepsilon(\lambda)$ for radiation propagated along a near-ground path carried out in 2002 near Tomsk. The technique for numerical simulation of the elements of orthogonal expansion of the correlation matrix, which characterize the spectral variations of the aerosol extinction coefficient $\beta_\varepsilon(\lambda)$ under the influence of random and regular geophysical factors, was tested using the data obtained.

It was shown that statistical variety of seasonal and diurnal variations of the $\beta_\varepsilon(\lambda)$ spectral dependences is the result of variations of the content of particles in the size range of three aerosol fractions: $r < 0.45$ μm; $0.45 < r < 1.8$ μm; $r > 1.8$ μm. The interannual variability of the spectral values of the aerosol extinction coefficient in the optical region for a near-ground layer of the atmosphere is analyzed in this paper using data obtained during long-term measurements.

Initial data

The arrays of spectral values of the aerosol extinction coefficient in the wavelength range from 0.44 to 3.91 μm were involved in the analysis. These data are the measurement data obtained using a long near-ground path since 2000 until 2003. Measurements were carried out in different seasons (Table 1).

Table 1

Year	Month	$\overline{t}$, °C	t_{min}, °C	t_{max}, °C	$\overline{Rh}$, %	Number of realizations
2000	February	–8.1	–20.5	0.5	65.3	35
	March	–0.7	–13.5	9.3	63.0	150
	April	–4.1	–9.9	19.6	53.4	184
	May	13.9	–0.8	28.0	56.3	127
	June	19.26	7.4	29.8	64.9	188
	July	18.0	7.1	31.1	67.9	163
	August	17.6	6.8	29.7	72.8	167
2001	April	1.9	–13.4	18.2	56	157
	May	16.9	–1.3	33.5	50.5	291
	June	18.4	6.2	30.4	71.4	158
	July	18.9	6.9	28.2	73.7	113
2002	May	15.4	0.3	32.4	48.1	166
	June	17.5	3.2	29.2	66.2	262
	July	19.8	9.6	32.7	65.9	236
	August	16.8	8.2	35.0	69.1	254
	September	11.1	–1.7	25.8	62.7	274
	October	2.9	–10	16	56.7	154
2003	May	12.9	–0.9	24.3	50.7	103
	June	20.3	7.4	31.7	59.7	309
	July	18.7	9.1	32.6	64.2	306
	August	18.0	5.6	28.7	63.6	270
	September	11.3	0.4	26.4	70.5	193

The seasonal mean values of air temperature $\overline{t}$, its minimum and maximum values t_{min} and t_{max}, mean values of the relative humidity of air Rh, and the number of the obtained realizations N are presented in Table 1. It follows from the Table that the main

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statistics of measurements (3891 realizations) is related to the seasons with positive monthly mean air temperatures. Realizations of $\beta_\varepsilon(\lambda)$ measurements in winter 2000 are only poorly provided statistically (369 realizations). So one should consider the principal conclusions about the specific features in the formation of the aerosol component in the region as characteristics of interannual variations of the aerosol component during warm seasons.

To illustrate the interannual variability of the aerosol extinction coefficients in the same season, temporal dynamics of the values of the coefficients $\beta_\varepsilon(0.44)$; $\beta_\varepsilon(1.06)$ and $\beta_\varepsilon(3.91)$ obtained in July of the years 2000–2003 is shown in Fig. 1.

It is seen that the mean level and the amplitude of the variations of $\beta_\varepsilon(\lambda)$ noticeably change from year to year. The greatest atmospheric turbidities (average over the sample) were recorded in July 2002 ($\bar{}$,$\beta_\varepsilon(0.44) = 0.268$ km^{-1}), when numerous forest fires in the Western and Eastern Siberia occurred. The greatest amplitudes of variations of the values $\beta_\varepsilon(0.44)$ were recorded in the same period. The atmosphere was cleanest (according to July data) in 2001 ($\bar{}$,$\beta_\varepsilon(0.44) = 0.178$ km^{-1}).

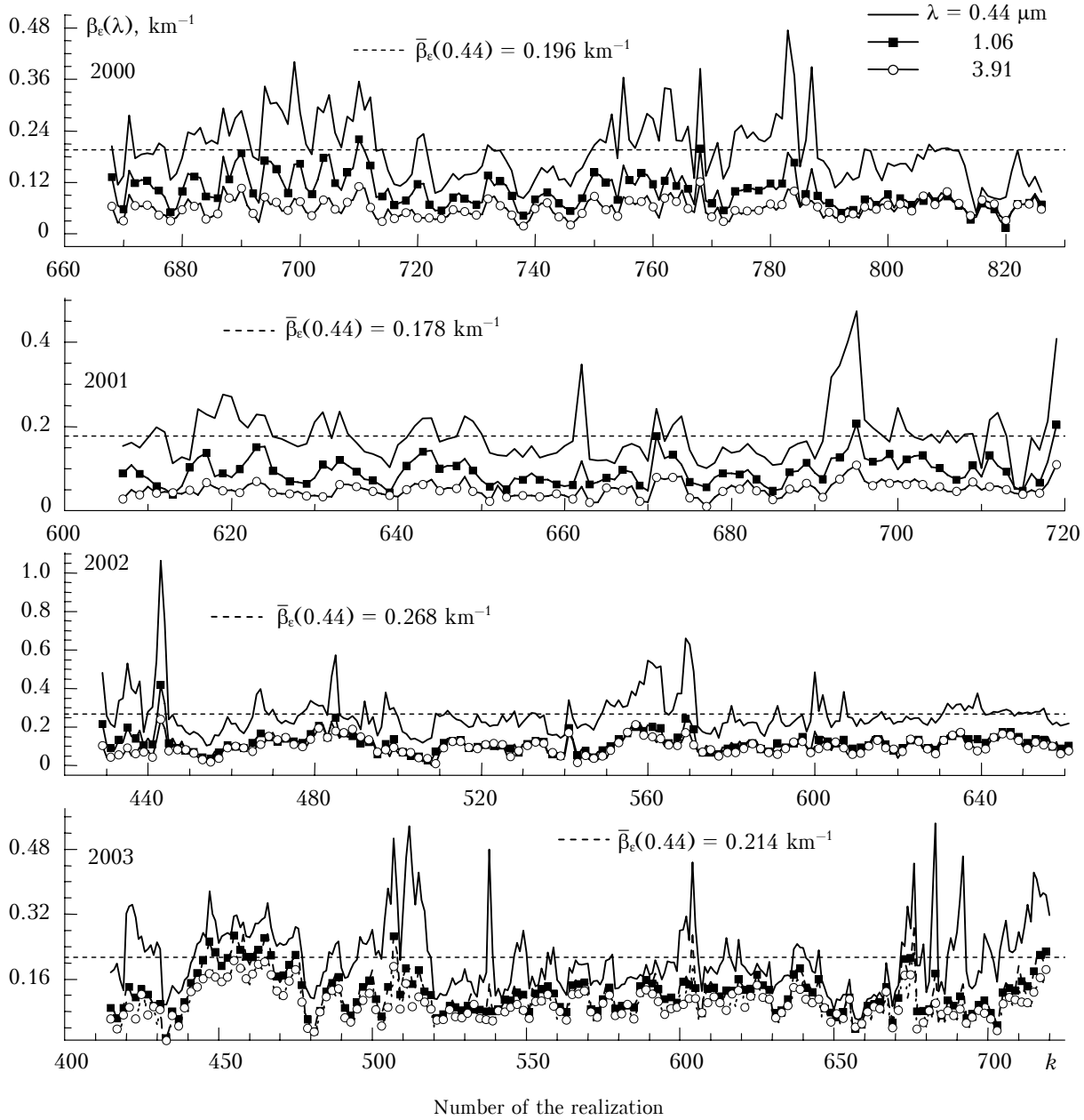

Fig. 1. Temporal dynamics of the July values of the aerosol extinction coefficient at the wavelengths of 0.44, 1.06, and 3.91 μm.

Results

Not only mean values of the aerosol extinction coefficients were used for analysis of interannual variations of the aerosol component, but also histograms of the distribution density $N(\beta_\varepsilon)$ of the measured $\beta_\varepsilon(\lambda_i)$ values in the characteristic range of the annual variability.

To estimate the distribution density $N(\beta_\varepsilon)$, the characteristic range of variability of β_ε was divided into equal parts, and the number of realizations in each part served the estimate of the frequency of occurrence of the extinction coefficient value in the specific annual sample.

Figure 2 shows the curves characterizing interannual variability in the distribution of the parameter $N(\beta_\varepsilon)$ at three wavelengths 0.44, 1.06, and 2.17 μm constructed based on the measurement data obtained in 2000–2003 since March to October inclusive.

It is seen from the data presented that the distributions of the frequency of occurrence obtained in different years are different in their amplitudes and half-width. At the same time, it is very interesting that the maxima of these distributions at all wavelengths are observed each year approximately in the same range of the $\beta_\varepsilon(\lambda)$ values (see details in Fig. 3*a*).

The range of the $\beta_\varepsilon(\lambda)$ values situated near the maximum of the distribution, by definition, corresponds to the most probable value (MPV) of the aerosol extinction coefficient for optical radiation in the hazes of the considered region. Let us denote it $\beta^*,_\varepsilon(\lambda)$.

It also follows from Fig. 3*a* that interannual differences in the distributions of the parameter $N(\beta_\varepsilon)$ are mainly seen in the range of the enhanced values of the aerosol extinction coefficient, which are considered below as "disturbed" states of the aerosol component.

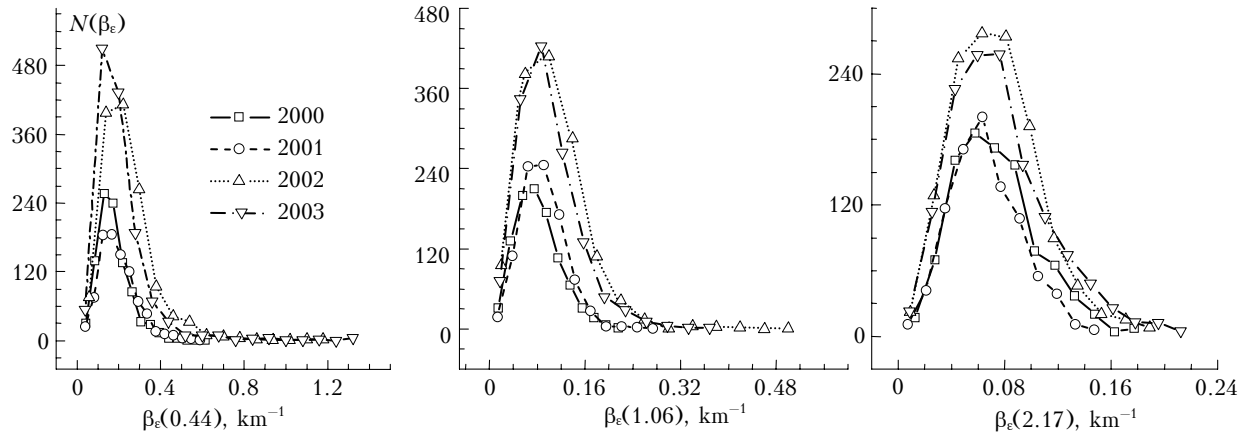

Fig. 2. Statistical distribution of the values of the aerosol extinction coefficient in the range of interannual variability at three wavelengths in the period from 2000 to 2003.

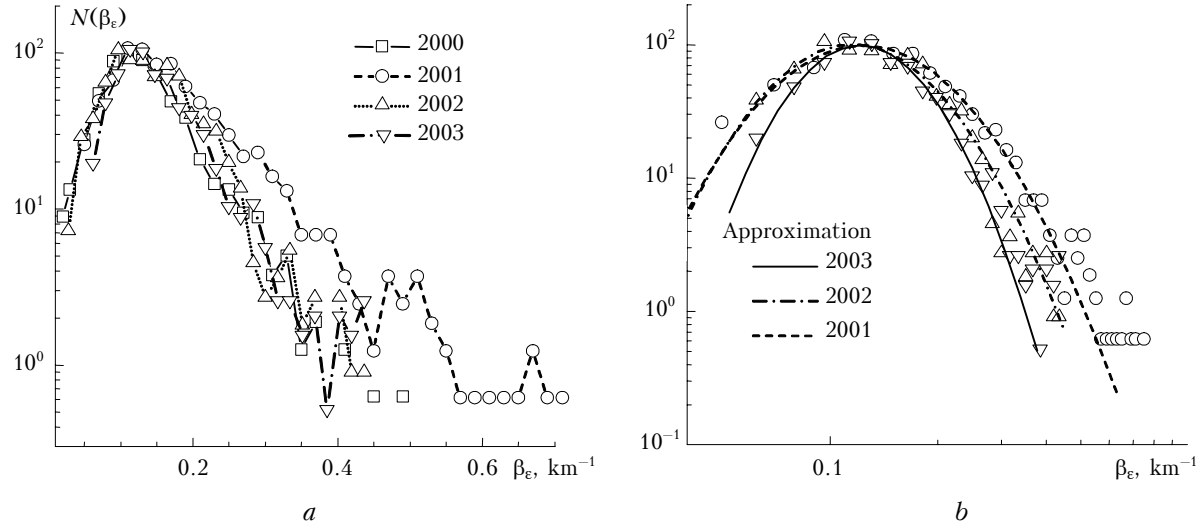

Fig. 3. Model approximation of the histograms of distribution of the frequency of occurrence of the values of the aerosol extinction coefficient $N(\beta_\varepsilon)$ measured in different years at the wavelength of the optical radiation $\lambda = 0.56$ μm: abscissa axis in linear scale (*a*) ; abscissa axis on the logarithmic scale (*b*) .

Detailed analysis of the annual series of spectral measurements of $\beta_\varepsilon(\lambda, k)$ has shown that statistical distribution of the values of the aerosol extinction coefficient in the range of the most probable values is quite well approximated by logarithmic normal distribution (Figs. 3*b* and 4*c*). The correlation coefficient between the measured values and the values of the approximating lognormal curve for the totality of empirical data is 88–97%.

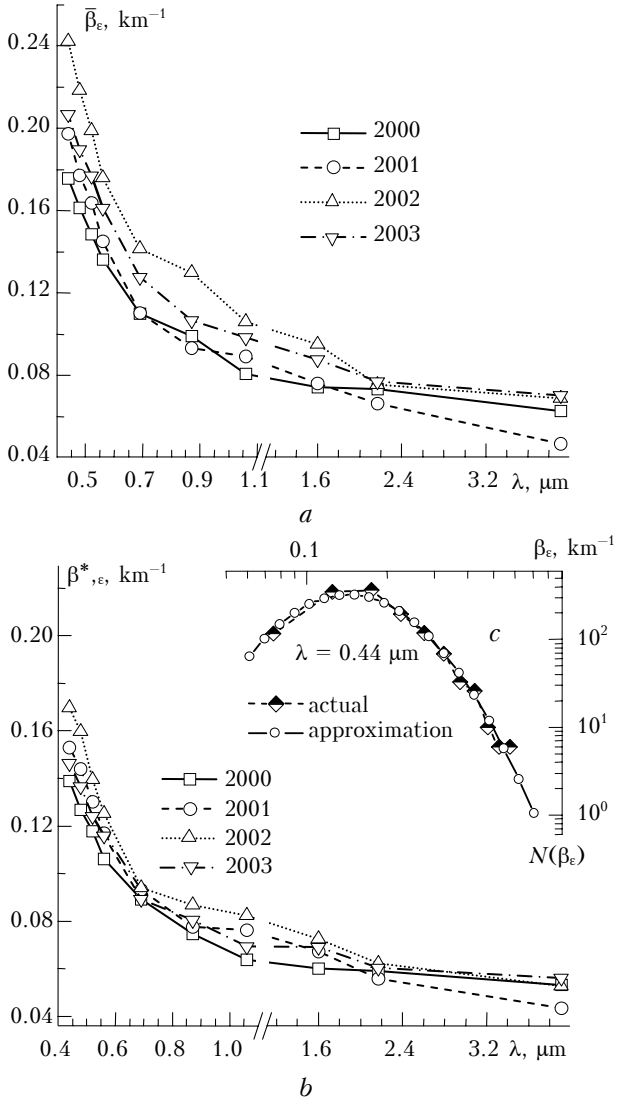

Fig. 4. Spectral change of the mean (*a*) and most probable values (*b*) of the aerosol extinction coefficient; an example of the model approximation of the frequency of occurrence at 0.44 μm wavelength (*c*).

This fact has allowed us to solve one of the important problems of this paper, to obtain reliable estimate of the most probable values of the aerosol extinction coefficient in the entire wavelength range. The matter is, that the relationship between the random and regular components of the error in experimental estimates of the values $\beta_\varepsilon(\lambda)$ from the spectral range of measurement can change due to not only some peculiarities in the instrumental technique, but also due to the variety of atmospheric situations. The relative contribution of different gaseous components to the extinction of optical radiation undergoes noticeable changes during a year. In order to obtain unambiguous estimate $\beta^*_{,\varepsilon}(\lambda)$ from experimental distribution $N(\beta_\varepsilon)$ at some wavelengths, it is necessary to have greater statistics of measurements, because they can have weakly pronounced maximum due to insufficient statistics (see, for example, Fig. 3*b*, the data of 2001).

Justified application of the model approximation of experimentally determined statistics $N(\beta_\varepsilon)$ by lognormal distribution (constructed from 10 and more points of histograms) enables one to obtain more reliable and unambiguous estimates of the most probable values $\beta^*_{,\varepsilon}(\lambda)$. An example of such an approximation at $\lambda = 0.56$ μm is shown in Fig. 3*b*, from which the estimate of the most probable value of the coefficient $\beta^*_{,\varepsilon}(0.56) \sim 0.116$ km^{-1} follows unambiguously.

According to long-term measurements of the aerosol extinction coefficient at the wavelength of 0.56 μm, about 84% of its values do not exceed 0.2 km^{-1}. Analogous situation is observed at other wavelengths. In other words, the data used in the analysis provide a good basis for physically justified conclusions, because they are based on the results of prevalent statistics of the measurements.

Earlier[3] we considered a situation of replacing the mid-latitude air mass (AM) enriched with smoke aerosol, by Arctic mass. The rare case of anomalous spectral dependence of the coefficient $\beta_\varepsilon(\lambda)$ was observed there, that was caused by the dramatic decrease of the content of accumulative fraction in the Arctic AM.

Comparison of the most probable values obtained in the present paper with the estimates of the aerosol extinction $\beta_\varepsilon(0.56)$ in Arctic AM[3] shows that those are approximately 2 to 2.5 times less than MPV. That means, that the content of particles of accumulative fraction ($r < 0.44$ μm) in the Arctic AM is noticeably less than the most probable level of their content in the atmosphere observed in long-term series of measurements in this region. Then the first conclusion follows that the aerosol component in warm season (close to the most probable) in the near-ground layer of the region under study is formed mainly by not Arctic AM.

Statistics of the $\beta_\varepsilon(0.56)$ variations shows that the aerosol component is distributed inhomogeneously in other air masses crossing the path. The measured $\beta_\varepsilon(0.56)$ values in some realizations exceed the level of MPV by 5 to 7 times, that can be considered as non-typical aerosol turbidity of the atmosphere.

The second conclusion from the results shown in Fig. 3 is that the "disturbed" states of the disperse component at the site of observation during the inner atmospheric development relatively rare reach minimum (background) values. The time series of

observations of $\beta_\varepsilon(\lambda, k)$ (see Fig. 1) show that the periods of enhanced turbidity often alternate with relatively clear air situations in the near-ground layer, that is an evidence of the essential inhomogeneity of aerosol distribution over the air mass.

Variations of the level of aerosol content predetermine different rate of development of the disperse mixture and duration of the cycle of relaxation of aerosol anomalies to the stage of quasi-equilibrium. So, the most probable values represent not only the local background level, but some cyclic mean, or statistically mean result of relaxation of many aerosol-plus-gas anomalies coming with air masses of different types. At the same time, at the stages with MPV the $\beta_\varepsilon(\lambda)$ values are the result of incomplete relaxation, and the atmospheric region under study is the zone of enhanced aerosol load.

It was shown[1,3] that the main reason for dramatic changes in the atmospheric turbidity due to aerosol load along the measurement path is the enhanced content of the accumulative aerosol fraction. Numerous inflammations of wood materials in boreal forest zone play important role in the formation of the aerosol component in the near-ground layer of the atmosphere (NGLA) in warm seasons. Local peaks of anomalously high values of the aerosol extinction coefficient were occasionally recorded by the instrumentation, as a rule, at crossing the measurement path by AM enriched with smoke aerosols.

At the same time, it is well known that the main mechanism of appearance of particles in the size range of the accumulative fraction is the complex of internal atmospheric processes determining the formation of particles from vapors of aerosol producing compounds with subsequent continuous coagulation growth. In this context, it seems that terminological combination "aerosol-plus-gas anomalies" more correctly presents the processes determining variations of the level of aerosol turbidity of the atmosphere.

The third conclusion follows from relative rareness of the values of aerosol extinction at the level of 0.03–0.05 km^{-1} (with spectral behavior in the visible and near IR wavelength range close to neutral) characteristics of the Arctic region, in Tomsk. It lies in quite fast reaction of Arctic AM to the local factors of formation of the accumulative fraction in NGLA. As Arctic air mass moves to the continent, its near-ground part is enriched with particles of accumulative fraction due to the activity of local sources. This circumstance explains the dramatic decrease of the left branch (see Fig. 3*b*) of the frequency of occurrence $N(\beta_\varepsilon)$ distribution.

Thus, analysis of the obtained results shows that the peculiarities of formation of the aerosol optical weather in the region of measurements and its variations are caused by specific sequence of air masses change including Arctic, mid-latitude continental, etc.[3]

The spectral values of the aerosol extinction coefficient, for which the values of the frequency of occurrence $N(\beta_\varepsilon)$ reach their maximum $\beta^*_{,\varepsilon}(\lambda)$ were estimated by means of analytical approximation of the frequency spectra in the vicinity of the most probable values. The estimates were obtained for each wavelength, the list of which from measurements in 2000–2003 is presented in Table 2.

Table 2. The most probable values of the spectral aerosol extinction coefficients $\beta^*_{,\varepsilon}(\lambda)$ (km^{-1}) in the hazes of Western Siberia in warm seasons

λ, μm		Year			
		2000	2001	2002	2003
0.44		0.139	0.153	0.166	0.146
0.48		0.127	0.144	0.160	0.136
0.52		0.118	0.130	0.140	0.124
0.56		0.106	0.117	0.125	0.116
0.69		0.089	0.093	0.094	0.089
0.87		0.075	0.078	0.087	0.080
1.06		0.064	0.076	0.082	0.069
1.60		0.060	0.067	0.072	0.069
2.17		0.059	0.056	0.062	0.060
3.91		0.053	0.038	0.053	0.056
0.44	Min	0.025	0.039	0.033	0,023
	Mean	0.176	0.197	0.242	0.211
	Max	0.603	0.574	1.198	1.343
Number of realizations		975	902	1346	1183

The "annual mean values" of the aerosol extinction coefficient in the range $\lambda = 0.44$ μm, as well as its maximum and minimum values are presented at the bottom of the Table. "Annual mean" here and below means mean values over warm season of the year. The important conclusion follows from the presented data, that the coefficients $\beta^*_{,\varepsilon}(0.44)$ have significantly less interannual scatter as compared with that of the "annual mean" values.

To quantitatively estimate the interannual stability of the spectra $\beta_\varepsilon(\lambda)$ and $\beta^*_{,\varepsilon}(\lambda)$ in the entire wavelength range, the mean values and rms deviations of these two parameters are presented in Table 3.

Table 3. Many-year (mean and most probable) values of the spectral aerosol extinction coefficients in the hazes of Western Siberia

λ, μm	Mean		Most probable	
	$\bar{}\,,\beta_\varepsilon(\lambda)$	rms deviation	$\bar{}\,,\beta^*_{,\varepsilon}(\lambda)$	rms deviation
0.44	0.205	0.028	0.152	0.013
0.48	0.187	0.024	0.142	0.014
0.52	0.172	0.021	0.128	0.009
0.56	0.155	0.018	0.116	0.008
0.69	0.122	0.015	0.091	0.002
0.87	0.107	0.016	0.08	0.005
1.06	0.094	0.011	0.073	0.008
1.60	0.083	0.010	0.067	0.005
2.17	0.073	0.005	0.059	0.003
3.91	0.062	0.011	0.051	0.006

Comparison of rms deviations of the "annual mean" and most probable values of the coefficients $\beta_\varepsilon(\lambda)$ characterizing the scatter of the data taking into account their mean values is unambiguous evidence of the fact that $\beta^*_{,\varepsilon}(\lambda)$ spectra are significantly more stable from year to year, in contrast to the "annual mean." It is also well seen from Fig. 4, which shows the "annual mean" spectral dependences of the aerosol extinction coefficient $\beta_\varepsilon(\lambda)$ and corresponding spectra of the $\beta^*_{,\varepsilon}(\lambda)$ coefficients.

For microphysical interpretation of the obtained data, the mean spectra of $\beta^*_{,\varepsilon}(\lambda)$ were inverted by means of the technique discussed in Refs. 1 and 3. Corresponding size spectra of the atmospheric haze particles obtained from the data of measurements in 2000–2003 are shown in Fig. 5.

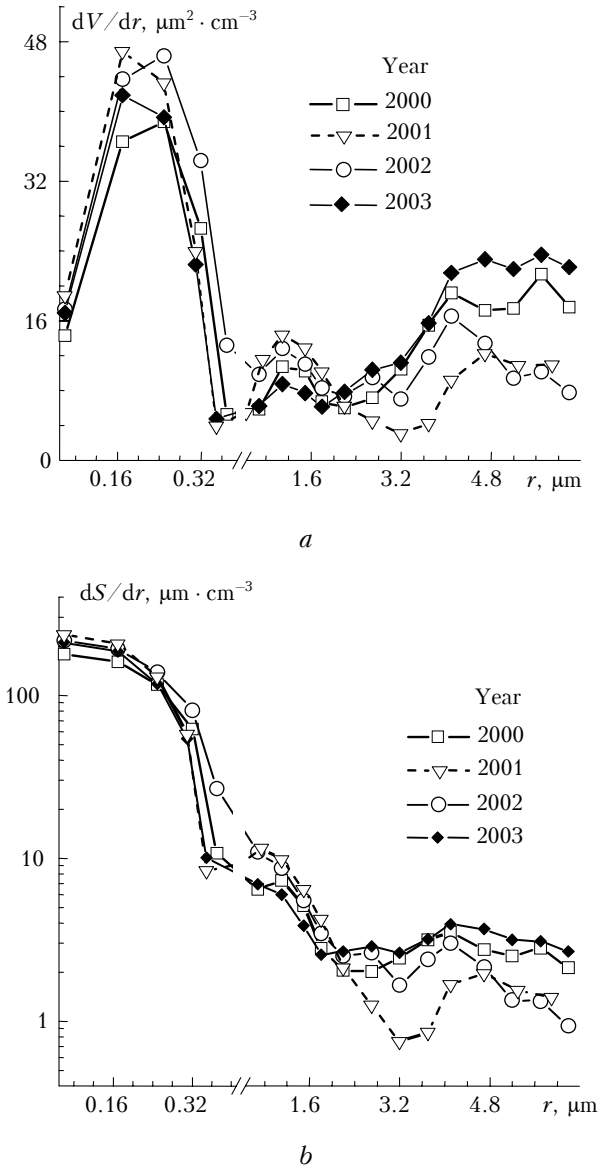

Fig. 5. Size spectra of particles of atmospheric haze retrieved from the data on $\beta^*_{,\varepsilon}(\lambda)$.

The results of inversion confirm the assumption about stability of the shape of the size spectrum of accumulative fraction. The particle size spectrum is also quite stable in the range of intermediate fraction $0.45 < r < 1.8$ μm. Variations of the content of large particles with $r > 2.0$ μm (Fig. 5*a*) are, possibly, related to the increase of the errors in measurements in the infrared wavelength range.

The estimates of the total cross section S_t and the volume V_t of particles of all fractions are shown in Table 4, as well as the volume content of the accumulative V_a, intermediate V_{id}, and coarse V_c fraction calculated from the spectra of the coefficients $\beta^*_{,\varepsilon}(\lambda)$ retrieved for each year (Fig. 5).

Table 4. Integral parameters of the size spectra retrieved in different size ranges

Parameters	Year			
	2000	2001	2002	2003
S_t, μm² · cm⁻³	65	72	73	68
V_t, μm³ · cm⁻³	86	62	73	97
V_a ($r < 0.4$ μm)	9	10	12	9
V_{id} ($0.4 < r < 2.0$ μm)	12	19	16	11
V_c ($r > 2.0$ μm)	64	32	45	76
V ($r \geq 0.4$ μm	76	51	61	88

The inversion results show that the total cross section (for MPV) weakly changes from year to year. The increase of the content of intermediate fraction in 2001–2002, when the noticeable effect of forest fires was observed, attracts one's attention. This fact does not contradict the principal conclusion about interannual stability of the most probable states of the aerosol component in the near-ground layer, because the optical significance of their variations is not great. At the same time, the estimates obtained from the inversion results specify the degree of the effect of some factors in the mechanism of formation of the MPV. In particular, the fact that no enhanced content of the particles of intermediate fraction was observed in 2003, means that the duration of the cycle of assimilation of smoke emissions of forest fires by undisturbed areas of AM does not exceed the winter time, and duration of the cycle of relaxation of individual anomalies to the most probable states is yet shorter.

The enhanced content of intermediate-size fraction of aerosol coincides with the decrease of the content of coarse fraction. This agrees with one of the conclusions[4,5] that the convective component of turbulent mixing becomes weaker at the anomalous increase of the content of smoke aerosol in the atmospheric column, and efficiency of the emission of coarse aerosols from the underlying surface decreases.

The aforementioned interannual stability of the most probable values of the aerosol extinction coefficient in the wide wavelength range is a non-trivial result, and, to some extent, unexpected (for the near-ground layer), so it requires additional discussion.

Indeed, according to its position, the near-ground layer of the atmosphere is an active zone of disturbing effects of inhomogeneously distributed primary and secondary aerosol sources, as well as of complicated changes of the meteorological conditions. So quite ambiguous statistics of the states of the aerosol component is observed in the long series of optical measurements (Fig. 1), which characterizes not only the properties of the ground-based sources but also the horizontal inhomogeneity of aerosol filling of air masses crossing the measurement path.

The most noticeable interannual differences in the statistics of distributions of the values $\beta_\varepsilon(0.56\ \mu m)$ (see Fig. 3) are observed in the range of high and low values. The arctic AM, which forms the statistics of realizations with high aerosol transparency in some years in the region under study (see histogram of the distribution $N(\beta_\varepsilon)$ in 2003 in Fig. 3), noticeably deform the left branch of the distribution $N(\beta_\varepsilon)$, deviating it (in the range of high transparencies) from the main tendency of the lognormal distribution. Analogously, quite high percent of significant turbidities with $\beta_\varepsilon(0.56\ \mu m) > 0.5\ km^{-1}$, falling out of the general lognormal tendency of $N(\beta_\varepsilon)$ was observed in 2001, that, evidently, is caused by enhancement of the annual statistics due to forest fires close to the measurement path.

Comparison of the histograms of the frequency of occurrence $N(\beta_\varepsilon)$ obtained from the results of measurements in different years shows that their shape in the range of high transparencies and strong turbidities depends on the specific annual statistics of different types of AM invasion to the region.

Nevertheless, in spite of the aforementioned list of factors determining the mobility of the state of the aerosol component, the measurement results have shown that the shape of the statistical distribution in the ranges close to MPV of the extinction coefficient weakly changes from year to year not only in the visible but also in the IR wavelength range. Interannual shifts of MPV of the aerosol extinction coefficient are, on the average, 2–7% (Fig. 4).

What is the reason for interannual stability of MPV? The aforementioned peculiarities of the obtained results enable us to assume that the heated aerosol-plus-gas anomalies transferred in the atmosphere by air flows from the fire centers initially fill the limited space inside the AM and can not be retained during long time because of spatial inhomogeneity of the aerosol fractions in them. They are unstable, non-equilibrium states.[3]

The exchange processes between atmospheric stratifications occurring during transfer of aerosol anomalies cause their continuous redistribution over the AM. The results of these processes depend on the effect of different combinations of geophysical factors,[2] including diurnal variations of meteoparameters (temperature, relative humidity, height of the mixing layer) and interseasonal trends in their mean values.[1]

In the process of the anomalies diffusion the aerosol components not only reach the quasi-equilibrium stages and characteristic (or MPV) level of the number density of particles of accumulative fraction, but gradually reduce the efficiency of kinetic changes, passing to the stages close to self-saving the size spectrum shape,[6,7] that is observed in the results obtained by inverting the optical data (see Fig. 5). Disperse aerosol mixtures in these states gradually fill the vast areas of AM, providing effective assimilation of anomalous aerosol emissions. Lognormal distribution of the MPV is the consequence of this universal process and, partially, the specific regional conditions.

In this context, the retrieved parameters of microstructure of the accumulative fraction for the most probable states are the experimental estimate of the values of the kinetically caused parameters of submicron aerosol fraction, the technique for estimation of which was proposed in Ref. 4. According to G.V. Rosenberg,[8,9] "aerosol component in the atmosphere is the continuously developing process." According to the data obtained in the near-ground layer, one should add – "reaching its quasi-equilibrium."

Asymmetry of the right- and left-hand branches of the histogram of the distribution of the frequency of occurrence $N(\beta_\varepsilon)$ (see Fig. 3) is an evidence of the fact that the statistics of the disturbed states is formed mainly in the evolution of submicron fraction (smoke anomalies) from the fire centers situated far from the measurement path, only fine aerosol fraction mainly comes to the region. The scatter of the $\beta_\varepsilon(\lambda)$ values and the most probable values in the IR range are approximately comparable (see Fig. 4), while the interannual deviations in the visible range at passing from the most probable values to the mean ones increase from 5–7 to 40–55%.

Interannual stability of the MPV of the aerosol extinction coefficient in the IR range, where the optical influence of the coarse fraction prevails, is an evidence of the relative stability of the level of the content of large particles in the disperse composition of haze. Disturbances caused by seasonal variations in the influence of the primary aerosol sources do not cause essential shifts of the most probable content of the coarse fraction.

Conclusions

Histogram of the frequency of occurrence distribution of the values of aerosol extinction coefficients measured along a near-ground path in the spectral range from 0.44 to 3.91 μm is close to the lognormal distribution. The correlation coefficient between the measured values and the approximating curve in the range close to MPV is 88–97%.

The most essential variations of the spectral values of the aerosol extinction coefficient in the region are caused by disturbances introduced by smoke from forest fires. Interannual variations of the

left-hand branch of the approximating dependence of the $N(\beta_\varepsilon)$ distribution are caused by the change in the statistics of the Arctic air mass invasions.

Realizations of the most probable values of the atmospheric transparency in 2000–2003 in one range of values is, evidently, caused by the absence of any essential interannual trend of conditions of formation of the accumulative fraction of aerosol during the period of observations.

Acknowledgments

The work was supported in part by ARM program (contract No. 5012) and Russian Foundation for Basic Research (grant No. 04–05–65197).

References

1. R.F. Rakhimov, V.N. Uzhegov, E.V. Makienko, and Yu.A. Pkhalagov, Atmos. Oceanic Opt. **17**, Nos. 5–6, 339–357 (2004).
2. M.V. Panchenko, Yu.A. Pkhalagov, R.F. Rakhimov, S.M. Sakerin, and B.D. Belan, Atmos. Oceanic Opt. **12**, No. 10, 883–894 (1999).
3. E.V. Makienko, R.F. Rakhimov, Yu.A. Pkhalagov, and V.N. Uzhegov, Atmos. Oceanic Opt. **16**. No. 12, 1008–1012 (2003).
4. E.V. Makienko, R.F. Rakhimov, S.M. Sakerin, D.M. Kabanov, and V.N. Uzhegov, in: *Proc. of the 5th Intern. Conf. "Wildlife Fires: Initiation, Spread, Suppressing and Ecological Consequences"* (Krasnoyarsk, 2003), pp. 285–287.
5. V.S. Kozlov, M.V. Panchenko, V.V. Pol'kin, Yu.A. Pkhalagov, V.N. Uzhegov, N.N. Shchelkanov, and E.P. Yausheva, Atmos. Oceanic Opt. **12**, No. 5, 390–394 (1999).
6. S.K. Friedlander, J. Meteorology **17**, No. 10, 479–483 (1960).
7. S.K. Friedlander, J. Meteorology **18**, No. 12, 753–759 (1961).
8. G.V. Rosenberg, Izv. Akad. Nauk SSSR, Fiz. Atmos. Okeana **19**, No. 1, 21–35 (1983).
9. G.V. Rosenberg, Izv. Akad. Nauk SSSR, Fiz. Atmos. Okeana **19**, No. 3, 241–254 (1983).