Fluctuations of microstructure of the coarse and fine aerosols in arid zones

A.V. Karpov

A.M. Obukhov Institute of Atmospheric Physics, Russian Academy of Sciences, Moscow

Received February 2, 2008

The size distribution function for aerosol particles, generated on the underlying surface by sand-wind flow, is reconstructed from the measured fluctuations in the arid aerosol microstructure in a deserted area. An estimate for the threshold wind velocity is obtained for the case when submicron and coarse-dispersed aerosol is carried out from the underlying surface.

Introduction

Earlier measurements of fluctuations in differential number concentrations of aerosol particles in the arid coastal region of Aral Sea[1–3] made it possible to reconstruct the microstructure of aerosol components, generated on the underlying surface under effect of the sand-wind flow, in a size range 0.3–1.6 μm.[4–6] In this paper, we reconstruct the size distribution function for the above-mentioned aerosol component in a range 0.5–5.0 μm from the measurement data on fluctuations in the aerosol microstructure in August, 2007 in Kharabali site of Astrakhan Region[7,8] (the nature reserve "Berli Peski"). Fluctuations in the aerosol microstructure were compared with turbulent pulsations of wind velocity components.[9]

Instrumentation

Fluctuations in differential number concentrations of aerosol particles were measured with the optoelectronic particle counter OEAC-05 designed at L.Ya. Karpov Scientific Research Institute of Physical Chemistry and registered in the Russian State Register of Measurement Tools (RU.E.31.002.A No. 134713047/1). Table 1 presents numbers of the counter channels, range boundaries, and average diameters of particles in the channels.

The measurement range for number concentration of aerosol particles was between 1 and 10^3 particles/cm^3 in all above-mentioned channels. The limit of accessible relative measurement error for the number concentration of aerosol particles (at the number of measured particles in each channel not less than 100) was ±20%. The particle counter was controlled by a PC: the measurement interval and the number of series were the input data. The measurements were recorded to a hard disc and displayed in the real-time mode. The number concentrations were averaged over nine-second intervals. The length of the averaging interval was chosen based on the compromise between a sufficiently high time resolution and statistical resources for the measured concentrations (for more detail see Ref. 11).

The particle counter was mounted at a height of 1 m, and the air intake was oriented toward the air flow. At a distance of about 10 m from the counter, two acoustic meteorological stations, Meteo-2M (made at Institute of Atmospheric Optics, Tomsk) and Metek were mounted at a height of 2 m, which recorded three components of wind velocity and air temperature with a time resolution of 0.1 sec.

Discussion

Fluctuations of aerosol differential number concentrations

The microstructure and differential number concentrations of the arid aerosol were measured in August, 2007 in a sandy arid territory (Astrakhan Region). A bounded sandy area (about 100×150 m) was chosen for measurements, aiming at more reliable separation of contributions of two aerosol components: the background one and generated by the wind-sand flow on the underlying surface.

Table 1. Specifications of the particle counter OEAC-05 and characteristics of arid aerosol

Channel number	1	2	3	4	5	6
Size ranges, μm	0.5–0.7	0.7–1.0	1.0–1.5	1.5–2.0	2.0–3.0	3.0–5.0
Average diameter, μm	0.6	0.85	1.25	1.75	2.5	4.0
Background distribution, cm^{-3}·μm^{-1}	2.5	0.73	0.25	0.12	0.05	0.02
Distribution of a generated aerosol component, cm^{-3}·μm^{-1}	0.86	0.73	0.26	0.20	0.07	0.02
Correlation coefficient ρ_i^*	0.912	0.964	0.958	0.948	0.907	0.881

0235-6880/08/10 733-05 $02.00

Figure 1 presents the turbulent pulsations (time averaging is 1 sec) of the wind velocity modulus (curve *1*) and fluctuations of the total concentration N of arid aerosol with sizes more than 0.5 μm (*2*), measured in August 14, 2007.

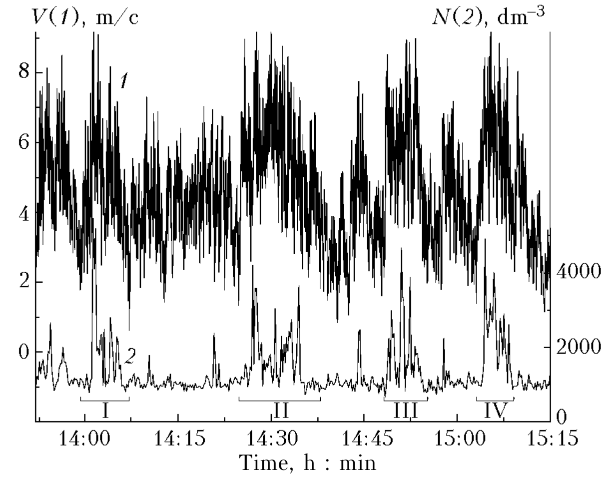

Fig. 1. Fluctuations of the horizontal wind velocity modulus (*1*) and number concentration of aerosol particles, whose sizes are more than 0.5 μm (*2*) according to the measurements on August 14, 2007 in the natural reserve "Berli Peski," Astrakhan Region (I, II, III, and IV are distinguished gusts and aerosol spikes).

According to our measurements, the results are typical for arid territories of Kalmykia and Astrakhan Region at an average wind velocity of less than 7–8 m/sec. The average wind velocity at a height of 2 m in the considered period was 4.6 m/sec.

According to classification proposed in Ref. 1, the spiking regime of fluctuations in the aerosol microstructure took place during the considered period, which was due to the spiking regime of aerosol generation on the underlying surface under action of a sand-wind flow.[4,6,10–12]

Figure 1 illustrates a typical situation under wind drift of submicron and coarse-dispersion aerosol from deserted territories.[2,6] It is easy to see that aerosol spikes are observed at gusts. In Fig. 1 the strongest gusts and corresponding spikes of the aerosol number concentrations are marked (I, II, III, and IV). Between the spikes, the number concentration of aerosol particles remains almost constant. Under conditions of our experiment, it is determined by the background aerosol component. Statistical characteristics[13] of variation of particle concentration N were calculated. For the case, presented in Fig. 1, the mean concentration of particles $\bar{N}$ turned to be equal to 1350 dm^{-3} at the standard deviation $\sigma = 700$ dm^{-3}. The empiric distribution function (EDF) for N (Fig. 2) has a distinct asymmetry

$$A = n^{-1}\sigma^{-3}\sum\nolimits_k (N_k - \bar{N})^3 = 2.75$$

and a comparatively high excess[13,14]

$$E = -3 + n^{-1}\sigma^{-4}\sum\nolimits_k (N_k - \bar{N})^4 = 9.06.$$

In the first approximation, EDF for N (Fig. 2) can be represented as a sum of two lognormal distributions[13]

$$p(\log N) = 96\exp\{-200(\log N - 3)^2\} + \\ + 19\exp\{-13.2(\log N - 3.2)^2\},$$

where p is the approximating distribution of probabilities.

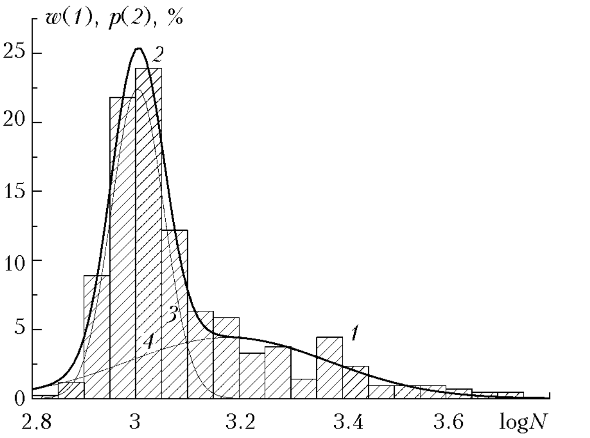

Fig. 2. The empiric distribution function w(*1*), the first (*3*) and second (*4*) modes, and total (*2*) approximating distribution for the logarithm of number concentration of particles, whose size exceeds 0.5 μm, according to the data of measurements on August 14, 2007 in the natural reserve "Berli Peski," Astrakhan Region.

Analysis of measurements of fluctuations in the aerosol microstructure shows that the differential number concentrations of particles N_i ($i = 1\div6$) of submicron and coarse-dispersed aerosol in size range from 0.5 to 5.0 μm fluctuate synchronically. This agrees with the earlier results for the particle size range 0.3–1.6 μm.[1] As an example, figure 3 presents the measurement results on differential number concentrations of particles for the size range 0.5–0.7 (curve *1*) and 1.0–1.5 μm (*2*).

We calculated the matrix of the correlation coefficients ρ_{1k} (Table 2) between variations of number concentration of particles in different size ranges. In particular, coefficients ρ_{1k} of correlation between the particle concentration in the first channel and the concentrations of particles in other channels vary within 0.747–0.835 (see Table 2).

Correlation coefficients ρ_i^* of differential number concentrations N_i with total concentration N (particle size is larger than 0.5 μm) are even larger: 0.881–0.964 (see Table 1). The observed correlation coefficients ρ_{1k} and ρ_i^* can be even larger if to use counters of aerosol particles with countable volume optimized in parameters of statistical support of measurements of the aerosol number concentrations.

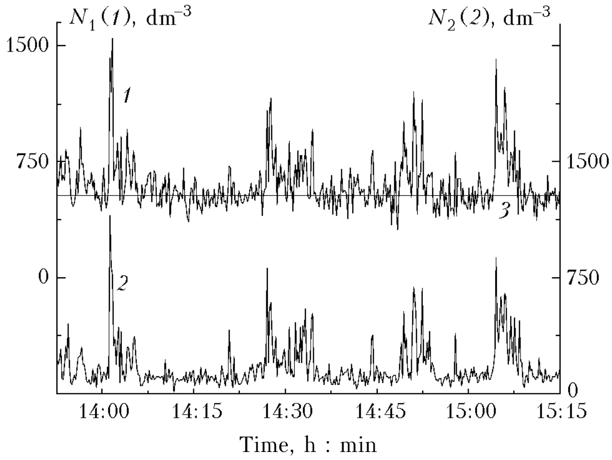

Fig. 3. Fluctuations of number concentrations of aerosol particles of 0.5–0.7 μm (*1*) and 1.0–1.5 μm (*2*) according to the measurement data on August 14, 2007 in the natural reserve "Berli Peski," Astrakhan Region (*3* is the background aerosol concentration).

Table 2. Coefficients of correlation between differential number concentrations of aerosol particles

Size ranges, μm	0.7–1.0	1.0–1.5	1.5–2.0	2.0–3.0	3.0–5.0
0.5–0.7	0.835	0.826	0.821	0.776	0.747
0.7–1.0	1	0.912	0.899	0.851	0.823
1.0–1.5		1	0.906	0.858	0.843
1.5–2.0			1	0.859	0.844
2.0–3.0				1	0.818

A high correlation between fluctuations in concentrations of different particles points to synchronous generation of submicron and coarse-dispersed particles up to 5 μm in a sand-wind flow.[1]

Distribution functions for the background aerosol and the aerosol, generated on the underlying surface

If the aerosol microstructure fluctuations are measured at bounded deserted (sandy) areas, the concentration of submicron and coarse-dispersed aerosol particles is determined almost solely by the background component of aerosol. Parameters of this component vary within narrow limits in our case (see Figs. 1 and 3). So the differential number concentrations of background aerosol $N_i^{\rm b}$ may be treated as constant in the considered period. In particular, line *3* in Fig. 3 determines the background level of concentration for aerosol particles with 0.5–0.7 μm in size. Thus, the relation

$$N_i^{\rm g}(t) = N_i(t) - N_i^{\rm b}, \qquad (1)$$

where t is time, yields particle differential number concentrations of aerosol generated on the underlying surface.

Figure 4 presents the particle size distribution function $g_{\rm b}(D)$, which was obtained by us (curve *1*). It can be satisfactorily approximated by the power function

$$g_{\rm b}^*(D) = C_{\rm b}(D/D_0)^{\nu_{\rm b}}, \qquad (2)$$

where $C_{\rm b}$ is a constant and D_0 = 1 μm. The index of the power $\nu_{\rm b}$ is equal to −2.50 in our case. The approximating function $g_{\rm b}^*(D)$ (*2*) for the background component of aerosol underestimates the concentration of particles within a size range 0.5–0.7 μm as compared to the observed distribution (see Fig. 4). Possibly, it cannot be extrapolated to the submicron range of particle sizes less than 0.5 μm. The values of $g_{\rm b}(D)$ for six size intervals are presented in Table 1.

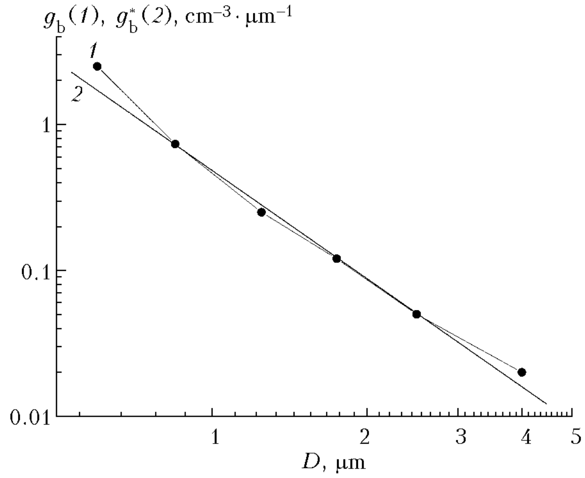

Fig. 4. Particle size distribution function for the background component of arid aerosol in size range 0.5–5.0 μm (*1*) according to the data of measurements on August 14, 2007 in Kharabali, Astrakhan Region (the natural reserve "Berli Peski") and the approximating power distribution (*2*) with an index of –2.5.

The particle size distribution functions for the aerosol component $g_{\rm g}(D)$, generated on the underlying surface, were determined separately for four spikes marked in Fig. 1 (I, II, III, and IV). The distribution function averaged by these spikes is presented in Fig. 5 (curve *1*), and Table 1 presents the values of this function in the above-mentioned ranges of particle sizes. Note that the total length of spikes reaches 40–45% of the total length of the analyzed realization. This distribution can be approximated with a satisfactory accuracy by the power function (curve *3* in Fig. 5):

$$g_{\rm g}^*(D) = C_{\rm g}\left(\frac{D}{D_0}\right)^{\nu_{\rm g}}, \qquad (3)$$

where $\nu_{\rm g} = -2.25$.

In each of the four spikes, time intervals of 2–3 min with maximal concentrations of aerosol particles (outliers) were discerned. The particle size distribution $g_{\rm g}(D)$ averaged by these outliers is represented by the curve *2* (see Fig. 5). It is seen that the shape of the distribution is qualitatively similar to the distribution *1*. However, the index of the approximating power function $g_g^*(D)$ (curve *4* in Fig. 5) is equal to -2.17, which is larger than the corresponding index for the previous function (curve *3* in Fig. 5).

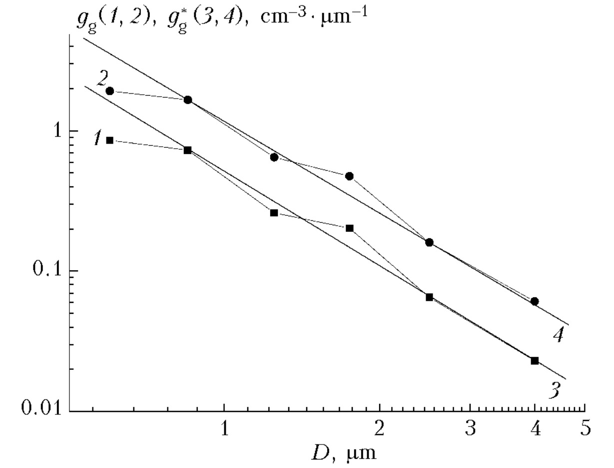

Fig. 5. Particle size distribution function for the arid aerosol component, generated on the underlying surface in size range of 0.5–5.0 μm (according to the measurement data on August 14, 2007 in Kharabali district, Astrakhan Region): average by four spikes (*1*) and average by four maximal spikes (*2*). Approximating power spectra have indices of -2.25 (*3*) and -2.17 (*4*).

The available data are still insufficient to understand the influence of wind velocity on the function $g_g(D)$.[15–24] So, to estimate microstructure parameters of the aerosol generated on the underlying surface, we use the data obtained for the "wide" spikes (see Table 1 and curve *1* in Fig. 5). Naturally, the proposed power approximation $g_g^*(D)$ noticeably distorts the distribution $g_g(D)$ in the submicron range of particle sizes. If necessary, the observed distribution function $g_g(D)$ can be approximated by a sum of two or three lognormal distributions. This makes it possible to represent the observed extremes of $g_g(D)$. It follows from the above-stated that the most significant difference between $g_g(D)$ and $g_b(D)$ is in peculiarities of their time variations.

Wind effects on aerosol generation

As is seen from Fig. 1, spikes of aerosol concentration are observed at gusts. It should be noted that concentration and vertical flows of the mineral aerosol at arid territories are comparable with the average wind velocity or dynamic velocity,[18] which characterizes the turbulence regime during a sufficiently long time interval, with characteristics of the saltation process of sand particles.[11, 12, 15] To understand the mechanisms of aerosol generation on the underlying surface, it is necessary to compare fluctuations of aerosol parameters with turbulent pulsations of wind velocity components and the air temperature.[4–6,10,16,17]

In particular, it is not difficult to estimate the threshold velocity of aerosol generation on the underlying surface from data on synchronous measurements of fluctuations of the aerosol microstructure and turbulent pulsations of wind velocity. According to Fig.1, it was about 5 m/sec in the period of measurements.

In this paper we presented the measurements of aerosol microstructure, obtained in convective conditions. This, in particular, follows from Fig. 6, which shows the power density spectrum for fluctuations of wind velocity modulus (*1*), computed by measurements on August 14, 2007.

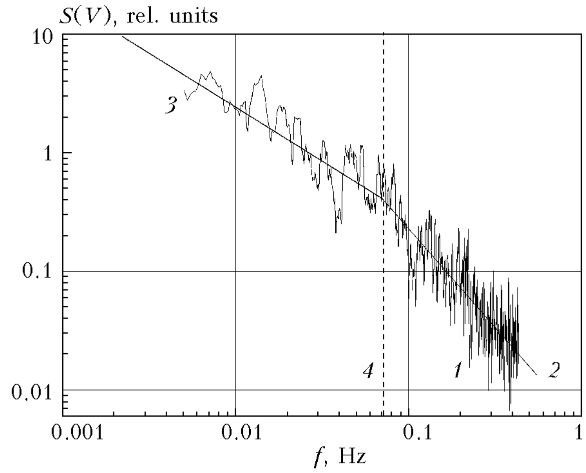

Fig. 6. Spectral power density of wind velocity module (*1*) by measurements on August 14, 2007: the boundary of turbulence regimes (*4*); approximating power spectra (*2*), (*3*).

The observed spectrum $S(V)$ can be satisfactorily approximated by a piecewise-power function, whose components are matched at a frequency f_0 of about 0.07 Hz (curve *4* in Fig. 6). In the frequency range $f > f_0$ the power index of the approximating function (curve *2* in Fig. 6) is about $-\frac{5}{3}$, what takes place for locally isotropic turbulence.[18] At low frequencies ($f < f_0$), the power index of the approximating function is about -0.9 (the straight line *3*), what is characteristic for convective conditions. In the low frequency range in Fig. 6 some maxima or convective modes[19] are discerned rather clearly. This is usually connected with quasi-periodical (coherent) vortex structures[5,20–22] or cell convection.[10,17,23]

Conclusion

1. Fluctuations of the submicron and coarse-dispersed aerosol microstructure, as well as turbulent pulsations of wind velocity components were measured at a deserted territory in Kharabali, Astrakhan Region.

2. Differential number concentrations of arid aerosol particles vary synchronously in size range of 0.5–5.0 μm.

3. For the spiking mode of aerosol generation on the underlying surface, particle size distribution functions were retrieved for background aerosol and for aerosol, generated on the underlying surface under action of sand-wind flows.

4. The spikes of differential number concentrations of aerosol are shown to be caused by wind gusts. According to the data of measurements in the natural reserve "Berli Peski," the threshold velocity of aerosol generation is approximately equal to 5 m/sec.

5. Turbulent pulsations of the wind velocity modulus during measurements of fluctuations of the arid aerosol microstructure in the frequency range less than 0.07 Hz are shown to be determined by convective motions.

Acknowledgements

The author thanks G.I. Gorchakov for his attention to this work and G.A. Kurbatov for the help in organization of the measurements.

This work was performed under support of Russian Foundation for Basic Research (Grants Nos. 07-05-01080-a, 07-05-10080-k, and 07-05-13610-ofic) and Department of Earth Sciences, Russian Academy of Sciences (Program "Geophysics of intergeospheric interactions").

References

1. G.I. Gorchakov and K.A. Shukurov, Izv. Ross. Akad. Nauk, Ser. Fiz. Atmos. Okeana **39**, No. 1, 85–97 (2003).
2. G.I. Gorchakov, B.M. Koprov, and K.A. Shukurov, Atmos. Oceanic Opt. **13**, No. 2, 150–153 (2000).
3. G.I. Gorchakov and K.A. Shukurov, in: *International Aerosol Conference*, Moscow (2000), pp. 249–255.
4. G.I. Gorchakov, B.M. Koprov, and K.A. Shukurov, Izvestia, Atmospheric and Oceanic Physics **38**, Suppl. 1, S138–S147 (2002).
5. G.I. Gorchakov, B.M. Koprov, and K.A. Shukurov, Izv. Ross. Akad. Nauk, Ser. Fiz. Atmos. Okeana **39**, No. 5, 596–608 (2003).
6. G.I. Gorchakov, B.M. Koprov, and K.A. Shukurov, Izv. Ross. Akad. Nauk, Ser. Fiz. Atmos. Okeana **40**, No. 6, 774–790 (2004).
7. A.V. Karpov, in: *Abstracts of Reports at XIV Workshop "Siberian Aerosols,"* Tomsk (2007), pp. 25–26.
8. G.I. Gorchakov and Yu.A. Pkhalagov, in: *Abstracts of Reports at XIV Workshop "Siberian Aerosols,"* Tomsk (2007), p. 25.
9. G.I. Gorchakov, A.V. Karpov, G.A. Kurbatov, and V.P. Yushkov, in: *Abstracts of Reports at XIV Workshop "Siberian Aerosols,"* Tomsk (2007), p. 24.
10. G.I. Gorchakov B.M. Koprov, and K.A. Shukurov, in: *Proc. of International Aerosol Conference,* Moscow (2000), pp. 237–248.
11. R.A. Bagnold, *The Physics of Blown Sand and Desert Dunes* (Morrow, New York, 1941), 265 pp.
12. E.K. Bütner, *Dynamics of the Near-land Air Layer* (Gidrometeoizdat, Leningrad, 1978), 158 pp.
13. N.V. Smirnov and I.V. Dunin-Barkovskii, *Brief Manual of Mathematical Statistics for Technical Applications* (Fizmatgiz, Moscow, 1959), 436 pp.
14. J.L. Lumley and H.A. Panofsky, *The Structure of Atmospheric Turbulence* (Interscience Publ., New York, 1964), 239 pp.
15. I. Tegen and I. Fung, J. Geophys. Res. D **99**, No. 11, 22897–22914 (1994).
16. G.I. Gorchakov Atmos. Oceanic Opt. **13**, No. 1, 96–107 (2000).
17. G.I. Gorchakov, A.S. Emilenko, V.M. Kopeikin, P.O. Shishkov, V.N. Sidorov, P.V. Zakharova, and K.A. Shukurov, in: *Proc. of the Conf. on Natural and Anthropogenic Aerosols* (St. Petersburg State University, St. Petersburg, 1998), pp. 408–413.
18. A.M. Obukhov, *Turbulence and Atmosphere Dynamics* (Gidrometeoizdat, Leningrad, 1988), 414 pp.
19. V.N. Ivanov, in: *Problems of Atmosphere Physics* (Gidrometeoizdat, St. Petersburg, 1998), pp. 467–487.
20. L.A. Mikhailova and A.E. Ordanovich, Izv. Akad. Nauk SSSR, Ser. Fiz. Atmos. Okeana **27**, No. 6, 593–612 (1991).
21. B.M. Koprov, V.M. Koprov, and T.I. Makarova, Izv. Ross. Akad. Nauk, Ser. Fiz. Atmos. Okeana **36**, No. 1, 44–54 (2000).
22. G.I. Gorchakov and K.A. Shukurov, in: *Proc. of the Conf. on Atmosphere Physics: Electrical Processes, Radiophysical Methods of Study*, Nizhniy Novgorod (2004), pp. 43–47.
23. G.I. Gorchakov, P.O. Shishkov, V.M. Kopeikin, A.S. Emilenko, A.A. Isakov, P.V. Zakharova, V.N. Sidorov, and K.A. Shukurov, Atmos. Oceanic Opt. **11**, No. 10, 958–962 (1998).
24. G.I. Gorchakov and L.S. Ivlev, in: *Proc. of the Conf. on Natural and Anthropogenic Aerosols* (St. Petersburg State University, St. Petersburg, 1998), pp. 401–407.