On fluctuations of the angular scattering coefficient of near-ground aerosol in deserted area

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The fluctuations of the mineral aerosol angular scattering coefficient are analyzed by data of measurements in July, 2007 in Kalmykia. Measurements were performed with the use of two nephelometers, placed at one site at heights of 0.5 and 2 m, or at two sites spaced by 30 m down the wind. The sampling frequency from nephelometers was equal to 1 Hz. The basic attention was paid to the estimation of the role of non-local effects in the processes of the aerosol generation in the wind-sand flow at wind speeds of 5–8 m/s. In the ground layer, the shape of the spectrum of power density of fluctuations of the scattering coefficient does not change with height. Non-local effects in variations of the scattering coefficient were revealed when measuring with spaced nephelometers.

Introduction

A significant part of mineral aerosol comes into the atmosphere from arid territories. Therefore, the mechanism of generation of mineral aerosol at the underlying surface under the impact of the sand-wind flows, as well as processes of aerosol transport in ground and boundary layers of the atmosphere need a thorough investigation. Important peculiarities of such processes can be understood from measurements of fluctuations of aerosol optical and microphysical parameters

As it was earlier established,[1,2] under convective conditions at a wind speed between 4 and 7–8 m/s at a height of 2 m the flashing mode of the parameter fluctuations and, correspondingly, aerosol generation is realized[3,4]; and at wind speed exceeding 7–8 m/s – the quasi-continuous mode. It was shown that the speed of vertical aerosol transport in convective atmospheric boundary layer can many times increase, when vortices and vortex structures appear.[2,5] The reproducibility of the particle size distribution[2,6] for the aerosol component, generated in the wind-sand flow at a mean wind speed less then 9–10 m/s is important for further investigations. This implies, in particular, that variations in the scattering coefficients of the aerosol component, produced on the underlying surface, should follow the variations of mass concentration at least in rough approximation.

Optical methods of measuring aerosol parameters have some advantages over other methods: quickness, reliability, efficiency, and relative simplicity of the technical realization. In field experiments, especially in desert conditions: at a high temperature and without stationary electric power sources, nephelometric methods are the necessary component of the complex aerosol experiment. In this paper, fluctuations of the angular scattering coefficients are analyzed based on measurements in Kalmykia in July of 2007. The experiment was aimed at the study of aerosol generation in deserted areas and its transport in the ground atmospheric layer. The main attention was given to estimates of the role of non-local effects in fluctuations of the scattering coefficient of the aerosol component, generated in the arid zones.

The process of aerosol generation in the wind-sand flow is stochastic. Hence, the qualitative estimates of the effects should be statistical. An estimate of the mode of some parameter fluctuation can be obtained by the spectral analysis techniques.[7,8] Based on transformations of the fluctuation power spectra, it is possible to understand deeper the role of non-local effects in the aerosol generation.

Instrumentation

Nephelometer measurements were conducted in July 21–31, 2007 in the deserted zone of Kalmykia, 15 km from Komsomolskiy settlement, in the framework of the complex experiment.[9] The angular scattering coefficient[10] D ($\mathrm{km^{-1} \cdot sr^{-1}}$) was measured with two compact flow-type nephelometers, produced at IAP RAS,[11] at a wavelength of 520 nm and a scattering angle of 45°. High correlation between scattering coefficients σ ($\mathrm{km^{-1}}$) and angular scattering coefficients,[12] including a scattering angle of 45°, allows a sufficiently reliable estimate of σ from the data on D:

$$\sigma = kD, \quad (1)$$

were k is the dimensional coefficient. Prior to the experiment, the comparison of the calibration characteristics of the IAP compact nephelometers and commercial nephelometers PAN-A, used at IAP RAS and IOA SB RAS, was carried out by specialists from the both institutes.

When measuring, nephelometers were located either at one site (see Fig. 1) at the heights H_1 = 0.5 m

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and H_2 = 2 m, or at two sites spaced by the distance L = 30 m. In the latter case the first nephelometer was mounted at the height H_1 = 0.5 m and the second one at H_2^* = 2 m.

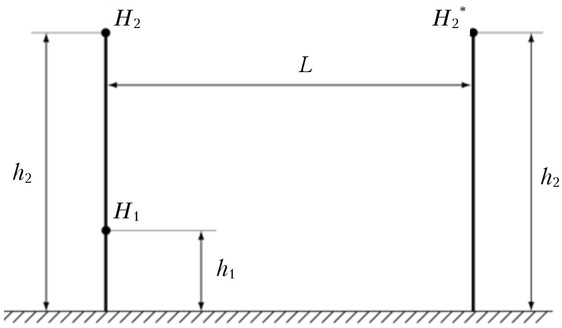

Fig. 1. Schematic view of positions of the nephelometer inlets.

The nephelometers' inlets were located at the above-pointed heights. The outdoor air came into nephelometers through hoses with internal diameters of 2 cm. The hoses, free of sharp bends, provided for delivery of the aerosol particles with sizes up to 5 μm without noticeable losses at a pump speed of 1–2 m/s. In such conditions, the averaging volume was about 0.3 dm^3, which guaranteed the statistical validity of measurements of the angular scattering coefficient.[1]

Time constant (averaging time) of the flow-type nephelometer, estimated as 1–2 s, was limited by the aerodynamic characteristics of air pumping. The nephelometers were connected with computer of the notebook type via multi-channel analog-digital converter E14-140. The survey frequency of nephelometers was equal to 1 Hz.

Discussion of results

At the first stage, the field measurements of the angular scattering coefficients were conducted at one site at H_1 (*1*) and H_2 (*2*). The results are exemplified in Fig. 2.

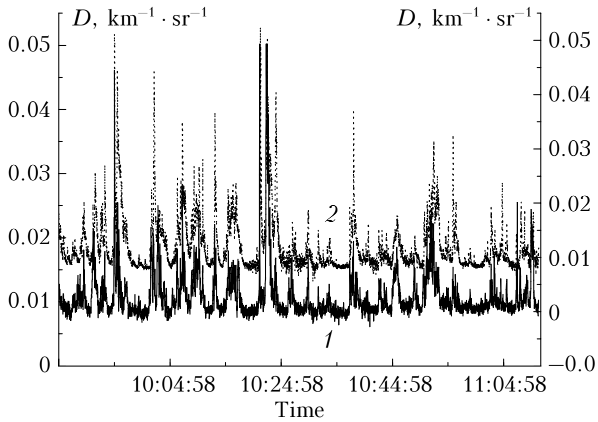

Fig. 2. Temporal variability of the angular scattering coefficient (wavelength of 520 nm, scattering angle of 45°); measurement date was 07.24.07.

The mean value of the angular scattering coefficient at a height of 0.5 m was equal to 0.012 km^{-1} · sr^{-1} in the time interval from 9:45 to 11:10 LT on July 24. The mean value of the angular scattering coefficient at a height of 2 m was by about 15% less than its value at a height of 0.5 m (see Table), and the standard deviation σ_D at a height of 0.5 m exceeded the standard deviation at a height of 2 m approximately by 40% (D_b is the background level between splashes of D).

Date, time	Height, m	D, km^{-1} · sr^{-1}	σ_D, km^{-1} · sr^{-1}	D_b, km^{-1} · sr^{-1}	V, m/s	φ, deg	T, °C
07.24 9:45–11:10	0.5	0.012	0.0051	0.0092	5.6	145	29.9
	2	0.011	0.0037				
07.31 10:45–12:25	0.5	0.024	0.0364	0.015	5.9	113	34.2
	2	0.021	0.00285				

The values of the mean wind speed, mean temperature, and wind direction are also given in the Table. Fluctuations of the angular scattering coefficient look like splashes with duration from shares of a minute to about 3 min. This qualitatively coincides with measurements of the splashing fluctuations of the aerosol differential number concentration near Aral Sea,[1] which appear in the case of flashing mode on the underlying surface under impact of wind-sand flow.[1,2] It is important to underline that splashes as a rule, are the series of spikes (short pulses) with lengths of a few seconds. In some periods, splashes follow each other with well-defined frequency, close in the order of magnitude to the frequency of variations of meteorological parameters, stipulated by transfer of convective structures.[13] Maximal amplitudes of spikes D at a height of 0.5 m, as a rule, exceeded the corresponding amplitudes at a height of 2 m.

The synchronism of splashes of the angular scattering coefficients at two levels is of interest. Note that the synchronism of spikes is expressed far weaker, that decreases the correlation between the time series under consideration. Maximal correlation between fluctuations of the angular scattering coefficients was observed at the time lag τ = 2 s. This was caused be the different lengths of the intake hoses at two levels.

Spectral analysis of fluctuations of the angular scattering coefficients

In addition to the standard deviation, fluctuations of the angular scattering coefficient can be characterized by the power spectrum of fluctuations D [Refs. 7 and 8]. Power spectra of fluctuations of the angular scattering coefficient at two above levels were computed for some realizations of $D(t)$, where t is time. An example of the spectrum $S(D)$ calculated from D measurements on 07.24.07 in the period from 9:45 to 11:10 at a height of 0.5 m is presented in Fig. 3 (curve *1*). The analysis has shown that the spectrum, presented in Fig. 3, is satisfactorily approximated by the power function

$$R_{0.5}(f) = \beta_{0.5} f^{-q_{0.5}} \quad (2)$$

with the exponent $q_{0.5} = -5/3$ (curve *3* in Fig. 3). It is easily seen that spectrum $S_2(D)$ of D_2 fluctuations (curve *2* in Fig. 3) differs from the corresponding spectrum $S_{0.5}(D)$ of D fluctuations at a height of 0.5 m only by a less power (see the results of standard deviation calculations in the Table).

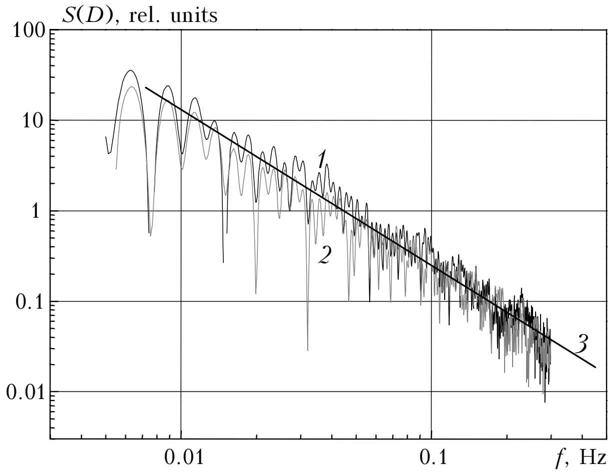

Fig. 3. Spectral power densities of the fluctuations of the angular scattering coefficient at heights of 0.5 (*1*) and 2 m (*2*) from measurements on 07.24.07 (sampling length is 5100 s at a time resolution of 1 s). The curve *2* is the approximating power spectrum of fluctuations at $H = 0.5$ m with an exponent of $-5/3$, *3* – at $H_2 = 2$ m with an exponent of $-5/3$).

It was shown[1] that at flashing aerosol generation, power spectra of fluctuations of differential number concentrations of submicrometer particles and coarse aerosol are approximated by the power functions with exponents from 1.3 to 1.7 (precise estimates are given in Ref. 1).

Thus, in summer of 2007 at the deserted area in Kalmykia, the flashing mode of fluctuations of the angular scattering coefficient and, correspondingly, the same mode of the aerosol generation under the impact of the wind-sand flow are observed.[1,2] It is important for the planning of the future experiments that the shape of spectra $S(D)$ in the ground layer (0.5–2 m) is practically independent of the height.

Calculations have shown that mean levels of fluctuations of the angular scattering coefficient at two heights differ noticeably (see the Table). This distinction is caused not only by the process of the vertical mixing in the atmospheric ground layer, but also by spatial inhomogeneities of the aerosol generation on the underlying surface, the problem of control of which is far beyond the scope of our present paper.

Influence of non-local effects on fluctuations of aerosol parameter

During the second stage of the experiment, synchronous measurements at two sites spaced by 30 m were conducted. The second site was placed eastward from the first one ($\varphi = 90$). During measurements, two sites not always were at the same ground flow layer. At the first site, the nephelometer inlet was placed at a height of 0.5 m and at the second site it was at a height of 2 m.

An example of the synchronous measurements of the angular scattering coefficient at two spaced points is shown in Fig. 4. Measurements were conducted on 07.31.07 (measurement time was 6000 s at a survey frequency of 1 s).

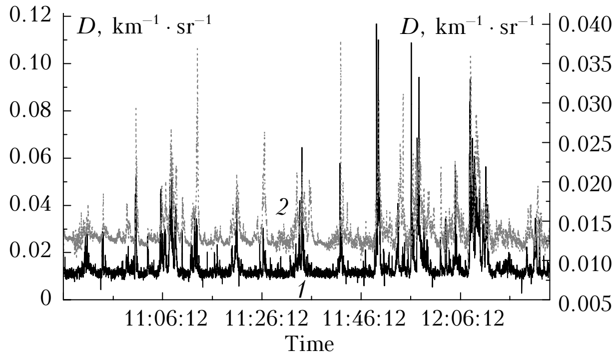

Fig. 4. Temporal variability of the angular scattering coefficient ($\lambda = 520$ nm, scattering angle of 45°) at $H = 0.5$ m at the first site (*1*, left axis) and at $H = 2$ m at the second site (*2*, right axis) on 07.31.07.

It is easily seen that measurements in two sites noticeably differ. The basic distinctions are better seen in the short period of measurements (see Fig. 5), where only one peak is shown.

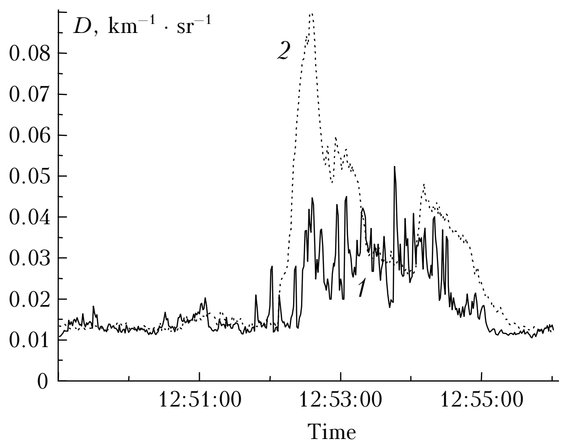

Fig. 5. Peak of the angular scattering coefficient during synchronous measurements on 07.31.07 at the first site at $H = 0.5$ m (*1*) and at the second at $H = 2$ m (*2*).

At site 1, fluctuations of the angular scattering coefficient are qualitatively similar by the measurements on 07.31.07 (curve *1*, Fig. 5) and 07.24.07 (curve *2*, Fig. 2), are qualitatively similar, while at site 2 at a height of 2 m, a smoothing or quenching of the high frequency fluctuations is observed. This can be explained by the increase of the duration of spikes, caused by an additional generation of aerosol when air passing from site 1 to site 2. It follows from the previous Section of the paper that vertical movement of the nephelometer inlet does not change noticeably the quenching effect.

It is seen in Fig. 5 that along with the quenching of the high-frequency fluctuations, the amplitude of fluctuations growths at periods, comparable with those, defined be splash lengths, as well as, naturally, at periods, comparable with intervals between splashes.

Individual examples do not determine the character of samples as a whole. Therefore, the power spectra of fluctuations of the angular scattering coefficient on 07.31.07 were also considered. Such a spectrum for 07.31.07 at site 2 is shown in Fig. 6 (curve *1*).

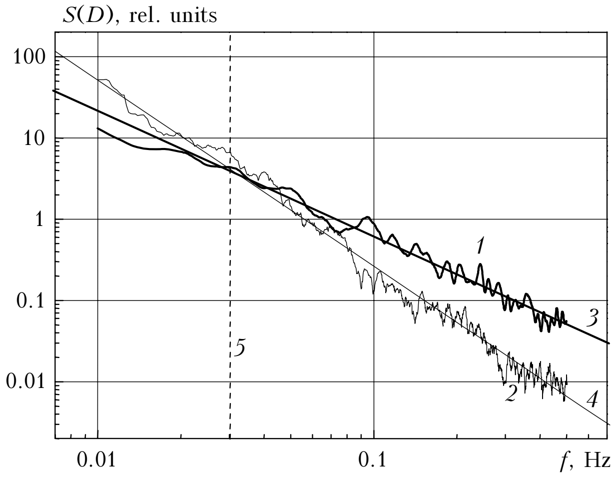

Fig. 6. Spectral densities of fluctuation power of the angular scattering coefficient at $H = 0.5$ m (site 1) and at $H = 2$ m at site 2 (*1*) for 07.31.07 (realization length is 6000 s, time resolution is 1 s). Power approximation of spectrum at $f > 0.03$ Hz was performed with exponents of -1.47 (*2*) and 1.32 (*3*) and with an exponent of $-5/3$ at a height of 0.5 m at the first site (*4*).

At the same figure the fluctuation spectrum at site 1 (curve *2*) and its power series approximation (curve 4) are shown. Spectrum of fluctuations for 07.31.07, just as for 07.24.07, is approximated by a power spectrum with an exponent of $-5/3$.

An attempt of power approximation of the power spectrum of fluctuations on 07.31.07 at site 2 failed. Therefore, the piecewise approximation of the spectrum was used. In the range of high frequencies $f > 0.03$ Hz, the spectrum considered was approximated by the power function with an exponent of 1.47 (curve *3*, Fig. 6), and in the frequency interval between 0.001 and 0.03 Hz – by the power function with an exponent of 1.32. This approximation describes both the effect of suppression of the "high-frequency" fluctuations of the angular scattering coefficient, and the amplification of the fluctuation power within the range of moderate frequencies. Naturally, other variants of approximation are also possible, but they do not change the character of the obtained result.

Thus, the non-local effect of the transformation of the power spectrum of the angular scattering coefficient fluctuations has been found, resulting from the non-local processes of the aerosol generation and its transport and mixing in the ground atmospheric layer.

On correlation between angular scattering coefficient variations at two spaced sites

To estimate correlation between the fluctuations at spaced points, the cross-correlation function $F(\tau)$ [Ref. 7] was calculated based on measurements on 07.31.07 (τ is the time lag). It follows from Fig. 7 that maximal correlation between fluctuations of the angular scattering coefficient takes place at $\tau = 10$ s, which satisfactorily agrees with measurements of the mean wind speed U at a height of 2 m. The same realization as for the power spectrum of fluctuations was used in the calculations. The value of τ at short samples and higher wind speed decreases, approximately, to 9 s, and increases at a less speed. Weak pronounced maximum of $F(\tau)$ (see Fig. 7) is explained by large spread of the wind speed in the measurement period.

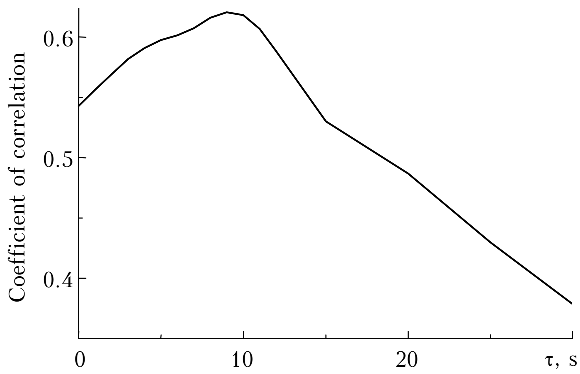

Fig. 7. Cross-correlation function of the fluctuations of the angular scattering coefficient (site 1, a height of 0.5 m and at site 2 at a height of 2 m) on 07.31.07 (realization length is 6000 s, time resolution is 1 s).

Conclusion

1. Measurements of the angular scattering coefficient fluctuations have been conducted at aerosol wind carrying from the deserted area.

2. It was confirmed that at mean wind speed less than 7–8 m/s, the flashing mode of fluctuations of the aerosol parameters, and, correspondingly, aerosol generation on the underlying surface is realized in deserted areas. Power spectra of fluctuations of the angular scattering coefficient are similar to the fluctuation spectra of the number concentrations near Aral Sea.

3. The shape of the power spectra of fluctuations of the angular scattering coefficient does not change with the altitude in the ground atmospheric layer.

4. Non-local effects in variations of the scattering coefficients have been revealed when measuring with spaced apart nephelometers.

5. The effect of suppression of high-frequency fluctuations ($f > 0.03$ Hz) of the angular scattering coefficient with simultaneous amplification of its fluctuation in the spectral region approximately between 0.001 and 0.03 Hz was found.

6. The time delay of splashes for spaced apart measurements of fluctuations of the angular scattering coefficient was estimated.

It is obvious that results obtained from the analysis of fluctuations of the angular scattering coefficient are applicable to fluctuations of many other parameters of the aerosol, generated on the underlying surface (scattering coefficient, differential number concentration, mass number concentration) and, on the whole, to the process of mineral aerosol generation in the deserted areas.

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