Aleurite particle concentration profiles in the surface layer of the atmosphere on desertified areas

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Abstract The large particle mass flux profile measurement at heights from 0.125 to 16 m and parameters of the size distribution function received by O.E. Semenov on the desertified areas in the Aral region were analyzed. The technique has been worked out for the large particle height profile characteristic retrieving. The aleurite particle number concentration profiles with sizes less than 50, 73 and 100 µm and sand particle concentration have been retrieved. Power-law approximations of the vertical aleurite and sand particles concentrations profiles are proposed.

1. Introduction
The climate warming in the 21st century is accompanied by the acceleration of desertification and aridization processes, including the process of the drying up of the Aral Sea, an increase in the frequency of weather anomalies, including sand and dust storms, which leads to the spread of the large particles (mineral dust, aleurite) over long distances. To assess the negative consequences for the environment, climate, public health and economic activity of long-range transport of the large particles, it is necessary to know the vertical distributions of large particles near the sources, which are still poorly studied, especially for the aleurite fraction.

A technique for reconstructing the vertical profiles of the concentration of the aleurite particles in the surface layer of the atmosphere on the desertified areas from the data of measurements of the large particle microphysical characteristics in the Aral Sea region \cite{1} is proposed. Examples of reconstructed vertical profiles of the aleurite particle concentration are given, which are approximated with satisfactory accuracy by power functions. Note that in the near-surface layer of the atmosphere, the concentration profiles of the aleurite and sand particles are approximated by exponents \cite{2}.

On the desertified areas in the Astrakhan oblast the differential particle number concentrations measurements in the layer from 3 to 15 cm were carried out \cite{2, 3}. It is shown that, in addition to the sand particles larger than 100 µm in size, the windsand flux contains the saltating aleurite particles less than 100 µm in size. According to the geological classification \cite{1}, the sand particles, the aleurite particles (10-100 µm) and the mineral dust particles with sizes less than about 10 µm are sedimentary rocks.

In the surface layer of the atmosphere, the aleurite particles transport due to turbulent diffusion. With further propagation in the boundary layer of the atmosphere, they can be transported over distances of tens and hundreds kilometers \cite{1}.
To assess the aleurite particle content and long-range transport results, it is necessary to have information on the vertical concentration and the particle size parameter distribution function profiles.

In [1], tabular data on the vertical profiles of the large particle mass fluxes with sizes from 50 to 500 µm at heights from 0.125 to 16 m are given, as well as some data on the particle size distribution function parameters. The data [1] were obtained during measurements on the desertified areas of Kazakhstan, including the Aral region.

This paper presents a method for retrieval the number concentrations of the aleurite particles with sizes less than 50 µm, 73 µm, and 100 µm, as well as the total sand particle number concentration using data on the mass flux and modal particle size profiles. Vertical concentration profile examples of the aleurite and sand particles are given.

2. Data used
The vertical profile measurement result examples of the mass flux $f$ (kg/m²s) of the large particles with sizes from 50 to 500 µm at heights of 0.125, 0.25, 0.5, 1.0, 2.0, 4.0, 9.0 and 16 m on the desertified areas are given [1]. At the levels of 0.5, 1.0, 2.0, 4.0, 9.0 and 16 m, wind speed measurements were also carried out. The wind speed profiles were used to determine the friction speed and the roughness parameter $z_0$ in accordance with the logarithmic wind profile

$$ U(z) = \frac{u_*}{\kappa} \ln \frac{z}{z_0}, \quad (1) $$

where $\kappa = 0.4$ is the Karman constant.

Samples of the sand (more precisely, the aleurite and sand particles) have been analyzed. In [1], estimates were obtained for the fractions of particles $\delta_d$ with sizes $d$ less than 50, 73, 100, 140, 250, 315, and 500 µm, as well as the modal particle size $d_0$ and the half-width $v$ of the observed distribution of large particles. Parameters $d_0$ and half-width $v$ of the observed distribution of large particles $g(d)$ are determined when it is approximated by a lognormal distribution

$$ g^*(d) = \frac{N}{\sqrt{2\pi \nu}} \exp \left\{ -\frac{(\ln d - \ln d_0)^2}{2\nu^2} \right\}, \quad (2) $$

where $N$ is the total concentration of the particles.

This paper analyzes the results of the measurements on the desertified areas in the Aral region.

3. Vertical profiles of the particle mass flux
The vertical particle mass flux profiles were determined [1] using traps installed on a mast 16 m high. The exposure time varied from several minutes to approximately three hours.

In Figure 1 shows the mass fluxes of the large particles according to measurements near the former Uzunkair Island in the Aral Sea on 06.18.1990 from 19:35 to 20:12 (1) and on 05.30.1992 from 17.30 to 18.30 (2). In logarithmic coordinates, the obtained dependences of the mass flux $f$ on the height $z$ are approximated by linear functions

$$ \ln f(z) = b_f + k_f \ln z, \quad (3) $$

which are equivalent to the power approximations

$$ f(z) = f_1 \left( \frac{z}{z_1} \right)^{k_f}, \quad (4) $$
where $z_1 = 1$ m, $f_1 = 9.1 \times 10^{-3}$ kg/m$^2$s (1) and $1.5 \times 10^{-3}$ kg/m$^2$s (2) - mass flux of the particles at the height of 1 m and exponent $k_f = -1.1$ (1) and -1.28 (2), respectively.

**Figure 1.** Vertical total mass flux profiles of the sand and aleurite particles on the desertificated areas 06.18.1990 in the period from 19:35 to 20:12 (1) and 05.30.1992 in the period from 17:30 to 18:30 (2).

### 4. The particle mass concentration profiles

In a windsand flux, where the influence of the saltation on the transport of the sand and aleurite particles prevails, the particle velocities differ markedly from the wind speed [5]. According to the measurement data in the wind channel at a height of about 8 cm [6], the average particles and wind velocities become close. Hence it follows that in the surface layer of the atmosphere, where the diffusion transfer of the large particles predominates [7], the mass flux of the particles is determined by the product of the mass concentration $M$ and the wind speed $U$:

$$f(z) = M(z)U(z).$$ (5)

In Figure 2 shows the profiles of the wind speed measured during the collection of samples of the large particles on a mast with a height of 16 m 06.18.1990 (1) and 05.30.1992 (2).

**Figure 2.** Profiles of the wind speed on the desertificated areas in the Aral region 06.18.1990 (1) and 05.30.1992 (2).

The analysis showed that the obtained dependences $U(z)$ are approximated by logarithmic profiles (1) with parameters $u_* = 0.73$ (1) and 0.45 m/s (2) and $z_0 = 5.5$ (1) and 0.1 mm (2).
According to the $f(z)$ and $U(z)$ data measurements, taking into account the extrapolation $U(z)$ to the height range $z<0.5$ m and using relation (5), the large particle mass concentration profiles $M(z)$ (g/m$^3$) were obtained. In the logarithmic coordinates $M(z)$ are approximated by linear functions

$$\ln M(z) = b_m k_m \ln z,$$

which correspond to the power-law approximations

$$M(z) = M_1 (z/z_1)^{-k_m},$$

where $M_1 = 0.95$ (1) and 0.0115 g/m$^3$ (2) and exponents $k_m = -1.28$ (1) and -1.39 (2).

Thus, the profiles of mass concentrations, as well as the large particles mass flux profiles are approximated by power functions.

5. The vertical profiles of the large particle size distribution function parameters

Knowing the vertical profiles of the mass concentration of particles, it is possible to determine the aleurite and sand particles number concentrations profiles if the vertical distribution of the particle size distribution function parameters is known.

The results of determining the modal particle size $d_0$ and the half-width parameter $\nu$ of the approximating log-normal distributions are presented in [1].

The mass concentration of the particles is determined by the distribution of particle volumes by size $V(d)$, where $d$ is the size of the particles.

In the case of a lognormal distribution, the modal size $d_v$ of the volume distribution $V(d)$ and the modal size of the particle mass distribution $d_m = d_v$ are determined by the relation

$$d_v = d_0 \exp \left\{3\nu^2 \right\},$$

where $d_0$ is the modal size for the distribution of the number particle concentration.

We have proposed approximations for the vertical profiles $d_v$ (in µm) (Figure 3)

$$d_v(z) = b_v + k_v \ln z,$$

where $b_v = 87$ (1) and 93 µm (2) and $k_v = 5.2$ (1) and 7.2 (2).

![Figure 3. The modal particle volume size distribution dependence on the height according to the measurement data in 1990 (1) and 1992 (2).](image-url)
The vertical profiles of the parameter $\nu$ are also approximated by linear function of $\ln z$.

6. The total large particles number concentration profiles

The substance density $\rho$ of the sand and siliceous aleurite particles equals 2.65 g/cm$^3$. Since, the particle mass $m = \rho \nu$ where $\nu$ is the volume of the particle, it is possible to determine the total number concentration of the particles $N$ through the total volume of particles $V$ using lognormal approximation for the particle size distribution function

$$V = \frac{\pi Nd^3}{6} \exp \left( \frac{9}{2} \nu^2 \right). \quad (10)$$

The results of calculating the $N(z)$ profiles for the cases considered by us are shown in Figure 4.

![Figure 4](image_url)

**Figure 4.** Vertical profiles of the total particles number concentration 06.18.1990 (1) and 05.30.1992 (2).

It is easy to see that the calculated profiles are approximated by power functions

$$N(z) = N_1 (z / z_1)^{k_1}, \quad (11)$$

where the number counting concentrations at the height of 1 m is $N_1 = 0.86$ (1) and 0.106 cm$^{-3}$ (2) and $k_1 = -1.09$ (1) and -1.13 (2).

7. The aleurite particle number concentration fraction evaluations

The fraction estimates for the aleurite particle concentrations with size particles less than 50 µm, 73 µm, and 100 µm were obtained in [1].

In Figure 5 shows the fraction dependences for particles with sizes less than 50 µm (in percent) on $\ln z$, received from the data of measurements in 1990 (1) and in 1998 (2). The indicated dependences are approximated by linear functions $\ln z$

$$\delta_{50}(z) = a_{50} + b_{50} \ln z \quad (12)$$

with parameters $a_{50} = 1.3$ (1) and 3.1 (2) and $b_{50} = 5.2$ (1) and 12.2 (2).

The dependence $a_{50}(\ln z)$ for 1992 is close to the analogous dependence for 1990 (1 in Figure 5).
8. Vertical profiles of the aleurite particle number concentrations

With the help of approximation (12), the profiles of the concentration of the aleurite particles $N^{(50)}$ ($\text{dm}^{-3}$) with sizes less than 50 $\mu$m were retrieved (Fig. 6). The profiles $N^{(50)}(z)$ are approximated by the power functions

$$N^{(50)} = N_1^{(50)} \left( \frac{z}{z_0} \right)^{k_{50}}, \quad (13)$$

where $N_1^{(50)} = 11.0$ (1) and 1.4 $\text{dm}^{-3}$ (2) and exponent $k_{50} = -0.73$ (1) and -0.80 (2). At the heights of less than 0.5 m, some differences from the power-law approximation are observed (13).

Approximations of the dependences $\delta_{73}$ and $\delta_{100}$ on the height were obtained, which made it possible to retrieve the vertical profiles of the aleurite particle concentrations with sizes less than 73 $\mu$m and 100 $\mu$m. In Figure 7 shows (in logarithmic coordinates) the vertical profiles of the particle concentration with sizes less than 73 $\mu$m, which are approximated by power functions

$$N^{(73)} = N_1^{(73)} \left( \frac{z}{z_1} \right)^{k_{73}}, \quad (14)$$
where \( N_{1}^{(73)} = 0.3 \) (1) and 0.027 cm\(^{-3}\) (2) and exponent \( k_{73} = -0.94 \) (1) and -0.91 (2).

**Figure 7.** Vertical profiles of the aleurite particle concentrations with sizes less than 73 µm (1-18.06.1990, 2-30.05.1992).

Vertical profiles of the concentration of the aleurite particles \( N^{(100)} \) with sizes less than 100 µm and sand particles \( N^{(s)} \) with sizes greater than 100 µm (Figure 8) were received from the data measurements in 1992. These profiles are approximated by power function

\[
N^{(100)}(z) = N_{1}^{(100)}(z/z_{1})^{k_{100}}, \tag{15}
\]

and

\[
N^{(s)}(z) = N_{1}^{(s)}(z/z_{1})^{k_{s}}, \tag{16}
\]

where \( N_{1}^{(100)} = 100 \) dm\(^{-3}\), \( N_{1}^{(s)} = 11.6 \) dm\(^{-3}\), \( k_{100} = -1.06 \) and \( k_{s} = -1.51 \).

**Figure 8.** Vertical profile of the total aleurite (1) and sand (2) particle concentration according to measurement data in 1992.
The exponents of power-law approximations of the vertical particle distributions depend on the ratio $w_g/u_*$, where $w_g$ is the gravitational settling particle velocity and $u_*$ is the friction velocity. According to the measurement data on 05.30.1992 $k_{50}$, $k_{73}$, $k_{100}$ and $k_s$ are equal to -1.13, -0.80, -0.91, -1.06 and -1.51, which qualitatively agrees with the existing data on the dependence of $w_g$ on the particle size.

On the desertified areas, the vertical saltating particle mass flux and concentration distributions are often approximated by exponential profiles [6, 9–12]. When passing from the saltation layer to the surface layer of the atmosphere, where the transport of the particles is determined by turbulent diffusion, deviations from the exponential profiles are observed [6, 10, 12, 13]. In the surface layer of the atmosphere, under stationary conditions, as a rule, these profiles are approximated by power functions [1, 14]. For the range of the heights from about 1 to 30 cm in [15] proposed the approximation

$$f(z) = A (z^{-1} - H^{-1})^n,$$

where $A$, $H$ and $n$ are parameters.

In general, the problem of the vertical profile concentration and the particle mass flux approximations requires further study.

9. Conclusions
The technique has been worked out for retrieving of the large particle height profile characteristics in the surface layer of the atmosphere.

The vertical profile measurements results of the large particles mass flux in the surface layer of the atmosphere, the profiles of the wind speed, the parameters of the particle size distribution function, including the fractions of particles with sizes less than 50, 73, and 100 µm, are analyzed. Based on the measurement data of the large particle height profiles of the mass flux and the wind speed in the surface layer of the atmosphere on the desertified areas in the Aral region, the profiles of the total mass concentration of the large particles in the height range from 0.125 to 16 m are received. Power-law approximations of the particle profile mass concentration are proposed.

The technique for retrieving of the total vertical number particle concentration distribution is proposed. The modal size of the large particles height dependences approximations are also obtained. The vertical profiles of the particle number concentrations in the surface layer of the atmosphere on the desertified areas have been retrieved. Power-law approximations of the total vertical number concentration profiles have been received.

Vertical profiles approximations of the aleurite particles proportions with sizes less than 50, 73, and 100 µm have been proposed.

The profiles of the aleurite particle number concentrations with sizes less than 50 and 73 µm in have been received. Power-law approximations of these profiles are obtained.

According to the measurements in the Aral region in 1992, the profiles of the total aleurite and sand number particle concentrations were retrieved. Power-law vertical profiles approximations of the aleurite and sand particle concentrations are proposed. It is shown that the rate of decrease in the aleurite particles concentration with increasing height is noticeably lower than the rate of the sand particle concentration decrease.

The results obtained are necessary for modeling the processes of the large particle transport from desertified areas to assess the consequences of desertification and aridization. They are of interest for the theory of climate, ecology, and geomorphology.

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