Vertical profile of saltating particle concentration over semidesert area

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Abstract. According to measurement data on the desertified area in the Astrakhan oblast in the conditions of non-intermittent saltation, a strong influence of convective quasiperiodic structures with periods from 1.5 to 8 minutes on variations of the saltating particle concentrations are found. Statistical characteristics of the saltating particle concentrations variations are received. The vertical profile of the average particle concentration in the height range from 3 to 15 cm is obtained. An exponential approximation of the particle concentration profile with a logarithmic gradient of -0.32 cm⁻¹ is proposed. It is shown that the average particle content in the saltation layer is 8.6 cm⁻².

1. Introduction

Global climate warming taking place in XXI century will inevitably influence upon desertification processes [1] including the saltation process in the windsand flux [2-4] which provides mineral dust aerosol uplift in the atmosphere [5-7]. As a rule saltation investigations carry out in wind tunnels [8-10]. In this work we analyze field measurement data over the desertified area.

Currently, much attention is given to studies of an effect of turbulence on the saltation [11-13]. The influence of convective quasiperiodic structures [14-17] (organized boundary layer convection) and discrete vortices [18, 19] that make a significant contribution to the uplift of dust aerosol has been poorly studied. It should be noted that in most cases the field studies are performed under conditions of the intermittent or burst saltation [20]. This paper analyzes the results of the study of quasi-continuous («nearly non-intermittent» [13]) saltation.

2. Data used

Concentrations of the saltating particles were measured using a photoelectric counter [21] on the desertified area in the Astrakhan oblast on 23.08.2011 in the period from 12: 00 to 15: 00. Synchronous measurements of the total concentrations of the saltating particles were performed at heights of 3, 11 and 15 cm. The measurement results at the level of 7 cm in the considered period of time were not used due to considerable errors. To reconstruct the information on the vertical profile of the concentration, measurement data were also used in the time periods from 11: 00 to 12: 00 and from 15:00 to 16: 00, when all the channels of the counter were placed at the level of 6 cm [22]. During the field experiment, measurements of wind velocity components in the surface layer of the atmosphere at
an height of 2 m were carried out using the meteorological station "Meteo-2" (Institute of Atmospheric Optics SB RAS, Tomsk).

3. Convective quasiperiodic structure influence on saltating particle concentrations

The measurement results of the total concentrations of the saltating particles in the windsand flux at the heights of 3 cm (a), 11 cm (b) and 15 cm (c), as well as the wind velocity module V the a height of 2 m (d) are presented in Fig. 1 (temporal resolution 1 s). Variability of the number concentrations and the wind velocity have been profoundly expressed. Quasiperiodic structures or zugs with 4 -5 periods are clearly distinguished (S₁, S₂, S₃ and S₄ in Fig.1). At the same time, the depth of modulation of concentrations Nᵢ significantly exceeds the depth of modulation V, that is explained by [23] the linear dependence of Nᵢ on V-V₀, where V₀ is the threshold wind velocity [2]. On the dependencies Nᵢ(t) and V(t), where t – time, two convective structures S₁ and S₂ with periods of about 380 and 485 s are distinguished (the "instantaneous frequencies" according to Harkevich [23], respectively, are 2.6 and 2.1 mHz). On figure 1 there are also convective structures S₃ and S₄ with periods of approximately 105 and 90 s (frequencies 9.5 and 11 mHz), which is consistent with the results of the spectral analysis of the variations Nᵢ(t) and V(t) (maxima of spectra 2, 3 and 4 at frequencies 10.0, 8.5 and 6.0 mHz (Fig. 2).

It should be noted that according to [24] during the saltation the relationship between the wind velocity V at the height of 2 m and a friction velocity u* (which do not depends from the height): 

$$u_* = 0.017V^{1.5}.$$ 

![Figure 1. Saltating particle concentration variations at heights 3 cm (a), 11 cm (b) and 15 cm (c) and wind velocity variations (d) at the height 2m 08.23.2011 in the period from 12:00 to 15:00.](image)

In the range of convective fluctuations the spectra considered (1 in Fig. 2) are approximated with satisfactory accuracy by power functions
which correspond to segments of straight lines 5 in Fig. 2a, b, c, d (C-constant). "High frequency” spectral region with \( f > 55 \) mHz for the wind velocity (6 in Fig. 2d) is approximated with satisfactory accuracy by a power function with an exponent \( n = 1.67 \) that is consistent with the shape of the spectrum for local isotropic turbulence. Spectra of \( N_i \) concentration fluctuations in the high-frequency region spectrum (6 in Fig. 2a, b, c, d) are approximated by power functions with exponent \( n = 0.87, 0.31 \) and 0.20, which is apparently due to the low signal-to-noise ratio. The spectral power of the wind velocity fluctuations \( V \) in the frequency range from 12 to 55 m Hz is approximated by the power spectrum exponent \( n = 1.275 \) (5 in Fig. 2d), which is noticeably different from \( n = 1.67 \) for the local isotropic turbulence. The exponent \( n \) for approximating spectra of the saltating particle concentrations in the region of frequent irregular convective pulsations (5 in Fig. 2a, b, c, d) takes values of 1.25, 1.03 and 0.875, which is apparently due to a decrease in the signal-to-noise ratio with an increase in the measurement height.

Note that we have discovered the phenomenon of quasi-periodic saltation in the range of frequencies from 30 to 160 Hz [24].

\[
P(f) = Cf^{-n},
\]

Figure 2. Fluctuation power spectra (1) of the saltating particle concentration at heights 3 cm (a), 11 cm (b), and 15 cm (c) and power spectrum of the wind velocity (1) at height 2 m (d). Convective mode fluctuations (2, 3 and 4). Low frequency (5) and high frequency (6) spectrum approximations.

4. Statistical analysis of particle number concentration variations

The statistical analysis of the saltating particle concentration variations and wind velocity in the surface layer of the atmosphere is performed (Table 1) using the measurement data 08.23.2011 in the period from 12:00 to 15:00. The empirical probability distribution functions (EPDF) of \( N_i \) are shown in Figure 3. The EPDF of wind velocity was close to the normal distribution. Statistical relationships between variations in the concentration of saltating particles at different levels are considered. Specifically, statistical relationships between \( N_i \) concentrations are described by linear regression.
equations \( N_2 = 0.086N_1 - 0.0086 \) and \( N_3 = 0.028N_1 - 0.0057 \), where \( N_1, N_2 \) and \( N_3 \) – the saltating particle concentrations at levels 3, 11 and 15 cm (correlation coefficients \( N_2 \) and \( N_3 \) with \( N_1 \) are equal 0.945 and 0.87, respectively).

Table 1. Statistical characteristics of the saltating particle concentrations and the wind velocity variations

| Height, cm | Parameters \( N_i \), V | Coefficient of variations | Asymmetry | Excess |
|------------|--------------------------|---------------------------|-----------|--------|
| 3          | 1055 dm-3                | 0.41                      | 0.34      | -0.39  |
| 11         | 90.9 dm-3                | 0.48                      | 0.43      | -0.33  |
| 15         | 23.6 dm-3                | 0.59                      | 0.66      | 0.18   |
| 200        | 7.55 m/s                 | 0.11                      | -0.07     | -0.32  |

Figure 3. Empirical probability distribution of the concentrations at height 3 cm (a), 11 cm (b) and 15 cm (c).
5. Vertical profile of the saltating particle concentration

According to the table, a vertical profile of average concentration (Fig. 4) of saltating particles (Fig. 4) is constructed in logarithmic coordinates using the measurement data on the desertified area (08.23.2011 from 12:00 to 15:00). The value of the average concentration at a height of 6 cm was obtained using the previously established regularity [22] according to measurements 08.23.2011 in the periods from 11:00 to 12:00 and from 15:00 to 16:00 for the wind velocity of 7.55 m/s according to table 1.

![Figure 4](image)

**Figure 4.** Average concentration of the saltating particles over the semidesert area in Astrakhan oblast. Exponential approximation of the height profile of saltating particle concentration (1).

The obtained profile of average concentration (1 in Fig. 4) is approximated by the exponent

\[ N(z) = N_0 \exp \left(-\frac{z}{z_*}\right), \]

where \( N_0 = 2725 \text{ dm}^3 = 2.73 \text{ cm}^3 \) and the scale factor \( z_* = 3.16 \text{ cm} \).

According to [27] the scale factor depends on the particle size and the wind velocity. Scale factor for the small sand (0.1 – 0.2 mcm) changes approximately from 4.0 to 4.8 cm and for coarse – grained sand (0.5 – 0.6 mcm) – from 5.4 to 10 cm. We are concerned with the particle sizes about from 30 to 200 mcm (aleurite and sand modes [22]). Thus our data are in good agreement with those obtained previously.

The rate of the decrease in the average concentration of the saltating particles with height is characterized by a logarithmic gradient

\[ \gamma = \frac{d \ln N(z)}{dz} = -\frac{1}{z_*} = -0.32 \text{ cm}^{-1}. \]

Logarithmic gradient value is a result of approximation of the linear relation between \( N(z) \) and \( z \). Uncertainty of the logarithmic gradient we estimated as 0.05 cm\(^{-1}\).

The total content of particles in the saltation layer

\[ Q = N_0 z_* = 8.6 \text{ cm}^2. \]
6. Conclusions
The synchronous measurement results of the particle concentrations at the height 3, 6, 11 and 15 cm for the non-intermittent saltation over the semidesert area are presented.

The exponential approximation of the profile of the average particle concentration under conditions of the non-intermittent saltation is proposed. The scale factor or “the thickness of the saltation layer” (3.16 cm), the logarithmic concentration gradient (-0.32 cm\(^{-1}\)) and the total content of particles in the saltation layer (8.6 cm\(^{-2}\)) are determined.

Acknowledgments
This work was supported by Russian Foundation for Basic Research (project No. 19-05-00758).

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