ISSN 1028-334X, Doklady Earth Sciences, 2006, Vol. 410, No. 7, pp. 1109–1111. © Pleiades Publishing, Inc., 2006.
Original Russian Text © G.I. Gorchakov, V.I. Ermakov, V.M. Kopeikin, A.A. Isakov, A.V. Karpov, A.V. Ul'yanenko, 2006, published in Doklady Akademii Nauk, 2006, Vol. 410, No. 2, pp. 259–262.

GEOPHYSICS

Electric Currents of Saltation in Windsand Flux

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Presented by Academician G.S. Golitsyn January 26, 2006

Received January 27, 2006

DOI: 10.1134/S1028334X06070245

Electric currents in the surface atmospheric layer in desertized areas were measured for the first time. At wind velocities equal to 5–7 m/s, the density of electric current due to saltation of sand grains at a height of 3 cm reaches 3–5 μA/m^2, which is six orders of magnitude greater than the density of electric current in the unperturbed atmosphere (2–3 pA/m^2). The burst-shaped currents are positive in the main (lower) saltation layer and alternating in the upper layer, which is approximately 0.5 m thick.

The processes occurring in the surface atmospheric layer in desertized areas under high wind speed play a notable role in the global changes of the environment [1, 2]. In particular, they influence the radiation regime of the atmosphere. One of the main peculiarities of windsand flux is its anomalously high electrization. It was found that the electric field strength can exceed 150 kV/m in the near-surface atmospheric layer [3] and rarely exceeds (in terms of modulus) 150 V/m in the surface layer of unperturbed atmosphere [4]. Mean specific electric charge of sand grains γ in the surface atmospheric layer was equal to 60 μC/kg [3].

The eolian transport (saltation) of charged sand grains should be considered as an electric current in windsand flux. The direction of these currents is determined by the trajectories of saltating sand grains. Therefore, they can be considered quasi-horizontal in the first approximation. We developed special traps with current receivers connected to electrometric amplifiers to measure electric currents in windsand flux. Forced air pumping with regulated current consumption allowed us to measure the electric current density.

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In August 2005, measurements of electric current density in the surface atmospheric layer were performed in desertized areas of Kalmykia near the settlement of Komsomol'skii. Current traps were oriented toward the windsand flux. The electric field strength was measured periodically. Turbulent pulsations of three wind components and air temperature were measured at a height of 2 m. Examples of synchronous measurements of electric current density J at heights of 3 cm (*1*) and 40 cm (*2*) are shown in Fig. 1. Electric currents of saltation have the form of bursts, which appear synchronously at all levels in the surface atmospheric level. At a height of 3 cm, electric current was positive in all cases (transport of charged sand grains). According to the data of our measurements, the maximum amplitude of current density at a height of 3 cm reached 5 μA/m^2, which is approximately six orders of magnitude greater than the electric current density in the surface layer of unperturbed atmosphere [4], or in other words greater than the electric current in good weather conditions (2–3 pA/m^2). In the upper saltation layer (Fig. 1, curve *2*), electric currents alternated. The electric current density in the main saltation layer, whose thickness at a mean wind velocity of 5–7 m/s (at a height of 1–2 m) is equal to 3–5 cm [2], can be estimated from the solid drainage Q (or height-integrated mass flux) of saltating sand grains over a length unit in the direction normal to the mean wind. It is known from [2] that the Q value varies in a relatively wide range. The mean Q value at a mean wind velocity of 7 m/s at a height of 2 m is approximately equal to 2 g · m^{-1} · s^{-1}. According to the Bagnold empirical relation, the solid drainage (in g · m^{-1} · s^{-1} units) is equal to

$$Q = 1.5 \cdot 10^{-9}(U_1 - 400)^3, \quad (1)$$

where U_1 is the mean wind velocity (cm/s) at a height of 1 m, which yields approximately 4 g · m^{-1} · s^{-1} at U_1 = 7 m/s.

If Q = 2 g · m^{-1} · s^{-1} and the height of the main saltation layer is h = 5 cm, the mean density of mass flux of sand grains ($F = Qh^{-1}$) is equal to 40 g · m^{-2} · s^{-1}.

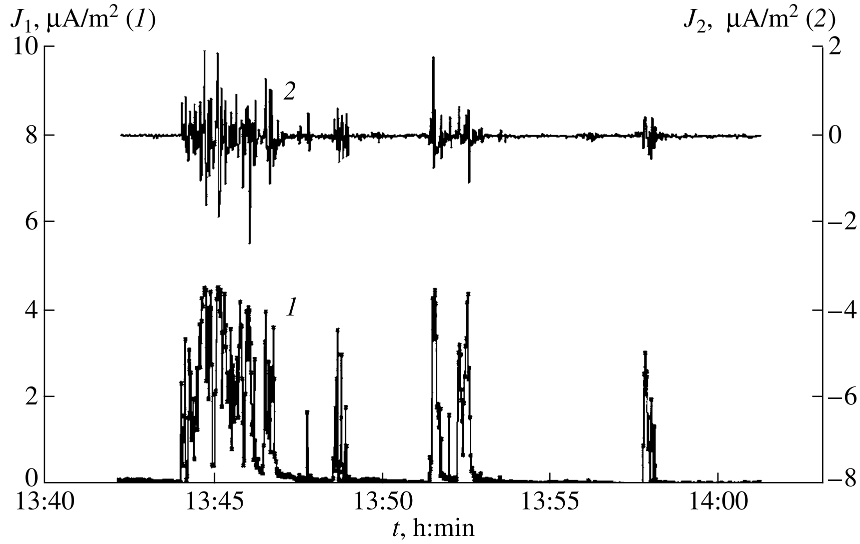

Fig. 1. Variations in the density of electric current J in windsand flux at a height of (*1*) 3 cm and (*2*) 40 cm based on the data of measurements on August 23, 2005 in desertized areas near the Settlement of Komsomol'skii (Kalmykia).

Knowing the specific charge of sand grains γ [3], we can easily estimate the electric current density in windsand flux:

$$J = \gamma Q h^{-1}. \tag{2}$$

At a height of 3 cm, we get $J \simeq 2.5\ \mu A/m^2$, which agrees with the results of our measurements in terms of the order of magnitude.

The main saltation layer, which carries a large electric charge, induces above itself an electric field of high strength E_1. In order to estimate the E_1 value, it is necessary to know the wind profile in the surface atmospheric layer and the height distribution of the saltation flux density. According to the previous investigations, the wind velocity profile in the surface atmospheric layer in desertized areas can be considered logarithmic [2]:

$$U(z) = k^{-1} u_* \ln \frac{z}{z_0}, \tag{3}$$

where z is height; $k = 0.4$ is the Carman constant; z_0 is the roughness parameter; and u_* is the dynamic velocity [5] determined from the data of gradient measurements of wind velocity. According to the data of measurements in desertized areas, parameter z_0 depends on the mean wind velocity and varies in a wide range [2]. At a mean wind velocity of 7 m/s (at a height of 2 m), the mean geometrical value of the roughness parameter is approximately equal to 3×10^{-3} cm. Elementary calculations showed that, in the case considered here, the mean wind velocity in the main saltation layer is equal to 4 m/s. Under these conditions, the surface density of the charge (averaged over the thickness of the saltation layer) is approximately equal to 30 nC/m², while the electric field strength E_1 over the main saltation layer is approximately equal to 3.5 kV/m.

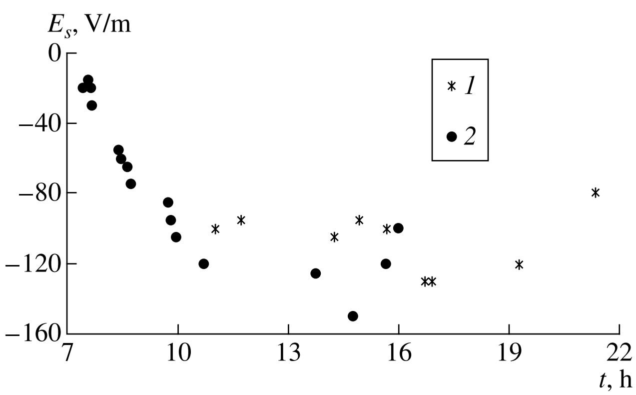

Fig. 2. Electric field strength in desertized areas based on the data of measurements near the Settlement of Komsomol'skii (Kalmykia) on (*1*) August 22, 2005 and (*2*) August 23, 2005.

Direct measurements of electric field strength E_s at a height of ~1.5 m showed that E_s changes relatively slowly in the daytime hours from –100 to –160 V/m (Fig. 2). This is consistent with the published data on the electric field in good weather conditions [4].

At a height of 0.3–0.4 m, the variability of electric field strength observed in desertized areas did not correspond to the concept about the electric field in good weather conditions: at this height, the field strength fluctuated with a period of ~1 s from –3 to +3 kV/m. It was shown in [3] that, in the surface layer of the atmosphere in desertized areas, the electric field strength drops sharply with height. At a height of ~0.3 m, it changes sign and stabilizes at a level characteristic of the unperturbed atmosphere.

The results listed above indicate that a negatively charged (in general) upper saltation layer should be located over a positively charged main saltation layer [2]. The electric field induced by the upper layer E_2 compensates the electric field E_1 of the main saltation layer at heights greater than 1 m and surpasses the latter parameter (in terms of modulus) by a small value equal to the electric field strength of unperturbed atmosphere. Owing to the nonstationary nature of saltation, positively and negatively charged elements of air volume in windsand flux can be displaced relative to each other, resulting in comparatively fast and significant (in terms of amplitude) variations in electric field stress at low heights (<1 m) and variations in the electric field polarity in the upper saltation layer.

Wind velocity and turbulence regime are among the factors influencing electrization in windsand flux. Figure 3 demonstrates the results of synchronous measurements of electric current density at a height of 3 cm (*1*) and absolute wind velocity U at a height of 2 m (2). In the case considered here, three sequential bursts of the current mimic three sequential wind gusts, which can be related to a quasi-periodical (coherent) structure with a characteristic spatial scale of approximately 700 m. As in the case of saltation [1], generation of electric currents is a nonlinear threshold effect. The threshold velocity for the saltation electric current is ~5 m/s at a height of 2 m. As in the case of solid drainage [1, 2], the dependence of electric current density on wind velocity is strongly nonlinear. Unfortunately, it is not yet possible to determine the analytical form of this dependence. We should note that maximal saltation current occurs with a time lag (<1 min) with respect to the maximal velocity in the corresponding wind gust (Fig. 3). The complex ambiguous correlation between saltation currents and wind velocity requires further investigation. Observation data on the possible time lag of saltation are absent in the literature because previously the results of the measurement of solid drainage were compared only with the mean wind velocity or with the dynamic velocity averaged over time.

The measurements of electric currents in windsand flux were carried out under convective conditions at an air temperature approximately equal to 30°C and low values of the relative air humidity (20–40%). During the measurements, turbulence parameters corresponded to convective conditions. In particular, during the period from 15:30 to 16:00 on August 22, 2005, the turbulent heat flux was equal to 160 W/m^2, while the dynamic velocity calculated from the data of measurements of turbulent pulsations of vertical (w') and longitudinal (u') components of wind velocity was equal to

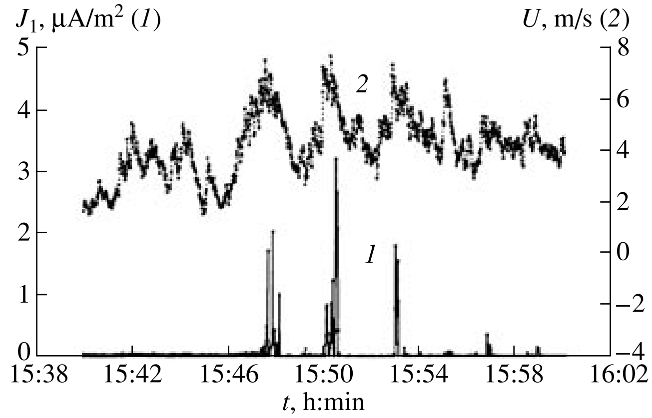

Fig. 3. Variations in (*1*) the electric current density J in windsand flux at a height of 3 cm and (*2*) absolute value of wind velocity U at a height of 2 m based on the data of measurements on August 22, 2005 in desertized areas near the Settlement of Komsomol'skii (Kalmykia).

$u_* = \sqrt{-\overline{u'w'}} = 0.09$ m/s. We note that u_* can differ from the dynamic velocity determined from the data of gradient measurements of velocity profile $U(z)$. The Monin–Oboukhov scale [5] was equal to –0.4 m, while parameter $\zeta = \frac{z_1}{L} = -5$, where $z_1 = 2$ m is the height of the measurements of turbulent pulsations of wind velocity components.

ACKNOWLEDGMENTS

We thank G.S. Golitsyn for the discussion of the results and K.A. Shukurov for measuring turbulent pulsations of wind velocity components and air temperature.

This work was supported by the Division of Earth Sciences "Physics of the Atmosphere: Electric Processes, Radiophysical Methods of Research." The work was accomplished at the Oboukhov Institute of Atmospheric Physics, Moscow.

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