Results of expedition research of thermodynamic conditions influence in atmosphere on charge transfer under the influence of mechanical forces

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Abstract. Observation results accumulated to date show that the processes of mechanical charge transfer in the surface atmosphere play an important role. Mechanical transfer current can be considered as a local generator of electric field acting everywhere in the surface atmosphere layer. Operation regularities studies of such a generator will make it possible to evaluate its effect on the formation of the electrode layer structure. To do this, it is necessary to identify the connections between the mechanical transfer current and other physical factors, which is a complex multiparametric task, the solution of which is facilitated by the analysis of experimental data on the electrical and meteorological characteristics of the atmosphere surface layer. The paper discusses the results of current density measurement of mechanical transfer from the atmosphere to the ground, obtained during a long-term expedition experiment in the Rostov region. Simultaneously with measurements of current density, meteorological parameters were recorded: air temperature, wind speed and direction, vertical air velocity at different levels. To assess the effect of meteorological parameters describing the thermodynamic state of the surface atmosphere on charges transfer under the influence of mechanical forces the method of one-way analysis of variance was used. The F-test calculated according to measurement results in the Rostov region for each investigated case made it possible to reveal the high reliability of this effect.

Introduction

In the surface atmosphere, vertical charge transfer under the influence of mechanical forces is the result of two mechanisms: diffusion and convection. The mechanical transfer current density in the atmosphere can be described by the equation:

\[ j_i = j_d + j_c = -D \frac{\partial \rho}{\partial z} + \rho \cdot \nu, \]

where \( \rho \) is space charge density, \( \nu \) is the velocity of vertical convection streams of air, \( \frac{\partial \rho}{\partial z} \) is the vertical component of the space charge density gradient, \( D \) is the diffusion coefficient equal to the sum of the coefficients of turbulent \( D_T \) and molecular \( D_M \) diffusion \( D = D_T + D_M \).

At the "atmosphere-earth" boundary, the air movement vertical velocity becomes zero, and the mechanical transfer of charges is mainly caused by diffusion processes. The mechanical transfer current density from the atmosphere to the ground \( i_i \) is not determined analytically, the \( i_i \) parameter...
can be estimated according to the results of direct measurements [1, 2].

Diffusion (turbulent and molecular) is a necessary, but insufficient, condition for the existence of a diffusion component of the vertical current of mechanical transfer. Vertical diffusion charge transfer is possible only if the density of the space charge in the atmosphere changes with altitude. In the lower atmosphere, there are various mechanisms of space charge formation. The space charge near the earth’s surface is formed as a result of the electrode effect, the divergence of the conduction current density, the processes of aerosols electrization, transfer with air masses from other territories, etc. It has been revealed that in the investigated lower four-meter atmosphere layer at sites of the Rostov region, as a rule, there is a vertical alternation of two or three layers of space charge of different charge [3, 4], which determines significant gradients of its density.

The observation results [3] show that the density of the space charge formed by ions of all mobilities, including a charged aerosol, is on average much higher than the density of the space charge of light ions. Thus, it can be expected that atmospheric aerosols play an important role in the formation of space charge, and a change in their concentration affects the mechanical transfer current density in the atmosphere and from the atmosphere to the ground. It should be noted that the mechanical transfer current density sign will be determined by the space charge density gradient, and the intensity of turbulent (or molecular) diffusion as well as the change in the concentration of aerosols will affect the absolute value.

**Methods**

In the present study, the results of direct measurements of mechanical transfer current density from the atmosphere to the earth are considered in combination with other atmospheric-electrical and meteorological characteristics, which makes it possible to evaluate the effect of thermodynamic conditions in the atmosphere on the charge transfer under the influence of mechanical forces.

The analysis involved the experimental material obtained at four different sites of the Rostov region. Three observation points – Pervomaiskoye, Mikhaylovka and Platov – are located in the Kashar district in the north of the Rostov region. This agricultural area is located in the steppe, away from industrial centers and related sources of pollution. The fourth site is located in the Tsimlyansky district in the southeast of the Rostov region, at Obukhov Institute of Atmospheric Physics RAS at Tsimlyansk IAP Research Station. Expeditionary observations are carried out annually in July-August, which period in the Don steppes is, as a rule, hot and dry.

The expedition of 2018 was conducted at the Kislovodsk high-altitude scientific research station of Obukhov Institute of Atmospheric Physics RAS, located on the Shadzhatmaz plateau in the alpine meadows zone at an altitude of 2100 m. The station is located 18 km south of the Kislovodsk resort, with no sources of air pollution in the station vicinity. The climate is characteristic for middle latitudes alpine areas. The temperature is characterized by weak variability during the day.

The measurement of the density of mechanical transfer current from the atmosphere to the earth is carried out by the plate method [2]. A round duralumin plate with an area of ≈ 0.2 m², covered with turf without grass, is used as a sensor. The plate is shielded from the electric field of the atmosphere with a 1×1 m² grounded copper grid with 4×4 cm² cells placed at the height of 20 cm above the surface of the plate (Figure1).

In the expeditionary conditions, Assmann aspiration psychrometer is used to measure air temperature. The accuracy of the psychrometer is high enough to use the obtained data on air temperature when calculating the coefficient of turbulence. To measure wind speed, a pan-shaped anemometer is used. Air temperature and wind speed were measured hourly.

Considering the importance of assessing the influence of aerosols on atmospheric-electrical processes, the expedition measuring complex was supplemented with a LAS-P counter of the submicron range aerosols concentration and dispersion composition.

To determine the validity of the influence of meteorological parameters and the aerosols concentration on the mechanical transfer current density, as well as to estimate the strength of this
influence, the method of one-way analysis of variance was used.

Meteorological parameters characterizing the thermodynamic regime of the atmosphere near the earth’s surface were chosen as the factors influencing the mechanical transfer current density: the air temperature difference $\Delta t$ at altitudes of 0.50 m and 2.0 m, the wind speed difference $\Delta U$ at the same levels and the turbulence coefficient $D_T$, calculated according to Orlenko’s method from measured air temperatures and wind speeds at altitudes of 0.5 and 2 meters [5]. The effect of the total aerosol concentration on the mechanical transfer current density was also analyzed.

![Figure 1. The installation for the atmosphere-to-the-ground mechanical transfer current density measuring, general view](image)

**Observation results and discussion**

To assess the effect of meteorological factors on the mechanical transfer current density, we selected arrays of long-term measurements data of atmospheric-electrical and meteorological parameters in points of the Rostov region [6, 7, 8], and the results of the year 2018 expeditionary measurements at the high-mountain plateau Shadzhatmaz.

Aerosol concentration measurement in 2017 in Tsimlyansk, Rostov region and in 2018 on the Shadzhatmaz plateau, made it possible to estimate the effect of the surface air aerosol state on charge transfer under the action of mechanical forces. To perform the variance analysis, each influencing factor was presented in the form of three or four gradations, which included several dozen of hourly observation series. The calculation of the F-test $F_f$ for the decomposition of the statistical data complex $|f|$ into samples corresponding to different gradations of the influencing factor made it possible to estimate the reliability of this influence. Table 1 shows the results of the dispersion analysis of the connection between the absolute value of the current density of mechanical transfer to the earth’s surface with meteoric factors and aerosol particles concentration of near the earth’s surface.

| Factor | $F_f$ | $F_{st}$ | $h^2$ |
|--------|-------|--------|-------|
| $\Delta t$ | 5.67  | 2.34   | 0.03  |
| $\Delta U$ | 4.56  | 1.23   | 0.04  |
| $D_T$ | 3.45  | 0.98   | 0.02  |

Table 1 shows the actual $F_f$ and standard $F_{st}$ values of the F-test for the corresponding data sets, as well as the factor strength of the $h^2$ factor, calculated using the Snedekor method [9]. It turned out that in sites of the Rostov region $F_f > F_{st}$ for all the investigated factors, which makes it possible to consider their influence on the variation of the current density of mechanical transport with a significance level not exceeding 0.03. Thus, the influence of each factor on the test feature is detected with a probability of more than 97%. Because of the multifactority of the processes influencing the mechanical transfer of charge in the atmosphere and from the atmosphere to the earth, the indicator of
the effect of meteorological factors for the periods studied was in the range from 6% to 37%.
The F-test, calculated for all meteorological parameters studied according to measurements on the Shadzhatmaz plateau, turned out to be below the table value (Table 1), which indicates low mechanical charge transfer sensitivity to the weather conditions in this site.

**Table 1.** F-test values: actual $F_f$ and standard $F_{st}$ and those of the index of the influence of factors $h_x^2$ on the absolute value of mechanical transfer current density

| Points observations | Factors | $F_f$ | $F_{st}$ | $h_x^2$ |
|---------------------|---------|-------|---------|---------|
| Pervomaiskoye       | $\Delta t$ | 7.5   | 3.1     | 12%     |
|                     | $\Delta U$ | 9.9   | 3.1     | 15%     |
|                     | $D_T$     | 3.7   | 2.6     | 7%      |
| Mikhailovka         | $\Delta t$ | 87.5  | 3.0     | 26%     |
| 1995-1998           | $\Delta U$ | 20.1  | 3.0     | 6%      |
|                     | $D_T$     | 35.1  | 2.6     | 19%     |
| Plavov              | $\Delta t$ | 7.6   | 3.1     | 7%      |
| 2003-2004           | $\Delta U$ | 16.0  | 3.0     | 13%     |
|                     | $D_T$     | 16.4  | 2.6     | 16%     |
| Tsimlyansk          | $\Delta t$ | 9.9   | 3.3     | 37%     |
| 2017                | $\Delta U$ | 6.9   | 3.3     | 29%     |
|                     | $D_T$     | 6.3   | 3.3     | 27%     |
|                     | $N$       | 3.4   | 3.3     | 16%     |
| Shadzhatmaz         | $\Delta t$ | 0.4   | 3.2     | -       |
| 2018                | $\Delta U$ | 0.3   | 3.2     | -       |
|                     | $D_T$     | 0.8   | 3.2     | -       |
|                     | $N$       | 3.7   | 3.2     | 12%     |

As expected, aerosols concentration also has a significant effect on mechanical transfer current density. Both in Tsimlyansk, Rostov region and on the Shadzhatmaz alpine plateau, it was found that the effect of aerosol concentration on mechanical transfer current density variations was highly significant. This factor strength indicator, calculated using the Snedecor method in Tsimlyansk, was equal to 16%; on the Shadzhatmaz plateau it was 13%.

**Table 2.** Average statistical characteristics of meteorological parameters for the measurement period

| Observation sites       | Statistical characteristic | Air temperature at a height of 2 m | Wind speed at a height of 2 m | Temperature gradient | Air Humidity | Coeff. Turb. |
|-------------------------|----------------------------|-----------------------------------|--------------------------------|---------------------|--------------|--------------|
|                         |                            | [°C]                              | [m/s]                          | [°C/m] | [%] | [m²/s] |
| Shadzhatmaz             | Mean value                 | 12.1                              | 3.0                            | -0.10   | 0.19 | 76      | 0.12      |
|                         | Std deviation              | 3.1                               | 1.9                            | 0.16    | 0.21 | 15      | 0.07      |
| Tsimlyansk              | Mean value                 | 28.4                              | 4.4                            | -0.24   | 0.34 | 35      | 0.16      |
|                         | Std deviation              | 5.1                               | 1.7                            | 0.34    | 0.31 | 14      | 0.08      |

It should be noted that there is a significant difference in the meteorological conditions at the measurement sites of the Rostov region and on the Shadzhatmaz plateau. Table 2 shows the average
statistical characteristics of meteorological variables that account for the thermodynamic state of the atmosphere surface layer on the Shadzhatmaz Plateau and in one of the Rostov Region sites (Tsimlyansk).

The differences in thermodynamic conditions at the observation sites determine the nature of the processes resulting in aerosols in the surface atmosphere. The arid steppe region of the Rostov region is characterized by a high content of aerosols of dispersive origin. In the lower atmosphere layer, their main source is wind dust lifting [10, 11]. In the summer months, the concentration of aerosols in this region is greatly influenced by steppe fires [10].

On the Shadzhatmaz plateau, topsoil weathering is hindered by the dense grass cover. The summer of 2018 turned out to be unusually rainy; the average humidity value for the period was 76%, and fog was often noted at the site during measurements. In conditions of significant humidity and low temperatures (see table 2), the appearance of aerosols is primarily associated with the processes of condensation.

Figure 2. Regression series of mechanical transfer current density absolute value by aerosols concentration: 1– Shadzhatmaz plateau, August 2018. 2– Tsimlyansk, Rostov Region. August 2017

Standard errors are shown in strips

According to the expedition data obtained in August 2017 and August 2018, a regression number of the absolute value of mechanical transfer current density $|i_t|$ by the concentration of aerosols $N$ was constructed (Figure 2).

Table 3. Regression equations of mechanical transfer current density absolute value $|i_t|$ by aerosols concentration $N$.

| Sites          | Regression equations | Approximation reliability |
|----------------|----------------------|--------------------------|
| Tsimlyansk     | $|i_t| = 0.12N + 0.47$ | 0.89                     |
| Shadzhatmaz    | $|i_t| = 0.37N + 0.89$ | 0.77                     |

The obtained empirical dependence is approximated by a linear function (Table 3) and shows that with an increase in the concentration of aerosols, the charge flow under the action of mechanical forces from the atmosphere to the earth’s surface increases.

Summary
Thus, the field experiment results show that in Rostov region sites the thermodynamic regime and the aerosol state of the surface atmosphere layer have a significant effect on the charge transfer to the
earth’s surface under the influence of mechanical forces. The index of the effect of meteorological factors at different points for the periods under study ranged from 6% to 37%, which corresponds to the concept of the multifactor character of mechanical charge transfer processes in the atmosphere and from the atmosphere to the earth. The F-test, calculated from the measurement data on the Shadzhatmaz plateau turned out to be lower than the table value for all meteorological parameters under study, which indicates low sensitivity of mechanical charge transfer to the weather conditions at this site.

For measurement periods in Tsimlyansk and on the Shadzhatmaz plateau, the influence of aerosol concentration on the absolute value of the mechanical transfer current density can be considered reliable.

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