Conduction current density profile transformation near the earth's surface, in connection with atmospheric stratification change

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Abstract. The paper considers physical conditions that influence the formation of vertical profiles of the conduction current density in the surface atmosphere. The proximity of the earth’s surface, which is a source of radioactive emanations and aerosols, determines the significant variability of atmospheric-electrical characteristics in height. The results obtained made it possible to identify the features of the conduction current density vertical profiles transformation with regard to the atmosphere stratification. The study of the weather conditions dynamics at the observation point, as well as the study of the conduction current density profile variability makes it possible to determine the nature of the influence of meteorological parameters on the process of charge transfer and accumulation in the studied layer.

1. Introduction
The spatio-temporal dynamics of the atmospheric electricity parameters near the earth’s surface is largely determined by meteorological conditions at the observation point, the influence of aerosols, and also by the interaction with the underlying terrain, which is a source of emanations of radioactive gases and ionizing radiation. The results of field observations in the atmospheric layer adjacent to the earth show that altitudinal profiles of atmospheric-electric quantities are formed under the influence of many factors, among which there is temperature stratification, which determines the degree of atmospheric stability [1-4].

This work continues the series of studies of the conduction current density vertical profiles obtained from measurements carried out from 1992 to 2012 in one of the agricultural steppe regions in the north of the Rostov Region. Several observation points (Pervomaiskoye, Mikhailovka, Platov, etc.) are located no farther than 30 km from one another and have a similar thermodynamic profile of the surface layer; each site has been used for expeditionary measurements for several years. Observations show the typical diurnal transformation of the conduction current density profile; also, groups of profiles for various mixing conditions in the atmosphere were identified [1]. It should be noted that anticyclone circulation with significant daily amplitude of temperature fluctuations prevails in the second half of summer in the north of the Rostov Region. At night, calm and temperature inversion are observed; due to radiative cooling air temperature can drop below 5°C, and at daytime it can rise up to 35 °C.
In 2014-2017, summer expeditionary measurements were continued in the southern Russia steppe zone of the Rostov Region, at Tsimlyansk scientific station of A.M. Obukhov Institute of Atmospheric Physics Russian Academy of Sciences (IAP RAS). Tsimlyansk is located in the southeast of the region; in August there are usually long periods of clear windy weather with high air temperature.

In August 2018 and 2019, expeditions were held in the North Caucasus, at the Kislovodsk high-altitude scientific research station of Obukhov IAP RAS, located on the Shadzhatmaz plateau in the alpine meadows zone at an altitude of 2100 m. During the measurements on the Shadzhatmaz plateau it was windy, high humidity was noted, air temperature ranged from 3°C to 20°C.

Table 1. Average statistical characteristics of meteorological parameters for the measurement period.

| Observation sites | Statistical characteristic | Wind speed at a height of 2 m [m/s] | Air temperature at a height of 2 m [°C] | Temperature gradient [°C/m] | Air Humidity [%] |
|-------------------|---------------------------|------------------------------------|---------------------------------------|---------------------------|---------------|
| Mikhailovka 1995-1998 265 hour series | Mean value | 1.4 | 17.6 | -0.24 | 0.77 | 65 |
| Std deviation | 1.3 | 7.6 | 0.17 | 0.68 | 25 |
| Platov 2003-2005 235 hour series | Mean value | 1.8 | 20.5 | -0.24 | 0.54 | 56 |
| Std deviation | 1.5 | 7.3 | 0.25 | 0.39 | 26 |
| Tsimlyansk 2017 37 hour series | Mean value | 4.4 | 28.4 | -0.24 | 0.34 | 35 |
| Std deviation | 1.7 | 5.1 | 0.34 | 0.31 | 14 |
| Shadzhatmaz 2019 220 hour series | Mean value | 3.5 | 12.0 | -0.17 | 0.37 | 85 |
| Std deviation | 1.2 | 3.8 | 0.32 | 0.47 | 11 |

Thus, each of the sites has its own set of physical quantities that determine the thermodynamic state of the atmosphere surface layer. Table 1 presents the average statistical characteristics of the arrays of meteorological parameters for the measurement period. As can be seen from the table, all points differ significantly in temperature, wind speed and air humidity.

2. Methods

The expeditionary measuring complex, which includes instruments traditionally used to record atmospheric-electric quantities, is repeated at each observation point, which provides for comparison of the measurement results obtained at different sites [1, 5, 6].

To calculate the conduction current density \( j_\lambda \) in the atmosphere, we used polar conductivities values \( \lambda_+ \) and \( \lambda_- \) measured at six levels in the lower three-meter layer (0.05, 0.3, 0.6, 1, 2, 3 m). The values of the vertical component of the electric field strength \( E \) at the corresponding level were calculated from the measured values of the atmosphere potential at heights of 1, 2, 3, and 4 m.

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j_\lambda = \lambda E = (\lambda_+ + \lambda_-)E
\]

One exception is the current density calculation at a height of 3 m on the Shadzhatmaz plateau in 2019, since at this site the specific polar conductivities were measured in a layer of up to 2 m. Given the fact that at heights above two meters the conductivity usually varies only slightly, to calculate the
current density at 3 m the conductivity values were used at a height of 2 m. The graph (figure 2, 3) shows the section from 2 to 3 m with a dashed line.

Simultaneously with atmospheric-electric values, a complex of meteorological parameters necessary to calculate the characteristics of the thermodynamic state of the surface layer was measured: temperature gradient, turbulence coefficient, stratification parameter.

In order to single out data arrays corresponding to each type of atmospheric stability, the atmospheric stratification parameter for the studied layer was calculated from the values of wind speed and air temperature at heights of 0.5 m and 2.0 m [7].

Stable stratification includes measurement periods when the stratification parameter did not exceed 0.7. Hourly series of measurements with the stratification parameter exceeding 1.3 (in Tsimlyansk more than 1.1) are assigned to the unstable stratification group. Indifferent stratification group encompasses measurement hours when the stratification parameter varied from 0.95 to 1.05.

3. Observation results and discussion

Unstable stratification of the atmosphere is observed, as a rule, at daytime, when with height growth the air temperature near the earth’s surface decreases. In this case convection develops, resulting in the vertical gradients of physical quantities and impurity concentrations eliminated, and the atmospheric parameters at different levels aligned. With stable stratification, inverse distribution of air temperature over height is observed; surface atmosphere mixing is weakened. These conditions, usually realized at night, are characterized by significant gradients in the values and concentrations of impurities. Indifferent stratification is observed at high wind speeds and intense turbulent mixing of the atmosphere, when the temperature in the layer is equalized.

![Figure 1](image.png)

**Figure 1.** Daily variations of the stratification parameter at the observation points:
1 – Mikhailovka, 2 – Platov, 3 – indifferent stratification \((m = 1)\), 4 – Tsimlyansk, 5 – Shadzhatmaz.

The atmospheric stratification change at the measurement points can be traced by the average daily course of parameter \(m\) over the period of measurements (figure 1), where the horizontal black line corresponds to indifferent stratification. It can be noted that the amplitude of oscillations of the stratification parameter in Platov (figure 1a, blue line) and Mikhailovka (figure 1a, red line) is greater than in Tsimlyansk (figure 1b, yellow line) or on the Shadzhatmaz plateau (figure 1b, green line).

**Table 2.** Average statistical characteristics the atmospheric stratification parameter at different points.

| Observation sites | Stable Mean value | Stable Std deviation | Indifferent Mean value | Indifferent Std deviation | Unstable Mean value | Unstable Std deviation |
|-------------------|-------------------|----------------------|------------------------|--------------------------|---------------------|------------------------|
| Mikhailovka      | 0.09              | 0.17                 | 1.00                   | 0.03                     | 1.83                | 0.51                   |
| Platov           | 0.18              | 0.23                 | 0.99                   | 0.03                     | 2.26                | 1.39                   |
The difference in average values of the parameter $m$ at different points is especially strong for stable stratification (Table 2). This is explained by the temperature inversion and calm that are observed in Mikhailovka and Platov in a significant part of the hourly series of measurements (36% and 21%, respectively), when the stratification parameter is close to zero. In Tsimlyansk and on the Shadzhatmaz plateau such conditions are rare.

| Location  | $m_0$ | $m_1$ | $m_2$ | $m_3$ | $m_4$ | $m_5$ |
|-----------|-------|-------|-------|-------|-------|-------|
| Tsimlyansk| 0.49  | 0.14  | 1.00  | 0.03  | 1.16  | 0.06  |
| Shadzhatmaz| 0.41 | 0.23  | 1.01  | 0.02  | 1.70  | 0.37  |

**Figure 2.** Diurnal transformation of the vertical profiles conductivity current density at the observation points: a) Mikhailovka, b) Shadzhatmaz plateau c) Tsimlyansk.

Bars show the standard errors.

It was found that the profiles of the conductivity current density at the points of Pervomaiskoye, Mikhailovka, Platov, Kasharsky district, Rostov region regularly change during the day [1]. A typical for this region profile transformation during the day in Mikhailovka is shown in figure 2a. Night and early morning hours with stable stratification (from 11 p.m. to 7 a.m.) see the first group of profiles with the maximum value of the conductivity current density directly at the earth’s surface. At daytime (from 11 a.m. to 5 p.m.), with the unstable atmosphere stratification, a second group of profiles is observed, with its maximum at a height of 1 m. With neutral stratification, the conduction current density profile is intermediate between the first two groups (figure 2a).

In the daily transformation of profiles constructed according to the data obtained on the Shadzhatmaz plateau (figure 2b) and in Tsimlyansk (figure 2c), the same periods of change in the nature of profiles can be distinguished as in Mikhailovka; however, the types of profiles differ significantly. To analyze the influence of stability conditions in the atmosphere on the variability of the vertical profiles of the conductivity current density, the profiles were grouped for stable, indifferent, and unstable stratification, respectively. Figure 3 shows the vertical profiles of the conductivity current density averaged for each type of stratification.

With stable stratification on the Shadzhatmaz plateau, the profiles are tilted to the left (figure 3d). In the daily profile on the Shadzhatmaz plateau (figure 3f), the maximum current density is noted at a
height of 2 m; for comparison: in Mikhailovka, an increase in current density values is observed only in the lower meter layer (figure 3c). The daytime profile in Tsimlyansk generally tilts to the right (figure 3i); however, given the nature of the change with the height of the electrical conductivity of the air and the electric field strength in the surface layer, we should expect a decrease in the conductivity current density with a further increase in height. Apparently, the maximum current density in Tsimlyansk was outside the studied layer.

Figure 3. Vertical profiles conductivity current density in the atmosphere by stable (a, d, g), indifferent (b, e, h) and unstable (c, f, i) stratification of surface layer at the observation points: in Mikhailovka (a, b, c), on the Shadzhatzam plateau (d, e, f), in Tsimlyansk (g, h, i).
Near the earth’s surface, which under undisturbed conditions acts as a negative electrode, the space charge of atmospheric ions is usually positive. The inconstancy of the conductivity current density in height leads to a change in the volume charge of small ions existing in this layer and its distribution in space.

When the conductivity current density decreases with distance from the earth’s surface in the layer, the concentration of positive small ions decreases with time, and the concentration of negative small ions increases. As a result, the density of the positive space charge decreases. An increase in the conductivity current density with height leads to an increase in space charge. As a result, a layer of small ions space charge is formed near the earth, the density of which is proportional to the divergence of the density of the vertical conduction current [1, 5].

The alternation of space charge horizontal layers with different density leads to the appearance of mechanical charge transfer vertically due to convection, molecular and turbulent diffusion.

4. Summary
With the atmosphere stability changing during the day, various kinds of physical situations are formed; they manifest themselves in various combinations of thermodynamic parameters, which in turn affect the course of electrical processes. The shape of the conduction current density profiles indicates a change in the density of the bulk formed in the lower atmosphere. The uneven distribution of space charge near the earth’s surface results in the appearance of the convective and diffusion components of the mechanical transfer current.

Thus, stratification of the surface layer and wind speed at the observation point, largely determining the degree of mixing of the atmosphere, affects the processes of charge transfer near the earth’s surface and, therefore, affects the electrical structure of the surface layer. The established regularities of the conduction current density vertical distribution in the surface layer can be used for comparison with the results of theoretical calculations.

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