# Experimental research of the surface layer electric structure with different concentration of radon-222

Galena Petrova*, Anatoly Petrov, Irina Panchishkina, and Olga Starostina

Southern Federal University, Rostov-on-Don, Rostov region, Russia

**ABSTRACT:** Longstanding field research of surface layer electric structure forming continued. In the latest expeditions on the territory of Rostov region, located in the area of the Don river steppe zone in the South of Russia, to obtain more accurate information about peculiarities of potential gradient vertical profiles at stable stratification of the surface layer, electric potential was registered up to the level of 4 m instead of 3 m, as it used to be before. Interpretation of experimental data based on the concept that passing of conduction current close to the ground causes forming of space charge of small ions, both as a result of conduction current divergence, related to electrode effect, and also due to the atmospheric conductivity gradient, caused by decrease of radon-222 concentration with height. In this cause the layers of space charge form close to the ground surface, which is discovered by the observed potential gradient profiles.

## INTRODUCTION

Interest in the electrical properties of the atmospheric surface layer a few meters in thickness is natural. Within this layer, the processes of charge exchange occur between the atmosphere and the earth surface and these processes determine the state of this atmospheric layer. Ground-based measurements of atmospheric electricity are performed within this layer, and it is impossible to interpret obtained results without consideration for typical space and time variations in the electrical characteristics of the surface atmosphere.

The results of observations show that these variations are especially complicated when the soil gas emanation at the point of observations is significant. In such a situation, in the case of attenuated atmospheric mixing, radon-222 accumulates in the vicinity of the earth surface, which results in significant gradients of polar conductivity. Israelsson [1978] noted that the gradients of natural radioactivity increase with an increase in atmospheric stability. In this case, high concentrations of radioactive particles cause high local densities of space charge, which finally results in significant field fluctuations.

As the observational results show, while the conduction current is passing, a multilayered structure of space charge may be formed under these conditions and, hence, the vertical distribution of electric field is complicated. The fact that a negative space charge occurs during nighttime hours under calm weather

* Contact information: Galena Petrova, Southern Federal University (B.Sadovaya, 105/46, 344006), Rostov-on-Don, Rostov region, Russia, Email: *georgpu@rambler.ru*

conditions in the warm seasons during soil emanation has long been known. Law [1963] and Crozier [1965] observed the occurrence of the negative space charges of small ions in the vicinity of the earth surface at a height of a few decimeters during calm nights, i.e., under the conditions of a stable surface layer and a low wind speed. According to observational data obtained by Crozier, under a negative charge there is a positive charge of electrode effect, and a negative charge is associated with the gradient of conductivity within a layer with the ion-formation intensity varying with height. An increase in wind speed at night resulted in blurred positive and negative space charges.

The two-layered structure of a space charge corresponds to the vertical field profile calculated by Hoppel [1969] for the nonturbulent electrode effect while the intensity of ion formation varies with height. The negative charge located above the surface layer (approximately 0.5-1 m thick) with positive charge significantly decreases field values at the ground level: 20-40 V/m as against usual 120-130 V/m.

Our observations carried out during summer in the Don steppes, when the soil gas emanation is significant, yield similar results. It is known that radon-222 is of special importance for atmospheric ionization. The half-decay period of radon-222 allows this radioactive gas to remain in the atmosphere for a sufficiently long time and, thus, to provide its ionization. Radon-222 and the products of its decay are $\alpha$-radioactive, which results in their high ionizing power. Therefore, estimating the role of radon-222 in the formation of the electric climate of territories is of no small importance. Radioactive emanations from the soil into the atmosphere are determined by the presence of radon-generating objects in the subsoil of observation point and by the conditions under which these emanations leave the soil: the presence of rock fracturing in a given locality and the gas permeability of soil directly under a measuring sensor.

According to measurement results obtained in the Rostov region, high radon-222 concentration gradients are observed under stable stratification in the vicinity of the earth surface and, hence, the intensity of ion formation varies with height. As a result, the specific conductivities of both signs within the lower 3-m air layer may decrease with height by 2-3 times [Petrov, Petrova, and Panchishkina 1999, 2009]. Owing to this, under the conditions of stable temperature stratification, the multilayered structure of a space charge is formed as well as typical vertical electric-field profiles, which, under stable conditions, exist in the vicinity of the earth surface during many hours and almost do not change with time [Petrova et al. 2011].

In this work, we proceed with studying the properties of the electric structure of the surface layer at different atmospheric radon-222 concentrations which are caused, in particular, by different regimes of atmospheric mixing under stable and unstable temperature stratifications. The special feature of the results given here is that the range of heights (at which the electric potential is measured) has been extended to 4 m when compared to 3 m in previous studies, because the main objective is to specify the details of the vertical distribution of the characteristics of electric field in the atmospheric surface layer.

## METHODS

The results of field measurements taken during summer in the Don steppe zone are used in this work. All observation points are situated in the Rostov region far from anthropogenic sources. This region is characterized by arid climate. Points of the Kashar district are located in the north of the region (Fig. 1, points 2-5); Orlovskij is located in its southern part (Fig. 1, point 1). All observation sites were located in vast even steppe areas. Vegetation under sensors was cut at the ground level on an area of no less than 20 m x 20 m. In this case, the sod formation remains intact to avoid dust raising from the earth surface. In these experiments, round-the-clock measurements were continuously taken during 10-15 days with the exception of the periods of rains and thunderstorms. Atmospheric parameters were measured using conventional instruments and methods. Table 1 gives data on parameters directly measured in such experiments.

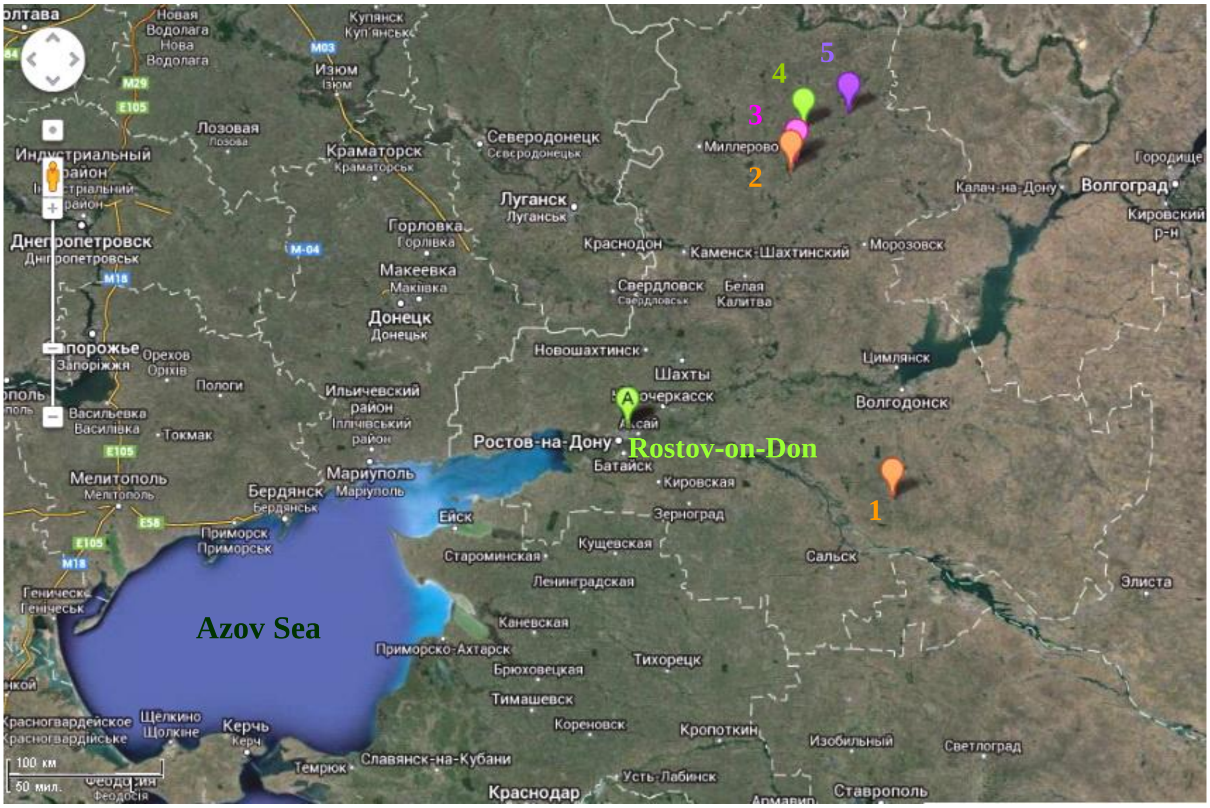


Fig. 1. The points of expedition observations in Rostov region: 1 - Orlovskij, 1999; 2 – Mikhailovka, 1995-1998; 3 – Pervomaiskoye (1992-1994); 4 – Talloverov (2006-2011) and Fedorovka (2012); 5 – Platov (2002-2005).

To measure the vertical profiles of polar conductivities, a Gerdien instrument is sequentially mounted on a wood mast at different levels so that the axis of an aspirated capacitor is located at the corresponding level. The measurement run at each of the levels amounts to 10 min. Thus, it takes one hour to measure one profile. The volumetric activity of radon-222 in the atmosphere is measured simultaneously with conductivity at the same levels of the same mast. When a radonometer is mounted on the mast at each of the levels, the air is intensively pumped out in order to promptly take an air sample from the corresponding level. Then, the air under study diffuses into an ionization chamber, which allows one to continuously measure the volumetric activity of radon. In order to synchronize the measurements of polar conductivities and radon activity, the instrument is adjusted so that the volumetric activity of Rn-222 is averaged over time by a sensor for 10-min intervals.

Potentials at heights of 1, 2, 3, and 4 m are measured using radioactive collectors. The active material of these collectors hanging on horizontal isolated wires is ionium radiating α-particles. Data on potentials are read in turn from different collectors connected in series to an electrostatic voltmeter. Five runs of such readings are performed for each height, which are averaged during data processing and yield the hourly means of potential for each height. After the connection of a successive collector to the instrument, the relaxation time of this installation (about 40 s) is considered in taking potential readings. An observer is at a distance of 10 m from the collectors not to distort electric field. It takes about an hour to read potentials (half an hour) and to take the preventive control of the collector installation (insulator cleaning, control of the distance between collectors, etc.), therefore, only one profile of potential can be obtained over one hour.

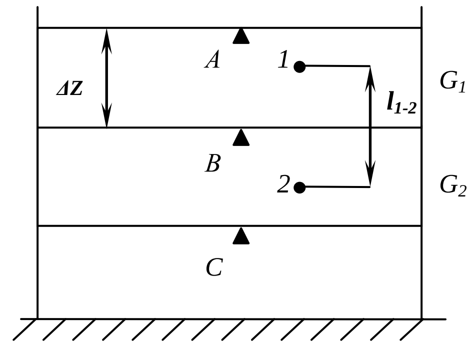


Fig. 2. To the calculating of the potential gradient and the total space charge density

Table 1 Direct measured characteristics

| Measured characteristics | Height,depth (m) | Devices, methods |
|---|---|---|
| Atmosphere electrical conductivity | 0,05; 0,3; 0,6; 1; 2; 3 | Gerdien device |
| Rn-222 volumetric activity in the atmosphere | 0,05; 0,3; 0,6; 1; 2 | Radon monitor “Alpha-guard” |
| Rn-222 volumetric activity in the soil gas | 0,1; 0,6; 0,9 | Radon monitor “Alpha-guard”, “Soil gas probe STITZ”, “AlphaPUMP” |
| Atmosphere electric potential | 1; 2; 3; 4 | Radioactive collectors (ionium) |
| Electric field intensity | 0 | Fluxmeter MGO |
| Air temperature and humidity | 0,15; 0,5; 2 | Aspiration psychrometers, meteostation M-49 |
| Wind speed | 0,5; 2; 5 | Cup anemometers, meteostation M-49 |
| Soil temperature | 0; 0,05; 0.1; 0,15; 0,2 | Savinov’s thermometers |

A number of atmospheric parameters are indirectly calculated. Among them are the gradients of atmospheric potential and the density of the space charges of small ions and ions of all groups. The potential gradient is determined by the horizontal homogeneity of the site of observations, which implies the constancy of potential values in a horizontal plane. An even homogeneous earth surface is chosen for such measurements. Then the potential gradient in thickness $\Delta z = z_A - z_B$ (Fig. 2) can be calculated as $G = \frac{\Delta\varphi}{\Delta z}$, where $\Delta\varphi = \varphi_A - \varphi_B$ is the difference between potentials at the corresponding levels. (Strictly speaking, $G$ is the projection of the potential gradient onto the vertical axis up-directed: $z_A > z_B$).

The Poisson equation for a one-dimensional case is used to estimate the density of the space charge of ions of all groups. Since the field values for a horizontal plane are constant, we obtain $\rho = -\varepsilon_0 \frac{\Delta G}{l_{1-2}}$.

Here $\Delta G = G_1 - G_2$, where $G_1$ and $G_2$ are the potential gradients for layers 1 and 2, respectively, and $l_{1-2}$ is the distance between the centers of neighboring layers 1 and 2 (Fig. 2). Despite the fact that such estimates are approximate, they make it possible to find some typical features of the vertical distribution of this parameter, which allow their quite reasonable physical interpretation.

The small ion density $\rho_{si} = e(n_+ - n_-)$ is calculated from the measured polar specific conductivities $\lambda_+$ and $\lambda_-$ with consideration for $\lambda_+ = n_+ e b_+$ and $\lambda_- = n_- e b_-$, where $e$ is an elementary charge, $b_+$ and $b_-$ are the mobilities of positive and negative small ions, respectively, $n_+$ and $n_-$ are their concentration. Hence, $\rho_{si} = \frac{\lambda_+}{b_+} - \frac{\lambda_-}{b_-}$. It is assumed that $b_+ = 1{,}36 \cdot 10^{-4} \frac{m^2}{V \cdot s}$ and $b_- = 1{,}56 \cdot 10^{-4} \frac{m^2}{V \cdot s}$.

The atmospheric surface layer stratification $m$ and the turbulence coefficient $k$ are estimated for every hour using the Orljenko method [1979] on the basis of measurement data on air temperature and wind speed at heights of 0.5 and 2 m. It is known from the theory that $m = 1$ corresponds to neutral stratification, $m > 1$ corresponds to unstable stratification, and $m < 1$ corresponds to stable stratification. In practice, there is no sharp boundary between these types of stratification. Therefore, measurement data for which $m < 0.7$ and $m > 1.3$ are selected for the cases of stable and unstable stratifications, respectively, in order to isolate the cases of neutral stratification for which $m$ is in the vicinity of 1.In southern Russia, in summer, in the atmospheric surface layer, stable stratification is usually observed during nighttime hours under windless conditions at temperature inversion in the lower 2-m layer, and unstable stratification is usually observed during daylight hours under the conditions of developed convection and noticeable wind. According to our observational data obtained in the Rostov region, the turbulence coefficient averaged for stable atmosphere amounts to 0.00-0.01 $m^2$/s, while that for unstable stratification is in the vicinity of the range 0.05-0.10 $m^2$/s.

## OBSERVATION RESULTS AND DISCUSSION

According to the results of correlation and regressive analysis a close connection between the conductivity of atmosphere and radon-222 volumetric activity is discovered in atmospheric air. The correlation coefficients for different points of Rostov region achieve the values of 0,7÷0,8.

The observations during summer season discover that the radon-222 content close to the ground, and consequently the conductivity of atmosphere are greatly determined by the wind speed in the range from 0 to 2 m/s, which can be seen at Fig. 3. (The bars here and at the following presentations show the standard error of measurements.)

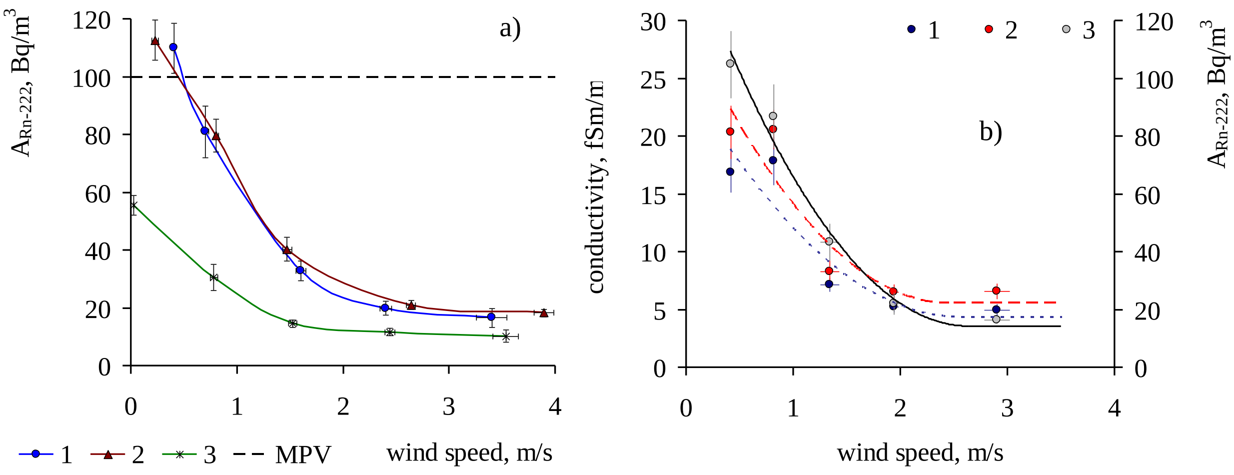


Рис.3. Empirical relationships of some atmospheric characteristics with wind speed at the height of 2 m:

a) Rn-222 volumetric activity at the height of 0,05 m (dotted line presents its indoor maximum permissible value MPV): 1 – Orlovskij, August 1999; 2 – Platov, August 2003-2005; 3 – Mikhailovka, August 1997;

b) negative (1) and positive (2) conductivities and Rn-222 volumetric activity (3) at the height of 0,05 m (Orlovskij, August 1999).

At higher the wind speed both volumetric activity of radon, and polar conductivities have low values, corresponding to typical values during day hours. In this situation the well developed turbulent diffusion in the surface layer facilitates radon transfer into the higher atmospheric layers, preventing its accumulation close to ground surface. It determined the well-pronounced diurnal rhythm of radon concentration and polar conductivities during summer months in the Don steppes (Fig. 4), when the diurnal variations of wind speed is well expressed with low values at night and their increase during the day hours. Within the periods of windy nights (August 19 and 20, see Fig. 4) the diurnal rhythm of radon-222 activity and polar conductivities variations breaks. Spatiotemporal variations of polar conductivities follow variations of radon, whose content in the surface layer is determined by the conditions of turbulent exchange and depends upon the temperature stratification. The result of the surface layer electric structure dependency from its stratification is particularly the typical diurnal transformation of vertical profiles of the atmospheric electrical characteristics. During a period with stable stratification (as a rule, from 9 p.m. to 7 a.m. of local time) the increase of radon-222 concentration (Fig.5, Column I) and polar conductivities (Fig.5, Column II) in general by the layer 0-3 m and considerable negative gradients of these values are observed. Wide spread of values, characteristic of radon-222 concentrations and polar conductivities of the atmosphere in these hours is explained by atmospheric irregularities, related to the weakened turbulent mixing under the conditions of stable stratification. Under unstable stratification the radon-222 concentration and polar conductivities values in the layer and their gradients decrease in general, which is related with intensification of turbulent mixing of atmosphere.

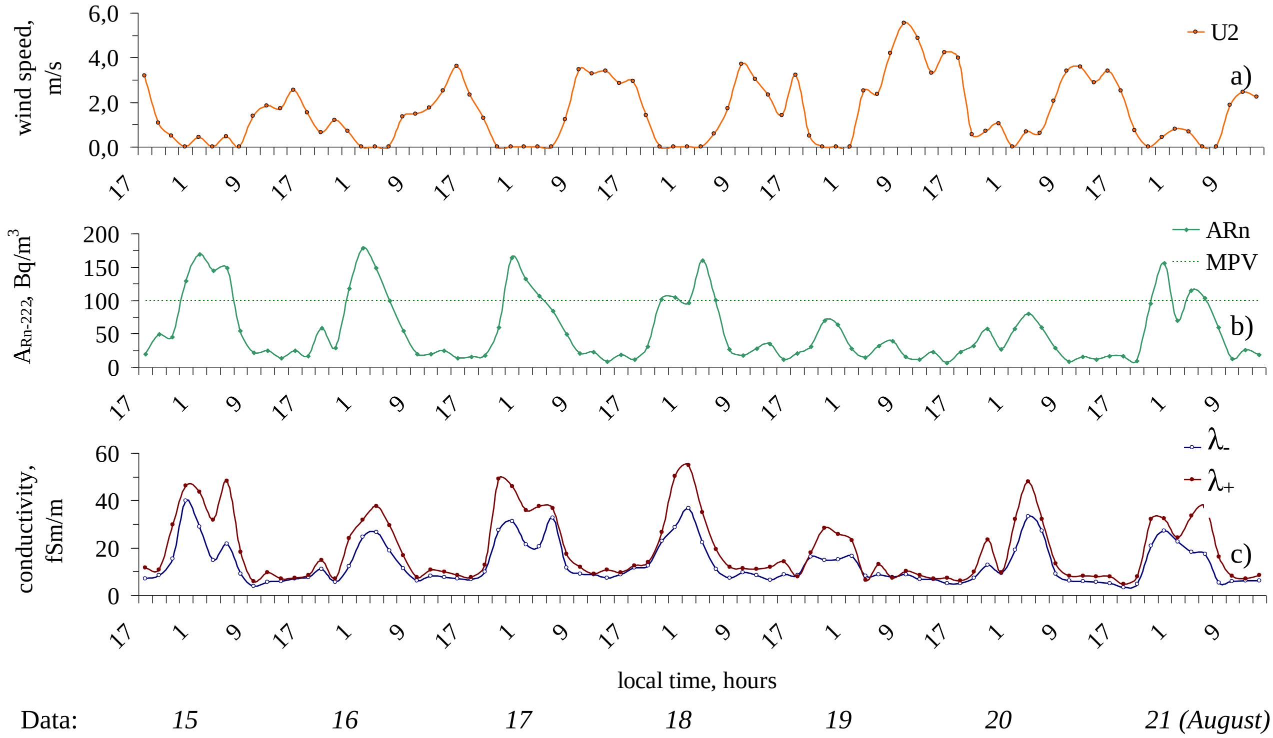


Fig.4. Temporal variations of atmosphere characteristics in the period of August 14-21, 2005 (Platov): a) wind speed at the height of 2 m; b) Rn-222 volumetric activity at the height of 0,05 m, dotted line represents its indoor maximum permissible value MPV; c) polar atmosphere conductivities at the height of 0,05 m.

Comparatively small spread of values during the day hours (approx. 9 a.m. – 19 p.m. of local time) is explained by homogeneity of atmospheric properties under intensive mixing.

Peculiarities of radon-222 concentration profiles and polar conductivities, which are discussed in length in the earlier published articles [Petrov et al. 1999, 2009], to our opinion determine the vertical distribution of characteristics of electric field in the surface layer. Our research work allowed to reveal three types of vertical distribution of potential gradient in the lower 3 m layer, which are observed most often and regularly change one another under transition from stable stratification (type I and II) to unstable (type III) and back during 24 hours [Petrova et al. 2011].

Diurnal transformation of the potential gradient profiles can be observed at Fig. 5 in column III. Column IV shows the diagrams of space charge density distribution, reconstructed according to Poisson's equation by the vertical profiles of potential gradient from column III. In this case space charge is considered as space charge of ions of all mobilities.

One of the sources of space charge in the lowest atmospheric layer, as it was shown by our observations [Petrova et al. 2011] and the results of other authors, is the raising of dust by wind from the withered ground surface. The examination of the records of potential gradient by fluxmeter at the ground level demonstrates, that the raising of dust by trucks at earth road gives an abrupt decrease, goes to “minus”, and then restores. It all lasts for 3-5 minutes.

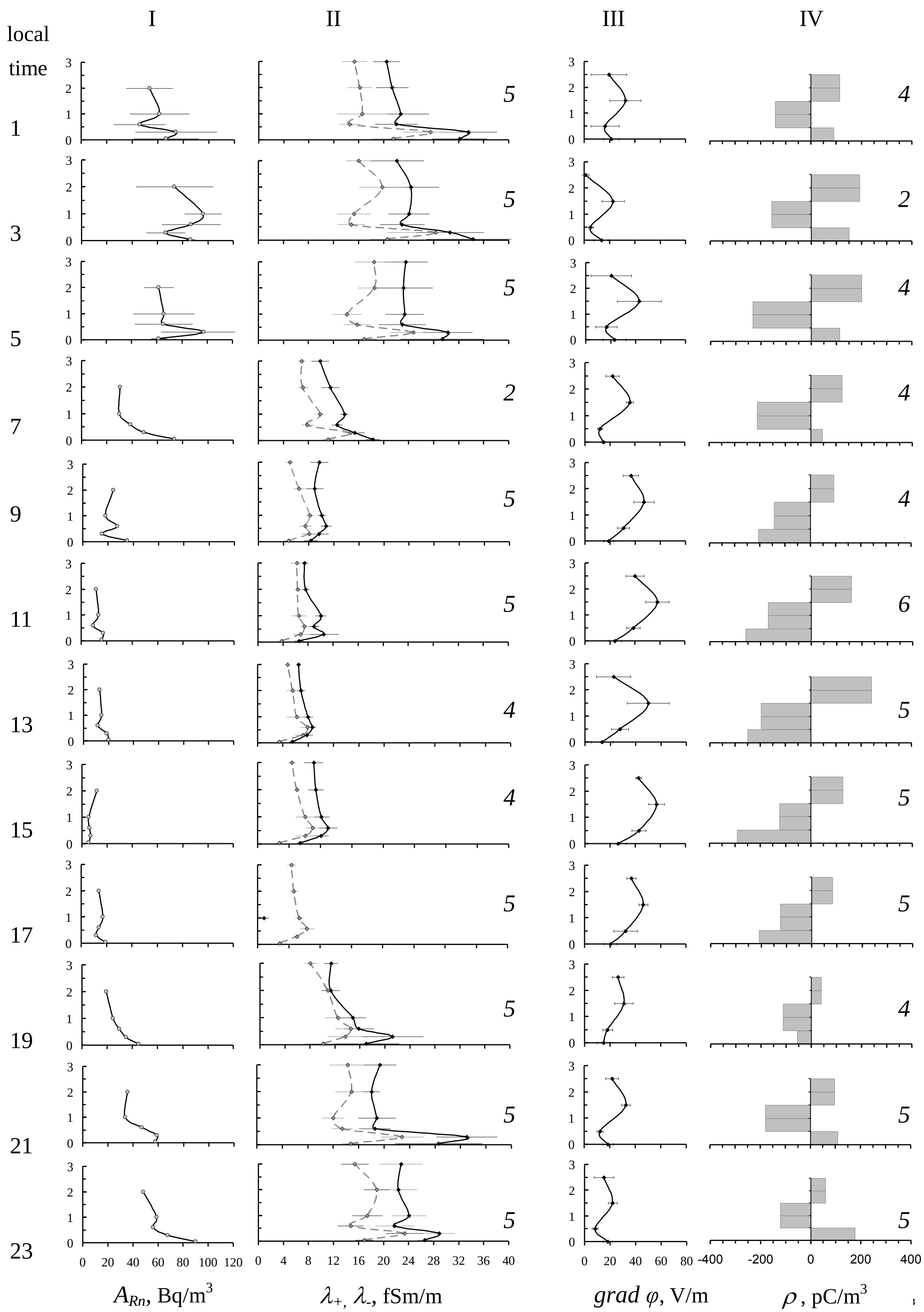


Fig. 5. Typical diurnal transformations of averaged vertical profiles of the radon-222 volumetric activity $A_{Rn}$ (I), positive $\lambda_+$ and negative $\lambda_-$ (dotted lines) atmosphere specific electrical conductivities (II), the potential gradient (III) and the calculated space charge density $\rho$ (IV) in the lowest 3-meter layer by the example of Platov, August 2004. (Italic type arabic numerals show how many profiles were averaged.)

The same duration for similar effects is indicated by Israelsson [1994], who observed the negative space charge at agricultural machinery operation close to the observation site, if soil surface was dry.

Saturation of lower atmospheric layers with the negatively charged dust in case of dust drift determines under unstable stratification conditions the formation of type III field profile with the negative space charge in the most lowest layer from 0 m to the height of approximately 0,5÷1,5 m, which is higher changed by the positive space charge (the period from 9 till 19 of local time at Fig. 4).

The peculiarity of the “night” profiles at stable stratification is formation of the negative space charge layer higher than 0,5 m due to the negative conductivity gradient observed here (the period from 9 till 19 local time at Fig. 4, columns III and IV). Lower close to ground surface, approximately 0÷0,5 m, the positive space charge is formed, caused by the electrode effect.

The problems of small ions space charge forming are studied in the well-known reviews [Hoppel et al. 1986, Mareev 2008]. On the basis of Poisson's equation it is possible to write down for the space charge density of small ions: $\rho = \varepsilon_0 \nabla \cdot \vec{E}$. Considering that field intensity may be determined as $\vec{E} = \frac{\vec{j}_\lambda}{\lambda}$ ($\vec{j}_\lambda$ - conduction current density, $\lambda$ - specific atmospheric conductivity), we shall get for the small ions density in quasi-steady-state conditions: $\rho_{si} = \frac{\varepsilon_0}{\lambda} \nabla \cdot \vec{j}_\lambda - \frac{\varepsilon_0}{\lambda} \vec{E} \cdot \nabla \lambda$. Here $\varepsilon_0$ - electric constant.

Space charge in case of conduction current passing in the atmosphere is formed by two ways: 1) at disbalance of ionic fluxes close to the boundary and 2) under the conditions of conductivity gradient. When the conduction current flows close to the ground the space charge of small ions forms in the result of both conduction current divergence, related to the electrode effect ($\rho_{ee}$), and also as the consequence of the atmospheric conductivity gradient ($\rho_{\Delta\lambda}$), determined by decrease of radon-222 content with height. The final value of small ions space charge density at every electrode layer horizon: $\rho_{si} = \rho_{ee} + \rho_{\Delta\lambda}$, - shall be determined by the sign and value of each summand, depending upon the layer state. As a result, the space charge density of small ions at stable stratification, when the conductivity gradients are especially high, has a complex profile. In the presence of aerosol the charges of small ions are absorbed by its particles, in the result of which the charge accumulates and can remain in the atmosphere for a long time, determining the electric field profile.

Measurements of atmospheric potential were made in August 2012 in Fedorovka settlement, Rostov region, in the vaster range of heights as earlier, namely up to the height of 4 m, to obtain more accurate data about vertical field distribution close to the ground at stable stratification.

The vertical profiles of the gradient were built for every hour with the stable stratification. Then the profiles were sorted by the types and averaged. Thus obtained average profiles, and the vertical profile of potential gradient, measured by Crozier [1965] during night hours without wind during summer period are represented at Fig. 6. A calculated profile Hoppel [1969] for non-turbulent case is placed next to every experimental profile.

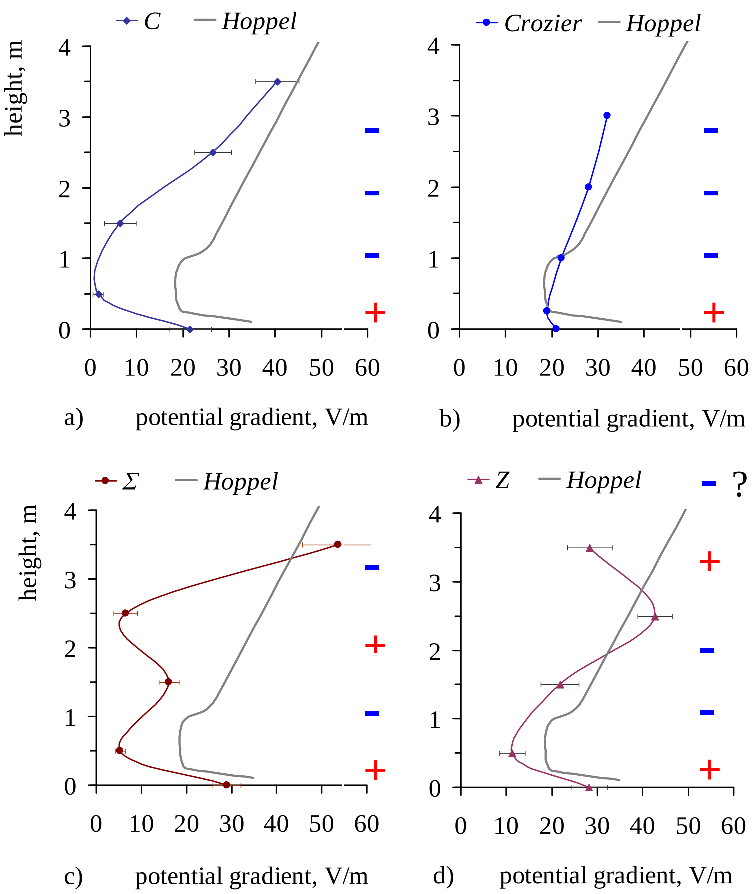


Fig. 6. Different types of the potential gradient vertical distribution in conditions of stable stratification, Fedorovka, August 2012 (a, c, d) and the experimental profile obtained Crozier [1965] for windless night periods (b). The grey line on each graphic represents the calculated profile of Hoppel [1969] for nonturbulent theory.

When considering the profiles shown at Fig. 6 it is possible to observe that in the lower part of each of them the potential gradient values decrease with height, which according to Poisson's equation shows the presence of positive space charge in the layer. (The arrangement options of space charge layers of different sign for different profile types are represented by the corresponding symbols). Above this layer in any case, as one can see from the shape of the profiles, there is a negative space charge. Further, in the case of C type profile up to the level of 4 m the field grows (Fig.6, a, b). Which refers to the profiles of Σ and Z types, in both cases, judging by the results of measurements (Fig.6, c, d), there is a second layer of positive space charge above the negative. Above it, in case of Σ type profile, the field grows with height again (Fig. 6c). It is possible to suppose, that it also happens in the case of Z type profiles, but out of the limits of 4 m layer of observations. Substantiation of such a supposition may be the fact, that the field values close to the ground, using the numerous longstanding data, are 120-150 V/m. If we assume that for Z type profile the field value decrease with height does not alter with the growth of its values vertically above 4-meter level, it is necessary to admit, that the field in the surface layer does not exceed 40 V/m, which is unlikely

Figure 7 shows the diagrams of space charge density values for each type of field profile in lower atmosphere at stable stratification. The evaluation is made by the vertical distribution of potential gradient according to the Poisson’s equation.

It is worth mentioning that observations reveal in the situation under study the complicated indented profile of electric conductivity, conditioned by the joint action of ionizers and electric field close to ground surface (Fig. 8). It can also explain the development of Σ type profiles of potential gradient along with the C type profiles.

## CONCLUSIONS

Analysis of the observational results of electric structure of the surface layer in summer period up to the height of 4 meters allows to detect, that under the conditions of stable temperature stratification the layers of negative space charge form in the atmosphere. Due to this the electric field on the ground level decreases considerably. The cause of the negative space charge formation is the passing of conduction current through the layers with the negative electric conductivity gradient, which develops under the conditions of a weakened turbulent mixing due to accumulation of radioactive emanations, firstly of radon-222, close to the ground. Generally in this situation in the layer 0-4 m the potential gradient increases with height. Evaluation of field vertical distribution under weakened mixing of the atmosphere out of the limits

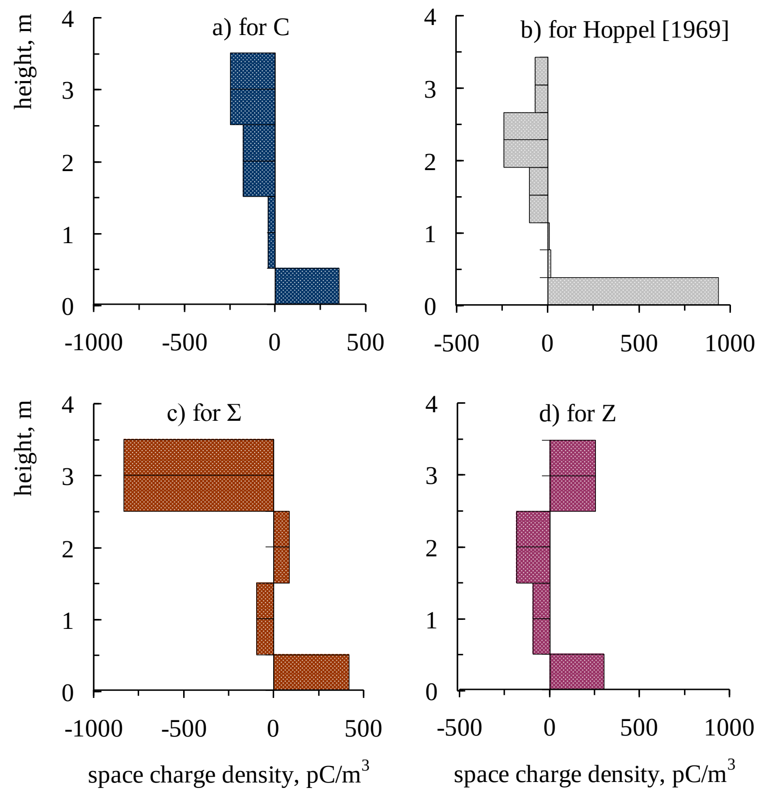


Fig. 7. Space charge density values calculated based on the potential gradient vertical distributions in accordance of Poisson equation: a, c, d - for different field profile types in conditions of stable stratification in Fedorovka, August 2012; b – for the calculated profile of Hoppel [1969], nonturbulent theory.

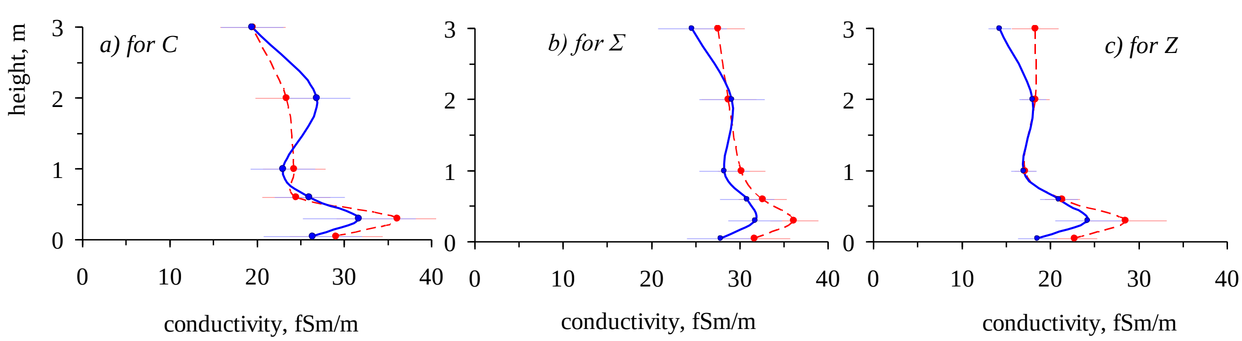


Fig. 8. Vertical profiles of positive (red dotted lines) and negative (blue lines) conductivities averaged for periods with different types of the potential gradient vertical distribution in Fedorovka, August 2012 (type C – 10 hours, type Z – 19 hours, type Σ – 9 hours).

of the 4-meter layer for different observation points, and also for the calculated results Hoppel [1969] and experimental results Crozier [1965] with the aid of linear extrapolation shows, that the value of the field 100 V/m under the above conditions is reached at the height of 5-10 m.

During the day periods with wind at dry warmed soil surface the lower layers of atmosphere become saturated with the negatively charged dust, due to dust drift. Apparently under unstable stratification this mechanism causes development of field profile with the negative space charge in the lowest layer from 0 m up to the height of approximately 0,5÷1,5 m, which is changed by the positive one higher up (period from 9 to 19 local time at Fig. 4).

Clear change of stable and unstable stratification of the atmosphere and change of turbulence intensity at alteration of day and night takes place in summer months in the Don steppes for the majority of the periods. As the result the typical diurnal transformation of electric structure of surface layer, conditioned by the diurnal pulsations of radioactive emanations, firstly radon-222, in the atmosphere is observed.

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