The atmosphere electrical characteristics’ monitoring as an element of technosphere safety

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Abstract. The data of the long-term observations on atmospheric electricity elements and the results of the surface layer’s electrical state modeling are analyzed. It is concluded that the surface layer electrical characteristics’ monitoring can serve as a control element of anthropogenic impact on the atmosphere to assess its aerosol and radioactive pollution.

1. Introduction
Atmospheric monitoring includes the atmospheric electrical observations. The general task is to obtain the information about the operational state of the atmospheric electric field. Special tasks are to study the mechanisms of various space charge generators in the lower and upper atmosphere and their contributions to the formation of an atmospheric electric field. The control of anthropogenic impact on the atmosphere is of particular scientific and practical interest. Mountain observation points in the absence of aerosol and radioactive air pollution can be globally representative and, due to their geographical location, can be used to control the regional and local anthropogenic impacts on the atmosphere.

2. Experimental studies
Modern studies of atmospheric electricity in the highlands of Elbrus started in 1986-1988 at the stations: Nizhny Arkhyz (2000 m above the sea level), Shadzhatmaz (2100 m above the sea level) and Cheget Peak (3040 m above the sea level) [1,2]. At these stations, a stable daily variation of the electric field with a morning minimum (01 h–04 h UT) and evening high (16 h–22 h UT) was recorded.

The similarity of the diurnal course of the electric field under the high-mountain conditions of the Carnegie curve suggests that it is caused by the global unitary variation of the ionosphere potential. In the atmospheric-electric observations’ practice, it is customary to consider the condition for unitary variation to be distinguished against the background of local variability of the electric field by the degree of the global data representativeness at the observation point.

At the Cheget Peak station, located in the high mountain part of the Baksan Gorge near Elbrus, the unitary variation in the diurnal course of the electric field was most clearly observed during the entire measurement period, therefore this item was recommended for background monitoring. In 1989-92 the complex observations of atmospheric electricity were carried out [1] at the Cheget Peak station. As a result, it was found that in the atmosphere of the observation point there are no significant aerosol impurities and there are no sources of local radioactive contamination, and the daily variations in the electric field are mainly due to the global unitary variation. In 2003-2004 similar observations were made at the stations of Kyzburun (700 m above sea level) at the beginning of the Baksan gorge and on
Terskol Peak (3003 m above the sea level) in Elbrus region [1].

Since 2012, regular observations of the atmospheric electric field at Peak Cheget and Kyzburun stations have been organized [3,4]. The used automated measuring and computing complex, which includes an automatic weather station, allows not only to receive and record the observation data, but also to process them in real time [5].

The main characteristics of atmospheric electricity “good weather” [1] are the intensity (potential gradient) of the electric field $V'$, specific polar conductivity of air $\lambda_\pm$ and the density of the total vertical electric current $j_0$. These physical parameters and, especially, their combination with meteorological data contain information about global and local electrodynamic processes in the atmosphere. These three electrical parameters are connected by the differential form of Ohm’s law and create a system of closed measurements [3].

The total electric current in the atmosphere may be the sum of the conduction current ($j_{\text{cond}} = V'(\lambda_+ + \lambda_-)$), turbulent and convective currents ($j_k$), due to the conduction ions’ movement and air movements.

Atmospheric-electrical characteristics are differential, therefore the meters ($V'$, $\lambda_\pm$, $j_0$) are recommended to be placed as close as possible. The suction capacitors for measuring air conductivity should be located approximately at the electric field measuring level. With this installation of sensors, convective current can be neglected. An independent criterion for this is the calculation of the Dolezalek parameter: $\Omega = j_0 / j_{\text{cond}}$ [1]. With a good arrangement of the sensors’ values $\Omega$ should not differ too much from the unity in the conditions of “good weather”, which corresponds to Ohm's law. It should be noted that in difficult orographic conditions, for example, in mountainous areas, the values $\Omega$ may vary significantly for a particular observation point and the installation method. Then you should experimentally establish a range of $\Omega$ values for the undisturbed atmospheric conditions.

The electrical characteristics of the surface layer depend on the aerosol particles of natural and anthropogenic origin present in the atmosphere. Significant aerosol pollution of the atmosphere reduces the electrical conductivity of air and, as a result, increases the electric field strength both in the surface atmosphere and in its higher layers [6,7]. A decrease in the electrical conductivity in the atmosphere is usually observed near the large cities or industrial centers, especially with wind directions from sources of aerosol emissions. This was recorded during the atmospheric electrical observations in the village of Voeikovo, the Leningrad Region and the city of Rostov-on-Don [8,9].

Radioactive pollution of the atmosphere leads to an increase in the ionization processes and, accordingly, to an increase in the air electrical conductivity [6, 10]. An example of this is the consequences of the accident at the Chernobyl nuclear power plant in 1986, which led to the changes in the atmosphere electrical conductivity, not only at the local but also at the global levels. In particular, the absolute minimum of average daily electric field values under undisturbed weather conditions was recorded on May 6, 1986 at the observation points on the Kola Peninsula and Elbrus Region. These facts are due to the powerful release of radioactive substances into the atmosphere [2].

Thus, the data on electrical conductivity and the atmospheric electric field can be used as the integral indicators of anthropogenic impact on the atmosphere.

3. The theoretical basis

The electrical characteristics of the atmospheric surface layer are due to the electrode effect existing at the Earth’s surface [11]. The spatial-temporal structure of the electrode layer depends on the strength values ($E$) electric field, degree of turbulent mixing ($D_T$) and ionization rates in the air ($q$), as well as the possible presence of aerosol and radioactive pollution in the atmosphere.

The surface layer electrodynamic model equations in the turbulent electrode effect approximation have the form [11]:

\[
\frac{\partial n_{1,2}}{\partial t} \pm b_{1,2} \frac{\partial}{\partial x} (E n_{1,2}) - \frac{\partial}{\partial z} (D_T(z) \frac{\partial n_{1,2}}{\partial x}) = q(z) + q_1(z) - \alpha n_1 n_2 - BN n_{1,2},
\]
\[
\frac{\partial E}{\partial z} = \frac{e}{\varepsilon_0} (n_1 - n_2 + N),
\]
\[
D_T(z) = D_I z, \tag{1}
\]
where \(n_1, n_2\) is the volume concentration of conduction ions; \(b_1 = 1.2 \cdot 10^{-4}; b_2 = 1.4 \cdot 10^{-4}, m^2 c^{-1}\) - defines their mobility; \(a = 1.6 \cdot 10^{-12}, m^3 c^{-1}\) - is the ion recombination coefficient; \(m_2\) - ion recombination coefficient; \(N\) - shows the aerosol particle concentrations; \(1,2 \cdot 10^{-12}, m^3 c^{-1}\) - is the ion reunion coefficient with aerosol; \(q(z)\) - is the surface air ionization rate; \(q_I(z)\) - defines ionization due to anthropogenic effects; permanent: \(\varepsilon_0 = 8.85 \cdot 10^{-12} F/m; e = 1.6 \cdot 10^{-19} C\).

The electrical air conductivity and the current conductivity density are calculated by the formulas [11]:
\[
\lambda = e (b_1 n_1 + b_2 n_2) ; \quad j = \lambda E. \tag{2}
\]
An experimental profile was used for the air background ionization rate [11]:
\[
q(z) = \left(7 + q_0 e^{-z/l}\right) \cdot 10^6, \tag{3}
\]
where the first term (in brackets) is the constant ionization of air near the Earth created by the galactic cosmic rays, the second is the local ionization in the surface layer, \(l = 0.4 m\) is the characteristic thickness of the ionization layer.

To assess the radioactive pollution of the atmosphere, it is necessary to determine the ionization function \(q_I(z)\), entering into the first equation of the system (1). The equation determining the transport of radioactive particles, primarily radon-220 and its decay products, in a turbulent atmosphere can be written as [12,13]:
\[
\frac{\partial q}{\partial t} - \frac{\partial}{\partial z} \left( D_T(z) \frac{\partial q}{\partial z} \right) = q_1(z) - K_I Q, \tag{5}
\]
where \(Q\) - is the radon-220 concentration, \(K_I\) - is the permanent half-decay.

The following expression is used to relate the ionization function to the radioactive radon-220 concentration [12,13]:
\[
q_1 = \frac{E_I}{\omega_1 \tau_1} Q, \tag{6}
\]
where \(E_I\) - is the energy of \(\alpha\)-particles emitted by radon -220; \(\omega_1\) - is the minimum ionization energy, \(\tau_1\) - is the half-decay of radon.

To simulate the structure of a turbulent electrode layer filled with aerosol particles at various concentrations, taking into account the radioactive background, we used the system (1) together with the equations (5) and (6) under various conditions in the atmosphere [7,10].

4. The results of modeling and their analysis
Obviously, the effect of radioactive impurities in air on the electrical state of the surface layer is determined by the background and impurity ionization ratio \(q_I/q_0\), degree of turbulent mixing and the constant half-decay.

Within the electrode layer, the values \(q_I\) and \(q_0\) can be considered as permanent. We set the values of the variables: the factor in the coefficient of turbulent diffusion \(D_I = 0.01 m/s, q_0 = 10^7 m^{-3} s^{-1}\), electric field values at the Earth’s surface \(E_0 = -100 B/m\), and we consider the concentration of aerosol particles to be negligible. Then, as a result of a computational experiment, we obtain the electrode effect value \(E_0/E_0 = 3\) for the relation \(q_I/q_0 = 10\), and for - \(q_I/q_0 = 100\) we have \(E_0/E_0 = 0.1\). The latter estimate is in good agreement with the study results of the Chernobyl accident effect on the electrical characteristics of the atmosphere described in [11].

Figures 1-2 show the results of numerical calculations of electrical characteristics profiles in a turbulent surface layer under conditions of aerosol and radioactive pollution of the atmosphere.
Figure 1. Profiles $E$ (a), $j$ (b) and $\lambda$ (c) in the presence of various concentrations aerosol in the atmosphere (curves 1-4 for $N \sim 10^8, 10^9, 10^{10}, 10^{11} \text{ m}^{-3}$).

Figure 2. Profiles $E$ (a), $j$ (b) and $\lambda$ (c) at various degrees of air ionization (curves 1-4 for $q_0 \sim 4.8, 40, 80, 120 \text{ m}^{-3} \text{ c}^{-1}$ in the formula (3)).
Increasing the concentration of aerosol particles with \( N = 10^8 \text{ m}^3 \) (background values) to \( N = 10^{11} \text{ m}^3 \) (urban conditions) leads to an increase in the electric field at the Earth’s surface at the height of about 1 meter by 30% (Figure 1a, the curves 1,4). And the values of the conductivity current density (Figure 1b, curves 1, 4) and air conductivity (Figure 1c, curves 1.4) decrease by approximately 2.5 times.

At background atmospheric ionization values, the volumetric electric charge is positive in the entire electrode layer. Under the conditions of strong air ionization, the electric charge becomes negative, which leads to a “electrode effect reverse” [11], when the electric field starts increasing with height (Figure 1a, curve 4). This is also confirmed in the experimental data [1.12]. From drawing 1a it follows that with an increase in the level of air radioactivity in the turbulent surface layer from the natural ionization level \( (q_0 = 4.8 \text{ m}^{-3}\text{c}^{-1}) \) to the state of severe radioactive contamination \( (q_0 = 120 \text{ m}^{-3}\text{c}^{-1}) \) there is an increase in the electric field by 10%. Current Density (Figure 2b, curves 1, 4) increase by more than 2 times, and electrical conductivity by more than 4 times (Figure 2c, curves 1, 4) at the Earth’s surface. In this case, a characteristic maximum appears in the electrical conductivity profile, which, with an increase in the amount of radioactive impurities, moves to the surface (Figure 2c).

**Summary**

So, the air electrical conductivity in the surface layer acts as a local indicator of aerosol or radioactive pollution of the atmosphere. The electric field and current flowing in the atmosphere are, at the same time, the integral characteristics of the global electric circuit. Thus, the electrical characteristics of the atmosphere can serve as the parameters for controlling the anthropogenic impact on the atmosphere as an element of technosphere safety.

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