Expeditionary research of electrical processes on a high mountain plateau taking into account aerosols and humidity

G G Petrova¹*, I N Panchishkina¹, A I Petrov¹, O G Chkhetiani²

¹Physics Faculty, Southern Federal University, Rostov-on-Don, st. Sorge, 5, Russia
²A.M.Obukhov Institute of Atmospheric Physics Russian Academy of Sciences, Moscow, trans. Pyzhevsky, 3, Russia

E-mail: georgpu@rambler.ru

Abstract. The work continues the analysis of the results of complex expeditionary measurements in the surface atmosphere, some of which have recently been published. It uses data from expeditions of the Laboratory of Geophysical Research of the Faculty of Physics of the Southern Federal University at research stations of the Obukhov Institute of Atmospheric Physics, Russian Academy of Sciences: 2017 at the Tsimlyansk Research Station in the steppe zone, 2018 and 2019 at the Kislovodsk alpine station located on the Shadzhatmaz plateau, 2.100 m above sea level. With the help of regression analysis, empirical relationships of the electric potential gradient near the earth’s surface and the concentration of aerosols with a diameter of more than 0.1 μm were obtained for four measurement periods. The investigated dependence has a linear character. Judging by the results obtained, the space charge of aerosols for the arid steppe zone is negative. For the Shadzhatmaz plateau, the results indicate the presence of a positive space charge in the atmosphere under high humidity conditions. The discovered facts are considered as a consequence of the differences in the physicochemical properties of aerosol particles under different conditions. Proceeding from the results of measurements at the alpine station, regression analysis revealed a close relationship between the concentration of aerosols and relative humidity for different size ranges of particles, which is well approximated by an exponential function.

1. Introduction

In the case of a natural experiment, the possibilities of varying the physical conditions at a particular observation point are limited. It is possible to expand the range of conditions for a field experiment by organizing expeditions in different physical-geographical conditions. For a long period of time, a summer field experiment in order to study the regularities of electrical processes in the surface atmosphere was carried out in the zone of the Don steppes with an arid hot climate. When conducting studies of electrical processes on an alpine plateau in the summer months of 2018-2019, the conditions were characterized by high humidity. Periods of measurements in fog were not uncommon. This made it possible to obtain new data on the formation of the electrical state of the atmosphere, taking into account aerosols at high humidity.

According to the earlier studies, the surface atmosphere is a system of electrically charged layers, which is revealed by the vertical profiles of the electric potential and polar conductivities. There are various reasons for formation of space charges in the atmosphere. So, according to our observations [1, 2] and the observations of other authors [3], one of the sources of charge in the surface layer is the removal of fine aerosol from the heated dried soil surface into the atmosphere by wind flows.
Observations show that this process results in the formation of a negative space charge in the immediate proximity of the earth’s surface. The formation of charged structures in the lower tens and hundreds of meters of the atmosphere is indicated by the authors of a number of papers, in particular, [4]. The formation of layers of the small ions space charges can be associated with the fact that the atmospheric conduction current flows through the layers with a vertical gradient of the atmosphere electric conductivity [5, 6]. This gradient can be caused, for example, by a change with height in the intensity of atmosphere ionization by cosmic rays or radioactive radiation [7, 8]. In addition, a space charge of the electrode effect is formed in the immediate proximity of the earth’s surface, due to the divergence of the conduction current.

When aerosols interact with small ions, selective adsorption of charges of different signs is possible. The physicochemical properties of aerosol particles affect the magnitude and sign of their charges and, as a consequence, the electrical state of the surface layer. Proceeding from the results of experiments in an adiabatic chamber, Smirnov [9] noted that an increase in humidity from 40 to 95% leads to the accumulation of charges on particles, and the sign of the charge depends on the chemical composition of hygroscopic nuclei. Furthermore, media with insoluble nuclei (porous silicas, etc.) are mainly characterized by negative particle charges. Smirnov explained the appearance of significant negative space charges on watering insoluble hygroscopic nuclei with an increase in humidity from 40 to 70% by the structuring of surface water films, which exhibit an affinity for negative small ions. In the case of media with soluble nuclei, an increase in humidity, according to Smirnov’s data, is accompanied by the formation of positive space charges. Moreover, at a humidity of 60-90%, the electrification of soluble nuclei can be interpreted within the framework of diffusion-kinetic models of ionic charging of aerosols.

Thus, it can be assumed that the phase transitions of water, depending on temperature, are important for the formation of variations in the atmosphere electric field.

The aim of the work is to define the features of the formation of the surface layer electrical structure, taking into account aerosols and the moisture-thermal regime of the atmosphere on the basis of a comparative analysis of experimental data obtained on a high mountain plateau and of earlier results obtained in the steppe zone.

2. Methods

The results discussed in this work are a continuation and development of long-term research of electrical processes in the surface atmosphere, carried out by the Laboratory of Geophysical Research, Faculty of Physics, Southern Federal University. Measurements over the past years have been carried out using the same measuring and computing complex, which makes it possible to perform an aggregate analysis of data from different expeditions. For the analysis, we mainly used the results of measurements during joint summer expeditions with the A.M. Obukhov Institute of Atmospheric Physics, Russian Academy of Sciences (IAP RAS) at scientific stations of the IAP RAS, which differ significantly in thermodynamic conditions. Tsimlyansk Scientific Station in the Don steppes zone in July-August is characterized by dry, hot and windy weather, with dried up soil surface. The Kislovodsk High Mountain Scientific Station is located on the Shadzhatmaz plateau in the zone of alpine meadows, 2100 m above sea level. In August the plateau is characterized by cool weather with high humidity, frequent rains and fogs. The soil is moist, covered with lush meadow vegetation. The observation sites at both stations are located on vast flat areas with low-cut grass.

The intensity of the atmosphere electric field at the ground level was recorded with fluxmeters (A.I. Voeikov Main Geophysical Observatory). Using radioactive collectors at altitudes of 1, 2, 3, and 4 meters, electrical potentials were recorded, which made it possible to calculate the average value of the potential gradient for a certain layer from the potential difference and the distance between the collectors. The potential values averaged over half an hour at different heights were used to calculate the potential gradients. The concentration of micron and submicron aerosols with field observations in the measuring complex in 2017-2019 was measured with the laser aerosol spectrometer LAS-P (Karpov Institute of Physical Chemistry) in the size ranges 0.1-0.2; 0.2-0.3; 0.3 0.4; 0.4-0.5; 0.5-0.7; >
0.7 microns. In earlier periods, an AZ-10 aerosol particle counter was used, which is designed to measure the concentration of aerosol particles with diameters from 0.3 to 10 microns in six ranges: 0.3-0.4; 0.4-0.5; 0.5-1; 1-2; 2-5; more than 5. At the same time, gradient measurements of meteorological parameters were carried out hourly. Measurements went on around the clock for about 10 days. For the analysis, the hourly averaged values were used mainly. A detailed description of the whole complex of measurements can be seen in [8, 10].

3. Observation results and discussion
According to the results of earlier research, carried out in the summer months in the steppe zone on the territory of the Rostov region, regression analysis revealed a decrease in the values of the potential gradient at the level of the earth’s surface with an increase in the concentration of aerosols (figure 1, a, b, the bars on all graphs here and below show the standard error values). This may indicate a negative charge on the aerosol particles.

Figure 1. Dependence of the electric potential gradient at ground level on the concentration of aerosol particles according to the results of summer expeditions:

- a) Kashar district of the Rostov region, 2012; b) Tsimlyansk Scientific Station, Rostov region, 2017, 296 hours; c) Kislovodsk High Mountain Scientific Station, 2018, 96 hours; d) Kislovodsk High Mountain Scientific Station, 2019, 230 hours.

At the same time, in a humid climate of an alpine plateau in the dustless atmosphere, the potential gradient increases with an increase in the aerosol content (figure 1, c, d). This indirectly indicates a positive space charge localized on submicron size aerosol particles. The differences found are apparently related to the peculiarities of the physicochemical properties of aerosols at the observation points. In the steppe zone, the amount of insoluble aerosol can be significant, and its transfer into the atmosphere is associated with the processes of soil erosion and wind transport of particles. In the
atmosphere of the Shadzhatmaz plateau, the aerosol may be dominated by soluble particles, for which an increase in humidity is accompanied by the formation of positive space charges according to Smirnov [9].

Figure 2. Vertical profiles of the atmosphere electric potential gradient, averaged for the groups of measurements:

a) Tsimlyansk, August 2017 (6 hours of observation), aerosol concentration \( N > 500 \text{ cm}^{-3} \); b) Shadzhatmaz plateau: curves 1, 2 – August 2018 (27 and 25 hours, respectively); curves 3, 4 – August 2019 (108 and 138 hours); curves 2.4 – aerosol concentration \( N > 500 \text{ cm}^{-3} \); curves 1, 3 – air humidity \( r > 80\% \).

As is known, the presence of a space charge in a certain layer of the atmosphere causes spatial change in the field, in accordance with the Poisson relation. For a horizontally homogeneous atmosphere under undisturbed conditions, the potential gradient decreases with height in a layer with a positive space charge and increases in a layer with a negative one. Figure 2 shows the vertical profiles of the electric potential gradient in the lower 4-meter layer of the atmosphere, averaged for several groups of measurements. The profiles in figure 2, a and curves 2 and 4 in figure 2, b were constructed by selection and subsequent averaging of those measurement periods when the total concentration of aerosols in all ranges (more than 0.1 \( \mu \text{m} \)) exceeded 500 \( \text{cm}^{-3} \). The slope of the profile to the right in figure 2a, plotted according to the measurements in Tsimlyansk in the summer of 2017, indicates that, in general, negative space charge prevailed in the atmosphere during this period of observations. In figure 2b, the slope of all curves of the potential gradient vertical distribution to the left corresponds predominantly to a positive space charge. To construct profiles 1 and 3, periods with increased relative humidity were selected: more than 80\%. As per the graphs, the profiles 1 and 2 appear identical in the

| Table 1. Approximation parameters of empirical regression series (to figure 3). |
|---------------------------------|-----|-----|-----|-----|
| \( d, \mu \text{m} \) | \( N_0 \) | \( k \) | \( R^2 \) |
| 2018 96 hours | 0.012 | 0.88 |
| 0.1-0.2 | 0.008 | 0.84 |
| 0.2-0.3 | 0.016 | 0.86 |
| 0.3-0.4 | 0.026 | 0.93 |
| 0.4-0.5 | 0.030 | 0.95 |
| 2019 230 hours | 0.022 | 0.98 |
| 0.1-0.2 | 0.013 | 0.78 |
| 0.2-0.3 | 0.026 | 0.99 |
| 0.3-0.4 | 0.034 | 0.94 |
| 0.4-0.5 | 0.040 | 0.93 |
same way as profiles 3 and 4. In our opinion, this correlation indirectly indicates the condensation nature of aerosols under high humidity conditions on the Shadzhatmaz plateau.

Figure 3. Dependence of aerosol concentration on air humidity according to the results of summer expeditions 2018 (blue, 96 hours), and 2019 (red, 230 hours) at the IAP RAS research stations for different particle diameters (μm): a) 0.1-0.2; b) 0.2-0.3; c) 0.3-0.4; d) 0.4-0.5.

Table 2. Correlation coefficient of aerosol concentration and relative humidity for aerosol particles of different diameters, Shadzhatmaz plateau.

| d, μm | all>0.1 | 0.1-0.2 | 0.2-0.3 | 0.3-0.4 | 0.4-0.5 | 0.5-0.7 | 0.7-1.0 | >1.0 |
|-------|--------|--------|--------|--------|--------|--------|--------|-----|
| 2018  | 0.68   | 0.51   | 0.71   | 0.80   | 0.79   | 0.77   | 0.76   | 0.51|
| 2019  | 0.60   | 0.22   | 0.68   | 0.66   | 0.58   | 0.56   | 0.53   | 0.58|

Figure 3 shows the empirical series of regression of aerosol concentration according to the values of relative humidity for the measurement periods 2018 and 2019 on the alpine plateau Shadzhatmaz. The empirical dependence of aerosol concentration \( N \left(10^6 \text{ m}^{-3}\right) \) on humidity \( r \ (%) \) is well approximated by an exponential function of the form \( N = N_0 \exp(kr) \) both for the total concentration of aerosols in all ranges, and for individual ranges of particle sizes. Table 1 shows the approximation parameters for various sizes of aerosol particles on the Shadzhatmaz plateau. The reliability of the approximation is estimated by the value of \( R^2 \). It is noteworthy that the coefficient \( k \) increased with an increase in the particle size both in 2018 and in 2019.

As can be seen from table 2, the correlation coefficient of aerosol concentration with humidity is the highest according to the results of both measurement periods for particles with a diameter of 0.2 - 0.5 μm.
4. Summary
The research shows that atmospheric aerosols are actively involved in the formation of the electric state of the surface atmosphere, and in different physical and geographical conditions their influence can be different. This is determined by the physicochemical properties of aerosol particles, thermodynamic conditions, and the state of the underlying surface. Selective adsorption of charges of small ions of different signs by aerosols determines the sign of space charges in the atmosphere, which form the vertical profile of the electric field and affect its value. The obtained regression dependences of the values of the potential gradient on the concentration of aerosols in the surface layer show that dispersive aerosols in arid steppe zones contribute to a decrease in the field near the earth’s surface, forming layers of negative space charge. Apparently, in conditions of high humidity of the Shadzhatmaz plateau, aerosols have a predominantly condensational nature. An increase in their concentration is accompanied by an increase in the electric field at ground level, and the shape of the potential gradient profile corresponds to a positive space charge in the atmosphere. Thus, the temperature regime and associated condensation processes indirectly affect the electric state of the surface atmosphere.

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References
[1] Petrova G G, Petrov A I and Panchishkina I N 2014 Radioph. Quant. Elec 56(11) 723–38
[2] Petrova G G, Panchishkina I N, Petrov A I, Chkhetianai O G, Egorov E V and Boldireva V A 2018 Bul. KRASEC. Phys. Math. Sci. 5(25) 42–54
[3] Hoppel W A and Frick G M 1986 Aeros. Sci. and Tech. 5(1) 1-21
[4] Anisimov S V, Galichenko S V, Afinogenov K V, Mareev E A, Shlyugaev Yu V, Prohorchuk A A, Gurev A V and Mikryukov P A 2018 Rep. Acad. Sci.V 481(2) 197–202
[5] Hoppel W A, Anderson R V and Willet J C 1986 Nation. Acad. Press. 149–165
[6] Mareev E A 2008 Space Sci. Rev. 137(1-4) 373–97
[7] Petrov A I, Petrova G G and Panchishkina I N 2009 Atm. Res. 91 206–14
[8] Petrova G G, Panchishkina I N, Petrov A I and Chkhetiani O G 2019 IOP Conf. Ser.: Mater. Sci. Eng. 698
[9] Smirnov V V 2010 Izv. Atmos. Oceanic. Phys. (Springer) 46(3) 294–304
[10] Petrova G G, Panchishkina I N, Petrov A I and Chkhetiani O G 2020 IOP Phys.: Conf. Ser. 1604 (2020)012001