Electrical Structure of the Unipolar Charged Aerosol Cloud

Stanislav S. Davydenko[1], Dmitry I. Iudin[1,2*], Vitaly Yu. Klimashov[2], Alexander Yu. Kostinskiy[1,3], and Vladimir S. Syssoev[1,4]

1. Institute of Applied Physics of the Russian Academy of Sciences, Nizhny Novgorod, Russia
2. Radiophysical Research Institute, Nizhny Novgorod, Russia
3. Higher School of Economics, Moscow, Russia
4. High Voltage Research Centre, All-Russia Electrotechnical Institute, Istra, Moscow region, Russia

ABSTRACT: The artificial charged aerosol cloud is used as a hand-operated source of the spark discharges similar to the thunderstorm lightning discharges. Based on the assumption that the intracloud space charge density could be presented as a superposition of the regular and irregular parts, a model of the electrical structure of the charged aerosol cloud is developed. The regular part of the charge density distribution is calculated in the steady-state current approximation taking into account the source current structure and disturbance of the electric conductivity in the vicinity of the cloud. The irregular part of the distribution describes random spatiotemporal fluctuations of the charge density. It is shown that a quasi-electrostatic field provided by the charged aerosol is characterized by significant spatial fluctuations showing the scale invariance. The mean-square fluctuations of the voltage between the different parts of the cloud are proportional to the square root of its linear dimensions and may reach significant values even in the absence of the regular field. The fluctuation intensity is proportional to the aerosol density and to the squared characteristic absolute value of the charge of the aerosol particles. The basic parameters of the extremely fluctuating spatial structure of the electric field inside the considered unipolar charged aerosol cloud are estimated. It is shown that the fluctuations of the electric field lead to the drop of the dielectric strength of the air and could serve as one of the important mechanism of the lightning initiation.

MODEL BASICS AND MAIN RESULTS

An original aeroelectrical facility based on the source of the aquated ions and high-voltage discharger was recently developed in High Voltage Research Centre of All-Russian Electrotechnical Institute (Istra, Moscow region). The facility is able to generate a unipolar charged aerosol cloud of the volume about 30 cubic meters under atmospheric conditions. The artificial charged cloud could serve as a hand-operated source of the spark discharges similar to the thunderstorm lightning discharges. The goal of this study is to consider an influence of the random inhomogeneity of the charge density distribution inside the electrified cloud on the small-scale local enhancement of the electric field. This small-scale electric field enhancement could play a crucial role in the lightning initiation [Trakhtengerts et al., 2002; Trakhtengerts et al., 2003; Iudin et al., 2003].

It is assumed that the electric structure of the cloud consists of the steady-state and perturbed

[*] Institute of Applied Physics RAS, 46 Ulyanova str., 603950 Nizhny Novgorod, Russia; *e-mail:* iudin_di@nirfi.sci-nnov.ru

components of the electric charge density. The steady-state component of the charge density is calculated in the framework of the stationary current approximation. Since the electrified cloud is generated by the given flow of the charged aerosols (see report by Andreev et al. [2014] for more details), the model assumes that the source current is started from a point at the ground level, directed upward, and has a cone shape. The value of the source current is equal to 90 μA. The electric conductivity in the vicinity of the cloud is assumed to be about 200 times more compared to the unperturbed conductivity of the atmosphere. As a result, the steady state distribution of the charge density and corresponding distribution of the electric field are obtained (see Fig.1). The maximal value of the steady-state electric field is less than 10 kV/cm, i.e. it is less as compared to the threshold of the negative streamer development.

The perturbed component represents the random fluctuations of the electric charge density within the electrified cloud. The spatial structure of the perturbations is described by a set of the Gaussian distributions with the spatial scales from a few decimeters up to several meters and standard deviations decreasing with the scale according to the power low (see Fig.2). The magnitude of the perturbations is proportional to the value of the steady-state component of the charge density.

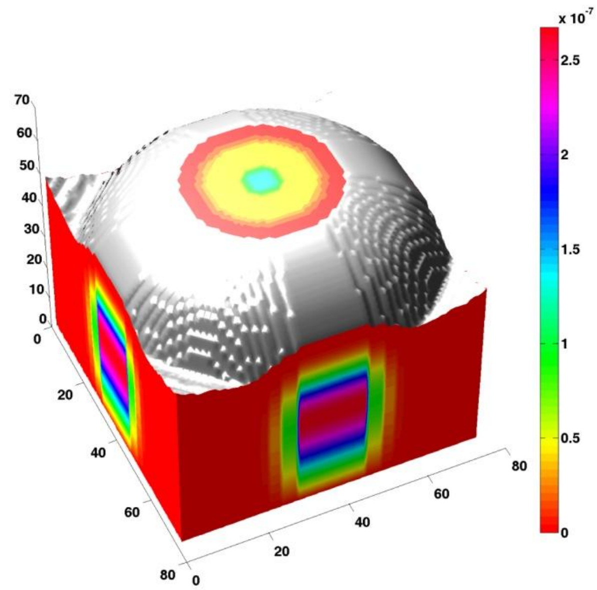

Fig.1. Distribution of the steady-state component of the electric charge density in the vicinity of the artificial aerosol cloud. The colour scale is graduated in C/m^3, horizontal and vertical axes are graduated in decimetres.

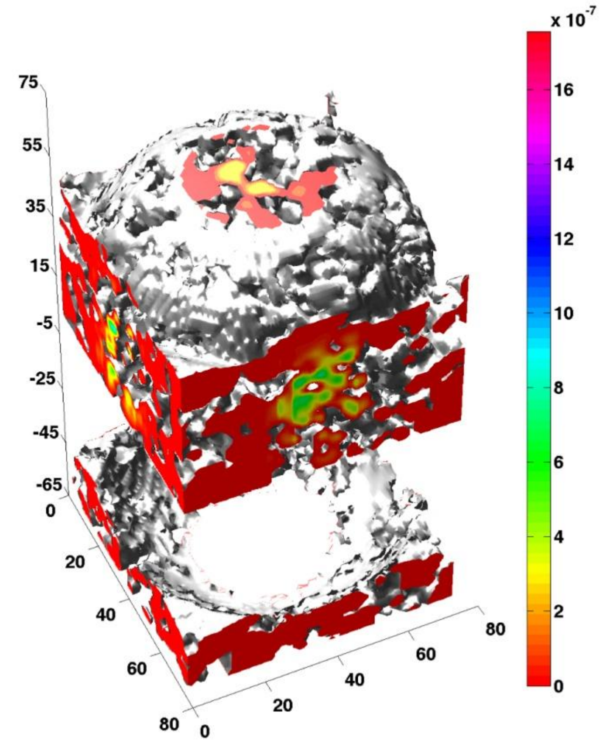

Fig.2. Distribution of the perturbed component of the electric charge density. The plane *z*=0 corresponds to the ground level.

The perturbed component of the electric field is calculated using the Coulomb low taking into account the perfectly conducting ground (since the decay time of the perturbed component is substantially less as compared to the Maxwell relaxation time in the vicinity of the cloud, such approach seems valid). The structure of the total, both steady-state and perturbed, electric field is presented in Fig.3. The calculations show that the maximal value of the total field exceeds the threshold value more than 2.5 times, i.e. the perturbation of the electric charge lead to the drop of the dielectric strength of the air and could serve as one of the important mechanism of the lightning initiation.

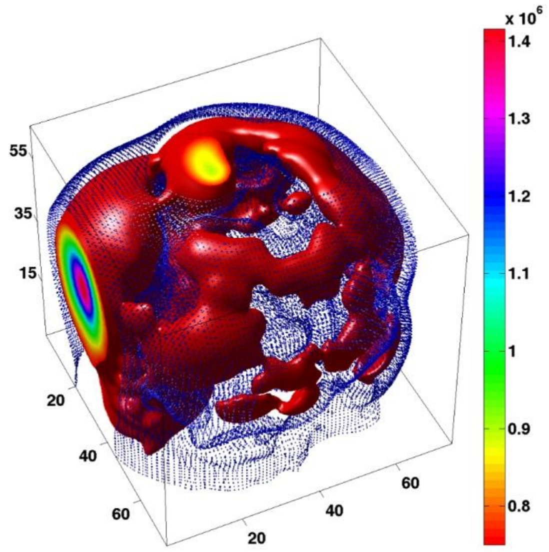

Fig.3. Spatial structure of the total electric field. The red surface corresponds to the electric field magnitude 7.5 kV/cm. The surface represented by the blue cones corresponds to the electric field magnitude 7 kV/cm. The plane *z*=0 corresponds to the ground level, the colour scale is graduated in kV/cm, the horizontal and vertical axes are graduated in decimetres.

ACKNOWLEDGMENTS

The work is supported in part by the Russian Foundation for Basic Research (projects 13-05-01100 and 13-01-97063) and the Government of the Russian Federation (contract No.11.G34.31.0048.).

REFERENCES

Andreev, M.G., N.A. Bogatov, A.Yu. Kostinskiy, L.M. Makal'sky, E.A. Mareev, D.I. Sukharevsky, V. S. Syssoev, 2014: First detailed observations of discharges within the artificial charged aerosol cloud. *Proc. XV Int. Conf. Atmospheric Electricity, 15-20 June, 2014, Norman, Oklahoma, USA.*

Iudin, D.I., V.Y. Trakhtengertz, and M. Hayakawa, 2003: Fractal dynamics of electric discharges in a thundercloud, *Phys. Rev. E*, **68**, 016601, doi:10.1103/PhysRevE.68.016601.

Trakhtengerts V.Y. , D.I. Iudin, A.V. Kulchitsky, and M. Hayakawa, 2002: Kinetics of runaway electrons in a stochastic electric field, *Phys. Plasmas*, **9**, No 6.

Trakhtengerts V.Y. , D.I. Iudin, A.V. Kulchitsky, and M.Hayakawa, 2003: Electron acceleration by a stochastic electric field in the atmospheric layer, *Phys. Plasmas*, **10**, 3290, doi: 10.1063/1.1584679.