Interaction between convective cloud systems and the Earth's surface

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Abstract. The nature of interaction between electric fields in convective cloud systems with the underlying surface is considered. Differences in charge potentials at different points of the Earth are indicated. Modern theories about the appearance of positive and negative charges in clouds, about the development of lightning and places of their destruction are presented. Data on the influence of cloud systems depending on the properties of the Earth's surface are presented. It is established that the interaction of cloud systems with the earth's surface depends on the electrical properties of clouds. This interaction depends on the following factors: humidity, density, temperature, chemical and mineralogical composition, soil particle composition, structure, nature and properties of the soil solution.

1. Introduction

The study of the nature of atmospheric and electrical processes continues to arouse the interest of many who have observed the manifestation of electrical activity in the atmosphere. Research in this area is of practical importance. The electrical properties of the atmosphere and the electrical phenomena occurring in it are important for many meteorological processes. The functioning of various radar systems, emissions from industrial enterprises and vehicles, and afforestation of the territory can change the electrical properties of the atmosphere. This can have various consequences, both positive and negative. In this context, it is interesting to identify the interaction of cloud systems with the earth's surface, which depends on the electrical properties of clouds. This interaction is determined by a number of factors that affect the induction of charges on the earth's surface under the influence of convective air masses [1-4].

Currently, the study of the Earth's atmosphere surface layer electric field is an urgent scientific problem. Research is relevant for studies of the natural phenomena dynamics. They are necessary for solving problems of the electric field disturbances propagation occurring in the surface layer of the atmosphere, for the analysis of the laws describing the distribution of the experimentally derived electric field characteristics in the ground atmospheric layer for the evaluation of the electric field amplitude spectral component in the atmospheric surface layer [5].

One of the important components of the scientific research success is the reliable information availability about the issue situation, available achievements and promising directions for solving a specific problem. In this regard, it is necessary to organize a monitoring system at the regional level, which would contribute to creating a global picture. Attention should be focused on creating a
database on the territory heterogeneity in terms of electrostatic indicators. It is necessary to systematize the latest achievements in atmospheric electrostatics.

2. Materials and methods
The atmospheric electrical properties are one of the main atmosphere characteristics. The objective of these studies is to monitor the atmosphere surface layer electric field in order to determine the causes of its violations and to identify the possibility of affecting the local circulation of cloud systems. The work is based on the results of measurements of the electric field in the surface layer of the atmosphere, carried out at different stations. The established regularities were compared with a set of ground-based geophysical data. The materials for the research were ground-based observations of the electric field at the earth's surface. Charge potential gradients were considered at various points of the Earth, including over the oceans. The mechanism of large volume charges formation in the cloud that lead to lightning discharges is described. Materials from meteorological stations, data from literature sources, own observation results and Internet resources were used. A package of standard statistical programs was used for processing materials [5-7].

3. Results and discussion
The atmosphere is an electrically inhomogeneous environment [8]. It has regions that have free volume charges of different sign and magnitude. The potential gradient (grad $\phi$) is numerically equal to the change in the potential per unit length of the force line. The gradient of the charge potential at the earth's surface is 130 V/m. But it can decrease to 70 V/m or increase to 203 V/m. The potential gradient is greater in moderate latitudes and decreases towards the poles and the equator (table 1).

| Observation point    | grad $\phi$, V/m | Observation point    | grad $\phi$, V/m |
|---------------------|------------------|---------------------|------------------|
| Pavlovsk (Leningrad) | 171              | Irkutsk             | 192              |
| Potsdam             | 203              | Oceans (average)    | 134              |
| Upsala (Sweden)     | 70               | Tashkent            | 128              |
| Shpitzbergen        | 78               | Java isle           | 86               |
| Yekaterinburg       | 161              | Antarctica           | 140              |

These fluctuations are a violation of the "normal" field condition. It is observed in clear cloudless weather. The reason for such violations:

- Variability of meteorological phenomena (precipitation, clouds, hail, etc.);
- Heterogeneity of land plots;
- Changes in the conductivity and volume charges values;
- Various types of underlying surfaces (open soil, sand, massive forest plantations, agricultural plants, and others).

The distorting role of the earth's surface is shown in figure 1, which shows the daily course of the potential gradient on the Eiffel tower and at the earth's surface.

The tension of the electric field at the earth's surface changes not only during the day, but also annually. The daily course over the oceans is simple and natural. It has a simple character with a maximum of 18-19 hours and a minimum of 3 hours (GMT). The daily course here remains almost unchanged in the function of the seasons.

Above the land surface, the daily course is complex and different in different places. It usually has the character of a double wave. The minimum is observed at 3-5 a.m. and 3-5 p.m. The maximum is observed in the evening and before noon. The position of highs and lows is shifted by month.
Such a course of field tension can be considered as the result of overlaying at the perturbations main simple course. Perturbations are caused in a function of time by changes in the conductivity and volume charges of the environment.

There is a close relationship between the field strength and other atmospheric-electrical and meteorological characteristics of the atmosphere. Tension is very closely related to conductivity. The relationship between them is inversely proportional. Therefore, all meteorological conditions (for example dust) that affect the conductivity, and especially those that significantly change the volume charges, affect the electric field tension.

Of particular interest is the connection of field tension with clouds, precipitation, and fog [9, 10]. The interaction of electric fields depends significantly on the distances between charged objects. Therefore, we can assume that the clouds of high tiers will not have a significant impact on the field tension at the earth's surface. This is not true of low rain clouds. Under their influence, the sign of the earth's surface field may change. Precipitation has a great influence on the field tension at the earth's surface. Under their influence, strong and irregular fluctuations in tension often occur. The tension at the earth's surface during intense precipitation can reach several thousand volts per meter of length [11, 12].

Figure 1. The course of the electric potential gradient at the earth's surface (1) and at the Eiffel Tower (2).

Figure 2. Electric charges in a thundercloud near the earth's surface.
The nature of the charge distribution in a thundercloud is shown in figure 2. As a result of the distribution of charges in the storm cloud, strong electric fields are created. These fields are observed inside and outside the cloud itself. There is a large field tension, which at the Earth's surface can reach several hundred kilovolts per 1 m of length.

The formation of large volume charges in a thunder cloud leads to a spark discharge in the form of lightning within it and in the space between it and the earth's surface. The nature of the accumulation of electric charges is little known. But they are most often formed when strong upward air flows are created inside the cloud.

Lightning is a discharge between an area with positive and negative charges. One theory explains the appearance of it in the following way. In clouds, when large drops of water or ice crystals are destroyed, small drops are negatively charged. That is, they acquire excess electrons. Larger drops are positively charged. Small negatively charged drops are grouped in the center of the cloud. Large, positively charged drops are collected closer to the outer parts of it. Thus, an electric charge accumulates in the cloud. The total force of interaction between the charged cloud, the underlying surface, and the sign of this force depends on the ratio of positive and negative point charges in the cloud, the nature of their distribution and location, and the amount of charge near the earth's surface at the location of the cloud.

According to another theory, positive charges are formed on ice crystals in the upper part of the cloud, as in the lower part of it, particles with a negative charge are grouped around positively charged particles. Usually the Earth is negatively charged in relation to the atmosphere. Negatively charged parts of clouds moving over the earth's surface induce separate areas with a positive charge on it. Since air is a poor conductor of electricity, the electric current between these differently charged regions occurs gradually. Lightning develops when the field tension of atmospheric electricity reaches 30,000 volts/cm.

Lightning strikes in some cases high objects, and in others it hits down. The trajectory of lightning is significantly affected by the terrain and electrical properties of the earth's crust. Lightning tends to hit those places where the electrical conductivity of the earth's crust layers is greater. Depending on which of the two factors (relief or electrical) is stronger, lightning strikes will hit either high places or lowlands.

The interaction of cloud systems with the earth's surface depends significantly on the electrical properties of clouds. However, this interaction is also determined by a number of terrestrial factors that affect the induction of charges on the earth's surface under the influence of clouds with good vertical development. Let's focus on some of them.

The value of soil electrical conductivity is a complex and highly variable value. It depends on the humidity, density, temperature, chemical and mineralogical composition, soil particle composition, structure, nature and properties of the soil solution. That is, the electrical conductivity of different soils and sandstones varies widely and is much stronger than any other characteristic.

Soil includes elements that have different conductive properties (metals, dielectrics, electrolytes). The ratio of these components can be different. Quartz sands have more dielectric properties. Ideal conductors of electricity (metals) are represented in soils by small inclusions. Minerals with a predominant content of metal compounds have a low resistivity from $10^{-1}$ to $10^{-3}$ Ohms and high conductivity. Quartz, feldspar, mica, and calcite have high dielectric properties. A certain contribution to the overall conductivity is made by interstitial air together the high soil porosity. Moisture and moisture saturation with salts are of great importance for assessing the electrical conductivity of the soil.

The soil solution composition depends on temperature, precipitation, evaporation, transpiration, etc. There is no single mechanism of conductivity in soils, since it is different for dielectrics, electrolytes, and metals.

For metals, there is a connection for resistivity ($\rho$):
\[ \rho = \frac{2m \nu}{ne^2 l_e} , \]  

where e – electron charge; m – electron mass; \( l_e \) – length of an electron free path, \( \pi \) – concentration; \( \nu \) – heat velocity of the electron.

For a soil solution (a typical electrolyte), there is a dependence:

\[ \rho = \frac{1}{\alpha ZC_k (U^+ + U^-)} , \]  

where \( \alpha \) is the coefficient of electrolytic dissociation; \( C_k \) – solution concentration; \( Z \) – valence of ions; \( U^+, U^- \) – velocity of ions in an electric field of \( E=1 \) (e.g., 1 v/sec)

Dielectric soil permittivity is determined (as well as its conductivity) by many factors. The most important of them are the dielectric properties of the soil mineral composition (in sands – its main mass), the chemical nature, soil particles structure and composition, their shape and size, and the dielectric characteristics of interstitial air and moisture. Since each of the phases is solid, liquid and gaseous in different soils and sands is in different ratios, their properties are accumulated in the total volume of the soil in different ways. Their contribution to the effective permittivity will be different. Dielectric soil permittivity increases with increasing moisture content and decreasing porosity. As the temperature increases, the effective value of the dielectric permittivity decreases.

4. Conclusion

The electrical interaction of convective cloud systems with the earth's surface is determined by the specific properties of both components. The nature of this interaction may affect the local circulation of cloud systems. On the other hand, it is easier to influence the earth component than the cloud one. This effect can be achieved by changing the conductivity and increasing the capacity of earth surface individual plots. One of the ways to solve this problem is the territory afforestation with high dielectric properties. This is the direction in agroforestry with a great opportunity. These studies need to be developed. The main focus should be on creating a database on the heterogeneity of the country's (region, district) territory by electrostatic indicators, classification of wood stands and soils by electrostatic characteristics. It is necessary to systematize the latest achievements in atmospheric electrostatics. Work on creating a model of interaction between clouds and the earth's surface is promising.

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