Simulation of the electrification process of a cloud due to the interaction of hailstones with cloud crystals

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Abstract. This paper is based on the simulation of the electrification process of a hail cloud resulting from the interactions (collisions) between hailstones (graupels) with cloud crystals. A thundercloud cell at the maturity stage was simulated. The process of cloud electrification due to the interactions (collisions) of hailstones with cloud crystals is considered. The thermohydrometric structure of the cloud is also taken into account. It is shown that the negative or positive charge acquired by hailstones, is dependent on the effective liquid water content and temperature of the cloud. The cloud charging current was also estimated. It is shown that the thermohydrometric parameters of the cloud determines the resulting polarization of the cloud.

1. Introduction
Thunderstorms are regarded as one of the most dangerous weather phenomena, as they cause significant damage to many industrial activities. This leads to a comprehensive interest in the study of thunderstorms. An important task of studying thunderstorms is to study the conditions that lead to the occurrence of thunderstorms and the possibilities of their prediction. One of the ways to solve this problem is numerical modeling.

As numerous studies have shown, a thunderstorm is possible if the upper boundary of the cloud is located above the level of intense crystallization. This indicates the importance of ice particles interactions to the electrification process of the cloud.

The results of laboratory experiments from studies carried out on the processes of electrification of particles are widely presented in the literature. As researchers have shown that, the most significant non-inductive processes are:

- electrification during freezing, deformation and splitting of supercooled droplets;
- electrification during collision and splashing of supercooled droplets on a large ice particle;
- electrification during collision and rebound of ice crystals from a large ice particle [4].

The first two processes depend primarily on the size of the supercooled droplet. In this case, the probability of splitting a supercooled droplet depends on its size. However, at the level of intensive crystallization, the concentration of large supercooled droplets is insignificant. Therefore, it seems that in order to analyse the process of macro-electrification of the cloud when the level of intensive crystallization is reached, it is necessary to consider first of all the collision of crystals with large ice particles of precipitation.

As shown by Brooks et [1] in their laboratory study, the magnitude of the charge separated during the collision of an ice crystal and a riming ice particle, which are falling graupels and hailstones at the
beginning of their evolution, depends on the microphysical conditions in the cloud. It is these conditions that determine both the sign and the magnitude of the charge separated during collision. This tends to determine the general process of electrification of the cloud. It is noteworthy that the spontaneous organized macro-electrification of the cloud begins and develops rapidly after the cloud has reached the level of intensive crystallization in the course of its development [1, 5, 7].

As shown in the work [4], the electrification due to collision between graupels or hailstones and crystals is determined by the structure of the interacting particles (features). As numerous experiments have shown that, the sign of the charge acquired by a hailstone depends on the same parameters as during its growth, that is dry and wet growth. In conditions close to the dry growth, the hailstone acquires a negative charge, in conditions close to the wet growth, the hailstone acquires a positive charge.

Results from the laboratory experiment published by [1] were taken into account. In their studies, it was established that the effective water content and the relative velocity of hailstones and crystals determine the sign of the charge, and that the magnitude of the separating charge depends on the relative velocity, the size of the crystal, effective water content, and temperature.

Hence, for simulating the process of cloud electrification, the method for modeling the hydro thermodynamical and microphysical parameters of the cloud is crucial.

2. **Hydrodynamic model of the cloud**

To build an electrical structure of the cloud, data from temperature sensing of the atmosphere were used. In this work, a one-and-a-half-dimensional model of a convective single-cell cloud with a variable radius of height was selected. The cloud was approximated by a stationary jet stream corresponding to the maturity stage of the studied cloud Reference to [3]. The height step was set to 100 m. Microphysical and hydro thermodynamical parameters averaged over the cross section. Experimentally and theoretically obtained dependencies, as well as some averaged cloud sensing data are used. The vertical profiles of the following cloud parameters were calculated using a numerical scheme: vertical velocity, air temperature, water content, ice content, and cloud radius. The concentration and size of the hail are assumed to be constant in height. This data was used as the basis for further calculations of the cloud electrification processes.

The model is based on the scheme of cloud electrification by precipitation [7]. Calculations of the electrical processes were performed on a stationary non-electrical parameter. This approach was determined by the task of the work: thus, to identify the non-electrical characteristics of the cloud and how to determine its electrical activity.

The specific conditions for the development of convection were observed in the south of England on June 10, 2016. The study of the peculiarities of the process of electrification of a cumulonimbus cloud is carried out for a thunderstorm situation. Figure 1 shows the profiles of the hydrodynamic parameters of the cloud, we see that the upper limit has reached 8600 meters. The temperature of the earth was 16°C. That is, the case of a sea storm during the transition period is considered.

Figure 2 shows the profiles of the radius of graupels (hailstones) and the radius of crystals. It was assumed that at the stage of maturity, the size of hailstones is assumed that the relative fall velocity to the earth's surface, from the upper boundary of the cloud to the maximum wind speed is 0.5 m/s, \( V_{\text{hail}, z - wz} \). The radius of the crystals is determined by the temperature and water content of the cloud and is calculated in accordance with [2].
Figure 1. Vertical profiles of a cumulonimbus cloud at maturity. 1-vertical velocity, 2-temperature in the cloud, adiabatic water content in the cloud, 3, ice content in the cloud.

Figure 2. Vertical profiles of the radii of hailstones and cloud crystals; 1 – the radius of hailstones, 2- the radius of crystals.
3. Analysis of the charging process of graupel, hailstones and cloud crystals

As noted by [1], the rate of fall of hailstones (and hence the radius and density of hailstones) has a twofold effect on the process of charge separation resulting from the collision of hailstones with crystals. First, it determines the mass of supercooled droplets captured by the hailstone per unit time. Secondly, it determines the magnitude of the separating charge. In addition, the magnitude of the charge separation during collision is determined by the effective water content in the cloud layer, the temperature and the size of the crystal.

Figure 3 shows the vertical profile of the charge separated by a single collision of a hailstone with a crystal (Δq(i) – [1]).

![Figure 3. Vertical profile of the charge separated by a single collision of a hailstone with a crystal (Δq(i) - from the article [1]).](image)

From the experiment, the separating charge ranges from +6·10⁻¹⁶ to -6·10⁻¹¹ C. The charge sign is reversed in the upper part of the cloud, that is, in the upper 200-meter layer of the cloud, where hailstones are positively charged, crystals are negatively charged. In the layer below the level of intense crystallization, where hailstones could be positively charged, there are no crystals. And, therefore, there is no layer of the lower reverse of the hailstone charge sign caused by the collision with cloud crystals.

4. The results and discussion

The charge generated at the different height levels of the cloud was carried out. As a result, the electric structure of the cloud is formed, which is a dipole. The negative charge is located below the level of 6900 m (T= -29 °C), while the central negative charge of the cloud is located at an altitude of 6100 m, corresponding to the isotherms T = -25 °C, positive charge is located above, where the temperature is below -29 °C, therefore, there is the high positive charges at altitudes of 8300 m (T = -47 °C).
5. Conclusion
The part of the cloud above the level of intensive crystallization, larger graupel particles and hailstones are shown to be negatively charged. This confirms the formation of a typical electrical structure of thunderclouds (cumulonimbus cloud): thus, in the upper part comprise accumulated positively charged cloud crystal, in the central part of the cloud- negative charge is accumulated on graupels and hailstones.

References
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Figure 4. Vertical profile of the bulk density of the charge charging current density 5 and 10 minutes after the start of the electrification process.