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ELECTRICITY OF WARM CLOUDS

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Abstract

Full Text

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GEOPHYSICS

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ELECTRICITY OF WARM CLOUDS

(Presented by Academician E. K. Fedorov, 12 XII 1967)

The electrical properties of a cloud are directly related to its meteorological characteristics—phase state, microstructure, stage of development, etc. In recent years attention to the study of the processes of development of warm clouds has increased considerably. However, despite the homogeneity of their phase structure, warm clouds have not been studied sufficiently—the difficulties associated with effective influence on this form of cloudiness have not been overcome, and the mechanism of formation of precipitation in warm clouds remains a matter of debate.

We have attempted to approach the question of the formation of precipitation in warm clouds from the standpoint of investigating the electrical parameters of the cloud. In this connection, in 1966 experimental studies were carried out on the distribution of charges of cloud particles, as well as on the potential gradient of the electric field in natural warm cumulus and stratocumulus clouds up to 1 km thick. Measurements of the parameters of cloud particles were made from an aircraft by the method of photoregistering the trajectories of their motion in the electric field of a plane capacitor ⁽¹⁾. The charge of the particles was determined from the angle of deflection of the trajectories of charged particles in the electric field from a certain fixed direction; the particle diameter in the range from 2 to 30 μ was determined by microphotometry of the trace formed by them on photographic film. The potential gradient of the electric field in the clouds and their vicinity was measured with dynamic field mills with a scale division value (on the sensitive scale) $\gamma = 0.01$ V/cm per division.

Fig. 1. Distribution of particles by charge (**a** and **c**) and by size (**b** and **d**) in stratocumulus clouds on 22 and 24 VII 1966.

Measurements of the charges of cloud particles in warm cumulus and stratocu-

Fig. 2

Figure 2: Fig. 2

stratocumulus clouds showed that there are two types of distribution—symmetric (Fig. 1a) and asymmetric with a shift, as a rule, into the negative part of the spectrum (Fig. 1c). The distribution law of the particle parameters and the character of the relationship between the mean charge and particle size depend on the coordinates (or on the level of the measurements in the clouds) and on the stage of development of the cloud. The mean charge q of droplets, as a rule, increases with increasing diameter d . In the general case this dependence is satisfactorily approximated by the equation: $q = k_1 d + k_2 d^n$, where k_i and n are constant coefficients depending on the type of clouds and on the level of the measurements. For $n = 2$, in our measurements k_i varied within the limits $0 \leq k_1 < 2 \cdot 10^{-4}$ and $0.01 < k_2 < 0.4$ (if q is measured in esu, d in cm).

With an asymmetric distribution, the particle charge increases with size faster than the first power of the diameter, $n > 1$ (Fig. 2). In this case the mean charge of the droplets is greater than in that part of the clouds where the distribution of particle charges is symmetric.

Electric fields in warm clouds are small—the potential gradient, as a rule, does not exceed 30 V/cm in absolute magnitude.

Comparison of the calculated equilibrium values with experimental data ⁽²⁾ showed that diffusion and adsorption of ions, as well as the induction mechanism of charging particles moving in an electric field, can be effective only in the initial stages of cloud development. In more developed clouds, the mean experimental value of the droplet charge is greater than the equilibrium value calculated under the assumption of any mechanism of interaction between ions and cloud droplets. Consequently, there must exist other mechanisms that would ensure a more rapid increase of charge than diffusion processes.

Fig. 2. Dependence of the mean charge values on droplet size in stratocumulus clouds, 24 July 1966.

$$q_+ = 0.07d^2; \quad q_- = 0.36d^2$$

Cloud size spectra, especially in the initial stages of cloud development, have a small dispersion. Consequently, enlargement of particles can occur mainly through the coalescence of droplets of comparable sizes. An increase in the charge of droplets during their coagulation is possible only if particles charged with the same sign coalesce. Measurements of charges in warm clouds confirmed the conclusion obtained earlier ^(2,3) that, along with the presence of a mixture of charges of both signs, clouds contain regions of predominantly like-charged particles. Consequently, in natural clouds there are objective conditions favoring the coagulation of like-charged droplets, provided that electric forces do not hinder their approach. It is therefore necessary, in this connection, to investigate the question of the influence of electric forces in natural clouds on the

coagulation of droplets.

Coagulation of droplets, generally speaking, is a nonstationary process dependent on many physical factors; therefore calculation of the coagulation growth of particles, especially of comparable sizes, is a very complicated problem, whose solution (even numerical) is possible only under certain simplifying assumptions.

First of all, it should be taken into account that coagulation of particles in warm clouds consists of two elementary acts—collision of particles (which depends on external fields and on electrical and hydrodynamic effects) and coalescence of particles (which depends on the moisture deficit and on the conditions at the droplet surface). Since the efficiencies of collision and coalescence of droplets are determined by different forces and different conditions, we considered it possible to examine the influence of electric forces on the collision and coalescence of droplets independently.

For the coagulation calculations we used experimental data on the distribution of particles by size and charge obtained in natural cumulus clouds in the free atmosphere. The collision efficiency as a function of particle sizes and electrical parameters was obtained theoretically by numerically solving the system of differential equations of motion of charged and neutral particles in the field of gravity and in an electric field ⁽⁴⁾.

Calculations of the collision efficiency were carried out under the following assumptions: 1) the droplets in the cloud are sufficiently far apart from one another,

so that pair collisions may be considered without taking into account the influence of other particles; 2) cloud droplets are conducting spheres and do not change their shape during motion; 3) the particles move in a viscous medium, in uniform electric and gravitational fields; turbulent and Brownian motion was not taken into account; 4) most of the calculations were carried out for particles of comparable sizes using equations in which the hydrodynamic interaction is represented by expressions given by Hocking ⁽⁵⁾, which are valid for diameter ratios in the interval $0.2 < d_2/d_1 < 0.8$; 5) to calculate the electric forces, the mathematical representation of the components of the electric forces given by Davis ⁽⁶⁾ for two conducting spheres in a uniform electric field was used.

Since numerical calculation of the collision efficiency from equations compiled with full allowance for the electric forces ⁽⁶⁾ is extremely complicated, for combinations of prescribed parameters most of the calculations were performed using equations with an approximate allowance for the electric forces ⁽⁴⁾.

Our investigations of the collision efficiency of particles of comparable sizes ^(4,7) showed that, under real conditions often encountered in natural cumulus clouds and, all the more, in thunderstorm clouds, electric forces will cause cloud droplets to collide precisely in that range of sizes in which, in the absence of electric forces, collisions would not occur. It is important that even weak electric fields and small charges, which are often encountered in natural clouds, bring

droplets into collision ⁽⁸⁾. This conclusion is also valid for like-charged droplets; moreover, the closer the sizes of the charged droplets, the greater the collision efficiency.

To consider the question of whether electric forces will prevent coalescence of droplets after their collision, it is useful to introduce a parameter characterizing the ratio of the electric energy U_q to the surface-tension energy U_σ . For all real values of charges on droplets this ratio is $U_q/U_\sigma \ll 1$. Consequently, despite the significant role of electric forces in droplet collision, the forces of surface tension will play the decisive role in the efficiency of their coalescence. In calculations of the electric coagulation of cloud droplets we took the coalescence coefficient $\alpha = 1$, i.e., we assumed that after each collision coalescence occurs.

As an example of a calculation of droplet coagulation, let us consider the problem of acting on warm clouds with an electrified reagent for the purpose of dissipating cloudiness or inducing precipitation.

Let the object of action be a stable fine-droplet cloud which, throughout its entire volume, is characterized by a symmetric charge distribution * (Fig. 1a, b). The maximum diameter $d_{\max} = 14 \mu$; the mean diameter $d_{\text{cp}} = 8 \mu$; the number of particles per unit volume $n = 700 \text{ cm}^{-3}$; the calculated water content $\omega = 0.2 \text{ g/m}^3$; the mean volume-charge density $\rho = -1 \cdot 10^{-8} \text{ e.s.u./cm}^3$, which is two orders of magnitude lower than the density encountered in developed clouds. The mean electric-field strength $E = 0.5 \text{ V/cm}$.

Let us assume, for simplicity, that the prescribed particle-distribution density $n(q, d)$ characterizes the cloud as a whole and changes neither in space nor in time. We shall consider the effect produced by a finely dispersed electrified reagent introduced into the cloud, with mean particle diameter $d_0 = 20 \mu$ and charge $q_0 = 10^{-4} \text{ e.s.u.}$ It is expedient to calculate the growth of the reagent particle with time only up to a size on the order of $30\text{--}50 \mu$ in diameter, after which gravitational coagulation will play the principal role in the formation of large droplets.

* The distribution function was deliberately taken with a small dispersion (Fig. 1b), so that the possibility of precipitation formation due to gravitational growth of particles would be excluded.

Since the charge and size of a reagent particle change as it moves through the cloud, the value of the collision efficiency will also be a function of time; therefore the entire interval of change in the charge and size of the drop falling through the cloud was divided into a number of sections, in each of which the collision efficiency and the distribution function were considered constant both in time and in space. The total effect was obtained by integration over all the layers into which the cloud was divided.

Fig. 3. Calculated curves of the change in size and increment of charge on a reagent particle introduced into a fine-droplet cloud

Fig. 3

Figure 3: Fig. 3

If the influence of turbulence on the collision efficiency of particles is not taken into account (it only increases the number of collisions), then the increments of diameter Δd_1 and charge Δq_1 are expressed as follows:

$$\Delta d_1 = \frac{\pi}{12} \int_{-\infty}^{\infty} \int_0^{\infty} N(q, d) d^3 dq dd,$$

$$\Delta q_1 = \int_{-\infty}^{\infty} \int_0^{\infty} N(q, d) q dq dd,$$

where

$$N(q, d) = \frac{\pi a}{4} n(q, d) \int_0^H K d_1^2(z) dz;$$

H is the thickness of the cloud layer through which the drop falls; $K(q_1, q_2, d_1, d_2, E)$ is the collision efficiency; q, d are the charge and diameter of cloud drops.

The results of the calculation showed that, despite the unfavorable conditions for the enlargement of particles in the cloud (fine dispersion and low water content), the growth of particles from 20 to 40 μ occurs in a finite time of the order of 12 min; at the same time the charge of the reagent particle changes by $\Delta q = -2 \cdot 10^{-6}$ e.s.u. (Fig. 3).

Thus, if in a natural fine-droplet cloud, as a result of artificial intervention or a natural process, particles with sufficiently large charges appear, then enlargement of particles in clouds will begin in the region of smaller sizes than is possible with gravitational growth.

If it is taken into account that drops become electrified when they break up, then electric coagulation in combination with gravitational growth may lead to the formation of sudden heavy showers, often observed during the development of cumulonimbus and thunderstorm cloudiness. The results of theoretical studies of the process of particle growth in warm clouds agree with the results of observations by Vonnegut and co-workers⁽⁹⁾, who showed that electrical activity arises in a cloud before large drops are formed, as a result of which, from their point of view, thunderstorm electrification is the cause (and not the consequence) of precipitation formation.

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