PHYSICAL PRINCIPLES OF INFLUENCING CLOUDINESS FOR THE PURPOSE OF PREVENTING HAIL PHENOMENA

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Abstract

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PHYSICAL PRINCIPLES OF INFLUENCING CLOUDINESS FOR THE PURPOSE OF PREVENTING HAIL PHENOMENA

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In works ([1], [2]) the mechanism of formation of hail falling from intramass cloudiness was considered. Subsequent experimental studies, carried out in the Northern Caucasus in 1959, as well as data from the Verona Observatory (Italy), kindly placed at our disposal by Dr. Sarika, confirmed the correctness of the proposed hypothesis. On the basis of the works mentioned, the following conditions necessary for the formation of hail may be formulated.

1. The temperature of the cloud top (T_{v}) must be below the threshold of natural crystallization of cloud particles, i.e. $T_{\text{v}} - T_{\text{k}};\ -20^{\circ} \leq T_{\text{k}} \leq -14^{\circ}$.
2. The velocity of the ascending air currents at the level of the 0° isotherm (if the height z_m of the level of maximum velocity of the updraft W_m is less than the height z_0 of the zero isotherm) must be greater than 12 m/sec, i.e. $W_0 > 12$ m/sec when $z_m < z_0$, or, if $z_m > z_0$, then $W_m > 12$ m/sec ([1],[2]).
3. The decrease in the hailstone radius ΔR due to melting in the "warm" ($T > 0^{\circ}$C) zone of the cloud and below the cloud must be less than the radius of the hailstone at the level of the 0° isotherm: $R_0 > \Delta R$.
4. The variation of wind speed with height must satisfy the condition that accumulation of the large-drop fraction occurs in the temperature interval from -1.5 to -8.0°. If accumulation occurs above the -8.0° isotherm, then in most cases hailstones do not grow.

In the overwhelming majority of cases these conditions are sufficient for hail to fall. If $z_m \simeq z_0$, then the radius of the hailstone at the level of the 0° isotherm is determined from the relation

$$R_m \sim R_0 \geq \frac{W_m^2}{\gamma} \frac{\rho_{zm}}{\rho_0'}, \tag{1}$$

where ρ_{zm} is the air density at the level of maximum velocity and ρ_0' is that at sea level, γ is a constant quantity ([1]). The amount of precipitation that falls is determined from the relation

$$Q = \rho \frac{W_{\text{pl}}^2 - W_{\text{kr}}^2}{2g}, \tag{2}$$

where W_{kr} is the critical velocity at which the droplet is broken up, and g is the acceleration of gravity. If, however, $z_m < z_0$ within 0.2-0.5 km, then the value of the hailstone radius is determined by the expression

$$R_0 = \frac{W_0^2}{\gamma} \frac{\rho_{z0}}{\rho_0'}, \tag{3}$$

where ρ_0 is the air density at the level of the 0° isotherm.

The case in which W_0 differs little from W_m and $W_0 \gg W_{\text{kr}}$ is the most dangerous in terms of damage caused by hail, since the amount of hail that falls, formed from the accumulated moisture, reaches the maximum value determined by equation (2).

The method of acting on cumulus cloudiness by crystallizing its upper part has been known for more than 10 years. However, there have been differing opinions about the effectiveness of this method of action as applied to combating hail processes ([5]). Radar, microphysical, and visual studies of cumulus and cumulonimbus clouds that were subjected to action showed that, when the supercooled zone of a cloud is seeded with silver iodide aerosols, the finest ice crystals suspended in the atmosphere are formed, which have been called "diamond dust." After 4-10 min, in the treated part of the cloud and beneath it, a large number of ice-graupel particles, sometimes rimed, appear. The formation of graupel probably occurs as a result of condensation processes, the migration of vapor from liquid drops to crystals, and, when the ice particles reach sizes of 15-20 μ, gravitational coagulation. The fallout of the ice particles that have formed (in some experiments the settling velocity of the echo zone ([1]) after the action was 10-13 m/sec) leads to the washing out of the lower part of the cumulus cloud, the formation of fall streaks, and, with the corresponding water content of the cloud, to precipitation reaching the Earth' s surface. However, all these experiments were carried out with clouds in which the velocities of the updrafts, both those calculated by the method of N. S. Shishkin ([4]) and those found from observations with pilot balloons ([1]), did not exceed 8-10 m/sec.

As is known, the sizes of falling hail depend mainly on the velocities of the updrafts with height ([1], [3]). Therefore, if the top of a hail cloud is crystallized, then as a result of the action it is possible either to accelerate somewhat the fall of hail (if, in its development, the cloud had reached the level of natural crystallization)* or, if the cloud top lies below this level, to cause the cloud to grow to the size of a thunderstorm cloud, which will make it possible to stimulate the fall of hail from it, whereas in the natural course of the process it would not have produced hail. Since artificial crystallization is associated with the release of the latent heat of freezing, as a result of action on the cloud the velocities of the updrafts in it can only increase. Therefore, episodic introductions of AgJ into the supercooled part of a cloud, in all probability, can neither prevent the fall of hail nor help reduce the size of the falling hail particles.

Taking into account the results of Ludlam' s work on hail growth, one should conclude that the physically justified method of action using crystallizing substances is the continuous and uninterrupted crystallization of the entire large-droplet supercooled zone of the cloud, beginning at temperatures of −2°, −1°. In this case, since the coalescence coefficient of ice particles is practically equal to zero, the growth of hailstones ceases, which leads to complete melting of the hail that had arisen before the beginning of the action when it falls below the 0° isotherm, or else to a significant reduction in the size of the hailstones compared with that which they would have had under the natural course of the process.

The second method of action on cloudiness for preventing hail processes consists in creating a large number of large drops at the lower boundary of the cloud in the initial stage of its development. In accordance with equation (2), the maximum possible amount of precipitation that falls is uniquely determined by the distribution of the velocity of updrafts and cloud heights, in other words, by the stratification of the atmosphere, and for the given aerosynoptic conditions is a constant quantity. But the amount of precipitation falling on 1 cm^2 from cumulonimbus cloudiness can be represented as the product of the sum of cloud particles by their mass in a vertical column with unit base, cut out in a large-droplet—

* According to our data, the level of natural crystallization for cumulus clouds in the summer period corresponds to a temperature of −12°, −14° in the North Caucasus and −14°, −22° in Transcaucasia.

cloud zone. If $\overline{R}$ is the mean radius of hailstones in centimeters, then the maximum possible amount of precipitation can be represented as:

$$Q = \frac{4}{3}\pi\rho_r\overline{R}^3 N(z - z_m), \tag{4}$$

where N is the number of particles of radius $\overline{R}$ in 1 cm^3, and ρ_r is the density of hail. It follows from (4) that an increase in the number of large particles decreases their mean diameter. But large particles serving as hail embryos in the upper part of the cloud, at the expense of which hailstones grow and moisture accumulates, are, according to some views, produced by the growth of individual "giant" drops arising in the lower part of the cloud at the initial stage of its development ([1],[6]).

For the production of "giant" ($R \sim 30$–$40\ \mu$) drops in the lower part of the cloud there are many different methods; the advantage of each of them depends on the height of the lower boundary of the cloudiness, the topography of the locality, etc. Reagents such as NaCl, P_2O_5, and other hygroscopic substances introduced into the cloud by various methods may lead to an increase in the number of hail embryos and, consequently, to a decrease in their mean size. Ludlam ([6]) came to the same conclusion on the basis of the distribution density of large drops in the cloud.

The question of how hail embryos arise remains unclear. If every large drop formed in the lower part of the cloud is a hail embryo, then Ludlam' s conclusion and the method of action set forth are fully applicable. But if not every large drop formed at the initial moment of cloud formation is a hailstone embryo, and these drops create a supercooled large-drop zone in which hail growth occurs, then such a method of action can hardly be used for combating hail.

In Ludlam' s work calculations are given from which it follows that the main, "wet" growth of hail occurs through coagulation at temperatures from -1° to -8° and with cloud water content of the order of 8-20 g/m^3. In other words, the main growth of hail occurs through coagulation of ice particles with the large-drop supercooled fraction. If these calculations are confirmed by experiment, then doubt will arise as to the possibility of using AgJ for combating hail, since the main growth of hail occurs at higher temperatures than the effective crystallization obtained under the action of AgJ.

Without an exact scheme of precipitation formation, it is impossible to establish the conditions for using different reagents and different methods of action. A method that can yield positive results if applied in timely fashion, when applied at the wrong time leads to the artificial formation of hail or else gives no results whatever. At the same time, the frequent precipitation of a large mass of cumulonimbus cloudiness is considered a positive effect in combating hail, although hail from these clouds might not have fallen even in the natural course of the process.

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Note: Figure translations are in progress. See original paper for figures.