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# Factors Affecting Hail Suppression Phenomenon

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## ABSTRACT

A review on factors affecting hail suppression is presented in this paper. Influence of external electric field, cloud droplet concentration, growth of deep convective feed clouds is discussed. Observations of the clouds often disseminate following of the lightning by a speedily increasing and intensifying echo and subsequently a gush of rain or hail fell nearby at the ground. The analysis showed that within 30 seconds next to a lightning discharge, the volume of some droplets increased upto 100-fold due to an electrostatic precipitation effect. Under the effect of a constant and uniform electric field, the water vapour condensation is enhanced by a variable dependent on intensity of electric field. when considering combined effect of an external electric field and field caused by the central dipole on a droplet, it is shown that at a given relaxation time and temperature, increase in electric field results in decrease of supersaturation and influence of electric field is explored in hail suppression. Influence of cloud droplet concentrations on hail suppression phenomenon is discussed. it is found that on decreasing cloud droplet concentrations, hail suppression is enhanced. Influence of merging of deep convective feed clouds with growing hail cloud in hail suppression is discussed. The significance of external electric field in hail suppression is concluded.

**KEYWORDS:** Hail, lightning, electric field, condensation, cloud droplets.

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## INTRODUCTION

Hail is a form of precipitation which falls as ice pellets in size range from small pea-size to as large as grapefruits. Hails, being form of ice, are often mistaken as cold weather events, but in reality, it is associated with thunderstorms instead of winter weather. Hail formation is a phenomenon of temperate climate which is rare in polar region. Hail is also rare in the Tropics due to very high freezing level in atmosphere. Hail clouds grow in the updrafts of convective clouds and differ in shapes. The layering of hailstones convey a lot of information about the hailstones. Charles et al[1] showed that Layering also provides the history of the shape of the stone along with its tumbling or wobbling at its fall. Suppressing hails appears to be a possibility as hail grows from supercooled water, which can be made to freeze by adding suitable tiny particles. Because of hailstones, a lot of damage to society had occurred in various forms by Singh[2].

There is existence of electric field in the clouds which is produced due per lightning discharge (~10e.s.u.). The electric field so generated may affect the rate of condensation of water vapor. Varshneya[3,4] and Pruppacher [5] found that interaction of charged ions and aerosols with the neutral drops, enhances nucleation process. The growth of electric field in thundercloud electrification and the role of ions have been discussed.Evans[6] and Connolly et al[7]showed experimentally the under effect of electric field in growth of ice crystals in cloud chambers and indicated that the accelerated charged water molecules proceed to the crystal tips, thereby increasing the nucleation rate. Ehre et al[8] demonstrated that water freezes in different manner on positively and negatively charged surface. The lightning is generally followed in the cloud by a rapidly intensifying echo and subsequently by a gush of rain or hail at the ground. The increase in radar reflectivity in small volume of cloud following the lightning suggested that the influence of electric discharge on the size of particles in the cloud (Moore et al)[9]. The analysis depicted that within 30 seconds subsequent to a lightning discharge, the mass of some droplets increases as much as 100 fold as the result of precipitation effect of an electrostatic field. Later observations disclosed that the rain gush phenomenon can also occur in regions are colder than that of $0^0$C and that here gush can be of rain as well as of hail. Explanation to the rain gush phenomenon has been provided by Levin and Ziv[10].

Effectiveness of external electric field in nucleation has been explored in hail suppression phenomenon by Singh et al. [11, 12, 13] It is found that application of a small external electric field is equivalent to large supersaturation ratio. Large sized hails are splitted into smaller particles at an early stage, so that damage caused by hails is reduced. Similar equivalence is shown between external electric field and temperature.

The main objectives of decades long weather modification activities have been hail suppression and rain enhancement. The success of hail suppression depends on the seeding time, initial seeding area of cloud and the content of seeding agent (Curic et al)[14]. The influence of natural cloud characteristics, such as the impact of the cloud droplet number concentration on precipitation (rain and hail) reaching the ground in unseeded and seeded cases is analysed (Guo et al)[15]. A portion of the overall aerosol spectra serves as cloud condensation nuclei (CCN) soluble in water and depends on CCN concentration. Thus, a higher CCN concentration heads to a greater concentration of cloud droplets of smaller sizes (Kovacevic and Curic)[16].

Noppel et al.[17] observed that hail storm intensity may depend on varying CCN characteristics, either from the inadvertent transport of anthropogenic aerosols (industrial emissions) or from cloud seeding. van den Heever et al.[18] analysed the influence of CCN concentration on a convective storm. They concluded that higher CCN concentration created stronger updrafts and subdued accumulated rain on the ground. Seifert and Beheng[19] noted that CCN concentration can cause varying effects for different clouds. CCN appears to have the greatest effect on small convective storms and the least influence on supercell storms. Lim et al.[20] simulated the indirect aerosol effects on idealized supercell storm. They showed that higher CCN concentration leads to a weaker storm intensity and less accumulated precipitation on the ground. Additionally, they concluded that CCN did not affect supercell storm when graupel is absent.

In Russia, hail suppression is based on the concept of precipitation acceleration, causing early precipitation formation and cloud water outpouring in regions of formation of hails of deep convective clouds. Hail protection phenomenon involves seeding of potentially formed hazardous hail clouds and seeding of regions of new growth of deep convective feed clouds, and subsequent merging with the basic hail cloud while growing, with a view of hail suppression.

## THEORETICAL CONSIDERATION

### *(i) In Presence of External Electric Field*

An external electric field induces an electric dipole moment on the embryo of water as well as on the surrounding water vapor molecules The dipole moment[2] induced on the embryo is

$$M = Er_w^3 \qquad \ldots\ldots\ldots\ldots\ldots\ldots(1)$$

with $r_w$, the radius of water embryo and E, the external electric field.

The dipole moment induced on a water vapor molecule is

$$\text{E}\, M_1 = \alpha E \qquad \ldots\ldots\ldots\ldots\ldots\ldots(2)$$

with α, the polarizability.

The induced moment on a vapor molecule can be written as

$$M_1^{'} = \alpha(\vec{E} + \vec{E}_1) \qquad \ldots\ldots\ldots\ldots\ldots\ldots(3)$$

The increase in mass ($dm_W$) of embryo in time (dt) is

$$\frac{dm_w}{dt} = \rho S_n v \qquad \text{..................(4)}$$

With surface area $s_n$ of water embryo of radius $r_w$ and $\rho$, the density of the water vapour molecules.

$$\frac{dm_w}{dt} = \rho S_n \left(\frac{9\alpha\lambda E^2}{m_w r_w}\right)^{1/2} \qquad \text{..................(5)}$$

$\lambda$ is the mean free path.

The increase in radius with respect to time

$$\frac{dr_w}{dt} = \frac{\rho}{\rho_w}\left(\frac{9\alpha\lambda E^2}{m_w r_w}\right)^{1/2} \qquad \text{..................(6)}$$

Further Integrating, critical radius and relaxation time for nucleation are determined and the combined nucleation rate in absence and presence of external Electric field is given as

$$J_{oN} = J_o + J_N = \frac{fn_1}{\tau_N} \qquad \text{..................(7)}$$

where $J_o$ is the rate of nucleation in absence of electric field, and $J_N$ is the rate of nucleation in presence of external electric field.

The factor of enhancement in nucleation rate

$$R_E = 1 + \frac{\tau_o}{\tau_N} = 1 + f(E) \qquad \text{..................(8)}$$

Similarly, factor of enhancement in case of heterogeneous nucleation[2] is,

$$R_E^{'} = 1 + f^{'}(E) \qquad \text{..................(9)}$$

The factor of enhancement on comparing heterogeneous nucleation in electric field with homogeneous nucleation in absence of electric field is

$$R_{E/O}^{'} = \frac{J_{ON}^{'}}{J_O} \qquad \text{..................(10)}$$

### *(ii) Influence of Cloud Droplet Concentration*

A modified cloud-resolving mesoscale model (Xue et al.)[21] is used which consisted of introducing two categories of precipitation elements as hail embryos (graupel and frozen raindrops) and the concentration as a existing variable for all microphysics fields except water vapor and cloud water. Additionally, the software package for cloud seeding model is mixed with ratio of silver iodide (AgI). This model incorporates time-dependent, non-hydrostatic and fully compressible equations. Thus, the existing variables of this model are the x, y and z components of the Cartesian velocity, perturbation potential temperature and pressure, mixed ratio of seeding agent and eight microphysics categories, represented by one or two moments of the size distribution. The mass and concentration level of frozen raindrops and hail were calculated at every grid point and at each time step in the model. The cloud droplet number concentration was fixed in every given experiment.

For simulations, the model domain used was 100 X 100 X 15 km, having a 1000 m grid interval along the horizontal axis and 500 m along the vertical axis. All simulations were integrated for 120 min. To integrate acoustic wave modes, 1-s time step was used. The other terms were determined for time step of 6-s. The wave radiation was taken along the lateral boundaries. The turbulence was treated by using a 1.5-order turbulent kinetic energy formulation and the Coriolis force was ignored in simulations.

For the combination of cloud droplets and rain drops, Mean radius of liquid spectra was determined as

$$R_M = \left(\frac{3\rho Q}{4\pi\rho_W N}\right)^{\frac{1}{3}} \qquad \ldots\ldots\ldots\ldots\ldots\ldots(11)$$

Where, Q represents the total liquid mixing ratio; $\rho$ and $\rho_w$ are the cloud air and the liquid water densities and N is the total concentration of cloud droplets and rain drops.

The seeding effect is investigated by taking Silver Iodide as seeding agent. The conservation equation (Chen and Xiao)[22] for seeding agent (AgI) is

$$\frac{dX_s}{dt} = D_{X_s} + S_{X_s} + S_o \qquad \ldots\ldots\ldots\ldots\ldots\ldots(12)$$

where $X_S$ is the mixing ratio of seeding agent. The terms on the right-hand side of Eq.....(12) represent the diffusion, sink and source of the seeding agent, respectively. The source term for the seeding agent, $S_0$, represents the agent summed at the time of seeding in the seeding zone. The sink represents the mechanisms by the silver iodide which can generate ice particles. These mechanisms are contact nucleation and deposition nucleation. Collisions due to cloud droplets and raindrops are the source for cloud ice and frozen raindrops, respectively. Deposition nucleation is the source for cloud ice. The activation curves of AgI for contact and deposition nucleation were established in accordance with Hsie et al.[23] The silver-iodide particles are assumed to be mono-dispersive and shape of these particles is taken to be spherical with 0.1 l m radius and 2.38 X $10^{-17}$ kg mass.

### *(iii) Effectiveness of deep convective Feed Clouds*

According to the concept, for precipitation acceleration, the concentration of imitating ice crystals in the seeded volume taken are of the order of $10^7$ $m^{-3}$ and above; which leads to rapid aggregation with subsequent grain-coating formation and precipitation during 6-8 min. Due to this reason, efficiency of seeding significantly depends on concentration of the crystallizing agent.( Abshaev et al)[24]

Here seeding of hail clouds is optimized with a view; to refine patterns of cloud seeding accordingly with the stage of the cloud formation; to specify required amount of aerosol particles in seeding rockets and projectiles; and to optimize discreteness of introduction of projectiles as well as rockets. Further, a theoretical simulation of the process of crystallizing

agent aerosol spreading in clouds of the Cu cong type is analysed after seeding made according to the hail suppression technology by means of anti hail rockets of new generation and by means of artillery projectiles as well as a theoretical simulation of interaction of crystallizing particles and cloud medium.

## RESULTS AND DISCUSSION

The variation of the factor of enhancement in the nucleation rate as a function of the electric field varies directly with the externally applied electric field corresponding to approximately breakdown electric field of moist air[2]. Such high electric fields are of existence within thunderclouds. Typical values of the factor of enhancement in the nucleation rate of water nuclei as the function of temperatures supersaturation ratio at 250K, 260K and 273K in an electric field of 10 e.s.u. (cut off value) are shown in table 1.

**Table 1. Variation of the factor of enhancement and temperatures supersaturation ratio**

| T(in K) | $S_{v,w}$ | $R_E$ | $R_E'$ | $R_{E/O}'$ |
|---|---|---|---|---|
| 250 | 1.005 | 8.17 | 171.63 | $9.73 \times 10^4$ |
| | 1.05 | 23.41 | 171.17 | $9.87 \times 10^3$ |
| 260 | 1.005 | 8.45 | 175.02 | $9.54 \times 10^4$ |
| | 1.05 | 24.31 | 174.51 | $9.67 \times 10^3$ |
| 273 | 1.005 | 8.83 | 179.28 | $9.31 \times 10^4$ |
| | 1.05 | 25.47 | 178.78 | $9.44 \times 10^3$ |

Thus, the factor of enhancement varies directly with the externally applied electric field. Hence, number of smaller ice particles is increased and large hails are suppressed. Also on increasing temperature, the factor decreases. But at a given temperature, with increase in supersaturation ratio, the factor decreases[2].

Increasing the concentration of cloud droplets the amount of rain on the ground decreases, on the other hand the amount of accumulated hail increases. a slower autoconversion from cloud droplets to raindrops and reduced rain growth by collision with cloud droplets. Greater amount of hail leads to stronger melting of hailstones. However, autoconversion process and rain growth by gravitational coagulation of cloud droplets are dominant mechanisms for rain formation and, so there is a suppression in the accumulated rain on the ground in comparison with unseeded case.[16]

The role of hail suppression whether it can lead to an increase in rain accumulation is examined. Rain and hail accumulation on ground for 120 min is shown in Table 2. It is showed that an increase in the concentration of cloud droplets results in a decreases of the amount of rain on the ground, on the other hand the amount of accumulated hail increases. The time evolution of the total amount of rain and hail on the ground is depicted in Figure1.

In the cloud seeding experiment, the extended seeding area over grid points, results in a seeding volume of 13.5 $km^3$. The seeding agent of total mass was 203 g was distributed uniformly within the seeding zone and the centre of this area was located in the cold part of the grid cloud with maximum radar reflectivity and upward velocities. The seeding operation is performed at maximum reflectivity of 10 dBZ at an early stage of cloud life, when it had small natural ice that would compete with the seeding agent. The seeding agent was released continuously within 90 s at a initial rate with the values of l.67 X $10^{-13}$ kg $m^{-3}$ $s^{-1}$ at all grid points.[16]

**Table 2. The total precipitation of rain $TP_{rain}$ and hail $TP_{hail}$ in the unseeded case**

| Test | Number of cloud droplets ($N_C$) | $TP_{rain}$ (kt) | $TP_{hail}$ (kt) |
|---|---|---|---|
| A | 50 | 9688.43 | 0.10 |
| B | 100 | 9269.67 | 56.76 |
| C | 150 | 8864.42 | 335.90 |
| D | 200 | 7646.35 | 525.70 |

Relative changes in total amount of rain versus hail due to seeding in the four cases are presented in Table 3. Increase in the cloud droplet concentration reduced the effectiveness of hail suppression due to cloud seeding.[16]

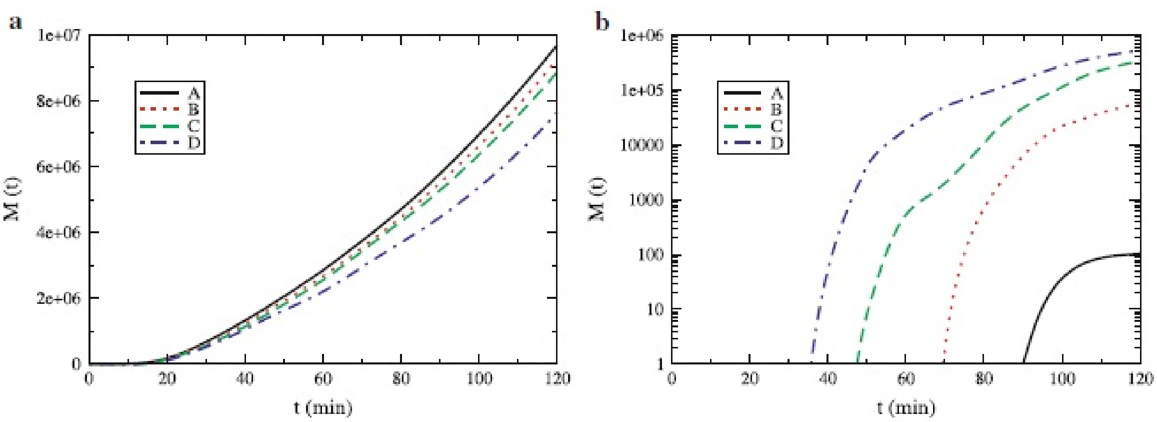


**Figure 1. Unseeded case precipitation for (a) rain and (b) hail.[16]**

In cloud seeding, an additional production of cloud ice due to cloud droplets and rain drops take place. Cloud droplets reacts via brownian collection of AgI ($P_{bc}$), inertial collection of AgI ($P_{ic}$), phoretic collection of AgI ($P_{ph}$) and depositional nucleation on AgI ($P_{int}$) to produce additional cloud ice. Similarly frozen raindrops reacts via Brownian collection of AgI ($P_{br}$) and inertial collection of AgI ($P_{ir}$) to produce additional cloud ice. Furhter, cloud droplets on collision with AgI particles are removed from the cloud environment and reduce the growth of ice elements (graupel, frozen raindrops and hail) through the addition of cloud droplets. Raindrops colliding with AgI particles produce large number of frozen raindrops that are competing for the same amount of available liquid water. Hail suppression depends on the natural processes of the hail formation due to the interaction of AgI particles with cloud droplets and raindrops.

**Table 3. Relative change in total precipitation of rain $P_{rain}$ and hail $P_{hail}$ with respect to the unseeded tests**

| Test | $P_{rain}$ (%) | $P_{hail}$ (%) |
|---|---|---|
| A | -0.16 | -91.85 |
| B | 1.34 | -29.92 |
| C | -6.05 | 3.61 |
| D | -10.16 | 20.26 |

Figure 2 depicts the dependence of contact nucleation mechanism on $R_M$. The typical values of $R_M$ in continental clouds are approximately—10 μm (Pruppacher and Klett)[25]. Here, a higher freezing rate of cloud droplets and raindrops by contact nucleation mechanisms is observed for large values of $R_M$. Thus, cloud seeding with lower cloud droplet concentration is more suitable to hail suppression due to a stronger sink of cloud water. in this way a small amount of cloud water leads to a reduced growth of the hailstone embryos.[16]

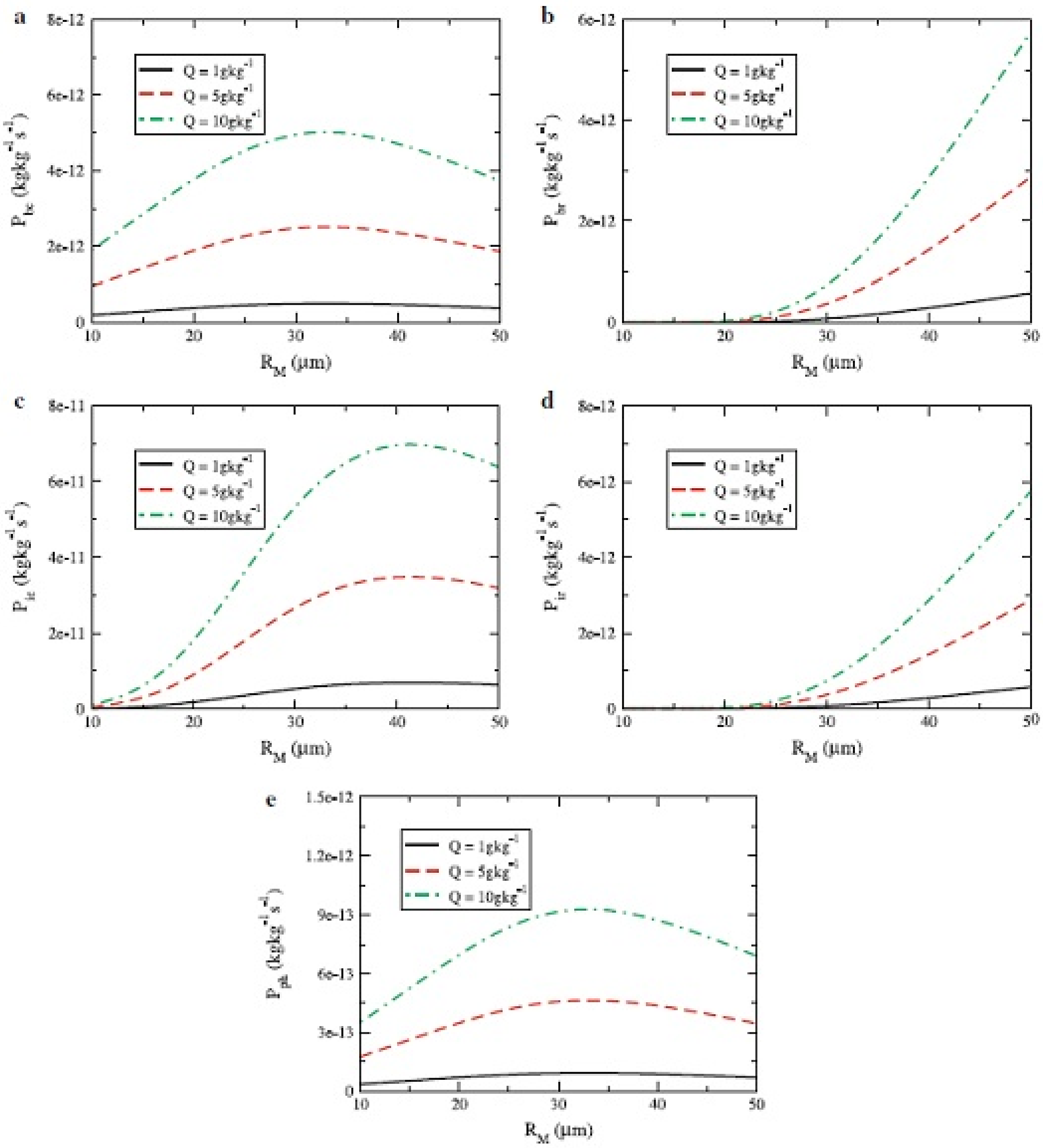

**Figure 2. Dependence of contact nucleation mechanism.[16]**

The present-day technology of hail prevention allows repeated seedings of regions of new growth of hail clouds at time intervals of 5 min and with separations of 1 km. The time interval of 5 min is specified on the basis of minimum formation time of 1cm-hail after its origination. the discreteness in space of 1 km is discussed by taking into account the regions of seeding of neighbouring sources merge during 1 min. This technology contributes to suppression of hail damage by 80-90%.[24]

## CONCLUSION

It can be reasoned out on the basis of all the factors affecting the hail suppression phenomenon outlined here, the mechanism by which hail suppression can be expected at a higher rate is presence of external electric field. In clouds, high electric field produces lightning discharge which results in ionization of medium. Subsequently, most of the ions get attached with ice embryo and due to small energy of formation results in critical nuclei of lesser radius. Therefore, for a given amount of water a large number of ice particles of smaller size are formed subsequent to lightning effectively suppressing the formation of larger hails.

However, lower cloud droplet concentration levels, high effectiveness on hail suppression is observed; but hail suppression effectiveness decreases on increasing cloud droplet concentration. Thus, the positive effects of hail suppression can be expected at lower cloud droplet concentrations. It is also noticed that lower concentrations of feed clouds leads to an acute evaporation of cloud droplets with decreased droplet water content. After a span of 2-3 min beyond seeding, radius of droplets is further decreased leading to hail suppression. Nevertheless, it begins to restore due to further addition of vapor from cloud medium and results in weakening of influence of crystals.

In this way, it can be concluded that hail suppression phenomenon is significantly affected by application of external electric field. Role of external electric field in water vapour nucleation is explored. Thus, big size ice crystals (hails) are fragmented into tinier particles, causing less damage and simultaneously at an early stage.

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