SOME POSSIBLE EFFECTS OF SEEDING CONVECTIVE CLOUDS

By

Arnett S. Dennis[1]

It is now widely accepted that the introduction of silver iodide crystals into a cloud system can freeze super-cooled droplets at temperatures of -5C or colder. Since much of the precipitation of the temperate zones is produced by the Bergeron process in clouds containing both ice crystals and super-cooled water droplets, and since natural freezing nuclei usually are inactive at temperatures warmer than -12 or -15 C, the addition of silver iodide nuclei can increase precipitation from some cloud systems. Many attempts have been made to increase rainfall from cumulus clouds by seeding but the results are in dispute, in contrast to the fairly definite results obtained with orographic clouds. One point that must be kept in mind is that convective cells go through a complete life cycle in less than an hour. Therefore to assess the effect of seeding by ground generators we must consider the life history of the clouds forming in air containing AgI nuclei, rather than consider the effects of injecting the nuclei into well developed clouds.

In order to determine possible effects of seeding we must first consider the life history of a typical shower. A cumulus cloud is formed by the ascent of currents of air in an unstable air mass. Recent work by Ludlam and Mason in England shows that the current inside the cloud is not continuous, but consists of a number of bubbles each containing as much as one million cubic metres of air. As the first bubble rises above its condensation level, a puff of cumulus cloud appears. Due to entrainment and mixing with environmental air cooling takes place near the outer edges of the bubble as the cloud droplets there evaporate. This causes the air to lose its buoyancy and may lead to sinking motions. Thus the bubble sheds its shell continuously, and eventually is broken down. However, a second bubble following the first entrains saturated air. Thus it is not cooled by evaporation and retains its buoyancy until it breaks out of the top of the original cloud, after which it too is broken down. Thus the cloud rises in a series of steps, with new turrets pushing up through the top, and evaporation and cooling, and hence slight downdrafts, around the outer edges.

If the top reaches levels with sufficiently low temperatures (-12 C or colder) some of the droplets at the top will freeze. This has several important effects.

The release of latent heat by freezing warms the cloud top slightly. Since the equilibrium vapor pressure over ice is less than that over water, evaporation at the cloud top is greatly reduced and may even be stopped altogether. Since the latent heat of condensation is 540 calories per gram compared to about 80 calories per gram for latent heat of fusion, the second effect is more important. The reduction in evaporation explains the fact that broad anvils of ice crystals often cap rather narrow cumulus towers.

If the ice crystals remain in the vicinity of super-cooled water droplets long enough (not being carried to the outside of the cloud), they will grow to small snowflakes in a few minutes and acquire a fall velocity. To grow to an appreciable size, however, they must be carried upward again by a fresh bubble of warm air. If the updraft is not maintained, the snowflakes will fall and melt to produce a very slight sprinkle below the cloud base, without much chance of rain at the ground.

In cases where the flakes are carried upward by a new bubble, much of the water in the new bubble is added to the snowflakes already present, although some of the new droplets may freeze to add to the number of flakes, especially in the center of the bubble. The snowflakes already formed have three advantages: First, they have fallen some distance and so meet the new bubble while it is too warm for its own nuclei to act. This advantage is even greater over later bubbles. Second, the shape factor operates against the very small crystals. Third, the larger flakes can grow by coalescence.

The size to which the particles grow before falling out depends on the vertical velocities in the bubbles and the time interval between successive bubbles. In extreme cases the particles may oscillate back and forth across the freezing level several times to become hailstones with a structure of clear ice and rime in alternate shells. Whether they reach the ground as hail or rain depends upon their size and upon the height of the freezing level above ground.

1/ Weather Modification Company, San Jose, California.

Once the precipitation commences the updraft in the middle of the cloud is destroyed. The air is chilled by the precipitation and hence begins to sink. This downdraft often attains speeds of 25 to 50 knots and spreads out at the ground to produce a miniature cold front. This in turn often causes new cumulus clouds to form around the edges of the original storm.

If there is pronounced wind shear present, the sequence of events is altered somewhat. The top of the cloud is displaced with respect to the base and successive turrets tend to appear on the upwind shoulder of the cloud. Snow formed in the upper part will fall out of the front of the cloud instead of entering the succeeding bubbles. In most cases this fine snow never reaches the ground. Therefore strong windshear decreases the chances of precipitation at the ground.

If the cloud forms in air seeded with silver iodide, the precipitation process starts earlier. Once the top reaches above the -5C level, large numbers of ice crystals appear. These grow into snow and/or small hail as moisture is added to them and then fall out of the cloud. The earlier onset of precipitation kills out the updraft earlier and thus tends to decrease the severity of the individual storms. It has been suggested that the smaller particles might never fall because their fall velocity might be less than the speed of the updraft. However, radar records of suspended rainfall are rare and it appears that, once a sizable amount of precipitation is formed, the updraft cannot support it indefinitely. The smaller particles fall more slowly than the large stones from unseeded storms and generally melt before reaching the ground. Seeding convective clouds with silver iodide reduces the intensity of hailstorms and in many cases can eliminate hail entirely.

The question of whether or not continuous seeding by ground generators can increase rainfall at the ground is much more difficult to answer. On the favorable side we have the following considerations:

1. Seeding can trigger the precipitation process in cumulus clouds which would never otherwise produce precipitation. This class of clouds includes those with cloud-top temperatures between -5 and -12C in most areas, and clouds with tops colder than -12C in some areas deficient in natural nuclei.

2. The heat released by freezing the top of a cumulus cloud can cause further growth of the cloud.

Against these we set the following:

1. The reduction in drop size reduces rain at the ground because it increases losses by evaporation below the cloud base. This can be very important in dry continental air masses where cloud bases can be as much as 12,000 feet above ground.

2. As noted above, seeding by ground generators releases the precipitation prematurely and shortens the life cycle of convective cells. This reduces the amount of water released by an individual cell.

However, the new cells set off by the downdraft will form earlier as a result. A violent updraft generally results in subsidence and increased stability in surrounding air, so killing off an original one renders the development of new ones more likely for this reason also. It appears then that seeding will increase the number of precipitation producing cells while decreasing the severity of the individual ones. This could increase the beneficial effects of a rain storm even without increasing the total amount reaching the ground.

It is possible that the amount of rain from a cell could be increased by seeding it just as it reached maturity and had a large amount of supercooled water in suspension. Large amounts of water often are left in dissipating shower clouds and seeding might wring out some of it. This selective seeding would require aircraft and a high degree of skill in judging the conditions in cumulus clouds.

There is some evidence that seeding convective storms reduces their electrical activity, but no definite figures are available. This is explainable on the basis that the reduction in drop size reduces the number of collisions between drops inside the rain core. Laboratory experiments show that the collision process can result in charge separation. More recent work indicates the charge separation may be due in part to phase effects between ice and super-cooled water. This too would be affected by seeding.