PHYSICAL ASPECTS OF WEATHER MODIFICATION

By

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The phrase weather modification has been used to cover a variety of proposals.

The most familiar form of weather modification is, however, cloud modification which will be the sole topic of this talk. It is much smaller in scale, and less ambitious--but on the other hand, it has been tried, and with some success.

It is beyond doubt that on some occasions, when the natural circumstances are delicately balanced, it is possible to drastically modify convective clouds on the scale of one mile or two.

The possibility of modifying clouds depends on the fact that there exist natural barriers to the formation of precipitation. The formation of a new phase--liquid water from vapor, ice from liquid water or vapor--is commonly attended with some difficulty. In the atmosphere the first product of condensation is nearly always liquid water, whatever the temperature, and no real barrier exists at this point owing to the ubiquity of particles in the air which are extremely efficient in nucleating or catalyzing the formation of water droplets. These appear to be particles which consist largely of soluble material and due to their presence the relative humidity in the atmosphere can rarely rise more than one or two percent above saturation. In the absence of particles, condensation can occur only at relative humidities of around 400%. However, it is the very ease with which this barrier is surmounted that gives rise to the difficulties which clouds encounter later in the precipitation process.

As our atmosphere is constituted, the air near the ground is unsaturated, and saturated regions in which condensation can occur are to be found only some distance above the surface, for the reason that the lifting of air with its consequent pressure drop is by far the most efficient means available to cool large volumes of air to the dew point. The particles of precipitation--rain or snow--which are formed in the clouds must be large enough to survive the trip to the ground without evaporating completely. Depending on circumstances, the required particle size at the cloud base may range from a fraction of a millimeter in the mountaneous region where the clouds lie close to the ground, to several millimeters in a dry place with high cloud bases like the plains of Colorado in summer. But, in any case, an effective precipitation particle must have a mass about 10^5 to 10^6 times that of the typical droplets which are found in clouds. Thus a precipitating cloud somehow produces a second family of vastly larger drops.

When the original droplets are forming near the base of a convective cloud the laws governing the diffusion of water vapor and heat ensure that the droplets will share the liquid water rather uniformly amongst themselves. As mentioned earlier, there is always an ample supply of cloud drop nucleating particles--indeed too ample, since the more drops that form, the smaller each one must be, and clearly the smaller the drops are to begin with the more difficult is the task of generating precipitation droplets.

There are regional difference in the concentration of these particles; over the oceans, far from land, clouds usually contain only some tens of droplets per $cm.^3$, but over the arid interiors of continents 500 to 1000 drops per $cm.^3$ seems to be typical.

Thus, there exists the ironic situation that just where there is the least water to share, the greatest number of particles are present to share it. There is strong evidence that the excessive number of nucleating particles found in the arid interiors of continents arise from the dry surface below.

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Even the clouds of the oceans are not as efficient in producing rain as they would be if oceanic air were even cleaner than it is, and all clouds face a natural barrier as they evolve towards producing precipitation particles. At this point we cannot say whether or not it is quite hopeless to try to modify the initial cloud formation--to make the continental clouds more like the oceanic ones or vice versa, but up to the present all efforts have taken the cloud as it was naturally formed and tried to assist the evolution of the family of larger droplets.

Such attempts obviously had to be based on an understanding of the natural processes. Two routes are known by which clouds produce precipitation:

1. As a result of the appearance of ice in a cloud of supercooled droplets.

2. By the coagulation of droplets of differing fall speeds into larger droplets.

By which ever route the process goes on, it is clear that it must be extremely selective, or unstable, since only one in 10^5 to 10^6 cloud droplets can eventually grow to a precipitation particle. In the case of the ice process, this selection is assured by the fact that water droplets of cloud droplet size supercool quite deeply and apparently freeze only after coming in contact with particles in the air which are capable of catalyzing the formation of ice--and these particles are rare. In contrast to the condensation nuclei involved in the initial cloud formation which have concentrations of 10^2 to 10^3 per cm.^{3} or 10^5 to 10^6 per liter, freezing nuclei have concentrations of only one per liter at temperatures like -15°C increasing to 100 per liter at -25°C. (Obviously the number of active particles must increase at lower temperatures.) Indeed it is the very rarity of these freezing nuclei which gives an opportunity for artificial modification and so far the only clear successes have been achieved by forming ice in a cloud before it had naturally formed in significant amounts.

Two methods have been used for this purpose. In the original experiments of Langmuir and Schaefer, dry ice pellets were dropped through the cloud leaving a trail of ice particles in their wake which diffused or mixed with the surrounding clouds, absorbing some of the surrounding droplets by distillation. The early experiments showed beyond doubt that it was possible to clear holes in stratiform decks, to cause convective clouds to release showers, and under very special circumstances to grow into thunderstorms. Very shortly after this, Vonnegut discovered that silver iodide was an extremely efficient freezing nucleus. Experiments with individual clouds have shown that by means of silver iodide it is possible to produce effects of the same kind as with dry ice.

Vonnegut was led to this discovery by the extremely close fit of the lattice parameters of silver iodide with those of ice, and although later work had indicated that there are other factors involved in the nucleation of ice, no inorganic material has been found which is as efficient.

Silver iodide can be dispersed as a fine smoke by a high temperature process and clearly offers great operational advantages over dry ice. There is a possibility of using ground generators and allowing the smoke to diffuse upwards into the clouds which it is desired to affect. This advantage has perhaps been overestimated. The only situation in which ground generators are certain to place the silver iodide smoke in the clouds is in the case of orographic clouds forming on a mountain range where the smoke is released into the very air which, further upslope, forms the clouds. These latter must of course be supercooled.

An experiment of this kind must be evaluated statistically. Although the results are not as clear cut as in the individual cloud experiments, the weight of evidence is that precipitation on a mountain range can indeed be increased in this manner.

There are many complications in cloud seeding with silver iodide. Early experiments showed that not all high temperature processes produce equally efficient particles; some produce non, presumably as a result of absorbed layers on the surface of the silver iodide particles. Another is that silver iodide suffers photo deactivation on exposure to sunlight which, in one experiment, varied from 10^6 per hour for acetone solution burnt in a hydrogen flame to 10^2 per hour when the acetone solution was burnt alone or in a kerosene flame. The higher temperature flame produced much smaller particles and these were apparently more readily affected.

It is obvious that it would, in principle, be possible to overseed a cloud with ice particles or freezing nuclei so that the necessary selectivity was lost. A cloud in which all the water drops were frozen would be in no better position to produce large particles than before. This kind of thought was the basis of attempts to mitigate hail--but hail is such an extremely erratic phenomenon that it is always difficult to detect any effect. Moreover, our physical understanding of the hail formation process is even poorer than that of rain and snow.

Returning to the second natural rain forming process, the first proposal concerning the generation of the "fortunate" particles was that they formed on the rare giant particles of sea salt which occur over the oceans in concentrations of the order of 100 per liter, and which penetrate far inland at times in dry weather. A later suggestion hinges on the essentially stochastic nature of droplet coagulation. (Telford, 1956) On the basis of the first theory, attempts have been made to influence precipitation by introducing salt particles into the air in regions where they are thought to be deficient. The results have so far not been convincing and it may well be that the stochastic process is in any case the dominant effect. Indeed, the detailed study of the aerodynamics of the coagulation process indicates that its efficient operation depends not only on the presence of droplets which somehow become larger than their neighbors and consequently fall with respect to them, but also on the size of their neighbors. Thus the process can be efficient only in clouds which, like those over the oceans, contain rather large droplets, and it seems unlikely at present that simple gravitational sweeping could be effective in the typical convective clouds of an arid region where the droplets are far too small. For the same reason, suggestions concerning the modification of the surface tension of droplets may fail. These are based on the notion that perhaps not all colliding droplets coalesce. The experimental evidence, however, is that they do with rather high efficiency; the familiar bouncing drop effect is due to an air layer influence which does not occur at smaller drop sizes. At very small droplet sizes, like those occurring in Colorado summer clouds, there is no experimental evidence and it may be that not all collisions result in coalescence, but in any case the aerodynamic efficiency of the collision process is extremely low.

Beyond sizes of 0.1 mm, the growth of precipitation is always controlled by coalescence, whether they originate in a particle, or as coalescing water drops. Indeed, recent work by Braham (1964) has indicated that frequently the overall natural precipitation process is dominated by coalescence growth, even at sub-freezing temperatures. In such a case there is the possibility that premature freezing by seeding would decrease the efficiency.

Apart from the pursuit of a clearer understanding of the physical processes, which is clearly essential, the outstanding needs in the study of weather modification are:

1. a better climatology of the clouds which it may be possible to modify, and of such factors as freezing nucleus concentrations, concerning which we know very little at present, and

2. the adequate dissemination of agents introduced into the atmosphere.

This aspect has often been seriously neglected in weather modification experiments, and careful studies of the diffusion and mixing of the atmosphere are clearly needed before one can say that any given plan of operation will produce adequate concentrations of the agent employed in the clouds.

REFERENCES

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