CLOUD SEEDING

A New Technology

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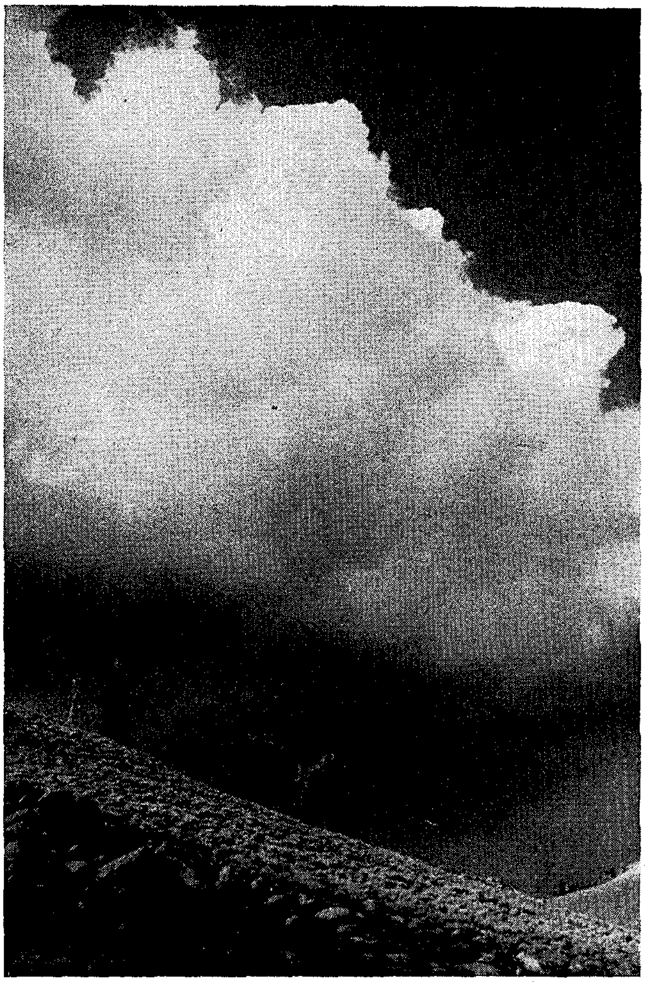


The artificial nucleation of clouds is already producing rain where and when it is needed. Someday it may even be used to prevent rain, hail and thunderstorm damage

SCIENTIFIC DISCOVERIES and technological developments in the field of cloud physics during the past four years have opened new and interesting avenues of approach to man's ever increasing endeavor to control nature. Already convincing evidence exists that it is possible for man to increase precipitation very significantly over what would occur naturally by application of cloud seeding techniques, or the artificial nucleation of clouds. This is popularly called "artificial rain-making." It is based upon the laws governing the formation of precipitation by natural means.

When an air mass is lifted by the large-scale upward motions within winter storms, by small-scale convection within typical summer thunderstorms, or by wind currents blowing normally to mountain barriers, condensation occurs at a level at which the temperature of the lifted air mass approaches the dew point. It must be remembered that the air mass expands adiabatically during its ascent to regions of lower pressure and therefore cools. This cooling is at the rate of about $5\frac{1}{2}°$ F per thousand feet in dry air, and less in moist air.

Unfortunately for those desirous of precipitation, rain does not ordinarily fall as an immediate consequence of the condensation process. Cloud droplets of about 20 microns in diameter are formed upon minute condensation nuclei such as sodium chloride and other salt particles which are nearly always present in the atmosphere. Such cloud droplets have an exceedingly small terminal velocity and therefore can drift almost indefinitely. For precipitation to occur, the droplets must be 10 to 100 times larger in diameter in order to have sufficient mass to fall through the random motions present in air. Collision and coalescence of droplets or additional condensation apparently do not contribute significantly to drop growth at this stage. Since we do know that precipitation occurs, there must be some mechanism to account for it.

There are many theories which attempt to account for precipitation. The most plausible, and the one best explaining the bulk of precipitation phenomena in middle latitude storms, is the Bergeron-Findeisen ice crystal theory which was advanced in the thirties.

Pioneers in the field of artificial nucleation—Doctors Langmuir, Vonnegut and Schaefer of General Electric.

It is known that cloud droplets do not freeze upon being lifted to sub-freezing temperatures. Super-cooling is observed at exceedingly low temperatures, even near —40° F. It is also known that the water vapor pressure over an ice crystal is much lower than that over a supercooled cloud droplet. Therefore if a small ice crystal were introduced into a supercooled cloud, water vapor would be transferred to the ice crystal and it would grow rapidly to snowflake size and descend. The ice crystal thus serves as a sublimation nucleus. After falling to lower regions of above-freezing temperature the snowflake would melt and change to a rain drop. In turbulent air the snowflake might be fractured and the various pieces could then serve as nuclei for other supercooled cloud droplets. This is the process which normally takes place within a thunderstorm cloud.

Until recently, not much was known as to where and how ice crystal nuclei were formed in nature. Now we know that they form spontaneously at about —40° F, which is usually at a rather high level in the atmosphere. In many middle latitude storms only a small fraction of the cloud tops exceed the self-nucleating level. Therefore, there exists a large potential of precipitation in the lower clouds, which can be realized if we can find artificial nuclei effective at temperatures between 32° F and —40° F.

Credit is due to Doctors Langmuir, Schaefer, and Vonnegut of the General Electric Laboratories for the basic exploratory work in this new field of artificial nucleation. It was Dr. Schaefer who demonstrated by a simple experiment that supercooled water droplets, which exist in great abundance in natural clouds, can be induced to turn into ice crystals at temperatures of about —40° F. He was able to generate ice crystals which in turn served as nuclei that grew at the expense of the surrounding supercooled water droplets. This method of producing ice crystals is known as seeding with dry ice.

Dr. Schaefer's experiment can be easily reproduced in any deep-freeze unit. A cloud of water droplets is created by blowing one's breath into a box set at about —10° F. The droplets quickly become supercooled. A small pellet of dry ice is then dropped through the cloud. In the path of the pellet a swarm of minute ice crystals becomes visible. They can be seen to scintillate in the beam of a flashlight. The crystals grow at the expense of the surrounding water droplets and slowly descend to the bottom of the box. If they were to fall through a great thickness of supercooled water droplets they would grow to snowflake size.

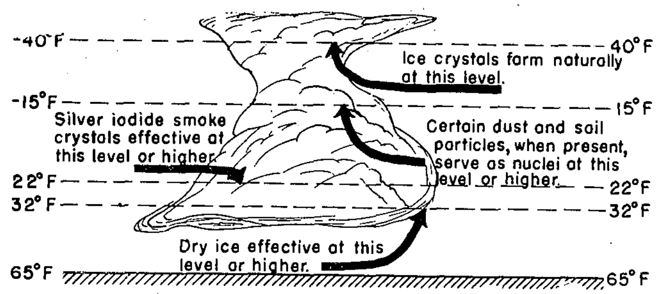
What happens is that the thin layer of air neighboring the dry-ice pellet is chilled to below the critical —40° F level and ice needles form spontaneously. Convection currents mix the trail of ice crystals throughout the box and they thereby nucleate all of the supercooled water droplets present.

Dr. Vonnegut of the General Electric Laboratories later discovered that silver iodide crystals, which are structurally similar to ice crystals, will serve as artificial nuclei at temperatures as high as 23° F. These silver iodide crystals can be easily produced in a silver iodide smoke generator at the rate of 10^{15} crystals per minute or per gram of silver iodide burned.

Subsequently it has been found that other substances will serve as nuclei, but not at temperatures as high as 23° F.

Some recent experiments

What happens when dry-ice or silver iodide smoke crystals are introduced into natural cloud formations? Many experiments have been conducted with varying results during the past four years. The bulk of the work is not described in publications, being held in confidence by the client in the case of work done by private concerns, and probably coming under military classification in the case of some government-sponsored investigations. By far the greatest amount of published



Different types of seeding processes become effective at different levels in the atmosphere.

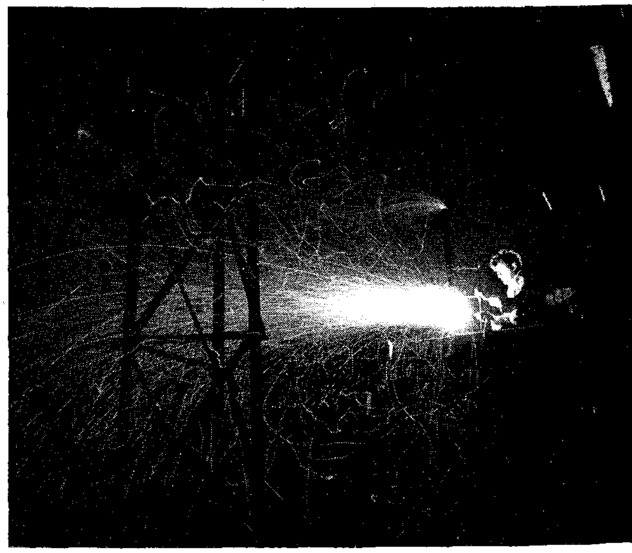
work appears in the General Electric Laboratories' *Project Cirrus* reports. The U. S. Weather Bureau has also published material covering its experiments.

The authors of this article are fortunate in having been in a position to examine data covering several thousand hours of operations by various groups and individuals, the results of which are not generally known. In what follows, the general features of the results of scientifically conducted operations will be outlined.

In order to seed a cloud properly there should be about one nucleus for every thousand water droplets. This permits a thousand-fold increase in drop volume, or a ten-fold increase in diameter, which is adequate to build up small snowflakes. Should there be one nucleus for each droplet, a swarm of small ice needles would form because of the sharing of the water by each crystal. Under these conditions no snowflakes could develop. Clouds treated in this manner would be completely "iced" and probably float away as a cirrus veil. This is what is known as "over-seeding" and it results in a decrease in precipitation, as might be expected.

In an average cloud there are about 10^{16} to 10^{17} cloud droplets per cubic mile; 10^{13} to 10^{14} nuclei are then needed per cubic mile to seed it properly. Langmuir has computed that one pea-sized dry-ice pellet will produce 10^{16} ice crystals before it is evaporated. Over-seeding therefore obviously occurs in the narrow shaft of the falling pellet. In summer cumulus clouds this concentration of ice crystals will be diffused rapidly by turbulent air motions throughout the cloud, so that a handful of pellets would eventually provide the correct nuclei concentration in an average cloud. A thousand pellets would inevitably produce partial over-seeding, and more dry-ice pellets might result in complete over-seeding. Seeding with dry ice in thin stratiform clouds where turbulent motion is less, or entirely lacking, usually results in over-seeding.

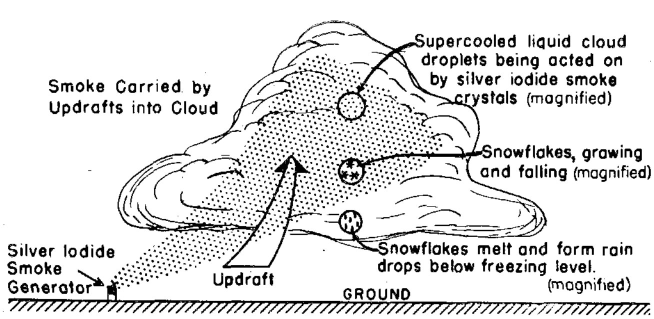
A silver iodide smoke generator produces 10^{15} crystals per minute. This is accomplished by first vaporizing the silver iodide at a high temperature, then cooling it rapidly or "quenching" it. Sublimation results in a swarm of smoke crystals about .01 microns in diameter. It is obvious that the direct introduction of this smoke into a supercooled cloud from a source producing 10^{15} crystals per minute, even if done from a swift airplane, must result in over-seeding as in the case of dry-ice seeding. Again, turbulent diffusion of the ice crystals resulting from the initial nucleation may result in an appropriate mixture of ice and water droplets far downwind where increased precipitation can occur.



Dr. Vonnegut uses fire to disperse silver iodide particles into atmosphere at General Electric Research Laboratory.

It may seem as though the generator output could be reduced sufficiently to avoid this initial over-seeding, but it is easy to show that a million-fold reduction in output would be required.

To avoid over-seeding the smoke must be introduced into the cloud from well beneath the freezing level so that diffusion will result in proper concentrations before the smoke reaches the supercooled portion of the cloud. Fortunately, as first demonstrated by Langmuir, the smoke can be used effectively in nucleating clouds when released from the ground. Under storm conditions currents exist which are capable of carrying the smoke particles from the ground to cloud tops in a matter of hours, or sometimes even minutes. Such currents account for the presence of pollen, dust, sea salt, and other types of small particles which are encountered at all elevations.



Effective seeding results when silver iodide smoke particles are released from the ground.

A factor of extreme importance is the release of heat of sublimation as the nucleated water droplets change phase and become ice crystals. If a one-minute supply of smoke from a silver iodide generator nucleated a cloud, then the heat energy equivalent to that of several atomic bombs would be released! Fortunately, this release does not occur in a small volume. Nevertheless, a rise of several degrees in temperature of the general cloud mass must result in a buoyancy force which propels the cloud mass upward with respect to its environment, lifting the cloud top perhaps even to levels where self-nucleation occurs. Simultaneously more moist air is lifted from below to replace that which ascends, and condensation releases even more heat to again increase the buoyancy of the cloud mass. A chain reaction thus develops which can result in a self-propagating storm mechanism perpetuating itself without the aid of further artificial nucleation. It is believed that a development of this type is often triggered by cloud seeding.

The results of experiments with dry ice drops into summer cumulus clouds reflect this release of heat. From Langmuir's experiments it appears that if dry-ice pellets can be shot into just the right part of the cloud, then such a self-propagating storm will develop. If the pellet is injected too high, the top part of the cloud may be over-seeded and become a detached cirrus veil, floating away from the lower cloud mass because of the swifter upper level wind.

Advantages of silver iodide smoke

In the opinion of the authors, seeding with dry ice has not produced as satisfactory results as seeding with silver iodide smoke. In many cases contradictory results are obtained and much developmental work remains to be done with this technique.

In areas where silver iodide smoke generators have been used the following general results appear: In mountainous terrain, where the smoke is released from windward slopes, appreciable increases in precipitation are noted in an area extending about 40 miles downwind and about 38 miles wide. No effect occurs in the first few miles, as the smoke has not diffused upward into the supercooled clouds in that distance. If the freezing level and cloud ceiling are low, there may be a region of over-seeding in the first 5 or 10 miles. In the center of the seeded area precipitation is apparently often more than doubled.

In flat terrain where the smoke is not aided in its upward diffusion by upslope winds, the area of effect may be at least 10 to 20 miles downwind, and may extend for a distance of 100 or even 200 miles downwind. It will be perhaps 50 miles wide at its widest part. If the generator is located at a below-freezing temperature level (either on the ground or in an airplane) and the clouds are close to the generator, over-seeding in the first 10 or 20 miles may quite materially reduce precipitation there.

Size of the area affected

The actual size and shape of the area is a function of numerous factors, such as the wind direction and force at different levels, the stability or instability of the air mass, and the height of the freezing level. But a rather large area is affected, especially in flat terrain. Therefore, there is no such thing as spotting rain on Farmer Brown's land. The economy of whole regions is involved. In areas of diversified agriculture, conflicts arise with respect to rainfall. In large regions where a single crop is raised, or where cattle ranching is the only industry, the problem is relatively simple. In such a situation, all agree as to when additional moisture will be beneficial.

Increasing snowpack

Cloud seeding to increase snowpack and subsequent water supplies for irrigation and hydro-electric purposes shows promise as a very beneficial field of application. There is much less danger of conflicting interests because of sparse population in these mountain watersheds. If activities are confined to the higher part of the watersheds, only snow will result. This will melt and run off slowly during the Spring and Summer to be stored in reservoirs. Seeding operations in lower areas, or during exceptionally warm weather, may produce rains and enhance flood danger.

It is well to point out here that there is no evidence of downwind deficiency of precipitation resulting from cloud seeding. There is no significant "robbing" of moisture from those downwind from the operations. Physical reasoning shows why this is so. There is a tremendous amount of moisture passing overhead in liquid, vapor, or solid form. In an area the size of that affected by cloud seeding, only about one percent of the moisture is removed as precipitation by natural process. Seeding might remove another one percent. The air passing downwind would then have a deficiency of one percent, which would soon be eliminated by turbulent diffusion of moisture.

The economic significance of this process is of national importance. The value of rainfall to economic existence, particularly in the western United States, is well known. With this new technology of cloud seeding we are on the threshold of controlling certain weather events on a fairly large scale. Already legislation to control this new technology is being discussed. It is hoped that legislation will not frustrate the development of this frontier of science, but rather serve to coordinate and collect data and license qualified groups to operate in this field.

Future possibilities

Finally it should be pointed out that the whole matter of cloud seeding to increase precipitation is considered largely in the experimental stage by the meteorological profession. There is no doubt that in the next few years a gradual development of operational techniques will permit a significant increase in the control of precipitation processes. We may see cloud seeding applied to the reduction, as well as to the augmentation, of precipitation. There is also a probability, already supported by a few experimental operations, that the over-seeding principle may be applied toward the prevention of hail by breaking up large cumulus clouds capable of developing hail storms. Thunderstorms might be similarly treated and the damage caused by lightning reduced.