File copy

NEW ZEALAND METEOROLOGICAL SERVICE

551.509.616/617(931)

TECHNICAL INFORMATION CIRCULAR NO. 135

Artificial Weather Modification

The following notes were prepared in answer to a number of enquiries. They are circulated for general information.

J.F. Gabites

(J.F. Gabites)
Director

N.Z. Meteorological Service,
P.O. Box 722,
Wellington.

5 March 1970

NEW ZEALAND METEOROLOGICAL SERVICE

ARTIFICIAL WEATHER MODIFICATION

The following notes outline the main factors involved in weather modification and the present status of attempts to modify the natural rainfall by cloud seeding.

Conditions for Formation of Rain

Two conditions have to be met before rain or snow will form. If either is not met, no rain or snow will eventuate.

The first condition is a dynamical one, and requires the maintenance of sustained ascending motion of moist air on a scale sufficient not merely to produce cloud, but to produce cloud deep enough and sufficiently long-lived for full-sized raindrops or snowflakes to grow within it.

The second requirement to be met is that physical conditions within the cloud must be conducive to the transformation of a vast number of tiny cloud particles (liquid droplets or ice crystals) into a smaller number of raindrops or snowflakes heavy enough to fall to the ground. It takes the moisture from something like a million cloud droplets to make a single full-sized raindrop.

The dynamical conditions can not be influenced by human agency on a practical scale. How, in what circumstances, and with what effect man can influence the physical conditions within clouds, have been the subject of intensive study in the laboratory and in the field over the last twenty-four years.

Dynamical Conditions

The ascending air motions necessary for the formation of rain may arise in three main ways, or in combinations of these.

Irregular convection currents ("thermals") may be produced when the air is heated from below. By this process cumulus clouds may develop over warm land on a summer day, or may appear in cool air arriving from the south over warmer surfaces. If the convective motions are sufficiently vigorous showers may eventuate. The life of an individual shower is usually between about ten minutes and an hour.

In most parts of the country the main cause of rain is found in ascending motion on a much broader scale that results from the convergence of major air streams. Near a front, which is simply the line of contact between converging air streams where one is undercutting the other, there may be a belt of rain up to a hundred miles or more wide and some hundreds of miles long. In the area where air streams converge into the forward side of a cyclonic disturbance ("depression" or barometric "low") the rain area may be hundreds of miles across.

A third cause of upward motion is forced ascent in an air stream crossing a mountain range.

The effects of these factors may be combined. Thus the rainfall pattern in a storm may be greatly modified by the topography. Both the ascending motion and the resultant rainfall may be greatly reinforced on the windward slopes of the ranges, while descent of air on the lee side may completely offset the effects of convergence in the storm so that little or no rain reaches that area.

Drought

Lack of rain results from lack of sufficiently vigorous or prolonged ascending motions. The dynamical requirements are not met.

Droughts are normally caused by either or both of two factors: the dominance of anticyclonic air circulations or the persistence of winds that have to cross mountains to reach the area concerned.

It is an essential feature of an anticyclone that through a large volume of the atmosphere there is a slow subsiding and spreading out of air. At low levels air spirals outwards with an anticlockwise motion. Any clouds that may have existed in the air before its descent and warming are soon dissipated. Any clouds that do persist in an anticyclone are likely to be confined to a shallow layer of moist air trapped near the ground; they are incapable of producing rain, or anything more than a fine drizzle. As a consequence of the characteristic subsiding motion, the anticyclone is typically a rainless circulation system.

Sinking and dissipation of cloud are also to be found on the lee side of a mountain range. Districts that are sheltered from the main rain producing winds have characteristically low rainfalls.

Broad scale atmospheric circulations around the hemisphere often take on configurations that result in pronounced anti-cyclonic activity continuing in one area or another for some time. Possibly also the hemispheric flow may be such that for some time only downslope winds reach a particular district. In either case the rainless period may on occasion be long-lasting.

In summer the pasture in most parts of New Zealand would need something like an inch of rain per week to offset loss by evaporation and transpiration. If the loss is not replaced by rain or irrigation, drought conditions soon develop. Basically the drought conditions are the result of the broad-scale patterns of air flow around the hemisphere and the immediate causative factor is the persistence of sinking motions in the air. As long as they continue, rain cannot be produced either naturally or artificially.

The American Meteorological Society, after reviewing the extensive laboratory experiments and field trials that have been conducted around the world, concluded in its statement on Weather and Climate Modification dated 27 October 1967 that "The evidence on hand indicates that cloud seeding can neither produce nor terminate droughts. Such conditions are associated with persistent patterns of air motion which inhibit the formation of clouds and precipitation."

Physical Conditions

Favourable dynamical conditions alone are not sufficient to ensure the formation of rain. Suitable physical conditions must exist for initiating the growth of raindrops or snowflakes within the cloud.

Individual cloud particles, usually liquid, grow through the condensation of moisture on small specks of dusts or salts that are floating in the air and serve as condensation nuclei. As long as the droplets remain small they float, rarely if ever coming into contact with each other. However two processes are available by which some may grow preferentially into raindrops or snowflakes: the so-called coalescence process and the ice crystal process.

Coalescence Process

If there is a wide disparity in the sizes of the droplets, perhaps because some developed initially on larger or more strongly hygroscopic nuclei than their neighbours, the largest droplets may tend to sink through the cloud, colliding and coalescing from time to time with smaller droplets. Usually the growing drops need to traverse a depth of at least 5000 to 8000 feet of cloud before they reach raindrop size. If the cloud is composed of liquid droplets at temperatures above freezing point (0°C) this coalescence process appears to provide the only effective process by which rain can form.

There is a marked difference between the composition of clouds that develop in air that has spent some time over continents and in marine air. In continental air the condensed water is likely to be shared by a large number of very small droplets, while in marine air there are fewer but larger droplets. It has been suggested that in the interior of continents the scarcity of larger hygroscopic nuclei may be overcome by scattering finely powdered salt, but tests so far have been inconclusive.

Clouds formed in marine air produce rain readily. The air over New Zealand at any time has never been long away from the sea, and indications are that it is never seriously deficient in particles of sea salt to initiate the coalescence process. The coalescence process appears to be the dominant one for the formation of rain in New Zealand.

Ice Crystal Process

If the cloud particles happen to be ice crystals, as in cirrus clouds, the only way they can grow is by the slow accretion of water vapour. There seems to be no practicable way to hasten or retard the process.

The interesting case occurs when the cloud is composed of supercooled liquid droplets at temperatures below 0°C. This is the state in which artificial modification is often possible.

It is normal for liquid cloud droplets to form even at temperatures appreciably below 0°C. The air however always contains a variety of dusts that can act as freezing nuclei. A few will induce freezing at temperatures not far below 0°C; others do not become effective until lower temperatures are reached. The lower the temperature the more of the natural freezing nuclei are likely to be effective, and the greater the probability that individual cloud particles will be frozen. Liquid droplets usually predominate at temperatures down to -10°C or -20°C and sometimes lower.

Once both ice crystals and liquid droplets are present together within the cloud the ice crystals grow preferentially at the expense of the neighbouring droplets, which tend to evaporate. If there are many ice crystals there is simply a slow transformation from a water droplet cloud to an ice crystal cloud. If however the proportion of ice crystals is not too great, and if the depth of supercooled cloud is sufficient, a large number of liquid droplets may eventually be replaced by a small number of snowflakes. These may melt on falling to warmer levels, and if still within cloud may continue to grow by coalescence.

If the proportion of ice crystals is below the optimum for the formation of snowflakes the creation of additional ice crystals by artificial means may speed up the natural process. If, on the other hand the proportion of ice crystals is already adequate, the creation of additional crystals will retard the formation of snow or rain, or even completely inhibit the process by simply transforming the cloud to one of ice crystals.

Experimental Cloud Modification

In the first successful modification of clouds in 1946 Dr Irving Langmuir and Vincent J. Schaefer dropped pellets of solid carbon dioxide ("dry ice") from an aircraft into a sheet of cloud composed of supercooled liquid droplets. The resultant chilling caused enough ice crystals to form to transform the droplets into snowflakes. In most cases they evaporated before reaching the ground, but the important thing was that a hole was left in the cloud sheets.

Shortly afterwards Dr Bernard Vonnegut found that fine crystals of silver iodide were particularly effective as freezing nuclei. Although silver iodide loses its potency fairly rapidly in sunlight, it has largely replaced dry ice for cloud seeding.

High hopes for stimulating the formation of rain led to a great wave of indiscriminate cloud seeding around the world in the 1940's and early 1950's, with little or no scientific assessment of the results. As statistical analyses were established and laboratory research developed many of the limitations were discovered. It became evident that not only had many farming communities "paid for rain which they previously got for free", but that the operations they had paid for must on occasion have decreased the amount of rain they received.

There was no doubt that on many occasions the composition of supercooled water droplet clouds could be altered, and often too their appearance changed. The question that is still not answered in detail is when the change in composition may have beneficial effects, when harmful, and when no significant effect at all.

One beneficial application of cloud seeding is established and in operational use. At several airfields, notably in Alaska, northwestern U.S.A., Scandinavia and the U.S.S.R., seeding is employed to dissipate supercooled fog or low cloud during winter.

Seeding is also employed extensively in parts of Italy, Switzerland, France, and the U.S.S.R. in the hope of inhibiting the development of lightning or damaging hail. Although the results have been inconclusive the seeding, usually by means of rockets, is continuing.

The third application of cloud seeding, aimed at increasing rainfall, has proved very difficult to establish or evaluate. The conditions necessary for successful artifical stimulation are so similar to those under which rain is produced naturally that the scope for profitable seeding activity is very limited. Natural rain forms readily in marine air. The best hope for artificial stimulation seems to be in continental clouds composed of very large numbers of very small droplets. Here seeding may speed up the production of snowflakes. This may not be beneficial, for in many cases the ultimate dissipation of the cloud will also be hastened, and the net rainfall may be reduced.

In most clouds the amount of liquid water present at any time is not great. Even if entirely converted to snowflakes or raindrops the water would be liable to evaporate again before reaching the ground. For worthwhile amounts of rain to be produced there needs to be a continuing inflow of moist air to maintain the cloud.

Results of Cloud Seeding

Because rainfall on any occasion tends to be so variable from place to place, it is impossible to determine the result of a single seeding operation. Nobody can be certain what rain would have fallen without the seeding. Only by statistical comparisons, e.g. with rainfalls in neighbouring unseeded areas, can the effects of sustained seeding operations be discovered. The confusing results of early field trials seem to have been due to the fact that tampering with the clouds has resulted in a decrease in rainfall perhaps as often as an increase, and often has had no significant effect at all.

Certain sustained seeding operations over mountain areas in northwestern United States appear to have increased the snowfall or rainfall from winter storms by something like 10 percent. It is largely from an analysis of these operations that the U.S. National Science Foundation reported in 1965 that:

> "While the evidence is still somewhat ambiguous, there is support for the view that precipitation from some types of clouds can be increased by the order of ten percent by seeding. If the results are confirmed by further studies they would have great significance. The question of corresponding decreases of precipitation outside the target area is unresolved."

The increases referred to were the result of uplift of air over mountain ranges in winter storms. Evidence from similar projects in other parts of the world is less certain and in some cases suggests a decrease in rainfall as a result of seeding operations.

Some extensive seeding trials have been conducted in Australia by the Commonwealth Scientific and Industrial Research Organization, concentrating mainly on the more promising continental clouds on the windward sides of the ranges. Some of the early trials brought spectacular changes to seeded clouds, but as observational data were accumulated, the success in increasing the rainfall seemed less certain. After five years of seeding in the Snowy Mountains experiment, the rainfall appeared to have been increased by 19 percent; in South Australia the rainfall appeared to have been decreased each year for three years, with an overall reduction of 5 percent, and the seeding was discontinued; in New England the result of six years seeding appeared to be an increase of 4 percent; and in the Warragamba experiment four years seeding apparently resulted in a reduction in rainfall of about 3 percent.

Several research groups have been trying to identify the particular circumstances under which seeding may increase or decrease the natural rainfall. Some elaborate and costly investigations have so far proved inconclusive. Special attention has been given to continental clouds, and in the Australian context Dr E.G. Bowen, head of the C.S.I.R.O. group has considered that :

"Sufficient experience has now been gained to indicate that conditions suitable for cloud seeding are relatively common over the eastern part of Australia. The only unfavourable regions are those along the coastal fringe, where suitable clouds occur quite frequently but rain easily of their own accord and are seldom stable enough to warrant seeding, and those in the far interior, which is essentially a desert over which clouds occur so infrequently that cloud seeding would be uneconomical."

The conclusion reached by the U.S. National Science Foundation after studying the results of field trials by many different agencies in the U.S.A. and elsewhere, and reported to Congress in 1965, was that

"Experiments in cloud seeding during the past decade have indicated that, at most, increases of precipitation can result from cloud seeding only in regions where forced lifting of air currents occurs over mountain ranges and that such increases will be relatively small. There seems to be no convincing evidence to date that seeding affects the amount and character of precipitation over flat country. This does not prove that there are no such effects, but suggests that if such effects do exist, they are too small to be detected by present statistical analysis technique."

In reference to the projects that appeared to show positive results of seeding the National Science Foundation added that

"These positive results are obtained in cases where rain would have fallen anyway without seeding; there is no evidence that seeding can induce rain to fall when normally there would be none. Thus seeding is of limited value in relieving drought situations."

In a later report to the President of the U.S.A. dated 28 August 1968, the National Science Foundation stated that

"One of the problems still facing the cloud seeder today is the determination of the proper concentration of silver iodide to administer to the particular cloud being treated. It is first necessary to know what concentration of natural ice forming nuclei already exists in the cloud, and then to determine how many additional nuclei should be added at the right time and the right place. This is further complicated by the fact that the efficiency of silver iodide generators varies widely from one type of generator to another, and for any particular type of generator the efficiency will vary over orders of magnitude depending upon the temperature of the supercooled droplet to which the silver iodide is administered."

Summary

Over the last twenty-four years an enormous effort has been devoted in several countries to investigating the possibilities of weather modification by seeding clouds with suitable chemical agents. Much remains to be learned, but some of the main conclusions are:

Before rain can develop it is essential that there be a sustained ascending motion of moist air to produce and maintain a deep layer of cloud.

In deep clouds in marine air rain forms readily by the coalescence of liquid droplets and there appears to be little opportunity for modifying the natural course of events.

In certain clouds composed of supercooled liquid droplets, freezing may be initiated by natural freezing nuclei already in the air or by seeding with a suitable agent, usually silver iodide. If the resulting proportion of ice crystals to liquid droplets is suitable the conversion to snowflakes may be hastened. Unless the cloud is continually renewed by inflow of moist air the snowflakes or raindrops that survive evaporation to reach the ground may be insufficient to constitute worthwhile precipitation.

If the proportion of ice crystals created is too great, the supercooled liquid cloud is simply converted to an ice crystal cloud, and the formation of precipitation is inhibited.

Opportunities for hastening the development of precipitation by the ice crystal process seem to be greatest in clouds formed in continental air, but the effect on the net amount of rainfall may sometimes be an increase, sometimes a decrease, and is not predictable with confidence.

The best evidence for a net increase in precipitation comes from the seeding of winter storms over the mountains of western U.S.A. In other situations the evidence is conflicting.

Cloud seeding is now employed mostly for dissipating winter fogs over airfields, in the hope of reducing lightning and hail damage, and in trying to increase the winter snowfall or rainfall on the windward slopes of mountain ranges.

Drought results from a persistent sinking motion of air, either in anticyclones or in the lee of mountains, which is caused by large-scale features in the flow patterns around the hemisphere. It is now generally recognized that drought cannot be terminated by any form of cloud seeding.

J.F. Gabites
Director

N.Z. Meteorological Service,
P.O. Box 722,
Wellington.

5 March 1970