WEATHER MODIFICATION IN CANADA

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In Canada, and no doubt elsewhere, what is desired is a clear and definite answer on the effectiveness of weather control. The need for this answer is very real. It is important to agriculture, forestry and hydro-electric interests and for obvious reasons to the prairie grain grower, or the market gardener surveying acres of ruin from a hail-storm, and those concerned with the increasing urgency for conserving and augmenting our water resources. To the farmer, any formula or cure, no matter how remote the possibility of its success, is worthy of serious consideration. To the latter, a proposal giving documented statements and an estimate of costs, usually receives and deserves careful study at executive and operational levels to determine the real merits of the offer, its monetary possibilities and operational significance.

The magnitude of the economic issues involved in proposals for large scale weather modification experiments necessitate scientific consideration and professional appraisal of the physical principles involved, of the merits of the techniques proposed, and authoritative opinions on the degree to which the proposals may apply.

In Canada the onus for providing a scientific and impartial appraisal of merits has been accepted by the scientific organizations best able to give an unbiased answer. These are the government weather service, the Universities and the Research Councils. Regarding the commercial firms operating in this field it must, I think, be recognized that when one is concerned with and guided by the profit making incentive, there is a tendency to overlook the basic research and critical study needed of the processes involved, which is essential to progress and good service.

The story of the discovery, and development of cloud seeding on a laboratory scale has been told and retold. The application and testing of laboratory techniques on the vast forces and complex natural conditions in our atmosphere is, in the opinion of many scientists, a new, and as yet relatively unexplored field. To those who disagree, and I see a number here, I suggest that although there is merit in the saying "Modesty is commendable, but like thrift, can be carried too far", yet those endeavouring to operate in and exploit the new fringes of our knowledge should remember too that the greatest of faults is to be conscious of none.

In Canada the first attempts to create additional precipitation by artificial means were, I believe, the experiments conducted in 1948 by the National Research Council with the cooperation of the Meteorological Service in which seeding techniques were tested using dry ice and aircraft. At this time experiments were being carried out in many countries and experience began to accumulate. Shortly after, private meteorological firms in the United States, who had quickly recognized the sales potential of large scale cloud seeding, expanded their operations into Canada. The skies over the provinces of Quebec and British Columbia were first to receive the cloud seeding test, in both cases with a view to increasing water power.

Seeding operations in Quebec in 1951 and 1952 were analyzed, using statistical techniques, by R. H. Douglas of the Meteorological Division and results published in September 1954. The evaluation indicated deficits in rainfall in five of the six seeded months in one target area and no significant effect in the other area. Evidence of a climatic abnormality suggested that the deficits were probably not caused by the seeding. It was suggested that better conclusions might have been obtained by a method of classification of rainfall pattern either by months or storms, and randomized seeding operations were recommended as likely to be most satisfactory to subsequent evaluation. At that time the chief problem was stated simply that studies in cloud physics had not reached the stage where the answer to the question, "How much rain would have fallen naturally?" could be answered on a purely physical basis. The alternative, a statistical study using a target on control regression technique, was therefore employed. Despite steady advances in our knowledge of the processes that operate in clouds, we are still far from being able to answer that same question today, and it appears evident that statistical studies, with their potentialities and limitations will have to be used for some time to come.

In 1953 cloud seeding operations were carried out by a commercial firm for a farming area in southwestern Manitoba under a contractual arrangement. In 1954 operations were again carried out for this area and for two areas in west-central Saskatchewan. The Meteorological Division was asked to provide an impartial assessment of the effects of these cloud seeding operations. The contracting firm co-operated fully by providing the necessary details on boundaries of contract areas, generator location and operation. A detailed evaluation was made using a multiple regression technique developed by Dr. W. L. Godson and a report was distributed.

The evaluation of the nine seeded months indicated that the most likely effect of the seeding was a decrease in rainfall of 14.1 percent. The odds were 39 to 1 against the hypothesis that seeding increased rainfall. These figures, although significant, were not considered necessarily the final answer. A longer period of operations might well increase or decrease the value given for the most likely effect, and would certainly increase the degree of confidence in the results.

Commercial cloud seeding was carried out in British Columbia by two contracting firms over the years 1952-56. Target areas were on the mainland and Vancouver Island. Three of the seeding projects were aimed at increasing water supply for hydro-electric use and a fourth was intended as a measure against forest fire hazard. The British Columbia Research Council was given the responsibility for an extensive study of weather modification operations in that province, and for producing a comprehensive report evaluating the cloud seeding operations. The study covered all available information on cloud seeding carried out in British Columbia, operations in other provinces and other countries, a review of modern statistical methods for assessing the effects of cloud seeding leading to the selection of the technique believed likely to be most effective in the study, selection of test areas, tests, collection of meteorological data, and evaluation of claims made by commercial operators.

The Interim Report covering Phase I issued January 25, 1957 summarized results as follows. "The reports prepared by the contractors on their cloud seeding operations in British Columbia claim appreciable increases in rainfall in all target areas during the seeding operations. The present report does not support this view. A check of the procedures used in estimating the increases in rainfall has shown that the calculations used in the reports are faulty and that no change in rainfall as a result of seeding has been found in any area." The final Project Report was issued August 7, 1957. The Summary of results states, "Examination of one additional contractor's report, not included in the first phase of this study, yielded conclusions similar to those reported previously. No change in rainfall as a result of seeding has been proved. Application of methods used by the contractor shows that the effects of seeding, if any, are small and undetectable.

Evaluation of cloud seeding operations in British Columbia by more detailed and advanced statistical methods shows the over-all effect has been to increase precipitation and streamflow by some value in excess of +0.33 percent. However, the probability that the increase could be as much as 10 percent is extremely small. The effect of seeding in the individual Powell Lake and Campbell River watersheds has been the same. The statistical methods used in this report, employed all the concurrent precipitation and streamflow records available for the target and adjacent control areas. Only limited improvements in accuracy could be expected by inclusion of future seeding operations into the existing evaluation. Consequently, further studies, based solely on commercial seeding programs, will not provide any additional useful information."

This evaluation for west coast areas is considerably less optimistic than that reported by Thom in Technical Report No. 2 of the Advisory Committee on Weather Control in which it was concluded on the basis of their results that commercial seeding operations on the orographic and West Coast projects increased natural precipitation on the average by 14 percent.

Promotion of commercial cloud seeding for rain increase, and to a lesser extent snow increase, has continued active in Quebec and Ontario. It might be mentioned that any talk of increasing rain in the three Maritime Provinces, where new rainfall records seem to be made with surprising regularity, - e.g. Liverpool, N.S. report 12.12 inches of rain this January, (normal 4.03) and Greenwood measured a six hour rainfall of 3.92 inches in a passing July storm - would in all probability result in the rainmaking salesman being chased out of the Maritimes and half way to the Pacific Coast.

Nevertheless, in Quebec and Ontario, hydro-electric and pulp and paper interests are very much interested in any measures that might ensure ample resources of rain and snow. Very serious consideration has been, and is being given to the possible economic value of cloud-seeding. As would be expected the executives concerned have had difficulty deciding what to do. They have listened carefully to and read the promotional material put out by the two private firms active in these areas. But industry generally despite its shrewdness in business matters is not able to fully understand the technical arguments and weigh the commercial rainmakers advertising against the caution of civil service meteorologists and university scientists. They may perhaps suspect that the real struggle is between opportunism on the one hand and lack of respect for the outsider on the other. As in any controversial issue there are a few who are firm believers, some who are critical skeptics - or outright disbelievers, while the large majority are from Missouri unable to believe all they are told, unconvinced that man has progressed to the point where he can actually control the weather at will, and above all wishing to have a firm scientific and fully reliable opinion on the effectiveness and economic worth of present day cloud seeding.

It has been said that public opinion is formed by that minute fraction of the population which thinks and speaks. In the field of weather modification public opinion on meteorological progress is largely dominated by the sheer weight of sales promotion now being distributed. The scientists concerned with the problem, who in the public mind, are only aware in a sort of abstract way of its great potential and the economic issues involved periodically review the situation and restate viewpoints while actively conducting research studies for further knowledge. The recent statement by the American Meteorological Society, while a valuable contribution, has received relatively little publicity. As with other controversial subjects the scientist believes weather modification to be one in which even basic theories undergo change, and solutions to one set of problems are apt to generate new and different problems. Perhaps it should be added that a pause is needed from time to time to organize the newest available research information on the subject and establish firm footholds for present requirements and further investigation.

At the present time the group in Quebec concerned with cloud seeding appears to have definitely decided to search for a firm scientific opinion on its merits. The Department of Transport was approached and the Meteorological Branch has been asked to review cloud seeding up to the present and advise on the many conflicting reports on its effectiveness, to comment on A Statistical Evaluation of Cloud Seeding Operations in Western Quebec, a report recently submitted by the contracting firm, and to recommend conditions which should be met in setting up an experiment in such a manner as to allow for dependable assessment.

As indicated earlier, on matters relating to weather modification, the Meteorological Branch, Department of Transport has endeavoured to maintain an open minded reasonable viewpoint, relying on accepted scientific facts and professional judgment in expressing opinions or giving advice. The seriousness of water shortages, the heavy hazard of hail, the potential good that could arise from the ability to lessen such hazards and augment resources, these warrant the most serious consideration of the possibilities of weather modification. We are also conscious of the disturbing possibility that the present techniques may at times work against the good of our country. The new wonder drugs, such as penicillin and auromycin with their proven value are available for the benefit of the public welfare, but not for indiscriminate use on every patient and for every ailment. The demonstrated value, and the potential for harm are recognized, and safeguards are organized against imprudent use as a cure-all. The application of the all purpose ground generator as a means for increasing rain, and snow, of preventing excesses of precipitation, for reducing hail, for eliminating lightning, is the so-called case in point, and the widespread use of these appliances before the effect of <u>local</u> cloud seeding, if any, is known and can be predicted for individual storms or situations, could be harmfully premature. The possibility certainly exists that artificial nuclei may be introduced into a cloud at a critical stage in which its presence may well initiate hail formation that would not otherwise have occurred, although elsewhere the nuclei may have a beneficial effect.

Mr. Thom, in the Technical Reports of the Advisory Committee on Weather Control has consistently stressed the need for a great deal more study of individual storm characteristics, of the need for widespread physical experiments, to include network sampling measurements of natural nuclei in the atmosphere and a study of the precise effect of experimental seeding under known conditions. The vast and complex variability of natural conditions, the lack of sound and adequate knowledge of the vertical diffusion process, the effects of turbulence, temperature, and photolytic action, stress the conservatism and caution of many scientists who doubt that silver iodide nuclei in an active state actually reach the areas where they could be effective, and which at present there is no means for predicting.

In the preparation of advice for the hydro-electric and forestry interests in southern Quebec Dr. W. L. Godson, Superintendent of our Atmospheric Research Section, again reviewed in detail all available literature on this subject. He surveyed, insofar as possible, the present state of knowledge of precipitation physics and cloud seeding potential. He applied this study to the situation in southern Quebec, related it to the difficulties in evaluating cloud seeding there and suggested a design for an experimental project which would yield much more significant results with increased sensitivity using a shorter seeding period.

Since the area considered is no doubt of considerable interest to you in as much as conditions may be assumed to be somewhat similar in southern Quebec and northeastern United States, I believe I should make reference to the results of Dr. Godson's study. I regret that he is not here to present these remarks to you in person.

In southwestern Quebec it is well known that the bulk of summer precipitation is showery, and usually accompanies thunderstorms. The major consideration, then, is the precipitation process in summer showers and thunderstorms. Evidence accumulated in the last few years has demonstrated that the major process yielding precipitation from cumuloform clouds in summer in temperate latitudes is the coalescence process. It is now known that this process does not require very many large cloud droplets. Large nuclei are certainly present in the free atmosphere over eastern North America, and recent theoretical studies have shown that a cumulus cloud can manufacture its own large droplets in adequate time provided only that the liquid water content is sufficiently high. It has been shown, for example, that most summer cumulus in central Sweden which yield precipitation do so because of a coalescence mechanism. Glaciation and ice crystals may appear in cloud tops in a late stage of their development, but apparently play only a trivial role in the release of precipitation. Moreover, the relative infrequency of hail in Quebec compared to other Canadian areas (the prairies, for example) is again evidence that the ice-crystal process is not a major factor in summer precipitation. Radar evidence to the east of the area in question also indicates the absence of zones of melting ice or snow in summer cumulus cloud, even though this zone is very readily identified when present. If coalescence is an adequate and effective mechanism for precipitation, silver iodide seeding would have little or no effect (in fact, the consensus of opinion is that it would decrease precipitation). In those cases in which the coalescence mechanism was inadequate, clouds would have to be so shallow that sufficiently cold temperatures for silver iodide nucleation would be very unlikely.

Winter precipitation is almost invariably released by the ice-crystal mechanism, chiefly from stratiform clouds. Stratiform clouds which do not form part of the cloud shield of large cyclonic storms yield an insignificant amount of precipitation in southern Quebec. When we examine the stratiform cloud systems in a typical cyclonic storm, we come to the conclusion that nature is operating in a very efficient manner with regard to precipitation release. The amount of precipitation is governed chiefly by the distribution in the vertical of vertical motions and cloud extent, neither of which may be modified by artificial means. Radar and flight studies of cyclonic storms crossing New England show that only in the rear portion of these storms is the precipitation mechanism inefficient.

Similar storms over southwestern Quebec would have relatively little condensed water available for precipitation in such storm sectors because of the colder air in these rear sectors. The basic reason for the highly efficient release of precipitation in cyclonic storms is that the cloud systems extend to considerable height. It appears that there are adequate natural freezing nuclei effective at -15°C (+5°F) in the Quebec and New England areas, and that clouds usually extend to much higher levels.

The opportunities for initiating or augmenting precipitation in southern Quebec, at any time of the year, will be relatively rare, and the additional amounts that could be produced will be small. Silver iodide seeding would be effectuve only if clouds extended to levels with temperatures at which nucleation could operate but did not extend to levels with temperatures of -15°C and colder. Thus, cloud tops must lie in a layer about two to three thousand feet thick between -10 and -15°C for seeding to be effective and natural processes inefficient, provided that no cirrus cloud is present aloft and that surface temperatures are colder than about 60°F. It is assumed in the above considerations that silver iodide particles are introduced into the cloud at the proper level and in adequate concentrations. The validity of this assumption is very much open to question. Further, multi-layer clouds associated with cyclonic storms are not fed from below by moisture or nuclei and in fact are effectively insulated from surface effects by very stable layers through which vertical diffusion is essentially inoperative.

With regard to evaluation of cloud seeding some of the pitfalls into which one may be led by the use of a regression analysis on a non-randomized project are well known. They arise simply because the method assumed that the variables are samples drawn from a stationary time series, whereas weather, as we are well aware, is subject to trends, spells, and similar non-random fluctuations. It is therefore normally impossible to establish a valid estimate of error in predicting target precipitation from that measured in control areas. The uncertainties can be minimized by certain tests such as application to unseeded non-history periods but can be eliminated only by a randomized operation.

A randomized seeding program is one in which the test occasions are divided into two groups, one of which receives the seeding treatment and the other of which does not, the selection of cases for the two groups depending on a purely random choice. The effect of randomization is to provide a simple and complete guaranty of a valid interpretation of the results of a test, regardless of uncertainties arising from incomplete control over the conditions of the test. Evaluation is performed by comparing the precipitation or its departure from a regression equation estimate on seeded occasions, with values in unseeded, or control, occasions. Since seeded and control cases will be interspersed, the effects of spells and other persistent weather sequences will apply to both classes of cases more or less equally, thus increasing the sensitivity of the evaluation as well as removing bias.

One important advantage of a randomized project is that, since historical data need not be employed, it is possible to install adequate rain gauges to sample target and control areas. This makes the results more significant and increases the sensitivity of the test since areal averages correlate better than point values. In short, a randomized project brackets the possible effects of seeding much more accurately than a non-randomized project, and these limits shrink faster as well. In addition, only a randomized project offers any hope of distinguishing between seeding effectiveness in different months and under different meteorological conditions.

The Presidential Advisory Committee carried out a series of detailed evaluations of similar projects in a very skillful manner, with results that cannot be questioned on grounds of either bias or statistical error. While results for selected west coast projects gave an increase as mentioned earlier, in eastern U.S.A. the mean effect was a slight decrease which was not significant statistically. From purely physical principles a realistic estimate of the increase possible in southern Quebec would be about 5%; 10% would be rather unlikely in this area. Thom in Technical Report No. 2 advises that it appears unrealistic to expect.... increases greater than 10 to 25 percent in present commercial seeding practice.

The evaluation given in the report "A Statistical Evaluation of Cloud Seeding Operations in Western Quebec" was carried out along the lines used by the United States Advisory Committee on Weather Control but did not make use of the elaborate safeguards employed by that Committee to minimize the effects of trends and spells on estimate errors and prevent intentional or unintentional bias.

The report claimed increases of 50%. It appears evident that the report presents a timely example of the pitfalls that lie open to this type of evaluation with non-randomized seeding.

Needless to say, in all the evaluations prepared by commercial firms seeding in Canada, that have come to our attention, results have been indicated as substantial and the outlook for further operations quite optimistic.

More remote, but of considerable current interest to us in Canada are the studies now being made of hail in Alberta. Briefly the situation is as follows. The possibility of reducing hail damage has been under study since 1952. In the summers of 1956 and 1957 extensive hail research programs have been carried out in Alberta. Co-operating in the project are the Meteorological Branch, the Stormy Weather Research Group at McGill University, the National Research Council, and the Research Council of Alberta. The aim of the project is to learn more about the natural processes by which hail forms. The principal tool of the project is a weather radar, specially designed and built for the purpose. The Alberta farmers; about 15,000 are in the project area, assist by supplying specific information on hail occurrence. Time lapse photography is integrated with the radar observations, and a study of the synoptic weather situations associated with hailstorms is under way. The radar program has certain unique features. The antenna rotating at 20 rpm is tilted upward $\frac{1}{2}$ degree each revolution to an elevation of 20 degrees, then returns to the horizontal and repeats the cycle every two minutes. The radarscope is photographed continuously on the 100 mile range as long as echoes are visible. The film was shipped to McGill University for controlled processing inspection and synthesis. The synthesis process is an ingenious procedure by which the filmed echo patterns are converted into plan maps at constant altitude. Although maps can be produced by the process for any altitude, 5,000, 15,000, 25,000 and 35,000 foot levels have been selected. Sets of plan maps for these altitudes have been produced for 2 minute intervals covering some 185 hours selected from the most informative periods in the development of hail. Detailed and co-ordinated analysis of the radar data, the related hail observations, and the upper air situation is greatly facilitated by this synthesis technique. The stormy Weather Group at McGill, under Professor Marshall, which is making an outstanding contribution to the project and Dr. R. H. Douglas, our Headquarters Research Specialist in cloud physics, are now proceeding rapidly with this investigation. New knowledge gained from data now available and from a continuation of the reasearch project will without doubt provide a much improved understanding of the physical processes governing hail formation, and in turn bring considerably closer the time when a scientifically sound opinion can be given on steps that should be taken to lessen the hazard of hail.

It should be mentioned that Alberta farmers in a heavy hail area contracted with a commercial firm for cloud seeding to suppress hail during the last two seasons. As is well recognized, evaluation of the effects of cloud seeding on hail fallout is exceedingly difficult, and development of a means for doing so probably awaits more knowledge of the physical processes. A subjective estimate of the value of cloud seeding based on extensive but incomplete hail reports gives little satisfaction but provides the only conclusions so far. In 1956 the target area seemed to have less hail than would be expected, but in 1957 hail claims were above average, and no hail premium rebates were made in the target area, where the percentage of claims was considerably higher than outside the area.

Co-operation, in Canada, between commercial firms undertaking cloud seeding and the Canadian Weather Service has been generally very good. Cross currents of feeling and motive are non-existent or properly suppressed despite the overstatement of abilities and knowledge on the one hand, and limiting moderate statements of meteorological progress on the other. The public is recognizing that if the best professional advice is asked for and not accepted the responsibility for frustration and wasted effort is theirs.

Meteorologists are human as other men, and we do not suggest that there is any obvious way in which to speedily resolve the contradictions and controversial issues of weather modification. But it is certain that if these issues are openly recognized they will have far less influence on decisions than if those concerned tried to pretend that they did not exist.