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CANADA

DEPARTMENT OF TRANSPORT
METEOROLOGICAL BRANCH

DESIGN AND OPERATION

PRECIPITATION PHYSICS PROJECT

BY

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The Precipitation Physics Project is a cooperative research project directed and coordinated by the Meteorological Branch with the active participation of the National Research Council and the assistance and interest of a number of other agencies. The Project is aimed at discovering fundamental knowledge of the mechanisms of precipitation as well as the possibility of its artificial modification.

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ABSTRACT

During the summers 1959 to 1963, a project of cloud seeding combined with physical studies of precipitation mechanisms was operated in western Quebec. Randomized cloud seeding of synoptic scale weather systems with silver iodide using an all-weather aircraft and a cross-over technique with two separated test areas was conducted for a test of the effect of seeding this type of storm. Studies of precipitation mechanisms were advanced by the collection of many observations of liquid water content, drop-size distribution and other parameters in the air and by radar observation, ice nuclei counting, rainfall measurement, lightning counting and other measurements on the ground.

The paper discusses the aims, experimental design and instrumentation of the project and describes the manner in which these plans were carried out during the five years of operation. Changes and improvements made in the project as a result of accumulated experience are also discussed.

Results of the project are being presented in other reports in this series.

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PROGRAMME DE PHYSIQUE DES PRÉCIPITATIONS
DEUXIÈME RAPPORT
OBJET ET MISE EN OEUVRE

par

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RÉSUMÉ

Au cours des étés de 1959 à 1963, un programme comportant à la fois l'ensemencement des nuages et l'étude physique des mécanisms de la précipitation a été mis en oeuvre dans l'Ouest du Québec. On a ensemencé au hasard des nuages de systèmes météorologiques à échelle synoptique au moyen d'iodure d'argent produit à bord d'un avion tous-temps survolant deux aires d'expérience distinctes, afin de vérifier l'effet de l'ensemencement sur ce genre de tempête. L'étude des mécanismes de la précipitation a fait des progrès grâce à l'obtention, à bord, de nombreuses mesures de la teneur en eau liquide et de la répartition des gouttes selon leurs dimensions ainsi que d'autres paramètres et grâce aux observations par radar, au comptage des noyaux glacigènes, à la mesure de la pluie, au comptage des éclairs et aux autres mesures au sol.

Les auteurs exposent les buts du programme, l'objet des expériences et les instruments utilisés et décrivent la façon dont les travaux ont été mis à exécution au cours des cinq années en cause. Ils exposent également les modifications et les améliorations apportées à la suite des résultats accumulés au cours des expériences.

Les résultats de ce programme sont également présentés dans d'autres rapports de la présente série.

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1. Introduction

Although there were earlier experiments and theories of weather modification, it was not until the experiments of Schaefer and Langmuir in 1946 (1) that scientific researchers as a whole, and the general public as well, became really excited about the possibilities of modifying the weather, particularly increasing rainfall. As soon as Schaefer and Langmuir reported on the results they noted upon dropping dry ice into supercooled laboratory clouds, however, there were rapidly increasing numbers of experiments and trials all over the world both by scientists and by commercial operators, testing the effects of many substances on clouds and rainfall. Silver iodide was found by Vonnegut (2) to be one of the most successful substances at causing modification, and it rapidly became the material most commonly used in attempting to bring about rainfall increases. It soon became generally established among scientists that silver iodide is capable of producing a modification in clouds and in the resultant precipitation, given the right kind of conditions. To have an effect, the silver iodide must get into the right cloud at the right level and at the right time. It is still not known just how the silver iodide acts to produce its effect, and quantitative evaluation of the effect has so far proven impossible except under very special circumstances. Apparently, the silver iodide influences the ice crystal mechanism of precipitation production rather than the coalescence mechanism, and apparently the reason that it is able to affect this mechanism is because of the absence or scarcity of natural ice-forming nuclei. However, the exact mechanism through which the silver iodide operates is still hotly debated. See, for example, Miura (3), Hosler (4) and Edwards and Evans (5). It is agreed that ice crystals in a cloud grow at the expense of nearby water droplets through an evaporation - sublimation process. It is the initial formation of ice crystals on ice nuclei that is in question. It is possible that the silver iodide crystals or other ice nuclei act as sublimation nuclei, with water vapor subliming directly to the ice nucleus to form an ice crystal. On the other hand, it may be that the silver iodide crystal touches or penetrates the supercooled water droplet, causing it to freeze, or that the

ice nucleus is present inside the water droplet and causes it to freeze when the threshold temperature of the nucleus has been reached. The most probable answer appears to be that both the sublimation process and the condensation - freezing process may take place at different times depending on the circumstances, with the circumstances most commonly found in nature favouring condensation followed by freezing. There are many other as yet unsolved problems in the physics of clouds. The general principles and theories of cloud modification have been reviewed in a previous report in this series, (6), as have the history of rainfall modification in Canada and elsewhere. The extreme importance and economic value of weather modification to such specific groups as forestry, agriculture, etc., have also been documented in the same report. Clearly, there was, and still is, a very great need for an impartial scientific assessment of the effectiveness of cloud seeding. To obtain this, very carefully designed and controlled cloud seeding experiments are required, in which the critical factors and the atmospheric conditions are known. Clearly also, the answers to the controversial questions arising from weather modification experiments can only come from an adequate knowledge of the physics of rain clouds.

It was against this background that the Precipitation Physics Project was initiated in 1959. Such a project had been envisaged by the Meteorological Branch for some time. However, it was not until a request was received from the Canadian Pulp and Paper Association in 1958 for an assessment of the potentials of increasing rainfall through the use of ground based silver iodide generators that the problem was brought to a head. A series of meetings among interested agencies followed, and the result was the Precipitation Physics Project which commenced operations in the spring of 1959. Participants in the meetings and in the project which followed were, besides the Meteorological Branch and the Canadian Pulp and Paper Association, such agencies as the National Research Council, the Department of Forestry, and the Ontario Department of Lands and Forests.

2. Aims of the Project

The Precipitation Physics Project as designed by the Meteorological Branch and other participating agencies in 1958 had a dual nature. The primary aim of the project was to make a contribution to the knowledge of basic precipitation processes, while the secondary,

but a very important aim, was to conduct an assessment of cloud seeding. The project was designed in such a way as to accomplish both these aims within a single project.

The weather situations under investigation by the project were the synoptic-scale travelling disturbances which bring a large proportion of the precipitation in many parts of Canada at all seasons of the year. The object of the cloud seeding was to determine whether seeding of these weather systems with silver iodide could produce an increase in the amount of rainfall over a given area of relatively flat terrain. At the same time the mechanisms operating to produce the rainfall from these systems were to be under intensive study, with comparison of the effectiveness of these mechanisms under various conditions including the seeded condition being one of the techniques of study. From the data accumulated in studying these storms both in the air and on the ground it was hoped that important discoveries governing the basic relationships in the chain of cause and effect in precipitation mechanisms would emerge.

3. Design of the Project

The project was designed in such a way as to conduct a test of cloud seeding with silver iodide and at the same time to carry on a physical investigation of precipitation mechanisms. The basic design of the cloud seeding experiment was conceived by Godson (7) in 1958 and combined with an observational program of atmospheric parameters both at the ground and in the air when the operational program was commenced in 1959. Its design and operation have also been discussed briefly by Crozier and Holland (8). The duration of the initial field project was proposed as five years, with the hope that significant statistical results on the effect of cloud seeding could be achieved in that length of time. If not, an estimate of the further period of investigation required to obtain significant statistical results could be made at that time and a decision taken on whether to continue with further field experimentation on this aspect of the project. The cloud physics investigations as such were designed as a continuing project.

Design of Physical Investigation

The physical investigation of cloud physics parameters was designed so as to be conducted both on the ground and in the air. The cloud seeding aircraft was, therefore, instrumented with

equipment for measuring not only basic atmospheric parameters such as pressure and temperature, but also to measure cloud physics quantities such as liquid water content of clouds and the sizes and distributions of cloud droplets. The instrumentation installed on the aircraft for measuring these quantities is described in Section 5. The aircraft was also equipped with instruments for measuring turbulence and icing and for photographing the clouds in which the various measurements were made. During the final year of the experiment, airborne ice nuclei counters of the Bigg-Warner type (9) and the Millipore filter type (10) (11) (12) were also installed in the aircraft for measurement of ice nuclei aloft. In addition to the above referenced instrumental observations taken in flight, observers aboard the aircraft made visual observations of the clouds and weather phenomena encountered.

Surface observations in the test areas for study of cloud physics parameters included a dense network of rainfall measuring stations in each area, and regular surface measurements of pressure, temperature, humidity, wind and sunshine by recording instruments at central observing stations in the areas. Counts of lightning flashes were also made in each area, ice nuclei were measured, and radar coverage of the entire area from a central station was obtained. Details of the instruments and observational program are given in the sections which follow.

Increasing our knowledge of the mechanisms of cloud and precipitation production will require a great many more observations of the basic atmospheric parameters and special cloud physics parameters mentioned above and their correlation into an integrated picture of the processes as they occur in nature in the various cloud types and under various atmospheric conditions.

Design of Cloud Seeding Test

It was recognized at the outset that there are many difficulties to be overcome in conducting a test of cloud seeding which will yield significant unbiased statistical results in a reasonable period of time and which will withstand critical appraisal of both its statistical and physical design. Some of the problems to be faced include making sure that the seeding material is reaching a location in the cloud where it can theoretically produce a cloud modification, adequate control of the seeding material to ensure that it does not contaminate the control area, choice of the control area so that it is suitably related to the test area, etc. Many otherwise excellent projects

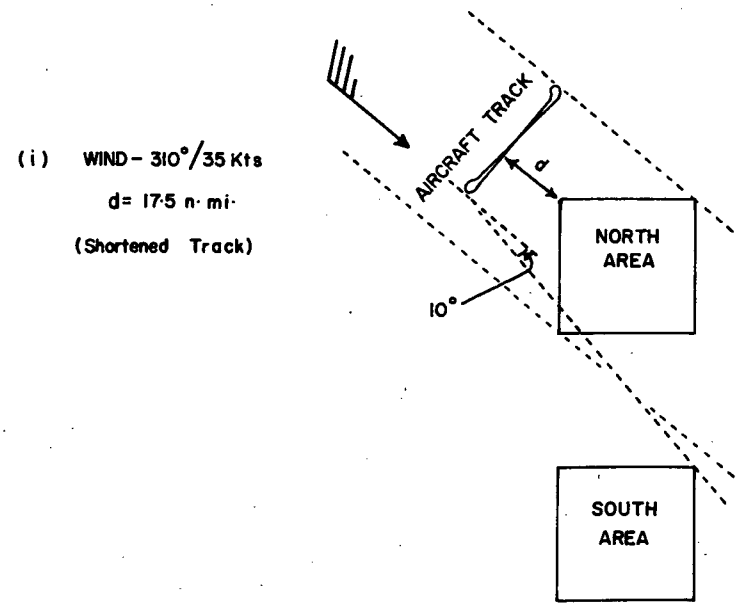
aimed at evaluation of the effect of cloud seeding have been rejected because of one or more of these difficulties. Ground based seeding operations have generally been suspect because of lack of control or knowledge of the actual movement of the cloud seeding material, while others have fallen into the pitfall of using control areas inadequately located with respect to the target areas. In addition to these physical objections, other projects have been rejected or criticized for inadequate statistical techniques.

It is believed that most if not all of these objections and pitfalls were overcome in the design of the cloud seeding test of the Precipitation Physics Project. To ensure that the cloud seeding material was placed in a suitable location in a suitable cloud where it could be theoretically expected to induce cloud modification, seeding was conducted by aircraft, using an airborne silver iodide smoke generator which followed very closely the design of the burner developed by the Commonwealth Scientific and Industrial Research Organization of Australia (13). On all seeding occasions, the seeding material was released in or near clouds of adequate horizontal and vertical extent at or near the -5°C level. Adequate control of the seeding material was ensured by establishment of ground tracking facilities to determine accurately the position of the aircraft and by frequent careful measurement of the winds and temperatures over the test areas. Seeding was only carried out under suitable cloud and temperature conditions and when winds were such that the seeding material would move with the winds over the target area but would not reach the control area, even allowing a ten-degree angle of a dispersion on either side of the wind flow. Aircraft seeding tracks were carefully regulated to ensure that the control area would not be contaminated and seeding was terminated whenever the winds shifted so that contamination might occur.

In order to enhance the possibility of obtaining significant statistical results in a reasonable length of time, the project was designed in such a way that the seeding was conducted on a randomized basis with a cross-over pattern. Two test areas were selected and on each suitable seeding occasion one was seeded using a random selection, while the other served as the control area. This design obviates the need for historical regression techniques relating the precipitation of the target area to that of the control area and tends to strengthen the statistical evaluation.

The project was designed so as to conduct a test of cloud seeding on the organized synoptic weather systems which provide a large proportion of the rainfall in Canada at all times of year. Because of the great areal variability of rainfall resulting from air mass showers, this type of precipitation occurring by itself was excluded from the seeding test, though cumulus type clouds occurring in conjunction with or embedded in synoptic weather systems were not excluded. Systems seeded thus, consisted generally of a front or a trough or a group of fronts or troughs. The unit for seeding and for evaluation was the storm, with a 24-hour separation between storms maintained in order to ensure separation of rainfall data. It was not considered necessary to seed all portions of a single storm, but the entire storm was treated as a unit for analysis purposes. In some cases seeding was carried out on two portions of a single storm depending on the development or maintenance of suitable conditions. There were also occasions when insufficient aircraft endurance resulted in breaks in the seeding period, during which the aircraft returned to base for refuelling and then resumed seeding. Criteria laid down for seeding were very strict both in the selection of storms to be seeded and in the final decision as to whether to seed or not. Only those weather systems were chosen for seeding which were organized synoptic weather systems expected to affect both target areas in the same manner, i.e., to produce similar rainfalls in the two test areas. Systems obviously producing unequal effects such as would occur when a system crossed only one target area were not seeded. Upper winds from 5,000 to 30,000 feet were required to be between 230 and 310 degrees in order to ensure no contamination of the control area by seeding material. When a storm fulfilling the above criteria was observed to be approaching the target areas, the aircraft was dispatched to the areas under sealed instructions known only to the pilot as to which of the two areas was to be seeded. These instructions were prepared earlier by a disinterested party having no connection with the project, using a table of random numbers (14), and sealed into separate envelopes for each mission. The project meteorologist made each decision as to whether or not a given weather system was to be seeded without information as to which area was to receive the seeding treatment. This information was also kept secret from all personnel associated with the project except the pilot. In particular, the personnel conducting the analysis of the rainfall data had no knowledge of which area was seeded on any occasion until after selection of storms and abstraction of rainfall data for analysis had been completed.

It was not the intention to seed air completely devoid of cloud or synoptic situations which did not have sufficient cloud to be capable of producing significant rainfall over the bulk of the areas. It was felt that such seeding would only cause an unnecessary decrease in the sensitivity of the test and contribute nothing to the statistics. Accordingly, a set of minimum acceptable cloud conditions was defined, and seeding was conducted only if these conditions were met. These seeding criteria were as follows: (a) clouds covering at least 50% of the seeding track at flight level or just above flight level; (b) clouds extending at least to the -5°C level; (c) a cloud system at least 3000 feet thick; (d) clouds showing signs of an active precipitation mechanism. Upon reaching the area to be seeded at the -5°C level, the pilot observed the clouds present and began his seeding provided the above criteria were met. If cloud conditions were suitable but flight at the -5°C level would be mostly in clear air the flight level was raised to the vicinity of the base of the next highest cloud layer. Seeding was conducted on a path normal to the wind flow, thirty minutes of wind flow upstream from the nearest point of the target area (Fig. 1). The length of the flight path including minimum turning radius turns upwind at each end of the path correspond to the projection of the target area upstream into the flight path. For winds of 230 and 310 degrees the flight paths were shortened on the end nearest the control area so that ten degrees of diffusion of material from the wind direction would not contaminate the control area. When winds fell to 10 knots or below the seeding flight path was changed to two inside squares of 4 and 12 nautical miles respectively inside the target boundaries. Seeding was continued for as long as suitable cloud conditions continued, with the aircraft returning to base for refuelling and resuming seeding in the same area in the case of storms of long duration. Project control was operated from a field office established at the aircraft operating base in close proximity to an aviation forecast office, so that synoptic weather information would be readily available at all times. Accurate positioning of the aircraft was provided by an aircraft tracking base located upwind of the test areas near the normal seeding paths and accurate winds and temperatures aloft were measured by a special rawinsonde station, also on the upwind side of the test areas. Project control was maintained by direct two-way land-line radio link joining all the major ground operations centres (project control, navigation and rawinsonde base, weather radar base) and the aircraft. This communication system permitted rapid exchange of synoptic weather information available at project



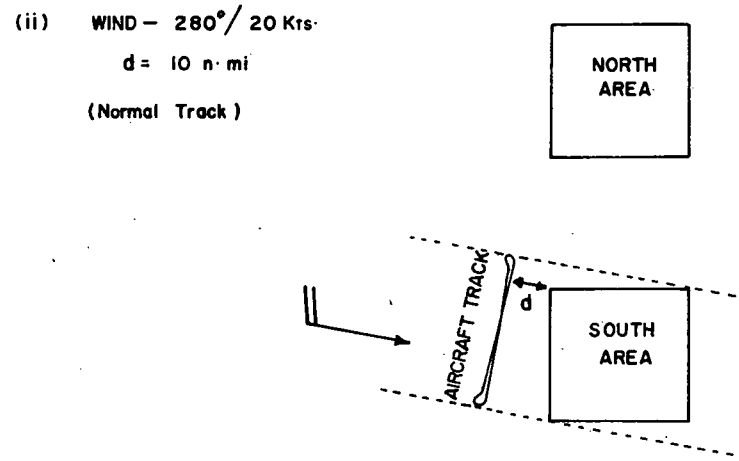


Figure 1
Seeding Tracks (i) Shortened Track.
(ii) Normal Track.
(iii) Inside Square Track.

control, pilot reports from the aircraft, accurate aircraft positions from the navigation base, wind and temperature information from the rawinsonde base and weather radar information from the radar base, and was essential to control of the project.

Design of Rainfall Network

For comparison of rainfall in the target and control areas, similar raingauge networks were installed in each area. Design features in the choice of the areas were that they should be located in similar terrain, relatively flat and free from any marked orographic influence so as to have similar meso-climates. Also required were that the areas should be reasonably well removed from frequently travelled airplane routes so as to allow maximum freedom of flight for the seeding aircraft, reasonably accessible by road to permit adequate instrumentation, and inhabited by a local population for assistance with rainfall measurements. It was also necessary that during the operating season the areas be frequently crossed by weather situations of the type to be seeded, while a desirable feature would be that the line joining the centres of the two areas be normal to the direction of prevailing winds during seeding situations or to the prevailing storm tracks, so that the two areas would receive comparable precipitation amounts from a maximum fraction of the passing storms. An additional advantage to this disposition of the areas (axis normal to the prevailing wind) would be that seeding upwind of either area would generally not affect the other area. It was also considered advisable to locate the test areas not too far from the main support bases at Toronto and Ottawa.

The size and separation of the test areas were not considered overly critical, but had to be consistent with operational and physical requirements of the project. Thus, the areas had to be large enough that a representative sample of rainfall would be obtained, but small enough and close enough together to ensure reasonably homogeneous weather over both areas on the synoptic scale. It was also necessary that the areas be sufficiently well separated that seeding of either area could be accomplished without affecting the other during a representative majority of storms. Square areas approximately 32 nautical miles to a side and 32 nautical miles apart were eventually decided upon.

Criteria in the establishment of the raingauge network in each area were that the gauges should be as evenly spaced as possible, suitably exposed, with the network of sufficient density to obtain representative areal mean rainfall data. Standard (ordinary) raingauges were selected as the standard of measurement and recording raingauges were used to monitor rates of rainfall and times of beginning and ending of rainfall.

An initial raingauge network of sixteen standard (ordinary) raingauges in each area distributed as evenly as possible throughout the area was selected. Measurements of rainfall were made at 7 a. m. and 7 p. m. E. S. T. by volunteer observers selected from the local population. Fourteen recording raingauges, not all at the same locations as the standard gauges, were used to monitor time of beginning and ending of rainfall. This distribution and density of raingauges was found to be inadequate to delineate times of beginning and ending of rainfall and in the second year of operation the density of raingauges was increased to thirty per area. The number of recording raingauges was also increased from fourteen to twenty-seven in the second year, and in the following year to sixty (one at each network station), but the standard ordinary raingauge continued to be the standard of measurement of rainfall. Two of the raingauge network stations in the first year of operation and four in subsequent years were designated as central observing stations and were equipped with recording instruments for measurement of pressure, temperature, relative humidity, wind direction and speed and hours of bright sunshine as well as rainfall. Counts of lightning strokes were also made at two of these stations after the first year of operation.

The project was designed to operate during the period May 15, to September 15, each year for a five year period. The choice of the summer season was dictated partly by ease of moving about in the area at that time, partly to ensure a more or less constant seasonal synoptic regime in the storms available for seeding, and also because it eliminated the measurement of snowfall with its attendant increased sources of error in precipitation measurement.

Design of Statistical Analysis

The design of statistical analysis technique to be applied in determining the effects of the cloud seeding was an integral part of the design of the project. This technique has been described

briefly in a paper by Godson, Crozier and Holland (15), and will be more fully presented in a subsequent paper in the present series. A brief description is included here in the interests of completeness. The technique originated from a concept described by Godson (7) and was adapted to fit the final design of the project. Rainfall recorded in seeded storms in the target area is compared with rainfall recorded in the control area and a seeding index ratio derived from the comparison.

The analysis was done independently by an evaluator who had not taken part in the seeding operations. Possible bias from this experience and information was thereby precluded. The information passed to the evaluator by the project meteorologist gave the date and time of each seeding, the description of the synoptic situation seeded, the approximate beginning and ending of the storm precipitation, information on the clouds, weather and temperatures encountered by the flight, and the seeding level, but no information as to which area was seeded. The evaluator reviewed each storm to make certain that the conditions laid down for seeding (see above) had been met. Confirmation was obtained without reference to the rainfall data from the project raingauge network that an organized cloud system accompanied by an area of rainfall discernible in the synoptic sense had crossed both target areas and that there were no obvious inequalities in the influence of the storm system on the two areas such as would occur when the system crossed one area, but did not cross the other, etc. Confirmation of clouds at least 3000 feet thick with their top extending at least to the $-5^{o}C$ level, covering at least 50% of the seeding track and showing signs of active precipitation mechanisms in operation was also obtained, mainly from the reports of the pilot. Seeded storms which met all of the above criteria were accepted for evaluation, while those which failed to meet all the criteria were rejected. Application of the seeding criteria was more stringently applied after the fact than was possible at the time of actual seeding operations. The next step in the evaluation was to make a check of the winds over the seeding and test areas for all storms to be evaluated and to determine whether a ten-degree angle of dispersion on either side of the mean wind between 5 and 30 thousand feet would have permitted any of the seeding material to reach the control area. Storms where no contamination of the control area would have occurred under this criterion were placed in category A and storms where some contamination was likely to have occurred were placed in category B. Storms in the two categories were then analyzed separately.

Upon confirmation that the seeding criteria had been met and separation into the two categories with respect to possible contamination of the control area, storm rainfall for each of the accepted storms was abstracted from the total rainfall data. Storm rainfall was defined to consist of one or more consecutive 12-hourly intervals of precipitation beginning at one of the standard synoptic observation times 00 GMT (7 p. m. EST) or 12 GMT (7 a. m. EST), corresponding as closely as possible with the passage of the associated seeded weather system. The duration of the storm was defined to be the same for both test areas, and the actual beginning of precipitation in the target area was required to be in the same or next adjoining regular 12-hourly observation period as in the control area. A similar provision applied to the ending of precipitation. Care was also taken both in the seeding and in the abstraction of storm rainfall to ensure separation of the rainfall of one seeded storm from the next. This separation was attained in abstracting the data by requiring that the actual time of beginning of rainfall in any storm period be in a regular 12-hourly observation period (00 GMT - 12 GMT or 12 GMT - 00 GMT) different from that containing the actual ending of rainfall in the preceding storm period. The corollary was also applied to the end of the storm period. Storm rainfall for each gauge in the raingauge network was abstracted from the total data for all seeded storms under evaluation according to the above rules. Missing rainfall data were interpolated linearly from adjoining gauge data.

The next step in the evaluation was to compute the mean areal rainfall for each of the two test areas for each seeded storm. This mean was computed by an adaptation of the Thiessen polygon method of weighting (16). In this adaptation, subdivision of the area by the right bisectors of the lines joining adjacent gauges was replaced by an electronic computer program which calculated the proportion of the total area represented by each gauge. Using these values as weighting factors, the mean areal rainfall and the standard error of the mean were calculated.

The seeding index ratio R was defined as the ratio of the precipitation in the seeded area to that which would have occurred in the area if no seeding had taken place. The value of R was calculated by using the ratio of the actual precipitation in the seeded area to that in the unseeded control area, taking logarithms of these individual ratios to semi-normalize the data, applying appropriate statistical weights based on the variance of the ratios and averaging the

weighted ratios. The value of log R can be shown to equal one-half the difference between the mean weighted ratio when one area is seeded and the mean weighted ratio when the other area is seeded, from which the value of R is readily derived. The variance of log R was also calculated, giving a measure of the statistical significance of the value of R, through application of Student's "t" test for significance (14). The seeding index ratio R was also expressed as a seeding index I, where $I = 100 (R - 1)$, expressed in percent, and represents the percentage influence of seeding on precipitation.

An individual seeding index ratio Rn, defined as the ratio of the precipitation in the seeded area to that in the unseeded area divided by the mean (all storms) areal ratio with potential seeding effects removed, was calculated for each storm. Correlations were sought between the individual seeding index ratio and the liquid water equivalent, instability and percentage of storm time seeded. Results of the analysis and a more detailed discussion of the method will be presented in Project Report No. 3 (17) and other subsequent papers in this series.

4. Area of Operation and Bases

The area of operation of the project, operations bases and test areas are illustrated in Fig. 2.

Test Areas

Two areas in western Quebec province, 32 nautical miles square and separated by 32 nautical miles, were selected as the test areas, following the design criteria outlined in Section 3. The two areas were aligned North-South, with their western edges lying along the Ontario-Quebec border and the southern edge of the south area running through Ville Marie, Quebec (Fig. 2). For purposes of identification the two areas were designated "South Area" and "North Area".

Raingauge Network Sites

Fig. 3 illustrates the raingauge locations for 1963. An initial 16-gauge network in 1959 was expanded to 30 gauges in 1960, with only minor location changes required in each subsequent year as a result of observer changes and site availability or access.

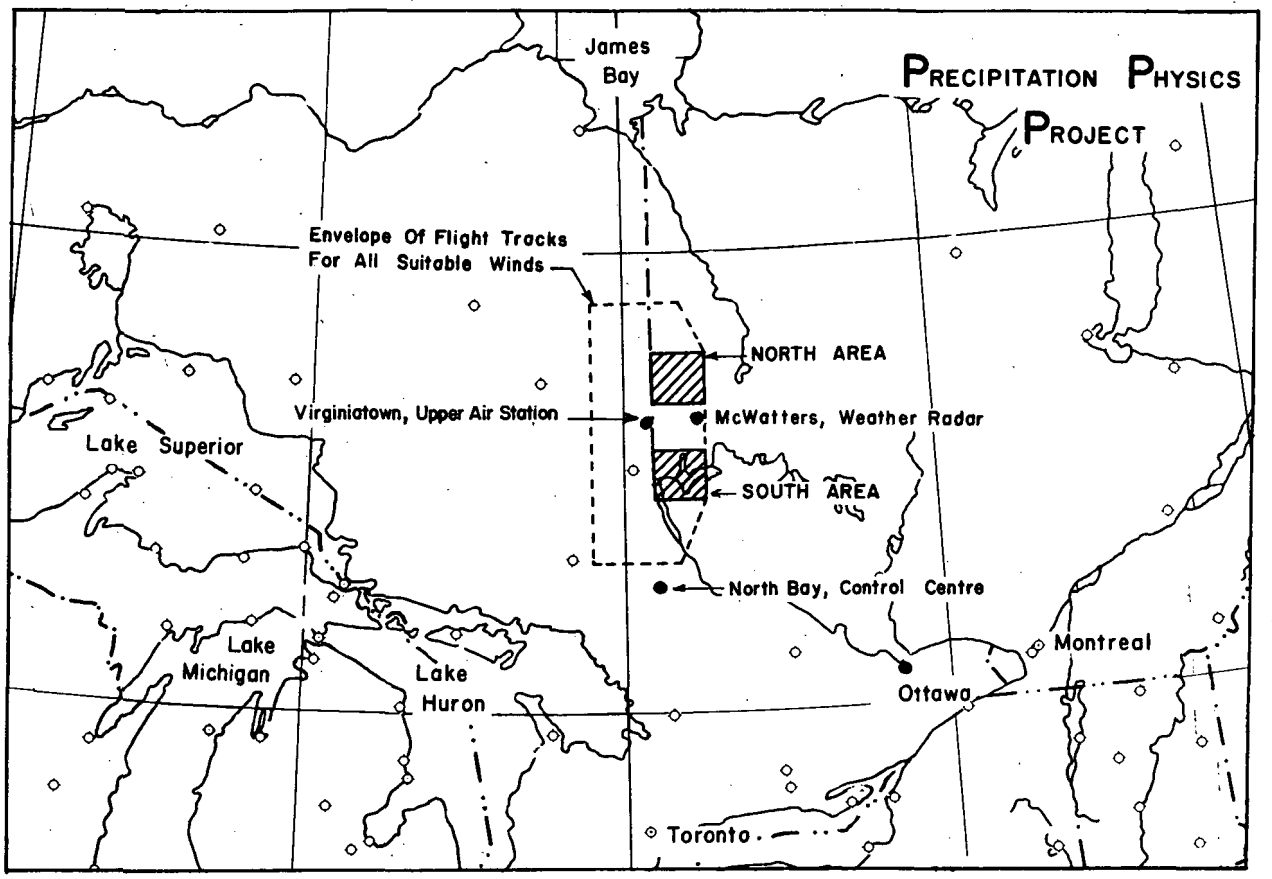


Figure 2
Precipitation Physics Project Areas of Operation

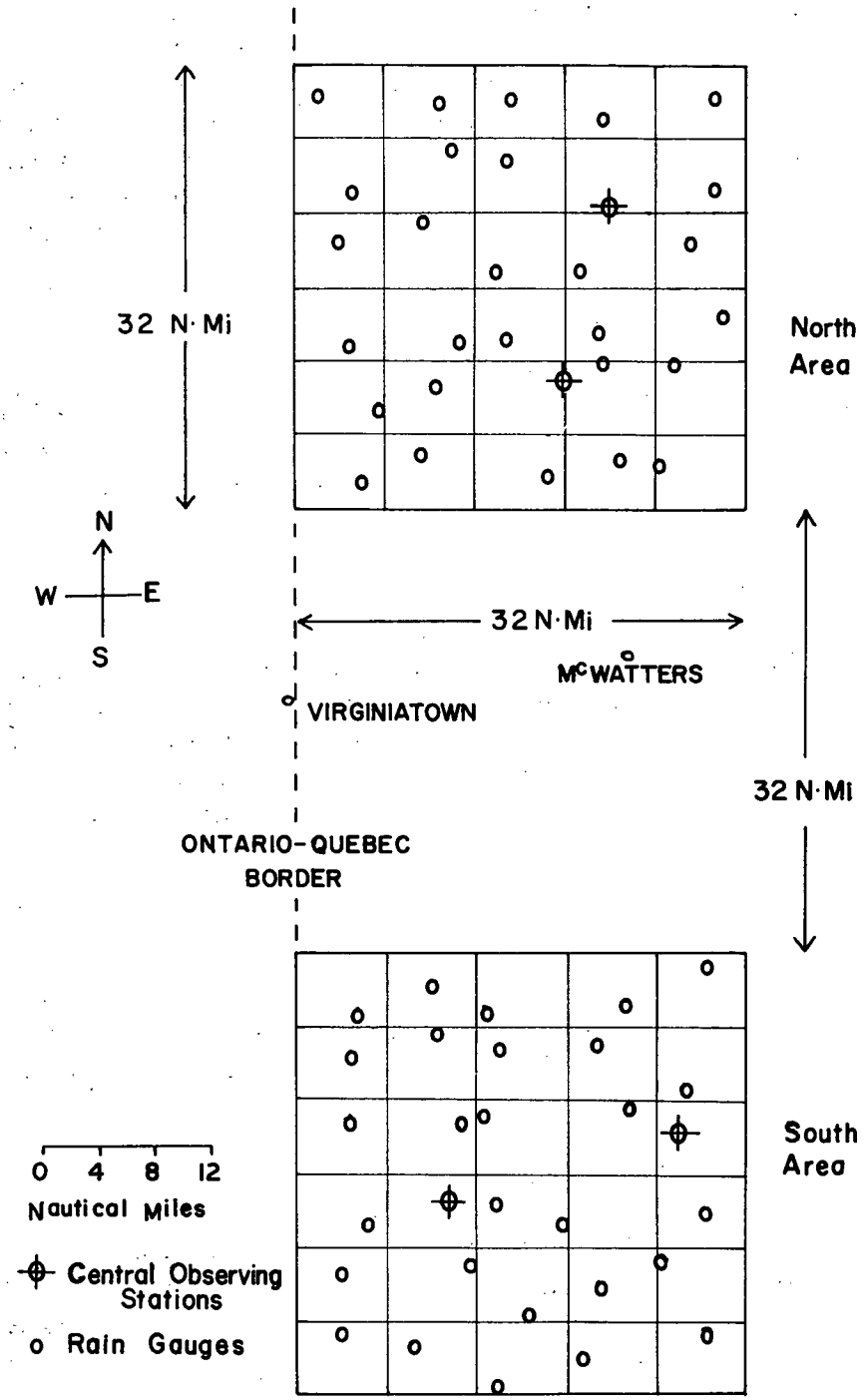


Figure 3
The Ground Observations Network

Central Observing Stations

More elaborate meteorological instrumentation, measuring pressure, temperature, humidity, wind and sunshine as well as rainfall, was established at Macamic in the North Area and Angliers in the South Area in 1959. This type of instrumentation, extended to an additional central observing station in each area in 1960, to Virginiatown in 1961 and McWatters in 1962, is described in Section 5. For locations of these stations see Figs. 2 and 3. The central observing stations in each area also served as operating bases for project personnel assigned to monitor the instruments and collect the observations each week.

Ground Observations Field Base

A field base to establish and maintain the raingauge and observations network, to provide a central communications site for field liaison and to provide an advance supply depot was located at McWatters, Quebec (Fig. 2).

Weather Radar Base

The weather radar base was located at McWatters, Quebec on a rise of land which gave a good unobstructed view in all directions. Its location was almost ideal, being about half way between the two areas, between the east and west boundaries of the areas and coincident with the ground observations field base and, thus, provided with a good communications system.

Virginiatown Rawinsonde Station

This site was chosen on the western boundary of the areas and about mid-way between the two areas to give representative values of the winds in the area of seeding and was coincident with the aircraft tracking radar base.

Aircraft Tracking Radar Base

This site was selected to be as centrally located as possible to all possible tracks which might be flown by the aircraft. While the site was designated as Virginiatown, the actual location was about 3 1/2 miles east of Virginiatown, just north of Ontario Highway No. 66

and a few hundred yards west of the provincial border in Ontario on a gravel hill designated as the Cheminis Pit. A large rock hill singularity nearby called the Chaudron because of its appearance caused a radar blind spot to the SSE on occasion, but otherwise the site was ideal and in fact the area allowed little other choice.

Aircraft Operations Base

In 1959, the seeding aircraft operated from Uplands Airport, Ottawa with an advance base at Val d'Or, Quebec. To reduce the flying time to the areas the base was moved to North Bay Airport in 1960. In 1963, with the acquisition of the North Star aircraft and greater problems of support in the field, the base was returned to Uplands Airport.

Project Control Base

Because of the need for ready access to current meteorological observations, reports and forecasts and for close liaison with the aircraft crews, the scientific operational control of the Project was located at or very near M. S. C. Forecast offices and the aircraft bases. Thus, the Project Control base was established at Uplands Airport in 1959 and 1963 and at North Bay Airport during 1960-62.

5. Instrumentation, Equipments and Observation Program

To realize the two-fold aim of the Project, instruments, equipments and adequate observations were required to conduct the experiments, to maintain adequate control and to measure physical parameters both for operational use and later analysis and study.

Surface Meteorological Network

The basic surface observations required both for the cloud seeding evaluation and further physical investigations of rain processes were the rainfall measurements, to which were added observations of pressure, temperature, humidity, wind, sunshine and lightning in each area and radar, ice nuclei and rawinsonde observations from central locations.

The original surface meteorological network established in 1959 consisted of 16 standard raingauges in each area, 14 recording gauges,

and two central observing stations (one in each area). In 1960, the network was standardized at 30 raingauge stations and two central observing stations per area, with the number of recording gauges increased to 27 in 1960 and to 60 (one at each site) in 1961. The instrumentation and operation of the sixty-gauge network and auxiliary stations is described in the paragraphs which follow.

The thirty raingauge sites in each test area were located as close as possible to the centre of a 5 by 6 rectangular grid (see Fig. 3). Each site was equipped with an M. S. C. pattern tipping bucket raingauge receiver designed to react to units of 1/100 of an inch of rainfall. The catchment area is 10 inches in diameter. A standard M. S. C. rainfall step recorder was housed in a nearby wooden shelter and recorded the 1/100 rainfall increments (See Fig. 4). The standard recording clock turns the chart drum once every 24 hours at which time the chart must be changed. About one third of the sites were too remote to allow daily attention of the recorder and for these locations the timing mechanisms were modified to turn the drum one revolution in seven days.

An M. S. C. ordinary raingauge with a catchment area of 10 square inches with the rim 12 inches above ground level was used as the standard of measurement at each site. The raingauge sites were all carefully selected to obtain the best exposure possible in accordance with standard approved practices.

Volunteer observers were recruited to tend the raingauge sites, record daily rainfall observations from the standard gauge at 7:00 a. m. EST and change rainfall recorder charts daily at 7:00 a. m. EST. The volunteers were farmers, storekeepers, gate keepers, forest rangers, etc., who were recruited in the area.

The two central observing stations in each area were at Macamic and Duparquet (Destor after 1961) in the north area, and at Angliers and Grassy Narrows in the south area. Continuous observations of pressure, temperature, humidity, wind direction and speed and hours of bright sunshine were made 24 hours each day with standard recording instruments.

A standard M. S. C. type A barograph was used to record station pressure. Three days' continuous record was contained on one chart. Temperature and humidity were measured using a bimetal type thermograph and a hair type hygrograph with each day's record contained

Figure 4
Typical Rainguage Field Station, South #2

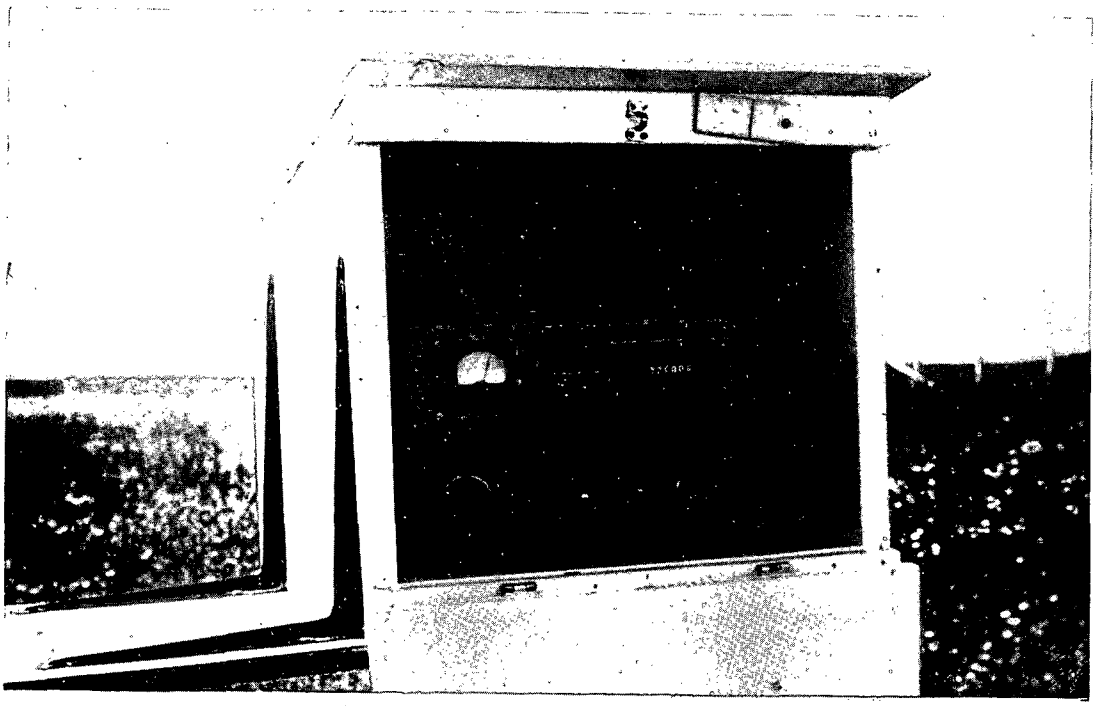


Figure 5
Lightning Stroke Counter -
Receiver, Shelter and Antenna at Macamic, Quebec

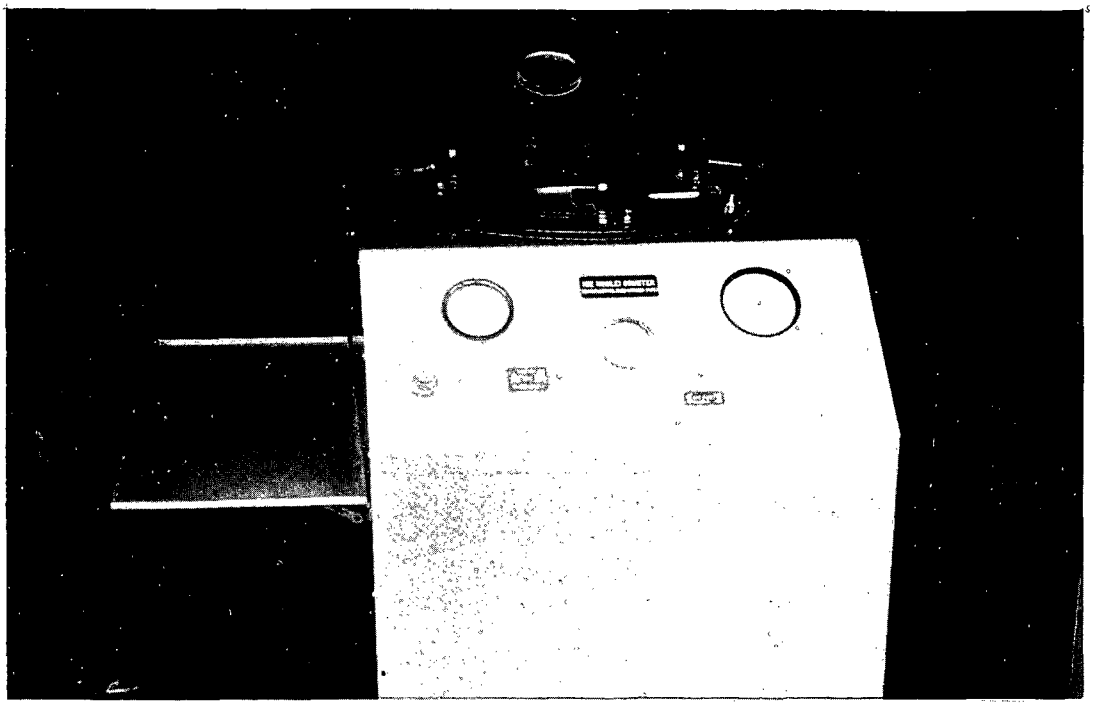
on a single chart. Wind was measured using M.S.C. pattern wind equipment consisting of a type 45 cup anemometer and vane connected to a type B anemograph which recorded the wind direction to 8 points of the compass and speed to the nearest mile per hour on a one-day chart. A Campbell-Stokes recorder was used at each station to record the hours of bright sunshine to the nearest tenth of an hour.

Similar instrumentation to that installed at the central observing stations was installed at Virginiatown from 1961 to 1963 and at McWatters in 1962 and 1963. These instruments were tended by Project personnel.

Hourly observations of all available data on charts were abstracted and placed on punched cards. Rainfall and sunshine observations were placed on a separate card. In abstracting the rainfall data from the recorder chart, the hourly amounts were corrected using the 24-hourly standard gauge measurements.

Lightning stroke counters were installed at Macamic and Angliers during 1960 and at Macamic, Angliers and McWatters during 1962 and 1963. (See Figure 5). The equipment used followed very closely the design recommended by the World Meteorological Organization (18), with only minor modifications. The lightning stroke total counts were registered on a Veeder counter and recorded on a chart type stop recorder as well. The recorder was a converted M.S.C. rainfall recorder. The total counts on the register were logged each day for comparison with the chart record. Often during the height of thunderstorm activity commercial power failed and for this reason an auxiliary power supply was developed using a 12-volt battery supply on a constant trickle charge operating the lightning stroke counter receiver through an inverter.

An experimental Bigg-Warner type freezing nuclei counter was installed and operated at MacWatters from 1961 to 1963 (Fig. 6). This equipment uses the rapid expansion principle and is based on the creation of an artificial supercooled fog and the subsequent formation of ice crystals. The supposition is that each ice crystal is produced by a freezing nucleus. The ice crystals grow in a tray of sugar solution to a size which can be readily counted with the naked eye. Samples of air were collected each day and the freezing nuclei counts determined over a spectrum of threshold temperatures.



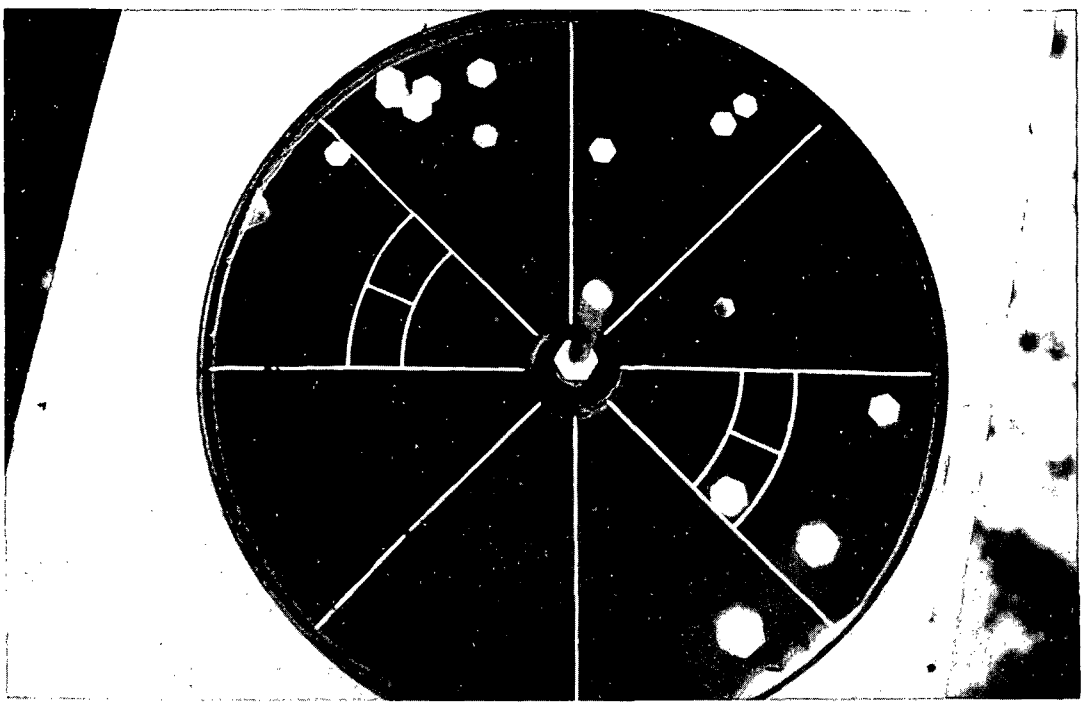


Figure 6
(a) Experimental Bigg-Warner Type Ice Nuclei Counter
(b) Growing Ice Crystals Around Ice Nuclei in Sugar Solution

In 1963, techniques for counting freezing nuclei collected from the atmosphere by sucking air through a cellulose type (Millipore) filter of 0.80 micron porosity for 12 and 24 hour periods was under development but an operational program stage was not reached. (Fig. 7).

Because of the unique ability of the radar to observe precipitation over a large volume of the atmosphere almost continuously, a radar program was instigated in 1960 and continued under development throughout the term of the Project. The basic radar was a modified MR-75 Decca 3-cm air surveillance radar (Fig. 8). A 6-foot parobolic reflector with a 1.25 degree conical beam was adapted to the set. The peak power was nominally 100-150 kw. with a pulse width of 2.0 microseconds at 400 pulses per second. The antenna rotated in azimuth at a rate of 14 rpm.

The antenna elevation was controlled by an electronically activated hydraulic rack and pawl mechanism providing positive locking at set elevations in one degree steps from zero to 20 degrees. A mechanical programmer geared to the rotating antenna controlled the antenna elevation sequence, the display information circuits and camera filming sequence. A Bolex Model H16 16 mm movie camera with a Switar lens 16-mm/f:1.8 was used to film the display and radar echoes throughout the scanning cycle. Du Pont Type 936A Fine Grain Superior and Eastman Background-X films were used for the photographic record.

The antenna was programmed to sweep through the atmosphere from zero to 20 degrees elevation in one-degree steps in a period of approximately three minutes. The P.P.I. radar echo display together with elevation angle, time, date and storm number information was recorded for each elevation on film with a time exposure technique. The filming program was drawn up to obtain a radar film record from six hours in advance of any seeding until twelve hours following seeding or until all radar echoes disappeared from range. This record was not always achieved because of radar or power failures and staff limitations.

A rawinsonde station was established at Virginiatown for the field operating season to meet the needs of the Project and provide upper air soundings and winds in the immediate area for both immediate operations use and later study and analysis (Fig. 9). To control the seeding adequately, it was mandatory to have accurate

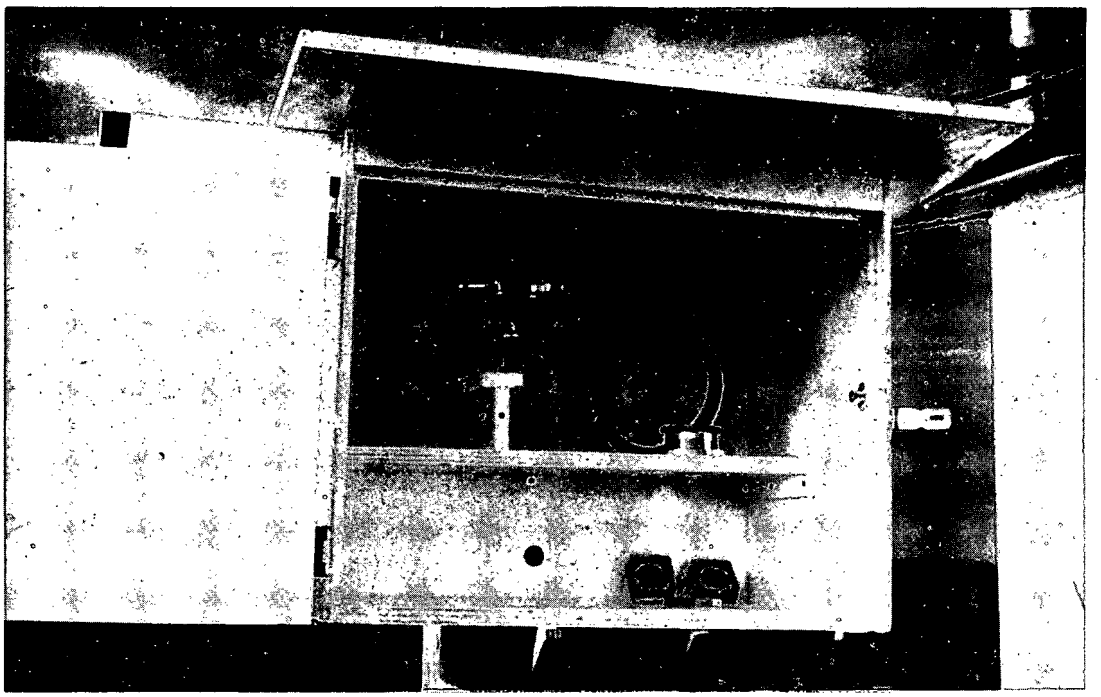


Figure 7
Cellulose Filter Ice Nuclei Sampling Equipment

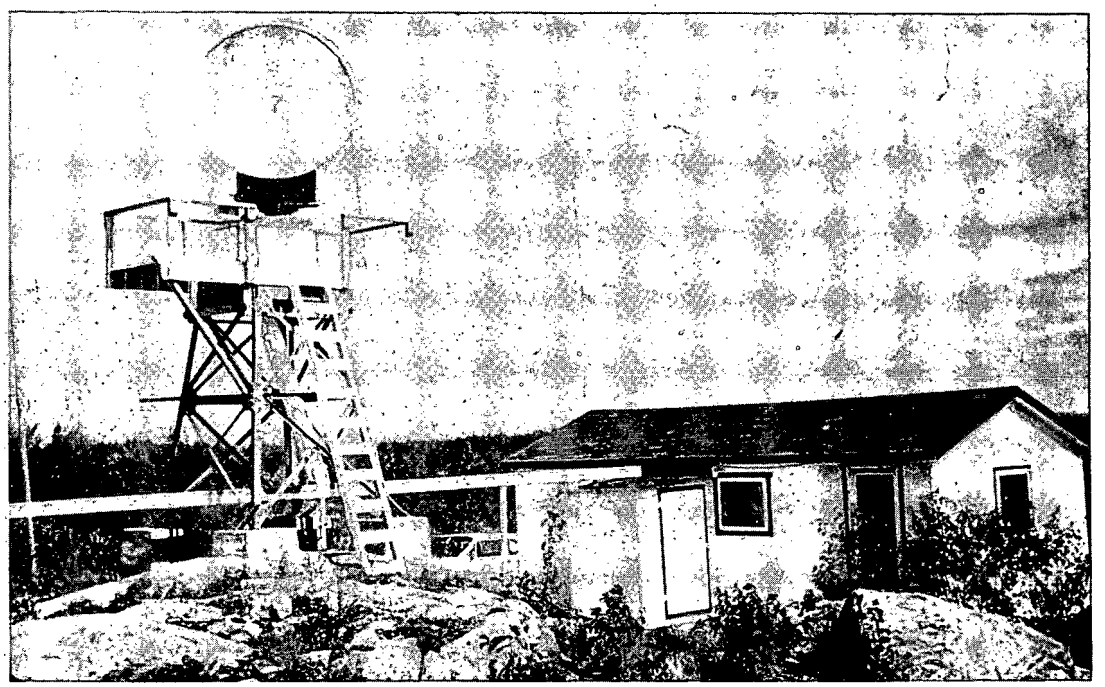
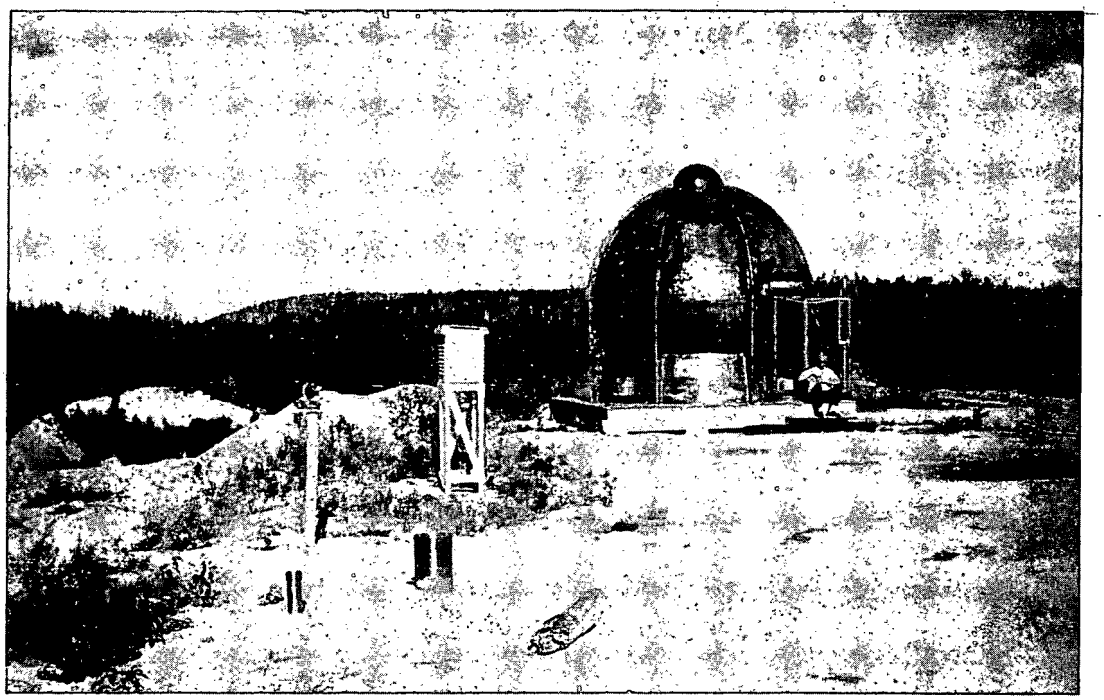


Figure 8
McWatters 3-cm Weather Radar Base



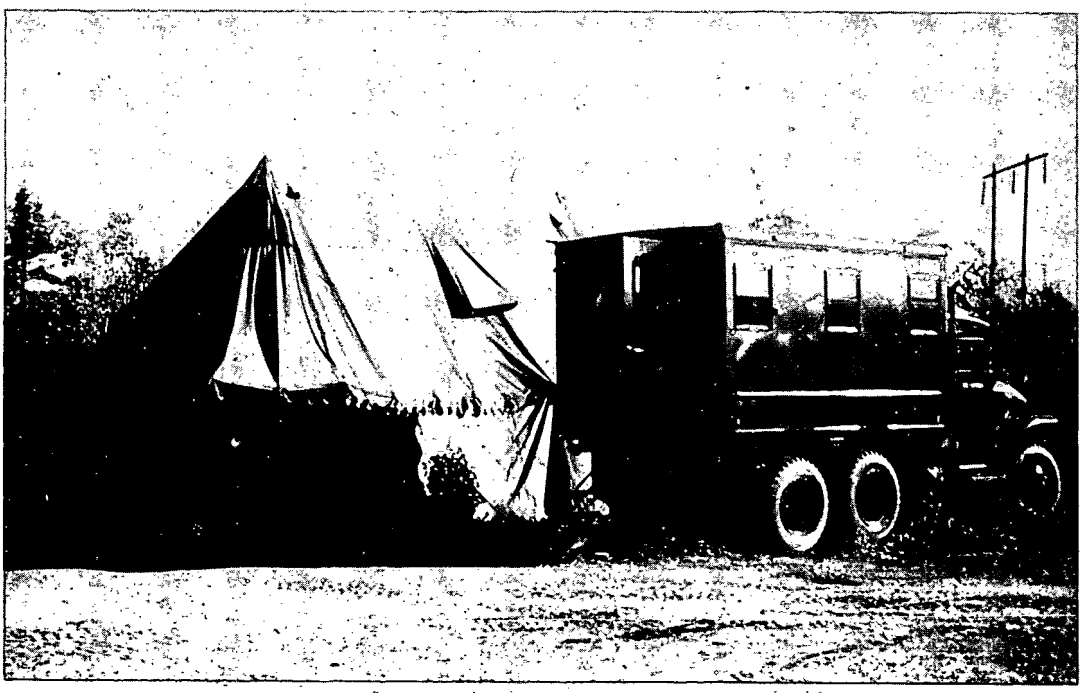


Figure 9
Virginiatown Rawinsonde Station (Cheminis).
(a) Radome
(b) Office Van and Storage Tent

winds when required. This facility was provided on a twice daily scheduled basis by a specially trained unit from the Canadian Army in 1960 and 1961, and by trained Meteorological Branch personnel in 1962 and 1963. Extra soundings were provided as required during operations. Standard M.S.C. radiosonde ground equipment was used in 1960 and 1961, using Kelk type sondes converted from 403 Mcs to 107 Mcs operation and Darex, Beritex and Koysam balloons. Winds were provided using the M33c radar tracking a standard corner type reflector on the radiosonde train. In 1962 and 1963, standard M.S.C. equipments were used for the complete rawinsonde sounding, i.e. SCR-658 radiotheodolite and receiver, Cycloray radiosonde recorder, 402 Mcs. Bendix-Friez audio modulated exposed thermistor (unshielded) sondes and Darex CDT #9 and 10 and Beritex 500-gram balloons.

In 1960, rawinsonde ascents were not scheduled, but were provided only on request. In 1961-63, twice-daily ascents at standard times were scheduled, with special ascents provided on request. During seeding flights rawinsondes were usually obtained every 3 hours to altitudes of at least 30,000 feet. Scheduled flights were made to the maximum termination altitude which was of the order of 80,000 to 120,000 feet.

Aircraft Instrumentation

The meteorological instrumentation for the aircraft was obtained or developed, installed and maintained by the National Research Council largely through the personnel and facilities of the Flight Research Section of the National Aeronautical Establishment at Uplands Airport.

Liquid water content of clouds during aircraft penetration was measured using a thermal method in which the amount of cooling of a heated body exposed to the airstream is related to the cloud water content. A simple type of heated wire instrument was used, consisting of a single loop of wire mounted on the end of an anti-iced strut (Fig. 10). This design is particularly attractive because of its fast response time. With suitable calibration and recording of the wire loop voltage and current, air speed, altitude and ambient temperature the liquid water content can be calculated fairly reliably. The instrument does not measure accurately liquid water in the rain drop size range and is also affected by impinging ice crystals. Under the conditions encountered liquid water contents in the form of cloud droplets to about 3.5 gm/m^3 could be measured with a probable error of $\pm$ 0.1 gm/m^3.

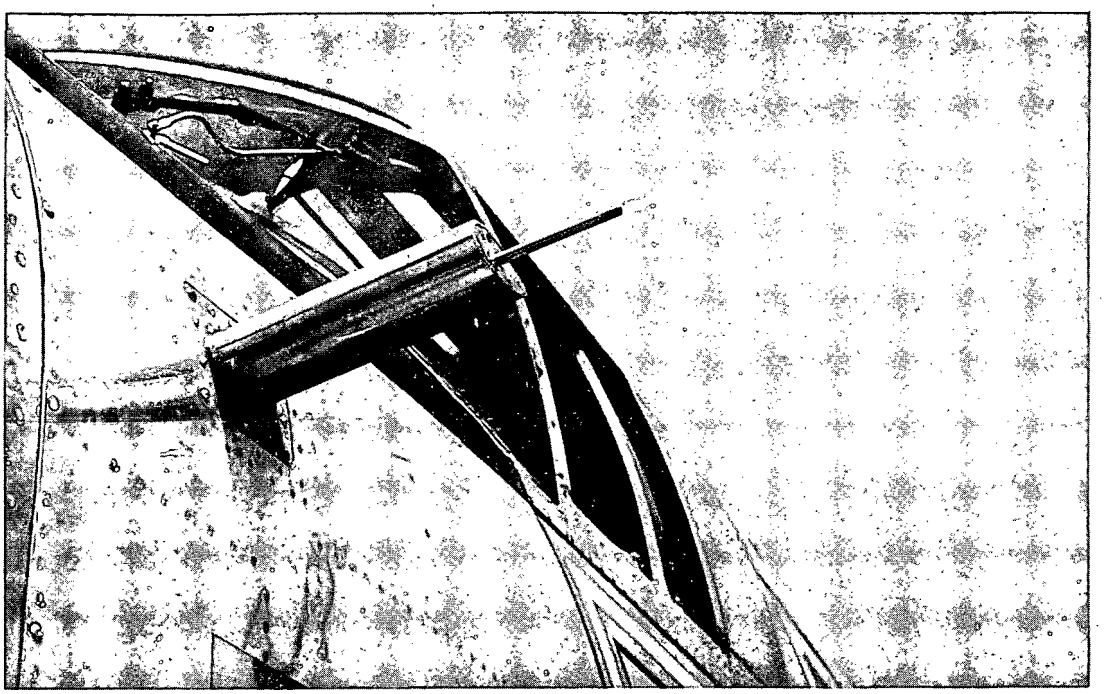


Figure 10
Liquid Water Content Heated Wire Device on Aircraft

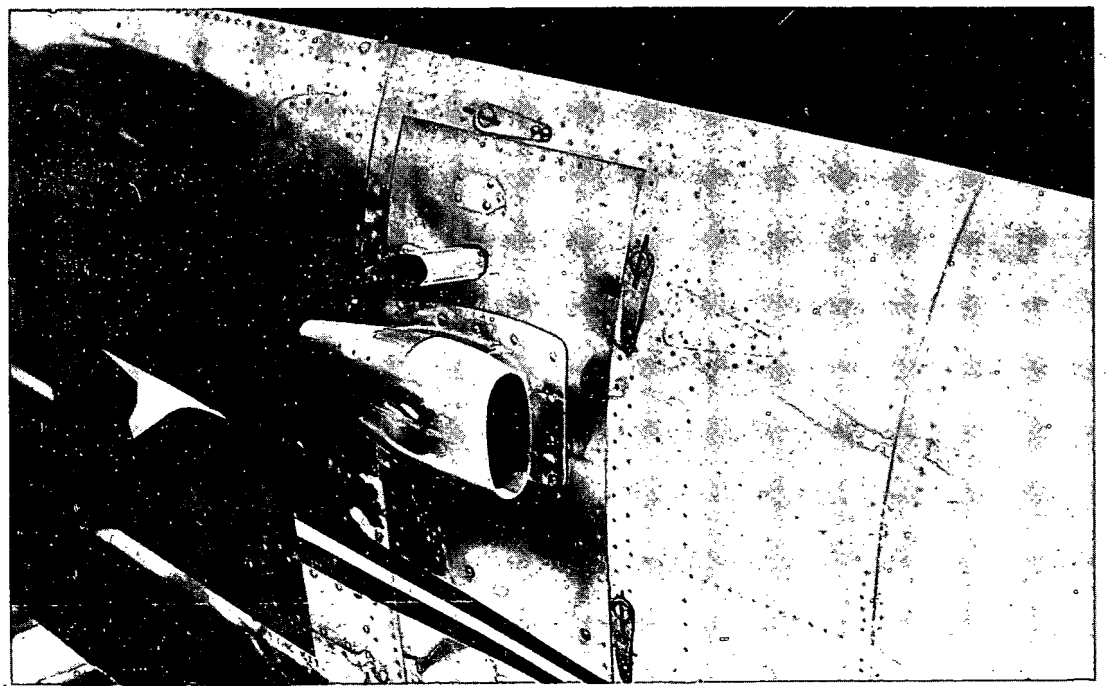


Figure 11
Reverse Flow (Thermister Type) Thermometer Housing

Temperature at flight altitude was measured using a low-lag thermistor mounted in a reverse flow housing to eliminate cloud and raindrop particles and with suitable ventilation and radiation shielding (Fig. 11). Temperature measurements were obtained with an accuracy of the order of $\pm$ 0.1 to 0.2° C. Tests in flight showed that the instrument readings were unaffected by cloud.

Icing in flight was detected using a CARL Type 260 Mk VIII dual probe baffled orifice type icing-detector system (Fig. 12). This system consists of two tubular probes connected between a pressure sensitive switch. One probe, the reference, is maintained at a temperature above freezing by a thermistor-controlled heater. The other probe is normally unheated and when the orifices become sealed with ice, the pressure differential between the two probes activates the pressure sensitive switch. Activation of the switch provides a signal indicating that icing has occurred as well as activating heaters in the normally unheated probe to de-ice the probe. The de-icing of the probe requires about one second. Under an average icing condition, the orifices become sealed with an accumulation of ice of the order of .025 inches which collects in a period of the order of 30 seconds. A qualitative rate-of-icing can be determined from the length of time between icing signals when corrected for temperature but is limited by the dependence of the system on the air speed, liquid water content and drop size.

An indication of turbulence was obtained using standard accelerometers. From 1959 to 1962, a Mechanism Limited (Croydon) Type M1831 Fatigue meter which totalled vertical accelerations over the flight period for six incremental levels between Og and 2.0g absolute acceleration. To increase the resolution and add a time reference, a commercially available Statham strain gauge accelerometer providing a continuous trace record was added in 1960. In 1963, an R.A.E. Type 4 observer unit and a Type 11 accelerometer was added. Twenty fixed acceleration levels were recorded on mechanical counters which were photographed automatically at two-minute intervals throughout the flight. A report on the preliminary analysis of this data has already been made (19).

Cloud droplet samples were obtained and recorded by catching the droplets on an oiled slide exposed for a fraction of a second to the air stream, and photographing them through a microscope (Fig. 13). Two sets of equipment were in use over the five-year period but the system were basically the same. The normal film used for the

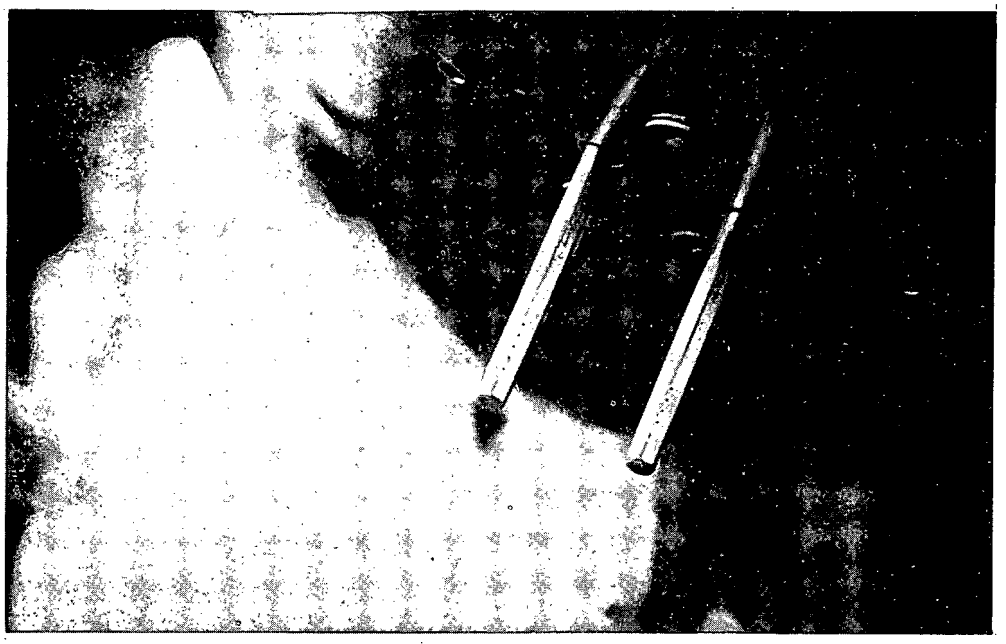
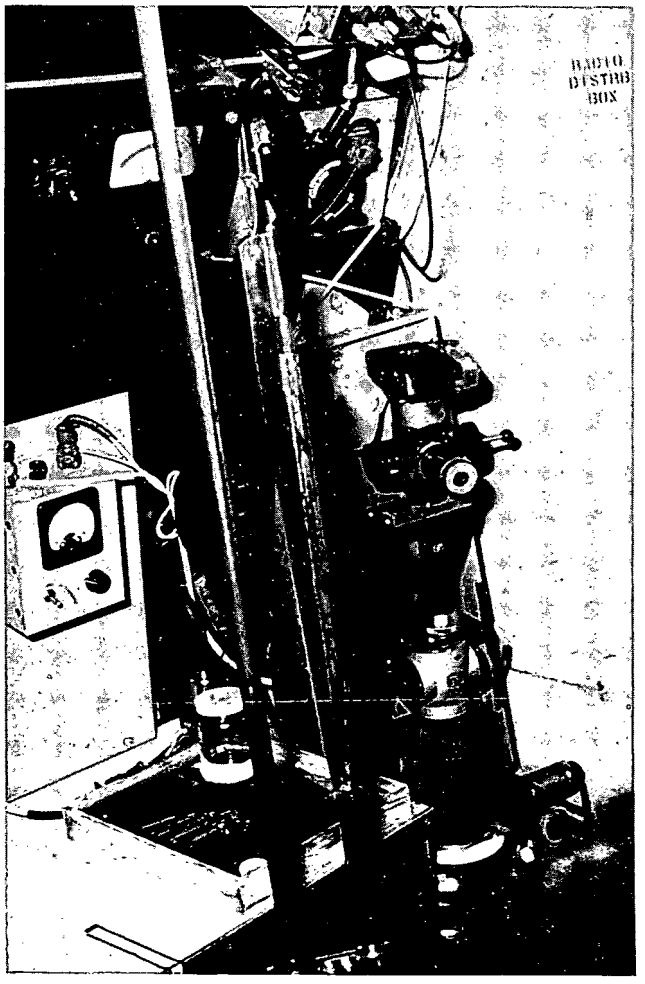


Figure 12
Icing Detection Probes



FLIGHT #59081 ROLL #8 PHOTO #11 DROPLET M.V.D. = 50.6 MICRONS

Date	: 20 September 1959	Ambient Air Temperature	: 1.0° C.
Time	: 18:19 G.M.T.	Pressure Altitude	: 10500 Ft.
Cloud Type	: Altocumulus	Median Volume Diameter	: 50.6 μ
Precipitation	: Light Rain	Total Drops in Sample	: 932

Figure 13
(a) Cloud Droplet Sampling Microscope, Camera, Slides and Rod
(b) Enlarged Photograph of Cloud Droplet Sample

photographic record was Kodak M-135 High Speed copy film. Initial magnification of the cloud droplet sample was nominally 25 or 40 times and further enlargement of the film provided a final magnification of 100 or 150 times. A total sample on the final record is equivalent to an area of about 2 mm^2 on the oiled slide and is amassed over a distance of the order of 10 metres (approximately $0.2 \times 10^{-4} m^3$). Collecting the samples, photographing the droplets and final measurement of the negatives was time consuming and requires a good degree of skill but produces fairly reliable results.

A film recorder developed by NRC was used to record as much of the airborne flight data as possible. The 5.5 inch film produces a continuous multichannel trace at a speed of about 2.0 inches/minute, representing a normal resolution of about 11,000 feet of aircraft travel per inch of record. The response of the instruments and quality of the records is such that with care, data can be scaled at intervals of 0.05 inches, i.e., 500 feet of aircraft travel. The following information was contained on the film strip:

(i) airspeed, (ii) altitude, (iii) air temperature, (iv) recorder temperature, (v) silver iodide generator on-off time, (vi) heated wire current, (vii) heated wire voltage, (viii) ice detector signals, (ix) automatic and deicing switch operation, (x) recorder galvanometer heater operation, (xi) accelerometer signal, (xii) observer coding, (xiii) time coding (xiv) scale reference.

The films were developed in the NAE photographic laboratories. Each film strip requires scaling and transfer to a digital form for data processing and/or information extraction which can be accomplished at the rate of about 20 sets per hour by an experienced operator.

A 35-mm Nikkorex F Camera was used for taking colour transparencies of clouds from the aircraft when suitable conditions existed. Often, however, flights were at nightime or in cloud for extended periods, precluding any such attempts. The normal film used was standard Kodak high speed Ektachrome.

In 1963, the development program for obtaining ice nuclei measurements with the aircraft reached the point where equipment was installed in the aircraft and tested. An experimental Bigg-Wainer type ice nuclei counter, similar to the one used on the ground

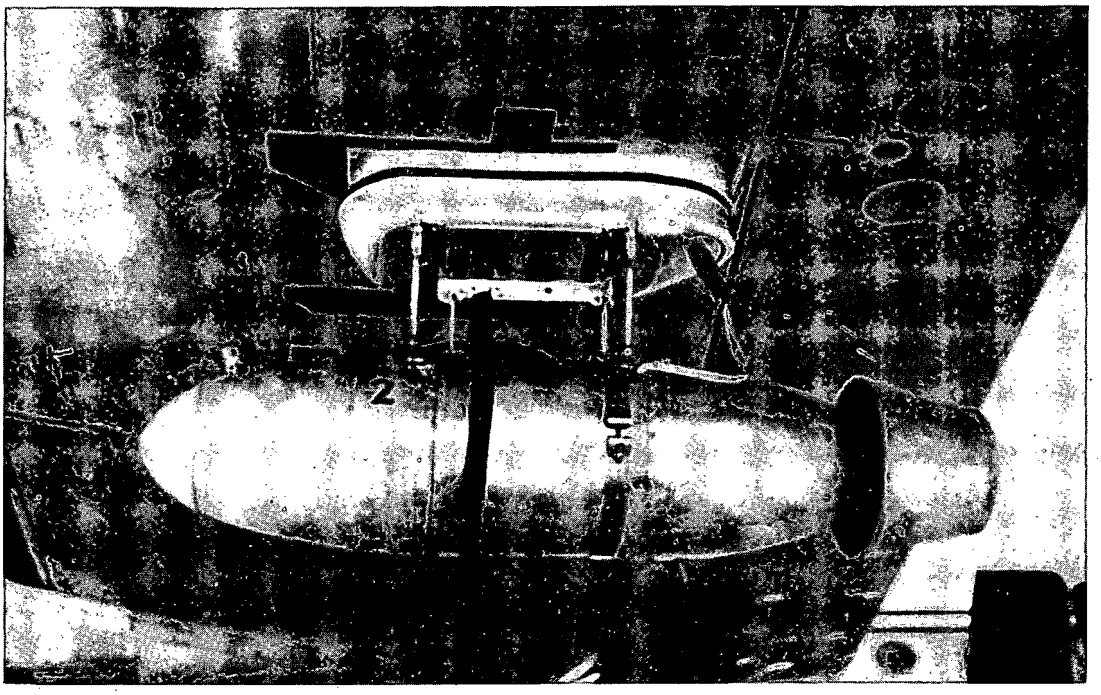
at McWatters and described above, was mounted in the aircraft. A few counts were obtained towards the end of the season. A cellulose (millipore) filter type system comparable to that used on the ground was also installed, but not perfected to the point where useful data were obtained. The size and weight of equipment for measuring ice nuclei together with the operating space requirements delayed the instigation of this program until the North Star aircraft was put into service on the project.

The silver iodide smoke generator was manufactured by the National Aeronautical Establishment, following very closely the burner designed by the Commonwealth Scientific and Industrial Research Organization, Australia (13). The complete generator was housed in a cyclindrical aluminum sheet metal body with faired ends, and was approximately 64" in length and 18" in diameter. A 12" shroud was attached to the end of the housing to streamline the air flow around the exhaust and carry the smoke away from the aircraft wing. (Fig. 14). The complete unit was suspended from a bomb rack on a hard point of the wing outside the outboard engines. While only one burner was ignited at a time, a second (back-up) burner was carried on the other wing.

The burner unit, including the air intake and exhaust, was located axially and ran the length of the housing. The forward section served as the 28 gallon fuel tank for the silver iodide/acetone solution while the aft section contained the auxiliary equipment such as the fuel pumping system, ignition system and fire warning system.

The complete unit could be jettisoned in flight if necessary. All operating controls and monitor displays were located on a panel at the instrument technician position with the exception of the jettison facility which was controlled from the pilot cabin.

The fuel is pumped into a swirl type atomizing nozzle in the burner or exhaust chamber where the spray once ignited continues to burn. The vaporized silver iodide crystals released into the cold air stream immediately recrystallize into very small (smoke) particles. The fuel mixture consisted of a sodium iodide, silver iodide and acetone solution in a ratio of 1:4:55 by weight which was made up using standard techniques (13) (20). Reagent grade chemicals were used in the production. The fuel consumption was approximately 2 gallons of solution per hour and that of the silver iodide



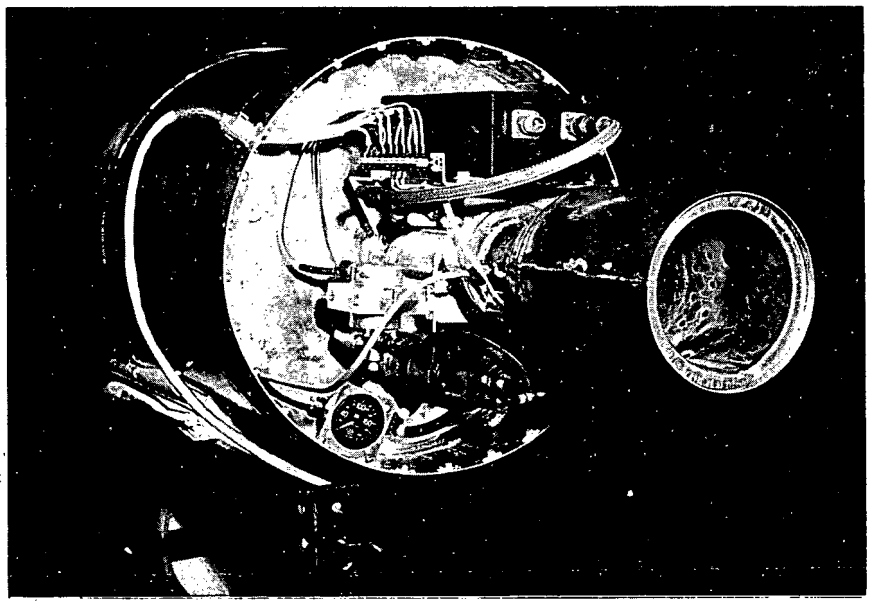


Figure 14
(a) Silver Iodide Smoke Generator on North Star Aircraft
(b) Silver-Iodide Smoke Generator with Rear Housing Removed Exposing Burning Chamber and Auxiliary Equipment

about one pound per hour. The generator produced about 2×10^{-15} crystals per minute active at - 17°C in the size range between about 0.005 and 0.15 microns diameter.

Visual observations were also made by the aircraft crew and were recorded on standard forms as supplementary information and for cross-checking purposes. These were made by an air weather observer, an instrument technician, the navigator and the second pilot. The pilot and crewman completed the crew complement.

The foregoing paragraphs outlining the aircraft instrumentation, while describing the facilities at some length, are, nevertheless fairly abbreviated and somewhat qualitative. Greater detailed description of the instrumentation, its limits and accuracies will be dealt with in later reports in this series or in laboratory reports.

Aircraft and Navigation Facilities

From 1959 to 1962 two B25 Mitchell type all-weather aircraft were used for cloud seeding and observational purposes (Fig. 15). This aircraft is a mid-wing twin-engine monoplane powered by two Wright Cyclone R2600 engines and has a fully retractable tricycle undercarriage. The basic weight of the aircraft was approximately 21,000 pounds, with a maximum gross take off weight of 34,000 pounds. The range of the aircraft on target was of the order of five hours at normal cruise speed but could be extended somewhat under certain circumstances. The nominal T.A.S. of the aircraft was about 180 knots. This aircraft performed excellently in all weather conditions encountered during seeding. Maximum altitude limits placed no restrictions on operations, but since the aircraft was unpressurized, oxygen was required at the normal operating altitudes encountered.

During the period 1960 to 1962, two aircraft were equipped for cloud seeding purposes, although only one was fully instrumented. The second aircraft provided back-up support for any mechanical failure of the first, as well as providing service during the 5-day inspection periods which were required every 100 hours of flying time.

In 1963, the two Mitchell aircraft were replaced by a single four engine DC-4M North Star type aircraft, when the Mitchell aircraft were phased out of service (Fig. 16). The North Star aircraft

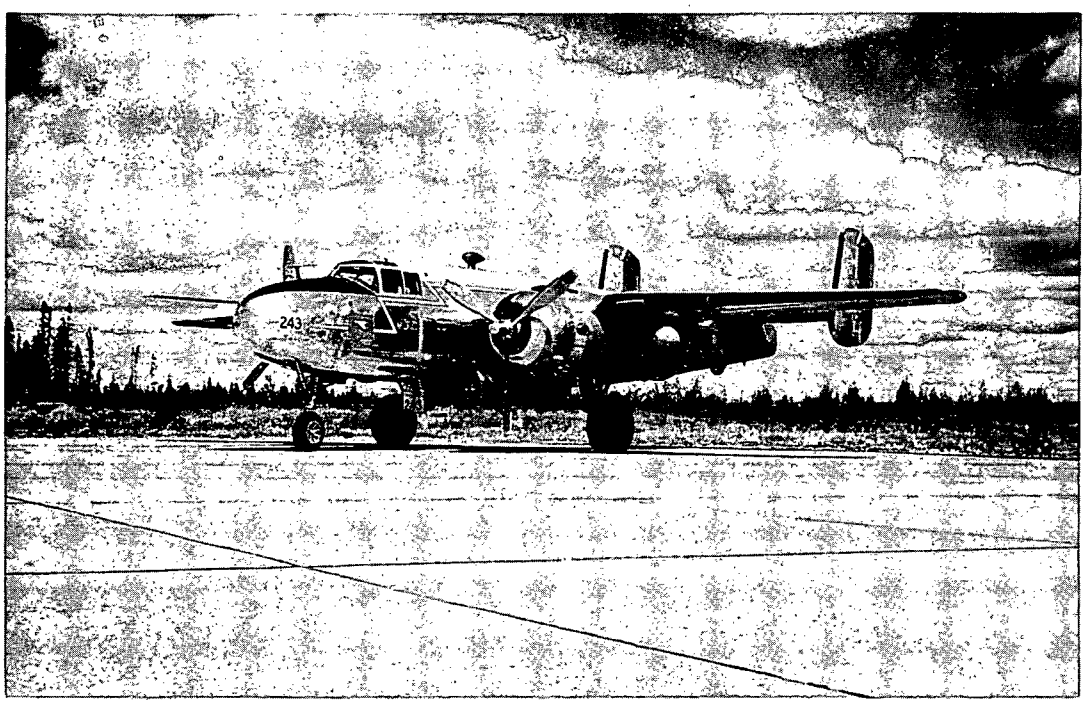


Figure 15
Project B-25 Mitchell Aircraft

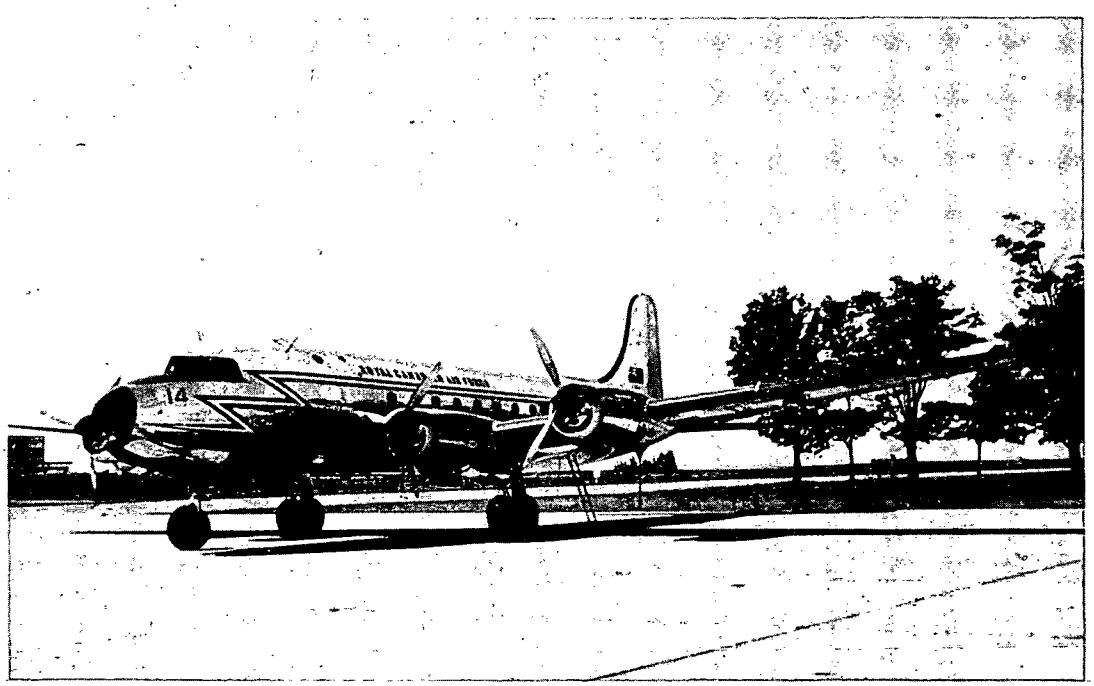


Figure 16
Project DC-4M North Star Aircraft

with its greater space and payload capacity, allowed the addition of more instrumentation. It also provided much greater crew comfort during flight and extended the on-target endurance to the order of eleven hours. This aircraft also performed very satisfactorily in all weather conditions encountered and flew at a T.A.S. comparable to the Mitchell aircraft, about 200 kts.

The aircraft were provided by the Royal Canadian Air Force to the National Aeronautical Establishment for flight research purposes. The air and ground crews were likewise provided by the RCAF through their Detachment at NAE from the Central Experimental and Proving Establishment, Uplands. The crews, therefore, were well qualified to handle the flying assignment and other required special duties in flight.

In order to satisfy the precise navigational requirements of the Project to maintain strict control of the seeding, a low power 300-watt two-slave Decca survey chain was installed in the seeding track area in 1959. The master station was located at Matachewan, Ontario with slave stations at Emerald Lake, approximately 73 miles to the south and at Cochrane, approximately 79 miles to the north. This equipment operated a Decca Navigator Mk VIII aircraft receiver, and a Model 750 flight log with Velodyne mounted in the aircraft. Essentially, the system provides a continuous visual display of the aircraft position on a chart by measuring the phase difference between very stable stationary wave patterns generated at the ground stations. This system was abandoned after one season's use, for while it did provide accurate positioning (within 1 1/2 mile), on some occasions the chain was of too low power to provide consistent accurate tracking during heavy weather, particularly when thunder-storms were in the area.

From 1960 to 1963, the aircraft were equipped with a Marconi CMA 623 Doppler Sensor and a CMA 601 Computer to provide navigational assistance. Information fed to the computer aside from the ground speed and drift was the aircraft heading obtained with a J-2 compass system and standard magnetic variations. The computer section of the system which was to provide information on the "along-track" and "cross-track" progress of the flight did not prove satisfactory. This was judged to be due in part to the type of track being flown, i.e., frequent turns after a relatively short straight flight distance. Part of the inaccuracy, however, is attributable to the

accuracy of the heading input data (J-2 compass system) and the suspected variation in magnetic variation with both altitude and time. The Doppler Sensor did, however, allow accurate winds to be calculated for the flight altitude with relative ease and frequency.

To supplement the navigational systems the Royal Canadian Army established, operated and maintained an aircraft tracking station near Virginiatown, Ontario, about mid-way between the two areas along their western border (Fig. 17). A standard Army Type AN/MPS 504 air surveillance (10-cm) radar system with I. F. F. capability was used to track the aircraft. This facility provided a ready and reliable means of tracking the aircraft during all flights. Two-way radio communication between the aircraft and radar operator allowed the operator to maintain a watch on the flight progress and pass information to the pilot for track vectoring.

Standard navigational facilities and air defence stations were used for cross-checking the aircraft position at regular intervals and in emergencies. With the navigational facilities available, it is thought that the tracks were maintained at all times with an accuracy of better than $\pm$ 2 miles.

6. Operation of the Project

In keeping with the dual aim of the project as outlined in Section 2, a continuous program of meteorological observations from the ground was sustained throughout the field season. This included a program of regular rawinsonde observations and special observations such as ice nuclei counts and lightning stroke counts. This part of the program was routine and continued whether or not seeding operations were in progress or experimental flights were being made. During seeding operations, in addition to the special observations which were being made by the aircraft, special rawinsonde flights were made, radar observations were recorded and special ice nuclei counts made.

During this five-season phase of the Project, the observation program was under a constant state of development and improvement. It was found that even with the standard Meteorological Branch instruments used regularly at observing stations, there were many special precautions and techniques which had to be exercised when used in this mode of field operation. These problems are outlined in a forthcoming report in this series. Some of the less familiar instruments

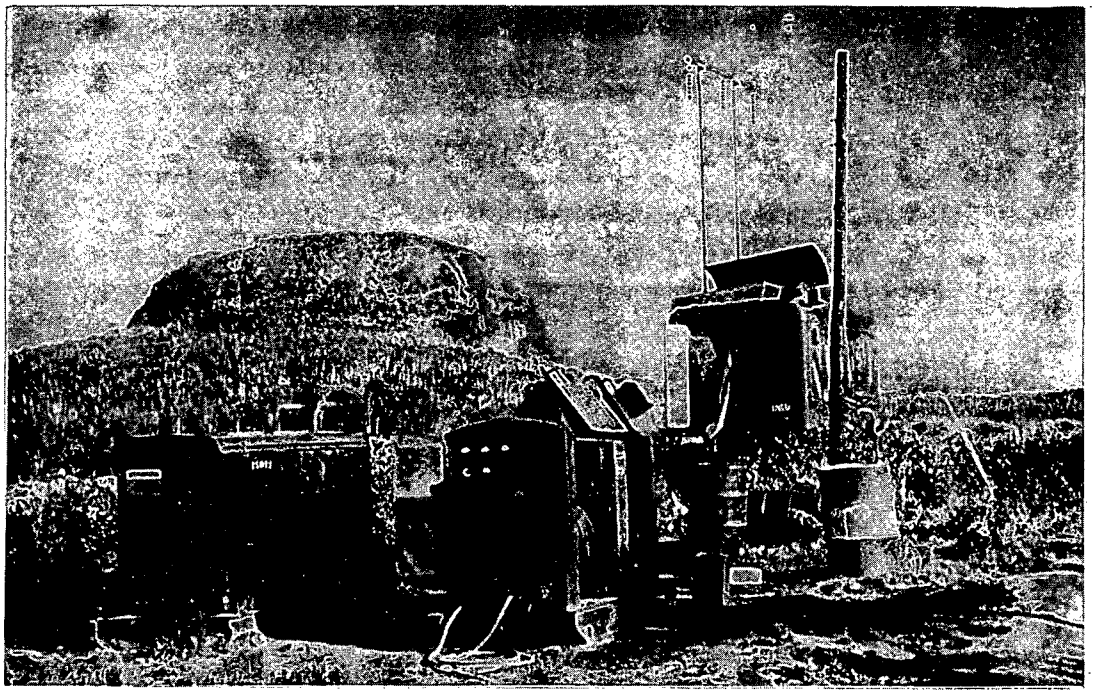


Figure 17
Army Aircraft Tracking Radar Base, Virginiatown (Cheminis)

such as those used to measure lightning strokes and ice nuclei counts were operated as a development program until it was felt satisfactory observations were being obtained. These, too, will be described in a later report of this series. Another report which will give the inventory of observations and operations will illustrate the improvements and developments during the Project.

The part of the field project which was not routine was connected with the seeding operations and this was developed to a state of almost routine once suitable weather conditions developed and the decision to seed a storm was made. The seeding took place as required without regard to time of the day or day of the week.

Cloud Seeding Operation

The project control office, under direction of the Project Meteorologist, was required to monitor the daily weather charts, usually in conjunction with the nearby weather office, and issue regular advisories twice daily on the liklihood of the development of weather conditions suitable for seeding during the succeeding 24 hours. In difficult synoptic situations, since placement of the aircraft in the seeding area was very critical with regard to time, it was often necessary to follow the weather very closely for 24-36 hours. In such situations all crews and personnel were required to be on standby for a possible operation. The aim of the control office was to have the aircraft arrive in the seeding area just as the weather conditions became suitable. When crews were on standby it required 3 hours to ready the crews and aircraft, fly to the seeding area from Ottawa (2 1/4 hours from North Bay) and establish a track for seeding.

Once it was decided that suitable conditions (as outlined in section 3) were imminent the aircrews were advised and a departure time from base or an arrival time in the seeding area specified. The crews were briefed on the weather, the seeding situation and any special instructions provided as to operational procedures.

At this point of the operation, the radar base was given instructions on the radar filming program if this had not already been done. The aircraft tracking radar base was alerted along with the rawinsonde station and the latest operation plans discussed.

Before flight planning, the aircraft Captain drew in sequence the sealed instructions designating which area was to be seeded once the decision to attempt seeding was made. The area to be seeded was not given to the control office personnel and the decision to seed, continue seeding or cease seeding was made with no reference as to the area being seeded.

The aircraft proceeded to the area with a full fuel load and crew complement and after establishing the required track at the -5°C level fired up the silver iodide smoke generator and began seeding provided the seeding criteria described in Section 3, were met, i.e., adequate cloud conditions at or near the -5°C level. If cloud conditions did not meet these criteria seeding was not commenced. If cloud conditions were suitable, but the flight at the -5°C level would be mostly in clear air, the flight level was raised to the base of the next highest layer of cloud. An unrestricted air space reservation was provided for the flight between 10,000 and 14,000 feet, which, in some occasions could be extended in altitude. This was not always possible and frequently the flight had to be made at the -2 to -3°C level, but in this instance, it was possible to confirm that the clouds did, in fact, extend to the -5°C level as well as meeting the other requirements. Seeding continued as long as suitable conditions existed and was only terminated by discussion with the control office or fuel limitations. If seeding was in progress and marginal cloud conditions were encountered, seeding was continued frequently for up to one hour or until a decision was made that cloud conditions would not likely improve.

The release of the silver iodide smoke from the aircraft was carefully controlled to ensure that it affected only the clouds which would, subsequently, pass over the test area, and not those which would pass over the control area. This was accomplished by frequent accurate wind measurements from both the aircraft and rawinsonde ascents, choice of suitable track, accurate radar determination of the position of the aircraft at all times and adjustment of the track at regular intervals as shown necessary by a wind change.

Seeding Track

The seeding material was released into clouds which were thirty minutes upwind from the target area. From experiences of Warner and Twomey (22) this was found to be a reasonable time

between cloud innoculation and the visible signs of effect below the clouds. The seeding track was at right angles to the wind flow, with its length equal to the projection of the target area upstream onto the flight path. Turns at the ends of the seeding track were always made upwind, so that the track became a very elongated figure eight (see Fig. 1). In order to keep the control area free of silver iodide smoke, it was necessary to limit the seeding to wind directions between 230° and 310° (T), and in the case of winds of 230° or 310°, to shorten the seeding track on the end nearest the control area so that a ten degree angle of horizontal diffusion would not allow contamination of the control area (See Fig. 1).

In cases where the winds were classified light variable, i.e., any direction and velocity 10 knots or less, a "double inside square track" was used. This consisted of two squares centrally located in the areas with sides of 8 and 24 nautical miles (see Fig. 1). The aircraft flew repetitively and consecutively the two squares of the track, clockwise in the smaller square, counterclockwise in the larger square, shifting from one square to the other along the line joining the SE (NE) corners of the squares in the North (South) Area.

Communications

In order to maintain adequate control of the seeding, to provide advice to the aircraft, to provide inflight observations to the control office and to provide aircraft position information to the aircraft, a rapid means of intercommunication was required. In addition, to provide operations advisories to the rawinsonde station, aircraft tracking radar base and weather radar base and to provide support and assistance to these bases as well as the ground observations field base, it was desirable to have good two-way communication with the control office when required.

In 1959, it was found that the existing public systems were not satisfactory for ground-to-ground communications. In addition, reliance on air-to-ground and ground-to-air communications through existing radio facilities proved unsatisfactory.

In 1960, VHF radio receivers and transmitters were installed at the aircraft tracking radar base and at the weather radar base, with land-line communication from the weather radar base to the control office. This was an improvement but still unsatisfactory.

In 1961, a single VHF radio receiver and transmitter was installed at McWatters. Voice and control lines were provided from this site to the control office and the aircraft tracking radar base/rawinsonde station, which allowed two-way communication between any of these ground bases individually or collectively as well as two-way radio communication between the aircraft and any of the ground bases on demand. This system proved very satisfactory from the standpoint of both performance and utility for the succeeding years.

Meteorological Facilities

In order for Project Control to constantly monitor the daily weather in watching for suitable storms, to become fully informed on current weather during operations, to provide advisories during operations and to maintain an aircraft flight watch, a certain minimum meteorological facility was necessary. To satisfy this requirement access had to be provided to current weather observations, forecasts and weather charts. It was not possible to integrate the Project Control program into the existing regular forecast office routines, at Ottawa or North Bay and as a result, a staff of 3 meteorologists and one meteorological technician was required to provide the project control and special meteorological services. This operation required the installation of suitable communications equipment such as teletype and facsimile.

Although some assistance was provided by the nearby forecast office, the operations were mostly kept independent, particularly during the actual flying and cloud seeding periods, when a very careful up-to-date analysis and prediction of weather conditions was required over a relatively small area. In addition, copies of observational data, analyzed charts, special charts and other operational data were required for later analysis and research. The meteorological technician and meteorologists undertook similar duties to those normally performed in a forecast office with the meteorologists also directing and coordinating the seeding operation and the operations at all field bases.

Project Personnel

During the course of the Project, a good proportion of the personnel were changed from year to year. While this was not desirable, it was necessary because of the seasonal nature of the field phase of the project. A good nucleus of personnel was carried from

year to year for continuity. Each year on the average there were 36 personnel working full time on the Project during the field phase, as well as 42 people who were devoting a proportion of each day to Project operations and a number of others who were providing support as required from time to time. A list of these personnel follows:

	Number	Employing Agency
(1) Project Control Office		
Meteorologist	1	M. B.
Meteorological Officer	2	M. B.
Meteorological Technician	1	M. B.
(2) Aircraft		
Pilots	3	RCAF
Navigator (1963 only)	2	RCAF
Meteorological Technician	1	M. B.
Instrument Technician	1	NAE
Crewman	2	RCAF
Ground crew	7	RCAF
Meteorological Officer (Instruments)	1	NAE/M.B.
Summer student (1963 only)	1	M. B.
(3) Ground Observations Field Base and Radar Base		
Meteorological Officer	1	M. B.
Meteorological Technicians	1	M. B.
Electronic Technician	1	T. T. E. B.
Asst. to Meteorological Technician	1	CPPA
Summer student 1961-63	1	M. B.
(4) Central Observing Stations		
Asst. to Meteorological Technician	2	CPPA
(5) Rawinsonde Station		
Rawinsonde Operators	4	M. B.
(6) Aircraft Tracking Radar Base		
O. C., Radar Operators, Mechanics,	(20-4)	RCA
etc., 1960-62, 1963	4	RCA
(7) Raingauge Network		CPPA,
Volunteer Observers (1963)	42	LOFPA,
(Other years approximately equivalent)		etc.

NOTE: Employing agency abbreviations:

M.B.	- Meteorological Branch, Department of Transport
NAE	- National Aeronautical Establishment
RCAF	- Royal Canadian Air Force
RCA	- Royal Canadian Army
TTEB	- Telecommunications and Electronics Branch, Department of Transport
CPPA	- Canadian Pulp and Paper Association
LOFPA	- Lower Ottawa Forest Protection Association

In addition, to the full time support of a number of employees, each agency also provided considerable other technical and professional support as well as funds for operating. The support of a number of other agencies and individuals was also appreciated.

Public Relations

Although there were no plans to conduct a special public relations program on the Project at the outset it soon became evident that this was necessary to insure its continuation. Record heavy rainfalls in the test areas in 1960 caused considerable public unrest and agitation through the press, radio, and private and group representations to Members of Parliament. It was the general feeling of these groups that the project was directly responsible for the very abnormal rainfalls which were seriously affecting agriculture and tourist industries as well as the general well-being of the citizens and strong objections were raised to the necessity of using this area for experiments. Descriptive literature was prepared for distribution to those interested, which described the project, the aims and the present state of knowledge of cloud seeding. The information was disseminated to the press and other communication media in the area as well. In addition, it was found necessary to meet with and address various groups in the area.

Other research groups in other areas of the world have been confronted with similar situations, and in fact it appears to be more the rule than the exception that objections will be received from irrate and vociferous groups in almost any area against any experiments on cloud modification. Depending on the circumstances, if the areas under test are suffering from either abnormal, dry or wet periods, the abnormality is attributed to the experiments. Experience shows that any similar project associated with cloud

modification should be prepared for this situation with a public relations plan and be prepared to carry it out if required or run the risk of disruption of the experiments.

7. Conclusion

The Precipitation Physics Project, which involved a field phase of five summer seasons, was conducted as a study of the basic processes of precipitation mechanisms and an evaluation of the effect of silver iodide cloud seeding or rainfalls. It was a relatively large project involving considerable organization, personnel and funds. The annual costs for the project from all contributors is estimated to be of the order of $250,000, including all operating costs, capital expenditures and Armed Forces contributions. A large body of data was collected during the operating period which will be used for continued analysis.

Aside from the direct results of the project with meteorological implications there were a number of other very useful benefits. The efficacy of cloud seeding has to date not been clearly demonstrated in most cases and it was necessary to make some practical attack on the problem from the Canadian standpoint of climate and weather and obtain detailed knowledge of the problem. This experiment brought out very clearly both the meteorological and operational problems associated with cloud seeding experiments and provided a wealth of practical background on field problems and techniques. The five years of field experiments allowed ample time to determine how the experiment could and should be conducted and pointed out very clearly the limitations on other similar experiments. A further accomplishment of the project was the inter-organizational co-operation which made the whole experiment possible and allowed the assemply of a group of scientists and technicians to pool their resources, skills and knowledge to successfully conduct the experiment. Excellent cooperation and assistance was received from many interested groups within industry, government departments and research organizations.

The project had a planned field study program of five years which operated from 1959 to 1963. This phase of the project is complete and the results of the cloud seeding evaluation have been produced according to the original plan outlined in the design of the experiment. A brief report on the project and its results was given in the

Proceedings of the International Conference on Cloud Physics, May 24 - June 1, 1965, Tokyo and Sapporo (15), and the detailed cloud seeding evaluation and results are being published in a subsequent report in the current series (17).

Additional statistical and physical analyses of the data collected are continuing and are expected to produce additonal results to add to our knowledge of cloud physics. They will also provide additional indication to that already gained of the direction in which the project should proceed in future attacks on the problems of cloud physics and cloud seeding.

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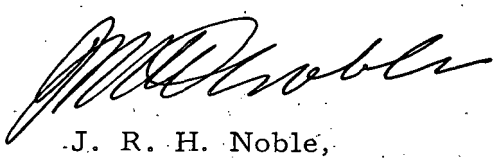

J. R. H. Noble,
Director,
Meteorological Branch.

8. References

(1) General Electric Research Laboratory, 1947: First Quarterly Progress Report on Meteorological Research, July 15, Schenectady, New York, General Electric Co., 37 pp.

(2) Vonnegut, B., 1947: The Nucleation of Ice Formation by Silver Iodide, J. Appl. Phys. 18, 593-595.

(3) Miura, A., 1959: Role of Solid Nuclei in Sublimation. Sci. Rpts. Tohoku University, 11, 162-177.

(4) Hosler, C. L., 1951: On the Crystallization of Supercooled Clouds. J. Meteor., 8, 326-331.

(5) Edwards, G. R., and L. F. Evans, 1960: Ice Nucleation by Silver Iodide: I Freezing vs Sublimation. J. Meteor., 627-634.

(6) Crozier, C. L., and J. D. Holland, 1965: Cloud Seeding to Influence Rainfall - Its Importance and Present Status. Canada, Department of Transport, Meteorological Branch. Technical Circular Series, CIRcular-4337, TEC-587.

(7) Godson, W. L., 1958: Cloud Physics and Cloud Seeding. Canada, Department of Transport, Meteorological Branch, Internal Circular, 16 pp.

(8) Crozier, C. L. and J. D. Holland, 1961: A Precipitation Physics Project in Northwestern Quebec Province, Canada. Proceedings of the Ninth Weather Radar Conference, Kansas City, Missouri, October 23-26, 337-347.

(9) Warner, J., 1957: An Instrument for the Measurement of Freezing Nucleus Concentration. Bull. Obs. Puy de Dôme, 2, p. 34.

(10) Bigg, E. K., G. T. Miles and K. S. Heffernan, 1961: Stratospheric Ice Nuclei, J. Meteor., 18, 804-806.

(11) Lodge, James P., and H. Bravo, 1962: An Improved Technique for the Determination of Freezing Nuclei Concentration, Bull. Obs. Puy de Dôme 10, 81-86.

(12) Bigg, E. K., S. C. Mossop, R. T. Meade and N. S. C. Thorndyke, 1963: The Measurement of Ice Nucleus Concentrations by Means of Millipore Filters. J. Appl. Meteor., 2, 266-269.

(13) Smith, E. J., K. J. Heffernan and W. J. Thompson, 1958: The Decay of the Ice-Nucleating Properties of Silver Iodide Released from an Aircraft. Quart. J. R. Meteor. Soc., 84.

(14) Snedecor, G. W., 1946: Statistical Methods, Ames Iowa State College Press, pp. 10-13, 62-70.

(15) Godson, W. L., C. L. Crozier and J. D. Holland, 1965: Silver Iodide Cloud Seeding by Aircraft in Western Quebec, Canada, 1959-1963. Proc. Int. Conf. on Cloud Physics, May 24-June 1, 1965, Tokyo and Sapporo, 424-428.

(16) Thiessen, A. H., 1911: Climatological Data for July, 1911, District No. 10, Great Basin. Mon. Wea. Rev. 39, 1082-1084.

(17) Godson, W. L., C. L. Crozier and J. D. Holland, 1965: Cloud Seeding Evaluation, 1959-1963 - Precipitation Physics Project. Canada, Department of Transport, Meteorological Branch. Technical Circular Series. CIRcular-4322, TEC-586.

(18) World Meteorological Organization, 1959: An Instrument for Counting Local Lightning Flashes. Bull. of the W. M. O., January, 14-18.

(19) Sewell, R. T. and K. G. Pettit, 1964: Analysis of V-G-H Records from a DC-4M Aircraft in the Vicinity of Frontal Systems and Troughs. National Research Council Aeronautical Report LR-402 (NRC No. 8136).

(20) Vonnegut, B., 1950: Techniques for Generating Silver Iodide Smoke. J. Colloid Sci., 5, 37-48.

(21) Warner, J. and S. Twomey, 1956: The Use of Silver Iodide for Seeding Individual Clouds. Tellus, 8, 453-459.

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The paper discusses the aims, experimental design and instrumentation of the project and describes the manner in which these plans were carried out during the five years of operation.

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