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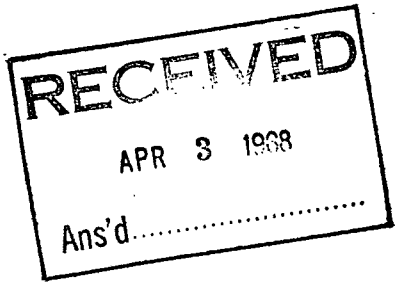
DETAILED STORM ACCEPTANCE AND EVALUATION CRITERIA

PRECIPITATION PHYSICS PROJECT

BY

C.L. CROZIER AND J.D. HOLLAND



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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. A major part of the project was devoted to the task of testing the effect of seeding synoptic scale weather systems with silver iodide using a randomized cross-over technique with two separated test areas.

This paper outlines the rules of the experiment as they were defined before commencement of the project. The sufficient conditions for cloud seeding are defined and their application in the field operations are discussed. The necessary conditions for acceptance of a seeded storm for the evaluation are also defined and their application discussed. Comments are made on some of the details of techniques required to meet the rules.

Details of statistical and physical design, operation and results of the evaluation are presented in other reports of this series.

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CRITÈRES DÉTAILLÉS D'ACCEPTATION ET D'ÉVALUATION DES TEMPÊTES

Programme de physique des précipitations

par

C. L. Crozier
et
J. D. Holland

RÉSUMÉ

Durant les étés de 1959 à 1963, un projet d'ensemencement des nuages combiné avec des études physiques des mécanismes de la précipitation a été mis en oeuvre dans l'ouest du Québec. Une partie importante du projet consistait à contrôler l'effet de l'ensemencement avec de l'iodure d'argent, au hasard suivant la technique de plan croisé, de systèmes météorologiques à échelle synoptique dans deux aires expérimentales distinctes.

Les auteurs exposent les règles de l'expérience telles qu'elles ont été déterminées avant le début du projet. Ils énoncent les conditions propices à l'ensemencement des nuages et traitent de leur application dans les opérations sur place. Les conditions nécessaires à l'acceptation, aux fins d'évaluation, d'une tempête au cours de laquelle les nuages ont été ensemencés sont aussi définies et les auteurs traitent de leur application. Ils font des observations relatives aux détails des techniques nécessaires pour satisfaire aux régles.

Les détails relatifs au plan statistique et au plan physique, à l'opération et aux résultats de l'évaluation sont présentés dans d'autres rapports de la présente série.

DETAILED STORM ACCEPTANCE AND EVALUATION CRITERIA

Precipitation Physics Project

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J. D. Holland

C. L. Crozier

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1. Introduction

As part of a continuing study on the physics of clouds and precipitation, a project called the Precipitation Physics Project was operated in the field by the Meteorological Branch from 1959 to 1963 inclusive. The project was conducted in the western section of the Province of Quebec, and involved extensive measurement of physical parameters both on the ground and in the air. In addition, a program of cloud seeding was carried out, to help in the study of precipitation mechanisms and to make an assessment of the effect of cloud seeding. Previous reports in this series have presented the physical design and operation of the project (1), the design of the statistical analysis technique used in evaluating the effects of the cloud seeding (2), and the results of the statistical evaluation of the cloud seeding tests (3). A summary of the design and operation of the project and the results of the statistical evaluation have also been given in a paper by Godson, Crozier and Holland (4). The present report gives the detailed storm acceptance and evaluation criteria used in the project, and in doing so provides background information and some of the philosophy underlying the project, covered only sketchily in the earlier reports.

The cloud seeding tests and physical measurements of the Precipitation Physics Project were carried out on synoptic scale weather systems. When a suitable weather system crossed the test areas, cloud seeding with silver iodide was conducted by aircraft upwind of one of the test areas selected by a random choice while the other area served as a control area. Suitable weather systems were considered to be organized cloud systems such as those associated with a front, low or trough. Indications that the system was likely to affect both test areas approximately equally and evidence of the operation of an active precipitation mechanism were required before cloud seeding was carried out. Other criteria laid down for

seeding suitability involved suitable cloud, wind and temperature conditions, and were strictly observed. The unit for seeding and for evaluation was the storm, with a 24-hour separation between seeded storms maintained in order to ensure separation of rainfall data. Measurement of rainfall at the ground during passage of the storm provided the basis for evaluation of the effects of seeding. The actual design and operation of the project in the field and the method of statistical evaluation have been described in the reports (1), (2) referred to above, and will not be repeated here.

The present paper is confined to discussion of the conditions or criteria under which seeded storms were considered acceptable for evaluation. It will be seen that the conditions necessary for acceptance of a storm for evaluation and the conditions sufficient to permit seeding to be carried out are the same, differing only in their time and conditions of application. Application of the criteria is obviously more difficult under field conditions than under the conditions which prevail during analysis. However, the criteria were adhered to as strictly as possible under both sets of conditions, and it was found necessary to reject seeded storms because of the seeding and evaluation criteria on only three occasions, described more fully in Section 7.

The conditions necessary for acceptance of a storm for evaluation and their application are discussed in Sections 6 and 7 of this report, while the conditions sufficient for seeding to be carried out are discussed in Sections 4 and 5. The controls exercised in order to ensure an unbiassed selection and analysis of the storms are also discussed in these sections of the report. A brief review of the method of storm selection and the cloud seeding program is provided in Section 3, while Section 2 defines the terms "storm", "storm rainfall", "storm duration" and "contamination" in the particular context used in this report.

In the process of making the definitions referred to above and defining and describing the storm acceptance and evaluation criteria, this report also effectively lays down the "rules of the game" insofar as the statistical aspects of the cloud seeding evaluation are concerned. This is an essential part of all experiments of this sort in order to ensure complete objectivity and freedom from bias. These rules must be (and were) laid down prior to commencement of the project and strictly adhered to during the subsequent years

of operation and evaluation. The rules are as objective as possible and leave very little room for subjective decision. This report provides for the record the strict procedures used in the operation and evaluation of the project.

2. Definition of Terms

For the purposes of this investigation a number of terms were used with special connotations somewhat different from normal usage. A "storm" was considered to be an organized cloud system accompanied by an area of rainfall discernible in the synoptic sense, while "storm rainfall" for each test area was defined as the rainfall measured in that area during the duration of the storm. While these definitions are not far removed from at least some conventional uses of the terms, the restrictions placed on the meaning of "storm duration" gave very special meanings also to the terms "storm" and "storm rainfall". As will be seen in the sections which follow, certain restrictions were placed on the storms selected for seeding and accepted for evaluation. Restrictions on the type of storm being seeded, the nature and extent of the clouds, the temperature range and the wind conditions under which seeding would be carried out were imposed in order to ensure a valid, controlled experiment. Restrictions on the definition of the duration of the storm for the purposes of the project were imposed in order to ensure separation of each seeded storm from every other storm and in order to ensure complete objectivity in the selection of storm rainfall data and comparability of storm rainfall in the two test areas. To ensure separation of the rainfall of one seeded storm from other storms, seeding was not carried out unless 24 hours had elapsed since the end of the preceding storm. In the evaluation procedure, separation of storm rainfall, comparability of storm rainfall in the two test areas and objectivity in abstracting the storm rainfall from the total rainfall data were achieved by adoption of the following definitions and rules:

(1) Storm periods were defined in terms of multiples of consecutive regular 12-hourly precipitation intervals, 0800-2000 and 2000-0800 local time, consistent with the times of measurement of rainfall.

(2) The "duration of a storm" or "storm duration" was defined to be the same for both test areas and to be the same as the period for which storm precipitation was measured.

(3) The period for which storm precipitation was measured was defined to be made up of one or more consecutive 12-hourly regular observation periods 0800-2000 and 2000-0800 local time, corresponding as closely as possible to the passage of the weather system in question.

(4) The actual time of beginning of rainfall in any storm period was required to be in a regular 12-hourly observation period different from that containing the actual ending of rainfall in the preceding storm period.

(5) The actual time of ending of rainfall in any storm period was required to be in a regular 12-hourly observation period different from that containing the actual beginning of rainfall in the succeeding storm period.

(6) The actual beginning of rainfall in both test areas was required to be in the same or adjacent regular 12-hourly observation periods.

(7) The actual ending of rainfall in both test areas was required to be in the same of adjacent regular 12-hourly observation periods.

Strict adherence to these objective criteria was maintained in order to ensure that the storm precipitation could be separated from the precipitation of preceding and succeeding storms, that the time of beginning, duration, and time of ending of the "storm rainfall" in one test area would not be greatly different from those in the other, and to ensure complete objectivity in the abstracting of "storm" rainfall data. Similar strict criteria were imposed regarding the separation of storms when conducting seeding operations, (see Section 4) so that no difficulty was experienced in separation of the actual rainfall of one seeded storm from the next.

The terms "contamination" and "contaminated" as used in this paper are also defined, so as to avoid possible confusion as to their meaning. These terms as used in this paper refer to the situation where silver iodide material aimed at the target area is considered because of wind conditions (allowing a ten-degree angle of dispersion on either side of the mean wind direction) to have reached some

part of the intended control area. In this case "contamination" of the control area is said to have occurred or the control area is said to be "contaminated".

3. Some Details of Technique

In the operation of the Project in the field it was necessary to maintain a constant watch of the weather in and around the test areas on a 24-hour basis and to alert the operational team in advance of impending suitable storm situations for seeding. A forecast group was assigned the weather watch duties. The group worked in association with a nearby Forecast office of the National Forecast System which provided advice and assistance when requested. This assistance was provided solely in the interests of saving manpower and the final analysis and prognosis of the weather system rested with the Project forecast and control group who were well versed in the conditions which were regarded suitable for seeding as laid down in Section 4. In order to set the seeding operation in motion, a forecast of "suitable conditions" was required approximately 3 to 6 hours in advance. A final decision to seed was mandatory about 3 hours in advance if the seeding aircraft was to be placed in the area at the most suitable time (i.e., assembly of crews, aircraft and instrumentation check, fuelling, enroute flight time, etc., consumed 3 hours time).

Choice of Area to be Seeded

The choice of the area to be seeded was determined by a randomizing technique. A person having no interest in or association with the Project was selected form Departmental staff. The person selected was issued with the following instructions. A sample of 50 numbers was to be selected from the table of random numbers in Snedecor (5), pages 10-13. The only stipulation was that the sample should not be seriously unbalanced as to the number of odd and even numbers. Seeding instructions were determined by letting even numbers represent "seed North Area" and the odd numbers represent "seed South Area". A table of instructions as to the area to be seeded on each mission was prepared using the first number of the random sample for seeding mission number one, the second number for mission number two, and so on. The table of instructions was used to type individual instructions to the Project Flying Officer on separate sheets marked Precipitation

Physics Project, year, number of the seeding and area to be seeded. The instructions were sealed in a set of envelopes marked with the same information except for the area to be seeded. A duplicate set of envelopes was prepared at the same time as a safety measure and these were all sealed in a separate large envelope together with a single copy of the table of instructions. All other copies of the random sample, table of instructions, and any other references were destroyed. The package of 50 sealed instruction envelopes was passed to the Project Flying Officer. The duplicate envelopes and the table of instructions were left in the sealed envelopes and retained on a Divisional file. The Project Flying Officer was therefore the only person with ready access to the seeding area instructions, and he maintained these under his control throughout the season, returning the unused sealed envelopes to the Project Office after completion of the field season. A new list of random numbers and instructions was drawn up each year.

Decision Regarding Seeding

The decision as to whether seeding was to be conducted was left to the Project Control Officer, who was the Project Meteorologist in almost all instances. This decision was made by careful examination of all the synoptic weather information and forecasts available, experience, and consultation with the Project Flying Officer, who was already in the area of seeding. A radio communication link was available between the Project Control Office and the Project Aircraft doing the seeding. The final decision was dictated largely by the existing weather conditions in the area as reported by the pilot, and their agreement with the conditions as set out in Section 4. Forecast skill was thus required to get the aircraft into the area during suitable weather conditions, but the actual seeding was only carried out if the observed weather conditions were verified as sufficiently suitable. The Project Control Officer was not aware at any time during the seeding as to which area the aircraft was to seed. The seeding was begun and ended on a consultation basis between Control Officer and Flying Officer. These decisions were based mainly on existing weather conditions, and, in the case of termination, on expected developments within the flight endurance time of the aircraft. The Control Office also provided the Flying Officer with a weather watch for safe conduct of flight.

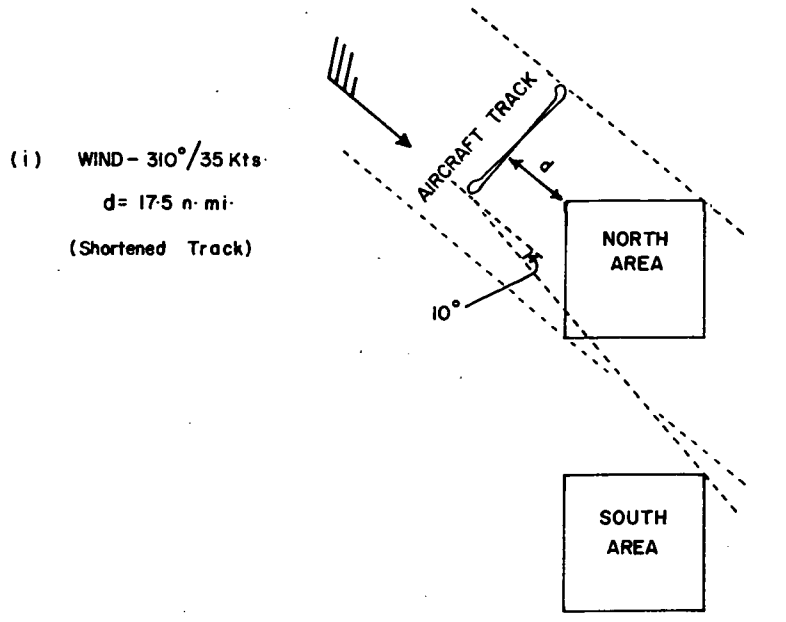
Seeding Flight Altitude and Pattern

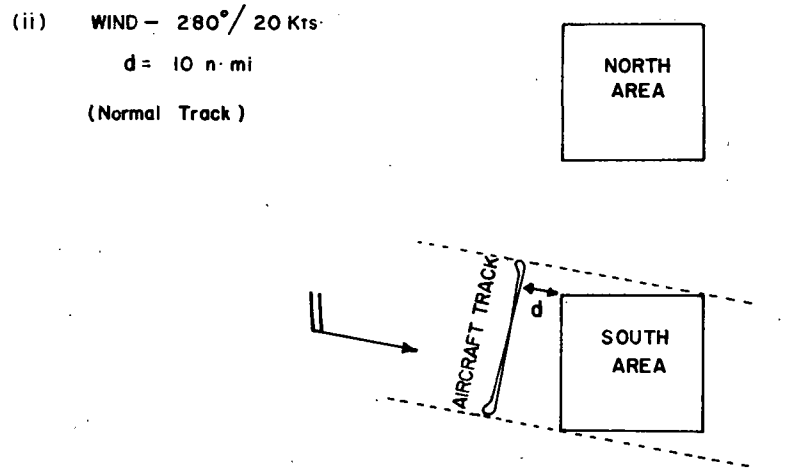
As has been explained elsewhere (1), a prime consideration in control of the experiment was to place the seeding material at the position where it was hypothesized to have a physical effect and in a location where any effect would be measurable. Two prime controls of the experiment were, therefore, the altitude of the seeding aircraft and the seeding track.

The seeding aircraft was directed to conduct seeding at an altitude where the temperature was -5°C. Thermometers on the aircraft were used for this seeding altitude determination, although for flight planning purposes a forecast of the -5°C altitude was provided. Operational restrictions on some occasions did not permit seeding at this altitude and seeding was then conducted at slightly higher temperatures. The aircraft, however, was sufficiently close to the -5°C level that it was no problem to determine that clouds in the seeding area did, in fact, reach the -5°C level.

Strict control of the aircraft on the seeding track was also required. Special navigation systems and equipments were used for this purpose along with the normal techniques and existing facilities. An accurate position was, therefore, known at all times and the aircraft seldom deviated from the prescribed tracks while seeding. 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 [Figure 2 (ii)]. The length of the flight path, including minimum turning radius turns upwind at each end of the path, corresponded to the projection of the target area upstream into the flight path. For winds of 230° and 310°, 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 [Figure 1(i)]. When winds fell to 10 knots or less, the seeding flight was changed to two inside squares of 4 and 12 nautical miles respectively concentrically located inside the target boundaries [Figures 1 (iii) and 3].

The seeding material was released upwind from the target area where the effect is to be measured. With a moving cloud system, time was, therefore, allowed for the seeding material to react within the cloud and the effects of any change in precipitation to be transmitted to the ground where the effect was being





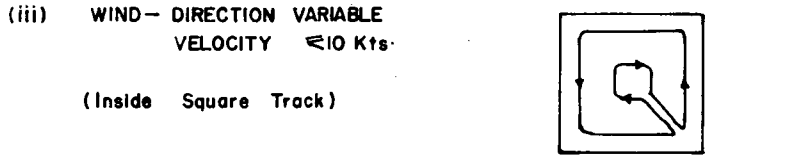


Figure 1
Schematic Diagram of Typical Seeding Flight Tracks

300°T

North Area 300°T

Speed	N.T.P.	S.T.P.	Track Length
15	49°13.5' N 79°28' W	48°36' N 80°02' W	43'5 n.mi.
20	49°15' N 79°32' W	48°37.5' N 80°05' W	43
25	49°16' N 79°35.5' W	48°39.5' N 80°08' W	42.5
30	49°17' N 79°38.5' W	48°41' N 80°10.5' W	42
35	49°18.5' N 79°42' W	48°42.5' N 80°13.5' W	41.5
40	49°19.5' N 79°45' W	48°44' N 80°16.5' W	41
45	49°21' N 79°48.5' W	48°45.5' N 80°19.5' W	40.5
50	49°22' N 79°51.5' W	48°47' N 80°22.5' W	40

South Area 300°T

Speed	N.T.P	S.T.P.	Track Length
15	48°10' N 79°29' W	47°32' N 80°01.5' W	44 n.mi.
20	48°11' N 79°32.5' W	47°33' N 80°04.5' W	44
25	48°12' N 79°35.5' W	47°34.5' N 80°07.5' W	44
30	48°13' N 79°38' W	47°35.5' N 80°10.5' W	44
35	48°14.5' N 79°41.5' W	47°37' N 80°14' W	44
40	48°16' N 79°45' W	47°38' N 80°17.5' W	44
45	48°17.5' N 79°48' W	47°39.5' N 80°21' W	44
50	48°18.5' N 79°51' W	47°40.5' N 80°24' W	44

Figure 2

Sample Page from "Tow Lines for Seeding Flights" for a Wind Direction of 300° (T)

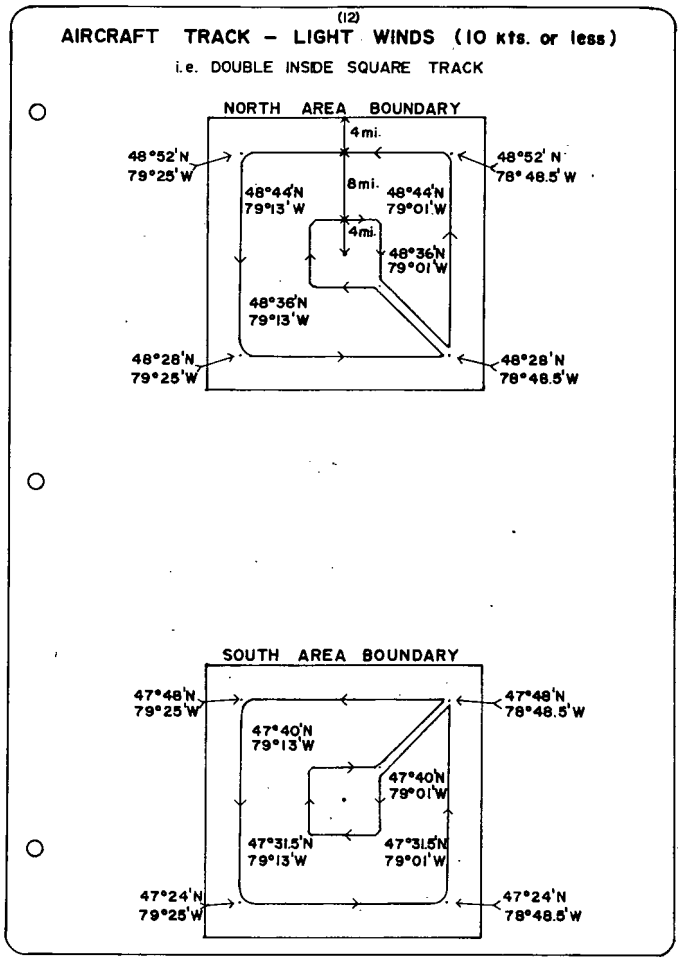


Figure 3
Seeding Track and Coordinates for Wind Velocities of 10 Knots or Less

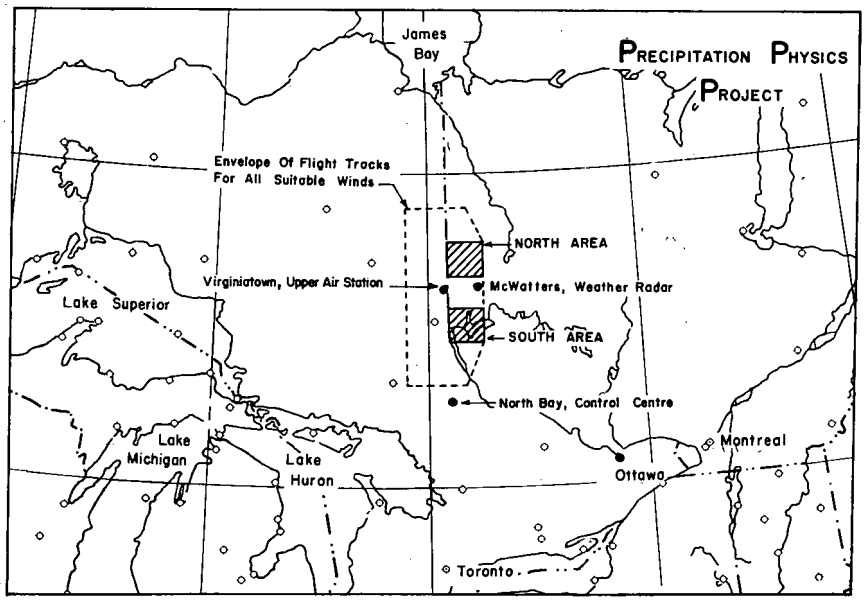


Figure 4
Precipitation Physics Project Areas of Operation

measured. The allowance of thirty minutes was based on earlier experiments by Warner and Twomey (6) and the application of these results to later experiments by Adderley and Twomey (7).

The exact seeding track was determined by the area to be seeded and the existing winds at flight altitude during seeding. Special rawinsonde observations and an airborne Doppler radar navigation system provided the wind information. The aircraft was flown on a path consistent with the existing wind and changed regularly whenever wind changes of $\pm$ 10 degrees or $\pm$ 5 kts occurred. A table of "Tow Lines for Seeding Flights" was drawn up prior to commencement of the Project, giving for both the North and South Areas the geographical coordinates of the North Turning Point (N.T.P.) and the South Turning Point (S.T.P.) for each wind direction (in 10-degree intervals) from 220 to 320 degrees and for each wind speed (in 5 kt. intervals) from 15 to 50 kts. A page of the table of tow lines is given in Figure 2. The prescribed track for winds of 10 kts or less is shown in Figure 3. This table allowed the Project Flying Officer to adjust the aircraft flight quickly during operations to changing conditions of wind.

The foregoing paragraphs have reviewed the need for strict control measures on the operations of the field experiment, and have provided the detail of some of the techniques and controls. Successful evaluation is very dependent on, and greatly assisted by, adequate control of the experiment. Great care is required in categorically defining the experiment and then following the rules and established procedures. The experiment is further defined by Sections 4, 5, 6 and 7, which describe the sufficient atmospheric conditions required before operations were considered feasible and the necessary conditions applied to determine the acceptability of storms for evaluation.

4. The Sufficient Conditions for Conducting Cloud Seeding Operations

The need for being as objective as possible in a cloud seeding evaluation experiment was realized and stressed during the design of the Project. The criteria for sufficient storm and cloud conditions which would warrant a seeding operation were, therefore, defined before beginning the experiment. These conditions were

felt to be reasonable from the standpoint of design and operational considerations discussed more fully elsewhere (1)(2). The sufficient conditions required before cloud seeding would be conducted were stated as follows:

(a) The storm system should be an organized cloud system accompanied by an area of rainfall discernible in the synoptic sense, crossing or expected to cross both target areas, and in the synoptic scale not giving any reason to believe that the system would affect the two test areas differently.

(b) Clouds in the system should cover at least 50% of the seeding track at flight altitude or just above flight altitude.

(c) Clouds should be at least 3000 feet thick.

(d) Clouds should extend at least to the level where the temperature falls to -5°C.

(e) The storm system should show some sign that an active precipitation mechanism is in operation in some clouds.

(f) The winds in the levels between 5000 ft. and 30,000 ft. should lie between 230° and 310°, or be $\leq$10 knots if lying outside these limits.

(g) The precipitation from the "storm" to be seeded should be separable from the previous "storm" and from the succeeding "storm", using the definition and criteria for "storm" and "storm duration" given in Section 2.

A few comments on the sufficient conditions can be made by way of clarification. It was felt from the beginning that storms which obviously affect the two areas differently in the synoptic scale would not provide a true test of seeding. Since the area of study was chosen to be a region of concentration of summer storm

tracks, such differences were a real possibility. If synoptic differences could be forecast before seeding occurred, seeding of such storms was not attempted. (If synoptic differences were suspected by the evaluation team after seeding took place, such storms were rejected before any knowledge of which area was seeded was obtained, as indicated in Sections 6 and 7). The main aim of condition (a) was to exclude any storm which would obviously introduce spurious effects or tend to dilute any seeding effect in the sample. An example of this type of situation would be a front which crossed only one area.

Precipitation can only form in the atmosphere if there is sufficient moisture to produce the water particles. Further, the particles will only survive and grow in the atmosphere and reach the ground if the environment is sufficiently moist and populated with other cloud particles. There are minimum cloud dimensions, therefore, which will allow precipitation development and thus, by inference, production of a measurable effect from cloud seeding. Conditions (b) and (c) recognize these facts. Since the effect of seeding is being measured by means of an areal rainfall estimate over an area of 32 n. miles square with a seeding path varying from 30 to 40 n. miles, to require that at least half the seeding track be covered with cloud does not seem an unreasonable condition to impose on the operation. It is certain that the vertical depth of the cloud is significant and the minimum thickness critical in the rainfall production process. This is adequately demonstrated by Mason (8) and Fletcher (9). The minimum thickness is also dependent on other characteristics such as liquid water content, cloud base temperature, etc. In selecting a minimum thickness condition, it is, therefore, only possible to choose some reasonable value. There are guide lines for this choice in the scientific literature from both observation and theory. Adderley and Twomey (7), basing their decision on some earlier experiments with individual clouds, recognized the need for thick clouds in their cloud seeding in the Snowy Mountains. Ludlam's (10) study of the coalescence of cloud droplets in showers indicated a critical depth of between 1.5 and 2 km for production of showers. Mason and Howorth (11), in their study of stratiform cloud observations, found that rain/snow fell only from clouds of thickness $>$ 3300 ft. (1 km.), continuous rain only from much thicker clouds, while no rain fell from clouds of depths $<$ 1500 ft. Other similar studies are reviewed by Mason (8). Selection of the minimum cloud thickness of 3,000 ft. as a condition of the experiment seems reasonable and perhaps slightly conservative.

In silver iodide cloud seeding experiments, it is generally assumed that the silver iodide acts as a freezing nucleus and initiates the Bergeron-Findersen precipitation process. If such is the case, then temperatures at least in the top of the cloud must be sufficiently cold to allow the silver iodide to act as a freezing nucleus. The threshold temperature of silver iodide has been determined by several scientists (12)(13), to be of the order of $-4^{\circ}C$ to $-5^{\circ}C$. Condition (d), therefore, insures that temperatures in the seeded cloud are suitable for action of this mechanism.

Condition (e), was imposed for various reasons. The interest in the Project was to determine the effects on rainfall of a cloud system. It was, therefore, apropos to have the cloud system in an active stage. Experience prior to and during the Project also showed that the absence of rainfall in the synoptic scale cloud system was a reasonable indicator that the clouds were not "sufficient" [i.e. condition (b), (c) and (d) likely not fulfilled]. Similar criteria have been used in other experiments to indicate suitability for seeding. Battan and Kassander (14), for instance, found that an atmospheric moisture indicator (precipitable water) could be used effectively by itself to indicate the occurrence of clouds suitable for seeding. The statistical procedures set up would also not handle cases of zero precipitation in either area. The sensitivity of the experiment would also be increased using larger storm rainfalls, i.e., lower percentage standard error in the rainfall determination.

Condition (f) was a requirement based on the wish to keep the control area free from any seeding material during the seeding period, and was governed by the geometry of the seeding areas and seeding track as outlined in Section 3.

Condition (g) was an analysis requirement. It was necessary to be able to separate the storm rainfall. If preceding or succeeding storms did not overlap, this could be done quite objectively. If there was an overlap and no seeding had taken place in the overlapping storm, the result was not too serious. The storm period could be lengthened to include the complete rainfall period with only a possible dilution of effect. Overlapping seeded storms could not be tolerated in a randomized experiment.

5. Application of Sufficient Conditions in Practice

While the sufficient conditions for the conduct of cloud seeding operations were carefully selected and defined as described in Section 4, it was not always possible to be absolutely strict in their application. Aside from the problems which were encountered in aircraft operation and associated equipments, there were also problems with the weather. During storm conditions the weather was generally changing rather quickly, and even with the good communications available, the process of observation, analysis, forecasting, operational planning and control was not instantaneous, and a great effort was required to keep the operations matched to the existing weather conditions. Nevertheless, during operations the "rules" of the experiment were adhered to as consistently and as rigourously as field conditions would permit at the time. If violations of the rules occurred, such as by miscalculation or poor forecasts, the evaluators who made the final appraisals and applied the necessary conditions for acceptance of a seeded storm for evaluation (without knowledge of which area was seeded) would eliminate these storms as unsuitable. (See Sections 6 and 7).

Action by Seeding Agency

The seeding agency was an integral part of the Project field team. The overall field team was directed by the Project meteorologist who also conducted the meteorological operation of weather watch, analysis, prognosis, operational planning and final direction and control of the seeding operation. The Project Flying Officer conducted the airborne seeding operation on the instruction and advice of the Project Meteorologist, following set procedures and rules defined at the outset of the Project.

Meteorologists at the Project Control Office monitored the daily weather charts independently using as much of the National Forecast System facilities as possible. A daily advisory was issued in the early morning of each day to all operational personnel, giving the likelihood of a seeding operation being conducted within the next 24 hours. Operational personnel planned their daily activities accordingly. Intermediate advisories were issued if seeding operations were expected or pending.

When conditions appeared likely to be suitable to conduct seeding operations, using all information available from the forecast system, special charts prepared by the Project team, special observations provided for the Project, etc., the Project Meteorologist determined whether the sufficient conditions (a) to (g) (Section 4) were fulfilled or made a best estimate as to when the conditions would be fulfilled. The meeting of criteria (a) and (g) was determined solely from the regular synoptic and other meteorological reports available to the Project Meteorologist and was uniquely determined prior to departure of the seeding flights. Determination of whether the other criteria (b) to (f) inclusive, were met contained input from both the general meteorological situation as known to the Project Meteorologist and from observations of the seeding aircraft personnel on reaching the target areas, with the aircraft input the deciding factor. In practice, criterion (g) was met by ensuring that no storm was seeded unless there had been a period of 24 hours without precipitation since the previous seeded storm. When it was decided that all these conditions (a) to (g) were met or likely to be met, the Project Meteorologist declared the storm to be a suitable case. This decision was usually required 3 to 6 hours in advance of a storm in order to place the aircraft into the area when conditions were suitable. This was particularly critical when storms of only 3 to 6 hours duration were expected to affect the area. This decision was made without any knowledge as to which area might be selected for seeding.

When this decision was made, the Project Flying Officer was briefed on the meteorological aspects of the operation, provided with a full scale flight briefing for safe conduct of the flight, and issued instructions as to the time the flight should be over the target area, and any other special procedures or tasks. The Officer was also provided written information on the expected duration of the storm, the altitude of the -5°C level (the flight altitude), the forecast wind speed and direction at the proposed flight altitude, and any other pertinent information. A copy of the information form provided is illustrated in Appendix I(a).

At this point the Project Flying Officer determined the "Area" to be seeded by drawing the appropriate sequential envelope. The "Area" to be seeded was not disclosed to any other personnel who

did not need to know; the exceptions were usually only the co-pilot and navigator. A flight plan was drawn up based on the seeding instructions and the required seeding track, which, in turn, was determined from the "Area" to be seeded, the wind speed and direction, and the table of tow lines. The aircraft then proceeded to the target area according to the instructions.

The Project Flying Officer, on reaching the seeding track, adjusted the flight altitude, if necessary, to correspond as closely as possible with the -5°C temperature level, and, based on observations made over the length of the seeding track, assessed whether the sufficient conditions (b) through (f), (Section 4), were fulfilled. The relevant weather information was passed directly to the Project Meteorologist by direct two-way radio. If all conditions were fulfilled, the actual seeding operation was begun. Care was still exercised in not disclosing which "Area" was being seeded. Winds were measured regularly and the seeding track adjusted accordingly.

If the sufficient conditions were not met, the situation was discussed by the Project Flying Officer and Meteorologist, using the new information provided by the aircraft on the spot. Usually two possibilities were presented. This reconnoitre phase could often determine that it was highly unlikely that sufficient conditions would be met with this storm. For example, a front might be clearly defined by the cloud and weather, with no significant cloud reaching or likely to reach the required altitude, or the winds might already be outside the limits defined by condition (f), Section 4, with the synoptic analysis providing no hope of them backing or veering to within the suitable limits. In this case, the seeding attempt was abandoned. The remaining possibility was that while conditions were not **presently** suitable, there was good reason to expect that they would improve, i.e., the frontal cloud had not yet reached the area, or winds had not yet swung to the suitable direction. In this case, the flight held to the seeding pattern and monitored the weather, beginning seeding if conditions became suitable, or abandoning the seeding if they did not or if the limit of flight endurance was reached.

The seeding was continued as long as the sufficient conditions were maintained; seeding was discontinued if weather conditions became unsuitable or if other operational requirements

demanded cessation. If the aircraft endurance was exhausted and conditions were still suitable, the aircraft returned to the operating base, refuelled, and returned to continue seeding. Occasionally, suitable storm conditions did persist beyond the endurance limit of the aircraft.

Occasionally, the wind direction during the storm period hovered around the limits of acceptability, i.e., 230^{o} and 310^{o}. In this special case, if the winds shifted to 220^{o} or 320^{o} while seeding was in progress, the seeding track was shortened appropriately to maintain the control area free of seeding material, and the seeding continued for a period of one hour. If the wind had not then returned within prescribed limits, the seeding was terminated. A seeding was not initiated, however, with these wind directions.

Strict control and adequate documentation of all phases of the operation were maintained. Suitable logs recorded all the operational and weather information. The Project Meteorologist maintained a record of all pertinent information on operations and transactions as well as original weather charts, weather observations and data. The inflight information and observations were recorded on forms by the Project Flying Officer [Appendix I(b)], the Instrument Technician [Appendix I(c)], the Air Weather Observer [Appendix I(d)], and the Navigator (in 1963 only) [Appendix I(e)]. The forms were designed to insure that certain required information would be recorded, but left scope for recording other information as it occurred.

It is beyond the intent of this paper to elaborate in detail on the operational problems encountered during the conduct of this experiment, but a few further comments are worthwhile. The positioning of the aircraft in the target area at the correct time to satisfy the operating criteria was a difficult but not insurmountable task. It did require a considerable expenditure of time, a great number of personnel and a good deal of care and diligence. The use of aircraft in experiments does require an additional amount of patience and expertise, as those familiar with this technique of experimentation will know and testify.

The statistical nature of the experiment implies repetition and sampling. In general, the larger the sample, the more accurate and reliable the result. Each sample in the experiment

was acquired at a considerable cost. The application of the sufficient conditions in practice and the design of the experiment took these facts into account. There were few cases missed during the period of operation of this experiment.

Information Provided Evaluator

At the completion of each year's field operation, data on the storms seeded and on the operations were gathered together to evaluate and determine whether in fact the storms and the actual seeding had met the necessary conditions for acceptance as a seeded storm case. The necessary conditions are detailed in Section 6. The case history and all pertinent observational and operational information were collated by the Project Meteorologist, who at this point in time might have (and probably had) become aware of which "Area" had been seeded. A second investigator (Meteorologist) associated with the Project, but with no active contact with the field operations, no knowledge of which "Area" had been seeded, and without reference to the network precipitation data, served as the "Evaluator" for storm acceptance purposes.

The following information was provided to the Evaluator for each seeded storm:

(i) the storm code number, the date and time of the seeding (but no information as to the "Area" seeded),

(ii) a description of the synoptic situation, together with synoptic analyses, tephigrams, special charts, intermediate hourly weather observations, and in general, all available synoptic data,

(iii) an approximate time of the beginning and ending of the storm period determined from the synoptic information as available in the field,

(iv) the altitude at which seeding was conducted,

(v) the flight information and observations made on clouds, temperature, winds, etc., garnered from the inflight report forms,

(vi) a note on operational problems encountered (if any), i.e., reason for partial seeding, late flight, early termination, equipment malfunctions, etc.

The information provided to the evaluator consisted mainly of the records obtained during the field operation on a routine basis and, therefore, posed no particular problems of supply. Later information which for various reasons, was not available at the time of the operation was also provided. Care was taken to screen the records before provision to the evaluator to insure that no information was made available which would point toward the seeding of one particular Area.

6. The Necessary Conditions for Acceptance of a Seeded Storm for Evaluation

The criteria for acceptance of a seeded storm for evaluation were the same as the criteria outlined in Section 4 as the sufficient conditions for conducting cloud seeding operations. Briefly, these required that the storm system be an organized cloud system accompanied by an area of rainfall discernible in the synoptic sense crossing both target areas in such a way as to give no reason to expect that the system would affect the two areas differently; the clouds of the system were required to be at least 3,000 feet thick near the seeding altitude, to have tops extending to at least the -5°C level, to cover at least 50 per cent of the seeding track, and to show signs of an active precipitation mechanism; in addition, the winds were required to be such that the silver iodide or clouds treated with silver iodide would not move over the control area; a final requirement was that the "storm" precipitation as defined in Section 2 should be separable from the previous and succeeding "storms". The reasons governing the establishment of these criteria have been discussed in Section 4.

The differences between the above criteria as sufficient to permit seeding and as necessary for acceptance of the seeded

storm for evaluation were mainly in the method of application. Obviously, it was not always possible under field conditions to adhere rigidly to the criteria, and at times, it was necessary to proceed with the seeding and determine later whether the storm was suitable for evaluation. In determining whether a seeded storm was acceptable for evaluation, the acceptance criteria were adhered to strictly so as to ensure objectivity and freedom from bias. In order to avoid possible bias on the part of the seeding team, the evaluation was conducted independently by an evaluator who had not taken part in the seeding operations. A description of the method of application of the criteria in determining acceptance or rejection of a seeded storm for evaluation is given in the section which follows.

7. Application of the Necessary Conditions

The data received by the evaluator from the seeding agency for analysis (as outlined in Section 5) consisted of the number identifying the seeded storm, the date and time of seeding (but not the area seeded), a description of the synoptic situation together with all available regular synoptic data, the approximate time of beginning and ending of the storm period as determined from the synoptic information available in the field, the seeding level, pertinent flight information and aircraft observations, but not the aircraft position as this would give away the location of the seeded area. No information considered likely to reveal the location of the seeded area was provided to the evaluator. The rainfall and other meteorological data collected by the special Project network installed in the test areas were also not made available to the evaluator until after he had made his determination of whether a storm was acceptable for evaluation using the other factors, as it was feared that possible bias could be introduced by knowledge of this information too early in the evaluation. As an additional precaution, the Project network data were also not made available to the seeding team during operations of the project in the field.

The evaluator proceeded first to verify whether each seeded storm fulfilled the criteria laid down as necessary for its acceptance for evaluation. The first five criteria, i.e. (1) that the storm system be an organized cloud system accompanied by an area of rainfall discernible in the synoptic sense, crossing both

target areas in such a way as to give no reason to expect that the system would affect the two areas differently; (2) clouds at least 3,000 ft. thick near the seeding altitude; (3) cloud tops to at least -5°C; (4) clouds covering at least 50 per cent of the seeding track, and (5) showing signs of an active precipitation mechanism, were verified through study of the regular and special synoptic meteorological data available (excluding the Project raingauge network data) and the aircraft reports. If any of these five necessary conditions were not fulfilled, the storm was rejected as a case for evaluation. In actual fact, only one of the seeded storms was rejected on the basis of the first five criteria.* The sixth criterion, that the winds would not carry seeded clouds or seeding material over the control area, was verified by plotting the aircraft seeding track and the mean wind over the areas on a chart and determining geometrically whether "contamination" would result. Since the aircraft track was changed whenever the wind changed, a separate computation was made whenever the aircraft track was changed. The best estimate of the mean wind from 5 to 30 thousand feet over the test areas was obtained for each aircraft track from the rawinsonde observations taken at Virginiatown, midway between the two test areas and just to the West of them (see figure 4). The mean wind was determined by averaging the 6, 10, 14, 18 and 25 thousand foot level winds obtained from the Virginiatown rawinsonde or rawinsondes corresponding most closely in time to the mean time of the airborne seeding. A rawin was usually available for the mean time or within $\pm$ 3 hours. Applying the mean wind to the aircraft seeding track and allowing a ten-degree angle of dispersion on either side of the mean wind, a geometrical determination was made as to whether any "contamination" of the control area would result. It was found that in a number of cases, the ten-degree angle of dispersion intersected a portion of the control area. The degree of "contamination" in most cases was

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* In all, three storms out of 48 seeded were rejected because of failure to meet the seven acceptance criteria. All of these storms were seeded inadvertently, largely through failure of communications or other operational difficulties. In the storm referred to above, the clouds failed to meet the sufficiency criteria. In the other two storms rejected, wind information later discovered to be incorrect led to the conduct of seeding which could have had little effect on either the target area or the control.

slight, so it was decided not to reject the "contaminated" cases but to place them in a separate category and analyse them separately. Accordingly, situations in which there was no "contamination" were labelled Category A while those with some "contamination" were labelled Category B. Of the forty-five seeded storms accepted for evaluation, thirty-nine were found to be in Category A and six in Category B.

The next step was to examine the rainfall data from the Project raingauge network for each seeded storm meeting the first five criteria, to determine whether the storm rainfall data could successfully be separated. Hourly rainfall amounts for each of the sixty stations of the raingauge network were tabulated on a single chart and the criteria outlined in Section 2 were rigidly applied. Starting with the actual time of seeding and the estimated time of beginning and ending of rainfall in the test areas provided by the seeding agency, the evaluator delineated the storm periods and abstracted the storm rainfall according to the rules laid down in Section 2. To review those rules briefly, it was insisted that the "storm duration" be the same for both the test areas, that the actual time of beginning of rainfall in both test areas be in the same or adjacent regular 12-hourly observation periods, that the actual time of ending of rainfall in both test areas meet this same criterion, and that the actual beginning of rainfall in any storm period be in a regular 12-hourly observation period different from that containing the actual ending of rainfall in the preceding storm period. (A similar criterion was applied to the ending of rainfall in any storm period.) The regular 12-hourly observation periods referred to as the units of which the storms were composed were 0800 to 2000 and 2000 to 0800 local time. Since these criteria had also been observed during the conduct of seeding operations, no difficulty was actually experienced in separating the rainfall of succeeding storms, and no seeded storms had to be excluded from evaluation for this cause.

Once the seeded storms had been found to satisfy all the criteria for acceptance for evaluation, the storm rainfall data for each storm were abstracted from the total data, following the rules and definitions for "storm", "storm rainfall" and "storm duration" as outlined in Section 2. Missing data were interpolated by linear interpolation among adjacent gauges.

Subsequent steps in the evaluation procedure involved computation of weighting factors for each gauge, weighted mean areal rainfall by area for each storm, determination of an index of the effect of seeding and the statistical significance of the index. These procedures have been described in papers by Derco (15), Godson, Crozier and Holland (3) (4), and Holland and Crozier (2), and will not be repeated here.

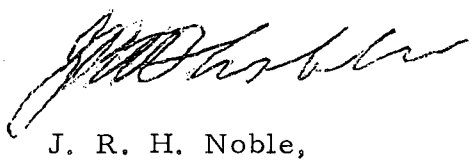
8. Conclusion

This report has presented the detailed storm acceptance and evaluation criteria used in the Precipitation Physics Project, a five-year field program of cloud seeding conducted in western Quebec, aimed at evaluation of the effect of cloud seeding with silver iodide on the rainfall of synoptic scale weather systems. In presenting these criteria, the report has documented the rules of the experiment as they were defined prior to the commencement of the project, and has also provided background information and some of the philosophy underlying the project but not covered in earlier reports. A detailed account of procedures used in the application of the criteria in the operation and evaluation of the project has also been given, including details of technique required to meet the rules of the game, such as special restrictive definitions for such terms as "storm" and "storm rainfall". These so-called "rules of the game" are an essential part of all statistical experiments of this sort, and are required in order to ensure complete objectivity and freedom from bias in the experiment. These rules, established prior to commencement of the experiment, were strictly adhered to throughout its duration, and permitted very little opportunity for subjective decisions.

The conditions judged sufficient for the conduct of cloud seeding have been outlined and their application under field conditions have been discussed. The reasons for the adoption of these criteria have been reviewed. The conditions considered necessary for acceptance of a seeded storm for evaluation have been shown to be essentially the same as those sufficient for conducting seeding, differing only in the strictness with which it was possible to apply them. The methods used in application of the sufficient criteria have been discussed.

The results of the evaluation of the effect of the cloud seeding, and details of the statistical and physical design and operation of the project have been presented in other reports in this series (3), (2), (1).

APPROVED,



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

9. References

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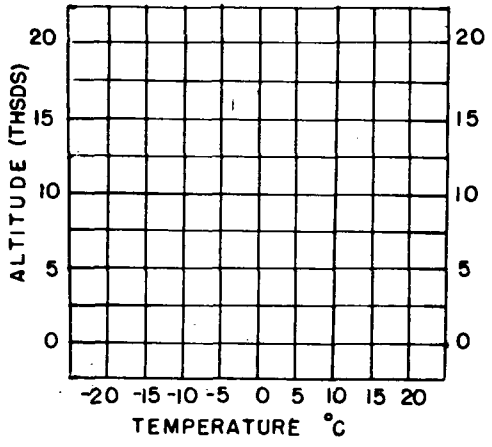
APPENDIX I (a)

SEEDING FLIGHT DOCUMENTATION FORM (FORECAST)

PRECIPITATION PHYSICS PROJECT
TARGET AREA FORECASTS

1. TEMPERATURE



FLIGHT NO.	
DATE	196
ENVELOPE NO.	
WEATHER REMARKS	

2. WINDS.

ALTITUDE THSDS.	
2	
5	
10	
15	
18	
20	
25	

FLIGHT ALTITUDE

WIND →

3. TIME

A BEGINING OF SEEDING G.M.T.

B DURATION HOURS.

TO BE FILLED IN BY CREW BEFORE RETURNING TO PROJECT CONTROL	
TIME OFF NORTH BAY. G.M.T.	REASON FOR TERMINATING FLIGHT
TIME ON NORTH BAY. G.M.T.	
SEEDING AREA	
ENDURANCE	ESTIMATED SEEDING TIME HOURS

PILOT OBSERVATIONS REPORT - PRECIPITATION PHYSICS PROJECT | SHEET NO.

FLIGHT NO. | DATE 196 | CAPTAIN | CO-PILOT | ACFT. IDENT.

FLT. PLAN TURN PTS. | FLT. PLAN WIND °T KTS | AREA

CODE	TIME (G.M.T.)	POSITION (LAT. and LONG. or DISTANCE FROM TURN)	ALT. (HNDS)	I.A.S. (KTS)	TEMP (°C) CORR.	HEADING (°M)	WIND IF CALCULATED (°M KTS.)	ICING	TURBC.	STATIC	PCPN.	CLOUD CONDITIONS AND REMARKS

APPENDIX I (b)

PILOT OBSERVATIONS REPORT FORM

APPENDIX I (c)

INSTRUMENT TECHNICIAN REPORT FORM

ALTIMETER READING

OFF

ON

MORSE

A ·−
B −···
C −·−·
D −··
E ·
F ··−·
G −−·
H ····
I ··
J ·−−−
K −·−
L ·−··
M −−
N −·
O −−−
P ·−−·
Q −−·−
R ·−·
S ···
T −
U ··−
V ···−
W ·−−
X −··−
Y −·−−
Z −−··

REVISED 4-4-62

CLOUD FILM NO.

DROPLET FILM NO.

RECORDER FILM NO.

INSTRUMENT TECHNICIAN REPORT – PRECIPITATION PHYSICS PROJECT | SHEET NO.

FLIGHT NO. | DATE 196 | TECHNICIAN | ACFT. IDENT.

CODE	TIME (G·M·T·)	ALT. (HNDS.)	I.A.S. (KTS.)	TEMP. (°C)	DROPLET PHOTO NO.	DROPLET PHOTO MAG.	CLOUD PHOTOS NO.	CLOUD PHOTOS SPD/APT.	CLOUD PHOTOS DIR.			REMARKS– Include on-off times of burner, hot wire, accelerometer, mech. zeros etc.
												ACCELEROMETER–BEGIN

APPENDIX I (d)

AIR WEATHER OBSERVER REPORT FORM

AIR WEATHER OBSERVER REPORT - PRECIPITATION PHYSICS PROJECT — SHEET NO.

FLIGHT NO. | DATE 196 | OBSERVER | ACFT IDENT

CODE (IF ANY)	TIME G.M.T	I.A.S. KTS	
TEMP °C	TEMP TREND	ALT. HNDS. FT	
ST. ELMO'S FIRE	STATIC		
ICING	TURBULENCE PERIOD STRENGTH		

PRECIP											OTHER & REMARKS
	L-	R-	S-	R↘	DIR.	A	SOFT	SP	SOFT	
	L	R	S	R↘+	DIR	A+	HARD	SP+	HARD	
	L+	R+	S+	↙	DIR.		SIZE	-	SIZE	

CLOUDS	TYPE	BASE HNDS. FT.	TOPS HNDS. FT.	AMT. TENTHS	REMARKS

SIGNIFICANT CHANGE SINCE LAST OBS. IF ANY-

REMARKS -

CODE (IF ANY)	TIME G.M.T	I.A.S. KTS	
TEMP °C	TEMP TREND	ALT. HNDS. FT	
ST. ELMO'S FIRE	STATIC		
ICING	TURBULENCE PERIOD STRENGTH		

PRECIP											OTHER & REMARKS
	L-	R-	S-	R↘	DIR.	A	SOFT	SP	SOFT	
	L	R	S	R↘+	DIR.	A+	HARD	SP+	HARD	
	L+	R+	S+	↙	DIR.		SIZE		SIZE	

CLOUDS	TYPE	BASE HNDS. FT	TOPS HNDS. FT.	AMT. TENTHS	REMARKS

SIGNIFICANT CHANGE SINCE LAST OBS. IF ANY-

REMARKS-

PAGE NO. ____

PRECIPITATION PHYSICS PROJECT

FLIGHT NO. _____ NAVIGATOR _____ AVERAGE WIND _____

DATE _____ ALTITUDE _____

DRIFT	G/S	TAS	HDG. (Mag.)	W / V (True)	Altitude - Position - REMARKS	TIME (GMT)

APPENDIX I (e)

NAVIGATOR REPORT FORM (1963 only)

TEC-666 UDC: 551.509.6
23 November 1967. 551.574.1

CANADA
Department of Transport - Meteorological Branch
315 Bloor Street, W. - Toronto 5, Ontario

Detailed Storm Acceptance and Evaluation Criteria
Precipitation Physics Project
by C. L. Crozier and J. D. Holland

22 pps. 4 figs. 15 refs.

Subject reference: 1. Artificial Precipitation.
2. Conditions for Cloud Seeding.
3. Rules of experiments.

TEC-666 UDC: 551.509.6
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